Current and future management of convergence insufficiency

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Abstract

Introduction: The existing literature indicated a lack of consensus on the most effective protocol for treating primary convergence insufficiency (CI), resulting in variability in treatment approaches and reported efficacy rates. This thesis investigates the treatment protocols for primary CI and their effectiveness. In addition, the role of tele-appointments in primary CI treatment.

Method:

Four studies were conducted:

Study 1: A retrospective service evaluation of CI patients who were treated with orthoptic exercises.

Study 2: A cohort study of primary CI patients comparing standard treatment to simple convergence exercises, as well as face-to-face appointments versus tele-appointments.

Study 3: Visually normal young adults were recruited to compare simple convergence exercises with a placebo and to evaluate the effectiveness of tele-appointments.

Study 4: Online questionnaires aimed at clinicians to explore the numbers of primary CI patients, treatment, and the use of tele-appointments.

Results: The service evaluation identified the standard treatment for primary CI and highlighted variability in treatment protocols. The cohort study of primary CI patients encountered unexpected recruitment challenges following COVID-19, resulting in no recruited patients. Simple convergence exercises targeting disparity demonstrated improvement in vergence and accommodation responses over placebo exercises, and tele-appointments were found to be as effective as face-to-face appointments. The questionnaire revealed variability among clinicians in the treatment of primary CI and limited use of tele-appointments.

Conclusion: There is variability in the protocols used by clinicians to treat primary CI, with no standardised approach yet. The improvement seen with simple convergence exercises targeting disparity is not attributed to the placebo effect. The use of tele-appointments for treating primary CI is still limited.

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List of abbreviations

AA Amplitude of Accommodation

AC/A Accommodative Convergence/Accommodation

ACBO Australasian College of Behavioural Optometrists

AF Accommodative Facility

AI Accommodative Insufficiency

AOA American Optometric Association

AOP Association of Optometrists

BABO British Association of Behavioural Optometrists

BAF Binocular Accommodative Facility

BI Base-In

BIOS British and Irish Orthoptic Society

BO Base-Out

CA/C Convergence Accommodation/Convergence

CF Calibration Factor

CI Convergence Insufficiency

CIRS Convergence Insufficiency Reading Study

CISS Convergence Insufficiency Symptom Survey

CITT Convergence Insufficiency Treatment Trial

cm Centimetre

CT Cover Test

COVD College of Optometrists in Vision Development

COVID-19 Coronavirus Disease 2019

cpm cycles per minute

D Dioptre

FODO Association for Eyecare Providers

HTS Home Therapy System

LOC Local Optical Committee

MA Metre Angle

MEM Monocular Estimated Method

NPA Near Point of Accommodation

NPC Near Point of Convergence

NRA Negative Relative Accommodation

PI Principle Investigator

PIS Patient Information Sheet

PRA Positive Relative Accommodation

RAF Royal Air Force

SD Standard Deviation

SE Standard Error

STH Sheffield Teaching Hospital

UK United Kingdom

UoS University of Sheffield

USA United States of America

VA Visual Acuity

WHO World Health Organization

Chapter 1 Introduction to the Thesis

The PhD project initially aimed to:

- Investigate what 'standard treatment' for primary convergence insufficiency (CI) was in a single UK hospital
- Compare simple convergence exercises to 'standard treatment' for adults with primary CI
- Investigate the long-term outcomes of CI treatment

The background to this PhD research stemmed from the considerable variation in the literature regarding the management of primary CI, particularly determining the most effective treatment for primary CI and the long-term results of treatment. As a result, the number of prescribed exercises, suggested frequency, and duration varied across clinics, and the effectiveness of CI home exercises, particularly in the long term, was not well understood. There was a clear need for robust evidence investigating the effect of different primary CI treatment in the short and long term.

The PhD research was planned to firstly include a comprehensive literature review to explore the existing evidence around primary CI, with particular emphasis on different primary CI treatment protocols and their treatment outcomes. A quantitative study was planned, combining a retrospective service evaluation of current practice to better understand 'standard treatment' for CI. The insights gained from this evaluation were intended to inform the design of a prospective treatment trial to contribute to the development of more effective and efficient primary CI treatment and outcomes.

The prospective trial was designed to recruit adult patients with primary CI from one UK hospital and randomised to either 'standard treatment', as determined by the literature review and the service evaluation, or to 'simple convergence exercises' that were determined by the literature review. The trial was planned to follow patients up for one year to measure their longer-term outcomes following primary CI treatment.

During the study, the service evaluation results highlighted that some patients and their CI treatment had been impacted by the COVID-19 pandemic, resulting in a greater use of tele-appointments to deliver and monitor treatment. This adaptation to clinical practice was

therefore incorporated into the design of the prospective trial, with the aim to determine if tele-appointments are as effective as face-to-face appointments.

The prospective trial recruiting adult patients with primary CI posed significant difficulties in recruitment. This unexpected problem was handled in a number of different ways, ensuring that the overall objectives could be fulfilled. To try and increase recruitment a number of additional sites (n=18) were approached to be part of the study, but they were unable to come on board for a variety of reasons. The main challenge was thought to be a significant reduction in the number of patients with primary CI being referred to the hospital eye service, post COVID-19 pandemic. In particular it was noted that the CI patients referred were tending to be secondary CI or those who had failed to improve following CI treatment delivered elsewhere and therefore did not meet our recruitment criteria.

These post-COVID changes to clinical referrals were discussed at length. In response to the unexpected changes in patient referral patterns and the characteristics of the patients with CI in the hospital eye service a number of changes to the planned studies were made. Two new studies were added and integrated into the PhD project framework. 'Normal' young adults were recruited to a prospective study investigating simple convergence exercises compared to placebo exercises, using either tele-appointments or face-to-face appointments. Additionally, a questionnaire study was conducted to try and explore in more detail the clinical observations that had limited recruitment to the prospective primary CI treatment trial. This questionnaire study aimed to gain a better understanding of clinician experiences of patients with primary CI following the COVID-19 pandemic, both in terms of the patients referred and the treatment used. Figure 1.1 illustrates the timeline of the PhD project.

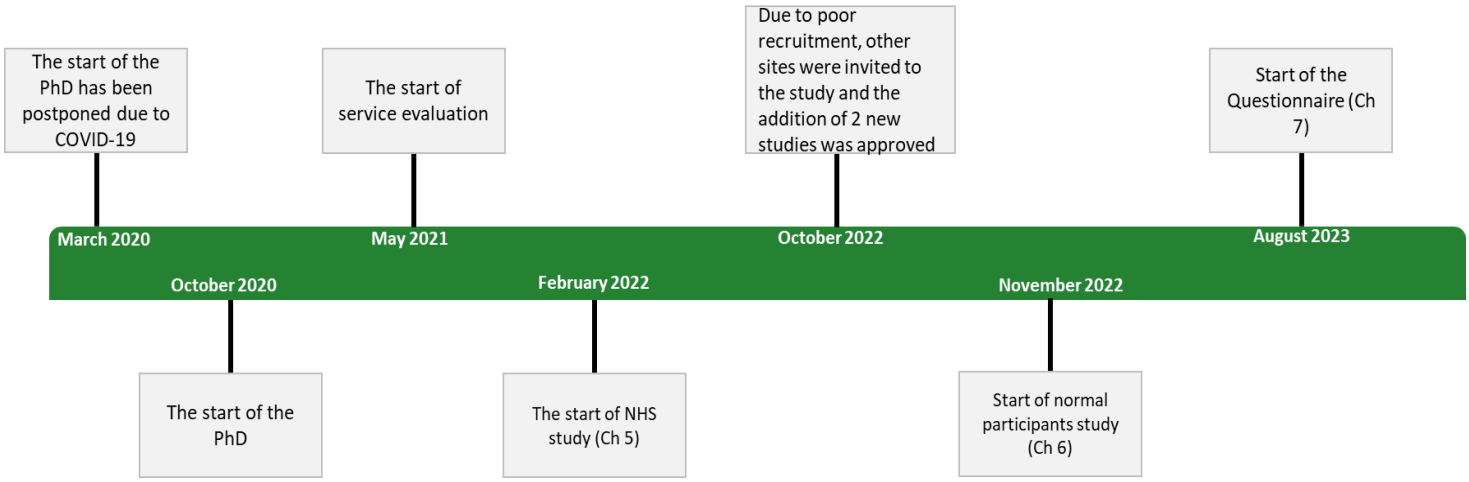


Figure 1.1 The timeline of PhD project and changes into the research framework.

