University of Reading

Ocular accommodation in primary school children.

Doctor of Philosophy

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Declaration of original authorship

Declaration: I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Siobhán Marie Ludden

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Abstract

Aim

Clear near vision would seem vital for education. Existing literature has suggested an association between accommodation and education. However, this evidence base is limited and conflicting. Furthermore, a causal relationship between accommodation response (AR) and education has not been shown to date.

This PhD thesis was funded by *Fight for Sight* charity as a “first step” to investigate typical accommodation in primary school children and establish *if* a relationship exists between accommodation and education. Should a relationship be identified, the results were designed to provide pilot data for further research to investigate causality.

Methods

Three studies were conducted:

1. A qualitative study, involving parents of primary school children, explored parental concerns regarding accommodation research.

2. During a controlled laboratory based study AR to a range of targets was objectively assessed using the Plusoptix PowerRefII photorefractor. The relationship between AR and academic ability markers was analysed; providing pilot data for a school based study.

3 A purpose built portable laboratory (incorporating a Plusoptix R09 photorefractor) was used to asses AR in participants, from a range of socio-economic backgrounds, to various targets in a community (school based) setting. AR was analysed in relation to reading and attention.

Results

The qualitative study established that parents would be willing to participate in future accommodation research but exposed concerns regarding research duration.

In both the laboratory and school studies increased AR was observed in response to complex targets. Accommodation was not related to performance on educational tests.

Conclusions

AR is influenced by target type. Under naturalistic conditions typical children will exert increased accommodation to more cognitively demanding targets.

Accommodation does not appear correlated to reading ability or attention. Even very able readers appear to function with a degree of accommodative lag.

Chapter 1 - Introduction

Clear near vision would seem vital for education; however, this is not currently assessed in the school eye test. Although it is recommended that all children should have an eye test upon school entry (Hall & Elliman, 2002), the current "gold standard" school eye test involves distance vision assessment only. Near vision differs from distance vision because extra focusing is required to see clearly at near; a process known as accommodation*[1]. If sufficient accommodation does not occur, the near image will remain blurred even if distance vision is clear. Circumstantial evidence suggests that children who do not accommodate* accurately are more likely to fall behind academically, in particular with reading (Grisham, Powers & Riles, 2007; Kulp & Schmidt, 1996; Motsch & Huhlendyck, 2000; Palomo-Alvarez & Puell, 2008; Quaid & Simpson. 2013; Shin, Park & Park, 2009; Williams et al, 2004), but causal relationships and whether successful eye treatment can improve literacy, are unclear.

My PhD studentship has been funded by the eye research charity *Fight for Sight* to investigate the relationship between accommodation and reading. It was funded as an exploratory study; therefore, the aims and objectives of this PhD thesis have been significantly influenced by the grant proposal and the terms of the studentship.

The purpose of this studentship is to establish how typical children focus for close work (accommodate*), to design and trial a suitable test battery to investigate the relationship between children's accommodation and educational ability and to assess parents' opinions regarding participation in future accommodation randomised control trials

[1] When a new term is first introduced it is marked with *. The definition of the relevant term can be found in the Glossary.

(RCT). If a relationship is identified between accommodation and education, the data obtained for this thesis would provide pilot data for a future prospective multi-centre intervention trial to investigate if this relationship is causal.

1.1 Background

To view a near object clearly our eyes must move inwards (converge*) and perform extra focusing (accommodation*). Accommodation involves the manipulation of the shape of the lens within the eye to obtain clear near vision, without this, near objects would remain blurred (Figure 1-1).

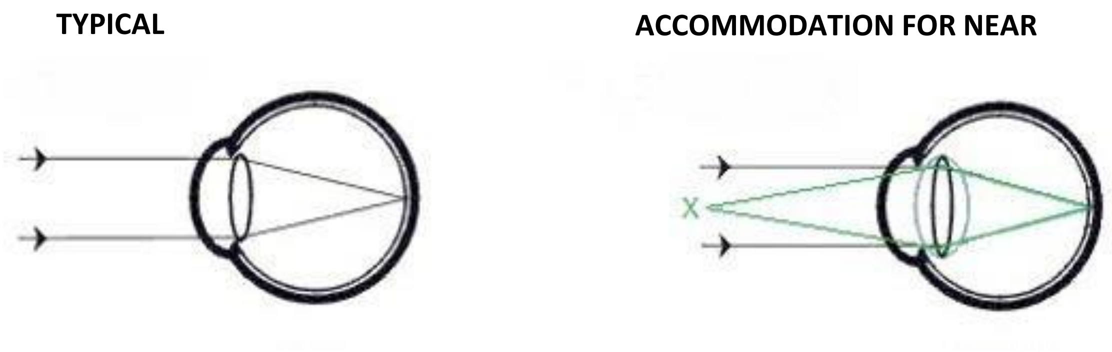

Figure 1-1: Illustration of light rays entering the emmetropic eye at distance and near fixation. In the "Typical" (distance) situation, light rays come to focus on the retina. For near fixation, the lens needs to become thicker and more rounded (blue line) to bring rays into focus on the retina.

The amount of accommodation required to see clearly (accommodative demand) is measured in lens dioptres (D) which is the reciprocal of object distance in metres:

$$Accommodative\ Demand = \frac{1}{Object\ Distance}$$

So 1D is required to clear an image at 1metre and 3D required at 1/3metre (m) (33 centimetres (cm)), Figure 1-2.

(A) (B)

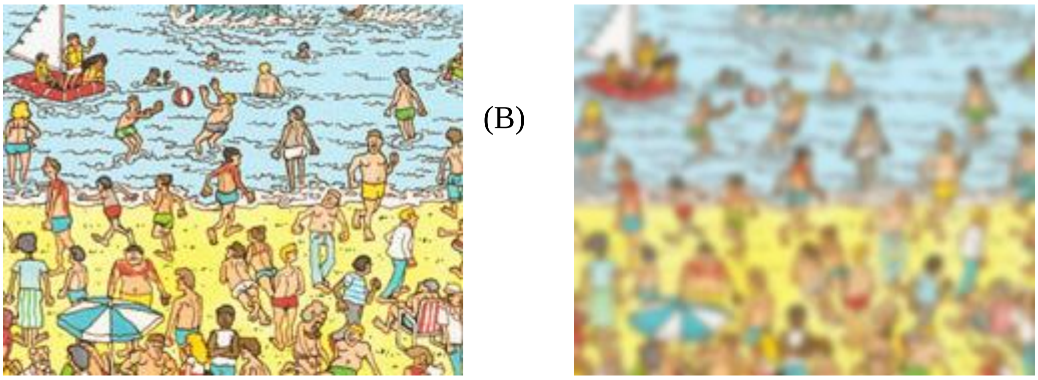

Figure 1-2: (A) Clear image at 33cm, a result of appropriate accommodation

(B) Blurred image at 33cm due to under-accommodation at target distance

Accommodation is generally considered an involuntary reflex controlled by the parasympathetic nervous system. If a blurred near image is detected by the visual cortex corrective signals are sent via the accommodation pathway to stimulate the ciliary muscles * and cause the crystalline lens* within the eye to “fatten”. This change in lens shape places the target image in focus on the retina*, resulting in clear near vision. This mechanism will be discussed in detail in *Chapter 2*.

The capacity to accommodate is affected by age and can also be influenced by refractive error*, e.g. long-sight (hypermetropia*) or short-sight (myopia*).

Accommodation is typically fully developed by the age of 3months (Bharadwaj & Candy, 2008; Tondel & Candy, 2007; Turner, Horwood, Houston & Riddell, 2002); the total amount of accommodation available peaks in childhood and steadily decreases with age. With increasing age, the lens becomes thicker and less elastic resulting in reduced accommodation in middle age (presbyopia*), so that eventually even people who do not wear glasses for general visual clarity (emmetropes*) need reading glasses to correct near vision. The general formula for calculation the expected average accommodation capacity is that derived by Hofstetter (1950):

$$Average\ Accommodation = 15 - (0.25\ x\ age)$$

This formula illustrates that younger subjects are expected to have an increased capacity to accommodate - the average accommodation of a 10year old child would be 12.5D (15 – (0.25x10)) whereas that of a 40year old would be considerably lower at 5D (15 – (0.25x40)).

1.2 Refractive error

Refractive status refers to the point within the eye conjugate to optical infinity when the eye is at rest i.e. under minimal accommodation (Rosenfield, 2006). Refractive error refers to the optical error of the eye – such that the point conjugate to optical infinity does not lie on the retina. Long-sight (hypermetropia/hyperopia*), short-sight (myopia*) and astigmatism* are examples of refractive errors. A refractive error may be the result of the eye being too long (e.g. myopia) or short (e.g. hypermetropia) anteroposteriorly or a result of the cornea* or ocular lens not bending (refracting) light rays sufficiently to place the image on the retina. This results in blurred vision requiring spectacle correction.

Accommodation is particularly relevant to hypermetropia. For the hypermetropic eye looking at a distance target, the image will fall “behind” the retina and appear blurred.

Without glasses, mildly hypermetropic eyes have to induce accommodation to overcome this and see clearly even at distance (Figure 1-3). As a near object requires additional accommodation to see clearly, hypermetropic eyes need to do even more accommodation than their myopic or emmetropic counterparts to see clearly at near. The correct glasses will make distance vision normal without this additional accommodation, but like non-hypermetropic people, extra accommodation is still necessary for near.

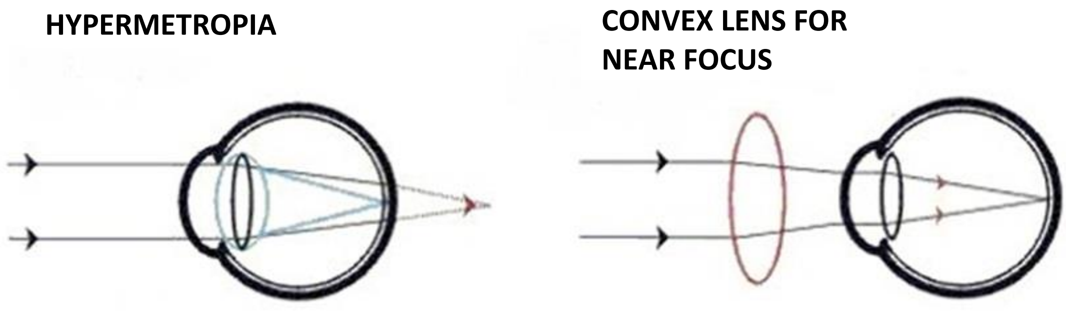

Figure 1-3: In the eye with "Hyperopia" looking at a distance object, light rays will fall behind the retina as the eye is too short or the lens does not bend light rays sufficiently. However, as indicated by the blue line, if the lens can thicken (accommodate) the rays will come into focus on the retina. A convex lens will alter (refract) the rays entering the eye to bring the image into focus on the retina. In this case extra accommodation is not needed for distance but will still be needed for near viewing as in Figure 1-1.

Clinically, it is frequently assumed that if a child can see clearly at distance they will see clearly at near, as children have a much higher physical capacity to alter their focusing compared to adults (Benjamin, 2006). For example, a child of 6 years of age can produce 13.5D of accommodation (Hofstetter's minimum 15-(0.25*age)), when normal reading would typically require 3D. Previous research at the University of Reading Infant Vision Laboratory (IVL), however, has shown that children do not always focus as well as it is assumed by most clinicians. Using an objective measure of accommodation, Horwood and Riddell (2008; 2010; 2011) identified that up to 40% of visually normal 5 – 9 year old children routinely under-accommodated by up to 1.2D, which is enough to induce noticeable blur. This suggests that there may be a significant proportion of children who have passed the school distance eye test but experience blurred near vision. Under-accommodation was especially apparent in hypermetropic children (Horwood & Riddell, 2011).

Under-accommodation suggests that there is residual blurred vision at near. It seems intuitively logical that blurred near vision has the potential to impact young children's reading, attention, concentration and education. Blurred vision could negatively impact a child's ability to decode letters on a page, resulting in slower reading, increased errors or poorer reading comprehension. Blurred print could result in disengagement or an avoidance of schoolwork which could impact concentration and behaviour. This apparently obvious assumption among scientists, eye professionals and probably parents, has a surprisingly weak evidence base. Previous research has indicated a link between hypermetropia and poorer reading ability (Kavale, 1982; Quaid & Simpson, 2013; Rosner, 2004; van Rijn et al, 2014; Kulp et al, 2016; Williams, Sanderson, Share & Silva, 1988; Williams, Latif, Hannington & Watkins, 2005). Current evidence also suggests that under-accommodation is associated with failure at school (Grisham et al, 2007; Kulp & Schmidt, 1996; Motsch & Huhlendyck, 2000; Palomo-Alvarez & Puell, 2008; Quaid & Simpson. 2013; Shin et al, 2009; Williams et al, 2004). However, this literature is not conclusive as it largely reports subjective measures of children's accommodation only and is limited by participant selection; this will be discussed in detail in the literature review. None of these studies have proven the directions of any causal linkages or provided evidence that ocular treatment would benefit literacy.

From the current evidence base it is not clear how common under-accommodation is in typical children, or whether under-accommodating children do exert extra accommodation if necessary and whether this is adequately sustained throughout a demanding task. Research in adults has shown that accommodation increases depending on the difficulty of the task (Ciuffreda & Hokoda, 1983). Limited evidence indicates that, similar to adults, children will also accommodate more to more demanding targets (Bharadwaj & Candy, 2008; Yeo, Atchison & Schmidt, 2013) although this area requires further investigation. A relationship between accommodation and reading/attention might not exist if children accommodate appropriately to overcome residual blurred near vision when necessary.

1.3 Aim of thesis/Research question:

This PhD was funded to carry out exploratory pilot studies and its aims were influenced by the terms of the studentship. The purpose of this research was to establish whether poor accommodation could be a significant predictor of poor attainment. If it seems that there is evidence for such a link, the work would also establish whether a large scale RCT to establish causal linkages and possible treatment is both justified and possible. Specific aims were:

1. Objectively establish children's typical accommodative responses to targets of varying complexity. Do children accommodate more to more difficult targets?

2. Explore the relationship between accommodation and reading ability and attention. Are the children that under-accommodate poorer readers or do they have poorer attention?

3. Establish a valid and practical testing battery and provide pilot data which will allow the relationship between accommodation and reading to be explored in depth in future larger accommodation studies.

4. Evaluate parental willingness to partake in future accommodation studies involving intervention such as spectacles.

1.3.1 Objectives:

To facilitate the above aims, I set out to:

- Perform an initial detailed investigation of sustained accommodation in typical primary school children in a laboratory setting, involving accommodative targets of varying complexity. Relate accommodation to reading/cognition/education in this group and provide pilot data for a larger study. Trial a wide variety of educational tests in this detailed study to establish which tests would be the most sensitive and appropriate for use in shorter test battery to relate accommodation to reading/cognition/education in a community setting.

- Explore typical accommodation in a larger school based study to obtain more representative data from children from different socio-economic backgrounds with a variety of refractive errors. Develop and trial a portable vision laboratory suitable for use in a school. Use the educational test battery, established during the detailed laboratory study, in the school study to relate children's accommodation to factors affecting education.

- Perform a qualitative study to establish parental knowledge of children's eyesight, eyesight problems and parental concerns and opinions on future accommodation studies, in particular if they would be prepared to participate in any future RCT. This will assist the design of any future accommodation intervention trials and provide information to funders regarding potential participant uptake.

1.4 Summary of chapters

A review of the relevant literature is presented in *Chapter 2*. I will begin by reviewing the literature on accommodation including, the anatomical pathway of accommodation, factors influencing the accommodative response and a brief overview of possible disorders of accommodation. I will then discuss the literature on refractive error and reading, including a review of studies that look at the influence of hypermetropia on education and the smaller number of papers which have included measures of accommodation. The literature surrounding the development of reading and dyslexia will then be introduced.

The qualitative study, evaluating the acceptability of an accommodation RCT to parents and their knowledge of children's eyesight is presented in *Chapter 3*.

Chapter 4 describes the laboratory study. This was a pilot study; therefore, the results were used to inform the methodology and test battery of the school based study. *Chapter 4* includes a detailed description of the IVL and the targets designed to investigate accommodation in typical children. A wide variety of tests of participants' reading and general ability were conducted to determine which would be the most practicable in a community setting. The results of these tests were related to accommodation, as assessed using the IVL.

The school-based accommodation study is presented in *Chapter 5*. This was a larger study involving children from a variety of socio-economic backgrounds. A detailed description of the portable accommodation laboratory designed for use in a primary school setting is given. Data from the calibration of this equipment and the subsequent investigation of children's accommodation responses and the observed relationship between accommodation and reading and attention is presented.

A discussion of the findings of each study will be included within the relevant chapter. A general summation will be presented in *Chapter 6*.

Chapter 2 - Literature Review

2.1 Introduction

This literature review will build on the information introduced in *Chapter 1*. This chapter will begin by defining and outlining the process of accommodation, which is essential for this thesis. This will be followed by a description of possible dysfunctions of accommodation and their consequences as well as accommodation assessment methods. The relevant literature regarding the factors that influence accommodation, as well as literature pertaining to under-accommodation (accommodative lag) will be introduced. Current evidence regarding the relationship between refractive error and accommodation on education will be discussed with a particular focus on the literature pertaining to hypermetropia followed by the more limited literature base that exists regarding the relationship between accommodation and education. An overview of the evidence base regarding reading, the key theories regarding its development and a brief overview of the dyslexia evidence base will then be presented.

2.2 Accommodation

Accommodation is defined as, the ability of the eye to increase dioptric power in order to obtain a clear image of a near object (BIOS, 2012). For optical clarity an image must be focused on the fovea of the retina at all times. When object viewing distance is altered so too is the image location in relation to the retina. For example, in an emmetropic eye, when an object is viewed at a short distance, hyperopic defocus will occur as the image will fall behind the retina. Consequently, the object would be perceived as blurred. Changes must occur within the eye to compensate for this and enable clear vision. The focal length of the eye is fixed and therefore cannot be manipulated. However, changes can occur in the crystalline lens that will allow a change in the eye's dioptric power - the process known as *accommodation*.

During accommodation the convexity of the crystalline lens is altered to allow appropriate refraction of light, thus, placing the image on the fovea (Figure 2-1). Accommodation is an involuntary reflex controlled by the parasympathetic nervous system (Figure 2-2). Parasympathetic fibres of the IIIrd (oculomotor) cranial nerve, originating from the Edinger-Westphal nucleus, innervate the ciliary muscle. When viewing a near object, contraction of the ciliary muscle relieves tension on the zonules of Zinn allowing the lens to take a more convex form (and producing a shorter focal length). This allows increased refraction to occur and places the image on the fovea, facilitating clear near vision. When changing focus from near to distance the image will fall in front of the retina (myopic defocus). Relaxation of the ciliary muscle and increased tension from the zonules of Zinn result in flattening of the crystalline lens, placing the image on the fovea.

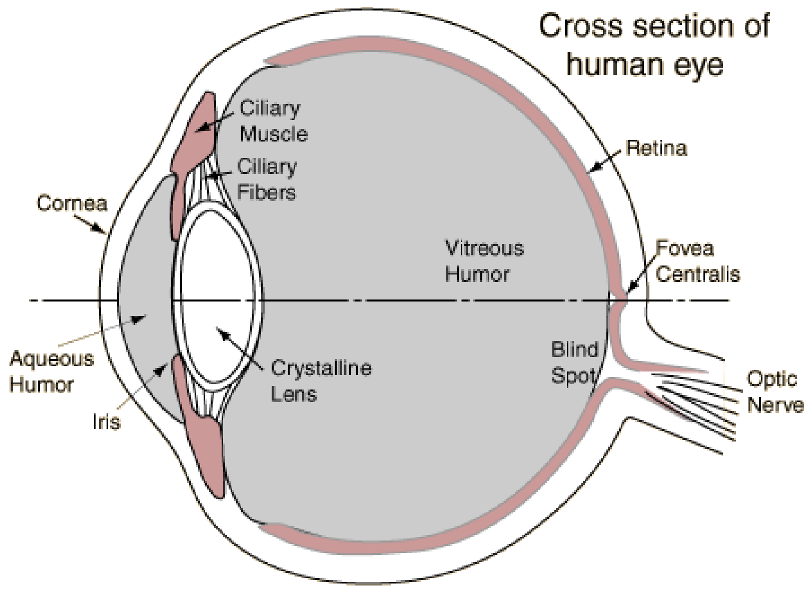

Figure 2-1: Cross section of the human eye (R Nave; http://hyperphysics.phy-astr.gsu.edu/hbase/vision/eye.html). During accommodation change in tension of the ciliary muscle results in a thickening of the lens – producing a convex shape. This allows increased refraction and the image will fall on the fovea resulting in clear near vision.

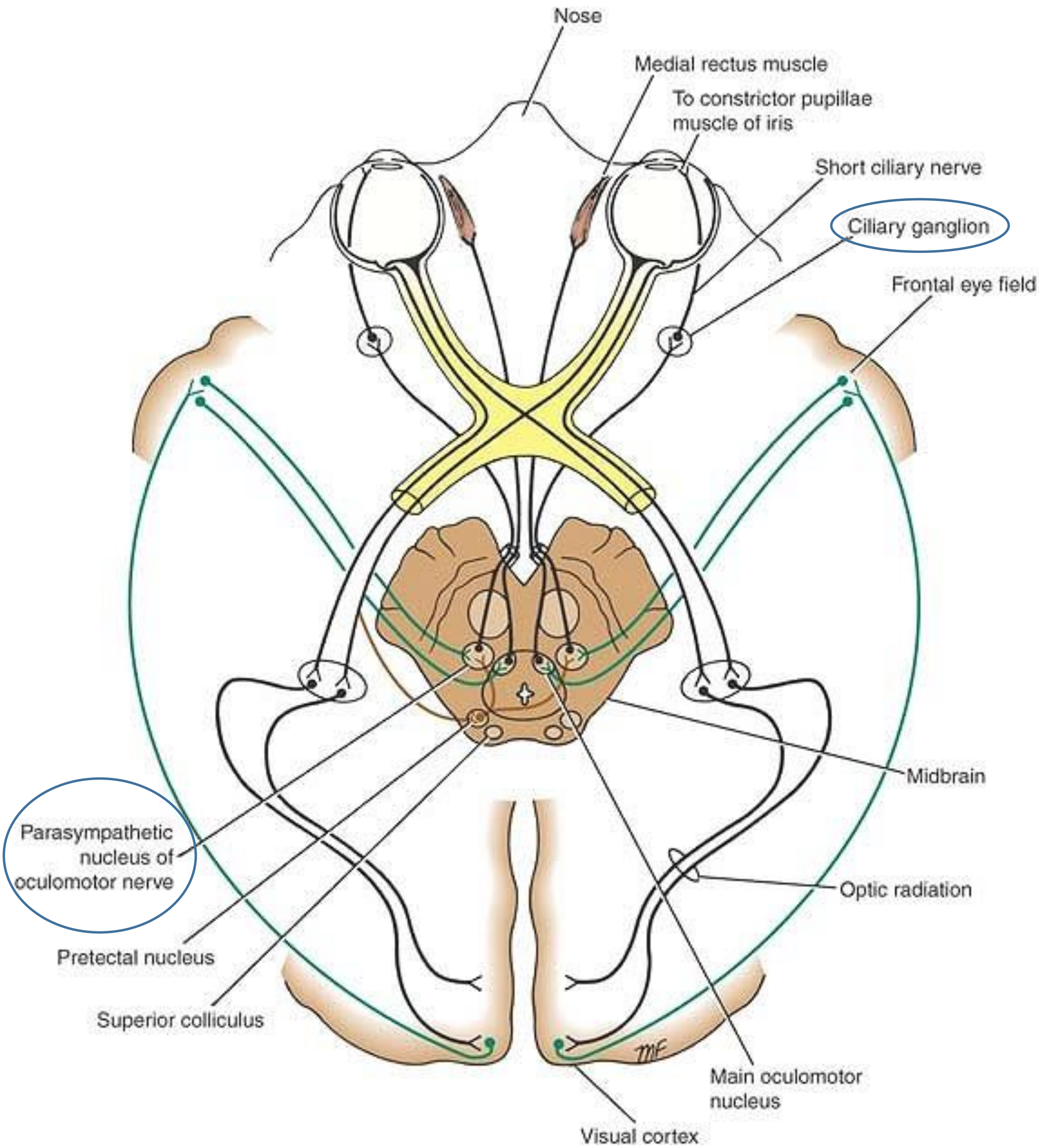

Figure 2-2: Optic pathway and near reflex innervation (http://ueu.co/ru/ovid-clinical-neuroanatomy-3/). Parasympathetic fibres of the IIIrd (oculomotor) cranial nerve innervate the ciliary muscle via the ciliary nerve. This stimulates ciliary muscle contraction and subsequent increased convexity of lens.

Accommodation is measured in dioptres (D); accommodative demand is the reciprocal of the target viewing distance in metres (m), e.g. at 1m an emmetropic eye will accommodate 1D. At optical infinity no accommodation is necessary - a point defined as the far point of accommodation. The closest point at which an object can be seen clearly is defined as the near point of accommodation. The difference between the near and far point of accommodation is known as the amplitude of accommodation. Clinically, among orthoptists, the amplitude is often recorded as a distance; however, in the literature, dioptres (D) are more commonly used to record the amplitude of accommodation. Accommodative demand is also influenced by refractive error (see *Chapter 1*) such that, hypermetropic eyes have to accommodate even more than their emmetropic counterparts to focus on a near target.

Whilst accommodating, humans also converge their eyes and pupil miosis* occurs. The combination of these processes is known as the near triad or near reflex. This close relationship can be quantified by the Accommodative Convergence/Accommodation (AC/A) ratio and the Convergence Accommodation/Convergence (CA/C) ratios.

2.2.1 Dysfunction of accommodation.

There are many different clinical disorders associated with accommodative dysfunction, including accommodative insufficiency, inertia and spasm. Accommodative insufficiency is defined as a condition in which the amplitude of accommodation is lower than would be expected for the individual's refractive state and age (BIOS, 2012). As a result, the individual cannot focus appropriately or sustain focus at near. This may lead to symptoms such as blurred near vision, an inability to sustain clear near vision, headache, eye strain or double vision. Ill-sustained accommodation, in which the accommodative amplitude will start out normally but deteriorate over time, can be considered an early indicator of accommodative insufficiency (Bartuccio, Taub & Kieser, 2008).

Accommodative inertia is a difficulty in changing accommodative response from near to distance fixation.

Accommodative spasm and pathological paralysis of accommodation can also be encountered clinically, although less frequently. Accommodative spasm occurs as a result of spasm of the ciliary muscle, this causes blurred vision at distance and near. It can be associated with convergence spasm and result in pseudo-myopia and double vision. Paralysis of accommodation is a very rare condition where there is no accommodative response to any stimulus. This may be caused by disease or trauma and may be induced clinically through use of cycloplegic drugs. Spasm and paralysis will not be discussed further in this thesis.

2.2.2 Accommodation and convergence

There is generally considered to be a neurological linkage between accommodative function and convergence. When accommodation is induced convergence occurs, likewise when one converges accommodation occurs (Ansons & Davis, 2001).

Although dysfunction of the accommodation and convergence systems can occur independently, due to their close linkage, dysfunction of one will typically be associated with dysfunction of the other, for instance, an accommodative insufficiency can coexist with a convergence insufficiency. For example, in an investigation of primary school children with convergence insufficiency, Marran, De Land and Nguyen (2006), reported that comorbidity between accommodation and vergence insufficiency increased symptom severity and demonstrated that it was the coexisting accommodative insufficiency that was responsible for the symptoms reported. Therefore, when investigating accommodation an assessment of convergence is also indicated.

2.2.3 Assessment of accommodation

Accommodation can be assessed subjectively and objectively. Before introducing research findings regarding accommodation, an awareness of accommodation assessment techniques is required. Therefore, a brief outline of the most relevant subjective and objective procedures in the current literature is given here.

The most frequently used subjective accommodation assessment methods in both UK clinical and research settings include amplitude (“push-up”) of accommodation and accommodative facility.

Amplitude of accommodation assessment (push-up) involves a small target, e.g. a letter/text. This is brought slowly towards the subject and the subject is asked to verbally report when the target appears blurred – this is considered the point at which accommodation has failed. The linear distance from the bridge of the nose to the point at which accommodation fails is the near point of accommodation. When this linear point is converted to a dioptre measurement it is known as the amplitude of accommodation. An alternative assessment method of the amplitude of accommodation involves the use of concave (minus) lenses to determine the strongest lens with which an image can be perceived clearly. However, this is generally performed less frequently than the push-up method in the clinical environment. As discussed in *Chapter 1*, the amplitude of accommodation decreases with age and the expected amplitude of accommodation can be calculated using Hofstetter’s formula. While useful, Hofstetter’s formula is an approximation, as lower accommodation has been reported in children than would be expected by this calculation (Sterner, Gellerstedt, & Sjöström, 2004).

Accommodative facility assesses one's ability to change accommodation easily. To assess this, the participant is given "flipper lenses", e.g. one side consisting of two +2.00DS lenses/other -2.00D, both of which can be overcome by typical young individuals. The participant is instructed to hold either the plus or minus side over both eyes. They are presented with a near target (generally at 40cm) and asked to make the image clear. As soon as the target is clear the lenses are then "flipped" to the other lens (e.g. from plus to minus) and the patient is asked to clear the target again. This is repeated for 1-minute and the number of "cycles" of plus to minus lenses subjectively overcome is recorded as accommodative facility. Accommodative facility is considered a difficult task, especially for children as it requires understanding and motivation to complete the task, the child must also comprehend and appreciate blurred vision and report it promptly.

Objective clinical assessment of accommodation is largely completed using a technique called dynamic retinoscopy. For this technique a patient/participant is instructed to look at a target while an instrument called a retinoscope is used to shine a light into the eye. The direction of movement of the reflected and refracted light across the pupil (with/against the movement of the instrument) indicates if lag/lead of accommodation is present (i.e. if the subject is accommodating at a point farther or closer to the targets actual position in space). This lag/lead can be quantified using lenses to neutralise the movement of the light (MEM retinoscopy) or by moving further from/closer to the participant (Nott retinoscopy). The merits of each method will be discussed later in this chapter in relation to the impact of accommodation on education. Both Nott and MEM retinoscopy are user dependant, artificial i.e. non-naturalistic tests and the results obtained with these methods are limited as the test is typically performed on one eye at a time in a dimly lit room.

A more naturalistic assessment of accommodation, without lenses or lights, can be achieved using photorefraction. This may well produce different results to those obtained with dynamic retinoscopy. Monocular assessment of accommodation can be made with many autorefractors*. A binocular photorefractor* can be used to assess the accommodative response of each eye simultaneously. However, this technique is less common and can be achieved using only one type of photorefractor. This method has only recently gained prominence in the accommodation literature and would appear to be the preferred assessment method. Photorefraction will be discussed in detail in *Chapter 4*.

2.2.4 Cues to accommodation.

The main cues that drive accommodation and convergence are disparity, proximity (looming) and blur. Studies have also investigated the effect of other less influential factors such as colour, contrast, spatial frequency and higher order control, which can also influence the accommodation response (Charman & Tucker, 1977; Owens, 1980; Switkes, Bradley, & Schor, 1990; Tucker, Charman, &, Ward, 1986; Ward, 1987; Wolfe & Owens, 1981).

Until recently, clinical and theoretical literature suggested that blur was the main cue for the accommodation response while disparity was the main cue for vergence responses (Heath, 1956; Maddox, 1886; Morgan, 1968). It seems logical that blur should be the main driver of accommodation – a blurred stimulus will signal that increased accommodation is required to compensate for that blur. This optics theory was held for a considerable time and was supported by highly controlled laboratory studies which did not systematically investigate the relative importance of each cue (Bharadwaj & Candy, 2008; Philips & Stark, 1977). Instead these studies generally investigated one eye at a time and individual accommodation cues in isolation. However, more recent studies have been able to investigate the cues to accommodation in combination and have subsequently refuted this long-held theory. It is now clear that disparity rather than blur is the main drive for both convergence and accommodation in everyday viewing (Bharadwaj & Candy, 2008; Horwood & Riddell, 2008; 2009). Horwood and Riddell (2008), at the Infant Vision Laboratory (IVL), investigated the role of blur, disparity and proximity cues on the simultaneous accommodative and convergence responses in both an adult (18 – 24 years) and child (8 – 9 years) population. Accommodation was assessed naturalistically, with all cues present, one cue removed in turn, and also with each cue individually. It was found that the largest reduction in accommodative gain was found when the disparity cue was removed; thus, suggesting that disparity is the main drive for accommodation as well as vergence. Such evidence refuting the long-held theory that blur is the main driver of accommodation emphasises the importance of assessing accommodation under binocular and naturalistic conditions to identify the true extent and impact of accommodation, in particular where accommodation is thought to be atypical.

Although disparity is the main drive for accommodation, other factors affecting accommodative response have also been identified in the literature.

Decreased gain and increased lag of accommodation has been found with reducing target contrast (Raymond, Lindblad, & Leibowitz, 1984; Wolfe & Owens, 1981). However, contrast is thought to have little practical effect on the accommodative response elicited (Denieul & Corno-Martin, 1994; Tucker, Charman, & Ward, 1986).

Colour contrast is reported as an ineffective stimulus for accommodation. Wolfe and Owens (1981) reported that participants could not accommodate appropriately to an isoluminant red-green border. Switkes, Bradley and Schor (1990) compared responses to gratings consisting of either isolumiant red-green colour modulations or isochromatic luminance modulations and found that changes in colour contrast were ineffective in stimulating accommodative response. Participants were however, found to accommodate accurately to luminance modulated gratings across a range of contrasts.

Spatial frequency (i.e. level of fine detail) is reported to influence the accommodative response (Heath, 1956). Charman and Tucker (1977, 1978) found that accommodation improves with increased spatial frequency. In contrast, Owens (1980) and Ward (1987) found less accurate accommodative response to higher spatial frequencies (sinusoidal gratings). Ward (1987) reported that intermediate spatial frequencies are important as accommodative stimuli. The author suggested that in order to avoid atypical accommodative responses, accommodative targets should possess a wide variety of spatial frequencies, with concentration around an intermediate spatial frequency of 5cycles/degree.

Target position is also considered to influence accommodation. Accommodation is less effortful in downgaze than upgaze and amplitude of accommodation has been shown to be lower in upgaze compared to that elicited in downgaze (Jampolsky, 2005).

Higher level control such as instruction and cognitive demand has also been shown to influence accommodative response. Ciuffreda and Hokoda (1985), using a sinusoidal grating target, found increased accommodation response amplitude when participants were asked to “try very hard to keep the grating at maximum high level contrast” rather than merely “relax” when viewing the target. Bharadwaj and Candy

(2008), in a sample of children aged 4.3 – 6.5 years, found visual demand can impact accommodative response. In this study children were instructed to read letters of 20/40 size and also watch a movie while accommodation responses were recorded. It was found that under monocular conditions higher gains of accommodation were found in the letter reading task than the movie task; suggesting that children generate larger accommodative responses to more visually demanding tasks.

The effects of the different factors on the accommodative response suggest that to obtain a representative accommodative response, it is not sufficient to simply have the main cues, blur disparity and vergence, available and that even with all these cues available participant responses can vary as a function of the task itself. Therefore, whilst one would anticipate an accommodative response would equal the demand of 1/target distance (in metres), the actual response might differ depending on the task design and level of detail in the target, as well as testing environment and instruction. This is an important consideration in accommodation research when investigating typical accommodation responses. Therefore, it is important that naturalistic testing conditions and a minimal instruction set are used to minimise the influence of environment and instruction to obtain a representative accommodative response; an approach which is employed later in the experimental chapters of this thesis.

2.2.5 Accommodative lag

The perfect accommodative response will equate to the reciprocal of target distance in metres. While this is considered the "perfect" response it is accepted that actual responses will differ to this to some extent. Eyes can over focus (over-accommodate) for target distance – known as a lead of accommodation. This occurs when there is accommodation in excess of the accommodative stimulus. Conversely, eyes can also under-focus for the target distance i.e. the actual accommodative response is lower than the dioptric stimulus, which is referred to as accommodative lag.

Child and adult accommodation studies alike frequently report some degree of accommodative lag as typical. Where dynamic retinoscopy has been used to evaluate accommodation, mean lag of accommodation of 0.25D – 0.75D has been reported (Jackson & Goss, 1991; Poynter, Schor, Haynes, & Hirsch, 1982; Rouse, Hutter, and Shiftlett, 1984; Tassinari, 2002). A lag of 0.25D – 0.75D is not immediately expected to be associated with blurred near vision as the level of blur induced by such lag is considered to be within an individual's depth of focus. Depth of focus is the amount of variation in a lens or optical system which can be tolerated without the perception of reduced sharpness or clarity (Benjamin, 2006). In both clinical and academic contexts typical lag is accepted to be 0.25D – 0.75D; however, larger lags have also been reported in the literature.

In naïve participants age 9 – 25 years, Horwood, Turner, Houston and Riddell (2001) employed a Remote Haploscopic Photorefractor to assess accommodation under binocular conditions while reading N5 (very small) text. The authors reported a lag of accommodation which was greatest at the nearest targets. At 4D (25cm) demand, a mean lag of accommodation of 1.2D was found to a small print target. While lag of 0.25D – 0.75D is considered typical in both adult and young children, and within one's depth of focus, the 1.2D of lag as reported by Horwood et al suggests a level of optical blur beyond expected tolerance. Therefore, theoretically the participants in the Horwood et al study should have experienced noticeably blurred vision. Interestingly, in reality, no subject reported blur or an inability to read the text. This finding suggests that there are some individuals functioning with significant under-accommodation on a daily basis who are asymptomatic and do not require clinical intervention i.e. reading glasses.

In a study of adult emmetropes and myopes, Harb, Thorn, and Troilo (2006) reported that observed accommodative lag remained stable during a sustained (10 minute) period of reading. This was consistent for reading distances of 66cm (1.5D), 40cm (2.5D) and 28.6cm (3.5D). This finding suggests that is possible that individuals who exhibit large lags of accommodation, such as those reported by Horwood et al (2001), will continue to experience such lag throughout sustained near tasks. While Horwood et al stated that their participants did not report subjective blur, one might expect eventual subjective difficulty with near tasks as the lag of accommodation persists and it is plausible that educational difficulties could arise as a result.

Studies have reported an association between inappropriate accommodative response and refractive error; particularly noting that increased lag of accommodation is present in hypermetropic children (Horwood et al 2011, Lyon and Candy 2006; Mutti et al 2009). Tarczy-Hornoch (2012) investigated accommodative lag in typically developing infants and reported that lag was generally <1.25D. However, accommodative lag was found to vary according to refractive error and increased lag was found with increased levels of hypermetropia. This is in agreement with the findings of Horwood and Riddell (2011), who examined the accommodative response of 94 infants and children. 38 typically developing infants (aged 6 – 26 weeks) were recruited and their accommodative response was tested at 2 week intervals. Older children between 5 – 9 years were also assessed; 29 hypermetropic children, who were recruited from a hospital eye clinic and 27 emmetropic children, who were recruited from a university database of typical children, underwent a single accommodation assessment. Hypermetropes of all ages were found to underaccommodate to a greater extent than emmetropic controls, both with and without their usual prescribed refractive correction. Greater hypermetropia was found to be associated with greater accommodative lag at each target distance. Typical infants are expected to be hypermetropic to a degree (Moller, 2005). This reduces and normalises with age – a process known as emmetropisation*. Horwood and Riddell (2011) further analysed the infant group, investigating whether or not they emmetropised during the assessment period. Interestingly, the emmetropising infants had the steepest accommodation response slope* due to better near accommodation – suggesting that a lower accommodative response slope may be indicative of failure to emmetropise*. This might suggest that failure of accommodation, not hypermetropia per se could be the primary problem when emmetropisation fails.

Accommodation has also been investigated in relation to Down's syndrome and has been identified as being defective in infants and young children in this group (Woodhouse et al, 1993; Cregg et al, 2001). Woodhouse et al (1996) used dynamic retinoscopy to assess accommodative responses in children with Down's syndrome and in typically developing children aged between 4 weeks and 48 months. Typically developing children showed accurate accommodation while those with Down's syndrome were found to underaccommodate at all target distances. This is supported by further studies from this group (Cregg et al, 2001) which found consistent under-accommodation in children with Down's syndrome, irrespective of the presence or absence of refractive error. The authors refer to the likely impact of this under-accommodation on learning and education in children with Down's syndrome. Bifocal spectacle use was advocated to correct under-accommodation in this subject group (Stewart, Woodhouse, & Trojanowska, 2005). Children with Down 's syndrome have been shown to be receptive to bifocals and normalisation of accommodation in some of these children has been reported following bifocal use (Stewart et al., 2005). Despite this implication in the literature, it is essential to remember that receptiveness to treatment or an association between accommodation and learning does not imply causality. It is as yet unknown if a causal relationship between accommodation and learning exists in either this Down's syndrome group or in the wider population. The relationship between accommodation and education will be discussed in further detail later in this chapter.

2.3 Vision and education

This section introduces the relationship between visual function and academic ability, in particular vision and reading. Discussion will focus on the associations between refractive error, particularly hypermetropia, and education. The literature pertaining to accommodation and education will then be discussed.

A joint statement issued by the American Academy of Pediatrics, Council on Children with Disabilities, the American Academy of Ophthalmology, the American Association for Pediatric Ophthalmology and Strabismus and the American Association of Certified Orthoptists (2009), states that undetected eye problems will prevent individuals performing to their full academic potential.

An inverse correlation has been identified between visual symptoms, measured using the College of Optometrists in Vision Development Quality of Life questionnaire (COVS-QOL), and academic scores (Vaughn, Maples, & Hoenes, 2006). Reading is essential for education. The initial stage of reading, involving the recognition and decoding of text, is a visual process for all sighted children. Vision anomalies can impede the discrimination of letter detail and subsequently result in the failure to decode text into sounds, leading to particular difficulties with reading (Simmons, 1993). Yet, contrasting literature also exists regarding the relationship between visual acuity and reading. While some studies report a significant correlation between visual acuity and academic ability (Kulp et al, 2016; Goldstand, Koslowe & Parush, 2005, Kulp & Schmidt, 2000; Maples, 2000), others do not (Helveston et al, 1985; Dirani et al, 2010). The influence of individual refractive errors on reading has been the subject of much research and an overview of the literature is presented below.

2.3.1 Myopia

As discussed in *Chapter 1*, myopia can result from eyes which are too long antero-posteriorly or which have too great refractive power; this results in a distant object image falling in front of the retina. Myopes therefore, have reduced distance visual acuity but often retain clear near vision. As a result, nearwork tasks are visually much easier for myopes than distance tasks.

It has been reported that myopes are more likely to be proficient at reading than emmetropes and hyperopes (Rosner & Rosner, 1997; Stewart-Brown, Haslum & Butler, 1985). There is also a long-held perception among researchers that myopia is associated with superior intelligence (Verma & Verma, 2015). Mutti, Mitchell, Moeschberger, Jones and Zadnik (2002) postulated that the increased reading and intelligence reported in myopic subjects may in fact be an artefact of behaviour rather than a link between the two – they proposed that children who have better near vision are more likely to read more and hence perform better in reading/IQ tests. In their 2002 study, Mutti et al investigated the relationship between myopia and hours per week of near work in 366 school children; the authors reported an association between increased hours of near work and severity of myopia which was strongest for studying and reading for pleasure. In comparison watching television and playing computer games were not associated with myopia.

While myopia has been associated with increased intelligence and reading ability the converse has been reported for hypermetropia, which will be discussed below.

2.3.2 Hypermetropia

Hypermetropia occurs when the eye has insufficient refractive power for its axial length (Rosenfield, 2006). This may be a result of the eye being too short anteroposteriorly or the lens within the eye having insufficient refractive power (see *Chapter 1*). Hypermetropia can result in blurred distance as well as near vision; however greater blur will be present at near. Accommodation can be used to compensate for modest hypermetropia in the distance however even more accommodation is then needed for clear near vision. It is generally assumed by clinicians that children will have sufficient accommodative ability to overcome modest hypermetropia and achieve clear near and distance vision most of the time, although it is unknown if this is true as it is not clear how much children typically accommodate at near.

There is an increased prevalence of hypermetropia in lower socio-economic (SES) groups (Williams, Northstone, Harvey, Harrad, & Sparrow 2008). Interestingly, academic achievement, in particular reading ability is also correlated with SES (Peterson & Pennington, 2015; Purcell-Gates & Dahl, 1991, White, 1982). The relationship between hypermetropia and academic achievement has been the subject of much research. Blurred near vision resulting from hypermetropic refractive error could result in failure to correctly identify and decode letters. This would predict that significant levels of hypermetropia would lead to difficulty reading and ultimately failure to learn. However, one could also consider an alternative scenario – disadvantaged children could fail to emmetropise and remain hypermetropic as a result of poor ability and/or a failure to engage with education and reading.

Studies have linked uncorrected hypermetropia in children with lower scores than their myopic and emmetropic counterparts on a range of cognitive and motor tests (Atkinson, Braddick, Nardini, & Anker; 2007; Krumholtz, 2000; Kulp et al, 2017; Kulp & Schmidt 1996; Quaid & Simpson, 2013; Roch-Levecq, Brody, Thomas, & Brown, 2008; Rosner, 2004; Kulp et al, 2016; Williams et al, 1988, Williams et al, 2005). However, no study has yet identified whether a causal link exists between the two (Simmons, 1993; Thurston, 2014).

Hypermetropia has also been associated with lower IQ – Williams et al (1988) investigated IQ scores in hypermetropic (> +2.25DS), myopic and emmetropic children at age 7 and 11 years. While verbal IQ was not significantly different between the groups at age seven, by age eleven those with hypermetropic refractive errors had significantly lower verbal IQ than both the myopic and emmetropic children. Performance IQ was lower in the hypermetropic group at both time points although the authors fail to account for this difference in performance and verbal IQ scores. Interestingly, no difference in reading ability was observed between the groups. Narayanasamy, Vincent, Sampson and Wood (2015) have shown that low levels of simulated hypermetropia negatively impacts academic performance, including reading. However, this result must be viewed with caution as the authors also reported a correlation between simulated hypermetropia and a change in participants' baseline eye position. Inducing hypermetropia by way of lenses can cause a sudden and unfamiliar change in accommodative demand and alter participants' control of binocular vision*. It is unclear from Narayanasamy et al if the participants concerned had sufficient capacity to adapt to these changes as motor fusion was not assessed. This can be considered a confound to the presented results.

Studies have also investigated the relationship between naturally occurring hypermetropia and reading ability, and report an inverse relationship between the two (Rosner & Rosner, 1997; Stewart-Brown, Haslum & Butler, 1985). An association between hypermetropia and poor reading has also been identified in very young children – uncorrected hypermetropic children have been found to exhibit lower emergent literacy scores than emmetropic controls (Shankar et al, 2007; Kulp, 2016). Following adjustment for race/ethnicity and parents/caregivers' education, Kulp (2016) reported that hypermetropic children continue to exhibit poorer emergent literacy than emmetropic controls; although, interestingly the magnitude of hypermetropia did not appear to influence this result.

Although hypermetropic children appear to show poorer reading ability, the relationship between hypermetropia and reading has not yet been shown to be causal. Roch-Levecq, Brody, Thomas and Brown (2008) identified ametropic* (Hypermetropia >4.00DS, Astigmatism >2.00DC or a combination) and emmetropic children (<2.00DS ± <1.00DC). Ametropic children were found to perform significantly worse than emmetropic children at baseline on a range of cognitive tests. Following glasses correction, ametropic children were found to improve performance on tests of visual motor integration and the Wechsler Preschool and Primary Scale of Intelligence, although the latter did not reach statistical significance. In a small study, van Rijn et al (2014) identified uncorrected hypermetropic children (spherical equivalent +0.50DS -

+4.63DS) and issued participants with either full, partial or no hypermetropic correction. Reading speed and non-word decoding was assessed prior to correction and again 4 – 6 months post correction. Reading speed of the full correction group was found to improve significantly compared to the partial or no correction group. No detail is given regarding the differences observed between the partial and no correction group. As only reading speed, and not reading accuracy, was found to improve this suggests that hypermetropia affects speed of letter recognition rather than decoding skills. However, the findings of this study cannot be considered conclusive. The control group in this study were not given glasses and therefore were not masked to examiners during repeat testing. The lack of a true control group (i.e. a group with plain lens (non-prescription) glasses) confounds the results as one cannot be certain that examiner bias did not influence results. Furthermore, the number of participants in this study who were issued with full hypermetropic correction and attended for a follow up reading assessment were limited (only 17 subjects), thus firm conclusions cannot be drawn from this study.

From the current literature, there are suggestions that a causal relationship could exist between hypermetropia and poorer reading/education. However, flawed methodologies and an absence of good quality control studies means that one cannot be certain at present if a causal relationship exists between the two. Perhaps hypermetropia does not cause poor reading/ability? One could hypothesise that the increased prevalence of hypermetropia in children with lower ability could be attributed to cognitive development or that children fail to emmetropise as a result of lack of engagement. Further high quality, controlled research is required to form definitive conclusions on this topic.

2.3.3 Accommodation and education

As outlined in *Chapter 1,* accommodation refers to the change of the shape of the ocular lens to enable clear near vision. Under-accommodation results in blurred near vision; therefore, it is possible that under-accommodation would have a detrimental impact on children's learning in the same way that uncorrected hypermetropia might. Both under-accommodation and hypermetropia can result in near blur which could impede word recognition and reading ability. An association between inappropriate accommodative response and refractive error has been reported in the literature, in particular that an increased lag of accommodation has been shown to be present in hypermetropic children (Horwood & Riddell, 2011; Lyon & Candy 2006; Mutti et al 2009). One could consider that under-accommodation in all children presents a barrier to clear near vision which is similar, albeit milder than hypermetropia. However, as previously discussed, while it appears that there is an association between poor reading/lower academic achievement and hypermetropia, conclusions regarding causality cannot be drawn at present. One could hypothesize that in fact failure to engage with a task, e.g. due to task difficulty or attention might lead to a secondary reduction in accommodation as opposed to under-accommodation/hypermetropia leading to poor reading.

Research has been carried out regarding the relationship between accommodation and education (Table 2-1) however, the current evidence base is conflicting as some studies report a correlation between accommodative function and education (Dusek, Pierscionek, & McClelland, 2010; Grisham, Powers, & Riles, 2007; Kulp & Schmidt, 1996; Motsch & Huhlendyck, 2000; Poynter, Schor, Hayes, & Hirsch, 1982; Quaid & Simpson, 2013; Shin, Park, & Park, 2009) whilst others refute this association (Creavin & Williams, 2015; Kedzia, Tondel, Pieczyrak, & Maples, 1999; Latvala, Korhonen, Penttinen, & Laippala, 1994). Differences between these studies could be attributed to participant selection; for instance, some of the existing accommodation research has focused on the difference in accommodation between children with a reading difficulty and those who have not. Other differences could be explained by methodological differences, as some studies report subjective accommodation testing while others report objective accommodation assessment or a combination of both. Indeed, of the studies which report an association between accommodation and reading ability, the method of accommodation assessment varies and the accommodation deficit found to be associated with reading ability is inconsistent suggesting that methodology is an important factor. Suggestions for differences observed in the current literature base will be discussed below.

Author	Year	Country	Cycloplegic Refraction?	Participant Age (years)	Number of Participants (n)	Known Reading Difficulty	Control group	Accommodation Assessment	Educational Assessment	Accommodation related to academic outcome?
Poynter, Schor, Hayes, & Hirsch	1982	USA	Not stated	9 – 11	74	N	N/A	Lag	Standardised test	✓
Evans	1994	UK	N/A	7 – 12	82	Y	Y	Amplitude Lag Facility	Diagnosed dyslexic subjects	✓
Latvala, Korhonen, Penttinen, & Laippala	1994	Finland	Y	12 - 13	105	Y	N/A	Amplitude	Diagnosed dyslexic subjects	✗
Kulp, & Schmidt	1996	USA	Y	5 – 7	181	N	N/A	Facility	Standardised test	✓
Kedzia, Tondel, Pieczyrak, & Maples	1999	Poland	N/A	8	76	N	N/A	Facility	Teacher assessment	✗
Motsch, & Huhlendyck	2000	Germany	N	9 - 10	89	N	N/A	Near point of accommodation	Orthoptist/ophthalmologist judgement of reading	✓

Grisham, Powers, & Riles	2007	USA	N/A	14 - 19	461	Y	N	Amplitude Facility	Teacher assessment	✓
Palomo-Alvarez & Puell	2008	Spain	N/A	8 - 13	119	Y	Y	Binocular relative accommodation Facility	Not stated	✓
Shin, Park, & Park	2009	USA	N	9 - 13	114	N	N	Amplitude Facility	Standardised test	✓
Dusek, Pierscionek, & McClelland	2010	Austria	N	6-14	1153	Y	Y	Amplitude Facility	Poor readers and writers identified by educational institution.	✓
Quaid & Simpson	2013	Canada	Y	10	100	Y	Y	Amplitude Facility	Poor readers identified through school education plan	✓
Creavin & Williams	2015	UK	N	7 – 9	172	Y	N	Amplitude	Standardised test	✗

Table 2-1: Details of studies specifically investigating accommodation and academic ability. It is clear that existing research has focussed on subjective methods of assessing accommodation. Conflicting results can be seen between studies although where accommodative lag has been assessed it consistently appears that lower accommodation is related to poor reading ability.

Grisham, Powers and Riles (2007) reported accommodative infacility and reduced amplitude of accommodation in poor readers. Palomo-Alvarez and Puell (2008) investigated monocular amplitude of accommodation, relative accommodation and accommodative facility in 8 – 13 year old children diagnosed as poor readers and a control group. The authors similarly reported a lower amplitude of accommodation and accommodative facility in the poor reader group, although no difference was found in assessment of relative accommodation. Quaid and Simpson (2013) also investigated accommodation in 10 year old children with an individual education plan and in age matched control subjects. The authors investigated both accommodative amplitude (push-up) and accommodative facility in both groups. However, in contrast to the previous two studies, children with an individual education plan were found to be poorer than age matched controls for the accommodative facility assessment only. Therefore, it is clear that study results can vary as a result of the accommodation assessment method used.

Amplitude of accommodation was measured subjectively in all studies. Numerous confounds to the subjective assessment of accommodation are reported in the literature, such as depth of focus and participant instruction set (Adler, Scally, & Barrett, 2013; Kedzia, Pieczyrak, Tondel, & Maples, 1999). This could account for the conflicting results observed in the literature reporting subjective accommodation. For instance, children might have difficulty understanding the concept or blur, be slower to report the blur or less motivated to overcome blur, e.g. during accommodative facility testing. The push up method of accommodative amplitude assessment in particular is associated with large intra-subject variability (Adler et al, 2013) and therefore may not be repeatable across studies.

Assessment of accommodative lag indicates the actual accommodation that an individual will exert at a given distance. It does not involve altering convergence as in accommodative amplitude (push-up) or rapid changes of accommodative demand as required for accommodative facility. Therefore, compared to accommodative amplitude/facility, accommodative lag is thought to be a more meaningful measure of how someone will accommodate during reading (Evans, 2001). In addition, accommodative lag can be measured objectively. This is considered a more reliable measure of accommodation than that achieved with subjective methods, particularly in the paediatric population.