1.1 Structure of the thesis

Chapter two describes vergence and accommodation, including definitions, physiological processes, and clinical signs, expected normative values of convergence and accommodation and prevalence. Chapter three reviews the literature on the diagnosis of primary CI and comorbidity of CI with accommodation insufficiency (AI), highlighting variability in treatment approaches and outcomes. Chapter four describes the retrospective service evaluation of patients who had been diagnosed and treated by orthoptic exercises for symptomatic CI and/or AI at Sheffield Teaching Hospitals (STH) NHS Foundation Trust. Chapter five describes the prospective study conducted at STH that used the results of the service evaluation, along with the literature evidence, to determine 'standard care' for primary CI. The study investigating the effectiveness of tele-appointments versus face-to-face appointments for patient undergoing CI treatment. It was also planned to compare the effectiveness of simple convergence exercises with standard orthoptic exercises.

Chapter six describes the prospective study investigating the effectiveness of tele-appointments versus face-to-face appointments and simple CI exercises versus placebo exercises in a population of ‘normal’ young adults. Chapter seven describes the questionnaire that was distributed to clinicians to investigate the number of CI patients referred pre- and post-COVID. The questionnaire also investigating primary CI treatment protocols and the

possibility of using tele-appointments as part of the care delivered to patients with primary CI.

Chapter eight discusses all of the study results together and compares the results to the available literature evidence. It presents a discussion of primary CI treatment and the possible implementation of tele-appointments in the management of CI. In addition, it addresses the limitations of this PhD study and makes recommendations for future research into primary CI. Finally, conclusions are made about primary CI treatment based on the study results.

Chapter 2 Convergence Insufficiency

This chapter provides an overview of vergence eye movements and defines vergence and CI. It discusses the prevalence and diagnosis of primary CI, including its signs and symptoms. The chapter also covers the definition of accommodation, assessment, and expected normal values. In addition, the chapter discusses accommodation insufficiency (AI) and the comorbidity of CI and AI. Moreover, it briefly overviews orthoptic exercises, vision therapy, and tele-appointments in the treatment of primary CI.

2.1 Vergence

Vergence eye movements are simultaneous disconjugate horizontal movement of the eyes in the opposite direction (Brune and Eggenberger, 2018) that aim to achieve and sustain binocular alignment (Ansons and Davis, 2014). The vergence system consists of two actions: convergence and divergence. Convergence is simultaneous inward rotation (adduction) of the eyes (Alvarez, 2015) and divergence is outward movement (abduction) of the eyes (Daftari et al., 2003). There are four components of convergence that contribute to the convergence process namely tonic, proximal, fusional and accommodative convergence (Worth, 1915). Convergence is mainly obtained by fusional vergence, which is driven by retinal disparity and accommodative vergence, induced by accommodation effort to a blurred image, generating convergence to occur (Ansons and Davis, 2014). While with less contribution to convergence, proximal vergence is driven by the awareness of a near fixation target and tonic vergence is generated by muscle tonus of medial recti (Ansons and Davis, 2014). Vergence can be measured in units of prism dioptre (PD) and metre angle (MA). The MA equals the reciprocal of the viewing distance:

Vergence in MA = 1/ (target distance in meters) (Hung and Ciuffreda, 1994).

The PD can be obtained from the multiplication of interpupillary distance (IPD) in MA:

Vergence in PD = IPD (cm) x MA (Hung and Ciuffreda, 1994).

For example, if a target is at 0.5 m, the vergence required is:

Vergence = 1 / 0.5 = 2 MA.

If the IPD of the observer is 6 cm for the above target (0.5 m), the convergence required to focus on an object 0.5 m is 12 PD:

Vergence in PD=6 cm× 2MA= 12 PD

2.1.1 Neural control of vergence

Vergence eye movements can be stimulated by proximal cues, alteration in image size, for example, an object size becoming larger, and retinal disparity, for example, diplopia (Searle and Rowe, 2016). The disparity stimulus signal reaches both retinas and is then sent to the primary visual cortex (V1) in the brain's occipital lobe, which is translated to an initial neural vergence signal (Ciuffreda *et al*., 2020). Then, this raw binocular vergence signal undergoes advanced processing in higher visual areas. Specifically, visual cortex area (V3), medial temporal and medial superior temporal areas (Ward *et al*., 2015). These areas integrate the retinal disparity with other depth cues, such as interpreting alteration in image size corresponding to changes in depth, and process the information into an explicit neural representation of depth perception (Ciuffreda *et al*., 2020). From this point, certain parts in the cerebellum receive this vergence signal, where the fastigial nucleus controls convergence, and the posterior interposed nucleus deals with divergence signals (Novello *et al*., 2024). In the final stage, to process the vergence neural signal, the supra-oculomotor area transfers the directional motor signals related to convergence/divergence to the Edinger-Westphal nucleus in the midbrain, resulting in the form of a completed vergence neural signal (Ciuffreda *et al*., 2020). Specifically, in the Edinger-Westphal nucleus, the vergence signals get generated for the specific vergence eye movement and sent to the muscles to carry out the required convergence or divergence movement. The process of initiation of vergence eye movement is summarised in Figure 2.1.

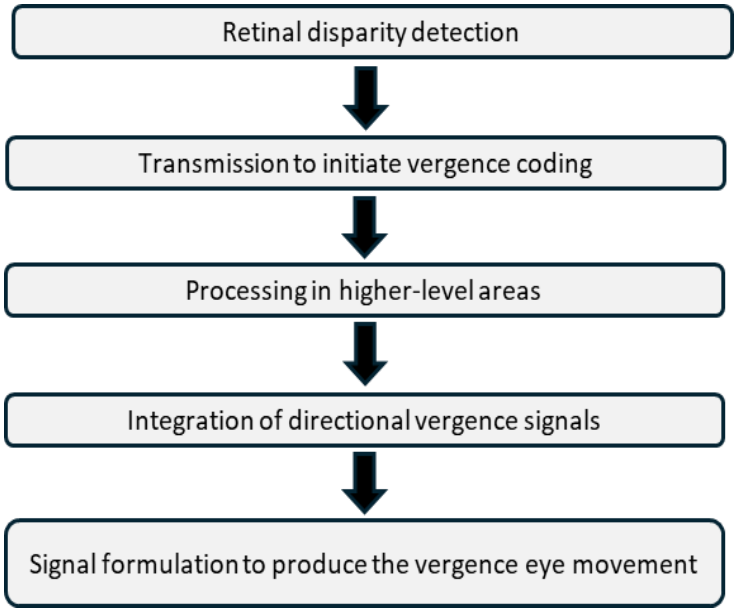


Figure 2. 1 Summary of process on how vergence eye movement initiated

2.2 Convergence insufficiency (CI)

The eyes converge when the fixation is changed from a distance to a near object to maintain binocular single vision. CI is defined as insufficient convergence ability to maintain adequate binocular fusion during near visual activities (Serna *et al*., 2011; Bade *et al*., 2013; Morales *et al*., 2023). In the United Kingdom (UK), the guidelines from the British and Irish Orthoptic Society (BIOS) 2016 stated that orthoptists typically define primary CI as Near Point of Convergence (NPC) greater than 10 cm from the nose. The Royal College of Ophthalmologists (2012) and The BIOS guidelines (2016) classified CI into primary (idiopathic) and secondary to disorder or disease such as accommodation anomalies, vertical deviation, Parkinson's disease and Graves orbitopathy.

It is important to highlight that in the UK, there is differentiation between CI with and without co-existing near exophoria (BIOS, 2016). In this regard, the terminology "convergence weakness" is used when a near exophoria is present. Ansons and Davis (2014) stated the term "exophoria of the convergence weakness type" when an exophoria is present for distance, but increases at near. Similarly, Evans (2001) used the term "decompensated convergence weakness exophoria" when the exodeviation is greatest at near. The Royal College of Ophthalmologists (2012) and Horwood and Riddell (2012) also referred to the term as

"convergence weakness exophoria", where the near exophoria is 10Δ or more than the distance. It is worth mentioning that decompensated convergence weakness exophoria is sometimes described as CI (Allen, Evans and Wilkins, 2009). Differences and variations in the CI definitions and diagnostic criteria are discussed in more detail in section 2.2.7 and Chapter 3.

2.2.1 CI symptoms

When patients with CI engage in near tasks, diplopia may occur due to the eyes unable to maintain binocular single vision. Increased convergence effort to fuse the diplopic images could lead to associated symptoms, such as diplopia, blur, headache and asthenopia (Kim and Chun, 2011; Revathy *et al*., 2011; Cooper and Jamal, 2012; Nawrot *et al.,* 2013; Whitecross, 2013; McGregor, 2014; Momeni-Moghaddam *et al.,* 2015; Aletaha *et al.,* 2018; Scheiman *et al.,* 2020). Interestingly, some patients with CI do not report any associated symptoms and that could be due to avoiding near tasks, suppression or closing one eye during reading (Scheiman and Wick, 2014). Nevertheless, Lavrich (2010) suggested that the patient must show CI symptoms for treatment to be recommended.

2.2.1.1 Assessment of CI symptoms

The CITT investigator group developed the Convergence Insufficiency Symptom Survey (CISS) (Borsting *et al.*, 2003) to quantify the severity and frequency of CI symptoms (Rouse *et al.*, 2009). Using questionnaires is a helpful method to systematically quantify CI symptoms easily as well as enable clinicians to monitor symptoms before and after treatment in a standardised manner (Scheiman and Wick, 2014).

The CISS survey consists of 15 questions as shown in Figure 2.2 (Scheiman *et al.*, 2005b). These questions were designed so that the patient chooses one answer from never, infrequently, sometimes, fairly often and always. The CISS score is on a 5-point scale, from 0 to 4 with 0 = “never” represent the lowest frequency of symptoms and 4 = “always” represent the highest frequency of symptoms; and the sum of the 15 items represents the CISS score. In terms of score, the lowest score is zero, which representing no symptoms of CI, while the highest score is 60, which indicates the highest symptoms of CI. The CISS is used as a tool to distinguish

symptomatic CI patients from asymptomatic ones, as scores of ≥16 in children aged 9-17 years and ≥21 in adults aged 18 and older are considered symptomatic (Borsting *et al.*, 2003; Rouse *et al.*, 2004). The assessment of symptoms as an indicator for treatment outcomes are discussed in more detail in Chapter 3.

Subject instructions: Please answer the following questions about how your eyes feel when reading or doing close work.

		Never	(not very often) Infrequently	Sometimes	Fairly often	Always
1.	Do your eyes feel tired when reading or doing close work?					
2.	Do your eyes feel uncomfortable when reading or doing close work?					
3.	Do you have headaches when reading or doing close work?					
4.	Do you feel sleepy when reading or doing close work?					
5.	Do you lose concentration when reading or doing close work?					
6.	Do you have trouble remembering what you have read?					
7.	Do you have double vision when reading or doing close work?					
8.	Do you see the words move, jump, swim or appear to float on the page when reading or doing close work?					
9.	Do you feel like you read slowly?					
10.	Do your eyes ever hurt when reading or doing close work?					
11.	Do your eyes ever feel sore when reading or doing close work?					
12.	Do you feel a "pulling" feeling around your eyes when reading or doing close work?					
13.	Do you notice the words blurring or coming in and out of focus when reading or doing close work?					
14.	Do you lose your place while reading or doing close work?					
15.	Do you have to re-read the same line of words when reading?					
		__ x 0	__ x 1	__ x 2	__ x 3	__ x 4

TOTAL SCORE _____

Figure 2. 2 The Convergence Insufficiency Symptom Survey (CISS) (Scheiman *et al.*, 2005b)

The CISS score may not always be the most effective tool for documenting symptoms of CI. In a study by Borsting et al. (2003), 218 school-age children were evaluated, showing that 12.7% (50 children) presented with moderate CI and 4.6% (18 children) with severe CI. Interestingly, the CISS scores did not align with the CI diagnoses; children with moderate CI had an average score of 4.6, while those with severe CI had an average score of 6.67. Similarly, Marran et al. (2006) screened 170 school-age children and identified 44 cases of CI, with an average CISS score of 12.88. Therefore, the accuracy of CISS is questionable.

Horwood, Toor and Riddell (2014) investigated these concerns by recruiting 167 young adults, all university students without CI, to complete the CISS survey and undergo orthoptic assessments. In their study, they asked additional questions on CISS questionnaire as shown in Figure 2.3 to ensure the answers given were specific to visual problems. In their study found that questions No. 4, 5, 6, 9, and 15 would be not specifically related to ocular symptoms. To address this, supplementary Yes/No questions were included alongside those questions to confirm whether the symptoms were linked to visual problems. If the answer to the supplementary questions showed unrelated ocular symptoms, the question was scored as zero and added to the overall score. Of the 167 subjects, 17 (10.2%) were diagnosed with CI. Among the remaining 150 participants without CI, 35 (21%) were found to have a high CISS score. Interestingly, when solely considering the CISS score, 41 (24.6%) participants were found to have high score, and only 6 of them had true CI. As a result of supplementary questions, only 15 subjects were identified with a high CISS score, with only 2 of them having true CI. Additionally, 13 participants without CI showed high CISS scores following the adjustment to the CISS items. The study concluded that the CISS is not indicated as a screening tool for CI in asymptomatic populations.

Please read this questionnaire and tick the appropriate boxes

	Never	Infrequently	Sometimes	Fairly often	Always
1. Do your eyes feel tired when reading or doing close work?					
2. Do your eyes feel uncomfortable when reading or doing close work?					
3. Do you have headaches (*that come on*) when reading or doing close work?					
4. Do you feel sleepy when reading or doing close work?					
If so, do you think that it is because you were tired at the time?	Yes / No				
5. Do you lose concentration when reading or doing close work?					
If so, do you think that it is because you were not engaged with the content?	Yes / No				
6. Do you have trouble remembering what you have read?					
If so, do you think that has anything to do with your eyes?	Yes / No				
7. Do you have double vision when reading or doing close work?					
8. Do you see the words move, jump, swim or appear to float on the page when reading or doing close work?					
9. Do you feel like you read slowly?					
If so, do you think that has anything to do with your eyes?	Yes / No				
10. Do your eyes ever hurt when reading or doing close work?					
11. Do your eyes ever feel sore when reading or doing close work?					
12. Do you feel a pulling feeling around your eyes when reading or doing close work?					
13. Do you notice the words blurring or coming in and out of focus when reading or doing close work?					
14. Do you lose your place while reading or doing close work?					
15. Do you have to re-read the same line of words when reading?					
If so, do you think it is because your eyes have made it necessary?	Yes / No				

Figure 2. 3 The modified CISS questionnaire with supplementary Yes/No option for unrelated ocular problems (Horwood, Toor and Riddell, 2014).