Research has indicated that accommodative lag is associated with poorer reading ability. For instance, Poynter, Schor, Hayes and Hirsch (1982) used MEM dynamic retinoscopy to assess accommodative lag in 9 – 11 year old children. Academic ability was measured with the Stanford test – a standardised test widely used in U.S. schools. Accommodative lag was found to account for 6 – 8% of the variance in children's test scores. Although the variance explained is low, the authors suggest that there is a relationship between accommodation and education.

This is supported by the findings of Dusek, Pierscionek and McClelland (2010), who investigated the relationship between reading and accommodation using both objective (MEM retinoscopy) and subjective (push-up and facility) assessment methods in a large study (825 participants with reading difficulties and 328 control participants) of 14 – 19 year olds. The authors reported that participants referred with reading difficulties were more likely to exhibit lower accommodative amplitude, monocular accommodative facility and increased accommodative lag than the control participants. However, the authors also report a small number of subjects with accommodative insufficiency in the control group. Individual data is not presented; therefore, it is difficult to establish the direction of the relationship between accommodation and reading from the data reported.

In addition, the findings of both studies are limited by the accommodation assessment methods used. The limitations of subjective methods, such as those used by Dusek et al (2010), have already been discussed and it is clear that objective techniques are preferable in a paediatric population as children are often unable/unsuitable for subjective testing. While the assessment of accommodative lag is preferable to subjective methods, the utilisation of dynamic retinoscopy might not actually provide the best measure of accommodation. Dynamic retinoscopy is an artificial task, and while it can be performed with both eyes open it is typically performed uniocularly. MEM retinoscopy, as used in the above studies, is particularly a non-naturalistic method as lenses are employed to assess lag. The dissociation between accommodation and convergence induced through lenses could alter essential vergence (disparity) accommodation cues, subsequently affecting the accommodative response. Similar disruption could be observed should dynamic retinoscopy ever be performed binocularly as the flashing streak of the light can disrupt disparity. These considerations are particularly pertinent given that it is now known that disparity is responsible for a large part of the naturalistic accommodation response. Should dynamic retinoscopy be used, the more naturalistic modified Nott method (Woodhouse, Meades, Leat, & Saunders, 1993) is preferable. This technique removes the need for lenses as the examiner must move their retinoscope to determine the amount of active accommodation. Whilst preferable, Nott retinoscopy is still limited by the requirement for dim lighting conditions during assessment and the typical measurement of accommodation response in one eye at a time. Research using binocular photorefraction to measure accommodation is required to evaluate the findings of the above studies under more naturalistic conditions.

It is difficult to draw conclusions about the relationship between accommodation and academic ability/reading from the current evidence base. Current available literature is limited by sampling issues and methodology.

The existing literature regarding accommodation and academic ability/attention largely details subjective measures of accommodation assessment, e.g. accommodative amplitude or facility. Numerous confounds to the subjective assessment of accommodation, such as participant instruction, appreciation and timely reporting of blur, are reported in the literature (Adler et al, 2013; Kediza et al, 1999). Such confounds might, in part, account for the conflicting evidence regarding accommodation and academic ability observed in the literature. Until recently, objective assessment of accommodation has been limited to dynamic retinoscopy to evaluate accommodative lag. As discussed, this method presents its own limitations; it is a monocular assessment and requires unnatural lighting conditions and often the use of lenses to complete the assessment. Therefore, it cannot be concluded that the accommodation measured reflects natural conditions for these children.

Sampling varies across the literature. While some studies have assessed reading and accommodation in an unselected population, others have compared poor readers with control participants. Group comparisons are somewhat limited in that group averages rather than individual data are compared. Therefore, while lower average accommodation may be reported in a group with reading difficulty, this does reveal the presence of individual cases of accommodative insufficiency that might require treatment. Furthermore, given the conflicting evidence base one must be aware of the possibility of bias within datasets, e.g. studies who recruited volunteers for reading research could have attracted participants with a particular interest in this who could be more likely to fail.

In addition, one could hypothesize that attention or engagement could account for the conflicting results in the current literature. It is not clear if children who experience difficulties with reading have the capacity to accommodate if they really need to, e.g. to really small print or if asked to "try very hard". For instance, it is plausible that some children with reading difficulties might not engage with a reading task or maintain sufficient attention, thus leading to a secondary loss of accommodation.

It is clear that there is a gap in the current literature base for a carefully designed study which uses an objective measure of accommodation and relates this to standardised measures of ability in order to draw firm conclusions on the relationship between accommodation and academic ability.

2.4 Reading and Vision

Much of the research pertaining to the relationship between vision and academic ability describes the impact of vision on reading outcomes; this section will introduce a background to reading, its relationship to other academic outcomes and the process of reading development. Visual ability is also often considered in research on reading ability and dyslexia. Therefore, a brief overview of dyslexia and the theories regarding its development will be introduced.

Reading is a complex process which allows a person to make sense of orthographic information. It has become essential for modern day to day living. Reading is especially important for education and is considered a marker for success (Cain, 2010; Cromley, 2009; Espin & Deno, 1993; Grimm, 2008; O'Reilly & McNamara, 2007).

While it facilitates the acquisition of knowledge, reading also involves the use of higher order skills which are employed in other areas of academia. Espin and Deno (1993) reported a correlation between reading measures and students' grade point average and performance on standard achievement tests. Reading comprehension has also been correlated with higher achievement in science (Cromley, 2009; O'Reilly & McNamara, 2007). In a study of over 170,000 students across 43 countries worldwide, Cromley (2009) reported a strong correlation (r= .840) between reading ability and science assessments. An association between reading and mathematical ability has also been shown in the literature; Grimm (2008) reported that reading comprehension is important for success in mathematics. In a large longitudinal study of children in US grades 3 – 8, Grimm found that reading comprehension was a significant predictor of mathematic ability, even when controlling for gender, socio-economic status and ethnicity. Vilenius-Tuohimaa, Aunola and Nurmi (2008) further support the association between mathematic ability and reading comprehension. After controlling for the level of technical reading required in the problems, the authors reported that performance of maths words problems was still strongly related to reading comprehension. Therefore, reading ability could be considered a marker for general academic ability. This is relevant to this thesis as it suggests that, in the case of accommodation, children who underaccommodate and have difficulty reading as a result of subsequent blurred vision could also experience difficulties in other areas of education.

Reading difficulties may prevent a child from reaching their full academic potential and are associated with negative outcomes in adult life, for example evidence suggests that low levels of literacy are frequently found in prison inmate population (Snowling et al, 2000; Tewksbury & Vito, 1994). Thus, the maximisation of reading ability is considered of the upmost importance. According to the simple view of reading, the reading process requires a combination of cognitive activities relating firstly to the visual recognition and subsequent decoding and reading of words on a page and secondly comprehension of the presented text (Gough & Tumner, 1986).

2.4.1 Word reading

Words may be read by sight, by decoding the individual letters in a word, by analogy and by prediction from context (Cain, 2010). When a reader has encountered a word on several occasions, has become familiar with it and has retained a memory of the word it can then be read by sight; this is thought to be the way most skilled readers decode words (Ehri, 1995). In the case of an unfamiliar word, readers can break down the component letters, sound them out and blend the letters to form the word; a process known as phonological decoding. When reading by analogy, the reader will use the pronunciation of a familiar word to aid pronunciation of an unfamiliar, yet similarly spelled, word. Prediction from context is another method of word reading, although it is considered a hallmark of less able/beginning readers, where the reader may use memory of the text read previously and knowledge of the topic to predict and read unfamiliar words (Stanovich, 1986). The stages of skilled reading development will be discussed in more detail below.

2.4.2 Development of word reading

Knowledge of letters and print are needed to develop word reading. In order to read, one must first understand certain concepts of printed text, including the recognition that print has meaning, the required orientation of a book/text and the direction of reading, e.g. from left to right in English, the understanding of letters versus words and knowledge that words have spaces between them (Clay, 1981). Phonological awareness refers to the recognition and manipulation of sounds (phonemes/graphemes) in language; a phoneme is considered the smallest unit of sound in a word while a grapheme is a letter or group of letters that represent a sound (phoneme) in a word. Grapheme-phoneme correspondence is used to match letters to sounds. Phonological awareness is also necessary for reading and has been shown to be strongly correlated to reading development (Muter, Hulme, Snowling, & Taylor, 1997; Roberts & McDougall, 2003).

Reading is thought to develop in phases and models of reading development have been proposed. Frith (1985) describes a model of reading development consisting of three stages. The first stage is the logographic stage where children recognise words instantly from certain features including shape and size, e.g. iconic recognition of the "M" for McDonalds. This is followed by the alphabetic stage where the letter/sound relationship is developed and children learn to merge sounds into words using grapheme/phoneme correspondences. This is only possible for regular words where there is a transparent match between graphemes and phonemes. The final stage proposed by Frith is the orthographic stage where readers no longer rely on letter/sound relationship and instead familiar words (regular and irregular) are stored in an internal dictionary (lexicon) and recognised automatically. Readers are considered proficient at this stage, only needing to sound out unfamiliar words.

An alternative model of reading development has been proposed by Ehri (1995). This theory comprises of four stages of reading development, the pre-alphabetic phase, partial alphabetic phase, full alphabetic phase and consolidated alphabetic phase. Ehri's model is considered more flexible than Frith (1985) and the author has stated that it is possible for children to be in two phases at once (Ehri, 2002). The pre-alphabetic phase corresponds to Frith's orthographic stage. In this phase, Ehri states that, similar to Frith (1985), the reader does not yet rely on a letter/sound relationship, instead establishing word pronunciation based on visual cues. The naming of this phase as pre-alphabetic has been criticized. Beech (2005) states that the name pre-alphabetic does not indicate the phase's role in reading development and should instead be considered the "salient visual feature phase". After acquiring knowledge of letter names and sounds children enter the partial alphabetic phase where Ehri (1995) suggests that readers will use "phonetic cue reading", placing importance on the first and final letters, to attempt word pronunciation. In the full alphabetic phase, the reader will map graphemes to phonemes. During this phase there is a transition from decoding to sight word reading. Ehri's final stage is the consolidated alphabetic stage which corresponds to Frith's orthographic stage. Recurring graphemes are consolidated and stored in an internal lexicon making reading new words easier (Ehri & Robins, 1992).

2.4.3 Model of word reading

Models of reading have been developed to explain the processes used by skilled readers to process words. The most influential of these models are the dual route cascaded

(DRC) model and the triangular (connectionist) model. These models of reading provide an understanding of the sources of reading difficulties.

The dual route cascaded model was developed from the dual route model of reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). The dual route theory concerns how pronunciation of a printed word is generated and describes two routes from writing to speech, the lexical and sublexical route. The lexical route consists of visual analysis of print and draws on stored memory of word pronunciation, an example being the pronunciation of irregular words such as “yacht”. The sublexical route consists of translating graphemes to phonemes to establish pronunciation of regular words and pseudowords.

The dual route cascaded model differs in that it consists of a direct lexical route and an indirect grapheme-phoneme correspondence (GPC) route. The lexical route may be either lexical semantic or non-semantic. The non-semantic route is used for familiar words while non-words can be read via the lexical semantic route where orthographically similar words will be used to enable the phonological information to pronounce the unfamiliar word. The GPC route enables the pronunciation of pseudo-words and non-words through grapheme-phoneme correspondence rules.

Connectionist models, such as that introduced by Seidenberg and McClelland (1989) provide an alternative to the dual route theory. This involves connections between written word (orthography), organisation of sounds in a word (phonology), semantics and context through direct links or hidden layer connections (Cain, 2010).

The visual analysis of print is the pathway that is likely to be affected by difficulties with accommodation. Logically, blurred near vision will impede the recognition of letters resulting in decreased reading accuracy and possibly influencing comprehension.

2.4.4 Additional factors influencing reading development

While visual analysis of print could be influenced by poor vision e.g. as a result of accommodation it must be acknowledged that vision is not the only factor which can influence reading development. Additional variables such as home literacy environment, language skills, hearing ability and attention have all been reported as potential confounds to reading development.

In a review of the literature pertaining to emergent literacy, Whitehurst & Lanigan (1998) highlighted the importance of the early literacy environment e.g. the numbers of books in the home, parental time spent reading with children, etc., on reading development. This was further supported by a report from Sénéchal, LeFevre, Thomas, & Daley (1998), who concluded that parental reports of how frequently they taught their child to read was predictive of written language skills, including decoding. In a 5 year longitudinal observational study of literacy development, Alston-Abel & Berninger (2018) provided further evidence regarding the importance of the home literacy environment on reading development. The authors used parental report to determine the home literacy environment. Parents provided details on the number of minutes their child read per week at home, the nature of the child's reading (i.e. for pleasure or homework) and time provided by the parent to help the child to read. From their analysis, Alston-Abel & Berninger reported that an active home literacy environment was associated with higher literacy achievement, providing further support to the relevance of this factor on children's reading development.

It has been suggested that the importance of the home literacy on reading development is related to language development. Language, in particular vocabulary has been implicated in reading development (Bradley & Bryant, 1983, Payne, 1994). As reading is the translation of written text to spoken language, familiarity with language and access to a varied vocabulary have been reported as important factors in reading development. An active home literacy environment, in particular storybook reading, has been found to predict oral language, and as such reading comprehension (Sénéchel, LeFevre, Hudson, & Lawson, 1996).

Home literacy environment has been found to be affected by factors such as socio-economic status (SES) and ethnicity. Van Steensal (2006) reported that higher SES was associated with a more stimulating home literacy environment. Increased variability in home literacy was identified in lower SES homes and ethnic minorities. This could account in part for increased reading ability identified in higher SES groups (Bradley & Corwyn, 2002).

Individual factors such as hearing and attention have also been considered in relation to reading development. Lederberg, Schick, & Spencer (2013) reviewed the literature pertaining to deaf children and reading development and reported that deaf and hard of hearing children have poorer reading outcomes than their hearing peers. The authors reported that language difficulties in deaf and hard of hearing children impacted literacy. It has been reported that speechreading and vocabulary are important for reading development in deaf children (Kyle, Campbell, & McSweeney, 2016) and suggest that drawing children's attention to visual speech is likely to help deaf and hard of hearing children to distinguish phonemes and improve reading skills.

Attention has also been reported in the literature in relation to reading and it is thought to play a crucial role in reading ability. Commodari & Guarnera (2005) assessed 98 children age 11 – 14 years and found that poor readers performed worse on measures of attention; therefore, concluding that a relationship between poor reading and attention exist, although it was not possible to determine from the data if this relationship is causal. This association between reading and attention was supported by a further report from Cain & Bignell (2013) who again found that poor reading was related to poor attention. Research has also investigated children with active diagnoses of ADHD and found that ADHD is associated with poor reading test scores (for review see Loe & Feldman, 2007) again inferring the influence of attention on reading ability.

In conclusion it is clear from the wider reading evidence base that numerous, non-visual, factors have also been implicated in reading development. To accurately investigate the relationship between reading and vision one needs to account, as much as possible, for other external factors which are known to impact reading. Factors such as attention and the home literacy environment will be addressed in the later experimental chapters (Chapter 4 and 5) of this thesis where attempts are made to control for these factors.

2.4.5 Dyslexia

Dyslexia is a specific learning difficulty in which reading and spelling fail to develop to the expected level. Depending on the definition used, it is thought to affect 3 – 10% of the population (Snowling, 2000). It has been shown to be a hereditary condition (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Dyslexia has been found to be comorbid with attention disorders such as attention deficit hyperactivity disorder (ADHD) (Germanò, Gagliano, & Curatolo, 2009; Willcutt & Pennington, 2000a; 2000b). Evidence suggests that this comorbidity has a genetic link (Willcutt & Pennington, 2000b).

Dyslexia is often diagnosed by exclusion and as such many different definitions exist. For the purpose of this thesis the definition approved by the British Dyslexia Association Management Board (2007) will be used;

"Dyslexia is a specific learning difficulty that mainly affects the development of literacy and language related skills. It is likely to be present at birth and to be life-long in its effects. It is characterised by difficulties with phonological processing, rapid naming, working memory, processing speed, and the automatic development of skills that may not match up to an individual's other cognitive abilities".

As reading is a visual task, visual function, in particular visual processing has been suggested as a possible cause of dyslexia (Evans, 2001). The first case of developmental dyslexia was made by general practitioner Pringle-Morgan in 1896; Pringle-Morgan and Hinshelwood, an ophthalmologist speculated that dyslexia was a result of "congenital word blindness" (cited in Snowling, 1996). Some researchers have proposed that dyslexia is a result of a deficit in the magnocellular visual system. Visual processing is divided into two streams, the dorsal magnocellular system which is responsible for detecting motion and the ventral parvocellular system, responsible for identifying form. A magnocellular deficit can result in the perception of words moving on a page and difficulty recognising and sequencing letters; therefore, resulting in blurred vision when reading text (Stein, 2001). Dyslexic subjects have been reported as having a reduced ability to detect flicker (Martin & Lovegrove, 1987; Talcot et al, 1998) and difficulties with motion processing (Talcot et al, 1998; Wilmer, Richardson, Chen, & Stein, 2004), which provides support to the magnocellular deficit theory of dyslexia. However, at present the evidence regarding the magnocellular deficit theory is considered insufficient to base treatment upon and as such, visual deficits are not considered the primary cause of dyslexia (American Academy of Pediatrics, 2009; Creavin & Williams, 2015; Snowling, 1996).

Interestingly, research has also demonstrated that individuals with reduced visual acuity (6/18) are capable of reading tiny print such as that found on medicine bottles (5 point print), with 22 point print suitable for individuals with moderate – severe (6/24 – 6/60) reductions in visual acuity (Drummond, Drummond & Dutton, 2004). Evidence does suggest that early readers read better with larger text (Hughes & Wilkins, 2000). However, recommended font sizes for beginning readers range from 12-24 point print (Burt, 1959; Tinker, 1959, Cited in Watts & Nisbett, 1974). Therefore, mild levels of blur may or may not interfere with reading development. The scientific consensus at present remains that dyslexia is a language based disorder which is primarily caused by phonological deficits (Peterson & Pennington, 2015; Shaywitz & Shaywitz, 2005; Vellutino et al, 2004).

2.5 Summary

The review of the reading literature presented above suggests that clear vision is necessary for reading development. It is possible that it would be especially important at the decoding stage of reading. Even though young children use large print when learning to read they still need appropriate visual function and clear near vision for appropriate letter discrimination and decoding. Indeed, visual function and visual processing have been implicated in the dyslexia literature.

The review of the ophthalmology and vision science literature also suggests that there is an association between vision and reading ability/education. Although they are separate entities, dysfunction of accommodation and hypermetropia similarly result in blurred near vision. Current evidence suggests that blurred near vision, resulting from hypermetropic refractive error or under-accommodation, is associated with poorer reading. While this association is plausible no study exists to date which proves a causal relationship between accommodation or hypermetropia and reading. Studies investigating accommodation and reading have either been limited by a reliance on subjective testing methods (which are difficult for young children to accurately complete and influenced by observer testing techniques) or limited by questionable participant selection. While studies have made assumptions and hypothesise regarding the relationship between reading and accommodation, actual evidence is conflicting and firm conclusions cannot be drawn from the existing evidence base.

There is a clear gap in the literature for a controlled study to objectively assess accommodation using a photorefractor under naturalistic, binocular conditions and relate this to reading ability - this will be explored in this thesis. If a relationship between reading/education and accommodation is identified then a much larger RCT would be require to prove causality. In this case, the findings of this thesis would provide the pilot data for any such future study.

Chapter 3 - Qualitative Study

3.1 Introduction

Correlation does not imply causation; only successful treatment of the intervention group during an intervention trial can be used to prove causality. A randomised control trial (RCT) is the accepted gold standard for evaluating the efficacy of prospective treatment modalities. If an association is identified between accommodation and academic achievement this would require an intervention trial to assess causality. An accommodation RCT would involve a group of children with normal distance vision, who had passed current school vision screening, to wear spectacles for close work to correct any under-accommodation found. The control group would also have glasses for close work although these would not have any prescription i.e., they would be plain glasses (Appendix 1).

The aim of this qualitative study was to identify parental opinions regarding participation in future accommodation studies of this nature and, in particular, parental opinions regarding research involving glasses wear. This will inform the design of future studies, e.g. an accommodation RCT and provide information to funders regarding the viability of the research.

Recruitment is one of the most challenging aspects of an RCT (Bower, Wilson & Mathers, 2007; McDonald, Knight, & Campbell, 2006; Treweek, Mitchell, & Pitkethly, 2010; Wilson, Delaney, & Roalfe, 2000). In their systematic review, Fletcher, Gheorghe, Moore, Wilson, & Damery (2012) reported that 50% of RCTs fail to recruit the participant numbers required for adequate statistical power. The authors also reported that only 50% of trials recruit sufficient participants within an acceptable time frame. Potential barriers to RCT recruitment have been identified and include low participant motivation, lack of interest in research and fear of negative effects (Fletcher et al, 2012). RCT recruitment in a paediatric population is reported to present unique challenges to investigators (Foster & Warady, 2009; Shilling et al, 2011). In a qualitative study exploring recruitment to paediatric trials, Shilling et al (2011) reported that paediatric trial decisions taken by parents were influenced by perceived trial safety, benefit and practicality. Participant safety is reported by the authors as the parent's primary concern. Due to the nature of an RCT, subjects have no control over the treatment modality which they will receive. As such, fear of negative effects may apply to either the treatment or non-treatment group within an RCT; thus, potentially negatively impacting upon recruitment. Perceived safety issues will also influence participant adherence to the prescribed treatment modality, as well as participant retention, as parents do not want to endanger or disadvantage their children.

Inadequate recruitment and adherence can result in an underpowered RCT with subsequent failure of the resulting analysis to identify a treatment effect due to type II error. It is therefore prudent to explore the potential effect of the aforementioned barriers to a paediatric RCT prior to commencement, in order to enhance study design, maximise participant recruitment, treatment adherence and retention.

An RCT to investigate causality in under-accommodation in a paediatric population would involve the prescription of low hyperopic spectacles for close work to a group of the participating children. These children would not typically be issued glasses by the hospital eye service or a high street optometrist. As children in the treatment group would be required to wear glasses on at least a part time basis it is essential to understand, prior to study commencement, if this study design would be acceptable to parents or if parents perceive potential negative effects in either the treatment or non-treatment group. It is also necessary to understand if glasses wear would be acceptable to parents and whether the treatment modality itself would pose a barrier to recruitment. Parental willingness to support and encourage glasses wear would also be integral to any future study to ensure treatment adherence.

While literature documenting the impact of refractive error on quality of life in adults and children has been identified (Kandel, Khadka, Goggin, & Pesudovs, 2017; Kumaran, 2015), evidence regarding the use and acceptability of corrective lenses in childhood is limited and has only recently been reported in the literature. Schikle et al (2014) reported the perception of young adults' (18 – 35 years) experience of wearing spectacles. The authors reported a focus group study where participants expressed a belief that glasses at a young age can appear "geeky" and are associated with bullying in childhood, with glasses becoming more socially acceptable with age. In another qualitative study, Kodjebacheva, Maliski, & Coleman (2015) explored parents' perception of the use of refractive correction in children. The authors reported parental concerns regarding glasses wear in childhood, similar to the perceptions outlined in Schikle et al (2014), which include disappointment and worry about teasing. The authors also reported societal and cultural barriers to wearing glasses, including that, despite professional recommendations, some parents were of the opinion that eye treatment was not necessary for children. Although it cannot be concluded from this research that similar attitudes or concerns would be held by parents consenting for their children to be involved in a research trial, the concerns highlighted in these studies are potential barriers to RCT recruitment as some parents may not want their children to wear glasses, particularly if the parents were aware that their children's vision would otherwise be considered 'normal'". Dudovitz, Izadpanah, Chung, & Slusser (2016), reported a qualitative study investigating perspectives on corrective lenses in relation to children's school work. The authors interviewed parents, teachers and students in a focus group setting. In contrast to Kodjebacheva et al (2015), this study draws interesting conclusions regarding the positive impact corrective lenses may have on students and their families in relation to school engagement and performance. All subject groups reported that corrective lenses had a positive impact on students' school function, ranging from improved grades to improved concentration and engagement. However, the refractive error of the children concerned in this study is unknown and as such conclusions regarding the acceptability of corrective lenses for small refractive errors or in the case of under-accommodation cannot be drawn from this. Furthermore, research has shown that improvement in visual acuity is not the sole factor for children to comply with glasses wear and that other variables such as fit and comments from peers are significant factors in glasses compliance (Horwood, 1998). Therefore, while Dudovitz et al's research does imply that glasses are acceptable to parents and children, it is possible that factors unrelated to visual acuity may have increased the positive response observed. Research investigating likely glasses compliance/parental adherence to treatment is needed to clarify if glasses would be acceptable in a research context.

3.1.1 Objectives

The primary objective of the study was to establish parental opinions regarding an intervention trial utilising glasses for close work and provide the necessary evidence regarding the acceptability of an accommodation RCT and the potential barriers which would hamper recruitment and retention.

The literature review revealed a surprising paucity of evidence regarding parental understanding of vision problems and their perception of children's eyesight. This information would also be useful to support the design of a future intervention trial. Thus, a secondary objective was to investigate parental understanding of common eyesight problems in children to address the current lack of literature in this area.

3.2 Method

A qualitative research approach was taken for this study. Fletcher et al (2012) reported that the utilisation of qualitative methods is the most promising approach to identify and overcome potential barriers to recruitment in RCTs. A qualitative approach places more emphasis on the participant's thoughts and opinions, thus allowing for a deeper exploration of their opinions. Qualitative research can also provide perspectives which clinicians/researchers have not previously considered; providing richer data than that achieved with quantitative methods.

Should an intervention trial be found to be unacceptable to parents, rich data obtained through qualitative research would provide a deeper understanding of the specific barriers and concerns that parents may have. As such, it would provide a clearer understanding of how to address parents' concerns and how best to adapt any future study design to make it more acceptable and viable.

In health care, qualitative research most frequently takes the form of focus groups or one to one interview (Tong, Sainsbury & Craig, 2007). Focus groups consist of a number of individuals participating in a group interview, whereby participants respond to questions from a moderator, although participants are also encouraged to discuss the subject amongst themselves. While focus groups would allow a researcher to identify parental concerns regarding RCTs and eyesight research, the group interview setting could limit the data obtained as participants may feel inhibited in a group setting and therefore restrict their opinions. One-to-one interviews explore participants’ opinions on an individual level and provide the researcher with the opportunity to obtain in-depth insight into the participants’ perspective through probing the interviewee to expand on particularly relevant points. The latter was therefore considered the most suitable method to investigate parental opinions in this study.

Validity in qualitative research is not measured in the same way as in quantitative research. In qualitative research, validity refers to the extent to which the findings are true to the research aim, the trustworthiness and authenticity of the data (Holloway, 2008). Guba and Lincoln (1989) proposed criteria to establish trustworthiness and rigour in qualitative research (Table 3-1). This study was conducted in line with these criteria.

Guba & Lincoln (1989) rigour in qualitative research	
1. *Credibility*	Refers to internal validity of the data. The account detailed by the researcher is representative of the participants' perspective.
2. *Transferability*	Findings may be applied to other settings. Requires "thick description" of research findings.
3. *Dependability*	Refers to truth and consistency of data over time. Achieved through detailed audit/decision trail.
4. *Confirmability*	The research findings have been shaped by the participants. This requires researcher neutrality and reflection on the researcher's role in the study.

Table 3-1: Criteria for rigour in qualitative research (Guba & Lincoln, 1989).

3.2.1 Ethical approval

Full ethical approval was obtained from the University of Reading Research Ethics Committee prior to the commencement of this study.

3.2.2 Participants

Parents of typically developing primary school children, whose children did not have any ocular complaints or had undergone previous treatment by an eye health professional, were recruited for participation in this qualitative interview study.

3.2.3 Recruitment

Parents were recruited during the laboratory accommodation study (*Chapter 4*). All parents consenting for their children to participate in this laboratory assessment were also approached for participation in an additional telephone interview with the investigator regarding children's eyesight. Parents were under no obligation to also participate in the interview study. Purposive sampling of consenting parents was subsequently conducted (*3.2.4*).

The author acknowledges that the recruitment of participants from a sample who had already volunteered for research could limit the variance and conclusions which could subsequently be drawn regarding future research participation. However, it could also be considered that because these individuals already have experience in research participation their views are particularly pertinent and informative as they would represent the concerns and opinions of likely future research participants. Furthermore, as no previous literature exists pertaining to this topic it was felt that such information would provide a valid starting point for further evaluation. If parents who would be considered as motivated to help with research were reluctant to support glasses wear it would suggest that less motivated parents would be even more reluctant. As this study was a pilot for a possible larger study with less selected families such a barrier in a motivated group would be important to identify and might indicated the need for a different approach.

3.2.4 Inclusion Criteria

Parents of children participating in the laboratory accommodation study (*Chapter 4*) were approached for participation in this study. Only one parent of each child – the parent that accompanied them to the laboratory session, was approached for interview. This interview study sought the opinions of parents of children who did not already use glasses. This was desired as under-accommodators are largely likely to have passed school screening and not already require glasses. Therefore, only parents of children who passed the vision criterion of the laboratory study without glasses were eligible for inclusion (Figure 3-1). Parents were also excluded from participation if their children had any previous treatment by the hospital eye service/local optometrists

Parents were not excluded from interview participation if there was any family history of eye problems or glasses wear i.e. if they themselves wore glasses or if a sibling/cousin etc. had been prescribed glasses.

These criteria were selected to ensure a representative sample of parents, those with and without prior knowledge and personal experience of glasses wear.

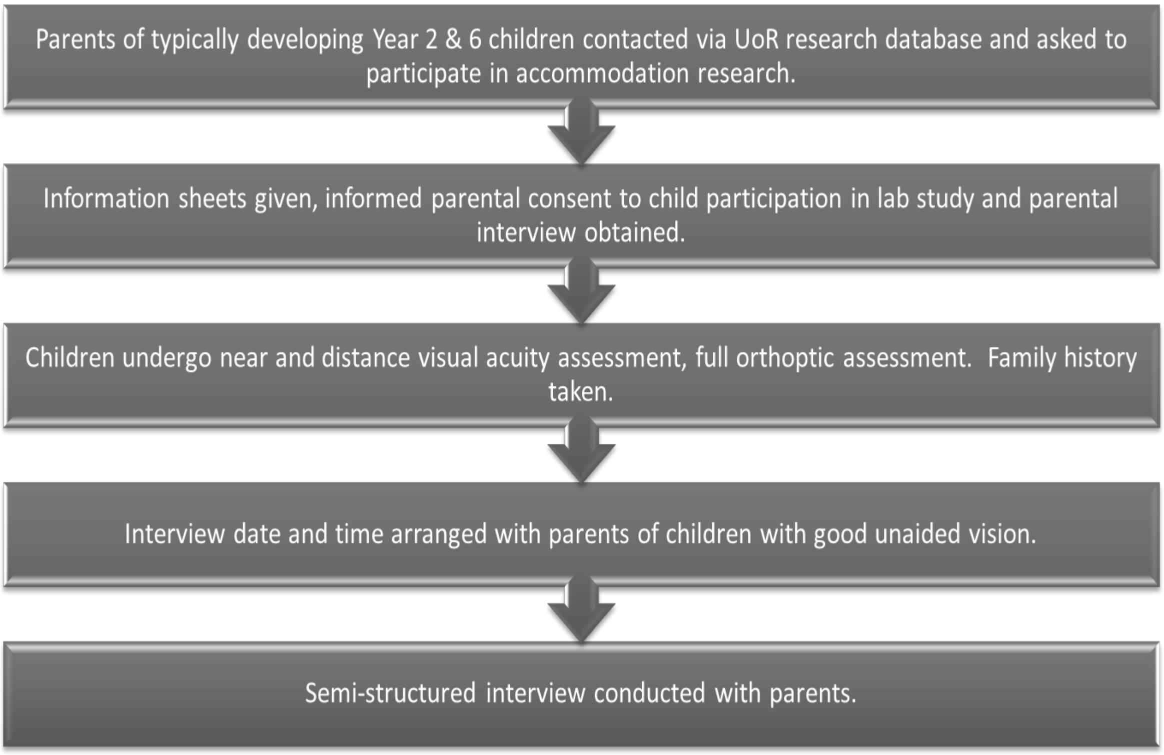

Figure 3-1: Recruitment/participant selection procedure for semi-structured interviews

3.2.5 Consent

Consent was sought alongside the consent for their child's participation in the laboratory study. Each participant was asked to read the information sheet (Appendix 2a) and was given the opportunity to ask questions regarding the study before consenting to participate. Written, informed consent to participate in a telephone interview regarding children's eyesight and future research was obtained from all participants. A sample consent form is given in Appendix 3. Immediately prior to commencement of the interview, verbal informed consent was confirmed by participants and audio recorded.

3.2.6 Topic guide

A topic guide (Appendix 4) was prepared, the aim of which was to encourage parents to speak about eyesight and eyesight research with minimal prompting. Based on 6 years of personal interaction with parents in a clinical setting, I felt that participants were unlikely to broach specific relevant eyesight terms spontaneously, a view supported by further consultation with four qualified orthoptists. Therefore, a funnelling approach was adopted for the topic guide (Smith & Osborn, 2015). This consisted of initial broad questions regarding understanding of eyesight terms and treatment of eyesight problems with specific probing questions regarding exact terms. This was followed by broad questions regarding participants' knowledge of clinical trials and concerns regarding participation, with specific questions regarding an accommodation RCT. As the lay community can rarely differentiate between a dispensing optician and an optometrist, "optician" was used throughout the topic guide to refer to an optometrist.

The topic guide was piloted on a select sample of University of Reading PhD students who did not have any current/previous eye problems to ensure it would be understandable to parents. No adaptations were required following the pilot.

The topic guide was applied flexibly throughout interviews and was adapted over the course of the study to include relevant questions which arose from previous interviews.

3.2.7 Interviewer

A single researcher (SL), a qualified orthoptist, conducted all interviews. Due to the nature of the recruitment procedure, all participants were aware of the interviewer's professional background. It was felt that this may inadvertently place pressure on parents to "know the right answer"; subsequently limiting the responses participants would volunteer during a face to face interview. It was felt that more open and honest answers would be obtained if the researcher was not physically present; therefore, telephone interviews were employed in this study.

The use of telephone interviews is further supported by Smith and Osborn (2015). The authors advised that interviews should be conducted in an environment the participant is familiar with and relaxed in. A telephone interview at a time suitable for the participant ensured that parents were in familiar surroundings and at ease during the interview.

3.2.8 Procedure

1. Participants were given the information sheet and written informed consent was obtained.

2. A telephone interview was arranged with eligible parents, at a convenient date and time of their choice.

3. The interview was recorded on a University of Reading dictaphone.
   i. Verbal informed consent was confirmed prior to commencement of the interview and audio recorded.
   ii. The researcher adhered to the topic guide to conduct a semi-structured interview, lasting up to 25 minutes in duration.

4. The researcher encouraged participation by utilising open-ended questions such as "can you tell me a bit more about that" until a mutual understanding of the parent's opinion was reached.

5. If a parent initiated a relevant subject, which did not feature on the topic guide, the researcher encouraged the expansion of this subject and rationale through the use of open ended questions as above.

6. Detailed field notes were made throughout the interview to ensure interviewer understanding and to remind the interviewer to return to a topic later on if necessary and areas to be discussed in interviews with subsequent parents.

7. On completion of individual interviews, interview recordings were transcribed verbatim into MS word documents and analysed.

8. No further interviews were completed following the achievement of theoretical saturation. Theoretical saturation is the point at which identified themes have been fully explored such that the collection of new data does not lead to substantive revision of concepts and signals the end of data collection in qualitative semi-structured interviews (Bryman, 2008).

3.2.9 Analysis

The management and analysis of transcripts was conducted using NVivo® software, version 11.

Analysis of interview data can focus on a rich description of the dataset or a detailed account of one element/theme within the data (Braun & Clark, 2006). Some depth and complexity may be lost with a descriptive analysis. However, this approach provides information on predominant themes across the dataset and is particularly useful when working with participants whose views on a topic are unknown (Braun & Clark, 2006). As the topic of this study is an under-researched area, a descriptive analysis providing breadth of themes across the whole dataset was desirable.

The constant comparative method of analysis (Glaser, 1965; Thorne, 2000) was used to group common codes and ideas across individual transcripts and generate themes. The researcher initially familiarised themselves with the data through multiple re-reads of each transcript. Line by line coding of individual transcripts was subsequently conducted identifying ideas within the transcripts. Initial codes were grouped according to overlapping ideas. Codes were compared across individual transcripts. Initial codes were subsequently revised and re-categorised, linking ideas from across the dataset. This was repeated until common categories could be grouped to form definitive overarching themes. Quotes were then selected to represent the themes.

All transcripts were coded by a single researcher (SL). The reduction and regrouping of codes and formation of themes was conducted by SL as well as separately by an external researcher, with qualitative experience (KH), to obtain new perspectives on the data and clarify ideas. The external researcher was not an eye care professional and therefore helped ensure a rounded view of the data. The themes derived from the codes were in high agreement between both researchers. Where disagreement occurred between the two researchers codes were discussed revised until agreement achieved.

3.3 Results

Thirteen parents participated in the semi-structured interviews. Although mothers were not purposefully sampled for participation, all interview participants were mothers. All participants met the inclusion criteria – interviewees' children did not use glasses or have any previous experience with the hospital eye service. As individual parent's opinions could also be influenced by their own family members' ocular status and individual experiences interviewees' ocular status is not detailed here.

Following the completion of ten semi-structured interviews with parents, it was judged that theoretical saturation had been achieved in this study. A further three interviews were conducted to confirm that there was no further change to the coding structure. No repeat or follow-up interviews were required with any participants.

Initial coding produced 77 codes; this was subsequently reduced to 51, as many codes overlapped and could be merged (Appendix 5). Three overarching themes were identified through grouping similar codes across the data:

1. Concern about eyesight
2. Establishing the presence of a vision problem and
3. Response to a vision problem

Subthemes were identified within each theme and are detailed in relation to the overarching themes below. Parents were specifically asked about an accommodation

RCT and as such this is not a theme as it did not develop from the data. The concerns and ideas raised by parents regarding an accommodation RCT are discussed in *3.3.4*.

3.3.1 Theme 1 - Concern about eyesight

The theme of concern about eyesight was derived from codes which were linked in that they encompassed parents' knowledge of different eyesight problems in childhood and the importance that they place on good eyesight. Some codes were found to group more readily with each other, resulting in the identification of subthemes within the overarching theme of concern about eyesight (Figure 3-2).

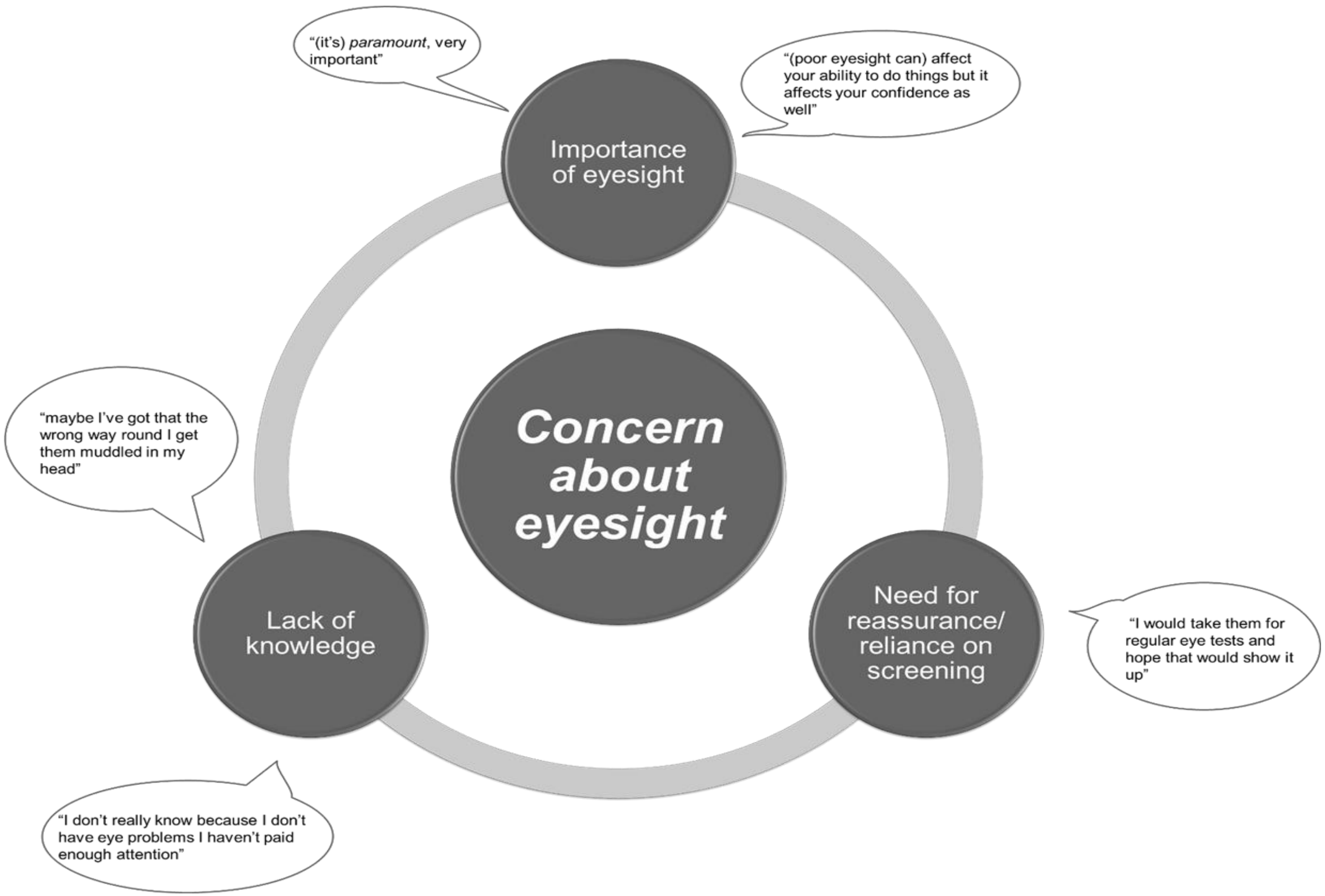

Figure 3-2: Theme "Concern about eyesight" and contributing subthemes

3.3.1.1 Importance of eyesight

The parents interviewed as part of this study unanimously reported that good eyesight in childhood is essential. Parents expressed the importance of clear eyesight for day to day life, academic progression, confidence and the development of interpersonal relationships. The importance of good eyesight for education was a recurring feature with many parents feeling it was imperative, particularly with regard to reading and close work.

Parent 1: *"[vision is] important particularly for school so they can see the board and participate in what's going on*

Parent 4: *"I think [vision] is just central for [children's] learning I think we rely a lot on our sight particularly when we are learning and especially in school settings"*

The negative impact of poor eyesight was not solely limited to perceived difficulties in a school setting, although this was a major concern. Parents also suggested that poor eyesight may negatively impact upon a child's confidence, subsequently resulting in behaviour difficulties or a failure to engage academically.

Parent 4: *"I think if you are probably struggling to read a text or even look at something then it probably would affect your concentration I think it would make it much harder for you to concentrate and much harder for you to learn"*

Parent 8: *"Because I think if you can't see properly not only does it affect your ability to do things but it affects your confidence as well so if everything is a bit blurry you're less likely to try things or want to go places"*

One parent in particular felt very strongly about the impact poor vision may have on children's confidence. The parent suggested that poor vision may result in feelings of isolation and that it may even lead to depression; thus, emphasising the absolute importance that parents place on good eyesight for their children's emotional as well as academic development.

Parent 6: *"well obviously if [poor vision is] not treated then I think [children] could become depressed…you could become introverted I think because if you didn't know what was going on because you couldn't see then you're excluded essentially it's a type of exclusion so I think it could be quite detrimental in that sense and it might make them feel like they were stupid…I think potentially [uncorrected poor vision] has quite strong consequences"*

Parents also linked problems with eyesight to poor behaviour. They expected that children would "act out" in compensation for the perceived difficulties children would experience if they were suffering with poor vision.

Parent 2: *"I think [vision] has a huge bearing on everyday life for children actually…. I think if children can't read words then they lose interest in trying to actually make the effort and so they become disengaged and start acting up or they just won't try"*

3.3.1.2 Lack of Knowledge

Parents were asked about their knowledge of different eyesight problems which can occur in childhood. While all parents were familiar with common terms such as long-sight/short-sight they were not confident in defining these terms.

Parent 10: *"No I know virtually nothing... not really to be honest with you I just know that you can be short and long-sighted and that's about it really yeah"*

Parent 1: *(when asked to describe long and short sight) "now I never get this right so I'm going to get this completely wrong"*

Parent 11: *(when asked what short-sighted means) "they have difficulty with reading for example or perhaps close concentrated work perhaps where their eyes need to converge and then erm but yet their long-sight is OK…. but I'm confusing myself by even saying that"*

All parents were asked "what do you understand by the term squint*?" Reponses to this question varied and it appears that squint is much less understood with few parents expressing a vague understanding that this referred to eye alignment while others frequently reported eyelid problems.

Parent 10: *"[squint is] when both eyes are not able to focus on the same point at the same time"*

Parent 4: *"I think you tend to squint if you are having trouble focusing… it's almost a narrowing of the eyes and you would probably frown and pull your face and your eyebrows inwards sort of thing"*

Parent 7: *"Hmm [squint] I guess it could be, erm, to look at visually their eye might be, erm, a little bit smaller, erm, and kind of closed sometimes maybe close the eyes quite a lot kind of thing?"*

Parent 1: *"[squint] No not much knowledge of that"*

Lazy eye* was understood as one eye struggling visually compared to the other, many parents however, again, demonstrated uncertainty when discussing the term.

Parent 6: *"I would use the definition as a clue so an eye that doesn't work as well as it should do but I don't know why it doesn't"*

Parent 8: *"A lazy eye is where one eye doesn't it lets the other eye do all the work so it doesn't it doesn't focus properly"*

Parent 5: *"Is [lazy eye] the one where it kind of doesn't go in the same direction as the other one?"*

Parent 7: *"I think I thought that lazy eye was just a muscle I think I thought it was the same as a squint I don't know"*

3.3.1.3 Need for reassurance

Linked to the aforementioned lack of confidence and knowledge of eye conditions (see *3.3.1.2*); parents also expressed a need for professional reassurance regarding children's eyesight, particularly in the event of a suspected visual problem.

Parent 6: "*I would take them to the opticians first thing so I would rely on professionals"*

Parent 13: *"Yeah I think if a healthcare professional said that he needed [glasses] then I would definitely defer my kind of concerns to them"*

3.3.2 Theme 2 - Establishing a Vision Problem

The theme of establishing a vision problem was derived from parental comments regarding the recognition of visual difficulty. Within this overarching theme three sub themes were identified (Figure 3-3).

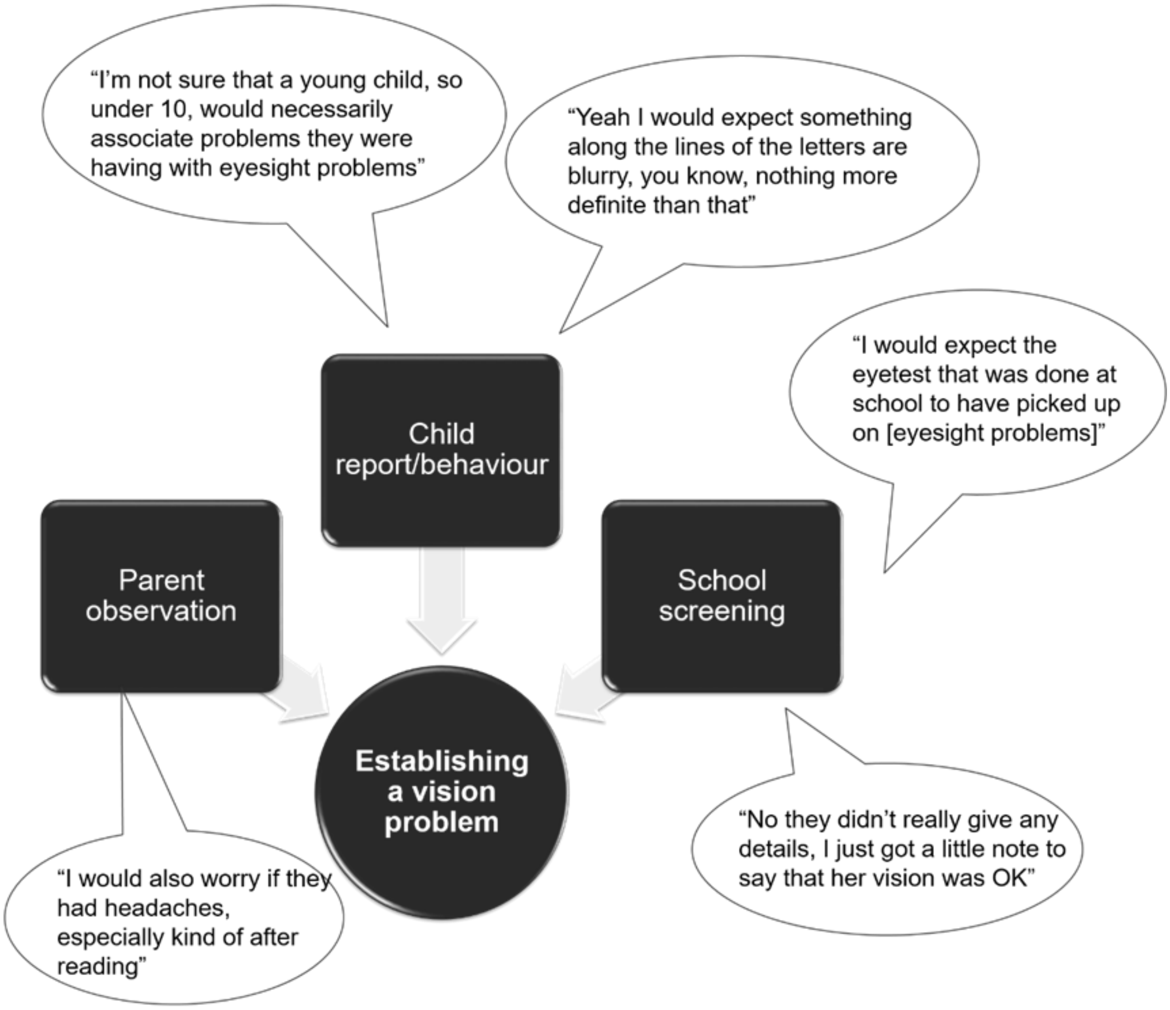

Figure 3-3: Theme "Establishing a vision problem" and contributing subthemes

3.3.2.1 Child report

Parents were divided in opinion regarding children's self-reporting of eye problems. While many parents expected their child to report difficulty others were unsure and felt children may not recognise poor eyesight as an issue, especially younger children.

Parent 10: *"I'm not sure that a young child so [sic] under 10 would necessarily associate problems they were having with eyesight problems"*

Parent 12: *"[children report eye problems] depending how bad it was, if it was bad enough for them to really realise then yeah possibly but they might not realise it's their eyes"*

Despite contrasting opinions regarding self-reporting of eye problems by children, childhood complaints of headaches were consistently associated across transcripts with potential visual difficulty in children. Parents reported that this symptom would alert them to an eyesight issue.

Parent 3: *"...mainly the headaches I think would give [a vision problem] away first"*

Parent 5: *"I would also worry if [the children] had headaches especially kind of after reading [sic]"*

3.3.2.2 Parent's role in monitoring eyesight

Parents frequently reported that they had a role to play in identifying eyesight problems in children. Responses such as that of "Parent 4" below were common across the transcripts when parents were asked what signs they might identify at home to alert them to the presence of a vision problem in their children. From professional experience, most children (with and without reduced vision) tend to sit close to a television or hold books close to their faces; as such this is rarely diagnostic of poor vision. However, parents associated visual behaviour such as moving closer to the TV with visual difficulty and reported that this would prompt them to seek professional advice for confirmation and reassurance.

Parent 4: *"I think there might be visual things that I might be able to see perhaps if I saw that they were squinting when perhaps watching the telly or reading or holding the book further or closer or further away"*

3.3.2.3 Teacher identification

In addition to child report and parental observation, teachers were described by parents as key identifiers of vision problems in children. However, despite all parents commenting that teachers are in a position to identify such an issue, some were more cautious, explaining they could not rely solely upon teachers as vision problems might not be easily recognisable to them.

Parent 4: *"I think [teachers] probably would pick [eyesight problems] up because they know the child really well"*

Parent 9: *"I would hope the teachers would notice if a kid was sitting at the back of the class and they couldn't see the board or something"*

Parent 11: *"several instances [of visual difficulty] are fairly undetected [by teachers] partly because the child might not be piping up and partly because there is not enough clues [sic]"*

Parent 13: *"the teacher if [child is] at the back of the class and he's struggling and he's putting his hand up I'd perhaps expect them to say something"*

3.3.2.4 Reliance on professionals

As detailed in *3.3.1.2* parents interviewed in this study expressed a lack of knowledge and confidence regarding children's eyesight, which fostered a need for reassurance (*3.3.1.3*). All children in Reading undergo school vision screening by an orthoptist upon primary school entry. As such, school vision screening by health professionals was one method of reassurance repeatedly mentioned by parents; it was also largely associated with the sub theme reliance on professionals as it was frequently reported by parents as a method on which parents rely to identify any vision problems in children.

Parent 12: *"I would expect the eyetest that was done at school to have picked up on [visual problems]"*

Due to the importance placed on good vision many parents reported engaging in their own screening behaviour through annual vision tests at the high street opticians to ensure that any potential vision issue would be quickly identified.

Parent 6: *"I would probably be quite ignorant [about vision problems] aside from the fact that obviously I would take them for regular eye tests and hope that would show [eyesight problems]"*

Parent 7: *"[child] had her eyetest when she first started school and we've always had a yearly check-up, I've always taken that upon myself to do it before school starts again in September I always take her in for a just a check at the opticians"*

In fact, one mother further suggested that annual screening at a high street optician ensured children's' good progression in school. She discussed that children who had not attended for regular exams resulted in poor progression as they were later found to have a need for glasses.

Parent 5: *"[my children] have gone to the opticians every year since they were five…. I know a lot of my friends have not taken their children to the opticians and suddenly discover at age eleven or twelve that they need glasses because their children can't actually see which is why they haven't progressed as well with reading and other things"*

3.3.3 Theme 3 - Response to a vision problem

Three subthemes were identified within the theme of response to a vision problem (Figure 3-4). As before, these subthemes combined to contribute to the overall theme of response.

Response to a vision problem includes a wide variety of parent concerns and perceived challenges, evident through codes such as “teasing while wearing glasses”, “following professional advice” and practical challenges such as “glasses difficulty in sports”.