2.2.2 CI and refractive error

Hirsch (1943) was one of the first to examine this possible correlation between CI and refractive errors. Hirsch reported that out of 48 university students with CI aged 17-41 years, 61% of patients had ametropia of ≤ 0.75 D. In a recent study, Singh *et al*. (2021) found among 176 CI patients aged 9-30 years myopia was present in 25%, hyperopia in 18% and emmetropia in 57% of the cohort. In comparison, Wajuihian (2017) reported lower rates of refractive error among 131 high school students aged 13–18 years with CI, 86.2% had emmetropia, while hyperopia, myopia, and astigmatism were present in only 6.8%, 6.0%, and 2.3% of cases respectively. Similar results were also found in the Convergence Insufficiency Treatment Trial (CITT) study on 47 children with CI aged 9-18 years where the mean spherical equivalent of refractive error was < 0.50D (Scheiman *et al.*, 2005a). Together, most of previous findings are within the estimated pool prevalence of myopia 11.7% and hyperopia 4.6% in the normal population reported by World Health Organization (WHO) regions (Hashemi, Pakzad, *et al*., 2018), suggesting no correlation between refractive error and CI. Schiemann and Weick (2014) and a review by Cooper and Jamal (2012) concluded that there was little evidence supporting an association between refractive error and CI.

2.2.3 Clinical signs of CI

The diagnosis of CI is based on the clinical findings (Scheiman *et al.,* 2007) but is not uniformly characterised in textbooks and studies (Lavrich *et al.,* 2019; Gantz *et al*., 2022). In the UK, the finding of receded NPC is generally used to diagnose CI (Evans and Doshi, 2001; The Royal College of Ophthalmologists, 2012; Ansons and Davis, 2014; BIOS, 2016). While, for example, in the United States of America (USA), CI is usually described as a set number of criteria (Evans, 2001; The Royal College of Ophthalmologists, 2012). Therefore, the main clinical signs used to diagnose CI, as well as their definitions and normative values are discussed below.

2.2.4 Near point of convergence (NPC)

NPC measurement assesses the nearest point where the eyes can maintain a single binocular vision (Phillips and Tierney, 2015). NPC is a widely used test among clinicians for assessment of CI. The NPC is measured by the examiner asking the patient to binocularly fixate on a target

at arm's length in the midline of the patient's head in a slightly depressed position. Then, the examiner slowly pushes the target towards the patient's eyes until the patients subjectively reports diplopia (Ansons and Davis, 2014) or objectively by the examiner observe one eye has diverged (Siderov et al., 2001). If convergence fails, the patient should be encouraged to exert additional effort to regain binocular single vision, for example if they report diplopia they should be encouraged to fuse the images if possible (Ansons and Davis, 2014). The last point at which convergence is maintained is recorded, in addition to what happens at the break point of convergence, whether that be the awareness of diplopia at the break point (Evans and Doshi, 2001; Rowe, 2012) or the observation of one eye diverging (Von Noorden and Campos, 2002). The recovery point can be assessed by moving the target away from the patient until it becomes single (Scheiman and Wick, 2014). The NPC and recovery points are typically assessed using RAF rule and recorded in centimetres.

The NPC measurement should be repeated multiple times (Ansons and Davis, 2014), but there is no consensus in the literature on the optimal number of repetitions. The NPC assessment with the RAF rule is usually repeated three times (Brautaset and Jennings, 2005; Adler *et al*., 2007). Additionally, there were suggestions for repeating the NPC 4 to 5 times (Mohindra and Molinari, 1980; Wick 1987), whereas Scheiman et al. (2003) proposed the repetition of 10 times to provide useful clinical information. Furthermore, Scheiman and Wick (2014) recommended repeating the NPC twice, firstly with an accommodative target followed by non-accommodative target.

2.2.4.1 NPC as a diagnostic sign

A receded NPC is considered as one of the most important diagnostic signs in CI (Borsting *et al.,* 1999; Von Noorden and Campos, 2002; Scheiman and Wick, 2014) and considered the most consistent sign of CI diagnosis (Scheiman and Wick, 2014). The NPC can be measured by moving a target in free space, either with a fixation stick or by utilising a specially designed ruler, such as The Royal Air Force (RAF) rule. The RAF rule has long been included in standard eye exams in the UK and Ireland, while The Bernell Accommodative Rule is the comparable tool used in the USA (Adler et al., 2007).

There are concerns about relying solely on NPC for diagnosing CI. Some studies suggest that NPC can effectively distinguish between symptomatic and asymptomatic CI patients (Hamed et al., 2013). Consequently, many clinicians reportedly use NPC as the primary assessment for identifying CI and initiating treatment if symptoms are present (Rouse et al., 1997). Hassan et al., 2018 noted that CI diagnosis often depends heavily on NPC assessment; as in their sample of 329 secondary school students, 98.78% showed reduced NPC.

2.2.4.2 Type of target

Various fixation targets have been utilised to test the NPC, including non-accommodative targets such as a fingertip, pencil, penlight, and a black vertical line on a white card as well as accommodative targets like a letter or 20/30 single column of letters (Scheiman *et al*., 2003). It was suggested that the convergence ability is more accurately assessed with an accommodative target compared to a non-accommodative target (Adler *et al*., 2007). Thus, the NPC should be assessed with an accommodative target (Trieu and Lavrich, 2018). Additionally, the convergence components: fusional, proximal, and accommodative convergence are thought to be maximised when an accommodative target is used (Adler *et al*., 2007; Pang *et al*., 2010).

Pang *et al*. (2010) tested NPC in young adults with normal binocular vision and another CI group with an accommodative target, a transilluminator (penlight), and a transilluminator with a red lens to investigate which target might be more sensitive to identify and assess CI. They concluded that measuring the NPC with the transilluminator with a red filter was more sensitive when diagnosing CI and screening suspected CI patients. Pang *et al*. found there was no significant difference in NPC measurement among young adults without CI when using the three targets. In a similar approach, Scheiman *et al*. (2003) measured NPC in students with normal binocular vision and patients diagnosed with CI. This study involved testing NPC using three different targets, including an accommodative target, a penlight, and a penlight with red and green lenses. Scheiman *et al*. (2003) suggested that assessment and clinical diagnosis could be achieved with any of the previous targets, but an accommodative target might give the highest accuracy.

2.2.4.3 Normal value of NPC

In terms of NPC normative values, data from orthoptic and optometric textbooks suggested that normal NPC is from 8 to 10 cm, and values greater than 10 cm are abnormal (Griffin and Grisham, 2002; Von Noorden and Campos, 2002, Ansons and Davis, 2014). Nevertheless, a number of studies had shown conflicting results for NPC normative values as shown in Table 2.1.

Table 2. 1 Different expected normal NPC findings with different viewing targets reported in the literature

Author – Year - Type	Population	Expected normal NPC (cm)	Point NPC measured from	Target type
Copobianco – 1952/ Study	Not recorded	6-10	Not reported	Non-accommodative
Hayes et al. (1988) - Study	297 School children	6	Not reported	Accommodative
Griffin and Grisham (2002) - Textbook	-	< 8	Not reported	Accommodative
Von Noorden & Campos (2002) - Textbook	-	8-10	The plane of the eyes	Not specified
Maples and Hoenes (2007) - Study	539 School children	≤ 5	Not reported	Accommodative
Pang et al. (2010) - Study	36 optometry students	< 6	Not reported	Accommodative
The Royal College of Ophthalmologists - (2012) - Guidelines	-	≤ 10	From the eyes	Not specified
Scheiman and Wick (2014) - Textbook	-	5 – 7	Not reported	Accommodative - Non-accommodative
BIOS (2016) - Guidelines	-	≤ 10	End of nose	Not specified

NPC: near point of convergence; BIOS: The British and Irish Orthoptic Society

Regarding the expected age-related normal NPC, several studies have reported varied results among the general population. Results of several studies of NPC among children and adults are shown in Table 2.2. However, the NPC measurement methods varied in terms of the type

of target, number of repetitions, and whether objective or subjective methods are utilised. Thus, the differences in normal values for NPC could be attributed to the various methods of administration as well as the lack of test technique standardisation (Scheiman *et al.*, 2003).

Table 2. 2 NPC break point findings among studies in children and adults in normal populations without CI.

Author - Year	Population Age (Years)	Mean NPC break (cm)	Point NPC measured from	Target type
Children				
Hayes et al. (1998)	297 Schoolchildren Kindergarten Third grade Sixth grade	3.3 4.1 4.3	Not reported	Accommodative
Rouse et al. (1998)	207 Schoolchildren 8-13	2.7	Not reported	Accommodative
Borsting et al. (1999)	14 Schoolchildren 8-13	3	Not reported	Accommodative
Jiménez et al. (2004)	1015 Schoolchildren 6-12	5.2	Not reported	Penlight
Darko-Takyi et al. (2021)	1261 schoolchildren 11-17	6.1	From the lateral canthus	Accommodative
Adults				
Siderov et al. (2001)	14 University students 25.1	5.3	Not reported	Accommodative
Adler et al. (2007)	14 optometric clinics 20-30	8.9	Not reported	Accommodative
Phillips and Tierney (2015)	39 General population 18-30	5.92	Not reported	Accommodative
Ostadimoghaddam et al. (2017)	2433 General population 31.2	8.59	Spectacle plane or the lateral canthus	Accommodative
Hamed et al. (2018)	82 University students 21.1	8.4	Plane of the lateral canthus	Accommodative
Heick and Bay (2021)	75 University students 21	6.2	Not reported	Accommodative
Coon et al. (2021)	30 University students 18-26	5.27	Not reported	Accommodative

NPC: Near point of convergence; NPC in centimetres

2.2.5 Prism fusion amplitude

Prism fusion amplitude is defined as the maximum amount of prism that the eyes can fuse (Ansons and Davis, 2014). Fusional amplitude is alternatively called fusional vergence, vergence reserve or vergence amplitude (Lança and Rowe, 2019). The positive fusion amplitude or positive fusional vergence (PFV) measures to what extent the eyes can converge with a base-out (BO) prism (Ansons and Davis, 2014).

The PFV is typically measured at both near and distance. PFV can be assessed either through the step vergence test using a prism bar or the smooth vergence test with rotatory prisms on the phoropter (Rovira-Gay *et al.,* 2023). Ansons and Davis (2014) describe the prism fusion range assessment method using a prism bar held over one eye in normal room illumination while the patient fixates binocularly on a target. At near the target would typically be an accommodative target. The prism power is gradually increased, and the patient is instructed to maintain fusion and to report when diplopia occurs, which is recorded as the break point (subjectively). It is important to keep the target clear during measurements to emphasise the fusion of the target. The break point is identified when the patient can no longer sustain accommodation on the target and starts to lose comfortable binocular function. The patient is instructed to report when the object becomes blurred but encouraged to keep the target clear until it appears double. After that, the prism power can be decreased until fusion is reached, which is the recovery point. The suggested normal PFV break point are 15Δ BO at distance and 35-40Δ BO at near (Ansons and Davis, 2014). A common criterion that has also been used in the literature to define reduced PFV is failing Sheard's criterion, which suggests that PFV is reduced when the near PFV is less than twice the near exophoria (Sheedy and Saladin, 1983). This criterion was used as part of the diagnosis of CI extensively in the CITT clinical trials as well as in various studies in the literature (Nawrot *et al*., 2013; Momeni-Moghaddam *et al.*, 2015; Aletaha *et al*., 2018; Nehad *et al*., 2018; Nabovati et al., 2020; Scheiman *et al*., 2020).

In tests like PFV, the relationship between accommodation and convergence differs from scenarios where both systems work in harmony, such as viewing a real object at a fixed distance. The purpose of this test is to decouple accommodation from convergence,

encouraging the vergence system to function independently of accommodation. During PFV measurements, patients are directed to keep the target clear while converging beyond the level naturally linked to their accommodation. This forces the brain to suppress the normal coupling between accommodation and vergence (the accommodative-convergence link).

It has been reported that some factors may affect the PFV result such as type of the target, the speed of increasing the prism and patient-directed instructions (Evans, 2007). Ludden and Codina (2012) reported that the increased viewing time per prism significantly extended PFV results. In their study, the near PFV changed with assessment speed from 31.9 Δ BO at 1 sec to 39Δ BO at 2 sec. They concluded that two-second viewing time per prism is recommended. Additionally, it has been reported that the PFV can be significantly affected by target size at distance while the PFV near is unaffected (Parkinson et al., 1998).

2.2.6 Exophoria

Heterophoria refers to a latent deviation in which visual axes are directed to the fixation point, but deviation occurs upon dissociation (Evans and Doshi, 2001; Rowe, 2012; Ansons and Davis, 2014). When the motor fusion amplitude is sufficient, resulting in heterophoria being asymptomatic it is termed compensated (Ansons and Davis, 2014). In comparison, inadequate fusional amplitude results in the decompensation of heterophoria, leading to symptoms and/or a manifest deviation (Ansons and Davis, 2014).

The UK definition of CI usually distinguishes between CI with and without concurrent near exophoria, and CI is considered secondary to large exophoria if present (BIOS, 2016). Furthermore, when there is 4Δ near exophoria greater than at distance, it is termed "non-specific exophoria" and not enough to be classified as convergence weakness exophoria unless the difference is 10 Δ or more (The Royal College of Ophthalmologists, 2012). Additionally, according to the BIOS (2016) and The Royal College of Ophthalmologists (2012) guidelines that the USA generally includes near exophoria and insufficient fusional vergence to primary CI definition, such as the CITT group.

There are objective tests that routinely measure exophoria such as the alternate prism cover test using a prism bar or loose prisms. The reported expected values of exophoria in children

and young adults are 1±1Δ at distance and 3±3Δ at near (Scheiman and Wick, 2014). It has been proposed that CI patients are more likely to have exophoria at near, but not necessarily part of the CI diagnosis (Cooper and Jamal, 2012).

In this regard, Rouse *et al.* (1998) noted that 51% of CI patients in an optometry sitting had exophoria at near. Similarly, among the 100 CI patients, Sarwat (2017) reported that exophoria at near was present in 64%. However, several studies have adopted the approach that the presence of exophoria at near at least 4Δ greater than distance for the diagnosis of CI (Rouse *et al.,* 1999; Scheiman *et al*., 2010; Kim and Chun, 2011; Revathy et al., 2011; Nawrot *et al.,* 2013; Momeni-Moghaddam *et al.,* 2015; Singh *et al*., 2021; Li *et al*., 2022). Conversely, a number of researchers has not included exophoria at near in CI diagnosis (Pickwell *et al*., 1986; Junghans *et al*., 2002; Abdi and Rydberg, 2005; Abdi *et al*., 2008; Rao, 2014; Elsayed and Abdou, 2015; Menigite and Taglietti, 2017). In this thesis, the definition of primary CI will be based on NPC and presence of symptoms and not be based on the presence or the size of an exophoria.

2.2.7 CI diagnostic criteria

The literature shows a variation in the criteria used to diagnose CI. Some researchers relied solely on NPC in diagnosing CI without considering exophoria at near or PFV. On the contrary, another perspective including exophoria at near greater than at distance along with reduced NPC and/or PFV for diagnosis of CI. It should be noted some researchers suggested that patients do not necessarily have all CI signs for definitive diagnosis of CI (Lavrich, 2010; Pillay and Munsamy, 2021). In the UK, according to the BIOS (2016) and The Royal College of Ophthalmologists (2012) guidelines, the definition adopted by orthoptists and ophthalmologists is NPC greater than 10 cm from the nose.

To date, there is no standardised set of clinical signs for the definition of CI. Therefore, the diagnosis of CI has been varied from one to multiple clinical signs. A receded NPC was used as a single sign to define CI. In addition, many authors considered receded NPC a primary diagnostic finding in CI and evaluating treatment outcomes (Scheiman et al., 2003; Jiménez *et al*., 2004; Adler *et al*., 2007). Rouse *et al.* (1997) conducted a survey in the USA and showed that 93.8% of the optometrists and 35% of the ophthalmologist diagnosed CI solely on NPC

and was sufficient criterion for CI diagnosis (Rouse *et al.*, 1997). Moreover, Pickwell and Stephens (1975) and Letourneau *et al.* (1979) used a remote NPC only with cut-off value of 10 cm for CI diagnosis. Similarly, Junghans et al. (2002) and Abdi *et al*. (2008) chose cut-off value of NPC > 9 cm to identify CI among children.