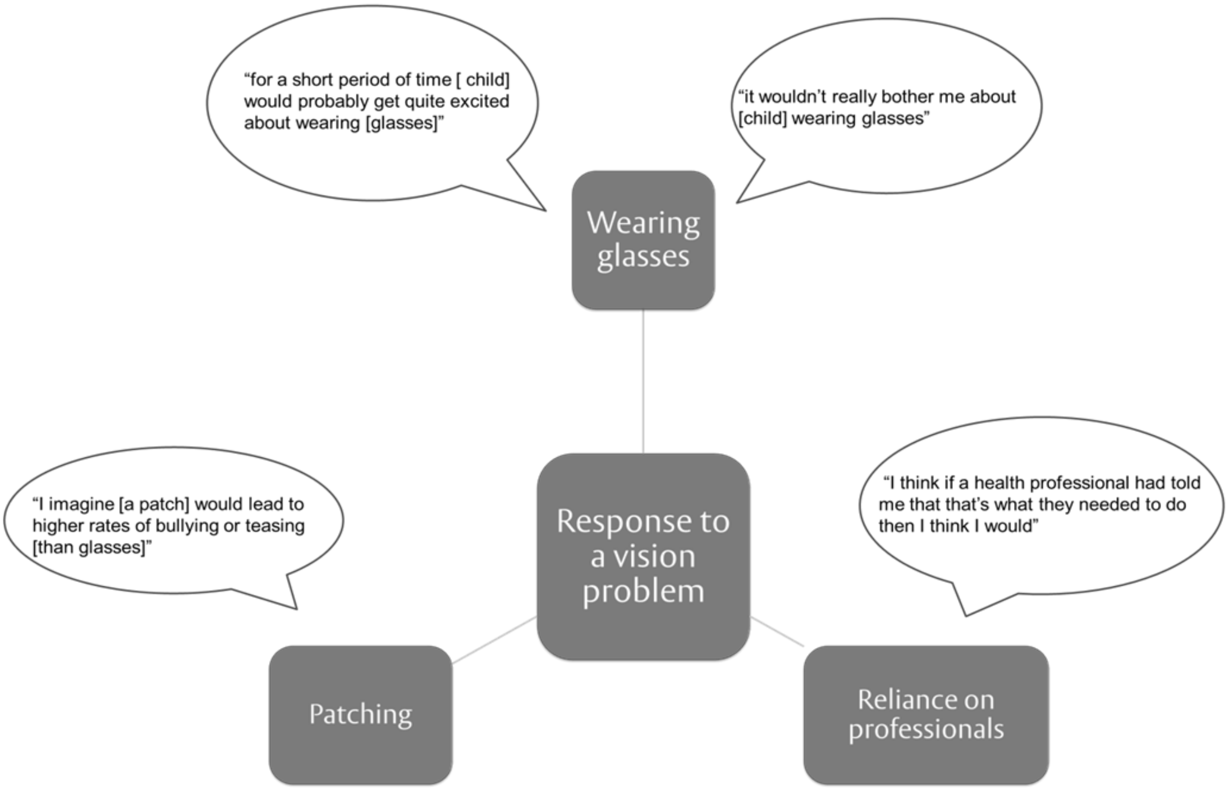

Figure 3-4: Theme "Response to a vision problem" and contributing subthemes.

3.3.3.1 Wearing glasses

Glasses were largely acceptable to the parents interviewed in this study. Parents expressed that they would be more concerned for a child's vision than the physical appearance of glasses.

Parent 9: *"obviously I'd be concerned if they were short-sighted or something but it wouldn't really bother me about them having to have glasses"*

There was frequent suggestion in the data that glasses are more acceptable today than they were when the interviewees were children and as such most parents did not report concern regarding potential glasses wear in their children.

Parent 2: *"these days no one really gets picked on for wearing glasses"*

Parent 13: *"I think lots of children wear glasses nowadays I don't think it's a big deal"*

Interestingly some parents expressed that their children would be excited at the prospect of wearing glasses.

Parent 5: *"my two were desperate for glasses at the age of five"*

Two of the interviewed parents did report some concern regarding teasing as a result of glasses wear; interestingly both parents also expressed child sensitivity to teasing by peers. Glasses wear was also perceived to be a limitation to sporting/outdoor activities by one parent.

Parent 10: *"I think he would be teased I think that's the way it is and I think he's quite sensitive to that"*

"I have a boy he's extremely sporty and physical and I think that [wearing glasses] could impair what he feels confident doing"

3.3.3.2 Patching

While parents often lacked confidence in the definitions of various childhood eye problems, as per 3.1.2, parents did express an awareness for other vision treatment modalities such as using an eye patch. While glasses were found to be largely acceptable to the parents interviewed in this study, eye patching treatment was identified as less favourable and associated with higher risk of teasing/bullying by peers.

Parent 11: *"I would be more concerned if she was wearing a patch for example at school because I imagine that would lead to higher rates of bullying or teasing"*

3.3.3.3 Follow professional advice

As reported in *3.3.2.4* parents rely on professional advice regarding children's eyesight. With regard to the treatment of eyesight, parents were receptive to professional opinion and most parents interviewed reported that they were likely to follow the advice given. With specific regard to glasses wear, parents reported that they would enforce spectacle wear if a professional had advised it. However, it is clear from the data that parents felt that compliance would be less likely in cases of weak spectacle prescriptions. In this situation, there is more diversity in the opinions expressed during the interviews as some parents reported that they would be less likely to strictly enforce glasses wear while others reported that the advice of an eye-care professional is to be followed at all times.

Parent 2: *"If a professional had told me that they were required then yes I would [enforce glasses wear]"*

Parent 9: *"it depends how much they need them if it stopped them being able to read or meant them having headaches then I would say they ought to [wear glasses] but I wouldn't make them kind of strap them onto their head or anything"*

3.3.4 Concerns regarding accommodation RCT

Unsurprisingly no parents spontaneously raised the topic of accommodation or an accommodation RCT. Therefore, all parents were asked directly for their opinions regarding participating in an accommodation RCT. All parents responded that they would be interested in participating in such a trial, indicating that the concept of an accommodation RCT is acceptable to parents. While one parent did raise concerns regarding a placebo treatment, parents largely reported that the establishment of treatment and non-treatment groups would not cause concern or prevent them from participating in such a trial as under-accommodation is currently not ordinarily treated.

Parent 6: *"I think you would struggle [recruiting] because I think [parents in placebo group] would feel you would be allowing your child to persevere with a problem and not trying to address it which I think a lot of parents would have a difficulty with"*

Parent 8: *"I would say yes it's not like they desperately need some medication and you're not going to give it to them"*

Parent 11: *"parents wouldn't mind because it's not that their child would be helped in that situation anyway"*

It was clear from earlier data that parents did not perceive a risk of teasing as a result of glasses wear (*3.3.3.1*) and this was reiterated in their willingness and interest in participating in an accommodation RCT.

Parent 7: *"for a short period of time she would probably get quite excited about wearing [glasses]"*

Parent 12: *"some parents wont [participate] because they don't want their child to have the stigma they maybe associate with them wearing glasses or they won't want their children to feel different but I think some parents would be acceptable to that [RCT]"*

However, parents did express some concerns regarding the RCT, most frequently the length of time a child would be enrolled in the study. When probed to expand on their attitudes towards length of trial, parents were less enthusiastic regarding the prospect of an RCT with many reporting concerns that an academic year was too long.

Parent 12: *"I think as a parent myself I think that's a long time to ask my child to wear glasses if he doesn't need to wear glasses"*

Parent 5: *"I think a term would probably be acceptable but maybe longer than that wouldn't be"*

While the parents interviewed in this study were positive about an RCT they did raise the issue that the presence of a non-treatment group would deter some parents from participating. A crossover trial was discussed as an alternative to an RCT. Parents reported that they felt this would alleviate the concerns of parents who may be deterred by an RCT, it was largely reported that the increased length in trial, resulting from a crossover situation, would be a larger barrier to potential participants.

Parent 1: *"I think you would probably find most people would do the randomised one because it would be shorter"*

Parent 4: *"From a parent's perspective I suppose you'd probably prefer it to be shorter so maybe you would prefer the random one"*

Parents highlighted the need for children to be involved in study design as well as adequate explanation to parents. They reported that many parents would not understand that under-accommodation is not routinely treated at present and as a result they may feel as if they are denying their potential child treatment.

Parent 12: *"I think [participating in RCT] would depend a lot on the child, on them understanding what they are being asked to do and if they are willing to wear [glasses] at school"*

Parent 6: *"I think [parents] would then feel [they] would be allowing a child to persevere with a problem and not trying to address it which I think a lot of parents would have a difficulty with"*

Parent 4: *"I think sometimes there is a bit of a fear of the unknown I suppose and I suppose [parents] just need a bit of reassurance that [a trial] is beneficial"*

3.4 Discussion

The purpose of this qualitative study was to establish parental understanding of children's eyesight problems, common eyesight terms and ascertain parental opinions regarding an RCT to investigate causality/the effect of correction in under-accommodation in children and establish any perceived barriers to participation.

It is clear from the interview responses that parents place immense importance on children's eyesight as all parents reported clear vision as essential to school work. It is interesting to note that parents not only felt it was essential for school work but also for a child's wider development as parents expressed the view that poor eyesight could have a detrimental effect on children's social interactions and on their confidence. However, from the parental responses given during the semi-structured interviews it is evident that parental knowledge of eyesight terms is limited and parents lack confidence in discussing the eyesight terms they are familiar with. Parents were hesitant in their responses and in many instances replied "I don't know" when asked to describe specific eye problems. Confusion frequently arose when discussing long-sight and short-sight with parents expressing that they frequently "got them the wrong way round". A similar lack of knowledge has also been reported by Schikle et al (2014); the authors reported a lack of awareness and understanding of eyesight problems and the examination undertaken by an optometrist in focus groups consisting of young adults, of which a majority were undergraduate medical students.

The lack of confidence and knowledge expressed by the parents in this study, manifests as a reliance on professionals to detect vision problems as parents are not convinced that they would recognise these themselves. Reliance on professionals included a reliance on school vision screening tests to detect eye problems, although again parents were unsure of the examination process undertaken during school vision screening. This lack of knowledge and awareness is interesting given the participant group in this study. All participants interviewed in this study were concerned, engaged parents. However, it is clear that they have little awareness and understanding of eyesight, suggesting that parental education may be beneficial as other, less engaged parents may have even less understanding.

While parents reported a reliance on professionals to detect children's eye problems and lacked confidence regarding signs of difficulty at home, headaches were mentioned repeatedly across the transcripts as a likely indicator of visual difficulty in children. While headaches can be associated with visual problems, in clinical practice it is uncommon for children, especially in the case of a low refractive error to experience headaches (Roth, Pandolfo, Simon, & Zobal-Ratner, 2014). Further education of and increased availability of information regarding signs of visual difficulty would be useful in view of this common misunderstanding to clarify the distinction between headaches associated with eye problems and those due to other causes.

Limited research has been conducted investigating parents' attitudes towards children's glasses wear and results are conflicting. Kodjebacheva et al (2015) reported that parents perceive that glasses wear in childhood is associated with negative effects on children's social interactions and confidence, while positive association of glasses with education is reported by Dudovitz et al (2016). The findings of this study support those of Dudovitz et al (2016), as parents highlighted the perceived detrimental impact that uncorrected vision may have on children's confidence, education and social interactions. As such, the majority of parents interviewed in this study also agreed that glasses were cosmetically acceptable. It is possible that sampling may have contributed to the finding that glasses are largely acceptable. For this study, interview participants were recruited from a university database which they voluntarily joined at the time of their child's birth as they had expressed interest in participating in research. Whilst socio-economic and demographic factors were not collected in this study, evidence suggests that higher socio-economic status is positively correlated with willingness to participate in research (Patel, Doku, & Tennakoon, 2003; Robinson, Adair, Coffey, Harris, & Burnside, 2016). It is therefore likely that mothers who agree to join a university database are more likely to be educated and interested in research. Glasses wear, in particular myopia, has been shown to be associated with education and socioeconomic status (Cumberland et al, 2015; Rahi, Cumberland & Peckham, 2011) and may have been more prevalent among interviewed parents or family thus, impacting the perception of glasses wear and concerns regarding teasing and accounting for the difference in opinion reported in this study compared with others. Anecdotal evidence from personal clinical experience would suggest that parents from different ethnic groups or lower socioeconomic groups may indeed respond differently to glasses wear.

As mentioned, no formal measure of SES was obtained from participants during this study. However, participants did provide their postcode to the researcher on their laboratory attendance. Postcode information has previously been recommended as a proxy/substitute SES measure (Danesh, Gault, Semmence, Appleby, & Peto, 1999) and could have been employed in this study to estimate the SES of interviewees. For instance, postcode information could be used to obtain a measure of relative deprivation of the area in which an individual lives e.g. through using tools such as the Index of Multiple of Deprivation (IMD). The IMD is a government measure, which combines information including income, health, education deprivation and crime to rank small areas in England from least deprived (score = 32,844) to most deprived (score = 1) areas. While this could be used as a proxy for SES status, this was not utilised in this study as evidence regarding the accuracy of postcodes and tools such as the IMD to estimate SES is conflicting.

Postcode data is limited as an SES proxy measure as it refers to area rather than individual level data. It has been recognised that tools such as the IMD cannot provide estimates of individual circumstances (Ministry of Housing, Communities and Local Government, 2015). One cannot assume that by living in an area which would be considered deprived necessarily equates to being of a lower socioeconomic status than someone who lives in a less deprived postcode. Affluent individuals can live in a deprived area and vice versa. It has been suggested that UK postcode assigned socioeconomic status is subject to ecological fallacy when applied on the individual level (Shack et al, 2008; Steven, Dowell, Jackson, & Guthrie, 2016; Strong, Maheswaran, & Pearson, 2006). Moreover, McLoone and Ellaway (1999) report correlation of just .38 between postcode level income and self-reported income and suggest that in view of this postcodes should not be used as a proxy for socioeconomic status. As such, the author considered that the evidence to support the use of postcodes as a proxy SES measure was insufficient and it was therefore not employed in this study. However, future qualitative research of this nature would greatly benefit from the inclusion of a robust measure of SES.

Parents' opinions regarding a potential RCT to investigate under-accommodation were also established during this qualitative study. An RCT to investigate accommodation was largely acceptable to the parents interviewed in this study. As discussed above, glasses intervention would be acceptable to parents as they did not express concern regarding teasing due to glasses wear. It would be prudent however, to verify this with a group of parents from broader socio-economic and ethnic backgrounds prior to commencing further research. Certain barriers to an RCT were established; from the interview data, it is evident that explicit information and parent education regarding the fact that accommodation is not routinely treated at present would be needed to maximise RCT recruitment. During the interviews, participants volunteered that, due to current lack of knowledge among the general public regarding accommodation, parents might be liable to think that their child is being denied glasses if they were assigned to a control group. Fear of negative effects is a recognised barrier to participation in RCTs (Fletcher et al, 2012). Adherence to accommodation RCT treatment allocation could be influenced by this confusion along with lack of knowledge regarding the necessity to treat accommodation. A crossover trial, which lasts longer than an RCT, could be used to encourage subject participation in the presence of a fear of negative effects as all children would be exposed to the treatment. However, following detailed questioning, an RCT with explicit information and parent education was preferred by the interviewees as trial duration was established as the main barrier to participation in future accommodation studies.

Participant retention in RCTs is a well reported difficulty in clinical trials (Davis, Broome, & Cox, 2002; Gul & Ali, 2010), however it is essential in order to ensure sufficient statistical power and accurate results. Trial duration was repeatedly mentioned by parents as a barrier to recruitment and continued participation in an accommodation RCT. During the interviews the proposed duration for a future RCT was one academic year. This length was suggested to ensure that any change in test scores could not be attributed to factors such as returning from school holidays/having a summer birthday etc. and to allow measurable changes to occur if the effect was not large. Parents repeatedly expressed the opinion that the proposed one year duration was too long for children to participate. This opinion, if widespread among a wider selection of parents, could negatively affect participant recruitment and retention to the trial. It is unlikely that the concern regarding trial length expressed by parents in this study was influenced by the age of participants' children. Although parents were recruited from the laboratory study involving Year 2 and Year 6 primary school children, most parents also had children of different ages who did not partake in the laboratory accommodation assessment. The overall age range of the children of parents in this study was 2 – 12 years; therefore, it is unlikely that this concern is specific to parents of a particular age group of children. However, as it is a significant concern expressed by parents in this study, it would be prudent to establish the impact of trial duration on participation among a wider population through the use of questionnaire or feasibility study to establish potential attrition rates. As length of time was such a significant concern for participants, this further supports an RCT, rather than a crossover trial as preferable for investigation of the role of accommodation in reading problems as the latter would require longer participation.

3.4.1 Limitations

The method of recruitment may be considered a limitation to this study. Purposive sampling from a convenience sample of parents attending a related laboratory study with their children was employed for recruitment. The participants were all recruited from a university database of parents already interested in research participation, as such conclusions and generalisations on parental willingness to participate in research, drawn from this study are limited to this particular participant group. All interview subjects were engaged, educated parents and provided generally homogenous responses to the interview questions. While potential barriers to RCT participation have been established from these interviews, it is possible that more diverse opinions could be obtained from interviewing parents who are not already actively participating in research. Further research through interviewing parents from wider socio-economic backgrounds or the administration of a questionnaire, developed from the interview data reported in this study, would be useful to capture more diverse opinion and so would be necessary in the next stage of the research.

As discussed, no measure of socioeconomic status (SES) was employed in this study. Considering the homogeneity of responses this would have been valuable information which could have facilitated further insight into the data. Limitations to the use of available information in this study, i.e. postcodes, in lieu of SES measures and the decision to not include such information in this particular study has been discussed. However, further research would benefit from inclusion of a robust measure of SES to allow further evaluation of parental responses and to ensure responses capture a variety of parental opinions.

A further potential limitation is that all interview coding was conducted by a single researcher. Coding by a second researcher would have been useful to increase the validity of the results however this was not feasible in this study. The grouping of codes and generation of themes was performed by an independent researcher (KH) in addition to the interviewer (SL), providing new insights into the data and increasing the validity of the results presented.

3.5 Conclusion

The parents interviewed as part of this study placed substantial importance on their children's eyesight for both academic and social development. Despite this, knowledge regarding common eye problems in childhood was limited and often factually incorrect. The interviewees suggested that parents may rely on services carried out by professionals, such as school vision screening, for the detection of eye problems and suggested that some parents may engage in further screening behaviour at local optometrists to ensure optimal vision for their children. The lack of confidence and knowledge from interviewees regarding children's eyesight suggests that public education regarding the need for sight tests and appropriate signs of visual difficulty might be beneficial; however, further replication with parents from broad range of socioeconomic statuses and backgrounds would be advisable prior to undertaking such efforts.

The above results suggest that an accommodation RCT may be acceptable to parents and could be a viable future study. However, the limitations of this study, e.g. participant selection, are acknowledged; as such, it can be concluded that an accommodation RCT is not immediately unacceptable to some parents and that further research targeting a wider variety of opinions e.g. by use of questionnaire is warranted. Interviewed parents were not concerned that childhood glasses wear would result in negative social effects such as teasing, and parents would be happy to enforce glasses wear should it be required. Fear of negative effects from placebo/non-treatment groups were a concern to interviewed parents although they felt that explicit information explaining that under-accommodation is not currently routinely treated would negate this concern. Trial duration was interviewees' main concern regarding the proposed RCT interviewed parents suggested that this could impact recruitment and participant retention. In view of this, further qualitative research to establish opinions from a wider selection of parents or a feasibility study to establish attrition rates would be prudent prior to the commencement of a full RCT. The concerns identified in this study could provide a suitable starting point from which to develop a questionnaire to investigate the opinions of a broader spectrum of parents.

Chapter 4 - Laboratory Study

4.1 Introduction

Research to date has suggested that blurred near vision resulting from under-accommodation could impact children's education, in particular their reading ability (Kulp & Schmidt, 1996; Poynter, Schor, Hayes, & Hirsch, 1982; Shin, Park, & Park, 2009). The overarching aims of this PhD thesis were to ascertain if an association exists between accommodation and academic ability; to design and validate a test battery for use in future accommodation research; and to assess the feasibility of assessing accommodation on a large scale in a non-laboratory setting, e.g. as would be required in a future RCT.

The aim of the highly controlled laboratory study reported in this chapter was to establish pilot data regarding children's typical accommodation and academic ability and in particular, to design a test battery suitable for use in a community setting.

As discussed in *Chapter 2*, previous research has identified an association between accommodation and academic ability (Kulp & Schmidt, 1996; Motsch & Huhlendyck, 2000; Palomo-Alvarez & Puell, 2008; Shin, Park, & Park, 2009); although some studies have refuted this association (Creavin & Williams, 2015; Keidza, Tondel, Pieczyrak, & Maples, 1999; Latvala, Korhonen, Penttinen, & Laippala, 1994). Accommodation has also been evaluated in relation to attention and behaviour; while some literature has suggested an association between accommodation and attention/behaviour (Borsting, Rouse, & Chu, 2005), contrasting evidence also exists (Fabian et al, 2013). Methodolgical or sampling differences could account for this conflicting evidence regarding accommodation and reading ability/attention. Studies have largely employed subjective measures of accommodation assessment; such measures are known to have numerous confounds e.g. depth of focus, participant instruction set and the communication of the concept of blur; of which the latter is a particular challenge when evaluating a paediatric population (Adler, Scally, & Barrett, 2013; Kediza et al, 1999). In addition, subjective measures of accommodation may be associated with large intra-subject variability, e.g. the push up method of accommodative amplitude assessment (Adler et al, 2013). Until recently, objective assessment of accommodation has been limited to dynamic retinoscopy to evaluate accommodative lag although as previously discussed, this technique is limited as it is largely performed as a monocular assessment and therefore is not representative of typical binocular accommodative behaviour. It is possible to evaluate accommodation objectively and binocularly using a photorefractor although to the author's knowledge there is no current literature investigating the relationship between reading ability and accommodation measured objectively with this method. Therefore, by assessing accommodation binocularly with a photorefractor this study will add to the current literature base on accommodation and reading and provide reliable data regarding accommodation under naturalistic and repeatable conditions.

As introduced in *Chapter 2*, accommodative response (AR) may not always be equivalent to target demand. Higher level control i.e. level of instruction and cognitive demand have been shown to influence AR (Ciuffreda & Hokoda, 1985; Jackson & Goss, 1991; Harb et al, 2006; Horwood et al, 2001; Poynter et al, 1982; Tassinari, 2002). Higher level control has been implicated as a mediating factor in paediatric accommodation research although the current available evidence is limited by design. Bharadwaj and Candy (2008) reported increased accommodation to letters rather than cartoon targets, however such increase was only found under monocular conditions.

Yeo, Atchison, and Schmid (2013) reported accommodation to Chinese and English characters. The authors reported lag of accommodation among myopic and emmetropic subjects to both targets although higher accommodative response was observed to the more cognitively demanding Chinese targets. However, these characters were of a smaller font size than the English characters which may have influenced results i.e. one could suggest the findings were a result of visual demand rather than cognitive complexity. Nevertheless, the limited available research does suggest that children can exert more accommodation if necessary. Therefore, it is reasonable to consider that target type might influence findings regarding the relationship between accommodation and academic ability. In order to effectively design a test battery and protocol to assess accommodation on a large scale in a community setting, selection of an appropriate accommodative target is required. However, in view of the limitations of the current evidence base, a more detailed study of the exact influence of target type and complexity on AR is required. Therefore, in addition to investigating AR and academic ability and designing a test battery, this study also aimed to investigate, under controlled conditions, the effect of target complexity on AR.

4.1.1 Aims/Objectives

1. Assess children's typical AR using binocular, objective methods through using a photorefractor and relate these findings to the existing literature.
2. Ascertain the influence of target type on AR by assessing typical children's AR to targets of different complexity under controlled laboratory conditions.
3. Establish preliminary data regarding the relationship between AR and reading ability/attention by relating AR to achievement on educational tests.

4. Design an appropriate testing battery for a larger RCT by trialling a wide variety of reading and attention tests to establish the most effective and appropriate educational test to relate to AR.

4.2 Method

Full ethical approval for this study was obtained from the University of Reading Ethics Committee prior to the commencement of this study.

4.2.1 Participants

Typically developing current Year 2 (6 – 7 years) or Year 6 (10 – 11 years) students, who did not have any prior diagnoses of reading or attention difficulties, were recruited for participation in this study. This was an opportunistic sample recruited from a typically developing population. The selection of these year groups provided comparison across primary school groups. Year 2 and Year 6 children were selected as these children are at the upper age for the UK national curriculum groups, Key Stage (KS) 1 and 2 respectfully. The upper age of KS1 was selected as it was considered that these children would be more co-operative and tolerant of the long testing duration required by the study. The upper age of KS2 was then selected for consistency.

4.2.2 Recruitment

Children were recruited from the University of Reading Infant Participant Panel. The participant panel is a database of potential child research volunteers. These children's details are collected at birth on the Royal Berkshire NHS Foundation Trust maternity ward from parents who wish to be contacted about future research studies with a view to their children participating. Contact details of parents of suitable children were provided to the researcher by the panel custodian. The researcher subsequently contacted parents via telephone or email to invite their child to participate. Parents were asked to verbally verify that at the time of contact their child did not have a diagnosis of reading, attention or development difficulties. Study information sheets (Appendix 2a & b) were emailed to interested participants and a convenient appointment time for laboratory participation arranged.

4.2.3 Inclusion Criteria

A minimum distance visual acuity* (VA) of 0.20 logMAR and a minimum near VA of 0.10 logMAR were required for participation. 0.20 logMAR is the current "pass" level for school entry vision screening (Public Health England, 2017) and was selected for use in this study to exclude children with large uncorrected refractive errors, including astigmatism and to achieve a sample of children whose vision is considered "normal". A stringent near VA was selected to ensure that participants had the capacity to see all accommodative targets clearly (see *4.2.9.2* for description of the smallest accommodative target). Such stringent near VA was also required to prevent the erroneous inclusion of significant refractive errors e.g. astigmatism (this was required as the PowerRefII required for this study (section *4.2.8*) refracts in only one meridian). Correction with habitual refractive correction was permitted for visual assessment where necessary; children were not excluded from participation if they had any current glasses prescription or were receiving care from a local optometrist or eye clinic.

As stated above, section *4.2.1*, children were excluded if they had a prior diagnosis of reading or attention difficulties e.g. dyslexia/ADHD. The overarching aim of this thesis was to provide pilot data for a potential RCT, as such the objective of this thesis was to establish how *typical* children accommodate. Therefore, to fulfil this aim it was necessary to exclude those children with diagnosed reading or attention difficulties. Furthermore, it was clear from previous research that participant selection is a confounding variable in studies investigating the relationship between accommodation and academic ability (*Chapter 2; 2.3.3*). Indeed, one could also hypothesise that even in studies recruiting from a completely unselected population, parents of children with known difficulties would be more likely to volunteer for research of this nature which would present an confound to the dataset.

Studies which have evaluated accommodation in children with reading or attention difficulties and have drawn associations between these difficulties and accommodation. However, they fail to account for the possibility that an additional third factor could influence both failure of accommodation and cognitive development issues impacting reading/attention. Therefore, to initially determine if an association between accommodation and academic ability exists it was considered necessary to limit recruitment to typical children, without diagnosed reading and attention difficulties.

4.2.4 Consent

Consent was obtained at the laboratory appointment – parents were given a minimum of 3 days to read the study information at home prior to this. The researcher explained the study to the participating children in a nature in which they would understand and children were allowed to ask any questions regarding participation. Once parents and children were satisfied with the nature of the study, written informed parental consent was obtained. Written child assent was obtained where appropriate.

4.2.5 Sample Size

A-priori sample size calculation using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009), based on power 0.8 and a medium effect size 0.5, indicated a large required sample size of 80 children. Previous studies carried out at the IVL indicated that groups of 20 participants provided sufficiently powered accommodation analyses. As this was a pilot study, partly aimed at estimation of effect size for a larger study, the researcher aimed to recruit 30 Year 2 and 30 Year 6 UK primary school children for participation. This was selected to ensure sufficient data collection should some children be unable to complete the entire assessment protocol.

4.2.6 Study Procedure

All participants were assessed in a single visit (approximately 2 hours duration) at the University of Reading Infant Vision Laboratory (IVL) as detailed below.

The parent accompanying each laboratory study participant was also approached for participation in a qualitative study (*Chapter 3*). Therefore, participants' ocular history/ocular family history was taken from all parents to facilitate purposive sampling for the qualitative study (*Chapter 3; 3.2.4*). As detailed in *Chapter 3* postcode information for each participant was obtained on their attendance to the laboratory. However, due to the limitations associated with using postcode information to determine an individual's socio-economic status (SES) this was not employed as a proxy (SES) measure (see *Chapter 3; 3.4* for full discussion). No further measure of SES was obtained from participants due to time constraints and breadth of tests to be completed during each individual assessment, as described below.

Due to the number of tasks to be completed by participants, tasks v – viii were interleaved to maintain attention and cooperation. Counterbalancing, where indicated below, was adhered to. Children and parents were reminded that they could stop testing at any point if they so wished. Regular breaks were given between testing.

i. Participants first underwent a standard orthoptic vision assessment to ensure that they satisfied the inclusion criteria and to facilitate the comparison of the laboratory results to those likely to be obtained at a school vision screening test. Participants were permitted to wear glasses, if habitually required, for all tests.
   - Participants' distance and near visual acuity was assessed using standard eye clinic tests (Keeler crowded logMAR and Sonkson near logMAR tests respectively).
   - Eye position (cover test) was assessed at near (1/3m) and distance (6m) fixation.
   - The ability of the eyes to work as a pair (motor fusion) was assessed using the near prism fusion range test* to a small target (6/6 letter). In accordance with the recommendations of Rosenfield, Ciuffreda, Ong, & Super (1995) the compensating fusion range was assessed first in all cases to minimise any vergence adaptation induced error.
   - 3D vision was assessed to threshold using the Frisby stereotest.
   - Convergence was assessed in free space using a small picture target (Lang cube (10mm^2) although the fixation target was smaller than this – typical height 5mm).

iv. Accommodation and convergence responses were assessed using the IVL Plusoptix PowerRef II (see this chapter *4.2.8*).

   a. A variety of targets (*4.2.9*) were employed for this assessment. These represented a range of typical close-work tasks for most children.
   b. Target presentation order was counterbalanced using a Latin-square design.
   c. All print, letter, cartoon and "Where's Wally" targets were presented at 1/3m (3D demand) only.
   d. Targets were presented for 1-minute.
   e. A minimal instruction set was used throughout; participants were asked to "read the print aloud", "watch the cartoon", "find Wally".

v. To compare the data obtained in this study with published research and to check that the participants did not have an unsuspected refractive error which can be revealed by photorefraction to receding targets (Horwood and Riddell, 2009), the clown target, used in previous IVL research, was presented at fixed distances from 0.25cm – 2m (*4.2.8.2*). This target routine provided participants with all accommodation cues (disparity, blur and looming).

   - The clown target routine was carried out after the above near tasks (*iv*).
   - The clown was presented at each distance for a minimum of five seconds.
   - A minimal instruction set was used, e.g. children were asked to "watch the clown".

vi. Participants completed a variety of education/ability tests (*4.2.10*).

a. Testing order was counterbalanced using a Latin-square design.
b. Educational tests were administered according to manufacturers' instructions and the in recommended subtest order – subtest assessment order was not counterbalanced.

vii. To assess participant attention/behaviour, parents/guardians completed the parent version of the Strengths and Difficulties Questionnaire (SDQ). This test is further described in detail below. (*4.2.10.3.2*)

viii. Prior reading experience can influence reading ability and as such it has been recommended that studies investigating reading should take a measure of reading ability (Cunningham & Stanovich, 1990). Therefore, an up to date author's test/title recognition test, as age appropriate, was administered in this study to evaluate individual reading experience. The authors test was employed for the older children in this study and was an adaptation of the authors test described by Ricketts, Nation, & Bishop (2007) (Appendix 6a). The title recognition test (Appendix 6b) was used for the younger children. The title recognition test used in this study was that developed by Lynette Atkinson (2015) as part of her PhD thesis, and was provided with permission for use in this study by her supervisor Dr Daisy Powell.

4.2.7 Photorefraction

Photorefraction is a rapid non-invasive method of measuring refractive error. Eccentric photorefraction, also known as "static photographic skiascopy", was described by Kaakinen (1979). If the eye is optically defocused light is reflected from the fundus and results in the illumination of the pupil indicating either myopic/hypermetropic refractive error (the “red eye” effect seen on flash photography). This reflected reflex forms a crescent of light in the pupil, the size, position and light gradient of which can be used to calculate refraction. Schaeffel (1987), introduced the Power Refractor which uses continuous infrared photorefraction of a series of LED lights arranged eccentrically from the camera aperture; this forms the basis of the method currently widely used for research and, more recently, vision screening

Many devices based on the principal of eccentric infrared photorefraction have been commercially produced, for example, Tomey ViVa and Topcon PR2000 as well the PowerRefractor and Plusoptix vision screener. The photorefractor currently used in the University of Reading IVL is the Plusoptix S04. This can measure refractive error across the range of +5D to -7D. The Plusoptix S04 consists of both a screening mode, allowing it to be used as a photoscreener and a PowerRef II (“R”) mode which allows the simultaneous collection of eye position and refraction data. The main advantage of the PowerRef method is that it takes continuous measurements of both eyes at the same time in addition to a measure of eye position. This allows the simultaneous measurement of both accommodation and convergence.

The photorefractor is placed 1m from the child and does not require head stabilisation, which is advantageous in both a vision screening setting and in this laboratory study which is concerned with the assessment of young children.

Various studies have been carried out on the validity of eccentric photorefractors. Both the PowerRefractor and Plusoptix S04 have been shown to have a myopic bias and may underestimate hypermetropia in screening situations (Dahlmann-Noor et al, 2009;

Erdumus, Yagci, Karadag, & Durmus, 2007; Ehrt, Weber, & Boergen, 2007). Horwood and Riddell (2009) compared the refraction obtained with the Plusoptix in an experimental setting, using a variety of targets, with gold standard cycloplegic refraction. Close correlation was found between both methods when targets containing both proximal and looming cues where used for the non-cycloplegic Plusoptix method. The Plusoptix is also useful and accurate method of assessing accommodation in children. Gabriel and Mutti (2009) showed, after the exclusion of some inattentive infants, that similar that estimates of infant accommodative error were obtained with the Plusoptix PowerRefractor and MEM dynamic retinoscopy.

4.2.8 Infant Vision Laboratory

The Infant Vision Laboratory (IVL) uses a Remote Haploscopic Photorefractor (RHP) to measure accommodation and convergence responses of participants in naturalistic conditions. The RHP was originally designed by Israel Abramov and Louise Hainline of the Infant Study Centre, Brooklyn College of the City University of New York. The RHP used in the IVL is a modification of this design, which originally used flash photography to record accommodative reflex and eye position. The system has been updated through the inclusion of the commercially produced Plusoptix PowerRef (Horwood & Riddell, 2008). The RHP is a unique apparatus, the only one of its kind worldwide. It has been specifically built by the technicians at the University of Reading to facilitate target manipulation without disrupting photorefraction. The RHP consists of two optical pathways (Figure 4-1); one for off-axis infra-red continuous photorefraction (see *4.2.8.1*) and the other for presentation of the fixation target (see *4.2.8.2*). This presentation allows for target presentation and manipulation independent of the collection of photorefraction data.

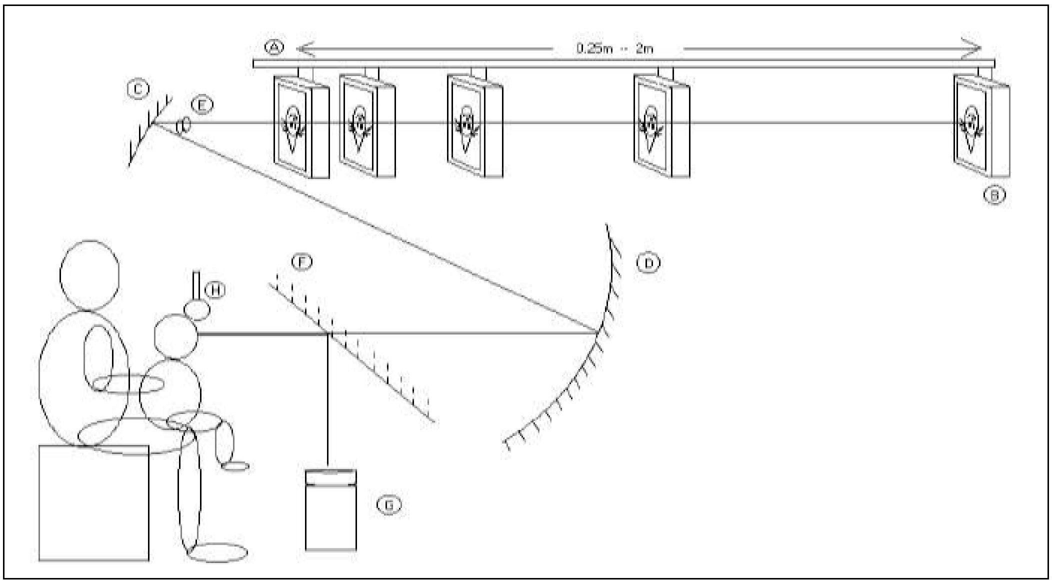

Figure 4-1: Remote Haploscopic Photorefractor. (A) Motorised beam (B) Monitor for target presentation (C) Upper concave mirror (D) Lower concave mirror (E) Occluder if required (F) Hot mirror (G) PlusoptiX S04 photorefractor (H) Headrest

4.2.8.1 IVL RHP Photorefraction Pathway

The RHP photorefraction pathway incorporates the commercial infra-red photorefractor, Plusoptix S04 PowerRef II (Plusoptix GmbH, Nurnberg, Germany). The PowerRef II (“R”) mode enables the collection of eye position and refraction data simultaneously; measured continuously at 25Hz. Plusoptix S04 data is obtained via a 600mm diameter “hot” mirror, set at 45°. This mirror is transparent to visible light but reflects infra-red light, allowing the subject to see the target through the hot mirror whilst the photorefractor records eye position and refraction via the photorefraction pathway.

4.2.8.2 IVL RHP Target Pathway

IVL targets are presented on a high resolution computer monitor which is fixed to a motorised beam. The monitor, and subsequently the target, is presented to participants via two concave mirrors such that the participant watches a virtual image moving in space directly in front of them, although the real target is presented on the beam above them. As the target is presented via the concave mirrors, an optical image of the participants face is situated just in front of the top mirror. Any optical change made between this virtual image of the participant and the actual target is the same as the optical change between the participant's actual eyes and the virtual target. Occlusion can therefore be achieved, if desired, by placing an occluder at the level of the upper mirror between the virtual image of the participant's eye and the target.

The beam moves at a speed of 0.4 metres/second and the screen may be positioned so that its image is static at distances of 2m, 1m, 0.5m, 0.33m and 0.25m from the participant's eyes, corresponding to an accommodative demand of 0.5D, 1D, 2D, 3D and 4D respectively. The beam moves the target in a pseudo-random order, alternating near and distance fixation (3D, 0.5D, 4D, 1D, 2D). The whole apparatus is enclosed in black painted shuttering to minimise any visual cues other than from the screen. During movement of the beam the motor can be heard which alerts participants to the movement of the target, however it does not give any indication regarding the direction of movement.

Participants are unaware that they are seeing a virtual image. Horwood, Turner, Houston and Riddell (2001) asked a sample of adults to touch the virtual image, the majority of subjects were surprised that the image was not where they pointed indicating that they did not know they were looking at a virtual image. This indicates that the image appears real and at the appropriate point in space during testing.

4.2.8.3 Processing IVL data - Accommodation Macro

Raw refraction and eye position data is recorded by the Plusoptix PowerRef II in a *.csv* file. This file requires manipulation to convert the recorded refraction data into useable data units prior to analysis. An excel macro (henceforth, IVL macro; copyright University of Reading, 2011) has been developed at the University of Reading to convert Plusoptix PowerRef II refraction data into units which can be utilised for analysis. This macro has been the standard method of converting Plusoptix refraction data into accommodation for many years and its procedure has been previously described by Horwood & Riddell (2008).

The IVL macro facilitates the conversion of the refraction data recorded by the Plusoptix PowerRef II into dioptres (D) of accommodation. Data for each target condition is calculated separately. The steps taken to achieve the unit of accommodation are described below.

Firstly, for refraction data to be converted to a useful measure of accommodation it is necessary to convert the refraction data from negative to positive or vice versa, e.g. if a refraction of -2D was recorded by the Plusoptix this would indicate 2D accommodative response to that target at that distance. To achieve this change in sign the macro multiplies each refraction value obtained during the target presentation by -1. The macro then cleans the recorded data for blinks and missing data; this is achieved by removing all refraction values recorded as “-100” – the device’s default missing data value.

In addition to refraction, the Plusoptix records eye position data in degrees. The macro allows this eye position data to be converted into a measure of vergence (in metre angles) by transposing one of the horizontal version (eyes moving left or right) measurements. The vergence measurement is relevant in this study, even though the primary interest is accommodation, as it provides information regarding fixation and whether appropriate convergence is initiated and maintained during the accommodative task.

Following this part processing of data by the macro, the data is displayed in a chart format (Figure 4-2). This is then visually inspected by the researcher to identify a vignette of 25 stable time points for each target or fixation distance i.e. in the usual laboratory routine (section *4.2.8.2*) this will produce one time point for 0.5D, 1D, 2D and 3D demand. This vignette of 25 time points equates to 1-second of continuous viewing in each condition which is sufficient for analysis. Eyeballing of data rather than a more objective mathematical method of identifying vignettes e.g. by using a specific program which would identify the same vignettes in each participant after accounting for predefined target onset/latency of response, is required as children do not necessarily always fixate steadily. As a result, the Plusoptix will sometimes fail to collect continuous data or will return extreme values from periods where fixation is off axis or if it fails to identify the pupil margin. The advantage of the eyeballing technique in this situation is that the inclusion of erroneous/inaccurate data points can be avoided. The output chart (Figure 4-2) has a very distinctive shape and to the trained observer it is easy to identify points of inaccurate or insufficient fixation which would not be representative of the response and as such would be unsuitable for analysis.

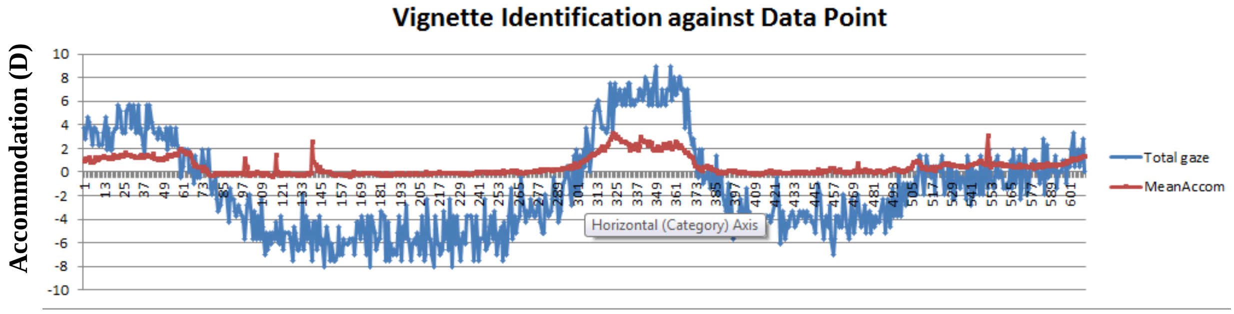

Figure 4-2: Example of vignettes produced during accommodation assessment using the clown target at different distances (*4.2.8.2*). Dioptres (D) of accommodation are represented on the y-axis. The numbers on the horizontal axis refer to individual data rows in the excel file, i.e. 1 represents line 1, these are listed on the graph for ease of vignette identification. AR is represented by the red line. Vergence is represented by the blue line indicating target distance during the assessment. In this example, good, consistent vignettes for analysis would be between data points 193 and 218, or 565 and 590.

Adequate training is required for the effective use of the above described macro. It is necessary for a new researcher to be proficient and competent in the identification of appropriate vignettes and proficient in the detection of unsuitable or unrepresentative fixation. Extensive training was undertaken by the author prior to the commencement of any data analysis procedures. The author reviewed a range of existing IVL datasets, including challenging datasets (multiple loss of data points) and straightforward datasets (steady fixation), and made decisions on which vignettes should be identified for analysis. The same datasets were reviewed, separately, by the supervisor (AH) and appropriate correlation and agreement analyses were conducted between the points identified by the author and supervisor; the results of this are reported below.

Vignettes for 596 conditions were identified by the author and supervisor. Pearson correlation analysis between the supervisor's and researcher's judgement was found to be very high, *r* = .97. Bland Altman Limit of Agreement analysis was performed to assess the level of agreement between researcher and supervisor decisions (Figure 4-3). Mean bias (SD) between researcher and supervisor was 0.009 (0.143)D. Bland Altman analysis indicated that 95% level of agreement between the researcher and supervisor ranged from -0.27D to 0.29D. From Figure 4-3 it is clear that most judgements showed strong agreement, while some are outside the 95% upper and lower limits of agreement the vast majority of these differences would not be considered clinically significant (clinically significant difference is defined as 0.5D difference, 95% limit of agreement were considerably below this level). In fact, as illustrated on Figure 4-3, only 10 of the 596 judgements analysed differed by more than 0.5D i.e. only 1.68% of total judgements had a difference greater than or equal to 0.5D. Where differences ≥0.5D did occur, these were not consistently higher/lower by one individual; the author identified a higher accommodative response in 4/10 and the supervisor identified a higher response in 6/10 of the cases concerned.

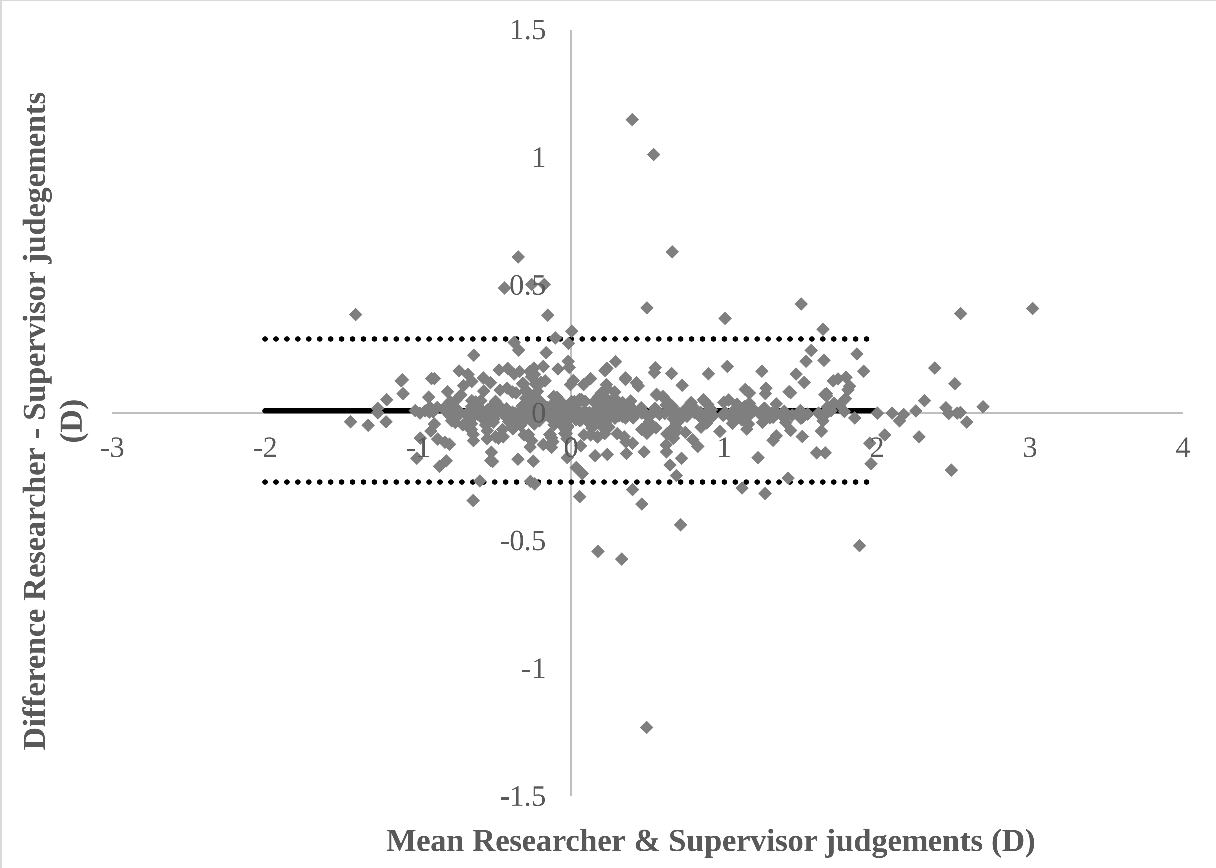

Figure 4-3 Bland Altman Limit of Agreement analysis of IVL macro vignette judgements between author and supervisor. Dashed line denotes 95% upper and lower level of agreement (bias ± 1.96 x standard deviation; range -0.27 – 0.29). Solid line denotes bias (0.009D).

The IVL macro was originally established to obtain useable accommodation measures at various testing distances, as per the previously described laboratory routine (section *4.2.8.2*). However, it can also be used to evaluate the accommodation response at a single testing distance, as will be reported in this thesis. In this circumstance it is possible to obtain four separate 25-vignette segments permitting evaluation of accommodative response over the target presentation period e.g. during the start, middle and end of the target presentation period. The method for vignette identification at a single testing distance remains the same as that described above. No additional correction of the macro is required to identify these vignettes at a single testing distance. For the purpose of this thesis it was decided to continue using the IVL macro to convert the Plusoptix refraction data to measures of accommodation as this would permit comparison with previous IVL research. This was considered important as the data reported in this thesis is novel and exploratory. Evaluation of accommodative response at a single testing distance had not previously been investigated in such depth in the IVL; thus, the facility to evaluate data with that obtained previously to ensure consistency and accuracy was considered essential.

4.2.8.4 IVL Photorefractor Calibration

Photorefractors such as the Plusoptix, utilise the size, gradient and position of light reflection on the retina to estimate refraction. These factors, and the resulting estimate, can be influenced by a pupil size, design of LED array, and higher order aberrations. Commercial photorefractors account for these issues through inbuilt device calibration factors arrived at during the equipment development phase; although limited information is available regarding these corrections due to protected patents and intellectual property of the devices. In a detailed study of photorefractor calibration, Bharadwaj (2013) reported that these inbuilt calibration factors are likely to be representative and have sufficient accuracy when examining a group of subjects, although error may still occur on the individual level. For example, individual anatomical differences may mean that the Plusoptix may return a reading of 0.9D of change in one child, and 1.1D in another, when 1D has actually occurred in both children when gold-standard methods are used.

There are two types of calibration error; absolute and relative. Absolute calibration error refers to the comparison between a photorefractor measurement and that obtained with gold standard retinoscopy under the same target condition; this calibration is considered impractical to carry out on a routine basis (Bharadwaj et al, 2013), however, a one off calibration is required to check the validity of the data. Absolute calibration of the IVL Plusoptix was previously conducted on a sample of 59 adult subjects (Horwood & Riddell, 2008). In this procedure, the examiner, blind to the Plusoptix outputs, performed MEM dynamic retinoscopy whilst lying inside the IVL apparatus to ensure accommodation estimates were obtained under identical conditions. Good correlation was found between the accommodation measurements obtained using the Plusoptix and MEM retinoscopy. A consistently smaller response was found with the RHP than the gold standard retinoscopy method; however, the differences between the two measures were not statistically significant. This small difference in the group calibration factor was incorporated into the macro used to calculate the accommodative response.

Relative calibration utilises a range of lenses, both hypermetropic and myopic, to examine the change in the photorefractor refraction estimate per dioptre change in individual eye defocus. Gold standard calibration involves the introduction of a range of lens powers (-6D – +8D) before the eye in 1D steps while the photorefractor calculates refraction estimate for each lens power. Ordinary least square linear regression analysis is then conducted to obtain the calibration factor utilising the anisometropia induced by each hypermetropic/myopic lens and the actual lens power. Relative calibration error has been found to vary across individuals, so routine individual relative calibration is recommended (Bharadwaj et al, 2013; Blade & Candy, 2006).

The aforementioned gold standard calibration procedure is recognised as a difficult task for young/uncooperative subjects (Blade & Candy, 2006; Horwood &

Riddell, 2008). Loss of attention and cooperation can influence intra-subject variability and as such calibration accuracy. In view of the already lengthy testing procedure (see *2.6*) it was felt that accurate individual IVL calibration would be impractical within time constraints and that large intra-subject variability was a considerable risk to the study. It was unlikely that adequate/useable data would be collected if calibration was carried out at the end of the session, and if it were carried out at the beginning, it would have been likely to compromise the main study aims. Therefore, it was decided that individual calibration would be attempted in the later school study (*Chapter 5*) once a shorter testing procedure was established instead of during the laboratory study.

4.2.9 Targets

A range of targets were employed to assess typical accommodative behaviour in children; including a brightly coloured clown, small size 5 text, age appropriate school book text, a "Where's Wally?" visual search puzzle, single letter targets and a cartoon target. All targets were presented on a black background within a MS PowerPoint presentation, displayed on a ViewSonic VX1932wm-LED computer monitor (screen resolution – 1440x900 pixels). Minimal overall target luminance was 10cd/m^2.

4.2.9.1 Clown target

The clown target has been used in previous IVL studies and was employed to assess accommodative behaviour at varying distances in this study. It is a high contrast brightly coloured target with a range of spatial frequencies. To maintain a child's interest the eyes and mouth of the clown alternate (Figure 4-4), at a frequency of 1Hz. This target was presented in pseudo-random order at 0.25m, 0.33m, 0.5m, 1m, 2m distance from the participant's eyes (as described in *4.2.8.2)*. It is an engaging, naturalistic target which was originally designed for young children/babies and is suitable for participants with a range of visual acuities. Accommodation to the fine detail is possible, but not necessary, to resolve the target. The central face portion of the clown subtended 3.15^{o} at 2m and 18.26^{o} at 33cm. Various level of detail was available within clown target (Horwood and Riddell, 2008); the concentric rings on the clown nose (Figure 4-4) were 3mm wide and therefore subtended 5 minutes of arc at 2m and 30 minutes of arc at 33cm. The black outline subtended 1 minute of arc at 2m. The use of this target receding into the distance also allows an accurate estimate of refraction to be obtained without cycloplegia* (Horwood & Riddell, 2009).

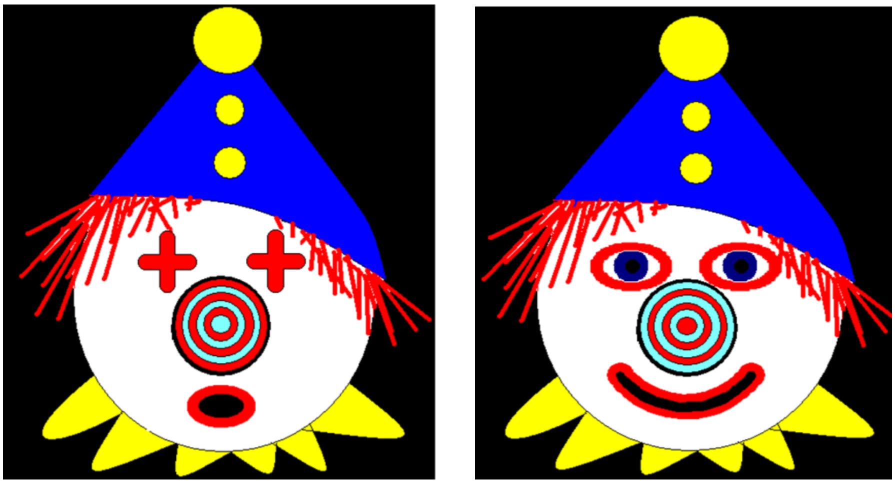

Figure 4-4: Clown target used with alternating eyes and mouth.