The CITT group has adopted diagnostic criteria which included four clinical signs for the definition of CI as NPC ≥ 6 cm, exophoria at near at least 4Δ greater than at distance and PFV < 15Δ Base-out at near or failing Sheard's criterion i.e. PFV < twice the near phoria and high CISS score (Scheiman *et al.,* 2020). The CITT chosen signs were conducted in several studies (Marran *et al,* 2006; Davis *et al.,* 2016; Hussaindeen *et al*., 2017; Menjivar *et al*., 2018; Nehad *et al*, 2018; Ma *et al.*, 2019a; Ma *et al.,* 2019b).

The Convergence Insufficiency and Reading Study (CIRS) Group adopted a grading diagnostic classification to define severity of CI based on the number of signs present (Rouse *et al*., 1998; Rouse *et al*., 1999). The CIRS classification is when the patients present with exophoria at near in addition to the number of the following clinical signs found:

1- Exophoria at near ≥ 4Δ than at far

2- Insufficient PFV (failing Sheard's criterion or minimum normative PFV of 12Δ BO blur or 15Δ BO break

3- Receded NPC ≥ 7.5 cm break or ≥10.5 cm recovery

Then severity of CI classified into:

- No Cl: no exophoria at near or < 4Δ difference between near and far

- Low suspect CI: exophoria at near and 1 sign

- High suspect CI: exophoria at near and 2 signs

- Definite Cl: exophoria at near and 3 signs

Table 2.3 reports the variation in CI diagnostic criteria in other publications. For example, Scheiman *et al*. (1996) defined the CI as a receded NPC with at least three additional signs: exophoria greater at near than at distance, insufficient PFV and low AC/A ratio. Note that some researchers included different accommodative measures as supportive signs such as the amplitude of accommodation (AA), low negative relative accommodation (NRA), low AC/A ratio, low accommodative lag and failing binocular accommodative facility.

It should be noted that the patients with two or three signs should be considered as clinically significant (Ma *et al*., 2019b). In addition, the clinical presentation of four signs or more is not common in CI patients (Cooper and Jamal, 2012; Pillay and Munsamy, 2021). Although both the patient's concerns and the clinician's efforts to address related symptoms, many early diagnostic criteria did not consider the presence of symptoms. Consequently, while the clinician aims to measure clinical findings, incorporating symptoms into the diagnostic criteria could help differentiate symptomatic from asymptomatic patients. However, without a consistent definition of CI and diagnostic criteria, the prevalence and treatment rates are inconsistent and difficult to compare.

Table 2. 3 Comparison of different CI definitions from previous studies with their cutoff values and used techniques.

Author/ Year of study	CI Diagnostic criteria	Main diagnostic signs and additional signs	Symptoms as diagnostic sign	Population
Letourneau et al. 1988	1) NPC > 10 cm (3 times) (Objective observation of the deviation on one eye) 2) Exophoria at near > exophoria at far (Cover test)	Two signs present	Not included	Elementary school
Porcar et al. 1997	1) Exophoria at near > 6Δ (Von Graefe method) 2) Receded NPC (cutoff value and method not reported) 3) AC/A < 3/1 (Gradient method) 4) Low PFV at near (no values specified)	All signs present	Not included	University students
Lara et al. 2001	1) Exophoria at near > 6Δ (cover test) 2) PVF ≤ 11/14/3 D 3) NPC > 10 cm break, > 17.5 recovery (Push-up method) 4) MEM ≤ 0D 5) Calculated AC/A < 3/1 6) BAF ≤ 3 cpm with + 2D 7) NRA ≤ 1.50D	Signs 1-3 (fundamental) and two signs from 4-7	Not included	Optometric clinic
Richman et al. 2002	1) >3 exophoria at distance and >7 exophoria at near 2) Receded NPC (cutoff value not reported) 3) Low PFV (method not reported) 4) Low NRA (method not reported)	At least two findings	Not included	University students
Junghans et al. (2002)	1) NPC > 9 cm	One sign	Not included	School children
Borsting et al. 2003	1) Exophoria at near ≥ 4 than at distance (cover test) 2) PFV at near ≤ 7 D break or 3 D recovery or fails Sheard's criteria 3) NPC > 6 cm (Push-up method)	Minimum 2 signs or all 3 signs present	CISS survey	School children
Abdi et al. 2005	NPC ≥ 10 cm (Push-up method)	Receded NPC	Not included	School children

	Mild CI: NPC of 10-14 cm; Moderate CI: NPC of 15-19 cm; Marked CI: NPC of 20-25 cm			
Abdi et al. (2008)	1) NPC > 9 cm	One sign	Not included	School children
Shin et al. 2009	1) Moderate to high exophoria at near, >6Δ (Von Graefe method) 2) Exophoria at near is greater than the far, ≥ 4Δ (Von Graefe method) 3) NPC ≥6 cm (free space) 4) Low PFV at near: failing Sheard's criterion or least normal PFV ≤ 12/15/4 for blur, break, and recovery (at least one of three) 5) Calculated AC/A ratio < 3/16 6) Fails BAF with +2.00D, ≤ 2.5 cpm. 7) Low NRA ≤ 1.50 D	Symptoms associated with near work in addition to signs 1–4 need to be present, and one of 5–7	Symptoms included	School children
Sharif et al. 2014	1) NPC of ≥ 10 cm (method not reported) 2) Exophoria at near ≥4Δ more than far 3) Low PFV (failing Sheard's criterion) 4) Normal AA (Hofstetter formula= 15- 0.25× age in years)	All signs present	Not included	University students
Hassan et al. 2018	1) Exophoria at near at least 4Δ greater than at distance (cover test) 2) NPC of ≥8 cm break (Push-up method) 3) PFV ≤15 base-out prism	Three signs present	Not included	General population

Failing Sheard's criterion: PFV is less than twice the near phoria. CI: convergence insufficiency; NPC: near point of convergence; PFV: positive fusional vergence; NRA, negative relative accommodation; cpm: cycles per minute; AC/A: accommodative convergence to accommodation. BAF: binocular accommodative facility; MEM: monocular estimation method retinoscop

2.2.8 Prevalence of CI

CI is one of the most common binocular vision disorders (Letourneau and Ducic, 1988; Scheiman *et al*., 1996; Rouse *et al.*, 1999; Barnhardt *et al*., 2012). Several studies have reported great variation in prevalence rates of CI in general and clinical populations. Recent meta-analysis by Mohamed and Alrasheed (2023) has reported that the overall prevalence of CI from 12 countries was 7.98%. While other authors indicated that prevalence rates ranged between 3.5% and 17.6% in general and clinical populations (Pillay and Munsamy, 2021). The different prevalence rates among young adults are shown in Table 2.4.

Table 2. 4 Different prevalence rates with different diagnostic criteria within general and clinical populations among young adults.