4.2.9.2 Small Text

Small, N5 equivalent (this size), age appropriate text was used to replicate an eye clinic children's near vision tests. For this study this target was presented at 1/3m only. The small print target was presented in a text box, width/height dimensions 3.5cm x 3.5cm, which subtended 6^{o} at 33cm.

Age appropriate text was derived from a test widely used in UK paediatric eye clinics – the Maclure Reading Test Type (Maclure, 1980). The Maclure test was designed as an alternative to adult texts which are considered inappropriate and ineffective for assessment of a young child. The words used were devised from the Ladybird Reading Scheme and are age appropriate for 4 – 10 years of age and older. As with typical adult near vision tests, text size ranges from N5 – N48. Font style however is different; adult text is largely presented in Times New Roman while the Maclure test uses a sans serif type, "school script", considered more familiar for young children. To best replicate the Maclure age appropriate text in a sans serif text, Helvetica, in N5 equivalent font size was used in this study (Figure 4-5).

(A)

Here are the boy and girl with the farm dogs. They go to look at the cows. They see a cow and go into the water. The cows give us milk. "Do you want some milk?". The girl has some milk for the cat. They go up to the farm to get some cows' milk for the cat. They give milk to the ca and then play with her. The cat likes to play with a toy on the rug. The children play with the cat and then they will all go into the garden. The children like to work with daddy. They all make a fire in the garden. "This work is like play", says the boy. They play a game by the tree. They run from the tree to the house. The children get wood for the fire.

(B)

After the meal they checked their equipment and went over The arrangements they had made for the climb. Their guide made them check every piece of equipment carefully. They had light tents with them as they had to spend two nights on the mountain side. The guide emphasised the importance of keeping together, and not going off in ones and twos, because of the difficulties and danger created should a mist descend upon them, which, he said, could happen so quickly that they might be unable to locate each other. For this reason, and also for safety, they would be roped together, and everyone was to carry a compass. At last they safely reached the mountain peak. They stood for a few minutes looking at the wonderful view all around them, then sat down as they were tired.

Figure 4-5 Small Print size 5 font for Year 2 (A) and Year 6 (B) participants

4.2.9.3 School-book Text

To design a target representative of children's everyday school books, books covering all levels of the UK national primary school reading scheme were examined from The University of Reading Learning Hub. Books from the Collins Big Cat reading scheme were compared on the basis of font style, size and use of pictures to guide target design. It was obvious from this comparison that wide variation exists in the typeface used in children's books; some books employed a sans serif while others used a serif font. Font size did not appear consistent, even in books aimed at more experienced primary school readers within the 8 – 10 year old age bracket. Books for the youngest readers consistently employed the largest text.

A literature search conducted on typefaces for young children yielded little guidance on an "ideal typeface" for young readers. Most research regarding the legibility of typefaces pertained to fluent, adult readers with little attention given to children (Sassoon 1993; Wood, Davis, & Scharff, 2005). As there is no current agreement on the most appropriate typeface for children, font selection is largely determined by individual publishers, with some consideration given to what teachers feel is most appropriate for children (Walker 2005; Watts & Nisbet 1974; Yule, 1988). The factors considered to influence the legibility of children's print and the available, relevant research, are discussed individually below. A sample of the school-book text target is given in Figure 4-6.

4.2.9.4 Serif vs Sans Serif typeface

Burt (1959) argued that serifs are important for early readers as a serif font has a finishing stroke at the end of the letter which may help discriminate individual letters and guide reading. Wood et al (2005) conducted a study investigating the effect of a serif vs sans serif typeface on discrimination and identification of letters by school-children from kindergarten to fourth grade. It was found that the sans serif font produced fewer errors than the serif type. A recent review (Tarasov, Sergeev, & Filimonov, 2015) concluded that a difference in the legibility of serif and sans serif text had not been identified in the literature and has questioned the external validity of some of the available research.

From examination of the sample of approved children's reading scheme books it was clear that a sans serif font type was predominantly used for the very early readers. As the literature does not advise serif over san serif and the latter was more common in children's books, a sans serif font was selected for the school-book target. Common sans serif typefaces including Arial, Helvetica, Gill Sans and Frutiger were all considered for use in this study. Helvetica was selected as the target font style as it is frequently used in early reading schemes and has appropriate letter spacing for early readers (Walker, 2002; Wood et al, 2005).

4.2.9.5 Font point size

It was clear from the examination of children's books that larger font sizes are used for early readers. Hughes and Wilkins (2000) report that in younger children small print is associated with decreased reading speed; however, this effect of font size was not significant in children above 8 years. Tinker (1959; Cited in Watts & Nisbett, 1974) made recommendations of point size between 14-18pts for Grade I readers 12-14pts for Grade 2-3 and 10-12pts for Grade 4 and above. Burt (1959) recommended slightly larger font size, of up to 24pts for children below age 7 years.

For this study, font sizes 12 and 18 point were selected for both year groups as this is in keeping with recommendation of children's font sizes. The x-height of both sizes were evaluated and found to be largely comparable to a selection of Year 2 and Year 6 children's reading scheme approved books in the UK.

(A)

Brown Bear was pleased to see them and jumped up, but the birds got a fright and flew away.

Clare first saw the spider on Saturday. It was in the bath, trying to climb up the side. Up and up it went … then down. Up and up and up … then down again. Again and again, it got half way up, but then – SPLOSH! “Poor spider, I’ll help you”

(B)

Gran’s the softest old bird ever. She’s part of a gang called the “hedgehogs”. They’re all women and they all ride

We stared at him. We didn’t get many children coming to school from outside the village so we were curious. He had blond curly hair and looked too small and thin and young to be in our class. The thing I remember the most is that his face was blank. Like a mask

Figure 4-6: (A) Example of age appropriate “Big Print” text size 18 and “Medium Print” size 12 for Year 2 children. (B) Example of age appropriate “Big Print” text size 18 and “Medium Print” size 12 for Year 6 children.

4.2.9.6 Where’s Wally?

The cognitive effort involved in a visual search activity may induce more accommodative effort than a simple picture, and particularly for children with literacy problems, may be very different from a reading task. To evaluate this, children were presented with a “Where’s Wally?” picture activity in this study. This is a high contrast picture which requires children to search for “Wally”, wearing a red and white striped top, in a crowded scene. The Where’s Wally? image patch measured 3.5cm x 3.5cm and subtended 6^o at 33cm. However, various level of detail was available within the picture. For instance, Wally the visual search target, subtended approximately 1^o at 33cm. The same image was presented to all children regardless of year group (Figure 4-7)

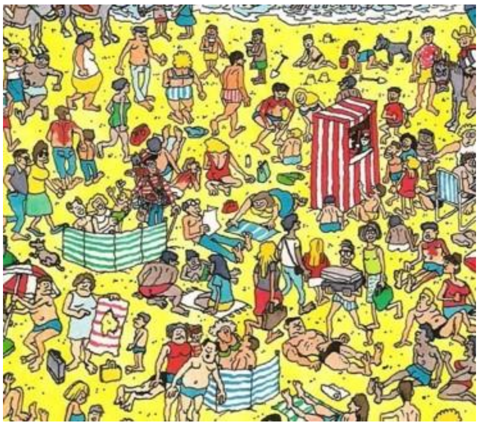

Figure 4-7: "Where's Wally" task for all participants. In the event that children found Wally immediately they were instructed to find the "lady with the green handbag" and the grey dog to maintain accommodative effort for the target presentation period

4.2.9.7 Single letters

A single letter A or H in Helvetica font style, font size equivalent to 18 point, was used as a target to assess accommodative demand to single letters. This was selected to replicate the accommodative demand of young children and very early readers who are presented with just one letter at a time. These single letters were presented in a text box, size 3.5cm x 3.5cm, which subtended 6^o at 33cms viewing distance.

4.2.9.8 Cartoon

A silent, high contrast, coloured humorous cartoon clip of "Tom and Jerry" (freely available from https://www.youtube.com/watch?v=LPRRoQ4MsEA) was downloaded and presented to the children. This clip measured 3.5cm width x 2.5cm height and subtended 4^{o} at 33cm. The same clip was presented regardless of age group.

4.2.10 Educational tests

A wide range of ability tests were trialled in this laboratory study to identify the most appropriate test(s), in both sensitivity and brevity, to use in the larger school study. The range of tests trialled in this laboratory study was selected following extensive consultation with the study collaborators, Dr Daisy Powell from the University of Reading Institute of Education and advice from Dr Rachel Pye from the School of Psychology. Both collaborators are highly experienced in reading and educational assessment. Appropriate test assessment training was obtained from relevant University of Reading psychologists prior to study commencement.

4.2.10.1 General Ability

The British Ability Scales – third edition (BAS-3) is a standardised psychological test which provides a measure of general ability in young children (Elliot & Smith, 2011; GL Assessment©). It consists of various subtests which can be combined to calculate a measure of General Conceptual Ability (GCA). GCA was calculated in this study to ensure that any relationship between reading and accommodation that might be found could not be attributed to individual differences in general ability. GCA is calculated through a combination of completed subtests representing non-verbal, verbal and spatial ability. The relevant subtests used in this study to calculate GCA were, Matrices (non-verbal reasoning), Verbal Similarities (verbal reasoning) and Pattern Construction (spatial ability).

4.2.10.2 Reading Ability

Under-accommodation could impact different facets of reading such as reading rate, accuracy or comprehension. Nonsense word reading relies on letter decoding; therefore, this could also be useful in the evaluation of a relationship between accommodation and reading. It was unclear from existing literature which aspect of reading would be most hampered by under-accommodation, therefore a range of tests were selected for use in this pilot study. The selected tests and the method of administration are discussed below; examples of the tests used are given in Appendix 7a – e.

4.2.10.2.1 York Assessment of Reading Comprehension (YARC)

The York Assessment of Reading Comprehension (YARC) 2nd edition (Snowling et al, 2009; GL assessment©) test is a rich standardised reading test which consists of a single word reading test (SWRT) and/or passage reading. It was selected as it provides measures of single word reading, reading rate, accuracy and comprehension. The YARC has been co-normed in line with the BAS-3.

In this study YARC assessment began with the SWRT to ascertain the appropriate testing level for each individual child. The SWRT consists of a list of real words – children were instructed to read as many words as possible while the researcher noted responses. Participants were then instructed to read two appropriate passages aloud while the researcher marked any errors made during the task. At the end of each passage the researcher asked the child eight comprehension questions about each reading passage and noted their responses. The calculation of the performance across both passages provided individual measures of reading rate, accuracy and comprehension.

4.2.10.2.2 Wilkins Rate of Reading

The Wilkins Rate of Reading test (Wilkins, Jeanes, Pumfrey, & Laskier, 1996; Institute of Optometry Sales Limited) is often used by eye care practitioners when assessing potential benefit of coloured overlays for children with visual stress or dyslexic tendencies. Its score provides an indication of the ease with which text is read. The Wilkins comprises of four nonsense paragraphs of repeated simple words, e.g. dog, cat, go, up. Although it is not a standardised test, the Wilkins was trialled in this laboratory pilot study as it is simple, quick and familiar among eye care professionals.

For this task children were asked to read as many words as possible in a minute while the examiner noted errors and kept time. The test was re-administered using a different paragraph and an average taken. This calculation produced a reading rate score.

4.2.10.2.3 Test of Word Reading Efficiency

The Test of Word Reading Efficiency 2nd edition (TOWRE-II) (Torgesen, Wager, & Rashotte, 2012; Pro-Ed©) is a rapid standardised reading test which assesses nonsense word reading (phonemic decoding efficacy (PDE)) as well as regular/sight word efficacy (SWE). It was standardised in the USA and has associated age and grade norms. USA standardisation is a limitation of this test – the norms are not necessarily representative of British children due to differences in the respective education systems. Due to its short assessment time it was selected for trial in the laboratory. In view of

USA standardisation, the precautionary measure of recording and analysing the data based on both raw and standardised scores was taken for this test.

To complete the SWE test children were instructed to read aloud as many words as possible from a list of words of increasing difficulty, in 45-seconds while the researcher noted errors. This process was repeated with a list of non-words to obtain a measure of PDE.

4.2.10.3 Attention/Behaviour

As poor accommodation has also been associated with attention deficits measures of attention/behaviour were also trialled in this laboratory study.

4.2.10.3.1 Test of Everyday Attention for Children

The Test of Everyday Attention for Children (TEA-Ch) (Manly, Robertson, Anderson, & Nimmo-Smith, 1999; Thames Valley Test Company Limited) was selected for use in this study. It is a wide ranging, standardised attention test which has been specifically adapted from the adult Test of Everyday Attention (TEA). It is well recognised as a useful tool in the assessment of behavioural difficulties such as ADHD (Heaton et al, 2001; Manley et al 2001). The recommended screening version of the TEA-Ch was employed for this study (20 minute duration).

The TEA-Ch screening version comprises of four subtests – Sky Search, Score!, Creature Counting and Sky Search DT - which assess selective attention, sustained attention, attentional control/switching and sustained-divided attention respectively (Appendix 7d & e).

- Sky Search – children were asked to circle matching pairs of spaceships as quickly as possible while timed by the examiner.

- Score – children were asked to listen to a cassette and silently count how many “beeps” were played. This subtest consisted of 10 separate trials.
- Creature Counting – children counted number of creatures on a page. Arrows on the page instructed when to swap from counting up to counting down. This test consisted of 8 trials.
- Sky Search DT – this combined Sky Search and Score, children circled matching pairs of spaceships while silently counting the number of “beeps” played on a cassette.

4.2.10.3.2 Strengths and Difficulties Questionnaire

A parental questionnaire, the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 1997), was used as a secondary measure of attention and behaviour. The SDQ is an emotional and behavioural screening questionnaire for children aged 4 – 16 years. The SDQ has five sub-scales for different aspects of behaviour including emotional problems, conduct/behaviour problems, pro-social behaviour, interaction with peers and inattention/hyperactivity; it may be completed by parents, teachers or the child/young person themselves. The SDQ is widely available, free of charge, and has been validated as an effective measure of children’s behaviour (Goodman, Ford, Simmons, Gatward, & Meltzer, 2000; Mathai, Anderson, & Bourne, 2003; Rimvall et al, 2014). In addition, the SDQ has been recommended by the National Institute for Health and Care Excellence as an adjunct to assessment of ADHD in children (NICE, 2008). Both parental and teacher SDQs are recognised as effective measures to identify children at risk of ADHD (Rimvall et al, 2014). The parent, rather than the teacher SDQ was selected for practical reasons – participating children were due to attend the IVL session with their parent(s)/guardian(s). The individual SDQ was not selected for administration as participating children were already required to complete a questionnaire pertaining to reading exposure, in addition to the numerous educational tests detailed above. It was considered that the addition of this extra questionnaire might have been beyond the attentional capacity of participants, especially the younger children, therefore individual SDQs were not administered.

4.2.11 Statistical Analysis

The IVL macro (*4.2.8.3*) was used to convert Plusoptix PowerRef II refraction data into accommodation into dioptres (D). The resulting dioptre measurement was used for analysis.

Clown target data was collected at different distances – for the purpose of analysis data from the 1/3m distance only was selected. All other targets were presented at 1/3m only – data was selected from the end of each target test period for analysis. This was selected to represent AR following sustained activity.

It was considered that an AR measurement taken after a period of target viewing would be most representative of a child's habitual accommodation as reading and similar tasks typically require more than a brief few seconds attention. As such it was felt that any relationship between AR and reading/attention would be more likely to be identified by using an accommodation measure from *after* a period of sustained viewing. The possibility of a change in accommodation between the beginning and end of target presentation period e.g. as a result of fatigue was considered and analysed, as per the method described below.

The standardised test scores and accommodation data were continuous data. Normality checks confirmed that the data satisfied the assumptions of parametric analysis.

Analysis was conducted in two parts:

1. Accommodative response (AR) to different accommodative targets at 1/3m, consisting of a:

a) one way repeated measures Analyses of Variance (ANOVA) with post hoc Bonferroni correction. There were 7 ANOVA levels in this analysis consisting of accommodation to each target at 1/3m i.e. AR to the small, medium and big print, individual letters, Where's Wally?, cartoon and clown target.

b) t-test analysis of difference in AR at the beginning and end of each target viewing period to identify if any significant difference in AR exists across the task.

c) two way mixed ANOVA to further investigate the effect of age on the observed AR to the various targets.

2. Relationship between AR and educational tests:

a) Pearson correlation analysis conducted between AR and the various reading/attention tests.

Organisation and initial analysis were conducted in MS Excel 2010. Main analysis was conducted using SPSS software for windows, version 22. Statistical significance was set at $p < 0.05$.

For the purpose of this thesis, statistical significance where a Bonferroni correction was applied remained at $p < 0.05$, The author notes that the Bonferroni corrected p value is calculated by the below equation:

$$Bonferroni\ Correction = \frac{alpha\ [0.05]}{number\ of\ comparisons}$$

Therefore, for the target analysis conducted in this thesis, the Bonferroni corrected p value is $p = 0.002$ (21 comparisons). However, Bonferroni correction in SPSS is applied by inflating the alpha (p value) by the number of comparisons rather than dividing it, i.e. the Bonferroni correction is applied "backwards" within this statistical package. As such, the significance level for Bonferroni corrected alpha on the applicable SPSS outputs remains at $p < 0.05$. Thus, where a Bonferroni correction has been applied in this thesis statistical significance will be reported in relation to $p < 0.05$ level.

Where Bonferroni correction has been applied manually i.e. not through SPSS, the corrected statistical significance value will be appropriately adjusted and the corrected statistical significance value provided.

4.3 Results

The following results are presented in two parts – pilot analysis and full dataset. Pilot analysis was conducted following the recruitment of $1/3^{rd}$ of the anticipated total participant number. This was conducted to facilitate the timely development of the test battery for the school based study and the submission of the relevant ethics application. As the school study test battery was designed based on the findings of the pilot analysis and verified by the full analysis it is necessary to report both results for the purpose of this thesis.

4.3.1 Pilot analysis

The purpose of this analysis was to inform the design of the school study test battery and provide pilot data. Due to smaller numbers than the full dataset, all children were analysed together as a single group. As the purpose of this analysis was to inform the school test battery accommodation to various target analysis was restricted to the one way ANOVA to identify differences across targets so the most suitable targets for the school study could be identified. A two way mixed ANOVA was not conducted on this dataset; results of this analysis will be presented during the full dataset results (section *4.3.2*; *4.3.2.2.4*). Correlation analysis was conducted as described in *4.2.11*.

4.3.1.1 Participants

Pilot analysis was conducted following the recruitment of 20 typically developing children (6 male; 14 female). Of these, 15 were current Year 2 pupils (mean age 6.13 years ± 0.35SD) and 6 were Year 6 pupils (mean age 10.33 years ± 0.52SD). All participants had a satisfactory orthoptic assessment indicating that they would have passed school vision screening. All had good visual acuity, no squint (controlled heterophoria* of $<8^{\Delta}$ near and distance), a good level of 3D vision (55" of arc of better using the Frisby stereotest), convergence was within normal limits (<10cms in free space) and no child spontaneously reported blurred vision during convergence.

19 children did not use any glasses. One participant did habitually use glasses for close-work (+1.00DS OU); this participant was assessed whilst wearing glasses. Refractive error was assessed in each individual participant by employing the maximum hypermetropic refraction technique described by Horwood and Riddell (2009), which reported that in a group of infants and children the maximum hypermetropic refraction

found during the prolonged five target position testing sequence was not significantly different from the refractive error identified under cycloplegia. 18 participants were found to be hypermetropic; mean (SD), +0.25D (0.20), range from +0.04D to +0.70D. 2 participants were recorded as myopic, mean (SD) -0.15D (0.14), range -0.06D to -0.25D.

4.3.1.2 Accommodation to various targets

Accommodation data were recorded for each participant for each target type. Data representing one-second of continuous viewing was selected from the end of the one minute the target viewing period and used in the analysis.

As can be seen from the mean accommodation detailed in Table 4-1, AR differed across target types. Text elicited the highest mean AR, with the smallest text, N5 equivalent print, producing the highest mean AR.

Target Type	Mean Accommodation 1/3m (D)	Standard Deviation (D)	Minimum Accommodation (D)	Maximum Accommodation (D)
Clown	2.46	0.36	1.80	2.97
Big Print (18)	2.90	0.51	1.59	3.56
Medium Print (12)	2.90	0.45	1.67	3.65
Small Print (5)	3.06	0.44	1.75	3.99
"Where's Wally"	2.82	0.41	1.76	3.60
Cartoon	2.55	0.36	1.69	3.55
Individual Letters (18)	2.48	0.36	1.48	3.06

Table 4-1: Mean, standard deviation, minimum and maximum AR elicited by each target at 1/3m. Target font size given in brackets, where appropriate.

A one-way repeated measures ANOVA indicated that target type has a highly significant effect on the accommodative response elicited $F_{6, 120}=10.409$; $p = <0.001$ (Appendix 10a).

Post hoc analysis, corrected by Bonferroni adjustment for multiple comparisons, was performed to identify the differences in AR elicited across target types (Figure 4-8).

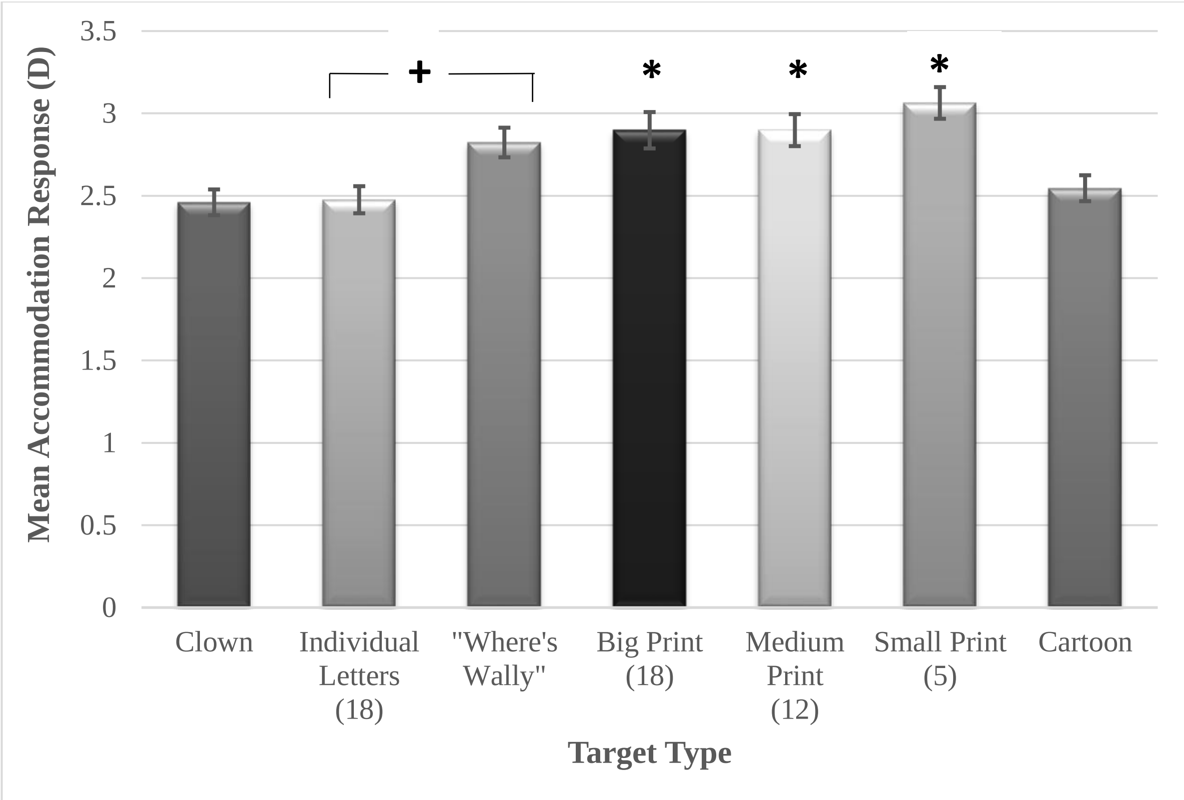

Figure 4-8: Mean accommodation to each target type at 1/3m. Bars denote ±1 standard error of the mean (SEM). Text font size is given in brackets where applicable. ***** denotes that the accommodative response elicited by text targets was significantly higher than that to the cartoon and individual letter targets. No significant difference was found between accommodation elicited to the various text targets. Accommodation to "Where's Wally target" was significantly higher than that observed to "Individual Letters" target (+). Text font size given in brackets where applicable.

All text targets, regardless of size were found to elicit a statistically significantly higher AR than the cartoon and individual letter targets, $p < 0.05$. AR to the big, medium and small print target was significantly higher than that to the cartoon at $p = 0.021$, $p = 0.005$ and $p = <0.001$ level respectively. AR to big, medium and small print was significantly higher than AR to individual letters at $p = 0.028$, $p = 0.001$ and $p = <0.001$ level respectively. AR to the small print target was also found to be statistically significantly higher than to the "Clown" target, $p = 0.005$. Although the small print target elicited a higher AR than the big and medium print targets this difference was not found to be statistically significant, $p > 0.05$. The difference in AR elicited by the visual search task, Where's Wally?, and the three text targets did not reach statistical significance, $p > 0.05$.

There was no significant difference in AR between the Where's Wally?, clown and cartoon target. A significantly higher AR was found with the Where's Wally? than the individual letters target, $p = 0.011$.
The difference between the AR to the clown, individual letters, and cartoon target was not found to be statistically significant, $p > 0.05$.

4.3.1.3 Accommodation at different time points

To replicate AR following a period of close-work one second of continuous data, from the end of the target viewing period was used for the main analysis. While AR appeared consistent across the target viewing period using visual inspection, e.g. Figure 4-9, the possibility of accommodative fatigue or AR drift during the task was considered. Therefore, analysis was also conducted to establish the difference in the AR at the beginning of the target viewing period (Time 1) and the AR at the end of which was selected for the main analysis (Time 2).

Time 1 was defined as the first consistent plateau response during the accommodation assessment, occurring within a few seconds of presentation. This was assessed by the researcher during the visual inspection of the vignettes. Time 2 was defined as the consistent response at the end of the vignettes. It was not possible to maintain a consistent time difference between Time 1 and 2 due to slight fluctuations in individual AR; however it expected that at least 50 seconds elapsed between Time 1 and 2. Two additional intermediate points were taken during visual inspection (Figure 4-9). The purpose of this was to provide numerical data to further inspect the stability of the AR across the target viewing period. All four points were similar on visual and dioptre inspection, and any differences between these two intermediate points and "Time 1" and "Time 2" appeared clinically negligible. It was therefore decided to limit the analysis on the difference in AR across viewing period to the difference between "Time 1" i.e. the beginning AR and "Time 2" i.e. near end of target viewing period. This approach was taken as data from after a period of sustained viewing was desired for analysis to represent habitual accommodation during near tasks; therefore, the difference between AR at the start (when the target was novel) and end (when the participant was most likely to be fatigued) was of maximum interest.

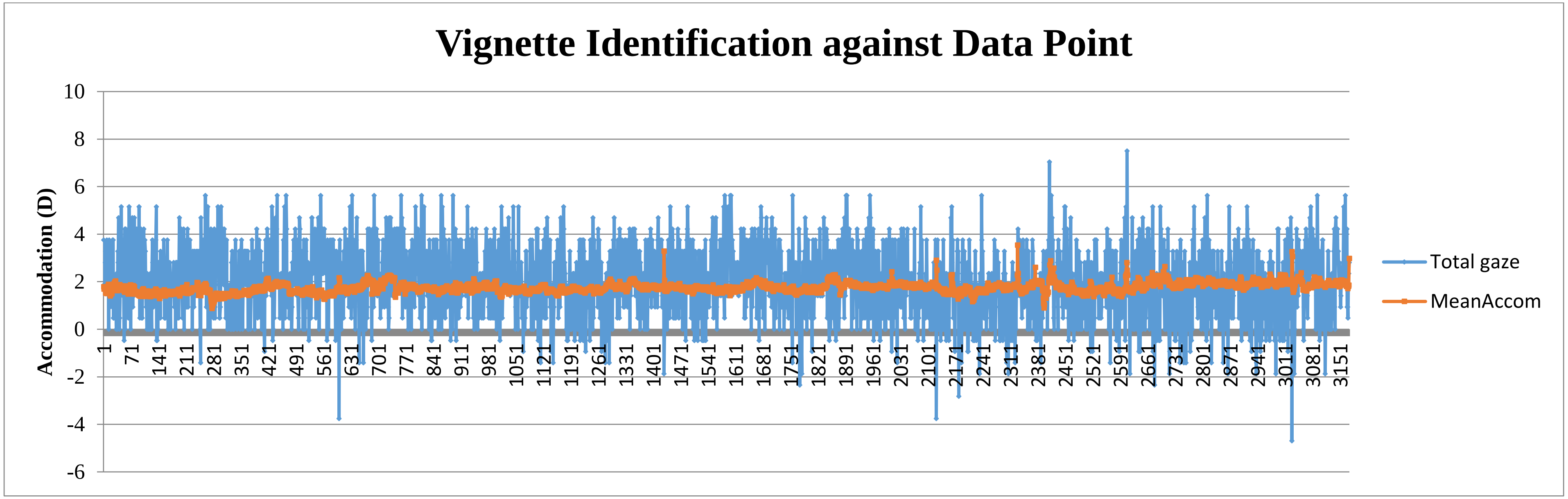

Figure 4-9: Vignettes produced by IVL macro for participant 0936 while looking at the small print (N5) target. Dioptres (D) of accommodation are represented on the y-axis. The numbers on the horizontal axis refer to individual data rows in the excel file, i.e. 1 represents line 1, these are listed on the graph for ease of vignette identification. AR was relatively stable across the target viewing period. In this example "Time 1" would have been taken from points 131-156, two intermediate points would have been from 1171-1196 and 1900-1925 and "Time 2" from 3060-3085. Taking four points across the fixation period allowed for evaluation of the stability of the accommodative response by converting four points to dioptre units. The difference in accommodative response was not statistically significant across the viewing period and was clinically negligible.

Target Type	Time 1 Mean Accommodation (Standard Deviation) (D)	Time 2 Mean Accommodation (Standard Deviation) (D)
Clown	2.63 (0.404)	2.46 (0.359)
Big Print (18)	2.80 (0.430)	2.90 (0.510)
Medium Print (12)	2.98 (0.538)	2.90 (0.445)
Small Print (5)	2.93(0.401)	3.06 (0.440)
"Where's Wally"	2.89 (0.426)	2.82 (0.413)
Cartoon	2.61 (0.338)	2.55 (0.361)
Individual Letters (18)	2.46 (0.457)	2.48 (0.360)

Table 4-2: Mean accommodation and standard deviation (D) on initial target presentation (Time 1); Mean accommodation and standard deviation (D) at end of viewing period used for analysis (Time 2).

Mean AR at Time 1 and Time 2 is given Table 4-2. Differences in the AR between Time 1 and 2 are apparent however they would be considered clinically negligible – none would have led to a noticeable change in clarity. A paired t-test was conducted for each individual target; the difference in AR did not reach statistical significance for any target, $p > 0.05$.

4.3.1.4 Relationship between accommodation and standardised test scores

Some of the younger children did not complete the full test battery due to fatigue/refusal. Sample size for each standardised test, published standardised mean and the observed mean and standard deviation of each standardised test in this study are given in Table 4-3. Participants demonstrated excellent reading ability; mean scores for both the YARC and TOWRE-II tests were at the upper end of the expected range. General ability (BAS-3) and attention (TEA-Ch) scores were within the expected range.

	N Completed Tests	Mean Score	Standard Deviation	Population Mean	Population Standard Deviation
YARC SWRT	20	113	8.46	100	15
YARC Reading Accuracy	20	117	11.7	100	15
YARC Reading Rate	20	115	9.01	100	15
YARC Reading Comprehension	20	111	8.15	100	15
TOWRE-II SWE	18	112	13.1	100	15
TOWRE-II PDE	18	110	12.1	100	15
Wilkins Rate of Reading	18	88.8	27.8	N/A	N/A
TEA-CH Selective Attention	17	9.53	4.20	10	3
TEA-CH Sustained Attention	17	11.8	4.01	10	3
TEA-CH Attention Switching	17	10.1	2.54	10	3
TEA-CH Sustained/Divided Attention	17	7.24	3.33	10	3
BAS-3 Matrices	19	53.1	6.78	50	10
BAS-3 Verbal Similarities	19	58.1	8.82	50	10
BAS-3 Pattern Construction	19	51.3	7.94	50	10

Table 4-3: Sample size (n), standardised mean and standard deviation for tests/study observed mean and standard deviation for reading and attention tests.

Pearson correlation analysis was conducted to establish the relationship between standardised tests and the AR to each target type (Table 4-4). No significant correlation was found between the AR to any target and scores obtained with the BAS-3, YARC, Wilkins or TOWRE-II, $p > 0.05$. No significant correlation was found between AR and the TEA-Ch selective, sustained or attention switching subtests ($p > 0.05$). A significant correlation was identified between AR to Where's Wally? and sustained/divided attention ($r = .558$, $p = 0.01$) and the letters target and the sustained/divided attention task ($r = .497$, $p = 0.042$). A highly significant correlation was identified between small print AR and sustained/divided attention, $r = .611$ $p = 0.007$.

Test	Big Print *r*	Medium Print *r*	Small Print *r*	Cartoon *r*	Clown *r*	Where's Wally? *r*	Individual Letters *r*
YARC SWRT	-.210	-.272	-.085	-.228	-.153	.180	-.377
YARC Reading Accuracy	-.427	-.388	-.150	-.262	.216	.138	-.390
YARC Reading Rate	-.471	-.155	-.041	-.121	.158	.100	-.367
YARC Reading Comp	-.328	-.149	-.193	-.360	.019	.150	-.275
TOWRE-II SWE	-.416	-.163	-.236	-.277	-.056	-.077	-.379
TOWRE-II PDE	-.281	-.135	-.098	-.089	.035	-.051	-.439
Wilkins Rate of Reading	.167	-.107	-.038	-.050	.430	-.227	-.266
TEA-CH Selective Attention	.103	.393	.125	.140	.060	.274	.079
TEA-CH Sustained Attention	.024	.042	.027	.181	.167	.225	-.058
TEA-CH Switching Attention	-.231	-.182	-.447	-.346	.212	-.285	-.241
TEA-CH Sustained/ Divided Attention	.134	.427	**.611***	.323	-.084	**.558***	**.497***

Table 4-4: Correlation matrix - Pearson's *r* for educational tests vs accommodation to each target. * denotes $p<0.05$

Following correction for multiple accommodation comparisons (statistical significance level adjusted to p = 0.008) only the positive correlation between small print AR and the sustained/divided attention score remained significant p = 0.007 (Figure 4-10). Thus, from this pilot analysis it appeared that those children who exerted less AR to small print also demonstrated lower standard scores on the sustained/divided task.

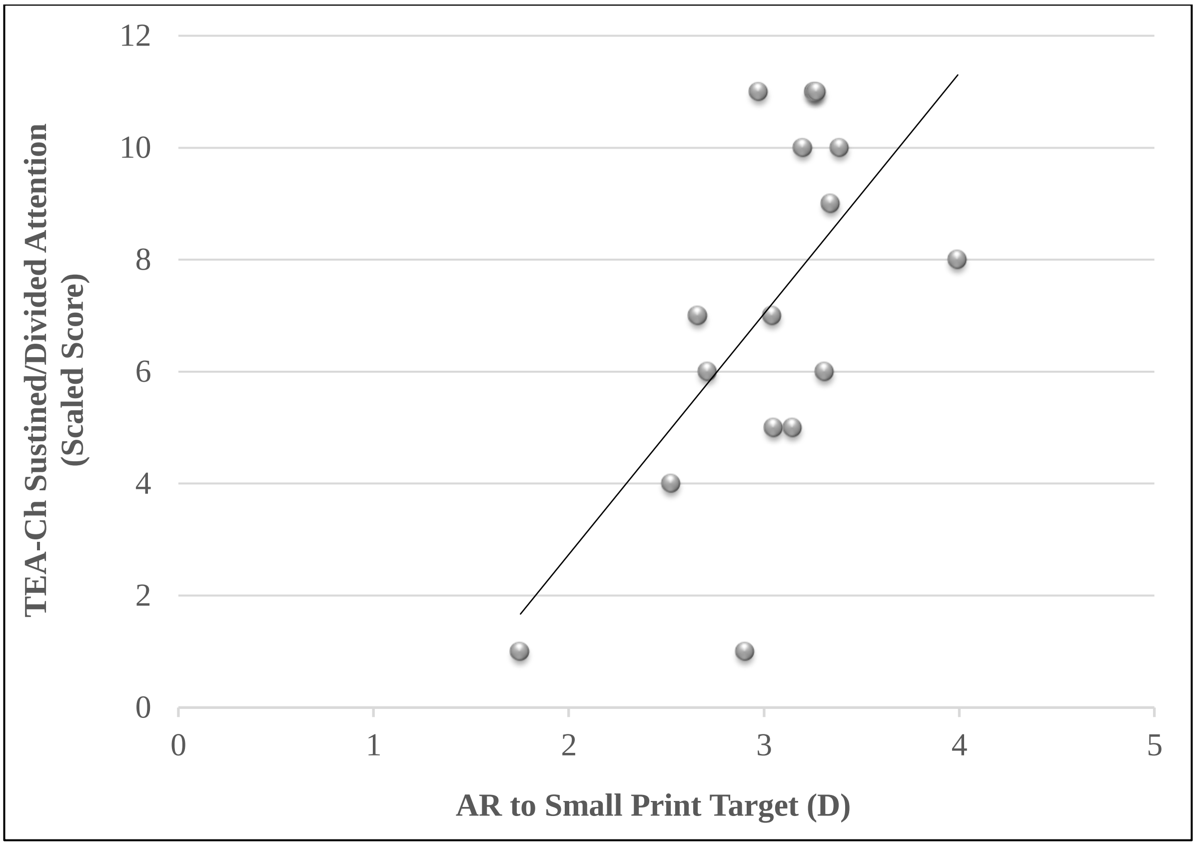

Figure 4-10: Scatterplot x-axis – accommodative response (AR) to small print target in dioptres (D), y-axis –Sustained/Divided Attention scaled score; $r = 0.611$, p = 0.007.

4.3.2 Full dataset analysis

The above pilot analysis (*4.3.1*) was conducted after the recruitment of 1/3rd of the anticipated total participants. The school study battery was derived from said analysis to ensure the timely submission of the relevant ethics application for the school based study. Therefore, it was necessary to present the full details of the pilot analysis in this thesis. This section will detail the analysis of the total participant group which, although reports broadly similar results, does include subtle variation on those presented above.

Due to the small number of Year 6 children all subjects, regardless of age group, were initially analysed together as a single group. Participants were subsequently analysed according to their relevant year group to explore if any differences existed between the two ages groups in this study. Both analyses are presented below.

4.3.2.1 Participants

44 (20 male; 24 female) typically developing children were recruited. This number includes those children presented in the pilot analysis above. 3 participants were excluded from participation as they did not satisfy the visual acuity criteria; two of these children failed the distance criterion only and were likely to be undetected myopes, the remaining child failed both the distance and near criterion and was found to have previously undetected mixed astigmatism. No child failed the near vision criterion in isolation and as such no child was excluded based on their near visual acuity alone.   Following the above exclusions, 41 (19 male; 22 female) children were eligible to participate. The number of participants per year group, mean age and mean refraction per year group is given in Table 4-5.

Only 1/3rd of the target number of Year 6 children were recruited. Difficulties contacting Year 6 parents significantly hampered recruitment - database contact details were frequently out of date or families had moved out of the area. As a result, recruitment of Year 6 children had to be curtailed.

	Pooled Participants	Year 2 Participants	Year 6 Participants
Total Sample n	41	30	11
Mean (SD) age in years	7.14 (1.91)	6.13 (0.24)	10.4 (0.50)
Mean (SD) refractive error (D)	+0.11 (0.36)	+0.06 (0.21)	-0.20 (0.25)
Hypermetropia n	31	22	8
Mean (SD) Hypermetropia(D)	+0.50 (0.67)	+0.42 (0.47)	+0.71 (1.1)
Range Hypermetropia (D)	+0.04 to +3.31	+0.05 to +2.14	+0.07 to +3.31
Myopia n	10	7	2
Mean (SD) Myopia (D)	-0.29 (0.16)	-0.30 (0.18)	-0.20 (0.14)
Range Myopia (D)	-0.05 to -0.46	-0.06 to -0.45	-0.30

Table 4-5: Number of participants, mean age (SD) and refraction details for total sample and per Year 2 and Year 6 subgroups.

No participant had any deficit on orthoptic testing that would have indicated the need for a referral from vision screening. No participant had a squint (heterophoria $<8^{\Delta}$ near and distance in all participants). All children demonstrated good 3D vision (Frisby stereopsis ranged from 30 – 85” of arc). All children had convergence within normal clinical limits and no child spontaneously reported blur.

2/41 children habitually used glasses to corrected mild (<2.00D) hypermetropia; these were issued < 6months previously. Where worn, accommodation was assessed with glasses on. Analysis was conducted including and excluding the participants wearing glasses. The results were not significantly altered by the exclusion; therefore, only the results including these participants are presented below.

4.3.2.2 Accommodation to targets (all subjects)

Accommodation data was available for all participants. The proportion of accommodative lag (to the clown target) in the total participant group is given in Figure 4-11.

As before (*4.3.1.2*) data were selected from the end of the target viewing period for analysis. Mean AR for each target type is given in Table 4-6. A one way repeated measures ANOVA revealed a highly significant difference in AR across targets $F_{6, 234} = 17.063$, $p < 0.001$ (Appendix 10b). Post hoc testing (Bonferroni corrected) revealed that, similar to the pilot results, text targets, irrespective of font size, elicited a statistically significantly higher AR than the clown, cartoon and individual letters target (Figure 4-12). AR to big, medium and small print targets were statistically significantly higher than that to the clown target at p = 0.002, p = <0.001 and p = <0.001 levels respectively. AR to big, medium and small print were significantly higher than cartoon target at p = <0.001 for all comparisons. AR to big print was significantly higher than individual letters (p = 0.002). AR to medium and small print were significantly higher than individual letters (p = <0.001 for both). Higher AR was observed with decreasing font size, although this again was not statistically significant, p > 0.05. No significant differences in AR were observed to big print, medium print or the Where's Wally? target.

In contrast to the pilot analysis, small print AR was significantly higher than Where's Wally?, p = 0.030. Where's Wally? AR was found to be statistically significantly higher than to the clown (p = 0.038), cartoon (p = 0.009) and individual letters (p = 0.023) targets.

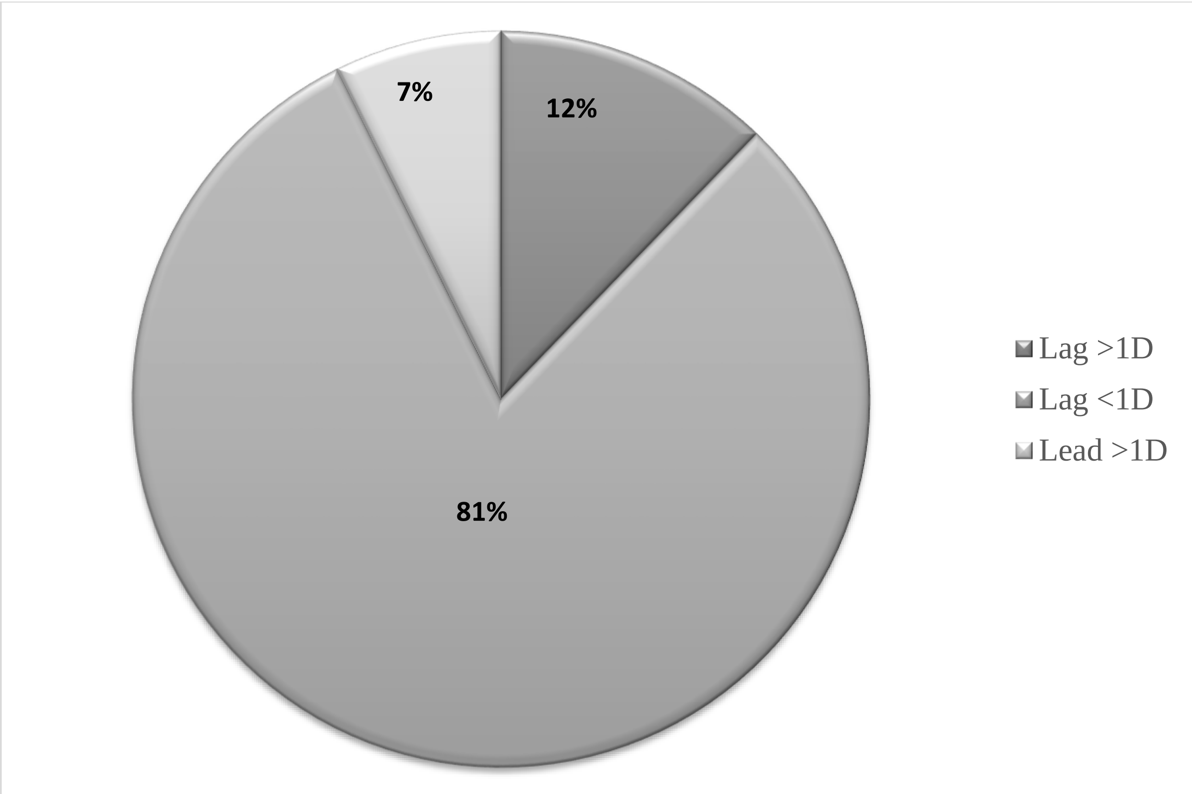

Figure 4-11 Proportion of accommodative lag and lead observed to the clown target at 1/3m in the IVL (n=41).

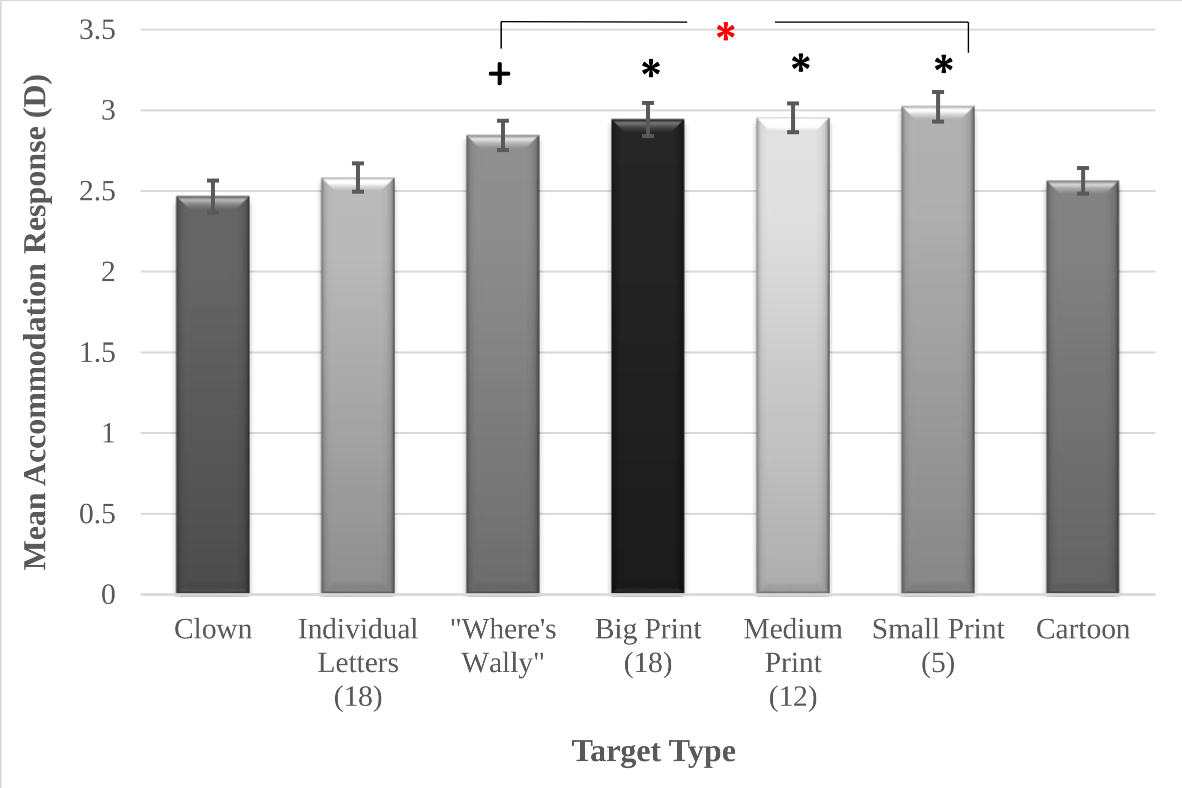

Figure 4-12: Mean accommodation at 1/3m to each target type. Bars denote ±1 standard error of the mean (SEM). Text font size is given in brackets where appropriate. * denote that the AR elicited by text targets was significantly higher than that to the clown and cartoon targets and individual letters target. No significant difference was found between AR to the various text targets. + denotes AR to Where's Wally? was significantly higher than the clown and cartoon targets and individual letters target. * denotes AR elicited by the small print target was significantly higher than to the Where's Wally? target; no significant difference was found between the other text targets and Where's Wally?.

Target Type	Mean AR	Standard Deviation (D)
Clown	2.47	0.58
Big Print (18)	2.94	0.61
Medium Print (12)	2.95	0.50
Small Print (5)	3.02	0.54
Where's Wally?	2.86	0.52
Cartoon	2.56	0.46
Individual Letters (18)	2.58	0.52

Table 4-6: Mean accommodative response (AR) and Standard Deviation (SD) for each target.

4.3.2.2.1 Accommodation at different time points

Paired t-tests were again conducted for each individual target to assess fatigue; AR was not statistically different across the time points (Table 4-7), $p > 0.05$.

Target Type	Time 1 Mean (SD) (D)	Time 2 Mean (SD) (D)	p-value
Clown	2.30 (0.81)	2.47 (0.58)	0.51
Big Print (18)	2.83 (0.47)	2.94 (0.58)	0.35
Medium Print (12)	2.90 (0.51)	2.96 (0.46)	0.37
Small Print (5)	2.93 (0.40)	3.02 (0.44)	0.40
"Where's Wally"	2.91 (0.41)	2.84 (0.45)	0.26
Cartoon	2.58 (0.38)	2.56 (0.41)	0.81
Individual Letters (18)	2.54 (0.52)	2.58 (0.36)	0.55

Table 4-7: Accommodative Response (AR) mean and standard deviation in dioptres (D) per target. T-test p value indicates no significant difference in AR elicited at Time 1, initial target presentation and AR at the end of target viewing period Time 2 for any target.

4.3.2.2.2 Accommodation to targets – Year 2 subjects

A one way repeated measures ANOVA was conducted on the AR of Year 2 participants (n=30). Mauchly's test was conducted but was not significant. The difference in AR elicited by different targets was highly significant $F_{6, 156} = 12.10$, $p = < 0.001$. Post hoc analysis, using Bonferroni correction for multiple comparisons, revealed that AR to all text targets was significantly higher than the clown and cartoon. Big, medium and small print AR were significantly higher than clown AR at $p = 0.011$, $p = 0.001$ and $p = <0.001$ respectively. Significant differences between big, medium, small print AR and cartoon AR were $p = 0.004$, $p = 0.001$ and $p = <0.001$ respectively, with text targets eliciting the high AR. The small print target elicited a higher AR than the individual letters target, $p < 0.001$. The difference between big print and individual letters AR did not reach statistical significance, p = 0.196. Mean accommodation and post hoc results are represented in Figure 4-13

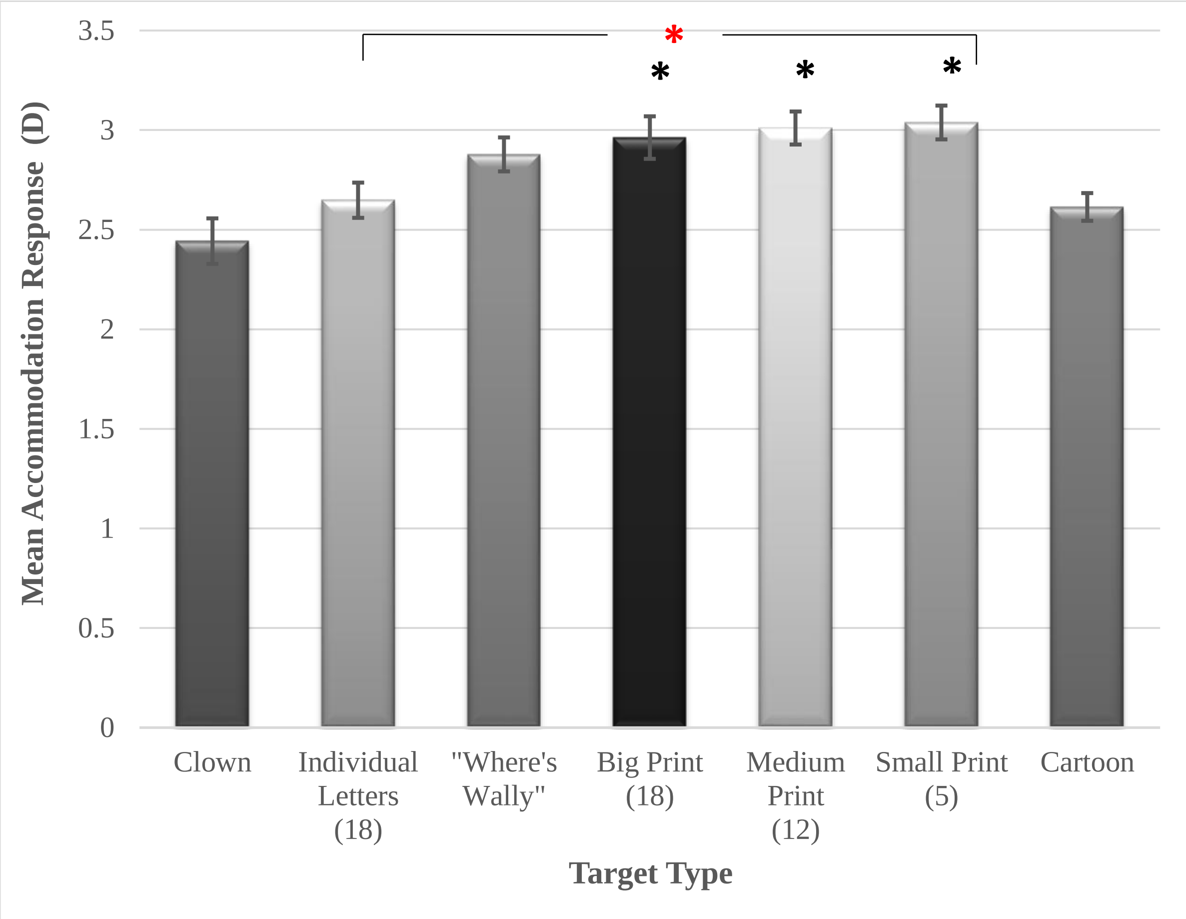

Figure 4-13: Year 2 mean accommodation to each target type at 1/3m. Text font size is given in brackets where appropriate. Bars denote ±1 standard error of the mean (SEM). * denotes that the accommodative response elicited by text targets was significantly higher than that to the clown and cartoon targets. No significant difference was found between accommodation elicited to the various text targets. * AR to small print was significantly higher than to the individual letters target.

4.3.2.2.3 <u>Accommodation to targets – Year 6 subjects</u>

AR of Year 6 participants (n=11) was analysed using a one way repeated measures ANOVA. Mauchly's test was conducted but not significant. Accommodative response was found to vary significantly with respect to target type, $F_{6,54} = 4.14$, $p = 0.002$. A trend for the AR to text targets to be higher than individual letters was identified although this did not reach statistical significance; p = 0.07, 0.11, 0.08 for comparisons of individual letters with big, medium and small print targets respectively. Following post hoc Bonferroni correction, only Where's Wally? AR was significantly higher than individual letters, p = 0.047 (Figure 4-14).

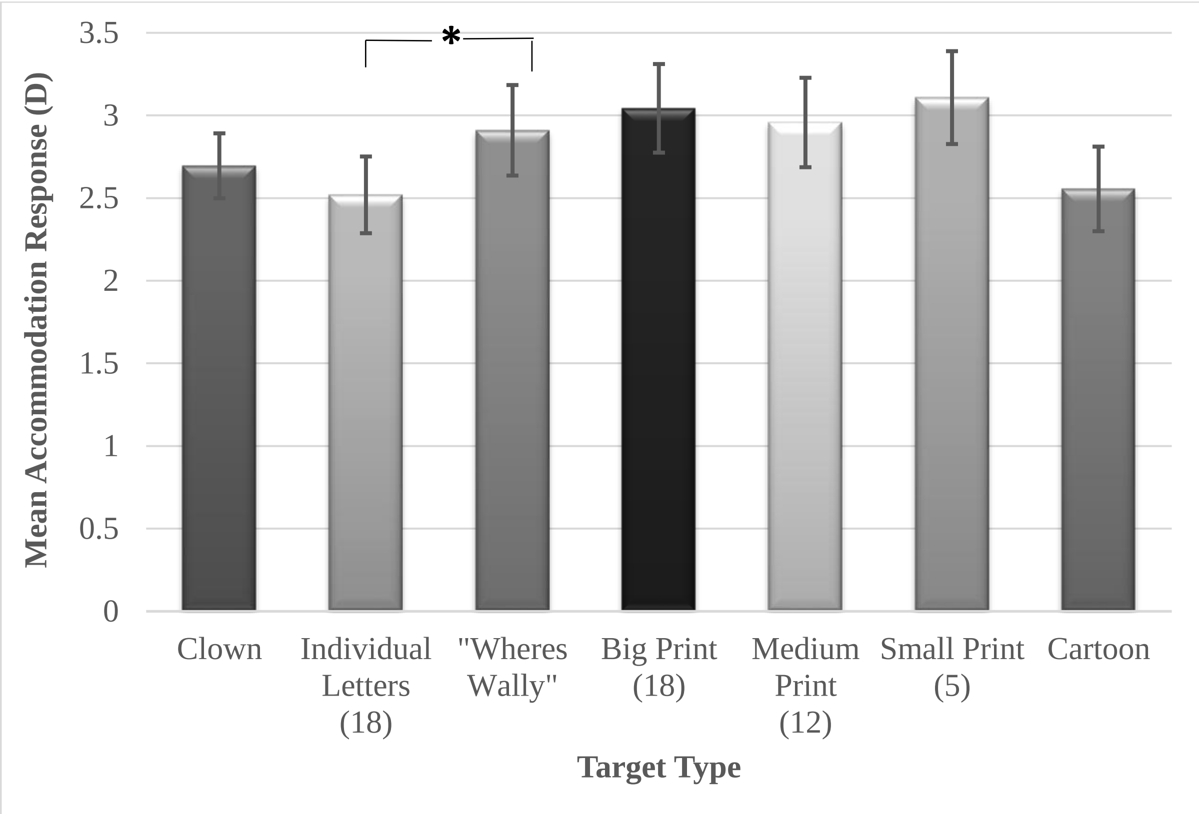

Figure 4-14: Year 6 mean accommodation to each target type at 1/3m. Text font size is given in brackets where appropriate. Bars denote ±1 standard error of the mean (SEM). * denotes that

the accommodative response to Where's Wally? target was significantly higher than the individual letters target, p = 0.047.

4.3.2.2.4 Age and accommodative response

A two way mixed ANOVA was conducted to further explore the effect of age, as opposed to year group, on AR. Mauchly's test for sphericity was conducted and was statistically significant (p = 0.03); therefore, Greenhouse Geisser was used to correct this.

The results of this two way ANOVA again showed that there was a significant effect of target type on AR. No significant interaction between age and target type was identified, (F = 0.665, p = 0.789), indicating that participants demonstrated a similar level of accommodation regardless of age. However, due to the limited number of Year 6 (age 10 – 11 year old) students in this dataset, this result should be viewed with caution and requires replication in a larger dataset.

4.3.2.3 Accommodation and standardised tests

The small print target elicited the highest AR during both the pilot (*4.3.1.2*) and full analysis (*4.3.2.2*). It was also the only target with which a standardised test was correlated in the pilot analysis (*4.3.1.3*). As such it was selected as the single accommodation variable for use in the full dataset correlation analysis. Pearson correlation analysis was conducted to explore the relationship between the small print target AR and the various standardised measures of general ability, reading and attention.

4.3.2.3.1 Accommodation and standardised tests – All Subjects

No significant correlation was found between AR and any measure of reading or attention ($p > 0.05$, individual p values are given in Table 4-8). The tenuous correlation between small print AR and sustained/divided attention identified in the preliminary analysis was not supported by the analysis of the larger full dataset (Table 4-8).

Test	Mean (Standard Deviation)	Small Print *r*	p-value
YARC SWRT	112 (18.8)	-.025	0.885
YARC Accuracy	115 (19.6)	-.065	0.703
YARC Rate	113 (19.2)	.085	0.616
YARC Comprehension	109 (18.2)	-.096	0.572
TOWRE-II SWE	112. (21.3)	-.022	0.897
TOWRE-II PDE	110 (20.6)	.011	0.949
Wilkins Rate of Reading	88.8 (32.7)	.212	0.221
TEA-Ch Selective Attention	9.42 (3.80)	.048	0.779
TEA-Ch Sustained Attention	11.8 (4.22)	.025	0.888
TEA-Ch Attention Switching	10.4 (3.27)	-.204	0.254
TEA-Ch Sustained/Divided Attention	8.90 (4.07)	.189	0.284
BAS-3 Matrices	53.3 (10.2)	.294	0.073
BAS-3 Verbal Similarities	57.2 (8.87)	.115	0.493
BAS-3 Pattern Construction	52.9 (8.00)	.151	0.357
SDQ Stress	5.51 (3.17)	-.163	0.308
SDQ Emotional Distress	1.61 (1.66)	-.233	0.143
SDQ Behaviour	0.81 (1.05)	-.089	0.579
SDQ Hyperactivity	2.30 (1.60)	.061	0.704
SDQ Interpersonal	0.83 (1.04)	-.126	0.434
SDQ Helpful	8.90 (1.62)	-.065	0.686
SDQ Impact	0.05 (0.31)	.001	0.996

Table 4-8: Reading and attention assessment mean score ± standard deviation, Pearson *r* correlation with accommodation with small print target. No correlation reached statistical significance – $p > 0.05$ in all cases.

4.3.2.3.2 Accommodation and standardised tests - Year 2

Accommodation, reading and BAS-3 data was available for all Year 2 participants (n=30). Three children did not complete the attention tasks due to fatigue/refusal. Mean reading and attention test scores are given in Table 4-9.

Pearson correlation analysis was conducted to test for correlation between AR, reading ability and attention/behaviour; no significant correlation was found between AR and any of the reading/general ability/attention tests or the parental SDQ ($p > 0.05$, individual p values are given in Table 4-9).

Test	Mean (Standard Deviation)	Small Print *r*	p-value
YARC SWRT	115 (9.11)	-.151	0.452
YARC Accuracy	118 (9.49)	-.090	0.656
YARC Rate	115 (9.84)	.030	0.883
YARC Comprehension	113 (8.29)	-.062	0.758
TOWRE-II SWE	115 (13.6)	-.133	0.517
TOWRE-II PDE	112 (13.5)	-.231	0.256
Wilkins Rate of Reading	75.1 (13.7)	.022	0.916
TEA-Ch Selective Attention	9.10 (3.22)	-.044	0.830
TEA-Ch Sustained Attention	12.1 (4.66)	-.143	0.505
TEA-Ch Switching Attention	10.7 (3.47)	-.149	0.498
TEA-Ch Sustained/Divided Attention	9.9 (4.26)	.109	0.611
BAS-3 Matrices	52.2 (10.7)	.196	0.316
BAS-3 Verbal Similarities	57.6 (10.2)	.152	0.440
BAS-3 Pattern Construction	52.4 (8.61)	.091	0.638
SDQ Stress	5.16 (3.46)	-.111	0.552
SDQ Emotional Distress	1.26 (1.61)	-.190	0.306
SDQ Behaviour	0.81 (1.11)	.007	0.971
SDQ Hyperactivity	2.42 (1.78)	-.065	0.727
SDQ Interpersonal	0.68 (0.91)	.034	0.856
SDQ Helpful	9.16 (1.13)	.039	0.836
SDQ Impact	0.06 (0.36)	.008	0.966

Table 4-9: Mean, standard deviations for reading and attention tests for Year 2 participants. Pearson *r* for correlation between each test and the accommodative response to the small print target. Correlation did not reach statistical significance for any test, $p>0.05$.

4.3.2.3.3 Accommodation and standardised tests - Year 6

Accommodation and test data were available for 11 Year 6 participants. Descriptive statistics, Pearson's *r* and associated p values for the reading and attention results are given in Table 4-10. There was a trend for a positive correlation between AR and sustained/divided attention. No significant correlation was found between AR to the small print target and any measure of reading, attention or general ability. No significant correlation was found between parental response on the SDQ and small print AR.

Test	Mean (Standard Deviation)	Small Print *r*	p-value
YARC SWRT	115 (7.86)	0.16	0.654
YARC Accuracy	118 (11.6)	-0.04	0.916
YARC Rate	119 (8.99)	0.14	0.692
YARC Comprehension	110 (7.06)	-0.13	0.725
TOWRE-II SWE	113 (17.1)	0.13	0.724
TOWRE-II PDE	112 (14.7)	0.36	0.314
Wilkins Rate of Reading	113 (25.6)	-0.07	0.841
TEA-Ch Selective Attention	10.7 (5.06)	0.09	0.808
TEA-Ch Sustained Attention	11.8 (2.57)	0.42	0.226
TEA-Ch Attention Switching	10.6 (2.17)	-0.40	0.250
TEA-Ch Sustained/Divided Attention	6.7 (2.63)	0.56	0.091
BAS-3 Matrices	56.4 (7.88)	.597	0.068
BAS-3 Verbal Similarities	55.8 (2.90)	.148	0.684
BAS-3 Pattern Construction	54.2 (5.94)	.319	0.370
SDQ Stress	6.80 (2.04)	-.478	0.163
SDQ Emotional Distress	2.70 (1.57)	-.458	0.183
SDQ Behaviour	0.80 (1.03)	-.286	0.422
SDQ Hyperactivity	2.00 (1.05)	.501	0.140
SDQ Interpersonal	1.30 (1.42)	-.346	0.327
SDQ Helpful	9.10 (0.99)	-.282	0.429
SDQ Impact	0.05 (0.31)	.011	0.370

Table 4-10: Mean and standard deviations for reading and attention tests for Year 6 participants. Pearson *r* for correlation between each test and the accommodative response to the small print target. Correlation did not reach statistical significance for any test, $p > 0.05$.

4.4 Discussion

4.4.1 Accommodation to various targets

Clinically the “perfect” AR at 1/3m is considered to be 3D; however, a degree of accommodative lag is considered normal and small lags would not cause blurred near vision as they would be within an individual’s depth of focus. Typical accommodative lag is considered <0.75 – 1D (Jackson & Goss, 1991; Poynter et al, 1982; Tassinari, 2002), although lag >1D has also been reported in the literature (Horwood et al, 2001; Yeo et al, 2013). Higher level control and cognitive demand have been found to influence the AR of adult subjects (Ciuffreda & Hokoda, 1985; Kruger, 1980). Current available literature regarding the influence of different target types on accommodation in typical children is limited. The results of this pilot study indicate that target type does have a significant influence on typical children’s AR.

The standard deviations observed in this study ranged from 0.39 – 0.88D; therefore, the above results indicate that most children accommodate only as much as necessary to resolve naturalistic stimuli, e.g. pictures/cartoons, however they will produce higher and more accurate AR to more demanding targets e.g. visual search/text. These findings are in agreement with those of Bharadwaj and Candy (2008), who, in a small group of 13 children, compared children’s accommodative responses to watching a cartoon and reading 20/40 sized letters. No difference was reported in the accommodative gain observed between the letters and cartoon targets under binocular conditions. However, under monocular conditions, the authors report increased accommodative gain, i.e. less monocular lag, to the letter target, suggesting children are capable of increased accommodation to more visually demanding targets. The above study details accommodation under binocular conditions. Similar to Bharadwaj and Candy (2008), a significant difference was not found in the binocular accommodative response observed to the cartoon and letter targets in this IVL based study. However, the difference in accommodation between the text and both the cartoon and individual letter targets was significant suggesting that children can produce higher AR to more complex targets.

Yeo et al (2013) similarly reported increased accommodation to more complex and cognitively demanding targets. The authors reported increased AR to Chinese compared to English characters, however, as the targets used were not of equivalent font size this may have influenced the AR observed. In this study, participants demonstrated somewhat increased accommodation to text of decreasing font size. However, the difference in AR between the text targets was not statistically significant suggesting that font size does not significantly influence AR, or that effects are too small to be clinically or functionally important. The letters and big text targets in the above IVL study were of equivalent font size. Increased accommodation was observed to the big text target compared to individual letters target. This suggests that regardless of font size children will exert increased accommodation to more cognitively demanding tasks such as reading rather than simply identifying single letters.

The above IVL results suggest differences in Year 2 and Year 6 children's AR to targets. When analysed as separate year groups, AR to big print was consistently higher than that to the letters target, however, neither reached statistical significance. This may be a result of decreased sample size, particularly in the older, Year 6, group and reduced statistical power in the subgroups and so requires further investigation in the larger school study.

Further analysis was performed to investigate the effect of age on the target type findings (*4.3.2.2.4*). This analysis failed to identify any significant interaction between

AR to various targets and participant age, suggesting that AR to the varying targets was comparable across age groups. However, these findings also remain limited by sample size, in particular by the small number of 10 – 11 year olds (n=11) included in this study. As such, further investigation is required to confirm that no interaction between age and AR to varying target type exists.

The twenty-five stable vignettes, representing one second of AR, for each target type employed for analysis were taken from the end of the target viewing period (*4.2.11*). This was selected as it was felt that AR at the end of the minute viewing period, i.e. after a period of prolonged viewing, would be more representative of a child's habitual accommodative response as tasks such as reading typically last a few minutes at a time. One could hypothesise that after some prolonged viewing AR might actually lessen e.g. due to fatigue/boredom and that this brief period towards the end of testing would be unrepresentative. While Harb et al (2006) reported that adult AR remains stable during an accommodative task and does not show an effect towards the end of testing this had not been previously replicated in children and as such remained an unknown. Therefore, the stability of individual's AR was investigated during this study; in particular, evaluating if AR differed from initial target presentation to end of testing (*4.3.1.3* and *4.3.2.2.1*), i.e. the AR measurement that was employed in the main analysis. By analysing the difference in AR at the beginning and end of the target viewing period, and visually inspecting the stability of the response across the same time period it was clear that little fluctuation in AR existed across individual responses. While slight differences in accommodation were identified these did not reach statistical significance and would be considered clinically negligible. Therefore, it was concluded that AR values taken from the end of the testing period i.e. “Time 2” data were appropriate for use in the above reported main analysis.

While AR was found to vary across targets, the mean lag observed in this study was considerably less than the reported norm of 0.75D (Figure 4-12). For the majority of participants, the lag of accommodation observed was within the expected depth of focus (Figure 4-11), i.e. one would not expect them to experience blur with the level of lag observed. While larger lags were observed to different targets with significant differences noted, the small lags observed are surprising.

Mean accommodation for the small print target was exactly 3D (Figure 4-12). While this is considered the “perfect response” a small lag of accommodation is considered typical therefore it is somewhat unexpected that mean values are so close to 3D.

The largest accommodative lag was seen with the clown target. This is perhaps unsurprising as compared to the more complex text target the clown has a variety of detail available. Uninstructed children can therefore decide themselves how much to accommodate to the target/what level of detail to accommodate to. The clown target has been used in previous IVL studies. Horwood et al (2001) report mean AR to the clown target was 2.16(0.77) D. The AR observed to the clown in this laboratory based study is comparable to previous research, albeit slightly higher (2.47(0.58)D). This indicates that it is unlikely that the experimental set up can account for these smaller lags.

One could hypothesise that the instances of smaller than anticipated lag of accommodation observed in some subjects could be attributable to participant characteristics or sub-conscious bias. The participating children in this study were all aware that they were attending for an eye test/research project and in some cases their appointment was arranged weeks in advance. Some mothers on presenting with the participant to the laboratory did remind their children to “do their best for the eye test”. While one cannot assume that this is relevant for all children it is plausible that similar comments will have also been mentioned at home prior to the session. It is reported that level of instruction can have a significant effect on the level of accommodation exerted such that higher responses can be elicited through instructing subjects to “work harder” (Horwood & Riddell, 2011). Comments prior to the appointment regarding behaviour and effort could have encouraged children to use maximal accommodation throughout the task which could in turn account for the smaller lags observed.

4.4.2 Accommodation and standardised tests

All participants in this laboratory study were visually typical, read the presented text aloud fluently and did not spontaneously report blur during assessment. Mean accommodative response was within expected depth of focus for the majority of subjects although some did exhibit lag >1D. In contrast to previous studies investigating accommodation and academic ability/education, the above study employed a minimal instruction set and a binocular objective technique to measure children’s accommodation under naturalistic circumstances. Analysis failed to identify a correlation between accommodation at 1/3m, as recorded with the Plusoptix, and any of the extensive measures of reading ability reported above. Examples were found throughout the dataset of children who exhibited lag of accommodation both more and less than 0.75D and demonstrated above average reading. Therefore, from the above data in this relatively small sample it appears that children who accommodate less to targets at 1/3m do not preform worse on reading tests than those children who accommodate more accurately.

Accommodative targets were presented for a sustained one minute viewing period. Although adult research has indicated that accommodation remains stable during sustained tasks (Harb et al, 2006) one must be cautious when drawing comparisons between adult and child responses and replication has not been shown with children to date. As discussed previously in relation to target type (*4.4.1*), one could hypothesise that the minimal instruction set and lack of continuous active encouragement throughout the task could have resulted in some children exerting less accommodation towards the end of the testing period, e.g. highly proficient readers may have found the task easy and become bored/disengaged and exerted as much accommodation as the task went on. Accommodative fatigue was therefore considered as a possible to explanation for the lack of correlation observed in this study. However, evaluation of the consistency of the accommodative response across the viewing period revealed that there was no statistically significant difference in the accommodative response elicited at the beginning and end of the target presentation period. Furthermore, any identified differences would also have been considered clinically negligible. It can therefore be concluded that the lack of correlation observed between AR and reading/attention cannot be explained by possible accommodative fatigue or unrepresentative AR during the task.

Previous studies have also failed to find a correlation between accommodation and ability. Following stringent controls for possible confounds to accommodative facility assessment, Kedzia et al (1999) failed to find any association between accommodation and reading or mathematic ability in 8-year old children. Similarly, Latvala et al (1994) report no association between accommodative amplitude and reading. More recently, Creavin and Williams (2015) also found that in a large sample of poor readers accommodation was not impaired in children with either moderate or severe reading impairments. All these studies report subjective methods of accommodation assessment and therefore are not directly comparable to the results observed in this laboratory study. However, the objective data obtained in this laboratory study does appear to support the findings that accommodation and academic ability are unrelated.

While accommodation and ability appear unrelated in this study, it must be noted that the findings may be limited by the participant sample. It is clear from Table 4-9 & 4-10 that our sample consisted of more proficient readers, evidenced from the higher than expected mean reading scores obtained. It is possible that the detection of any correlation with accommodation was limited by the homogenously proficient participants. Further study, involving the recruitment of more poor/less able readers as well as inclusion of children with increased accommodative lag compared to that observed in this study is required to confirm the above findings.

No significant correlation was identified between accommodation and the standardised measures of selective attention, sustained attention and attention switching. However, unlike the reading scores, mean attention scores observed in this study were comparable to the reported standardised mean and can be considered to be representative of the general population. The pilot analysis (*4.3.1.4*) indicated that accommodation was significantly positively correlated with the measure of sustained/divided attention (Figure 4-10) however this was not supported in the full dataset analysis. The pilot analysis was conducted on a small dataset and as such was underpowered. While the pilot analysis dataset did not contain significant outliers, it is likely that it was disproportionally influenced by certain participants. The full dataset analysis, which has improved power, indicates that accommodation is not correlated with sustained/divided attention, p = 0.28. While it did not reach statistical significance there was a trend for sustained/divided attention to be positively correlated with accommodation in the Year 6 group (*r* = 0.56, p = 0.09). As a result of recruitment difficulties this group consisted of only 11 participants therefore, the Year 6 data lacks sufficient statistical power to draw conclusions.

In addition, accommodation was not found to be significantly correlated with parental reports of child behaviour, as assessed with the parental Strengths and Difficulties Questionnaire. This is in contrast to Borsting et al (2005) who reported a significant difference in the Conners Parent Rating Scales in children with accommodative dysfunction and typical children. The authors found that parents reported a higher incidence of learning/behavioural difficulties in children with accommodative dysfunction than those without. Borsting et al (2005) defined accommodative dysfunction as accommodative amplitude 2D less than Hofstetter's criterion (see *Chapter 1* for calculation) or monocular accommodative facility of <6 cycles per minute. Sterner, Gellerstedt and Sjöström (2004) reported that amplitude of accommodation of children is not as high as anticipated by Hofstetter's formula. In a study of 76, 6 – 10 year old children Sterner et al reported that monocular accommodation in particular was on average 3.6D below that expected by formula. Therefore, it is unclear how useful the criterion selected by Borsting et al is for determining accommodative dysfunction.

It is unlikely that the lack of correlation between SDQ scores and accommodation observed in this study is due to questionnaire inaccuracy or invalidity. Although different to the Conners Rating Scales used by Borsting et al (2005), the SDQ is a well validated form and reported to be an effective community based screening tool to identify childhood disorders (Goodman et al, 2000). In a European study of 2315 children aged 5 – 7years, Rimvall et al (2014) also confirmed the parent and teacher SDQs to be effective in identifying a group of children with increased risk of ADHD diagnosis.

Child behaviour can be situation dependant; therefore, it is possible that the SDQ data in this laboratory study lacks sufficient variance to detect a correlation with accommodation. The parent SDQ (score range 0 – 10) includes questions regarding home life; these are omitted in the teacher SDQ (score range 0 – 6). In a review of both the parent and teacher versions of the SDQ, Stone, Otten, Engles, Vermulst and Janssens (2010), reported that the reliability of the teacher SDQ was stronger than the parent SDQ at the subscale level. As the SDQ gives measures of both positive and negative aspects of behaviour, the subscales are particularly important for analysis. It is possible that the SDQ teacher form may yield more diverse information that the parental questionnaire; as such, further research utilising the teacher SDQ is required to further investigate the relationship between accommodation and behaviour.

4.4.3 School Study Battery Design

The aim of the pilot analysis (section *4.3.1*) was to identify which tests would be most relevant to take forward into the school study (*Chapter 5*), where such extensive testing would be impractical. The battery was designed based on the results of the pilot analysis.

Despite literature suggesting there may be an association between accommodation and reading, no such correlation was found in the pilot analysis. It could not be determined from the laboratory study analysis which of the reading tests trialled would be most sensitive and appropriate to use in the school testing battery. Following extensive discussion with supervisors and collaborators, it was decided that because the YARC was the richest reading test trialled (providing measures of single word reading, reading accuracy, rate and comprehension) this should be carried forward to the school battery. While the pilot analysis was underpowered, consisting of only 20 subjects, the full dataset analysis did not provide further insight. Therefore, the YARC was retained in the school battery.

The sustained/divided attention task was the only test to show a correlation with accommodation; however, this was only found in the pilot analysis. Participants exhibiting a lower AR to the small print target performed worse on the sustained/divided task than those with a higher AR. In view of the positive correlation identified it was decided that a sustained/divided attention task should be included in the school study test battery. It was decided that the TEA-Ch should be used again for comparison. However, as the attention/switching subtest proved too difficult for many younger children to complete in the laboratory session, leading to lost data, it was decided that this subtest would be omitted from the school battery. Full dataset analysis did not confirm a correlation between AR and attention. Despite this it was decided that the TEA-Ch would still be included in the school battery to further explore the laboratory findings regarding attention and to ensure that the battery retained a wide breadth of assessments.

Participants in the above laboratory study also completed measures of verbal, non-verbal and spatial reasoning. However, no significant correlation was identified between accommodation and these measures of ability (*4.3.2.3.1*). If a relationship between accommodation and reading/attention does exist it could be mediated by general ability. As the above laboratory study was a pilot, consisting primarily of very able readers, analysis controlling for general ability was not conducted. It was planned that this would be instead be undertaken in the later school study to further explore the relationship between reading/attention and accommodation in a more representative sample of children. Therefore, a measure of general ability was also retained for the school study. In the interest in time it was decided only one BAS-3 subtest be carried forward. Following discussion with Dr Rachel Pye and Dr Daisy Powell it was decided that the non-verbal reasoning subtest (Matrices subtest) would be the most appropriate to use in the school test battery and as a co-variate in subsequent school study correlation analyses.

4.5 Interim Summary

Under binocular naturalistic conditions, typical, asymptomatic children produce a wide range of accommodative responses at 1/3m. Although lags of accommodation were observed some children exhibited more accurate accommodative responses than would be expected based on existing literature. Clinically, and in the available literature, typical accommodative lag is considered to be ≤0.75 – 1D. This is considered to be within an individuals' depth of focus and not result in appreciable blurred vision. While on an individual level some children exhibited lag of >1D while completing the accommodative tasks the majority of children exhibited an accommodative lag less than 1D and within expected depth of focus. However, children appeared to exert higher accommodative responses to more cognitively demanding tasks such as reading print or visual search tasks. Increasing accommodative responses were observed with decreasing print font size however, these differences are small and font size itself did not appear to significantly influence the accommodative response. This may have clinical implications for example, when measuring the angle of deviation of squint as this can be influenced by the amount of accommodation exerted and comparisons between clinicians rely on an assumed consistent accommodative response. Practitioners must consider that typical children may in fact not exert maximal accommodation during assessment – in particular if simple, minimally cognitively demanding targets are used.

Accommodation does not appear to be correlated with reading or attention however further investigation with a more varied sample is required to confirm this. An appropriate battery of standardised tests has been established for use in the larger school study which will investigate accommodation and reading/attention in more detail.

Chapter 5 - School Based Study

5.1 Introduction

This study expanded on the detailed laboratory based study (*Chapter 4*) and further investigated typical children's accommodative response (AR) to targets of different complexity, in order to relate AR to reading ability and attention in a school setting.

The laboratory study findings indicated that children exert more accommodation to cognitively complex targets. No correlation was found between AR and reading/attention in the laboratory study. However, the laboratory study was designed to establish a testing protocol for wider use, and provide detailed data on a small sample. As a result, the relationship between the above variables may not have been accurately reflected due to lack of power.

A further limitation of the laboratory study was insufficient participant variance, in particular regarding reading ability. All participants recruited for this study were highly proficient readers. A university research database was used to recruit children to the laboratory study. While socio-economic status (SES) was not formally established during the laboratory study it is accepted that research volunteers are more likely to be from higher SES backgrounds (Patel et al, 2003; Robinson et al, 2016). Parental education levels are related to children's reading ability - children of educated parents with a high SES often have increased exposure to print than those from lower SES backgrounds (van Steensal, 2006) and as such are more likely to be proficient readers at a younger age. In addition, higher SES status is related to increased incidence of myopia which, as introduced in *Chapter 2*, is associated with higher intelligence levels and reading ability. Hypermetropia, which is associated with under-accommodation, is more prevalent in low SES groups and previous research has indicated that hypermetropic children are poorer readers than their emmetropic and myopic counterparts. It is therefore possible that an association between accommodation and attainment was less likely to be identified amongst the volunteers for the previously described laboratory based study. Thus, to accurately investigate if a relationship exists between accommodation and reading ability, in typical children, a representative sample of participants from varied SES backgrounds including both good and poor readers was required.

5.1.1 Objectives

This study set out to obtain a more representative sample through recruiting and testing children in schools. A variety of primary schools from both affluent and deprived areas were utilised as recruitment sites to achieve a representative sample from a broad socio-economic background.

Sample size and methodology were determined from the results of the laboratory study (*Chapter 4*).

5.2 Method

5.2.1 Participants

Full ethical approval for this study was obtained from the University of Reading Ethics Committee prior to the commencement of this study.

Children were recruited through participating primary schools in Berkshire and London. Year 2 (age 6 – 7years), Year 4 (age 8 – 9years) and Year 6 (age 10 – 11years) pupils were recruited for participation. These year groups were selected to provide an age continuum across the whole participant group and to allow for any age effects to be assessed.

Inclusion criteria were: typically developing children i.e. did not have a formal diagnosis of reading or attention difficulties with a minimum corrected distance visual acuity (VA) in each eye of 0.200 logMAR and a minimum uniocular near VA of 0.100 logMAR. As in the laboratory study the distance VA criterion was selected as this corresponds to a “pass” on a school vision screening test. The near VA criterion was selected to ensure that all children would be able to resolve the smallest accommodation targets and also to exclude any large uncorrected refractive errors e.g. astigmatism which could influence the Plusoptix calculation of refraction resulting in erroneous accommodation data.

5.2.2 Participating primary schools

Participants were recruited across six primary schools; two in Reading, Berkshire (Reading Council), three in West Berkshire (West Berkshire Council) and one in Greater London (London Borough of Wandsworth). The schools represented a variety of socio-economic backgrounds; the Reading schools included a Church of England and Catholic school in a disadvantaged area on the outskirts of Reading town. The West

Berkshire schools comprised of small Church of England schools in predominately rural areas. The London school was a Church of England school located in a large, high rise, council estate and included children from a variety of ethnic backgrounds with a large proportion of pupils from Black/African/Caribbean background.

As previously introduced in *Chapter 3; 3.4*, the Index of Multiple Deprivation (IMD), can be used to obtain information regarding levels of relative deprivation across neighbourhoods by using postcode data. It is a government measure, which combines information including income, health, crime, education deprivation to rank small areas in England from least deprived (32,844) to most deprived (1) areas (Ministry of Housing, Communities, & Local Government, 2015). The IMD can be accessed online via http://dclgapps.communities.gov.uk/imd/idmap.html. Using this IMD tool, it was found that the area in which both Reading schools were located ranked 6,087/32,844, indicating that both schools lie within 20% of most deprived small areas in England. The West Berkshire schools were in areas 25,780, 26,717 and 27,444 of 32,844, i.e. the 20% least deprived areas. The London based school was 9,091/32,844 which is within the 30% most deprived small areas in England. It is evident that the primary schools from which participants were recruited for this study have catchment areas which differ on relative deprivation and SES. Therefore, in theory, these schools include pupils from differing socio-economic backgrounds. However, as previously discussed this information represents the catchment area of the school and cannot be used to infer SES of individual participants in this study (McLoone & Ellaway, 1999; Shack et al, 2008; Steven, Dowell, Jackson, & Guthrie, 2016; Strong, Maheswaran, & Pearson, 2006). Individual participant postcodes were not collated as part of this school study.

All participating schools were rated “Good” at their most recent Ofsted inspection, ensuring any participant reading difficulties recorded could not be attributable to teaching standards or other significant differences between the schools. Provision of school entry vision screening varies across the U.K. All schools included in this study were under an established orthoptic led vision screening programme; therefore, the vast majority of children tested would have undergone expert vision screening on school entry.

Participating schools were provided with study information packs, containing researcher contact information, relevant information sheets (Appendix 8) and study consent forms (Appendix 9), to distribute to parents of typically developing Year 2, 4 and 6 children within their school. Signed consent forms were returned to the school by parents willing for their child to participate in the study.

5.2.3 Sample Size

A priori power analysis was conducted using GPower®. Using a conservative effect size of 0.4, obtained from the preliminary analysis of the laboratory data, and alpha = 0.05, analysis indicated that 40 participants would be required to achieve power of 0.8. As independent analysis of year groups was planned, required sample size was defined as 40 participants per year group.

5.2.4 Testing procedure

A test battery was derived from the laboratory study data (*Chapter 4*) to comprehensively assess reading ability and attention in a timescale suitable for carrying out in a school environment. Participating children were tested in their respective schools, in a quiet room designated for use by the researcher.

Children completed two 30 minute testing sessions over two days. During the first testing session the children underwent an orthoptic assessment, objective accommodation assessment using the portable lab and completed a non-verbal reasoning task. The administration of the remaining standardised tests (*Chapter 4*; *4.4.3*) was performed in the second session. Testing was divided across two sessions to prevent fatigue during testing and potential data loss. The time of day of participant testing was not formally recorded as a variable. However, in an effort to maintain consistency across testing children were recalled in the same order for day 2 testing as they were called in day 1.

Session One:

1. The orthoptic assessment included near and distance visual acuity testing (Sonkson near vision and Keeler Crowded LogMAR test respectively), examination of eye position (cover test) and assessment of 3D vision (Frisby stereotest).
2. Near point of accommodation was assessed – participants were presented with a small target (6/6 single letter target) at a distance of 40cm from the bridge of their nose. This was brought slowly towards them; participants were asked to report when the letter target became so blurry that they could not see it.
3. Individual calibration of the Plusoptix PowerRef3 was attempted on 40 of the study participants. Calibration was subsequently abandoned as it became unfeasible to conduct (see later in this section *5.2.5.1* for justification and explanation).

4. Accommodation was assessed objectively using the portable vision lab (see next section *5.2.5*). Plusoptix recommends dim lighting conditions when using the PowerRef3, therefore room lights were switched off for the duration of the accommodation assessment but some natural daylight was still available. Accommodative targets included; age appropriate text of varying font sizes, individual letters, a "Where's Wally?" visual search task and the clown picture. These targets are discussed in more detail in *5.2.6.1*. Target presentation order was counterbalanced and a minimal instruction set was employed. Participants were instructed to simply "look at the clown", "find Wally" or "read the story aloud". Each target was presented for a minimum of one minute. Accommodation responses to each target were recorded by the Plusoptix while the researcher made field notes pertaining to participants' reading fluency during the task.
5. Following the accommodation assessment, participants completed the BAS-3 Matrices subtest. This provided a measure of individual participant's non-verbal reasoning.

Session Two:

6. All participants completed the YARC Reading Test (assessment procedure described in *Chapter 4*; *4.2.10.2.1*).
7. Participants then completed the TEA-Ch attention test. Children completed the selective, sustained and sustained/divided attention subtests (assessment procedure as per *Chapter 4*; *4.2.10.3.1*).
8. A test of print exposure, title recognition task/author test as appropriate for age, was administered (for example see Appendix 6a & b). This was either

completed by the participant at the end of session two or between the YARC and TEA-Ch assessments if the participant required a break.

9. Class teachers were asked to complete the teacher version of the SDQ questionnaire.
10. Calculation of the YARC, TEA-Ch, SDQ and authors test scores were completed by the researcher at the end of the session.

5.2.5 Portable Vision Laboratory

A portable, smaller scaled version of the IVL used in the laboratory study, was built by University of Reading technicians following the researchers' design instructions (Figure5-1 & 5-2). The portable laboratory was designed to facilitate the objective assessment of accommodation in a school setting. All elements were fixed on a wooden board which could be mounted on a classroom table to ensure appropriate equipment height and maximum comfort for young participants.

Similar to the IVL design (*Chapter 4*; *4.2.8*), the portable laboratory utilised a commercial photorefractor (Plusoptix R09 PowerRef 3) to objectively assess accommodation. As with the Plusoptix S04, the Plusoptix R09 uses the premise of eccentric photorefraction, allowing the simultaneous, continuous measurement of eye position and refraction data. Photorefraction data was obtained via a "hot mirror" set at 45^{o} and encased in metal shuttering, this allowed the participant to have an unrestricted view of the target while the PowerRef3 recorded eye position and refraction data. Data was recorded at a speed of 50Hz (in comparison to the 25Hz for the laboratory study). Targets were presented on high resolution, Retina Display iPad tablet computers. iPads were fixed in holders set at a distance of 33cm and 1m, thus producing accommodative demands of 3D and 1D respectively. A third iPad was used to present a target at 2m

(0.5D demand); this iPad was not fixed in a holder and was instead held by the tester for this measurement. The 2m distance was measured and marked in each testing room to ensure accuracy during assessment.

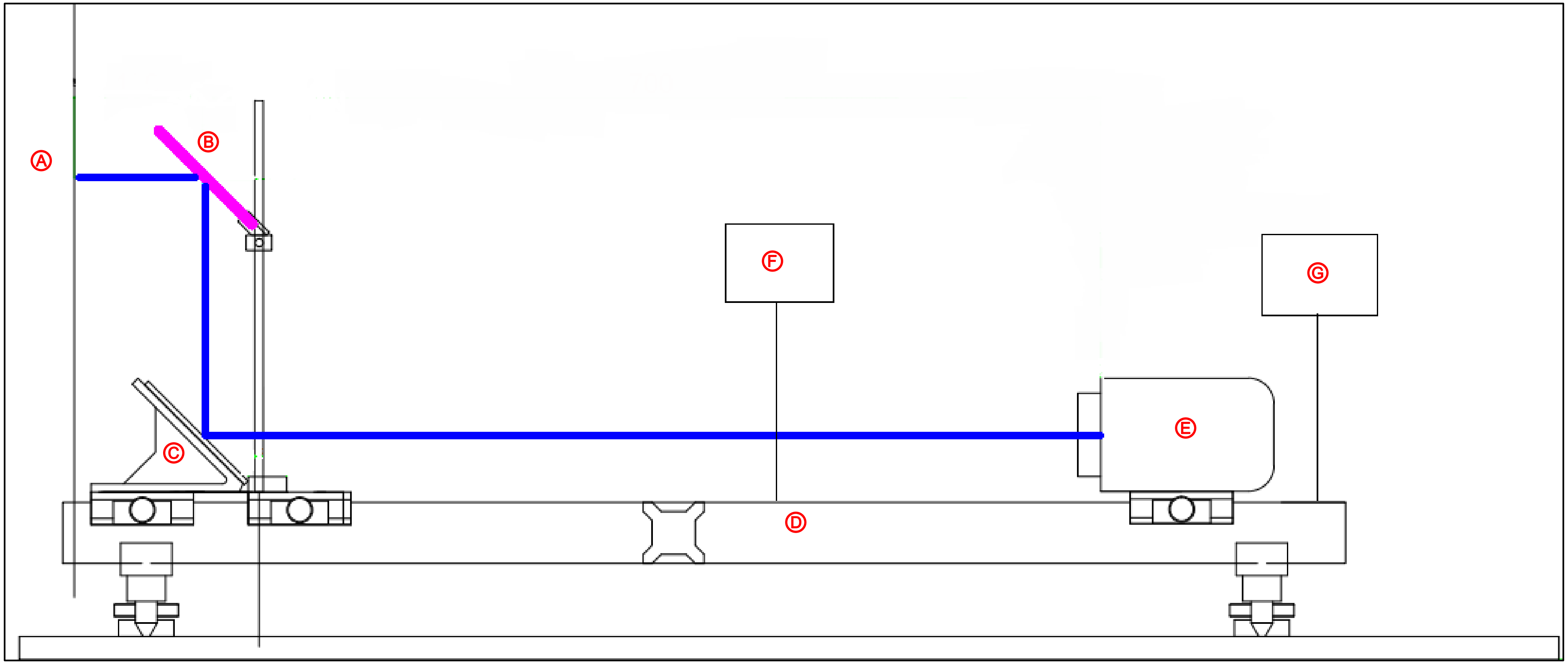

Figure 5-1: Schematic diagram of portable accommodation laboratory. A: Headrest location, B: Hot Mirror, C: Hot Mirror, D: Fixed metal beam, E: Plusoptix R09 PowerRef 3, set 1m from the participant, F: iPad holder for use at 33cm, G: iPad holder for use at 1m. Blue line represents photorefraction pathway

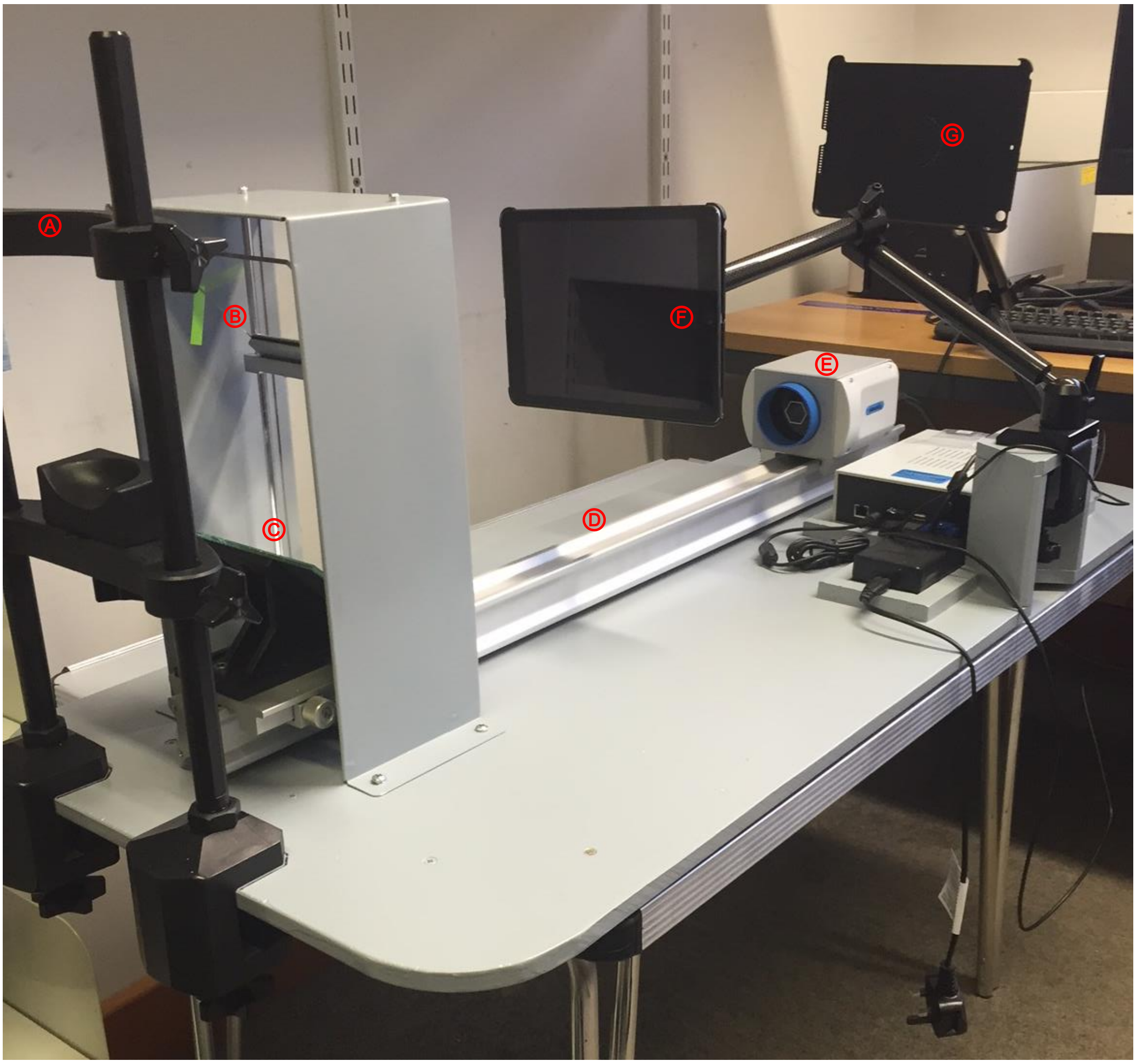

Figure 5-2: Photograph actual portable accommodation laboratory. A: Headrest, B: Hot Mirror, C: Hot Mirror, D: Fixed metal beam, E: Plusoptix R09 PowerRef 3, set 1m from the participant, F: iPad Holder for use at 33cm, G: iPad Holder for use at 1m distance

5.2.5.1 Calibration

Due to time constraints in such a long and detailed testing session, individual calibration was not carried out in the laboratory study (*Chapter 4*). As discussed in *Chapter 4; 4.2.8.4,* calibration errors may give rise to inaccuracies in the photorefraction estimate obtained, therefore individual calibration is advised to minimise relative error (Bharadwaj 2013, Sravani, Nilagiri, & Bharadwaj, 2015). In view of this, individual calibration of participants was attempted for the school study.

The objective of calibration is to induce a known refractive error (i.e. introducing a lens) in an eye that cannot see the target and then to assess the accuracy with which the photorefractor measures this known error. Any systemic differences can then be corrected through the application of a calibration factor to subsequent data, e.g. if the Plusoptix recorded 1.1D when a 1D and 2.2D when a 2D lens had been used a calibration factor of 10% would need to be applied to the data to adjust for this.

Prior to carrying out calibration on children in schools, the calibration routine was piloted on 4 young adult subjects. Participants were either emmetropic or wore corrective lenses if required.

Pilot Calibration Procedure:

1. As the Plusoptix photorefractors are both designed for use in dim lighting conditions the calibration procedure was carried out in a dimly lit room.
2. Participants were instructed to look at a clown target (*Chapter 4; 4.2.9.1*), displayed on an iPad fixed at 1m, while holding an IR filter over their right eye. A range of lenses (-3 – +3) were then introduced in front of the filter over the right eye. No lens was held over the left eye.

3. The IR filter permitted the passage of IR light, however the participant was unable to see through the filter; this enabled the PowerRef3 to refract and record the power of the lens in front of the filter rather than the refractive error of the eye underneath the filter.
4. Data was recorded for a minimum of 5 seconds for each individual lens power.

Individual calibration, as per the above procedure, was attempted during the school testing however this was subsequently abandoned for two reasons. Firstly, the calibration procedure required children to hold an IR filter over one eye while the researcher simultaneously held lenses over the filter and operated the PowerRef3; due to a combination of the design of the portable lab, school classroom layout and children making large head/eye movements, single handed operation was not possible. Secondly, calibration data obtained was largely of poor/insufficient quality. This is likely a result of issues with pupil identification by the PowerRef3 and artefacts from eyelashes and head movement.

The PowerRef3 provides a video output which an examiner can use to monitor subjects' fixation during photorefraction. The device estimates pupil location during photorefraction and this estimate is visible to the examiner on the video output. The pupil estimation is represented by a green circle; in theory this green circle should correspond to where the examiner can see the actual pupil location on the video output. It was clear from the video output that Plusoptix at times had great difficulty identifying the pupil location. In order for the PowerRef3 to pick up the image of the eye under the filter, it was frequently necessary to twist and tilt the lenses held in front of the filter to avoid reflection from either the lens or filter surface. The manipulation of lens position in such a way can induce unknown optical aberrations which can result in inaccurate refraction estimates. In addition, the filter often pressed against the eye during calibration, under this circumstance the PowerRef3 struggled to identify the pupil edge under the IR filter (Figure 5-3); particularly in the presence of long eyelashes. Reflections from participants' own glasses also impacted pupil identification and data recording. As previously discussed (*Chapter 4*; *4.2.7.*), refraction estimates are calculated by a photorefractor from the gradient of the retinal light reflection crescent in relation to pupil size. It is possible that refractive error determination could be influenced by inaccurate identification and recording of the pupil location. This potential error therefore calls the accuracy of any calibration estimates that were obtained into question. This coupled with the difficulties associated with single handed operation meant individual calibration routine of this school study was not practical or reliable and was subsequently abandoned. Instead, group calibration was undertaken to ascertain the relevant calibration factor for the PowerRef3; this will be discussed in detail below (*5.2.5.2*).

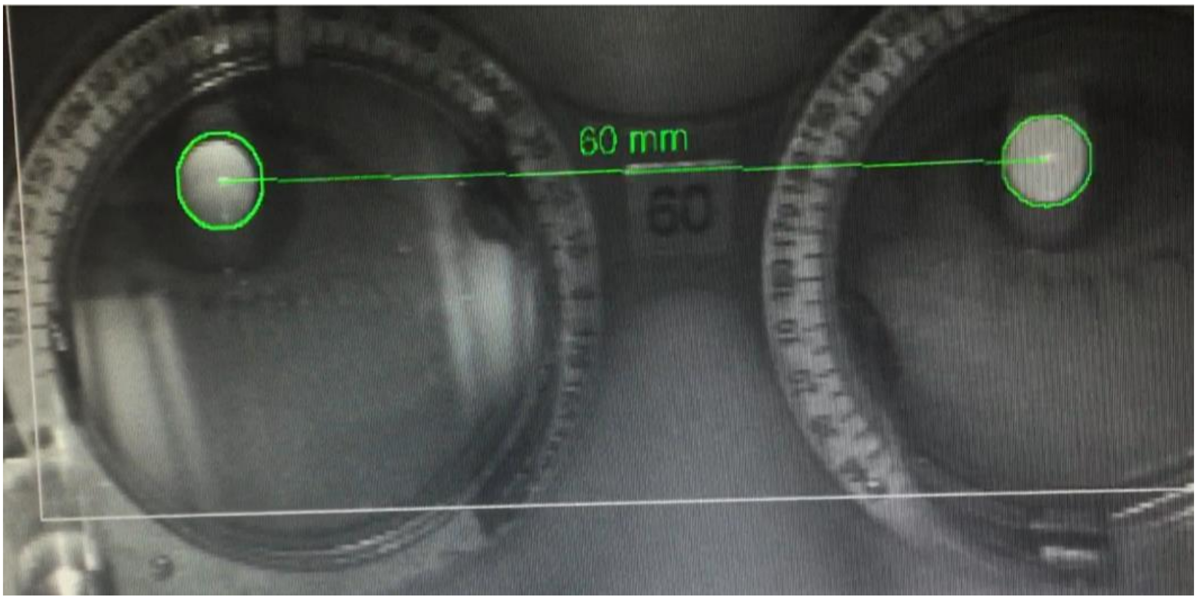

Figure 5-3: Image of the Plusoptix R09 PowerRef3's estimation of pupil location. The green line represents inter-pupillary distance. The green circle represents the PowerRef3 pupil estimation. In this case the PowerRef3 failed to correctly identify the pupil edge and its estimation of pupil size is noticeably larger than the actual pupil size (bright reflex). This overestimation is particularly evident on the left pupil.

5.2.5.2 Portable lab (PowerRef3) Group Calibration:

In the absence of individual calibration of participants, a small repeated measures study was conducted on a group of co-operative adults. The aim of this study was to compare the calibration estimates obtained with the portable lab to those obtained in the IVL in order to obtain an appropriate group calibration factor and to validate the portable lab for the purpose of this thesis.

Method:

12 young adult subjects (8 females, 4 males; mean age 27.85 years ± 4.09SD) were recruited to participate in the calibration study. Participants were either emmetropic or wore corrective lenses (spectacles or contact lenses) if required. All subjects had a

minimum corrected uniocular visual acuity of 0.100 logMAR at near and distance; participants did not have any binocular vision problems i.e. no significant heterophorias (>10^{Δ}), good convergence (<10cms) and normal stereopsis (≤85" of arc, Frisby).

Portable Lab Calibration:

1. Portable lab calibration was performed before IVL calibration for all participants.
2. Calibration was carried out in a semi lit room as per Plusoptix guidelines and to mimic the lighting conditions encountered in schools during the main study.
3. Two examiners performed the calibration protocol simultaneously; one examiner moved the lenses (SL) and one operated the Plusoptix PowerRef3 start/stop recording functions (AH).
4. Participants were instructed to look at a clown target on an iPad fixed at the optical equivalent of 1m from the participant, while holding an IR filter over their right eye.
5. Lenses (-3D – +3D) were then introduced over the filter on the right eye. Data was recorded in an individual data file for each lens power. Lens presentation order was not randomised.
6. Data was recorded in both eyes simultaneously for a minimum of 5 seconds.

IVL Calibration:

7. Calibration was carried out in a dark room.
8. A single examiner (SL) performed the calibration protocol.

9. Participants were instructed to look at a clown target on a computer screen fixed at the optical equivalent of 1m from the participant, while holding an IR filter over their right eye.
10. Lenses (-3D – +3D) were then introduced over the filter on the right eye. As above, data was recorded individually for each lens power. Data was recorded in both eyes simultaneously for a minimum of 5 seconds. Lens presentation order was not randomised.

Statistical Analysis:

Data was tabulated and analysed using MS Excel 2010. The difference in refraction between the two eyes (anisometropia) recorded by the Plusoptix with the –3D – +3D lenses was calculated. Paired, two-tailed t-tests were used to compare the induced anisometropia recorded by the portable lab and the IVL for each lens power.

Results

The above procedure permitted the use of refraction, obtained using lenses of known dioptric value, to calculate the slope of the output of the photorefractor and to compare slopes between the IVL and the portable lab. Anisometropia recorded by the IVL and portable lab for each lens power is given in Table 5-1. A difference in refraction obtained by the IVL and the portable lab estimates was observed; the portable lab appeared to consistently underestimate refraction compared to the IVL. This underestimation did not reach statistical significance ($p > 0.05$) for any minus lens strength or for the highest power plus lens used (+3D) (Table 5-1). However, the anisometropia induced with a +1D and +2D lens was found to be significantly higher in the IVL than with the portable lab (Table 5-1), suggesting a significant underestimation of low myopic refraction by the portable lab.

Lens Power (D)	Mean (SD) Anisometropia Portable Lab	Mean (SD) Anisometropia IVL	p-value
-3	1.72 (0.948)	2.24 (2.926)	0.591
-2	1.44 (1.282)	2.24 (1.709)	0.141
-1	0.873 (1.623)	1.03 (1.092)	0.624
+1	0.289 (0.517)	1.18(0.738)	0.003
+2	1.07 (0.704)	2.16 (1.425)	0.035
+3	1.44 (0.814)	2.27 (2.278)	0.127

Table 5-1: Lens power and induced anisometropia as recorded with the Plusoptix PowerRef3 (Portable Lab) and Plusoptix PowerRefII (IVL).