Author/Year of study	Country of study	Sample size and population	Age (years)	Criteria for diagnosing CI	Symptoms as diagnostic sign	Prevalence rate
Richman and Laudon (2002)	United States	48 University students	24–31	At least two signs: • >3 exophoria at distance and >7 exophoria at near • Receded NPC • Low PFV • Low NRA	Not included	13%
Sharif *et al.* (2014)	Iran	160 University students	18-30	Three signs must present: • NPC > 10 cm • Exophoria at near ≥4Δ more than distance • Low convergence amplitude	Not included	10%
Hoseini-Yazdi *et al.* (2015)	Iran	83 Patients – Optometry clinic	21.3 ±3.5*	All three signs need to be present: • Moderate to high exophoria at near, > 6Δ • Low PFV at near, ≤11/14/3 for blur, diplopia and recovery (at least one of three) • NPC >10 cm, >17.5 cm for recovery And two of diagnostic findings:	Not included	3.6%

				• Calculated AC/A ratio, < 3/1 • Fails BAF testing with +2.00D, ≤3 cpm • Low MEM, < +0.25 D • Low NRA, ≤1.50 D		
Ma *et al.*, (2019b)	China	415 patients – Ophthalmology clinic	21-38	Three clinical signs must present: • Exophoria at near ≥ 4Δ than at distance • Receded NPC, ≥ 6 cm • Low near PFV (break point ≤15△ or failed Sheard's criterion[#]	CISS survey	9.6%
Moon, *et al.* (2020)	South Korea	184 University students	18-28	Presence of three signs: • Exophoria at near ≥ 4Δ than at distance • PFV at near < 14Δ for blur or <18Δ for break • NPC ≥ 7.5 cm	Not included	Two sign CI 18.5% Three sign CI 10.3%

*Age is written with mean ± standard deviation, because the study did not indicate the age range. # Failing Sheard's criterion: PFV is less than twice the near phoria. CI: convergence insufficiency; NPC: near point of convergence; PFV: positive fusional vergence; NRA, negative relative accommodation; MEM: monocular estimation method retinoscopy; AC/A: accommodative convergence to accommodation.

Several previous studies investigating the prevalence of CI have shown great variation among school-age children ranging from 1.6% to 32.6% (Wajuihian and Hansraj, 2014; Ma *et al*., 2019a). Differences in the diagnostic criteria, techniques, and instrumentation used might have contributed to this great diversity in reported prevalence rates. A number of researchers used the CIRS criteria (low suspect CI, high suspect CI and definite suspect CI) to determine the prevalence in the children population. Rouse *et al*. (1999) used the CIRS grading to investigate the frequency of CI among fifth and sixth graders. Their findings showed that 8.4% had low suspect CI, 8.8% had high suspect CI and 4.2% had definite CI. Atowa *et al*. (2019) also determined the frequency of CI based on the CIRS method among 537 school children aged 10–16 years. The frequency of low suspect CI, high suspect CI, and definite CI were 9.6%, 5.8%, and 4.1%, respectively. It can be noted from previous studies that using the same diagnostic criteria has led to less variance in the results. Table 2.5 illustrates the different prevalence rates reported in children.

Table 2. 5 Different prevalence rates with different diagnostic criteria within general and clinical populations among school-age children and paediatric clinical population.

Author/Year Country of study	Sample size/ population	Age (years) *	Criteria for diagnosing CI	Symptoms as diagnostic sign	Prevalence rate
Scheiman *et al.* (1996) United States	1650 children Optometry clinic	6-18	• Receded NPC break > 10 cm or recovery > 17.5 cm And at least three signs from • PFV blur < 11 Δ, break < 14 Δ, recovery < 3 Δ • BAF: can't clear with + 2.00 D • Exophoria at near > than distance • AC/A ≤ 2/1 • MEM < 0 • Fails Sheard's criterion# • Exofxation disparity with type I curve or type III curve	Not included	5.3%
Rouse *et al.* (1998)** United States	415 children Optometry clinic	8-12	CIRS criteria: exophoria at near and • Exophoria at near ≥ 4Δ than distance • Failing Sheard's criterion# or minimum normative PFV at near of 12/ 15 (blur/break) • Receded NPC ≥ 7.5 cm or ≥ 10.5 cm recovery	Not included	• Low suspect CI - 33% • High suspect CI - 12% • Definite CI - 6%
Rouse *et al.* (1999)**	453 school children	9-13		Not included	• Low suspect CI - 8.4%

United States			Low suspect CI: exophoria at near and 1 sign High suspect CI: exophoria at near and 2 signs Definite CI: exophoria at near and 3 signs		• High suspect CI - 8.8% • Definite CI - 4.2%
Atowa *et al.* (2019) Nigeria	537 school children	10-16		Not included	• Low suspect CI - 9.6% • High suspect CI - 5.8% • Definite CI - 4.1%
Hussaindeen *et al.* (2017) India	920 school children	7-17	At least two or more signs present: • Exophoria at near > 2Δ than distance • Receded NPC > 7.5 cm with accommodative target • Receded NPC > 12 cm with penlight and red filter • PFV break < 15	Not included	Urban group – 16.5% Rural group – 17.6%
Hassan *et al.* (2018) Sudan	4211 high school students	15.5 ± 2.5*	Three signs present: • Exophoria at near > 4Δ than distance • Receded NPC ≥ 8 cm break • PFV ≤ 15Δ	Not included	6.12%

**The difference between two studies is the patients recruited; *Age is written with mean ± standard deviation, because the study did not indicate the age range. # Failing Sheard's criterion: PFV is less than twice the near phoria. CI: convergence insufficiency; NPC: near point of convergence; PFV: positive fusional vergence; BAF: binocular accommodative facility. cpm: cycles per minute; MEM: monocular estimation method retinoscopy; AC/A: accommodative convergence to accommodation.

Previous studies mentioned above have reported high prevalence rates among school-age children and young adults. This observation raises the question of whether it might be due to the increased near demand for studying and using e-devices (Pillay and Munsamy, 2021). However, there was a great diversity of CI prevalence rates in different population groups. The possible reasons for such variance between studies are differences in the sample size as well as cutoff values and measurement methods. Additionally, the CI definitions differed in populations being studied. Therefore, direct comparisons of the studies mentioned above are probably inconsistent and challenging. It is noteworthy that the studies used stringent criteria such as CIRS criteria with four signs i.e. definite CI, led to lower prevalence rates. Examples of such are Rouse et al. studies where definite CI were 6% and 4.2%. In contrast, CI rates were doubled for the same populations when signs lowered to two i.e. low suspect, to become 12% and 8.8%. However, the prevalence rates are also affected by the type of study population. For example, clinical populations include participants who have been diagnosed or referred to hospitals or clinics. Consequently, the prevalence rates in samples from clinical populations are likely to be high and considered biased data (Cacho-Martínez *et al*., 2010).

2.2.9 Impact of population type on outcomes

The selection of study participants can greatly affect research findings due to differences in baseline characteristics, symptom severity, and prior exposure to interventions. For example, recruiting participants from an asymptomatic, unselected school cohort would likely yield very different results compared to a symptomatic hospital population. A typical school cohort represents a general population, with varying levels of CI severity, including a significant proportion of children who are either asymptomatic or only mildly symptomatic. In contrast, a hospital-based cohort, for example optometric clinic is composed of individuals who actively seek treatment. This variability in demographics markedly different outcomes in studies on prevalence and treatment of CI. Additionally, in the UK, optometrists often encounter the CI cases and treat with simple orthoptic exercises (Adler, 2007). A similar challenge arises in the context of the UK's orthoptic department caseloads. Patients referred to orthoptic departments might have already undergone basic treatment, such as pencil push-ups, typically prescribed by primary optometrists. Thus, the referral pathways as in orthoptic

practice in the UK, where patients might often arrive with a history of sever conditions or failed treatments.

The outcomes of any intervention tested on these two populations are unlikely to be comparable. These differences highlight the importance of carefully considering recruitment strategies and the populations they represent when interpreting research findings.

2.3 Accommodation

Accommodation is the process where the eye adjusts refractive power to maintain a clear retinal image (Von Noorden and Campos, 2002). Without the accommodation process, near objects will be blurred. Convergence and accommodation are linked, both occur when viewing an object at near. Accommodation is measured in dioptres (D), which is the reciprocal of the fixation distance, for example, *when the fixation target is positioned at 1/2m, the accommodation equals 2D* (Von Noorden and Campos, 2002).

The nearest point where the eyes can make a fixation target clearly focused is termed the near point of accommodation (NPA) and the amplitude of accommodation (AA) refers to the difference in the eye's optical power when fixating on near and far distances (Rowe, 2012).