The refraction data was further explored and regression slopes for each participant were calculated. Higher regression slopes were found in the IVL compared to those obtained with the portable lab; this difference was highly statistically significantly, p = 0.007.

Mean induced anisometropia was plotted against lens strength. As illustrated in Figure 5-4, the portable lab underestimated refraction at each lens strength, such that the slope of the function for the portable lab was considerably less than that of the IVL. To address this offset a group mean calibration factor was applied to the refraction data obtained by the portable lab. Following the application of this group calibration factor the slope of the portable lab was much increased and more comparable to that of the IVL (Figure 5-5).

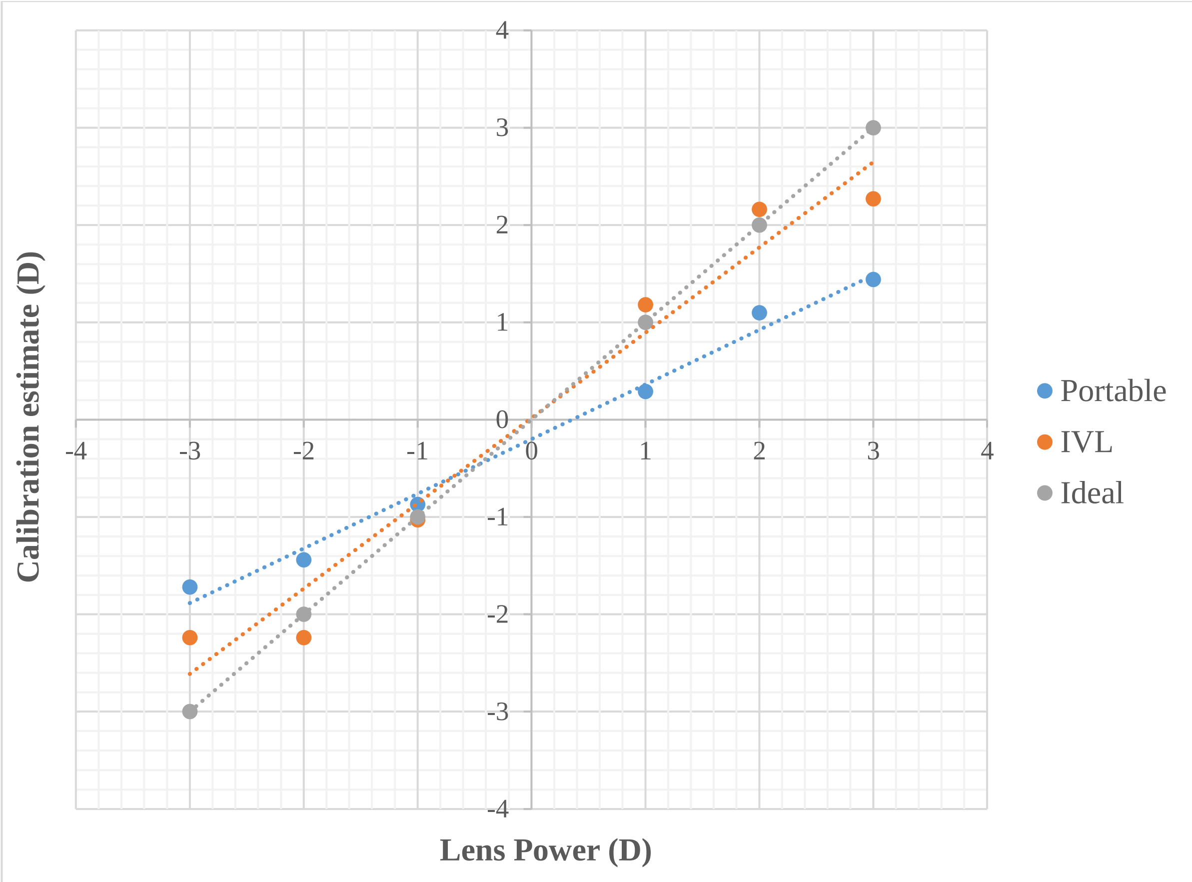

Figure 5-4 Estimation of refraction (induced by way of plus and minus lenses) of the Portable Lab (blue line) IVL (red line) and the ideal response (grey line). Systematic underestimation of all lens power occurred with the Portable Lab compared to the IVL or ideal response.

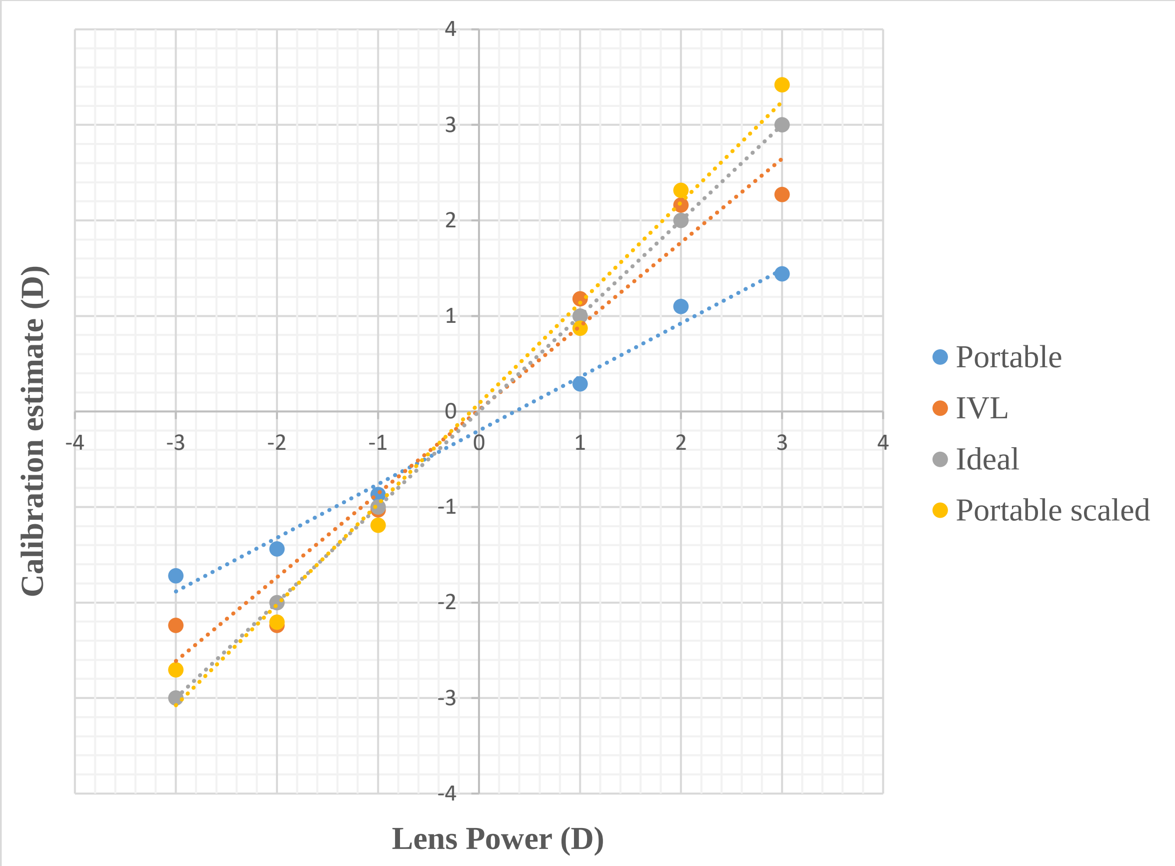

Figure 5-5 Estimation of refraction by the portable lab (blue), IVL (red line), ideal response (grey line). Scaled portable lab data, i.e. data post application of group calibration factor, is indicated by the yellow line. After application of the calibration factor this scaled data is more similar to that of the IVL and the ideal response, indicating more accurate responses are obtained after application of the calibration factor.

Discussion

The purpose of this brief study was to compare the refraction estimates obtained with the portable lab (Plusoptix R09 PowerRef3) to the IVL (Plusoptix S04 PowerRefII) to assess the accuracy and consistency of refraction estimated by the PowerRef3. From the results it was evident that the PowerRef3 (portable lab) underestimated both induced hypermetropic and induced myopic refractions. The consistent nature of the underestimation of refraction, as seen in Figure 5-4, suggested a constant offset of the PowerRef3. It is not clear why this underestimation occurred. In particular, it is not clear why the PowerRef3 was found to underestimate myopic refractions. Evidence has suggested that the Plusoptix may underestimate hypermetropia however, it is considered to be accurate in the assessment of myopic error (Dahlmann-Noor et al, 2009). In fact, it has been reported that Plusoptix photorefractors actually have a myopic bias which can result in a slight overestimation of myopic refractions by the device (Payerols, Eliaou, Trezequet, Villain & Daien, 2016).

The Plusoptix PowerRef3 used in this calibration and school study was setup and installed according to Plusoptix instructions and the portable lab design was physically re-measured and dimensions confirmed following its assembly by University of Reading technicians. This would suggest that despite the significant difficulties in obtaining and having confidence in the individual calibration data that the observed underestimation of refraction is the result of a discrepancy or anomaly within the Plusoptix PowerRef3 device itself.

Following the application of the calibration factor, the estimation of refraction of the PowerRef3 became comparable to that of the IVL as well as the ideal response anticipated (Figure 5-5). It was therefore clear that application of this calibration factor to the data obtained with the PowerRef3 was required prior to any data analysis, to ensure a representative estimate of accommodation was recorded and to avoid erroneous results, including a potential underestimation of accommodative response during the main school study.

5.2.6 School Study test battery

The test battery was derived from the preliminary analysis reported in *Chapter 4*.

5.2.6.1 Targets

The targets used in this study were selected from those piloted in *Chapter 4*. As analysis of accommodation to different targets (*Chapter 4; 4.3.1.2*) revealed no significant difference between the cartoon, individual letters and clown targets, the cartoon target was excluded from the school study in the interest of time. Thus, the targets used for the school study were:

- "Big Print" – equivalent 18 point print, Helvetica font style
- "Medium Print" – equivalent 12 point print, Helvetica font style
- "Small Print" – equivalent 5 point print, Helvetica font style
- "Individual Letters" – equivalent 18 point print, Helvetica font style
- "Where's Wally?"
- "Clown"

A detailed description of each target is given in *Chapter 4; 4.2.9*. All targets were presented binocularly at 1/3m via a MS PowerPoint presentation file displayed on an Apple iPad Air; 9.7inch Retina display, screen resolution 2048x1536 pixels. Luminance measurements during testing, where available, ranged from 16-24cd/m^2.

As in the Laboratory study, the "Clown" target was also presented at 2m and 1m distances. Data collection at these additional distances facilitated the estimation of maximum hyperopic refraction obtained in conditions most likely to reveal them without cycloplegia. Maximum hypermetropic refraction was recorded to enable further exploration of relevant data during statistical analysis e.g. in the case of outliers to examine if observations were attributable to refractive error. To estimate maximum hyperopic refraction, the examiner held an iPad at 1m (initially) and asked the participant to look at the clown. The examiner, while holding the iPad, then walked backwards slowly to 2m while the participant maintained fixation on the target. This action provided a binocular receding cue; the maximum hypermetropic refraction obtained with such a target has been shown to be a good proxy measure for true refractive error (Horwood & Riddell, 2009).

5.2.6.2 Reading/Attention tests

The test battery used to assess reading and attention in this study has been described in detail previously (*Chapter 4; 4.4.3*) and so is only briefly mentioned here. The battery was derived from preliminary analysis of the laboratory data.

The reading test selected for use was the York Assessment of Reading Comprehension (YARC). Three subtests of the Test of Everyday Attention for Children (TEA-Ch) were used to assess attention. These subtests included Sky Search, Score! and Sky Search DT. The teacher version of the Strengths and Difficulties Questionnaire (SDQ) was also employed to assess attention/behaviour. In addition, children were asked to complete an Authors/Title Recognition Test as appropriate to assess prior exposure to print. The individual test administration method has been detailed previously (*Chapter 4; 4.2.10*) and therefore will not be described here.

5.2.7 Statistical Analysis

Raw refraction data recorded by the Plusoptix PowerRef3 for each target condition was converted to useable measures of accommodation using the IVL macro as described in the laboratory study (*Chapter 4; 4.2.8.3*). As was carried out in the laboratory study (*Chapter 4; 4.2.11*), one second of stable, and representative data taken from the end of the minute testing period was used in the analysis. The group calibration factor, derived during the calibration study (*5.2.5.2*) was then applied to this data to account for any underestimation of refraction by the Plusoptix PowerRef3. The resulting accommodation measurement in dioptres (D) was used in the analysis.

Data was organised using MS Excel 2010, analysis was conducted using SPSS for windows, version 22.

Following checks for normality, parametric statistical analysis was conducted as follows:

1. A one way repeated measures ANOVA was conducted to analyse the differences in accommodation to the various targets. Post hoc testing was corrected using Bonferroni correction for multiple comparisons. There were 6 ANOVA levels in this analysis consisting of accommodation to each target at 1/3m i.e. AR to the small, medium and big print, individual letters, Where's Wally? and clown target.
    a. A two way mixed ANOVA was conducted to further explore the relationship between age and target type.

2. Pearson correlation analysis was used to ascertain the relationship between accommodation and individual performance on standardised tests.

Statistical significance was set at $p < 0.05$. As per *Chapter 4, 4.2.11*, as a result of the SPSS method of applying Bonferroni correction (inflating rather than dividing), where such correction has been applied in this chapter the statistical significance level remains at $p < 0.05$. The author acknowledges that the relevant Bonferroni corrected p value in this chapter (15 comparisons) would be $p = 0.003$ if carried out by hand.

5.3 Results – School Study

5.3.1 Participants

714 parent packs, consisting of information sheets and consent form, were distributed to the six participating primary schools (*5.2.2*). Three of the participating schools communicated with parents, e.g. via school newsletters and email, in advance of distributing the parent packs that a vision study would be running at their school and that they would be approached for participation. For the remaining schools, parental receipt of study information was the first point of contact regarding research.

128 completed consent forms were returned. 6 children were excluded from participation as they had previously undetected refractive errors and failed the distance vision criterion for participation. These children were referred to a local optometrist for further evaluation. No child failed the near vision criterion in isolation. As no child was excluded solely on the basis of poor near vision it is unlikely that a child with some degree of accommodative lag was erroneously excluded from participation.

Following these exclusions 122 children were tested as part of this study. 42 children were tested from Year 2 (age range 6 – 7 years), 40 from Year 4 (age range 8 – 9 years) and 40 from Year 6 (age range 10 – 11 years).

All participants underwent an orthoptic assessment and were not found to have any significant visual abnormalities. No participant had a manifest squint, any latent squint (heterophoria) was small angle ($<10^{\Delta}$ at both distance and near fixation) and was well controlled. All participants demonstrated good stereopsis (85” of arc or better) using the Frisby stereotest. Convergence, as assessed in free space, was within normal limits in all participants and no participant spontaneously reported blur during testing. Near point of accommodation* (NPA) was assessed in free space using an N5 letter target. All participants reported a NPA within normal clinical limits for their age

(≤8cms) i.e. all children reported subjective accommodation which would be considered clinically acceptable. Measurement of refractive error was obtained using the previously described maximum hypermetropic refraction technique (Horwood and Riddell, 2009). Some loss of data was experienced due to difficulties associated with the Plusoptix e.g. loss of pupil identification. As the examiner was not able to view the video output while performing the maximum hypermetropic refraction routine it was not possible to identify when data had been lost e.g. when the Plusoptix could no longer recognise pupils and rectify the situation e.g. by adjusting device brightness etc. Descriptive statistics of the refractive error identified across participants is given in Table 5-2. Hypermetropia was defined as refraction > +0.50DS and < -0.50DS respectively. Any participant with a refraction between +0.50DS and -0.50DS was classified as emmetropic. Hypermetropia was further classified into mild (+0.50DS - +2DS), borderline (> +2.00 but < +3.00) moderate (> +3 but < +4.00DS) and high (> +4.00).

	Year 2	Year 4	Year 6
Total sample (n)	42	40	40
Available refraction data (n)	37	40	38
Mean refraction (SD) (D)	+1.04 (0.38)	+0.21 (0.61)	+0.39 (0.46)
Hypermetropia (n)	37	36	35
Mean (SD) Hypermetropia (D)	+1.04 (0.38)	+0.97 (0.46)	+1.16 (0.46)
Range Hypermetropia (D)	+0.08 to +2.04	+0.02 to +1.83	+0.44 to +2.48
Myopia (n)	0	4	3
Mean (SD) Myopia	N/A	-0.55 (0.14)	-0.38 (0.39)
Range Myopia (D)	N/A	-0.35 to -0.69	-0.11 to -0.80

Table 5-2 Refraction data recorded using maximum hypermetropic refraction method per individual school year group.

5.3.2 Accommodation to targets

Objective accommodation data was available for all 122 participants. Proportion of accommodative lag/lead among participants was established (Figure 5-6). A higher AR was observed to the more complex targets (Figure 5-7). For each year group, accommodative response (AR) was found to vary to across targets (Table 5-3).

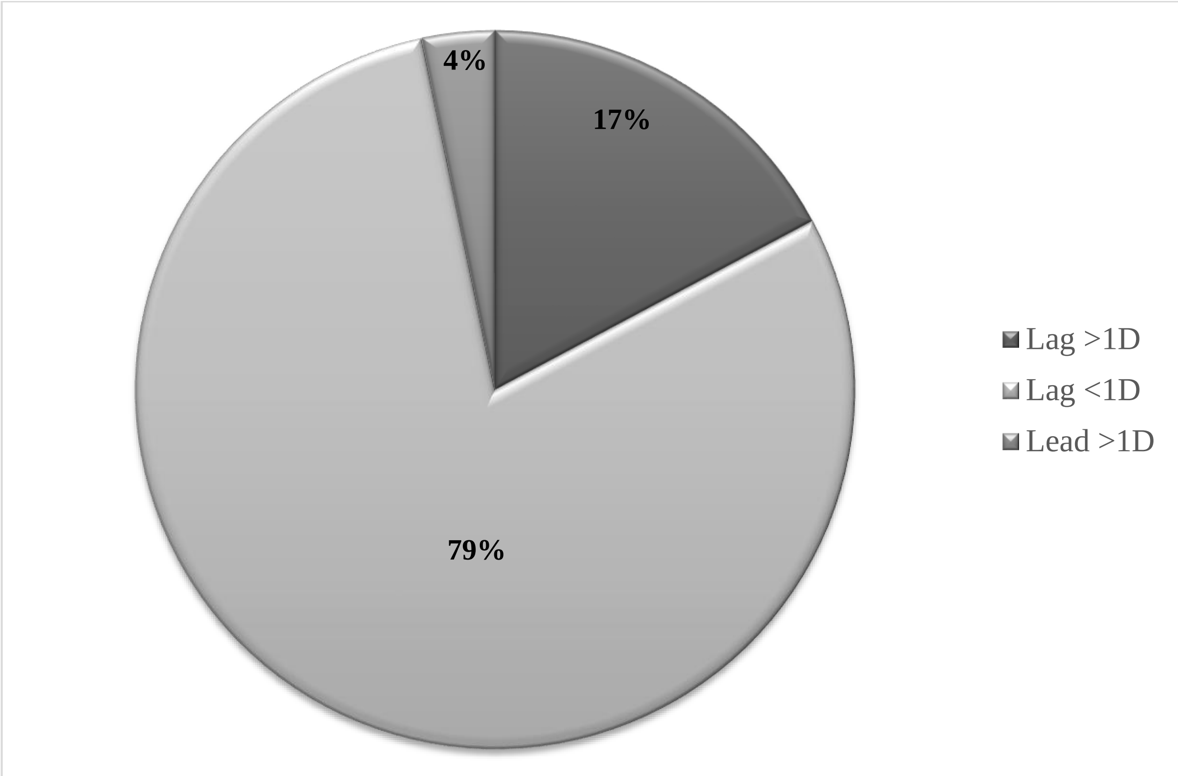

Figure 5-6 Proportion of accommodative lag and lead observed to the clown target at 1/3m in the school study participants (n=122).

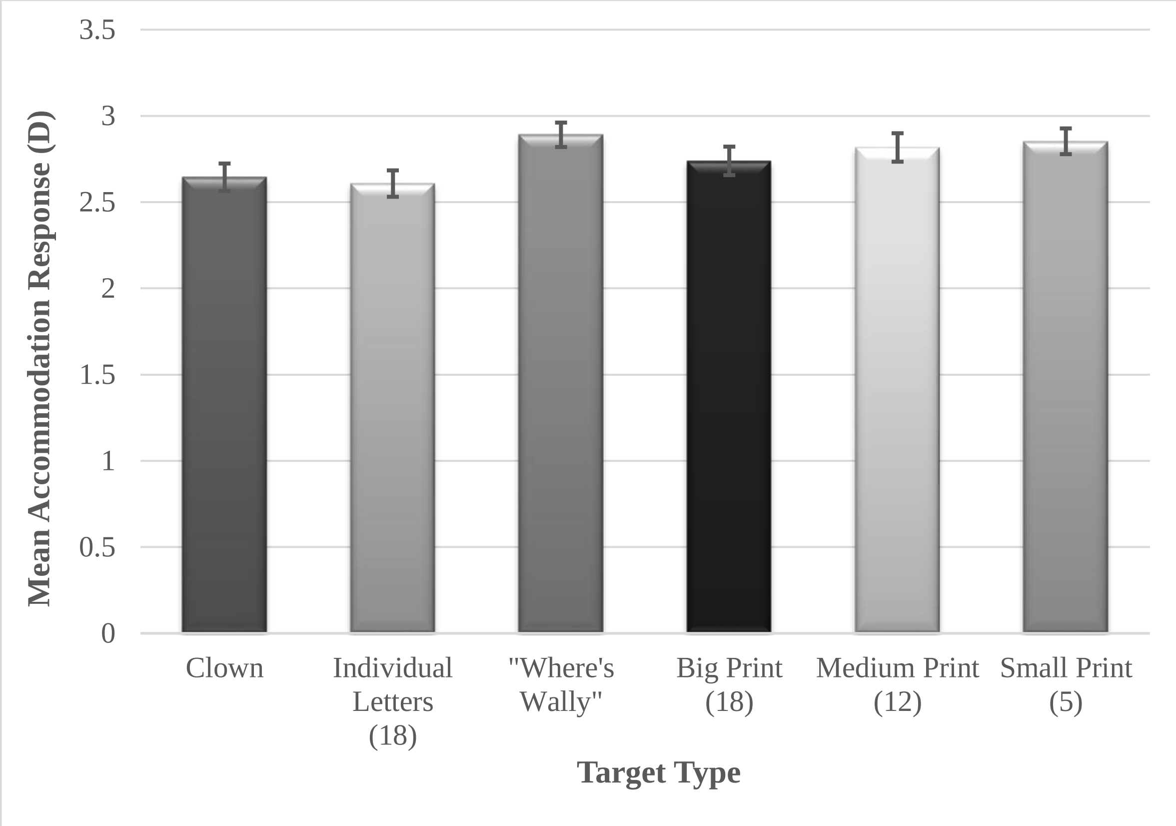

Figure 5-7 Mean AR (D) to each target type at 1/3m for all participants (n=122). Bars denote ±1SEM. Where relevant font size of text targets is given in brackets.

Target Type	Year 2 (n=42) Mean AR (SD) (D)	Year 4 (n=40) Mean AR (SD) (D)	Year 6 (n=40) Mean AR (SD) (D)
Clown	2.83 (0.835)	2.78 (1.06)	2.49 (0.887)
Big Print (18)	2.79 (0.943)	2.67 (1.14)	2.72 (0.999)
Medium Print (12)	2.85 (0.794)	2.74 (1.21)	2.87 (1.12)
Small Print (5)	3.02 (0.491)	2.72 (1.18)	2.92 (0.829)
Where's Wally?	3.01 (0.431)	2.83 (1.08)	2.85 (1.01)
Individual Letters (18)	2.78 (0.685)	2.54 (1.06)	2.47 (1.01)

Table 5-3: Mean (Standard Deviation) AR for each accommodative target at 1/3m per year group.

Repeated measures ANOVAs were conducted to investigate the difference in AR for individual targets for each year group. Individual group results are presented below. Mauchly's test indicated that the assumption of sphericity had been violated in each group ($p < 0.05$). This was corrected by using the Greenhouse-Geisser estimate statistics.

5.3.2.1 Year 2 children

AR was found to vary slightly across targets (Figure 5-8). This variation followed a similar pattern to that observed in the laboratory study and was found to be statistically significant $F_{(3.27, 94.94)} = 2.492$, $p < 0.05$. AR to small print was found to be significantly higher than that observed to the individual letters target ($p = 0.04$). No other significant differences in AR were identified.

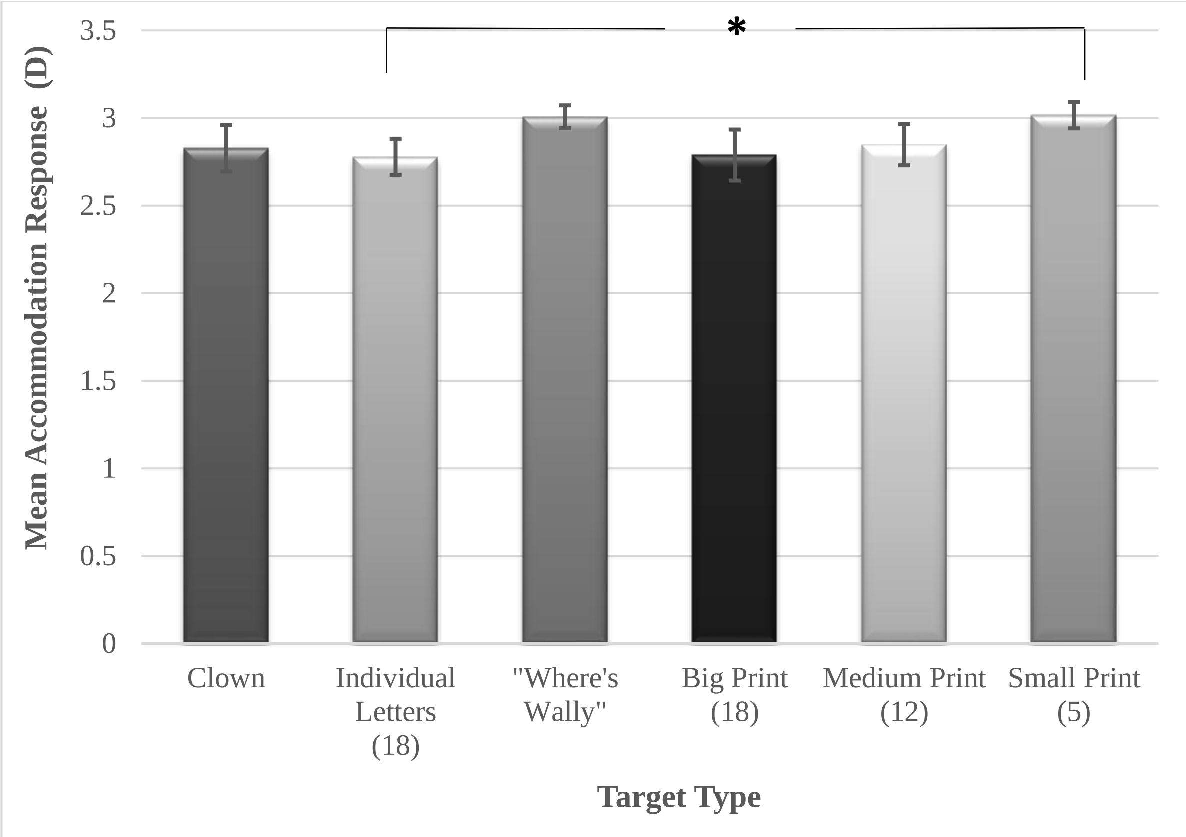

Figure 5-8: Mean AR (D) for each target at 1/3m in Year 2 participants. Error bars denote ±1 SEM. Where relevant text font size is given in brackets. * denotes statistically significant difference in AR between small print and individual letters; p= 0.04.

5.3.2.2 Year 4 children

AR was again found to vary slightly across targets (Figure 5-9); this did not reach statistical significance for any target $F_{(1.33, 44.35)} = 8.68$, $p = 0.45$.

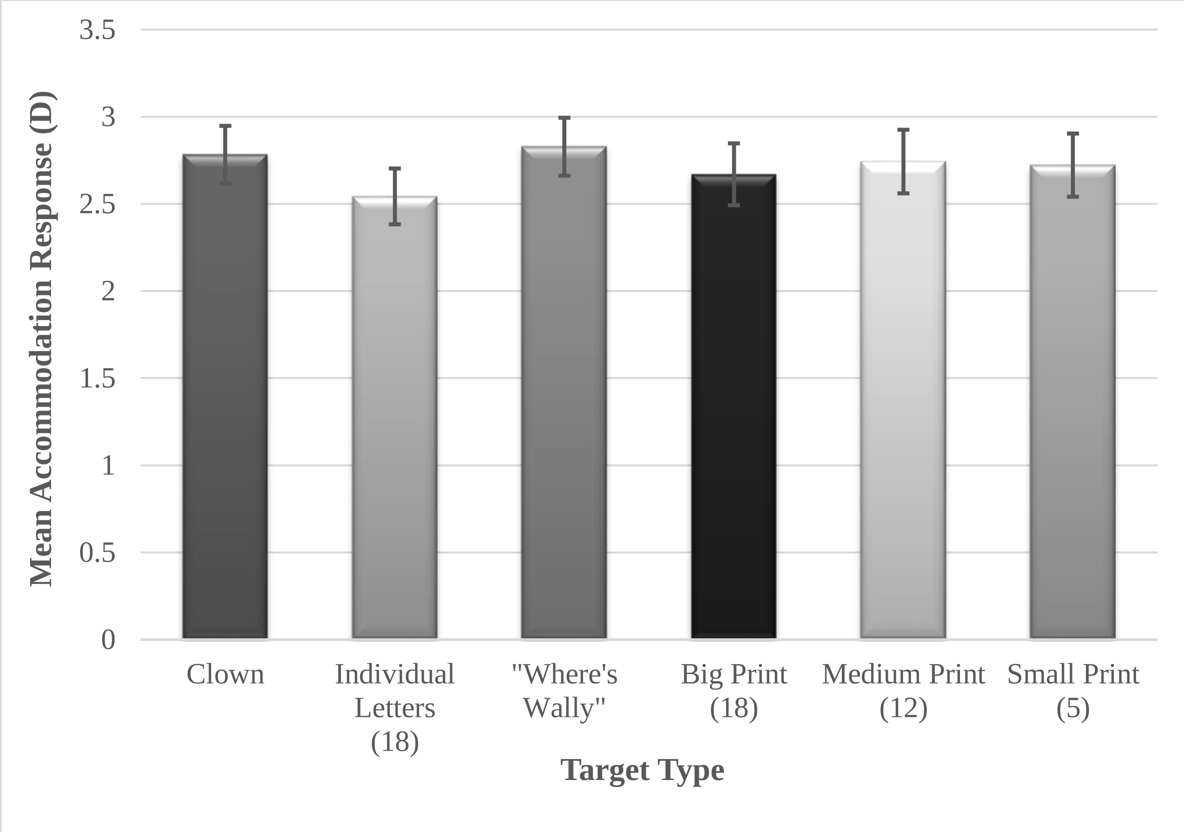

Figure 5-9: Mean AR (D) for each target at 1/3m in Year 4 participants. Where relevant text font size is given in brackets. Error bars denote ±1 SEM.

5.3.2.3 Year 6 children

AR was found to be statistically significantly different across target types; $F_{(3.50,\ 122.60)} = 5.51$, $p < 0.001$. Post hoc analysis, with Bonferroni correction for multiple comparisons, showed that AR to the small print targets was significantly higher than that observed to the individual letters and clown target, $p = 0.017$, $p = 0.032$ respectively (Figure 5-10). The difference in AR observed to the rest of the targets did not reach statistical significance, $p > 0.05$.

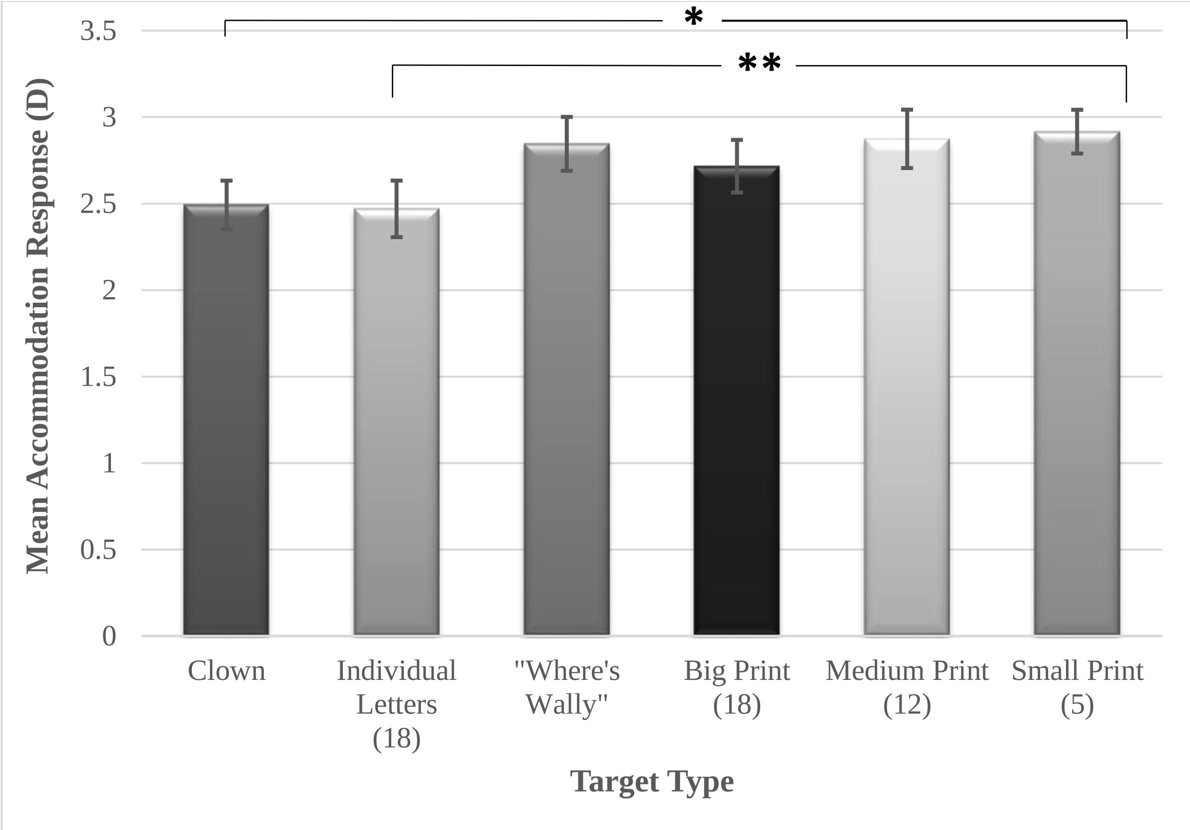

Figure 5-10: Mean AR (D) for each target at 1/3m in Year 6 participants. Where relevant text font size is given in brackets. Error bars denote ±1 SEM. *denotes that AR to small print was statistically significantly higher than AR to clown target at $p < 0.03$ level. ** denotes that AR small print was statistically significantly higher than AR to individual letters at $p < 0.02$ level.

5.3.3 Age and accommodative response

A two way mixed ANOVA was conducted to further explore the effect of age, as opposed to year group, on AR (Appendix 12). Within subject factor was target type, between subjects factor was age. Mauchly's test for sphericity was conducted and was statistically significant ($p = < 0.001$); therefore, Greenhouse Geisser was used to correct this.

There was a significant effect of target type on accommodative response ($F_{3.79, 329.7}$ = 2.87; p = 0.26). The interaction between target type and participant age was statistically significant ($F_{18.9, 329.7}$ = 1.70; p = 0.035). To further explore this interaction the dataset was first separated by age group. Unless otherwise stated below, a one way repeated measures ANOVA with Bonferroni correction for post hoc testing, was conducted to explore the influence of target type in each age group i.e. age 6 – 11 years. Statistical significance was set at p < 0.05 unless otherwise indicated.

Age 6 years participants (n=34)

Mauchly's test for sphericity was conducted and was statistically significant (p = 0.001) therefore Greenhouse Geisser was used to correct this. Target type was found to have a statistically significant effect on the AR of the age 6 years participants, $F_{2.93, 73.3}$ = 3.12; p = 0.033). Small print was found to produce a significantly higher AR than the individual letters target (p = 0.002). No other significant differences were identified in the age 6 years group.

Age 7 years participants (n=8)

Due to the limited number of 7 year old children, t-test analysis was conducted, using MS excel, to test differences in AR across target types. Post hoc Bonferroni correction was applied. As this analysis was conducted in MS excel the Bonferroni correction was calculated manually; statistical significance was set at p < 0.003 (0.05/15 comparisons). The differences in AR across target type in the age 7 years group did not reach statistical significance.

Age 8 years participants (n=23)

Mauchly's test for sphericity was statistically significant ($p < 0.001$) therefore Greenhouse Geisser was used to correct this. Target type did not have a statistically significant effect on AR in age 8 year old participants; $F_{2.44, 44.0} = 1.61$, $p = 0.208$.

Age 9 years participants (n=17)

Mauchly's test was significant, $p = 0.011$, Greenhouse Geisser was again used to correct this violation of sphericity. Target type did have a significant effect on AR in the age 9 years group, $F_{2.32, 23.2} = 6.045$. AR to Where's Wally, medium and small print targets was significantly higher than AR to individual letters target; p = 0.022, 0.008 and 0.007 respectively.

Age 10 years participants (n=17)

Mauchly's test was significant, $p = 0.01$, this was corrected by using Greenhouse-Geisser. Target type did not have a significant effect on AR in 10 year old participants ($F_{3.26, 52.1} = 1.58$; $p = 0.202$)

Age 11 years participants (n=23)

Again, Mauchly's test was significant ($p = 0.003$) and was corrected using Greenhouse-Geisser. Target type had a significant effect on AR in the age 11 years group, $F_{2.99, 50.9} = 7.601$, $p = <0.001$. Medium print elicited a significantly higher AR than the clown target ($p = 0.003$) and individual letters target ($p = 0.006$). No significant differences in AR were observed between any other target types, $p > 0.05$.

5.3.4 Accommodation and standardised tests

Data was available for all participants (n=122). Pearson correlation was performed to establish the correlation between AR to small print and standardised test scores. The small print target was used as the sole measure of accommodation in the laboratory experiment (*Chapter 4; 4.3.2*), as during the pilot study it was found to elicit the highest mean AR. Small print also elicited the highest AR in Year 6 and Year 2 participants of this school study; Where's Wally? was found to elicit a marginally higher AR in the Year 4 participants, however this was not statistically or clinically significant. Therefore, in keeping with the laboratory study, the small print AR was considered to be the most sensitive accommodative measure within the dataset and as such was used for the below correlation analysis.

Analysis was initially performed on the pooled group of school study participants (n = 122). Mean reading, attention and SDQ scores, and their correlation to AR, are given in Table 5-4. Previous research has indicated that there may be a relationship between poor accommodative response and poor reading ability. It is possible that this relationship is mediated by attention. Data analysis indicated that in this study there is no significant correlation between AR and any of the measures of reading or attention. As reading ability can be mediated by attention, partial correlation analysis (controlling for attention) was conducted to further analyse the relationship between AR and reading. No significant correlation was found between accommodation and any measure of reading ability in this partial correlation analysis (Table 5-5). Further partial correlation controlling for non-verbal reasoning was conducted. Again, no significant correlation was identified between AR and any reading measure (Table 5-6).

Increased accommodative lag could influence less experienced readers who are at the decoding stage of reading development more than older more experienced readers. Therefore, analysis was subsequently conducted on each year group individually. Findings are reported in section *5.3.2.1 – 5.3.2.3*.

Test/Subtest	Mean (SD)	*r* (Small Print v Test)	p value
YARC SWRT	104 (13.0)	.059	0.483
YARC Accuracy	108 (11.4)	.136	0.106
YARC Rate	107 (13.1)	.043	0.614
YARC Comprehension	104 (11.3)	.004	0.959
TEA-Ch Selective Attention	8.76 (3.03)	-.038	0.655
TEA-Ch Sustained Attention	9.33 (3.73)	-.083	0.324
TEA-Ch Sustained/Divided Attention	6.76 (4.09)	-.020	0.818
BAS-3 Matrices	46.4 (8.81)	.152	0.068
SDQ Stress	7.12 (5.74)	-.099	0.474
SDQ Emotional Distress	1.61 (1.73)	-.112	0.417
SDQ Behaviour	1.25 (1.69)	-.084	0.543
SDQ Hyperactivity	3.07 (3.12)	-.145	0.291
SDQ Interpersonal	1.19 (1.77)	.126	0.360
SDQ Helpful	7.96 (2.29)	.187	0.172
SDQ Impact	0.35 (0.90)	.043	0.754

Table 5-4: Mean (Standard Deviation) (SD) for each reading, attention and SDQ subset in all participants (n=122). Pearson's *r* for correlation with AR to small print target. No significant correlation (ns) was found between AR and any test/subtest.

Test/Subtest	*r* (Small print v test controlling attention)	p value
YARC SWRT	-.287	0.51
YARC Accuracy	-.166	0.265
YARC Rate	-.210	0.156
YARC Comprehension	.024	0.872
BAS-3 Matrices	.167	0.261

Table 5-5 Partial correlation of AR to small print with reading measures controlling for attention (as measured with TEA-Ch). No significant correlation was identified.

Test/Subtest	*r* (Small print v test controlling non-verbal reasoning)	p value
YARC SWRT	-.273	0.058
YARC Accuracy	-.052	0.721
YARC Rate	-.159	0.274
YARC Comprehension	-.036	0.875

Table 5-6 Partial correlation of AR to small print with reading measures controlling for non-verbal reasoning (as measured with BAS-3 Matrices). No significant correlation was identified.

5.3.4.1 Year 2 children

Mean reading and attention test scores for Year 2 children are given in Table 5-7.

A weak positive correlation was identified between the AR to small print and SWRT standard score (Figure 5-11), this was statistically significant (*r* = .333; p = 0.029). The dataset was formally explored to ensure no individual was an outlier and as such driving the observed correlation. No outliers were identified on box plot or histogram inspection. Standardised residuals were inspected and no value was found to have a value >3.29; therefore, it can be concluded that none of the individuals were formal outliers. Partial correlation analysis, controlling for prior reading exposure, as measured with the Title Recognition Test, was conducted to further explore the relationship between AR to small print and SWRT. Following this partial correlation the observed relationship failed to reach statistical significance; *r* = .187, p = 0.248.

No other correlation in the Year 2 cohort reached statistical significance. Partial correlation analysis, controlling for attention and non-verbal reasoning (BAS-3, Matrices), was performed; no significant correlation was identified between the measures of reading ability or attention and AR to small print (Tables 5-8 and 5-9).

Test/Subtest	Mean (SD)	*r* (Small Print v Test)	p value
YARC SWRT	112 (9.41)	.333*	0.029*
YARC Accuracy	110 (13.0)	.208	0.154
YARC Rate	105 (12.0)	.164	0.269
YARC Comprehension	112 (9.41)	.042	0.656
TEA-Ch Selective Attention	8.76 (3.03)	-.191	0.190
TEA-Ch Sustained Attention	9.33 (3.73)	.100	0.391
TEA-Ch Sustained/Divided Attention	6.76 (4.09)	.165	0.513
BAS-3 Matrices	44.7 (5.55)	-0.17	0.913
SDQ Stress	7.12 (5.74)	-.555	0.332
SDQ Emotional Distress	1.61 (1.73)	.014	0.982
SDQ Behaviour	1.25 (1.69)	-.193	0.756
SDQ Hyperactivity	3.07 (3.12)	-.426	0.475
SDQ Interpersonal	1.19 (1.77)	.128	0.837
SDQ Helpful	7.96 (2.29)	.406	0.497
SDQ Impact	0.35 (0.90)	-.450	0.446

Table 5-7: Mean and Standard Deviation (SD) for each reading, attention and SDQ subset for Year 2 participants (n = 42). Pearson's *r* for correlation with AR to small print target. *denotes statistically significant correlation, $p < 0.05$.

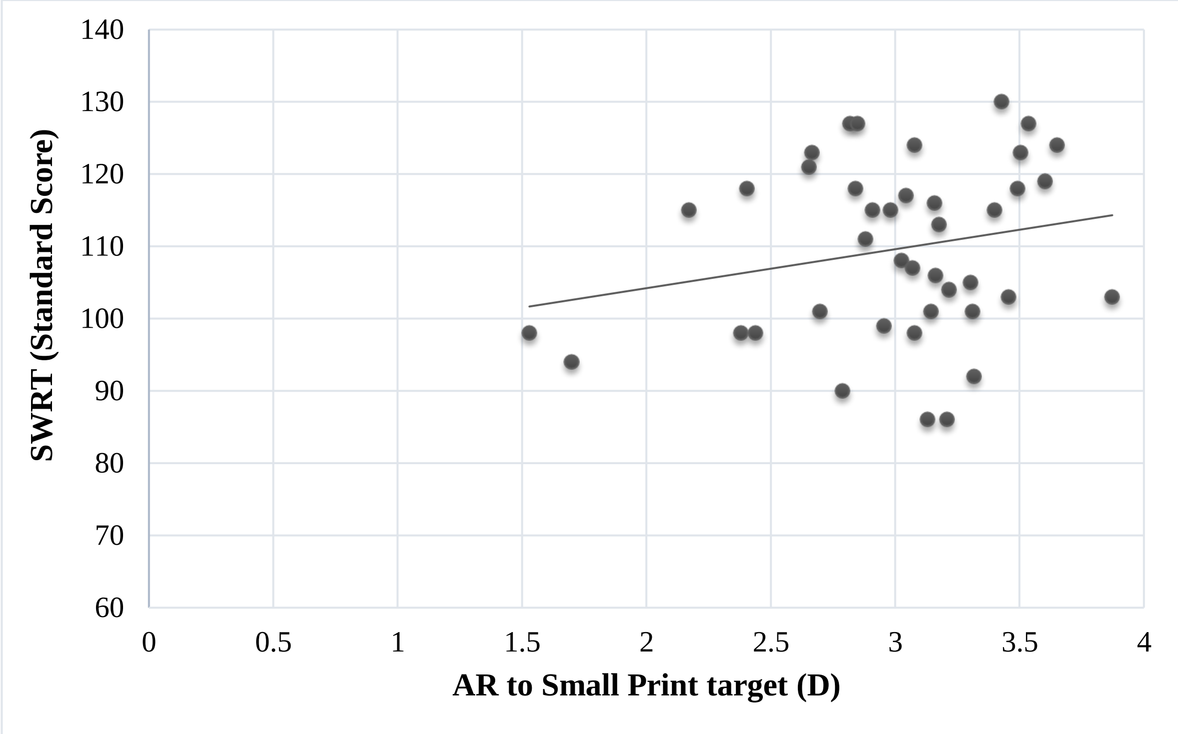

Figure 5-11: Scatterplot illustrating relationship between AR Small Print in dioptres (D) and the Single Word Reading Test (Standard Score). N=42. Pearson's *r* .333; p = 0.029.

Test/Subtest	Partial correlation *r* (Small print v test; controlling for non-verbal reasoning)	p value
YARC SWRT	.163	0.336
YARC Accuracy	.095	0.576
YARC Rate	.086	0.611
YARC Comprehension	-.030	0.860
TEA-Ch Selective Attention	-.041	0.809
TEA-Ch Sustained Attention	.078	0.645
TEA-Ch Sustained/Divided Attention	.041	0.810

Table 5-8 Partial correlation analysis of small print target and standardised measures of reading ability/attention while controlling for non-verbal reasoning, as measured using the BAS-3 Matrices subtest, in Year 2 participants. No correlation was found to reach statistical significance, $p > 0.05$ in all cases.

Test/Subtest	Partial correlation *r* (Small print v test; controlling for attention)	p value
YARC SWRT	.296	0.084
YARC Accuracy	.228	0.188
YARC Rate	.216	0.213
YARC Comprehension	.008	0.965

Table 5-9 Partial correlation analysis of AR to small print and standardised reading measures while controlling for attention, as measured using the TEA-Ch, in Year 2 participants. No significant correlation was identified, $p > 0.05$.

5.3.4.2 Year 4 children

Reading and attention test mean and standard deviations for the Year 4 group are given in Table 5-10. No significant correlation was found between any subtest and AR, $p > 0.05$. No significant correlation was identified between AR and any measure of reading ability following partial correlation controlling for attention/non-verbal reasoning, $p > 0.05$ (Table 5-11 and 5-12). Individual p values are detailed in the relevant tables.

Test/Subtest	Mean (SD)	*r* (Small Print v Test)	p value
YARC SWRT	99 (12.1)	-.084	0.601
YARC Accuracy	106 (11.8)	.127	0.429
YARC Rate	105 (13.6)	-.052	0.748
YARC Comprehension	103 (10.6)	.069	0.666
TEA-Ch Selective Attention	8.85 (3.09)	.067	0.685
TEA-Ch Sustained Attention	8.41 (3.24)	-.317	0.052
TEA-Ch Sustained/Divided Attention	6.53 (3.97)	-.107	0.524
BAS-3 Matrices	44.9 (7.93)	0.025	0.879
SDQ Stress	6.53 (7.25)	-.016	0.949
SDQ Emotional Distress	1.16 (1.74)	-.224	0.372
SDQ Behaviour	1.53 (2.14)	-.060	0.813
SDQ Hyperactivity	2.84 (3.40)	.072	0.776
SDQ Interpersonal	1.00 (1.76)	.087	0.731
SDQ Helpful	7.47 (2.91)	-.017	0.947
SDQ Impact	0.42 (1.12)	-.031	0.902

Table 5-10: Mean (Standard Deviation) for each reading, attention and SDQ subset for Year 4 participants (n = 40). Pearson's *r* for correlation with AR to small print target. No significant correlation was found between AR and any subtest.

Test/Subtest	Partial correlation *r* (Small print v test; controlling for non-verbal reasoning)	p value
YARC SWRT	-.139	0.420
YARC Accuracy	.101	0.556
YARC Rate	-.038	0.827
YARC Comprehension	.082	0.634
TEA-Ch Selective Attention	.074	0.669
TEA-Ch Sustained Attention	-.314	0.062
TEA-Ch Sustained/Divided Attention	-.110	0.521

Table 5-11 Partial correlation analysis of small print target and standardised measures of reading ability/attention while controlling for non-verbal reasoning, as measured using the BAS-3 Matrices subtest, in Year 4 participants. No correlation was found to reach statistical significance; $p > 0.05$ in all cases.

Test/Subtest	Partial correlation *r* (Small print v test; controlling for attention)	p value
YARC SWRT	.006	0.971
YARC Accuracy	.180	0.308
YARC Rate	.069	0.698
YARC Comprehension	.255	0.145

Table 5-12 Partial correlation analysis of AR to small print and standardised reading measures while controlling for attention, as measured using the TEA-Ch, in Year 4 participants. No significant correlation was identified, $p > 0.05$.

5.3.4.3 Year 6 children

Mean test scores for Year 6 participants are given in Table 5-13. No significant correlation was found between AR and any measure of reading, attention or any SDQ subset, $p > 0.05$. Partial correlation, controlling for attention and non-verbal reasoning, did not find any statistically significant correlation between AR and any measure of reading ability, $p > 0.05$ (Table 5-14 and 5-15). Individual p values can be found in the relevant results tables.

Test/Subtest	Mean (SD)	*r* (Small Print v Test)	p value
YARC SWRT	108 (14.4)	.043	0.647
YARC Accuracy	108 (14.0)	.006	0.784
YARC Rate	108 (14.8)	-.091	0.971
YARC Comprehension	104 (12.3)	-.071	0.559
TEA-Ch Selective Attention	8.71 (2.49)	-.026	0.865
TEA-Ch Sustained Attention	10.2 (3.24)	-.167	0.272
TEA-Ch Sustained/Divided Attention	7.86 (3.34)	-.067	0.662
BAS-3 Matrices	49.5 (11.2)	.140	0.358
SDQ Stress	8.92 (6.39)	-.004	0.650
SDQ Emotional Distress	1.83 (1.47)	.363	0.171
SDQ Behaviour	1.50 (1.68)	.192	0.434
SDQ Hyperactivity	3.92 (3.40)	.197	0.063
SDQ Interpersonal	1.67 (2.15)	.117	0.265
SDQ Helpful	8.5 (1.93)	.097	0.712
SDQ Impact	0.5 (1.67)	.164	0.549

Table 5-13: Mean (Standard Deviation) for each reading, attention and SDQ subset for Year 6 participants (n = 40). Pearson's *r* for correlation with AR to small print target. No significant correlation was found between AR and any subtest.

Test/Subtest	Partial correlation *r* (Small print v test; controlling for non-verbal reasoning)	p value
YARC SWRT	-.203	0.198
YARC Accuracy	-.074	0.643
YARC Rate	-.089	0.575
YARC Comprehension	-.184	0.244
TEA-Ch Selective Attention	-.041	0.796
TEA-Ch Sustained Attention	-.148	0.350
TEA-Ch Sustained/Divided Attention	-.164	0.299

Table 5-14 Partial correlation analysis of small print target and standardised measures of reading ability/attention while controlling for non-verbal reasoning, as measured using the BAS-3 Matrices subtest, in Year 6 participants. No correlation was found to reach statistical significance, $p > 0.05$ in all cases.

Test/Subtest	Partial correlation *r* (Small print v test; controlling for attention)	p value
YARC SWRT	-.059	0.761
YARC Accuracy	-.003	0.986
YARC Rate	-.003	0.986
YARC Comprehension	.126	0.439

Table 5-15 Partial correlation analysis of AR to small print and standardised reading measures while controlling for attention, as measured using the TEA-Ch, in Year 6 participants. No significant correlation was identified, $p > 0.05$.

5.4 Discussion

5.4.1 Accommodation to targets

5.4.1.1 Variation across targets

As discussed previously accommodation may be influenced by level of detail and target complexity (Bharadwaj & Candy, 2006; Ciuffreda & Hokoda, 1985). A significantly higher AR was elicited to the more detailed/cognitively complex targets in the laboratory study (*Chapter 4; 4.3.2.2*). The findings of this school study are broadly in agreement with the controlled laboratory study as a higher AR was elicited to the more complex targets such as small print and visual search (Table 5-3). Increased AR to the more complex targets was observed in all three year groups however, there was a slight variation in the pattern of significance observed between the laboratory and school study and between the different subgroups within the school study itself.

In the Year 2 laboratory group the AR to all text targets was found to be significantly higher than the AR to the clown target (*Chapter 4*; Figure 4-13). In the school study AR to small print was again found to be higher than that to the clown target (Figure 5-8); however, in contrast to the laboratory findings no significant differences in AR between the text targets and the clown target were identified. In the Year 6 school group a significantly higher AR was observed to the small print target than with the clown and individual letters (Figure 5-10). AR to Where's Wally? was not statistically different to any other target in the Year 6 school group; however, in the laboratory study only Where's Wally? was found to elicit a significantly higher AR (*Chapter 4*; Figure 4-14). The AR in the school study Year 4 group followed the same pattern as that observed in Year 2 and 6, i.e. text targets elicited a higher AR however, these differences did not reach statistical significance in this group. There was no Year 4 group in the laboratory study for comparison.

Slight differences such as those observed between the school/laboratory study and between the individual school year groups can be expected over studies conducting multiple comparisons. The slightly increased accommodative lag, and subsequent increased variability, observed in the school study dataset (Figure 5-7) compared to that of the laboratory study (Figure 4-12) could also have contributed to the subtle differences observed between the two studies. Despite the minor inconsistencies between the school and laboratory overall, the variation in AR observed in the school study was in agreement with the laboratory findings and as such supports the overall conclusion that increased target complexity can elicit a higher AR. On a practical note this supports the earlier suggestion in *Chapter 4* that target type should be considered when conducting a task which requires a stable accommodation response and consistency across sessions/examiners, e.g. in a clinical setting when measuring eye position.

5.4.1.2 Accommodative lag

Accommodative lag is common and typical lag is considered to be less than 1D in both adult and paediatric populations (Jackson & Goss, 1991; Poynter et al, 1982; Tassinari, 2002). In the previous laboratory study a small amount of lag (≤0.75D) was frequently observed and mean lag was somewhat less than what would be expected clinically. Slightly larger lags of accommodation were observed in the school study (Figure 5-7) compared to that of the laboratory (Figure 4-12) indicating increased variability in this school population. It was considered earlier in *Chapter 4* (*4.4.1*) that the small lag observed in the laboratory could have been a result of sub-conscious bias or prior instruction from parents to the participants to "work hard for the eye test". The potential influence of parental instruction or prior encouragement in the school study was limited by the school study design. Parents/guardians provided their written consent in advance of testing and were not present during the participants' assessment. Indeed, the parents/guardians did not know exactly which day their child would be participating in the accommodation assessment; instead they were aware of the period of time that the researcher was present in the school, during which their child would be assessed. It is possible subtle differences in prior instruction from parents/guardians could account for some of the difference in accommodative lag between the two studies. Lighting could also have contributed to the marginally increased lag seen in the school study. Depth of focus is the change in retinal image quality without perceived change in blur (Benjamin, 2006). This is known to be influenced by pupil size which in turn is influenced by light levels (Zinn, 1972). The light levels of the previous laboratory study were low (minimum overall target luminance 10cd/m^2). Such low light levels encourage pupil dilation and could theoretically demand increased accommodation due to reduced depth of focus. It was not possible to stringently control lighting conditions in the above school based study due to school design, which favours the facilitation of natural lighting (Tanner, 2009). While efforts were made to dim lighting during AR testing it was unfortunately impossible to completely eliminate natural light. A smaller pupil size, caused by increased light level, could have increased individuals' depth of focus therefore reducing the necessity for maximum accommodation resulting in slightly increased accommodative lag in the school study.

Seventeen percent of school study participants were found to have a lag of accommodation >1D. This is a level which would be assumed by clinicians to produce noticeable blur and possible asthenopic symptoms. Interestingly however, none of the participants with increased accommodative lag complained of blur during assessment nor were they observed to struggle more in completing the accommodation tasks than those who accommodated more accurately, e.g. by reading less fluently. Lag greater than 1D has been reported previously; Horwood and Riddell (2008; 2010; 2011) found that 40% of children they tested in the IVL underaccommodated by over 1D. In both the laboratory study (Figure 4-11) and the above school study (Figure 5-6) the total percentage of children who underaccommodated by such a degree was considerably lower. It is accepted that increased accommodative lag is observed in hypermetropic individuals (Horwood et al 2011, Lyon and Candy 2006; Mutti et al 2009). Therefore, one possible explanation for the reduced proportion of accommodative lag in the above study could be age of participants and the lack of uncorrected hypermetropic participants in the dataset. Those that were excluded from participation in this study due to reduced visual acuity were likely to be myopic rather than hypermetropic as they failed the distance visual acuity criterion. Therefore, it is unlikely that their exclusion could account for the reduced proportion of lag. Hypermetropia is more prevalent in younger children as it reduces with age during the emmetropisation process. It is therefore possible that increased accommodative lag would be observed in a younger age group than that assessed in this thesis.

5.4.2 Accommodation and standardised tests

Previous literature has identified a link between accommodation and reading (Evans, 1994; Kulp & Schmidt, 1996; Palomo-Alvarez & Puell, 2008, Shin et al, 2009). However, consistent with the laboratory findings reported in this thesis, no significant correlation was found between AR and the measures of reading rate, ability, or comprehension in this school study. It was hypothesised that the higher than average mean reading score may have influenced the results of the laboratory study – that there was insufficient variance/not enough poor readers to detect an association. The children tested in the school study were from a broader SES background than in the school study and the reading scores obtained were comparable to the standardised norm for the tests used (Table 5-4). Despite this there was no association detected with attention or reading rate, accuracy or comprehension, even after controlling for the effect of attention on reading ability.

It is interesting to note that a statistically significant positive correlation was found between single word reading and AR in this study. This association was detected in the Year 2 group only; as such, it suggested that an association between reading and accommodation is present only in early readers who rely most heavily on decoding. However, this finding must be interpreted with caution. Despite reaching statistical significance the observed correlation was tenuous and disappeared after controlling for prior reading exposure. This highlights the importance of the consideration of prior reading exposure when investigating the relationship between vision and reading. It also highlights the relevance of obtaining more than one reading measure. While an initial correlation was observed between AR and word reading, accommodation did not correlate with overall reading performance in this year group. If no measure of prior reading exposure had been taken, this finding in isolation would raise questions regarding the relevance of such a correlation as it did not appear to influence overall reading ability i.e. comprehension.

Consistent with the findings of the laboratory study, no significant correlation was found between the objective AR and the attention measures in this school based study. No significant correlation was found between AR and the teacher SDQ behaviour questionnaire (*Chapter 4*; *4.3.2.3.1*). No correlation was identified between the parent SDQ and AR in the laboratory study. The teacher SDQ was selected for this school study as it was hypothesised that the parent version lacked sufficient variance to detect change in scores. The teacher SDQ is considered more representative than the parent version on the subscale level (Stone et al, 2010). Despite this adaptation, no correlation was identified between the SDQ and AR. Previous research has identified an association with ADHD as measured with the Conner's Rating Scale and accommodation (Borsting et al, 2005). Similar to the SDQ, the Conner's Rating Scale is a questionnaire which can be completed by parents, teachers or individuals; the short form has four subscales – hyperactivity/cognitive problems, inattention, oppositional and an ADHD index. The SDQ rather than the Conner's Rating Scale was selected for this study due to ease of access and cost. The SDQ consists of five sub-scales relating to emotional problems, conduct/behaviour problems, pro-social behaviour, interaction with peers and inattention/hyperactivity. As discussed in *Chapter 4*, the SDQ is a widely accepted and validated measure of attention and useful in screening for ADHD, as such it is unlikely that the questionnaire lacked sensitivity to detect an attentional disorder. It appears that the differences in the findings between this study and those of Borsting et al could be more appropriately attributed to participant selection, definition of accommodative dysfunction and accommodation assessment method. The question regarding Borsting et al's definition of accommodative dysfunction has been discussed previously in (*Chapter 4; 4.4.2*) and will not be revisited here. The difference in accommodative assessment method could also have contributed to the contrasting results. This study utilised a binocular, objective method to assess accommodation; Borsting et al employed subjective methods, namely accommodative facility and amplitude of accommodation which are known to have numerous confounds e.g. depth of focus, instruction set etc., and are difficult for young children in particular to perform accurately and relies them reporting blur in a timely manner. Difference in participant sampling could also have influenced results. Borsting et al exclusively recruited children with symptomatic accommodative/convergence dysfunction. For inclusion in the above school study participants were required to exhibit visual acuity equivalent to a "pass" on a school screening test. All children underwent a standard orthoptic assessment and while it was not a requirement for participants to be asymptomatic no child reported any difficulties with their eyesight.

The purpose of this study and thesis overall was to identify how typical children accommodate and if typical accommodation relates to reading ability or attention. The above presented results involve a more heterogeneous participant group than that assessed under controlled conditions in the IVL and are support of the laboratory study findings in *Chapter 4* – it appears that accommodation is not related to reading ability or attention in typically developing children.

5.4.3 Limitations

This study sought to recruit only typical children, those without a diagnosis of dyslexia or attention disorders. While the reading ability of the children in this school study was more representative than that of the laboratory study, the spread of data reveals that few poor readers/borderline dyslexic students were recruited. This could be considered a limitation of this study. However, recent research has indicated that under-accommodation is not related to moderate or severe reading impairment (Creavin & Williams, 2015); therefore, it is unclear if the inclusion of dyslexic participants would alter the results. Future research could aim to purposely sample an even broader range of readers to improve the validity and variance of the data.

This thesis investigated if under-accommodation i.e. accommodative lag was related to reading ability. Unfortunately, in the laboratory study mean accommodative lag was low. It was hoped that recruiting from a wider sample that more children with lag >0.75 – 1D would be identified; however, this was not the case in this school study as mean lag remained <1D, and the number of children with lag >1D was too small for representative analysis. As such the degree of accommodative lag in this school study could be considered a limitation. It is difficult to identify how best to address this issue, especially considering the objective of this thesis was to investigate typical children. By relaxing the distance vision inclusion criteria in an effort to include more children with lag one risks instead recruiting those with uncorrected refractive errors; this would be a limitation in itself as it would be difficult to tease apart the influence of under-accommodation versus blur from hypermetropia for example. Replication with a younger population or sampling from a hospital population might address this and provides an avenue of future study. Furthermore, relaxation of the near visual criterion would be prudent in any future replication study to prevent the erroneous exclusion of a child with accommodative lag. Stringent near visual acuity was selected for this study to exclude refractive errors such as astigmatism and to ensure that participants could resolve the smallest accommodative targets and as such ensure adequate data for the exploration of the effect of font size on accommodative response as evidence pertaining to this was lacking in the existing literature base. While no participant recruited for participation in the studies in this thesis was excluded as a result of their near visual acuity in isolation (any excluded participant had failed the distance vision criterion which was assessed before near vision) it would not seem necessary to have as strict an inclusion criterion for any future study so to ensure the capture of maximum number of typical children with accommodative lag.

Accommodative data obtained may be influenced by calibration errors (Bharadwaj et al, 2013; Blade & Candy, 2006, Seidemann, & Schaeffel, 2003). As discussed above (*5.2.5.1*), individual calibration was not feasible in this study due to a combination of limitations with single handed assessment and the resulting very poor quality calibration data. Further effort to improve calibration data capture e.g. through adjusting light levels or the use of different specification IR filters are indicated to address this.

To address calibration concerns a group calibration factor was identified (*5.2.5.2*). The findings of the group calibration experiment revealed that the PowerRef3 used in this study underestimated refractive error for reasons which remain unclear. One can only speculate if this underestimation is a result of a change in Plusoptix inbuilt calibration factors or if the device purchased for use in this experiment had an unknown fault. Further discussion is warranted with the manufacturers to address this issue, which is beyond the scope of this thesis. A group calibration factor was calculated and applied to data collected by the PowerRef3, whilst this did address the issue of underestimation of refraction this is a limitation of this study as the data required further manipulation before processing.

Future study would also benefit from an updated macro or possibly a programmed approach to the selection of data points for analysis. The author acknowledges that the "eyeballing" approach employed in conjunction with the current macro and taken in this thesis is a limitation. It is a subjective measure and while there is high agreement between other lab users regarding data selection (see *Chapter 4; 4.2.8.3*) and replication would be possible with a trained user, it would be more difficult to replicate as an external observer. A programmed approach i.e. where data is removed at the same timepoint for each individual would be preferable and ensure consistency across datasets. As both accommodation studies described in this thesis were exploratory in nature it was not considered a priority to develop a program with such functions. Little evidence was available which would indicate likely sustained accommodation in children. In view of this and the limitations associated with loss of fixation in young children it was not possible to identify from the outset when such an ideal timepoint would be. It was considered more useful to examine the entire data trajectory, from the approach taken it was evident that children's accommodation response is stable across a sustained time period (save micro-fluctuations which are clinically insignificant) therefore future study could consider a programmed approach to data extraction to enhance the validity and replicability of the results presented in this thesis.

Chapter 6 - Summary

Clear near vision would seem vital for education. Clinically it is assumed that if insufficient accommodation occurs for the target demand near vision will be blurred. While it seems logical that under-accommodation would have a detrimental impact on a child's learning the current evidence within the ophthalmic literature to support this theory is limited and no study to date has proved that any such association is causal. Furthermore, the current available literature pertaining to the relationship between accommodation and ability is conflicting. While some studies report an association between these two factors, others dispute this. Therefore, as highlighted in *Chapter 2*, the true nature of the relationship between accommodation and education is still very unclear.

The purpose of this PhD thesis was to address the evident gap in the literature base and investigate typical children's accommodative behaviour using binocular objective methods and relate this to academic ability. This thesis was funded as the "first step" of what was thought would be a much larger study, i.e. the prelude to a randomised control trial (RCT) to investigate if the reported relationship between academic ability and accommodation is causal. Therefore, it was planned that this thesis would;

1. Establish sufficient pilot accommodation data for a future RCT
2. Establish and validate a test battery to assess accommodation and ability which would be suitable for use in a community setting with a large number of participants
3. Identify parental willingness to participate in an accommodation RCT

These aims have been achieved.

The literature review (*Chapter 2*) introduced the anatomy of accommodation, the cues to accommodation, the current methods used to evaluate and quantify accommodation and introduced accommodative lag. An introduction was given to current reading literature, with a particular focus on the development of reading and a brief discussion regarding dyslexia. The literature pertaining to the relationship between refractive errors, e.g. hypermetropia and myopia, and academic ability was introduced. Current research pertaining to accommodation and academic ability highlighted the variability in research findings and opinions regarding the relationship between accommodation and education and identified a gap in the literature. Methodological differences across studies suggested that the current discrepancies in the literature result from the varying methodologies employed in existing research. In addition, one cannot be sure if the methods that have been used to date to investigate accommodation and academic ability were the most suitable or if they record an accommodative response which is representative of a child's usual activities. Until recently studies investigating accommodation relied on subjective methods of assessing accommodation e.g. push-up/amplitude of accommodation and accommodative facility. As highlighted in *Chapter 2*, these techniques are reported to have a large intra-subject variability and are known to be influenced by instruction set. Subjective methods are also recognised as being particularly difficult for children to perform as they rely on a child understanding what is meant by blurred vision, appreciating it and reporting it in a timely manner. Therefore, objective methods are preferable. Dynamic retinoscopy was the most commonly reported objective accommodation assessment method in the literature pertaining accommodation and academic ability; however, this method also has associated limitations e.g. it is routinely performed uniocularly and is carried out in unnatural lighting conditions. MEM retinoscopy in particular could be considered less true to life as it requires lenses to measure accommodative response.

Photorefraction appears to be the preferred method with which to assess accommodative response. This technique has numerous advantages over subjective methods and dynamic retinoscopy. Photorefraction is an objective assessment method and it can be carried out in ambient lighting conditions, which are somewhat more representative of real life that the dark room required for dynamic retinoscopy. It is also a binocular technique and as such more representative of how children will accommodate under habitual circumstances. To date no previous study has prospectively investigated the relationship between accommodation and education using a binocular photorefractor. This thesis addresses this gap in the literature.

In the qualitative study (*Chapter 3*), semi-structured interviews revealed that parents had limited knowledge regarding eyesight terms and conditions and relied heavily on professionals and school vision screening for the detection of eye problems. Glasses wear was largely acceptable to the parents interviewed. This is reassuring for all eyecare professionals and is also a promising finding as an accommodation RCT would involve at least some children using glasses which they would not otherwise be prescribed. Therefore, it appears that glasses wear would not be a barrier to participation, in the participant sample interviewed. It was clear from the interviews that length of the trial would be a potential barrier to participation and this would require further exploration before undertaking any future work. Should an RCT have been indicated following the results of this thesis, this data would have been useful to provide to potential funders regarding viability and strategy to enhance recruitment.

The detailed laboratory study (*Chapter 4*), indicated that children will exert increased accommodation to more cognitively demanding targets such as print or visual search targets. This is an interesting finding which supports adult and preliminary paediatric research which indicates that higher level control and cognitive complexity can influence the accommodative response.

No association was identified between accommodation and reading during this study. Preliminary data analysis suggested an association between accommodation and sustained/divided attention. However, this result appeared to be driven by a few individuals in the relatively small sample and was not replicated in a larger dataset. This study was limited by a homogenous population of proficient readers. It was considered that there was insufficient variability in reading ability to detect a possible association with accommodation across a wider range of abilities. Therefore, further investigation was required in the larger, school based, accommodation study with individuals from broader socioeconomic (SES) backgrounds with more varied reading ability.

A wide variety of educational tests were carried out during the laboratory study to devise a test battery appropriate for the larger school based study. As no relationship between reading and accommodation was found a rich reading test was selected for use in the larger school based study. In view of the preliminary findings the attention test was retained as an element of this battery.

Chapter 5, the school study expanded on the detailed laboratory study. A portable accommodation laboratory was purpose built for this study. This was found to be practical method with which to assess of accommodation in a community setting. However, the Plusoptix PowerRef3 was found to systematically underestimate refractive error. This underestimation was corrected by a calibration factor derived during an adult group calibration experiment. It was not possible to conduct this calibration on the young participants due to practical limitations, e.g. single handed testing and resulting poor quality data obtained. Accommodative response was found to increase with increasing target complexity; thus, supporting the findings of the laboratory study. As such it can be concluded that under naturalistic circumstances children will accommodate only as much as necessary to resolve a target.

The school study sampled participants from a range of SES backgrounds. The reading ability observed in this school study was more heterogeneous than that in the previous laboratory study. However, still no association was observed between reading ability or attention and accommodation. It would appear from this result that accommodation measured under naturalistic conditions with a minimal instruction set is not related to academic ability in typical children, without large uncorrected refractive errors. This research has advantages over the current evidence base as the technique used to measure accommodation was objective and binocular.

Mean accommodative lag observed in the laboratory study was low. Somewhat increased accommodative lag was observed in the school study; however, only a few individuals exhibited lag >1D and mean accommodation remained within the expected range. While inspection of individual data did not suggest that those children with increased accommodative lag in the school study performed worse on the reading and attention tests used compared to their counterparts who accommodated more accurately further study in a purposefully selected sample of children with lag outside of the clinical norms may be warranted to confirm these findings. This would most likely require recruitment from a hospital eye clinic population rather than the school population sampled in this thesis.

The school study could be considered to be somewhat limited in that individual calibration was not performed. Furthermore, the author acknowledges that the group calibration factor applied to the data to address the underestimation of refractive error by the PowerRef3 was not ideal. More work is required to address why the Plusoptix PowerRef3 systematically underestimated refractive error. This is beyond the scope of this thesis and discussion with the manufacturer is warranted to establish the quality and accuracy of this particular device with other similar PowerRef3s before further work could be undertaken.

6.1 Conclusion

A degree of under-accommodation is expected clinically however typical accommodative lag is expected to be small (<0.75 – 1D) and not associated with blurred vision. From the results of this thesis it appears that under naturalistic conditions accommodative lag will vary as a function of target complexity and that under a minimal instruction set children will accommodate only as much as necessary to resolve a target. In addition, accommodative responses in typical children appear to vary and some children function with a lag >1D which is outside expected clinical norms and would be considered to cause blurred near vision.

It may seem logical and intuitively obvious that under-accommodation would be related to lower reading ability or attention. Previous research has suggested that such an association exists although these studies were limited by methodology, e.g. monocular and subjective testing (Kulp & Schmidt, 1996; Poynter, Schor, Hayes & Hirsch, 1982; Shin, Park & Park, 2009). The results of both the laboratory and school study in this thesis indicate that in fact, accommodation is not related to reading ability or attention in a typical population. An investigation of causality could only be justified if such an association could be found in everyday children. Therefore, while the qualitative study indicated that glasses wear is acceptable to parents and that parents would be willing to partake in an accommodation RCT, although replication would be required in a larger and more varied sample, such research would not appear necessary at present as an association between accommodation and education was not identified in a typical, unselected community population, assessed under naturalistic conditions.

Glossary

Accommodate: to carry out accommodation.

Accommodation: focusing of the eye to enable clear near vision. It the process whereby the lens within the eye becomes more convex allowing a near image to come into focus on the retina.

Accommodative response slope/accommodative slope: describes the relationship between the accommodative stimulus and the accommodative response. If accommodative response equals stimulus the accommodative slope would be 1.0. If no response to the stimulus were observed the accommodative slope would be 0.

Anisometropia: the situation where different refractive errors exist between the two eyes.

Astigmatism: a type of refractive error where the cornea is unevenly curved. The eye is more “rugby ball” shaped as opposed to “football”. This results in blurred vision as light entering the eye does not focus on a single point.
Astigmatism can be corrected with glasses (*cylindrical lens*). Accommodation cannot be used to manipulate/overcome astigmatism. Astigmatism may occur on its own or in conjunction with hypermetropia or myopia.

Ametropia (Ametropic): the state of having a refractive error, e.g. hypermetropia, myopia, astigmatism.

Autorefractor: automated device used to measure refractive error, typically records responses from one eye at a time.

Binocular Single Vision: the ability of the eyes to work together as a pair. This requires both eyes to fixate on the same target. The retinal images obtained by each eye are then fused through sensory and motor processes to produce a single image and ultimately stereopsis (3D vision).

Ciliary muscles: the muscles that control the lens. Contraction of these muscles facilitates change in the shape of the lens.

Converge: the process of convergence.

Convergence: inward rotation of both eyes to maintain binocular alignment when viewing a near object. Convergence is usually accompanied by pupil constriction and accommodation. These three processes together are known as the near triad.

Cornea: the epithelial layer/clear window at the front of the eye which covers the coloured iris and pupil.

Crystalline lens (lens): the lens within the eye – a translucent window through which images are seen. The shape of the lens accounts for refractive error within the eye and can refract up to 22D.

Cycloplegia: the inhibition of the ciliary muscle which prevents accommodation (near focussing).

Cycloplegic refraction: glasses test under cycloplegia. Considered the “gold standard” to test for glasses in young children.

Divergence: outward rotation of both eyes to maintain binocular alignment while viewing a distant object.

Emmetrope: a person with emmetropia.

Emmetropia/Emmetropic: the state of not having a refractive error i.e. clear vision without the need for glasses. Lights rays from a distant object are appropriately refracted by the eye and placed on the retina resulting in clear vision.

Emmetropise/Emmetropisation: the process of becoming emmetropic. At birth the newborn is rarely emmetropic. There is typically some measurable refractive error (i.e. glasses prescription), most usually a low degree of long-sight. This reduces over time and it is accepted that children will reach emmetropia between the ages of 6 – 8years.

Fovea: a small area of the retina which enables the clearest vision. The fovea is comprised solely of cone cells which facilitate colour detection and the most acute vision.

Heterophoria: a latent squint. The eyes may have an underlying tendency to diverge horizontally or vertically when one eye is covered. When both eyes are open they are pointing at the same target and work together as a pair to achieve 3D vision.

Hypermetrope: a person with hypermetropia.

Hypermetropia/hyperopia: a type of refractive error. Also known as long-sightedness. As a result of under-refraction or the axial length of the eye being too short, light rays fall behind the retina. Low levels of hypermetropia result in blurred near vision but distance vision remains clear. Moderate hypermetropia can result in blurred distance vision as well. Glasses (convex, *plus lens*) are used to correct hypermetropia. However, when only mild amounts of long-sight exist hypermetropes (in particular hypermetropic children) can manipulate their accommodation to achieve clear near vision without glasses.

IVL: Refers to the Infant Vision Laboratory at the University of Reading which incorporates the unique apparatus for measuring accommodation including the Plusoptix, mirrors, motorised beam and computer screen.

Lazy eye: medically referred to as amblyopia. Usually affects one eye. In the absence of pathology vision which has not developed properly, thus resulting in weak vision, is referred to as lazy eye/amblyopia. This is treated with eye patches or drops. Confusion exists among the general public therefore lazy eye is also used by some of the lay community to describe squint or droopy eyelid (ptosis).

Miosis: pupil constriction. Observed during accommodation and convergence.

Myope: a person with myopia.

Myopia: a type of refractive error. Also known as short-sightedness. Due to axial length of the eye being too long or over refraction by the eye light rays fall in front of the retina. This results in blurred distance vision but clear near vision. Corrective glasses (concave, *minus lens*) enable clear vision in myopes. Accommodation cannot be used to overcome myopia.

Near Point of Accommodation: the closest point at which an image is seen clearly. The near point is close to the nose in early childhood and steadily recedes with age until presbyopia.

Nott retinoscopy: a method of performing dynamic retinoscopy. This method requires the examiner to move position relative to the patient/participant in order to identify the point at which the participant is accommodating i.e. where a neutral reflex can be seen. A measure of accommodative lag/lead can be calculated by determining the location of the neutral reflex point in relation to the actual target position. Nott retinoscopy is considered to be a more naturalistic method of performing dynamic retinoscopy as it does not require lenses to measure accommodative lag.

Photorefractor: automated device which records refractive error. This differs from an autorefractor as photorefractors utilise the red reflex of the eye to determine refractive error and can be used to measure responses in both eyes simultaneously.

Presbyope: a person with presbyopia.

Presbyopia: age related point at which accommodation no longer occurs. With increasing age, the lens within the eye becomes more solid and inflexible meaning accommodation can no longer occur effectively. This process begins at age 30 and steadily increases through middle age, at which time insufficient accommodation occurs to focus near objects and reading glasses are required for clear near vision.

Prism Fusion Range: a clinical test used by orthoptists to measure an individual's range of motor fusion i.e. how well one can maintain binocular single vision under increasing vergence demands.

Refraction/Refract: (as a procedure) the assessment of refractive error i.e. a glasses test.

Refraction/Refract: (in relation to light) the bending of light by the eye in order to bring it into appropriate focus.

Refractive error: the state whereby light rays are inadequately or inappropriately refracted by the eye. As a result, light rays do not reach the correct location on the retina and resulting in blurred vision. Glasses are required for appropriate refraction and clear vision.

Retina: the photosensitive nerve fibre layer, consisting of rod and cone cells, at the back of the eye through. Light entering the eye is received and processed by the retina and then transmitted information via the optic nerve to the brain.

RHP: Refers to the Remote Haploscopic Photorefractor.

Squint: medically referred to as strabismus. This is misalignment of the eyes whereby the eyes will point in different directions. One eye may be straight while the other will be misaligned horizontally or vertically.

Vergence: the movement of the eyes in opposite directions while maintaining fusion/single vision.

Visual Acuity: clarity of vision – the spatial resolving capacity of the visual system.

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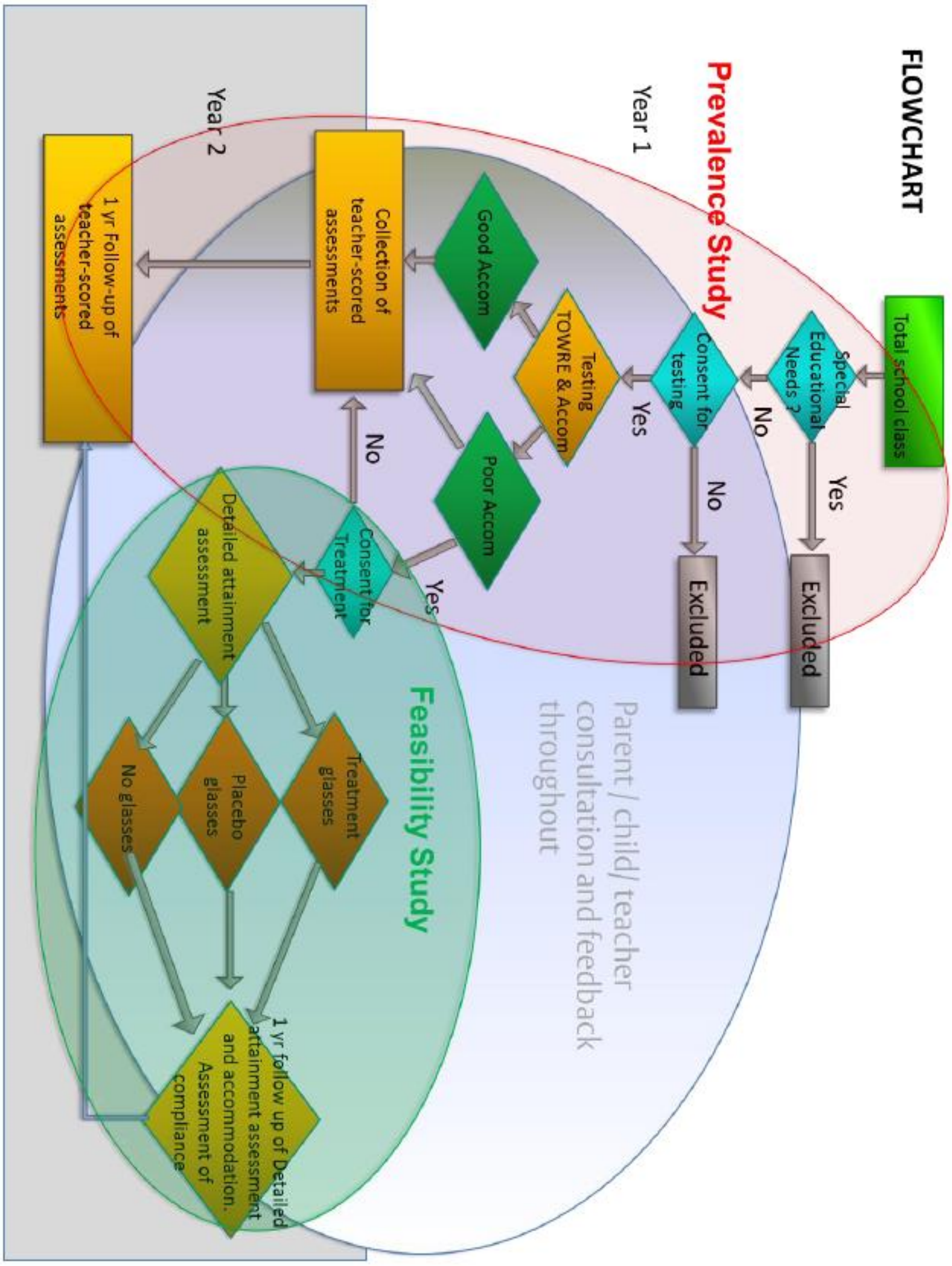
Appendices

APPENDIX 1



Flowchart illustrating potential accommodation trial.

Accommodation would be assessed in a school environment. Those children identified as having poor accommodation would be randomised into treatment glasses or placebo glasses. Academic ability would be monitored after one year.

APPENDIX 2a

University of Reading

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Focusing during close work in primary school children.

Principal Investigator Dr Anna Horwood PhD DBO(T) Fight for Sight grant GS14-40 entitled "Ocular accommodation and convergence during close work in primary school children".

Information for Participants

Your child is being invited to take part in a research study taking place at the University of Reading into how eyes focus on near objects. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Talk to others about the study if you wish.

- *Part 1 tells you the purpose of the study.*
- *Part 2 tells you what will happen to you in this study if you take part.*
- *Part 3 gives you more detailed information about the conduct of the study.*

Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Contact Details

If you have any queries please contact **Dr Anna Horwood, School of Psychology, University of Reading, Earley Gate, Reading, RG6 6AL Phone 0118 3785553 e-mail a.m.horwood@reading.ac.uk**
Alternatively, contact Siobhán Ludden, e-mail s.m.ludden@pgr.reading.ac.uk.

Part 1

Why do we need to do the research?

- As eyesight develops, your eyes learn to **focus** to make near objects clear (accommodation) and also turn inwards to look at them (convergence). They get information that this is necessary from the changing of the images of visual targets as they come closer.
- Work that we have already done in Reading has given us new insights into focusing in everyday situations, both in normal development and people with vision problems. We have found that people across a range of age groups tend to under-focus during close-work, which could result in some blurred vision at near. We are not sure if this happens during sustained close-work, how important it is, or if it is associated with either general ability or attention. We are particularly interested in how it may affect children as they learn to read.
- The eye charity Fight for Sight is funding this study to be carried out until September 2017. We will look at focusing in young children during close-work in much more detail than ever before. The research will be supervised by Dr Horwood and carried out by Siobhán Ludden, a PhD student at the University of Reading, who will be using the collected data for her studies

Do you have to take part?

No. It is up to you to decide whether or not to take part. If you would like to take part, you will be given this information sheet to keep and be asked to sign a consent form on behalf of your child. We will also try to explain what would be involved to children in a way they should understand. You are free to withdraw at any time and without giving a reason.

Part 2

What will happen in the lab if I do want to help with the research?

- We test all participants, whatever their age, in the same way.
- Visits to the laboratory at the School of Psychology may take up to two hours. We won't be testing for the full two hours; we will give your child breaks in between testing whenever they want. We would be happy to pay your travelling expenses if you are not a University staff member or student.
- We will start off by taking a history of your child's vision development, family history and any previous eye treatment such as glasses.
- We will then use a special piece of equipment called a Remote Haploscopic Videorefractor, which takes continuous photographs of their eyes as they look at different targets & pictures as they approach. From these photographs we can measure how much focusing is happening.
- The Remote Haploscopic Videorefractor is a large piece of equipment in a dimly lit room. It was designed for, and we have successfully used it with, tiny babies, so we know it is easy for participants. Testing does not involve any eyedrops, electrodes or head restraint. Images are collected using infra-red sensors that are invisible and harmless. It is not at all uncomfortable or unpleasant, but if your child is often scared of the dark please contact us so we can explain in more detail before you decide whether to attend.
- All your child will have to do it look at the pictures. If your child already wears glasses they can keep these on for the test.
- We will also do some general clinical tests of vision, similar to those used for children in the Eye Clinic at the hospital. This is so we can compare our lab results with established tests.
- We will then carry out some simple tests of your child's general development, reading level and attention.
- All tests are designed to be fun for young children
- So that we can improve our future research designs and make information more accessible for parents and the public, we may ask some parents/guardians to return to the lab for a short interview about what they know and feel about children's eyesight in general. These interviews are expected to last approximately 20 minutes. If you would be happy to re-attend for an interview we ask that you indicate this separately on the consent form.

Are there any risks?

The laboratory and clinical assessment methods carried out in the Infant Vision Laboratory are easy and generally enjoyable for the participants and do not involve any significant health risks.

Are there any benefits?

Previous experience in our lab has shown us that parents and children find the visits informative and interesting. You may find out things about eyesight that you did not know before. We hope that by doing this study we will learn more about focusing during close-work and determine if under-focusing is typical behaviour or if it is something that should be treated.

What if there is a problem?

Any complaint about the way you have been treated during the study or any possible harm you might suffer will be addressed. The detailed information on this is given in Part 3. Testers are all professionally qualified to detect eye problems and if we detect anything wrong with your or your child's eyes we will tell you and can advise you how to get prompt treatment.

Will my taking part in the study be kept confidential?

Yes. All the information about your participation in this study will be kept confidential. Further details are given in Part 3.

Part 3

What if new information becomes available?

If our results suggest our tests could aggravate any existing problem we would stop the testing immediately and refer you to the hospital for further investigation. Both investigators are State Registered Orthoptists so can make referrals directly. If this is the case, we will then also ask your permission to write to your GP.

What will happen if we don't want to take part any more?

You are free to withdraw at any time without giving a reason why.

What if I have a problem with the study ?

If you have a concern about any aspect of this study, you should ask to speak with the researchers who will do their best to answer your questions (Dr Anna Horwood on 0118 3785553). If you remain unhappy and wish to complain formally, you can do this through Head of School of Psychology & Clinical Language Sciences, Professor Laurie Butler. If your complaint is not dealt with to your satisfaction you can contact the Chair of the University Research Ethics Committee. Details can be obtained from the School of Psychology and Clinical Language Sciences.

In the event that something unforeseen does go wrong and you are harmed during the research study there are no special compensation arrangements. If you are harmed and this is due to someone's negligence then you may have grounds for a legal action for compensation against the University but you may have to pay your legal costs.

Confidentiality

All information that is collected about you or your child during the course of the research will be kept strictly confidential and laboratory records will be given a unique reference number for analysis. Paper records will be stored securely in a locked room or cabinet and computer records will be password protected. Personal details will be kept separate from research data once the data collection phase has finished and will be destroyed at the end of the study. If you join the study, some parts of the data collected for the study may be looked at by authorised and statutory bodies from the University, to check that the study is being carried out correctly. All will have a duty of confidentiality to you as a research participant and nothing that could reveal your identity will be disclosed or taken outside the research site. Consent forms will be kept for 5 years in line with University guidelines.

Participants and parents have the right to check the accuracy of data held about them and correct any errors. All investigators working on this project have had criminal records checks and have been approved by the school to work with children.

What will happen to the research results?

We will give you feedback about any test results we have available each visit. At the end of the study, once we have analysed the data on all the participants, we will send you a newsletter or email you with a link to our website (*http://www.personal.reading.ac.uk/~sxs96amh/)* to explain the findings. We will aim to publish the findings in international vision science journals and meetings. No identifiable names or photographs will be used without your express permission.

Who is organising the research?

Dr Horwood PhD, DBO(T) is the Principal Investigator, working at the Infant Vision Lab set up by Professor Patricia Riddell in the School of Psychology and Clinical Language Sciences. Siobhán Ludden, BMedSci(Hons) is a PhD student and will be using the collected data in her thesis. There is no commercial involvement.

Both Dr Horwood (OR01039) and Siobhán Ludden (OR05900) are state registered orthoptists and hold current Health and Care Professions Council Registration. All staff working on the project have undergone Disclosure and Barring checks.

Who has reviewed the study?

This application has been reviewed by the University Research Ethics Committee and has been given a favourable ethical opinion for conduct.

Thank you very much for reading this sheet and considering taking part in the study.

Dr Anna Horwood PhD DBO(T):

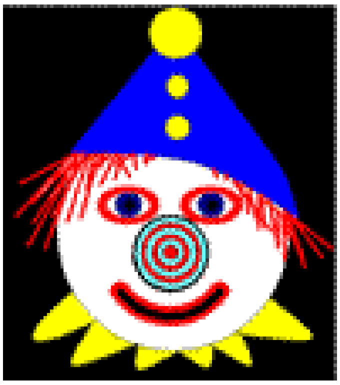
Miss Siobhán Ludden BMedSci(Hons)

APPENDIX 2b

University of Reading

INFORMATION FOR CHILDREN

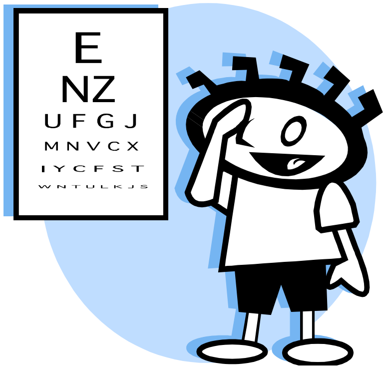
OCULAR ACCOMMODATION AND CONVERGENCE DURING CLOSEWORK IN PRIMARY SCHOOL CHILDREN.



We would like you to take part in this study because we want to find out how your eyes work when you are looking at things up close.

What will happen?

First we will check how well your eyes can see letters and if they work together. Then we will use our special equipment to see how your eyes work when you are reading and watching pictures. It will be very easy, all you have to do is look into our big black box while we show you some pictures like our clown here moving around.



After we have checked your eyes we will do some other tests and puzzles like reading words out loud. Easy!

If you want to stop and go home at any time, just say so – that would be fine too

Why should I do it?

If you take part you will help us learn about how children's eyes work while doing different things up close, something we don't know much about yet!

APPENDIX 3

University of Reading

Infant Vision Laboratory
School of Psychology & Clinical
Language Sciences
Earley Gate, RG6 6AL
Postcode for SatNav RG6 7BE

phone +44 (0)118 3785553
fax +44 (0)118 8523
email a.m.horwood@reading.ac.uk

Study Number: GS14-40

Patient Identification

Number for this trial: ………………..

CONSENT FORM

Title of Project: ***Ocular accommodation and convergence during close work in primary school children***

Name of Supervisor: Dr Anna Horwood

Investigators: Siobhán Ludden

Name of Participant: ______________________________

DOB of Participant:_________________________________

Please initial box

- I confirm that I have read and understand the information sheet dated 30/10/14 (version 1) for the above study. I have had the opportunity

to consider the information and discuss it with ______________________

and have had any questions answered satisfactorily.

- The nature of the tests have been explained to me and I understand what will be required for my child to take part in the above study.

- I understand that my, or my child's, participation is voluntary and that I am/we are free to withdraw at any time and do not have to explain the reason for my decision.

.

- I understand that the project has been subject to ethical review, according to the procedures specified by University of Reading Research Ethics Committees, and has been allowed to proceed

- I understand that all personal information will remain confidential to the investigators and arrangements for the storage and eventual disposal of any identifiable material have been made clear to me. ☐

- **I agree for my child to take part in the above study.** ☐

- I am willing to attend a future interview regarding my understanding about children's eyesight and eyesight research. I understand that this interview will be audio recorded and that the information I give in the interview will only be used for the purposes of the above study. ☐

Name of Parent /Guardian:

____

Signature of Parent/Guardian: Date:

__________________________________ ____________________

Child Assent if appropriate:

Name of child:

____

Signature of child: Date:

____________________________________ ___________

I confirm that I have explained the above mentioned study, as detailed in the corresponding Information Sheet dated 30/10/14, such that, in my judgment, it is understood by the participant.

Name of Researcher:

____

Signature of Researcher: Date:

_______________________________ _____________

When completed, 1 for participant; 1 for researcher site file

APPENDIX 4

Topic guide – Ocular accommodation and convergence in children

Thank you for attending.

I'm going to be asking you a few questions to learn more about what you understand about children's eyesight.

Are you still happy to proceed with the interview?

Have you or any of your family ever needed glasses?

Before you had agreed to participate in this study how much did you think about your child's eyesight?

How important do you think children's eyesight is?

Do you know much about the different types of eyesight problems in childhood.

1. What do you understand by long-sight/short-sight/astigmatism?
2. What do you understand by squint?
3. What do you understand by lazy eye?

If parent doesn't volunteer misalignment of eye with either of these prompts eg "squint = screwing eyes up" and "lazy eye = vision problem" will then ask **"What about eyes that point in different directions, what do you refer to this as? Is that different to a lazy eye?"**

4. Are you aware that there are different types of squint/eye turns?
    a. Are you aware that an eye may turn inwards or outwards?
    b. Which do you think is more common in children?
5. What do you know about treatment of squint/lazy eye?

How would you expect to know if your child had a problem with their eyesight?

1. Would you expect it to be picked up at school or by health professionals?
    a. If so, who??
2. What types of tests do you think GP/opticians/school nurses use to test children's eyesight?
3. Would you expect your child to mention if there was a problem with their eyesight?
    a. What would you expect them to say?
4. Would you expect a difference between what a child can see at near and far distance?
    a. Are you aware of a need to do extra focusing at near?
    b. Had you ever thought about this?
    c. If yes, expand, what did you think/is it something you were concerned about…

Would you be concerned if your child needed glasses?

1. If yes, why?

2. Would you worry about them being teased in school?
3. If an optician/health professional told that your child needed glasses for schoolwork/reading but they didn't like wearing them would you be willing to persevere with the glasses?
    a. What about if they seemed to have good vision at home would you still persevere with them?

What effect do you think a problem with eyesight might have on a child?
1. Do you think it might affect their behaviour or concentration?
2. Would this be a problem?

We think it's possible that reading glasses might help under-focusing in some children in school, and we're thinking about conducting some research to find out.

Would you be willing to participate in research of that kind?
1. If not, why not?

To find out if reading glasses helped children, we would need to give them to only some of the children who need them, so that we can make comparisons. So, one of the ways we might do that would be to conduct a Randomised Control Trial (RCT).
1. Have you ever heard of an RCT?

Do you think parents would be willing for their child to participate in an RCT, given that the child might not get genuine glasses when you would now know your child is under-focusing (for the duration of the study)?

Would you be willing?
1. If not, what would put you/parents off?

An alternative would be a crossover trial.

Do you know what a crossover trial is? (If crossover trial not understood then explain to interviewee – i.e. Crossover trial is where groups will have two treatments, in this case one could be reading glasses and the other plain lens glasses. Both groups will receive both treatments but in different orders.)

Do you think parents would be willing for their child to participate into a crossover trial?
Given that this would mean the child would wear glasses for double the time?

Would you be willing?
If not, what would put you/parents off?

Which do you think would be better from a parent's perspective?

Thank you for your help. End.

APPENDIX 5

Themes: sub-themes

1) Concern about eyesight: the importance of eyesight; lack of knowledge; need for reassurance.

2) Establishing the presence of a vision problem: child report; parents’ role in monitoring eyesight; teacher identification; reliance on professionals.

3) Response to vision problems: wearing glasses; patching; following professional advice.

Theme 1 - Concern about eyesight

Codes:

1. Professional reassurance if differing reports
2. Importance of eyesight
3. Lacking awareness/confidence in eyesight terms
4. Knowledge dependant on experience
5. Uncertainty regarding eyesight terms
6. Parents recognise eyesight problems
7. School screening detects eyesight problem
8. Prior consideration of eyesight
9. Eyesight problem might be masked
10. Eyesight important for education
11. Poor eyesight and sports difficulty
12. Near vision better than distance in children
13. Problems arising with poor eyesight
14. Social aspect to eyesight
15. Eyesight important for education

Specific knowledge examples found in ocular definitions codes:

1. Shortsight
2. Squint
3. Lazy eye
4. Longsight
5. Aware of accommodation

These codes also highlight lack of knowledge/uncertainty and therefore may be double coded in places.

Sub theme 1: Importance of eyesight

1. Importance of eyesight
2. Eyesight important for education
3. Poor eyesight and sports difficulty
4. Problems arising with poor eyesight
5. Social aspect to eyesight
6. Eyesight important for education

Sub theme 3: Need for reassurance/reliance on screening

7. Professional reassurance if differing reports
8. School screening detects eyesight problem
9. Eyesight problem might be masked
10. Lacking awareness/confidence in eyesight terms
11. Knowledge dependant on experience
12. Uncertainty regarding eyesight terms

Sub theme 4: Lack of knowledge

16. Lacking awareness/confidence in eyesight terms
17. Knowledge dependant on experience
18. Uncertainty regarding eyesight terms
19. Prior consideration of eyesight
20. Near vision better than distance in children

6. Shortsight
7. Squint
8. Lazy eye
9. Longsight
10. Aware of accommodation

<u>Theme 2 - Establishing presence of vision problem</u>

Codes:

21. Child mentions eye problem
22. Children too young to mention eyesight problems
23. Headaches = poor eyesight
24. Poor eyesight linked to behaviour problems
25. Eyesight problem might be masked
26. Teachers recognise eyesight problems
27. Poor eyesight and sports difficulty
28. Poor distance vision
29. Childrens vision tests age dependant
30. Parents recognise eyesight problems
31. School screening detects eyesight problem
32. General visual difficulty indicates eyesight issue
33. Optician more detailed that GP exam
34. Esotropia more common squint
35. Squints less common in this generation

<u>Sub theme 1: Child report/behaviour</u>

1. Child mentions eye problem
2. Children too young to mention eyesight problems
3. Headaches = poor eyesight
4. Poor eyesight linked to behaviour problems
5. General visual difficulty indicates eyesight issue
6. Poor eyesight and sports difficulty

<u>Sub theme 2: Teacher identification</u>

1. Poor distance vision
2. Teachers recognise eyesight problems

<u>Sub theme 3: Parent observation</u>

1. Headaches = poor eyesight
2. Poor distance vision
3. Parents recognise eyesight problems
4. General visual difficulty indicates eyesight issue

<u>Sub theme 2: Parents role in monitoring eyesight</u>

1. Parents recognise eyesight problems

Also some overlap with codes that children too young to report eyesight problems although these primarily fit in establishing vision problem theme.

<u>Sub theme 4: reliance on professionals</u>

1. School screening detects eyesight problem
2. Eyesight problem might be masked
3. Optician more detailed that GP exam
4. Childrens vision tests age dependant

Misc - squint

1. Squints less common in this generation
2. Esotropia more common squint

Theme 3 - Response to vision problem

Codes:

36. Concern about teasing glasses
37. Teasing depends on child
38. Glasses not an issue
39. Glasses more acceptable than patch
40. Child sensitivity influences teasing concern
41. Willing to enforce glasses
42. Follow professional advice
43. Following advice re glasses depends on level of vision
44. Glasses cause difficulty in sports
45. Glasses suggest physical difficulty
46. Glasses impact confidence
47. Children's vision tests age dependant
48. Treat eyesight when young
49. Experience with glasses influences acceptability
50. Vision changes with age
51. Patching for lazy eye

Sub theme 1: Wearing glasses

1. Concern about teasing glasses
2. Teasing depends on child
3. Glasses not an issue
4. Child sensitivity influences teasing concern
5. Glasses cause difficulty in sports
6. Glasses suggest physical difficulty
7. Glasses impact confidence
8. Experience with glasses influences acceptability
9. Worried about glasses

Sub theme 2: Patching

1. Glasses more acceptable than patch
2. Treat eyesight when young
3. Patching for lazy eye
4. Vision changes with age

Sub theme 3: Follow professional advice

1. Willing to enforce glasses
2. Following advice re glasses depends on level of vision
3. Follow professional advice
4. Childrens' vision tests age dependant

University of Reading

APPENDIX 6a

Participant No: ____________________

Author Recognition Task

Please read through the list of names below and put a mark beside those that you know to be real authors of books. Some of the names below are the names of real authors and some are fake. You get a point for each real authors you spot, but you lose a point for each of the fake ones you select, so only mark the ones you are reasonably confident are real authors of books you know. It's important that you don't look up the names or ask anyone, as we just want to know which authors you know from your own reading experience.

Author	√
DA Allport	
Laurence Anholt	
Paul Azzopardi	
Eoin Colfer	
John Boyne	
PE Bryant	
Lewis Carroll	
G Claridge	
A Cowey	
Roald Dahl	
Lucy Daniels	

Author	√
Jane Mellanby	
S Millar	
Michael Morpurgo	
Kate Nation	
Kia Nobre	
K Parkes	
Dick Passingham	
Michelle Paver	
Kim Plunkett	
David Popplewell	
Philip Pullman	

Cressida Cowell	
Ann Dowker	
Anne Fine	
Martha Finley	
D Gaffan	
Debi Gliori	
Kenneth Grahame	
GB Henning	
Eric Hill	
Anthony Horowitz	
Clive King	
Mansur Lalljee	
C.S. Lewis	
J.M. Barrie	

Mark Haddon	
Nick Rawlins	
Brian Rogers	
Edmund Rolls	
Tony Ross	
Rick Riordan	
M Rushworth	
Charles Spence	
M Treisman	
V Walsh	
Larry Weiskrantz	
Lois Lowry	
Jacqueline Wilson	
Gary Paulsen	

T= __________/25

F= __________/25

Total: ________/25

DA Allport	**Foil**
Laurence Anholt	**Target**
Paul Azzopardi	**Foil**
Eoin Colfer	**Target**
John Boyne	**Target**
PE Bryant	**Foil**
Lewis Carroll	**Target**
G Claridge	**Foil**
A Cowey	**Foil**
Roald Dahl	**Target**
Lucy Daniels	**Target**
Cressida Cowell	**Target**
Ann Dowker	**Foil**
Anne Fine	**Target**
Martha Finley	**Target**
D Gaffan	**Foil**
Debi Gliori	**Target**
Kenneth Grahame	**Target**
GB Henning	**Foil**
Eric Hill	**Target**
Anthony Horowitz	**Target**
Clive King	**Target**
Mansur Lalljee	**Foil**
C.S. Lewis	**Target**
James Matthew Barrie	**Target**

Jane Mellanby	**Foil**
S Millar	**Foil**
Michael Morpurgo	**Target**
Kate Nation	**Foil**
Kia Nobre	**Foil**
K Parkes	**Foil**
Dick Passingham	**Foil**
Michelle Paver	**Target**
Kim Plunkett	**Foil**
David Popplewell	**Foil**
Philip Pullman	**Target**
Mark Haddon	**Target**
Nick Rawlins	**Foil**
Brian Rogers	**Foil**
Edmund Rolls	**Foil**
Tony Ross	**Target**
Rick Riordan	**Target**
M Rushworth	**Foil**
Charles Spence	**Foil**
M Treisman	**Foil**
V Walsh	**Foil**
Larry Weiskrantz	**Foil**
Lois Lowry	**Target**
Jacqueline Wilson	**Target**
Gary Paulsen	**Target**

University of Reading

APPENDIX 6b

Participant No: ______________________

Title Recognition Task

Read the list of names of books and put a mark next to the ones that you know are real titles of books. Some of the names below are real book titles and some are fake. You get a point for each real title you spot, but you lose a point for each of the fake ones you select, so only mark the ones you are sure are the names of books you know.

Title	√	**Title**	√
My Sister's Snail		Stanley and the Duck	
Mog the Forgetful Cat		The Kitten with the Dream	
Ring Ring Who's There?		Dear Zoo	
We're Going on a Bear Hunt		The Bear Under the Stairs	
Owl Babies		The Gruffalo	
Under the Deep Blue Sea		Rosie's Farmhouse	
The Very Hungry Caterpillar		The Dolphin Who Didn't Like Water	

Maggie and the Wolf		The Tiger Who Came to Tea	
The Little Pink Dress		The Adventure Gone Wild	
Monkey Puzzle		Charlie in the Jungle	
The Big Light in the Sky		Each Peach Pear Plum	
Burglar Bill		The Bad-Tempered Ladybird	
John and Edward's Hair Adventure		My Naughty Little Sister	
Not Now Bernard		Dogger	
Bag It!		Grandma's Bedroom	

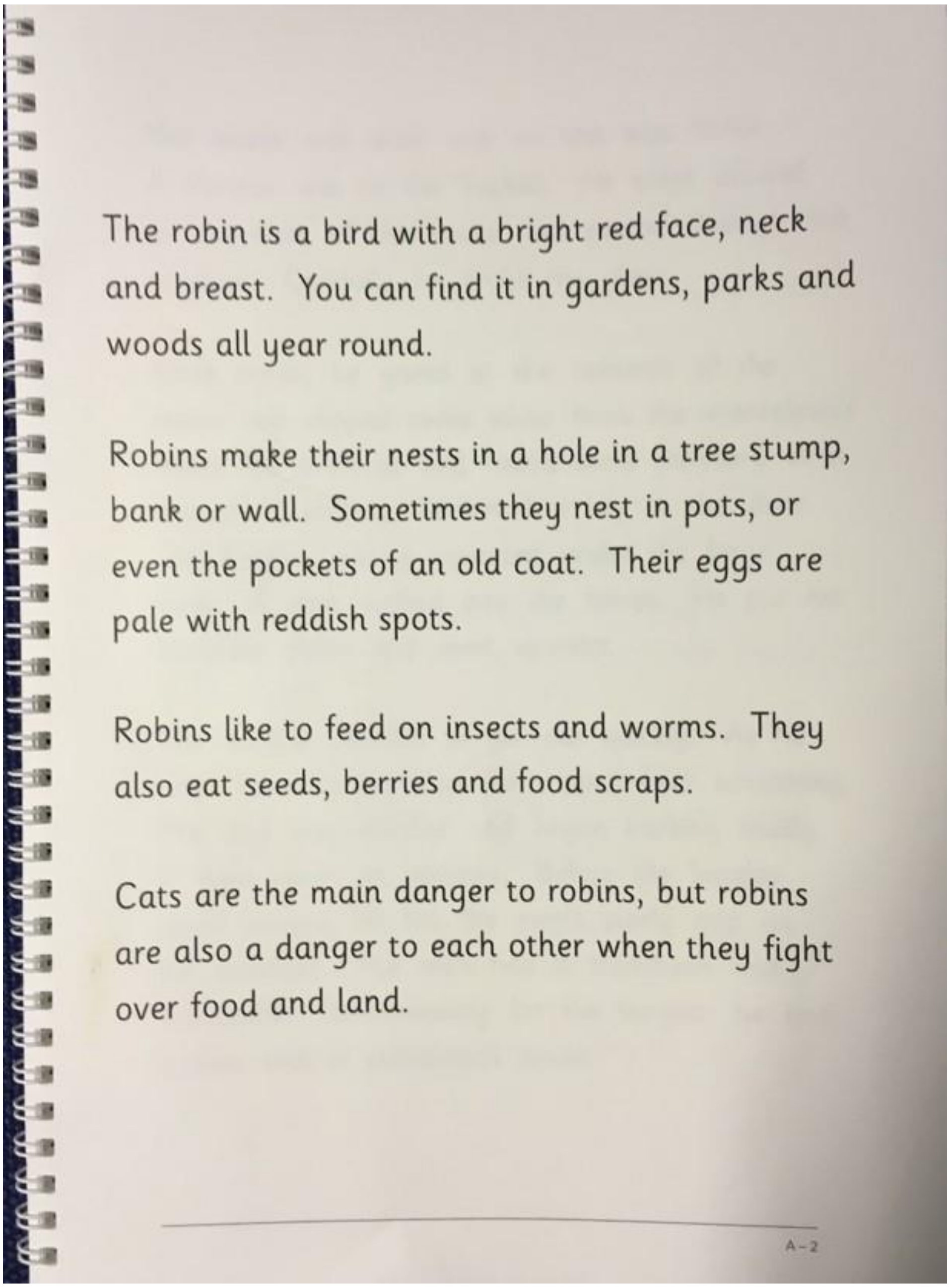
T= __________/15

F= __________/15

Total (T-F): ________/15

My Sister's Snail	**F**	Stanley and the Duck	**F**
Mog the Forgetful Cat	**T**	The Kitten with the Dream	**F**
Ring Ring Who's There?	**F**	Dear Zoo	**T**
We're Going on a Bear Hunt	**T**	The Bear Under the Stairs	**T**
Owl Babies	**T**	The Gruffalo	**T**
Under the Deep Blue Sea	**F**	Rosie's Farmhouse	**F**
The Very Hungry Caterpillar	**T**	The Dolphin Who Didn't Like Water	**F**
Maggie and the Wolf	**F**	The Tiger Who Came to Tea	**T**
The Little Pink Dress	**F**	The Adventure Gone Wild	**F**
Monkey Puzzle	**T**	Charlie in the Jungle	**F**
The Big Light in the Sky	**F**	Each Peach Pear Plum	**T**
Burglar Bill	**T**	The Bad-Tempered Ladybird	**T**
John and Edward's Hair Adventure	**F**	My Naughty Little Sister	**T**
Not Now Bernard	**T**	Dogger	**T**
Bag It!	**F**	Grandma's Bedroom	**F**

APPENDIX 7a



The robin is a bird with a bright red face, neck and breast. You can find it in gardens, parks and woods all year round.

Robins make their nests in a hole in a tree stump, bank or wall. Sometimes they nest in pots, or even the pockets of an old coat. Their eggs are pale with reddish spots.

Robins like to feed on insects and worms. They also eat seeds, berries and food scraps.

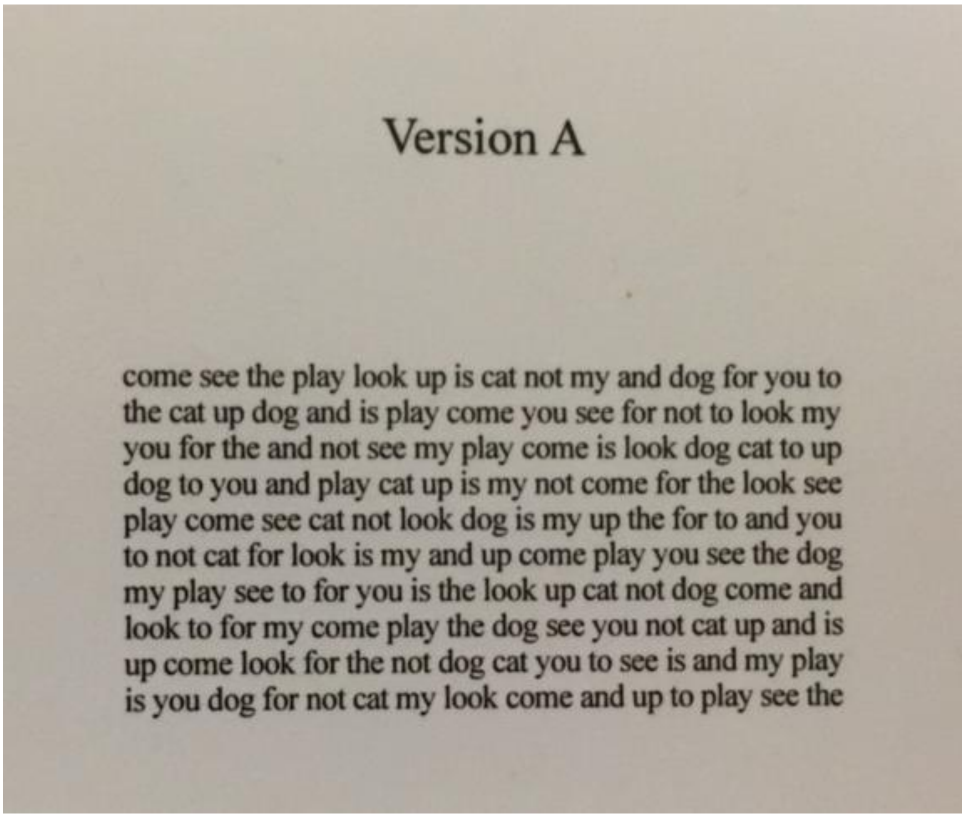
Cats are the main danger to robins, but robins are also a danger to each other when they fight over food and land.

A–2

Excerpt from YARC Form A level 2.

Children were asked to read the passage aloud while the examiner noted any errors, e.g. reversals/omissions/mispronunciations. Children were timed but instructed to read carefully. Children completed two passages each to obtain an average score.

APPENDIX 7b



Version A

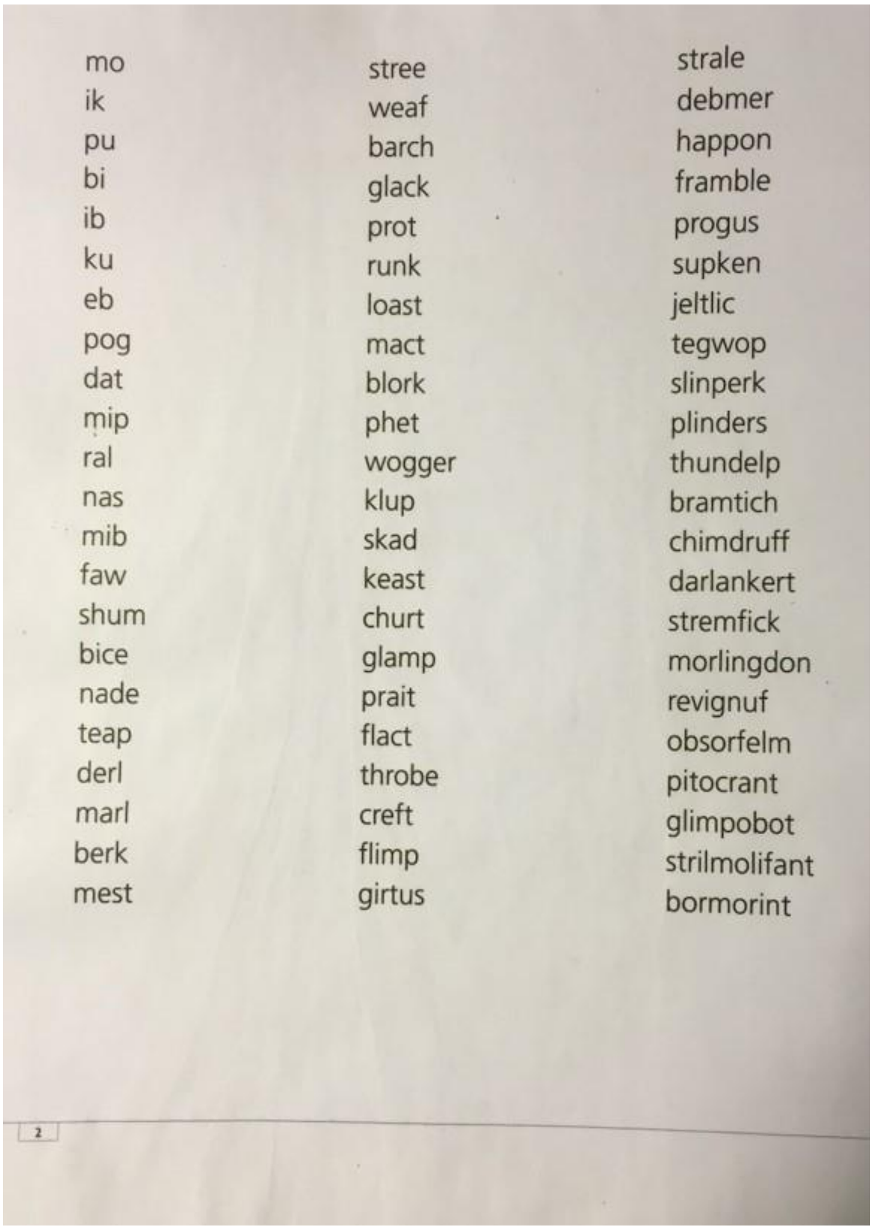
come see the play look up is cat not my and dog for you to
the cat up dog and is play come you see for not to look my
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
to not cat for look is my and up come play you see the dog
my play see to for you is the look up cat not dog come and
look to for my come play the dog see you not cat up and is
up come look for the not dog cat you to see is and my play
is you dog for not cat my look come and up to play see the

Wilkins Rate of Reading Test (Example: Version A)

This is a rate of reading test which is familiar to eyecare professionals. It is frequently used in the assessment of coloured overlays for visual stress. It consists of four nonsense passages of simple real words. No words other than those seen in the above example are used in any passage of the Wilkins Rate of Reading Test.

Children were asked to read as many words from the passage as they could in one minute. The examiner noted errors and ommisons. Children were aware that they were being timed. Children then repeated the test using a different passage version. The number of words read correctly per minute for each passage was calculated and the result was averaged to give a rate of reading.

APPENDIX 7c



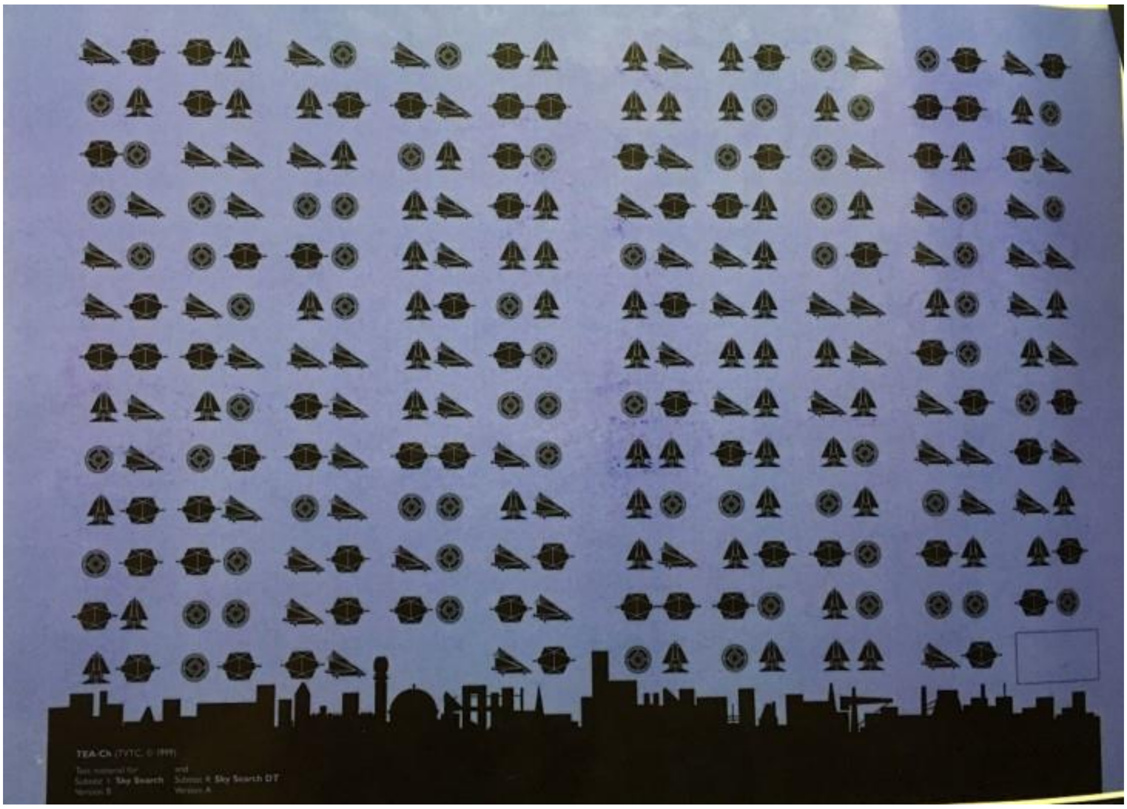
mo	stree	strale
ik	weaf	debmer
pu	barch	happon
bi	glack	framble
ib	prot	progus
ku	runk	supken
eb	loast	jeltlic
pog	mact	tegwop
dat	blork	slinperk
mip	phet	plinders
ral	wogger	thundelp
nas	klup	bramtich
mib	skad	chimdruff
faw	keast	darlankert
shum	churt	stremfick
bice	glamp	morlingdon
nade	prait	revignuf
teap	flact	obsorfelm
derl	throbe	pitocrant
marl	creft	glimpobot
berk	flimp	strilmolifant
mest	girtus	bormorint

2

TOWRE-II (Example Given: Non word reading test)

Children were instructed to read down each column and read as many words as possible from this list in 45seconds. The examiner noted how many words were read correctly in this time. This was repeated with TOWRE sight word reading card. TOWRE Sight Word Reading consists of the same number of words as the above example and employs the exact same procedure however instead of non-words real words of increasing complexity are given.

APPENDIX 7d

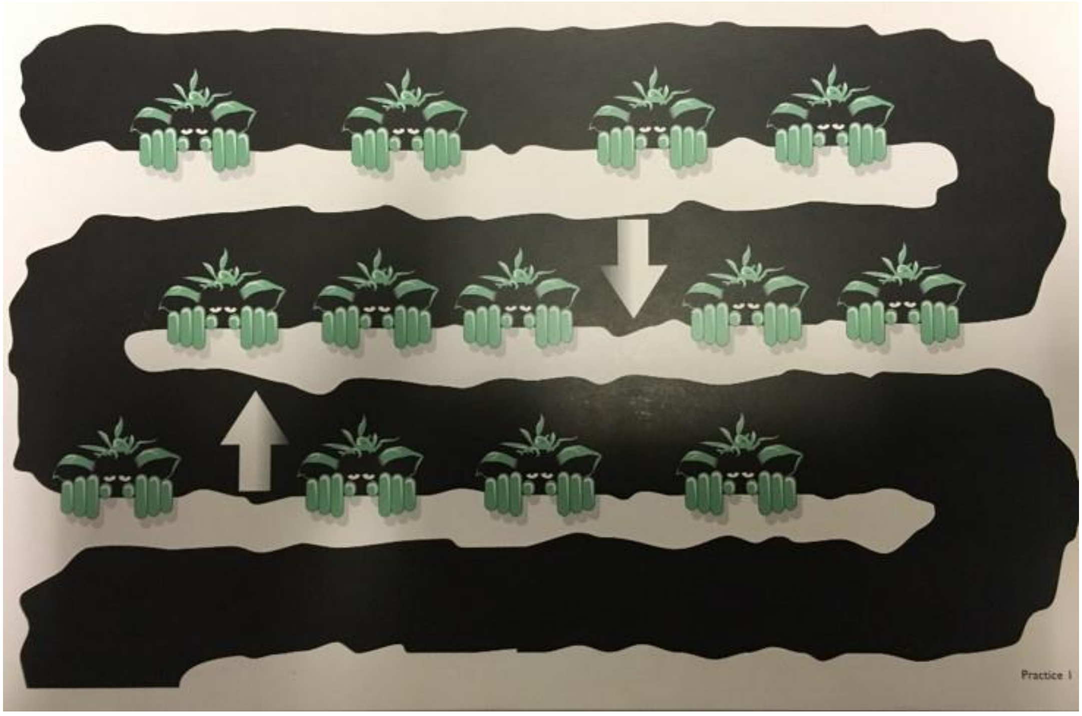


TEA-Ch Selective attention task.

Children were asked to circle as many matching spaceships as possible as quickly as possible. The examiner kept time using a stopwatch.

This same task was also used for the sustained/divided task – in this instance children were asked to circle the matching spaceships while completing an aural counting task.

APPENDIX 7e



TEA-Ch Attention switching task.

Children were asked to count the number of “creatures” the presence of an arrow indicated that the child must swap the direction of counting, e.g. a down arrow indicates that they must swap to counting down. In this example the correct answer would be 5. Children were timed and completed 8 switching tasks in total. The examiner kept time during the task using a stopwatch

APPENDIX 8

University of Reading

Infant Vision Laboratory
School of Psychology & Clinical Language Sciences
Earley Gate, RG6 6AL
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Focusing during close work in primary school children.

Principal Investigator Dr Anna Horwood PhD DBO(T) Fight for Sight grant GS14-40 entitled "Ocular accommodation and convergence during close work in primary school children".

Information for Parents or Guardians of Participants

Your child is being invited to take part in a University of Reading research study into how eyes focus on near objects. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Talk to others about the study if you wish.

- *Part 1 tells you the purpose of the study.*
- *Part 2 tells you what will happen to you in this study if you take part.*
- *Part 3 gives you more detailed information about the conduct of the study.*

Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Contact Details

If you have any queries regarding this study please contact Principal Investigator Dr Anna Horwood, School of Psychology, University of Reading, Earley Gate, Reading, RG6 6AL Phone 0118 3785553 e-mail a.m.horwood@reading.ac.uk. Alternatively contact researcher Siobhán Ludden, e-mail s.m.ludden@pgr.reading.ac.uk.

Part 1

Why do we need to do the research?

- As eyesight develops, your eyes learn to **focus** to make near objects clear (accommodation) and also turn inwards to look at them (convergence). They get information that this is necessary from the changing of the images of what they see as they come closer.
- Work that we have already done in Reading has given us new insights into focusing in everyday situations, both in normal development and people with vision problems. We have found that people across a range of age groups often under-focus during close-work, which could result in some blurred vision at near. We are not sure if this happens during sustained close-work, how

- important it is, or if it is associated with either general ability or attention. <u>We are particularly interested in how it may affect children as they learn to read.</u>

- The eye charity Fight for Sight is funding this research to be carried out until September 2017. We will look at focusing in young children during close-work in much more detail than ever before. The study will be supervised by Dr Horwood and carried out by Siobhán Ludden, a PhD student at the University of Reading, who will be using the collected data for her studies.

-

- **<u>Do you have to take part?</u>**

No. It is up to you to decide whether to let your child take part. If you do, you can keep this information sheet and will be asked to sign a consent form on behalf of your child before we test them in school. We will also explain what would be involved to children in a way they should understand. You are free to withdraw at any time and without giving a reason.

<u>Part 2</u>

<u>What will happen in the if I do want to help with the research?</u>

- We test all participants, whatever their age, in the same way.

- We will carry out the testing at your child's school, at a convenient time so that their school work is minimally interrupted. The research will involve two testing sessions which will last no more than 30minutes each. Your child can have a break during these sessions if they would like.

- We will do some easy general clinical tests of vision, similar to those used for children in the Eye Clinic at the hospital. This is so we can compare our results with established tests.

- We will then use a special camera called a photorefractor, which takes continuous photographs of their eyes from about a metre away as they look at different targets & pictures. From these photographs we can measure how much focusing is happening as your child looks at pictures or text.

- Testing does not involve anything unpleasant or uncomfortable such as eyedrops, electrodes or head restraint. Images are collected using infra-red sensors that are invisible and harmless.

- All your child will have to do it look at the pictures. If they already wear glasses they can keep these on for the test.

- We will carry out some simple quick tests of your child's general development, reading level and attention, and we will also ask you to fill in a brief attention and behaviour questionnaire about your child.

- All tests are designed to be fun for young children.

- If your child has previously had a school vision test when they started Reception, we may ask your permission to access this record. This will allow us to compare our results with the level of vision that was found when they had their school eye test.

<u>Are there any risks?</u>

The tasks used in this study are child friendly. We have trialled these tasks with children in our lab at the university, children generally find the tasks enjoyable and they do not involve any significant health risks.

Are there any benefits?

Your child will have an extra eye test which includes a focusing assessment that is not available elsewhere. Results of the ability tests that we do can be shared with you following testing if you choose.

We hope that by doing this study we will learn more about focusing during close-work and determine if under-focusing is typical behaviour or if it is something that should be treated. At this stage there is no evidence to suggest that treatment is necessary, but our research may change that situation.

What if there is a problem?

Any complaint about the way you have been treated during the study or any possible harm you might suffer will be addressed. The detailed information on this is given in Part 3. Testers are all professionally qualified to detect eye problems and if we detect anything wrong with your or your child's eyes we will tell you and can advise you how to get prompt treatment.

Will my taking part in the study be kept confidential?

Yes, all information regarding participation will be kept confidential. Further details are given in Part 3.

Part 3

What if new information becomes available?

If our results suggest our tests could aggravate any existing problem we would stop the testing immediately and if we find any eye problems we could refer your child to an optician or hospital for further investigation. All investigators are State Registered Orthoptists so can make referrals directly. If this is the case, we will then also ask your permission to write to your GP.

What will happen if we don't want to take part any more?

You are free to withdraw at any time without giving a reason why.

What if I have a problem with the study ?

If you have a concern about any aspect of this study, you should ask to speak with the researchers who will do their best to answer your questions (Dr Anna Horwood on 0118 3785553). If you remain unhappy and wish to complain formally, you can do this through Head of School of Psychology & Clinical Language Sciences, Professor Laurie Butler. If your complaint is not dealt with to your satisfaction you can contact the Chair of the University Research Ethics Committee. Details can be obtained from the School of Psychology and Clinical Language Sciences.

In the event that something unforeseen does go wrong and you or your child are harmed during the research study there are no special compensation arrangements. If you or your child are harmed and this is due to someone's negligence then you may have grounds for a legal action for compensation against the University but you may have to pay your legal costs.

Confidentiality

All information that is collected about you or your child during the course of the research will be kept strictly confidential and records will be given a unique reference number for analysis. Paper records will be stored securely in a locked room or cabinet and computer records will be password protected. Personal details will be kept separate from research data once the data collection phase has finished and will be destroyed at the end of the study. If you join the study, some parts of the data collected for the study may be looked at by authorised and statutory bodies from the University, to check that the study is being carried out correctly. All will have a duty of confidentiality to you as a research participant and nothing that could reveal your identity will be disclosed or taken outside the research site. Consent forms and any identifiable records will be kept for 5 years in line with University guidelines.

Participants and parents have the right to check the accuracy of data held about them and correct any errors. All investigators working on this project have had criminal record checks and have been approved by the School to work with children.

<u>What will happen to the research results?</u>

We will give you feedback about any test results we have available. At the end of the study, once we have analysed the data on all the participants, we will send you a newsletter or email you with a link to our website (*http://www.personal.reading.ac.uk/~sxs96amh/)* to explain the findings. We will aim to publish the findings in international vision science journals and meetings but no identifiable names or photographs will be used without your express permission.

<u>Who is organising the research?</u>

Dr Horwood PhD, DBO(T) is the Principal Investigator, working at the Infant Vision Lab set up by Professor Patricia Riddell in the School of Psychology and Clinical Language Sciences. Siobhán Ludden, BMedSci(Hons) is a PhD student and will be using the collected data in her thesis. This research has been funded by the eye charity Fight for Sight (registered charity 1111438; grant number GS14-40).

Both Dr Horwood (OR01039) and Siobhán Ludden (OR05900) are state registered orthoptists and hold current Health and Care Professions Council Registration which you can check online (www.hcpc-uk.co.uk).

<u>Who has reviewed the study?</u>

This application has been reviewed by the University of Reading Research Ethics Committee and has been given a favourable ethical opinion for conduct.

Thank you very much for reading this sheet and considering taking part in the study.

Dr Anna Horwood PhD DBO(T)

Miss Siobhán Ludden BMedSci(Hons)

APPENDIX 9

University of Reading

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email a.m.horwood@reading.ac.uk

Study Number: F4024300

Participant Identification

Number for this trial: ………………..

PARENTAL CONSENT FORM

Title of Project: ***Ocular accommodation during close work in primary school children***

Name of Supervisor: Dr Anna Horwood

Investigators: Siobhán Ludden

Name of Participant: ______________________________

DOB of Participant:_________________________________

Please initial box

- I confirm that I have read and understand the information sheet dated 05/01/16 (version 1) for the above study. I have had the opportunity to consider the information and discuss it with ______________________ (if I chose to) and have had any questions answered satisfactorily. ☐

- The nature of the tests have been explained to me and I understand what will be required for my child to take part in the above study. ☐

- I understand that my child's participation is voluntary and that I am/we are free to withdraw at any time and do not have to explain the reason for my decision. ☐

Please initial box

- I understand that the project has been subject to ethical review, according to the procedures specified by University of Reading Research Ethics Committees,

  and has been allowed to proceed

- I understand that all personal information will remain confidential to the investigators and arrangements for the storage and eventual disposal of any

  identifiable material have been made clear to me.

- I confirm that, to my knowledge, my child does not have any current, un-treated, vision problems.

- **I agree for my child to participate in the above study.**

- I am willing for my child's results from the educational tests carried out as part of this study to be shared with my child's class teacher.

-
- I grant the researchers of this study permission to access my child's school vision screening result (if applicable).

- I consent to the storage of unidentifiable data, collected during this study, in a University of Reading databank.

Parent/Guardian Consent:

Name of Parent /Guardian: Relationship to Participant:

______________________________ ________________

Signature of Parent/Guardian: Date:

______________________________ ________________

Participant (child) Assent if appropriate:

Name of child:

____

Signature of child: Date:

______________________________ ________________

I confirm that I have explained the above mentioned study, as detailed in the corresponding Information Sheet dated 05/01/16, such that, in my judgment, it is understood by both the participant and their parent/guardians.

Name of Researcher:

____

Signature of Researcher: Date:

______________________________ ___________________

When completed, 1 for participant; 1 for researcher site file

APPENDIX 10a

SPSS output of pilot analysis of laboratory study group (Chapter 4; *4.3.1*)

Within-Subjects Factors

Measure: MEASURE_1

Accommodation	Dependent Variable
1	bdp1_33cm
2	big_print
3	med_print
4	sml_print
5	wally
6	cartoon
7	letters

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Accommodation	Pillai's Trace	.882	18.764[b]	6.000	15.000	.000	.882	112.584	1.000
	Wilks' Lambda	.118	18.764[b]	6.000	15.000	.000	.882	112.584	1.000
	Hotelling's Trace	7.506	18.764[b]	6.000	15.000	.000	.882	112.584	1.000
	Roy's Largest Root	7.506	18.764[b]	6.000	15.000	.000	.882	112.584	1.000

a. Design: Intercept
Within Subjects Design: Accommodation

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Accommodation	.235	25.772	20	.180	.690	.892	.167

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Accommodation

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Accommodation	Sphericity Assumed	7.231	6	1.205	10.409	.000	.342	62.453	1.000
	Greenhouse-Geisser	7.231	4.139	1.747	10.409	.000	.342	43.078	1.000
	Huynh-Feldt	7.231	5.353	1.351	10.409	.000	.342	55.722	1.000
	Lower-bound	7.231	1.000	7.231	10.409	.004	.342	10.409	.866
Error(Accommodation)	Sphericity Assumed	13.895	120	.116					
	Greenhouse-Geisser	13.895	82.773	.168					
	Huynh-Feldt	13.895	107.068	.130					
	Lower-bound	13.895	20.000	.695					

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) Accommodation	(J) Accommodation	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.438	.143	.131	-.936	.060
	3	-.438	.129	.061	-.888	.011
	4	-.603*	.136	.005	-1.075	-.131
	5	-.363	.136	.311	-.836	.110
	6	-.086	.109	1.000	-.463	.292
	7	-.021	.132	1.000	-.481	.438
2	1	.438	.143	.131	-.060	.936
	3	-.001	.095	1.000	-.331	.330
	4	-.166	.108	1.000	-.543	.211
	5	.075	.115	1.000	-.326	.475
	6	.352*	.091	.021	.034	.670
	7	.416*	.112	.028	.028	.805
3	1	.438	.129	.061	-.011	.888
	2	.001	.095	1.000	-.330	.331
	4	-.165	.082	1.000	-.449	.118
	5	.075	.090	1.000	-.237	.388
	6	.353*	.079	.005	.077	.628
	7	.417*	.083	.001	.127	.706
4	1	.603*	.136	.005	.131	1.075
	2	.166	.108	1.000	-.211	.543
	3	.165	.082	1.000	-.118	.449
	5	.240	.090	.313	-.073	.554
	6	.518*	.070	.000	.273	.763
	7	.582*	.077	.000	.313	.850
5	1	.363	.136	.311	-.110	.836
	2	-.075	.115	1.000	-.475	.326
	3	-.075	.090	1.000	-.388	.237
	4	-.240	.090	.313	-.554	.073
	6	.277	.099	.228	-.066	.621
	7	.342*	.083	.011	.054	.629
6	1	.086	.109	1.000	-.292	.463
	2	-.352*	.091	.021	-.670	-.034
	3	-.353*	.079	.005	-.628	-.077
	4	-.518*	.070	.000	-.763	-.273
	5	-.277	.099	.228	-.621	.066
	7	.064	.098	1.000	-.276	.405
7	1	.021	.132	1.000	-.438	.481
	2	-.416*	.112	.028	-.805	-.028
	3	-.417*	.083	.001	-.706	-.127
	4	-.582*	.077	.000	-.850	-.313
	5	-.342*	.083	.011	-.629	-.054
	6	-.064	.098	1.000	-.405	.276

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

APPENDIX 10b

SPSS output of full analysis of full laboratory study group (Chapter 4; *4.3.2*)

Within-Subjects Factors

Measure: MEASURE_1

accommodation	Dependent Variable
1	Clown
2	BigPrint
3	MedPrint
4	SmlPrint
5	Cartoon
6	Wally
7	Letters

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
accommodation	Pillai's Trace	.719	14.502[b]	6.000	34.000	.000	.719	87.010	1.000
	Wilks' Lambda	.281	14.502[b]	6.000	34.000	.000	.719	87.010	1.000
	Hotelling's Trace	2.559	14.502[b]	6.000	34.000	.000	.719	87.010	1.000
	Roy's Largest Root	2.559	14.502[b]	6.000	34.000	.000	.719	87.010	1.000

a. Design: Intercept
Within Subjects Design: accommodation

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
accommodation	.334	40.336	20	.005	.690	.782	.167

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: accommodation

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
accommodation	Sphericity Assumed	11.174	6	1.862	17.063	.000	.304	102.380	1.000
	Greenhouse-Geisser	11.174	4.138	2.700	17.063	.000	.304	70.612	1.000
	Huynh-Feldt	11.174	4.691	2.382	17.063	.000	.304	80.041	1.000
	Lower-bound	11.174	1.000	11.174	17.063	.000	.304	17.063	.981
Error(accommodation)	Sphericity Assumed	25.540	234	.109					
	Greenhouse-Geisser	25.540	161.392	.158					
	Huynh-Feldt	25.540	182.942	.140					
	Lower-bound	25.540	39.000	.655					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2051.578	1	2051.578	762.022	.000	.951	762.022	1.000
Error	104.999	39	2.692					

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) accommodation	(J) accommodation	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-.435*	.099	.002	-.755	-.114
	3	-.453*	.092	.000	-.751	-.155
	4	-.526*	.093	.000	-.828	-.223
	5	-.037	.084	1.000	-.310	.236
	6	-.338*	.101	.038	-.667	-.010
	7	-.123	.091	1.000	-.420	.174
2	1	.435*	.099	.002	.114	.755
	3	-.019	.065	1.000	-.230	.193
	4	-.091	.063	1.000	-.297	.115
	5	.397*	.074	.000	.158	.636
	6	.096	.070	1.000	-.131	.324
	7	.312*	.070	.002	.084	.540
3	1	.453*	.092	.000	.155	.751
	2	.019	.065	1.000	-.193	.230
	4	-.073	.051	1.000	-.238	.092
	5	.416*	.068	.000	.194	.638
	6	.115	.050	.586	-.048	.278
	7	.330*	.059	.000	.137	.523
4	1	.526*	.093	.000	.223	.828
	2	.091	.063	1.000	-.115	.297
	3	.073	.051	1.000	-.092	.238
	5	.488*	.064	.000	.280	.697
	6	.187*	.055	.030	.010	.365
	7	.403*	.058	.000	.213	.593
5	1	.037	.084	1.000	-.236	.310
	2	-.397*	.074	.000	-.636	-.158
	3	-.416*	.068	.000	-.638	-.194
	4	-.488*	.064	.000	-.697	-.280
	6	-.301*	.078	.009	-.556	-.046
	7	-.085	.071	1.000	-.316	.145
6	1	.338*	.101	.038	.010	.667
	2	-.096	.070	1.000	-.324	.131
	3	-.115	.050	.586	-.278	.048
	4	-.187*	.055	.030	-.365	-.010
	5	.301*	.078	.009	.046	.556
	7	.216*	.061	.023	.017	.415
7	1	.123	.091	1.000	-.174	.420
	2	-.312*	.070	.002	-.540	-.084
	3	-.330*	.059	.000	-.523	-.137
	4	-.403*	.058	.000	-.593	-.213
	5	.085	.071	1.000	-.145	.316
	6	-.216*	.061	.023	-.415	-.017

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

APPENDIX 11

SPSS output of full target type analysis of school study group(s) (Chapter 5; 5.*3*)

Within-Subjects Factors

Measure: MEASURE_1

accommodation	Dependent Variable
1	ScaledClown
2	ScaledBigPrint
3	ScaledMediumPrint
4	ScaledSmallPrint
5	ScaledWheresWally
6	ScaledIndividualLetters

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
accommodation	.502	72.367	14	.000	.779	.813	.200

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
 Within Subjects Design: accommodation

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
accommodation	Sphericity Assumed	6.540	5	1.308	4.545	.000	.041	22.726	.973
	Greenhouse-Geisser	6.540	3.897	1.678	4.545	.001	.041	17.714	.938
	Huynh-Feldt	6.540	4.063	1.610	4.545	.001	.041	18.467	.945
	Lower-bound	6.540	1.000	6.540	4.545	.035	.041	4.545	.561
Error(accommodation)	Sphericity Assumed	153.972	535	.288					
	Greenhouse-Geisser	153.972	417.019	.369					
	Huynh-Feldt	153.972	434.752	.354					
	Lower-bound	153.972	107.000	1.439					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	4766.153	1	4766.153	1116.929	.000	.913	1116.929	1.000
Error	456.590	107	4.267					

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) accommodation	(J) accommodation	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.070	.083	1.000	-.320	.181
	3	-.121	.084	1.000	-.373	.130
	4	-.194	.090	.501	-.463	.076
	5	-.226	.082	.104	-.472	.020
	6	.058	.080	1.000	-.181	.297
2	1	.070	.083	1.000	-.181	.320
	3	-.051	.061	1.000	-.235	.132
	4	-.124	.053	.317	-.283	.035
	5	-.156	.059	.138	-.332	.020
	6	.128	.068	.934	-.076	.332
3	1	.121	.084	1.000	-.130	.373
	2	.051	.061	1.000	-.132	.235
	4	-.072	.062	1.000	-.258	.113
	5	-.104	.063	1.000	-.293	.085
	6	.179	.077	.322	-.051	.410
4	1	.194	.090	.501	-.076	.463
	2	.124	.053	.317	-.035	.283
	3	.072	.062	1.000	-.113	.258
	5	-.032	.060	1.000	-.211	.147
	6	.252	.086	.063	-.007	.510
5	1	.226	.082	.104	-.020	.472
	2	.156	.059	.138	-.020	.332
	3	.104	.063	1.000	-.085	.293
	4	.032	.060	1.000	-.147	.211
	6	.284*	.075	.004	.059	.509
6	1	-.058	.080	1.000	-.297	.181
	2	-.128	.068	.934	-.332	.076
	3	-.179	.077	.322	-.410	.051
	4	-.252	.086	.063	-.510	.007
	5	-.284*	.075	.004	-.509	-.059

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

APPENDIX 12

SPSS output of two way mixed ANOVA with post hoc testing of the school study group (Chapter 5; *5.3.3*)

Two way mixed ANOVA (age*target type)

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
target_type	.447	68.571	14	.000	.758	.842	.200

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Age
Within Subjects Design: target_type

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Between-Subjects Effects

Measure: MEASURE_1

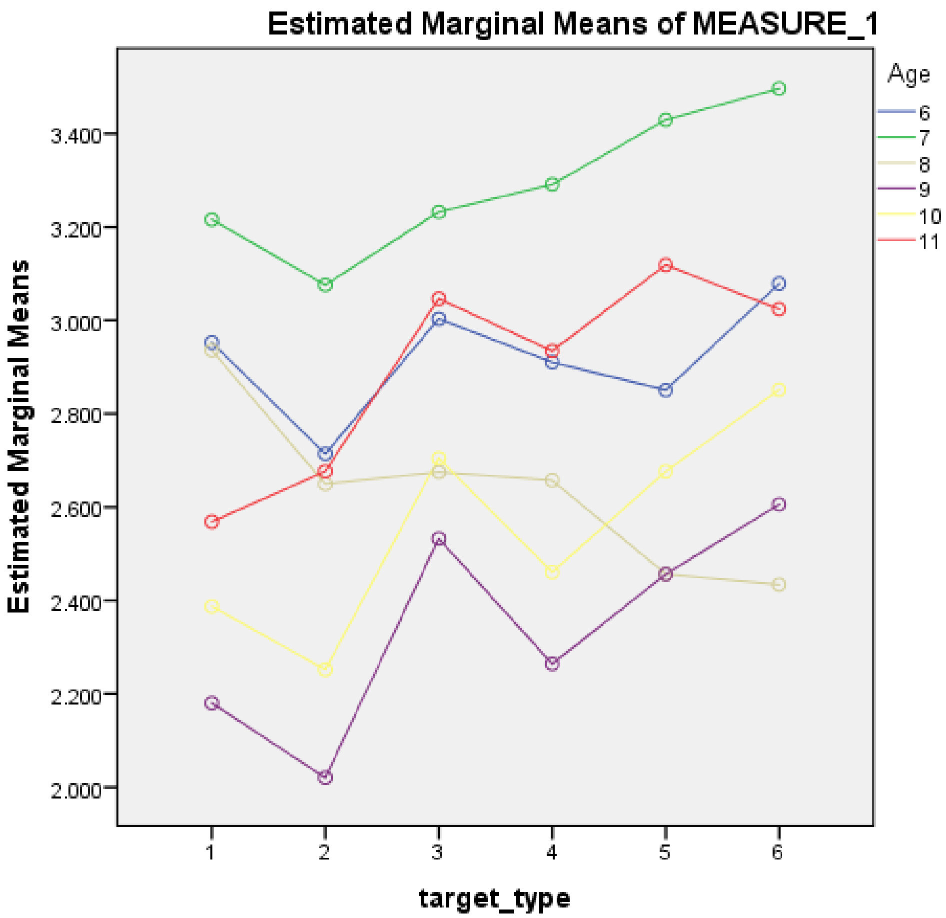
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2085.191	1	2085.191	466.012	.000	.843
Age	26.262	5	5.252	1.174	.329	.063
Error	389.285	87	4.475			

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
target_type	Sphericity Assumed	3.633	5	.727	2.866	.015	.032
	Greenhouse-Geisser	3.633	3.789	.959	2.866	.026	.032
	Huynh-Feldt	3.633	4.211	.863	2.866	.021	.032
	Lower-bound	3.633	1.000	3.633	2.866	.094	.032
target_type * Age	Sphericity Assumed	10.783	25	.431	1.702	.020	.089
	Greenhouse-Geisser	10.783	18.946	.569	1.702	.035	.089
	Huynh-Feldt	10.783	21.055	.512	1.702	.028	.089
	Lower-bound	10.783	5.000	2.157	1.702	.143	.089
Error(target_type)	Sphericity Assumed	110.270	435	.253			
	Greenhouse-Geisser	110.270	329.663	.334			
	Huynh-Feldt	110.270	366.355	.301			
	Lower-bound	110.270	87.000	1.267			



Estimated Marginal Means of MEASURE_1
Estimated Marginal Means
3.400
3.200
3.000
2.800
2.600
2.400
2.200
2.000
1
2
3
4
5
6
target_type
Age
6
7
8
9
10
11

One way ANOVA with post hoc Bonferroni correction

Within-Subjects Factors

Measure: MEASURE_1

target_type	Dependent Variable
1	Clown
2	Individual_Letters
3	Wally
4	Big_Print
5	Med_Print
6	Sml_Print

#

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

						Epsilon[b]		
Age	Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
6	target_type	.198	37.418	14	.001	.586	.672	.200
7	target_type	.000	.	14	.	.200	.000	.200
8	target_type	.084	39.946	14	.000	.489	.571	.200
9	target_type	.025	29.756	14	.011	.464	.612	.200
10	target_type	.119	30.047	14	.008	.652	.838	.200
11	target_type	.114	32.845	14	.003	.599	.741	.200

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: target_type

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Age	Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
6	target_type	Sphericity Assumed	2.093	5	.419	3.108	.011	.111
		Greenhouse-Geisser	2.093	2.931	.714	3.108	.033	.111
		Huynh-Feldt	2.093	3.362	.623	3.108	.026	.111
		Lower-bound	2.093	1.000	2.093	3.108	.090	.111
	Error(target_type)	Sphericity Assumed	16.840	125	.135			
		Greenhouse-Geisser	16.840	73.265	.230			
		Huynh-Feldt	16.840	84.048	.200			
		Lower-bound	16.840	25.000	.674			
7	target_type	Sphericity Assumed	.234	5	.047	2.358	.184	.702
		Greenhouse-Geisser	.234	1.000	.234	2.358	.367	.702
		Huynh-Feldt	.234	.000	.	.	.	.702
		Lower-bound	.234	1.000	.234	2.358	.367	.702
	Error(target_type)	Sphericity Assumed	.099	5	.020			
		Greenhouse-Geisser	.099	1.000	.099			
		Huynh-Feldt	.099	.000	.			
		Lower-bound	.099	1.000	.099			
8	target_type	Sphericity Assumed	3.134	5	.627	1.607	.166	.082
		Greenhouse-Geisser	3.134	2.443	1.283	1.607	.208	.082
		Huynh-Feldt	3.134	2.855	1.098	1.607	.201	.082
		Lower-bound	3.134	1.000	3.134	1.607	.221	.082
	Error(target_type)	Sphericity Assumed	35.107	90	.390			
		Greenhouse-Geisser	35.107	43.973	.798			
		Huynh-Feldt	35.107	51.391	.683			
		Lower-bound	35.107	18.000	1.950			
9	target_type	Sphericity Assumed	2.801	5	.560	6.045	.000	.377
		Greenhouse-Geisser	2.801	2.319	1.208	6.045	.006	.377
		Huynh-Feldt	2.801	3.060	.915	6.045	.002	.377
		Lower-bound	2.801	1.000	2.801	6.045	.034	.377
	Error(target_type)	Sphericity Assumed	4.634	50	.093			
		Greenhouse-Geisser	4.634	23.186	.200			
		Huynh-Feldt	4.634	30.599	.151			
		Lower-bound	4.634	10.000	.463			
10	target_type	Sphericity Assumed	4.319	5	.864	1.581	.175	.090
		Greenhouse-Geisser	4.319	3.258	1.325	1.581	.202	.090
		Huynh-Feldt	4.319	4.190	1.031	1.581	.187	.090
		Lower-bound	4.319	1.000	4.319	1.581	.227	.090
	Error(target_type)	Sphericity Assumed	43.709	80	.546			
		Greenhouse-Geisser	43.709	52.130	.838			
		Huynh-Feldt	43.709	67.040	.652			
		Lower-bound	43.709	16.000	2.732			
11	target_type	Sphericity Assumed	4.418	5	.884	7.601	.000	.309
		Greenhouse-Geisser	4.418	2.993	1.476	7.601	.000	.309
		Huynh-Feldt	4.418	3.704	1.193	7.601	.000	.309
		Lower-bound	4.418	1.000	4.418	7.601	.013	.309
	Error(target_type)	Sphericity Assumed	9.882	85	.116			
		Greenhouse-Geisser	9.882	50.882	.194			
		Huynh-Feldt	9.882	62.960	.157			
		Lower-bound	9.882	17.000	.581			

Pairwise Comparisons

Measure: MEASURE_1

Age	(I) target_type	(J) target_type	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
6	1	2	.239	.133	1.000	-.194	.671
		3	-.051	.137	1.000	-.495	.394
		4	.042	.132	1.000	-.386	.470
		5	.102	.131	1.000	-.323	.527
		6	-.126	.142	1.000	-.585	.333
	2	1	-.239	.133	1.000	-.671	.194
		3	-.289	.089	.051	-.579	.001
		4	-.196	.073	.187	-.433	.040
		5	-.136	.085	1.000	-.411	.138
		6	-.365*	.079	.002	-.622	-.107
	3	1	.051	.137	1.000	-.394	.495
		2	.289	.089	.051	-.001	.579
		4	.093	.067	1.000	-.125	.311
		5	.153	.099	1.000	-.169	.475
		6	-.075	.058	1.000	-.263	.112
	4	1	-.042	.132	1.000	-.470	.386
		2	.196	.073	.187	-.040	.433
		3	-.093	.067	1.000	-.311	.125
		5	.060	.078	1.000	-.193	.313
		6	-.168	.067	.284	-.386	.049
	5	1	-.102	.131	1.000	-.527	.323
		2	.136	.085	1.000	-.138	.411
		3	-.153	.099	1.000	-.475	.169
		4	-.060	.078	1.000	-.313	.193
		6	-.228	.096	.382	-.540	.083
	6	1	.126	.142	1.000	-.333	.585
		2	.365*	.079	.002	.107	.622
		3	.075	.058	1.000	-.112	.263
		4	.168	.067	.284	-.049	.386
		5	.228	.096	.382	-.083	.540
7	1	2	.140	.039	1.000	-7.364	7.644
		3	-.016	.141	1.000	-26.852	26.819
		4	-.075	.009	1.000	-1.759	1.609
		5	-.214	.107	1.000	-20.626	20.199
		6	-.281	.212	1.000	-40.776	40.215
	2	1	-.140	.039	1.000	-7.644	7.364
		3	-.156	.180	1.000	-34.496	34.183
		4	-.215	.030	1.000	-6.036	5.605
		5	-.354	.146	1.000	-28.270	27.563
		6	-.421	.251	1.000	-48.420	47.579
	3	1	.016	.141	1.000	-26.819	26.852
		2	.156	.180	1.000	-34.183	34.496
		4	-.059	.149	1.000	-28.578	28.460
		5	-.197	.034	1.000	-6.620	6.226
		6	-.264	.072	1.000	-13.924	13.396
	4	1	.075	.009	1.000	-1.609	1.759
		2	.215	.030	1.000	-5.605	6.036
		3	.059	.149	1.000	-28.460	28.578
		5	-.138	.116	1.000	-22.235	21.958
		6	-.205	.221	1.000	-42.384	41.974
	5	1	.214	.107	1.000	-20.199	20.626
		2	.354	.146	1.000	-27.563	28.270
		3	.197	.034	1.000	-6.226	6.620
		4	.138	.116	1.000	-21.958	22.235
		6	-.067	.105	1.000	-20.150	20.016
	6	1	.281	.212	1.000	-40.215	40.776
		2	.421	.251	1.000	-47.579	48.420
		3	.264	.072	1.000	-13.396	13.924
		4	.205	.221	1.000	-41.974	42.384
		5	.067	.105	1.000	-20.016	20.150
8	1	2	.286	.227	1.000	-.480	1.052
		3	.261	.190	1.000	-.383	.905
		4	.278	.188	1.000	-.357	.913
		5	.479	.192	.341	-.171	1.129
		6	.502	.217	.495	-.233	1.236
	2	1	-.286	.227	1.000	-1.052	.480
		3	-.025	.196	1.000	-.689	.638
		4	-.008	.198	1.000	-.676	.661
		5	.193	.256	1.000	-.673	1.058
		6	.216	.334	1.000	-.915	1.346
	3	1	-.261	.190	1.000	-.905	.383
		2	.025	.196	1.000	-.638	.689
		4	.018	.107	1.000	-.343	.378
		5	.218	.162	1.000	-.329	.766
		6	.241	.199	1.000	-.432	.915
	4	1	-.278	.188	1.000	-.913	.357
		2	.008	.198	1.000	-.661	.676
		3	-.018	.107	1.000	-.378	.343
		5	.201	.145	1.000	-.291	.692
		6	.224	.192	1.000	-.424	.871
	5	1	-.479	.192	.341	-1.129	.171
		2	-.193	.256	1.000	-1.058	.673
		3	-.218	.162	1.000	-.766	.329
		4	-.201	.145	1.000	-.692	.291
		6	.023	.137	1.000	-.441	.487
	6	1	-.502	.217	.495	-1.236	.233
		2	-.216	.334	1.000	-1.346	.915
		3	-.241	.199	1.000	-.915	.432
		4	-.224	.192	1.000	-.871	.424
		5	-.023	.137	1.000	-.487	.441
9	1	2	.160	.146	1.000	-.400	.719
		3	-.352	.127	.298	-.840	.135
		4	-.084	.118	1.000	-.535	.368
		5	-.276	.190	1.000	-1.002	.450
		6	-.426	.201	.905	-1.195	.344
	2	1	-.160	.146	1.000	-.719	.400
		3	-.512*	.118	.022	-.963	-.061
		4	-.244	.089	.315	-.584	.097
		5	-.436*	.088	.008	-.771	-.100
		6	-.585*	.116	.007	-1.028	-.143
	3	1	.352	.127	.298	-.135	.840
		2	.512*	.118	.022	.061	.963
		4	.269	.117	.677	-.181	.718
		5	.076	.101	1.000	-.311	.464
		6	-.073	.114	1.000	-.509	.362
	4	1	.084	.118	1.000	-.368	.535
		2	.244	.089	.315	-.097	.584
		3	-.269	.117	.677	-.718	.181
		5	-.192	.117	1.000	-.639	.255
		6	-.342	.151	.713	-.921	.238
	5	1	.276	.190	1.000	-.450	1.002
		2	.436*	.088	.008	.100	.771
		3	-.076	.101	1.000	-.464	.311
		4	.192	.117	1.000	-.255	.639
		6	-.150	.092	1.000	-.501	.202
	6	1	.426	.201	.905	-.344	1.195
		2	.585*	.116	.007	.143	1.028
		3	.073	.114	1.000	-.362	.509
		4	.342	.151	.713	-.238	.921
		5	.150	.092	1.000	-.202	.501
10	1	2	.135	.276	1.000	-.814	1.085
		3	-.317	.295	1.000	-1.332	.697
		4	-.073	.294	1.000	-1.088	.941
		5	-.289	.292	1.000	-1.296	.717
		6	-.464	.267	1.000	-1.384	.455
	2	1	-.135	.276	1.000	-1.085	.814
		3	-.453	.330	1.000	-1.589	.683
		4	-.209	.274	1.000	-1.153	.735
		5	-.425	.308	1.000	-1.486	.637
		6	-.600	.254	.468	-1.474	.275
	3	1	.317	.295	1.000	-.697	1.332
		2	.453	.330	1.000	-.683	1.589
		4	.244	.197	1.000	-.435	.923
		5	.028	.206	1.000	-.683	.739
		6	-.147	.143	1.000	-.638	.345
	4	1	.073	.294	1.000	-.941	1.088
		2	.209	.274	1.000	-.735	1.153
		3	-.244	.197	1.000	-.923	.435
		5	-.216	.209	1.000	-.935	.504
		6	-.391	.129	.117	-.834	.052
	5	1	.289	.292	1.000	-.717	1.296
		2	.425	.308	1.000	-.637	1.486
		3	-.028	.206	1.000	-.739	.683
		4	.216	.209	1.000	-.504	.935
		6	-.175	.229	1.000	-.965	.615
	6	1	.464	.267	1.000	-.455	1.384
		2	.600	.254	.468	-.275	1.474
		3	.147	.143	1.000	-.345	.638
		4	.391	.129	.117	-.052	.834
		5	.175	.229	1.000	-.615	.965
11	1	2	-.108	.157	1.000	-.644	.427
		3	-.478	.164	.147	-1.038	.083
		4	-.366	.116	.087	-.762	.030
		5	-.550*	.118	.003	-.954	-.146
		6	-.456	.151	.117	-.971	.060
	2	1	.108	.157	1.000	-.427	.644
		3	-.370	.123	.120	-.790	.050
		4	-.258	.088	.139	-.558	.042
		5	-.442*	.101	.006	-.787	-.097
		6	-.347	.114	.107	-.735	.040
	3	1	.478	.164	.147	-.083	1.038
		2	.370	.123	.120	-.050	.790
		4	.112	.088	1.000	-.189	.413
		5	-.072	.095	1.000	-.396	.251
		6	.022	.093	1.000	-.295	.340
	4	1	.366	.116	.087	-.030	.762
		2	.258	.088	.139	-.042	.558
		3	-.112	.088	1.000	-.413	.189
		5	-.184	.064	.164	-.404	.036
		6	-.090	.104	1.000	-.444	.265
	5	1	.550*	.118	.003	.146	.954
		2	.442*	.101	.006	.097	.787
		3	.072	.095	1.000	-.251	.396
		4	.184	.064	.164	-.036	.404
		6	.095	.073	1.000	-.153	.343
	6	1	.456	.151	.117	-.060	.971
		2	.347	.114	.107	-.040	.735
		3	-.022	.093	1.000	-.340	.295
		4	.090	.104	1.000	-.265	.444
		5	-.095	.073	1.000	-.343	.153

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.