2.3.1 Assessment of accommodation

The accommodative function can be measured through the NPA, accommodation facility and accommodation response (McClelland and Saunders, 2003; Saladin, 2006). The RAF rule is typically used in orthoptic practice to measure the NPA subjectively, for example via push-up method (Esmail and Arblaster, 2016). The push-up method is the most common method for NPA assessment (Mathebula *et al*., 2016; Hashemi *et al*., 2019). In the push-up method, the fixation target is gradually moved towards the eyes until the target starts to blur (Esmail and Arblaster, 2016). It is recommended that the measurement be repeated several times (Ansons and Davis, 2014). The NPA typically measured in centimetres and then converted to AA. The expected normal AA was suggested by researchers and used as a reference in several studies. The are three equations derived by Hofstetter (1950) can predict the AA are as follows:

The minimum AA = 15 - (0.25 x age in years)

The mean AA = 18.5 - (0.30 x age in years)

The maximum AA = 25 - (0.40 x age in years)

2.3.1.1 Accommodative facility

The accommodative facility measures how quickly the patients how quickly a patient can exert and relax accommodation, typically done using plus and minus flipper lenses. The test can be performed monocularly (monocular accommodative facility (MAF) or binocularly (binocular accommodative facility (BAF) with flipper lenses such as ±1.50D and ±2.0D. The patient reports when the accommodative target (at near or distance) becomes clear through a lens before flipping to the other lens. One cycle consists of one alternation between plus and minus lenses, and the test is recorded in cycles per minute (CPM). The average expected values for adults are BAF: 11 CPM and MAF: 13 CPM (Scheiman and Wick, 2014).

2.3.1.2 Accommodative response

The accommodative response refers to the level of accommodation produced by the crystalline lens and is typically less than the required demand (Little, 2015). When the accommodative response is less than the accommodative demand there is lag of accommodation, and if greater than accommodative demand there is lead of accommodation (Nguyen *et al.,* 2018). Assessment of the accommodative response has an important role in the diagnosis and treatment of accommodation anomalies (Antona *et al*., 2009). For example, a high accommodative lag might be related to anomalies such as AI (Nguyen *et al*., 2018).

The accommodative response can be assessed objectively using dynamic retinoscopy, optometer incorporating an autorefractor (León *et al*., 2012) or Videorefractor incorporating a PlusoptiX SO4 (Horwood and Riddell, 2009) which makes simultaneous measurements of vergence and accommodation. The PlusoptiX SO4 is discussed in more detail in Chapter 6.

The monocular estimate method (MEM) and Nott retinoscopy are the most commonly used dynamic retinoscopy in clinical practice (Goss, 2010).

Koslowe (2010) has described the MEM as follow:

- The test is performed both eyes open

- The examiner tested one eye and then repeated the procedures for the other eye in light room.

- The fixation target is mounted to the retinoscope, and the patient is instructed to focus on the target from a distance of 40 cm.

- The examiner observes the retinoscope reflex and places plus or minus lenses based on the direction of the reflex at the spectacle plane until the reflex motion is neutralised.

- The power of the lens that neutralises the reflex represents the degree of accommodative response, for instance, +0.75 DS.

In Nott retinoscopy, there are no trial lenses used for neutralisation of the retinoscope reflex. The Nott retinoscopy is described by Koslowe (2010) as follow:

- The test is performed both eyes open

- The examiner tested one eye and then repeated the procedures for the other eye in light room.

- The fixation target is placed, for example, at 40 cm from the patient. The patient is instructed to fixate on the target.

- The examiner performs retinoscopy by adjusting the retinoscope's distance farther or closer to the patient's eye based on the direction of the reflex until a neutral reflex is observed.

- The difference in dioptres between the fixation target and the retinoscope position where neutralisation is observed is the accommodative response.

- *For example: the distance of fixation target from patient is 40 cm, in dioptres is 100/40 = 2.5 D.*

The distance of retinoscope position when neutralisation is observed 50cm, in dioptres is 100/50 = 2.0 D.

The accommodative response value is:

2.5 D - 2.0 D = +0.50 D (lag of accommodation)

Antona *et al.* (2009) investigated the inter examiner repeatability of accommodative response measurement with MEM and Nott retinoscopy. The study determined that Nott retinoscopy was the best clinical method for accommodative response assessment. Scheiman and Wick (2014) reported the expected normal finding with MEM retinoscopy is +0.50 ±0.25D. Additionally, Koslowe (2010) reported that expected normal findings for both MEM and Nott retinoscopy are +0.5D. In children, Rouse *et al*., (1984) reported that MEM values outside plano to +0.75D might be considered abnormal.

2.2.9.1 Subjective versus objective measures

Accommodation can be evaluated using subjective or objective methods, each with its advantages and limitations. Subjective measures rely on the individual's responses to visual stimuli, making the test outcome dependent on the patient's perception and communication. Common example is the push-up test where patients report when a target becomes blurry.

Subjective tests are easy to administer and require minimal specialised equipment, making them widely accessible in clinical settings. These tests actively involve the patient, providing insights into their perceived visual experience and functional vision. Additionally, subjective measures are well-suited for large-scale screenings or settings where quick assessments are needed. Results depend heavily on patient cooperation and understanding, which can introduce variability, especially in children. It should be noted that subjective tests may not detect involuntary or reflexive accommodation accurately.

Objective measures evaluate accommodation without relying on the patient's subjective input, using instruments such as autorefractors or Plusoptix photorefractors. These devices measure the refractive state of the eye directly while the patient focuses on targets at varying distances. Objective methods provide accurate, quantifiable data, reducing the variability associated with patient responses.

Such a method is particularly beneficial for assessing populations unable to provide reliable subjective feedback, such as children. In addition, objective measures can detect small

changes in refractive state, making them valuable for diagnosing accommodation anomalies (Horwood and Riddell, 2008). Moreover, they can be standardised across clinicians and settings, facilitating comparisons in research and clinical practice. On the other hand, instruments for objective measurement are often expensive and may not be available in all clinical settings. Measurements can sometimes be influenced by factors such as pupil size, instrument alignment, or accommodation induced by the testing apparatus itself. Furthermore, objective tests can be more time-consuming to set up and perform, particularly in non-specialist clinics.

The choice between subjective and objective measures depends on the context and purpose of the assessment. Objective methods are preferred in research due to their precision, standardisation, and reproducibility, which are critical for drawing reliable conclusions. While subjective measures provide insights into the patient's perceived visual performance.

2.3.2 Accommodation insufficiency (AI)

AI is defined as the inability to focus sufficiently for near vision (Nunes et al., 2019). AI is the most common type of accommodative anomaly (Hokoda, 1985; Bartuccio et al., 2008) and is characterised by reduced AA or inability to sustain focus at near (Birnbaum, 1993). The direct clinical findings are insufficient AA, difficulties in achieving clarity with -2.00D during monocular and binocular accommodation facility tests, decreased positive relative accommodation (PRA) and high lag of accommodation (Weissberg, 2004). The AA assessment is important in diagnosing AI, and for many clinicians, insufficient AA is the most frequent and often the only sign needed to diagnose AI (Cacho *et al*., 2002). It is noteworthy that AI is considered the most common type of accommodation anomalies (Hokoda, 1985). The most common symptoms associated with AI are blur, reading difficulties, movement of the print (Scheiman and Wick, 2014) headache, eye strain and asthenopia (Bartuccio *et al*., 2008). Additionally, symptoms associated with AI are usually simultaneous with the increased near demand (Bartuccio *et al.*, 2008).

2.3.2.1 Diagnostic criteria of AI

In a systematic review that explored the diagnostic criteria used for accommodation anomalies between 1986-2012, Cacho-Martínez *et al*. (2014) indicated that AI was the most studied condition among accommodation anomalies. The AA is considered the gold standard for assessing accommodation function (Cacho *et al*., 2002; Bartuccio *et al.,* 2008). Additionally, several studies mainly diagnosed AI if the AA is less than Hofstetter's age-expected amplitude formula (Daum, 1983; Russell and Wick, 1993; Dwyer and Wick, 1995; Borsting *et al.,* 2003; Marran *et al.,* 2006; Ma *et al*., 2019). Furthermore, Scheiman and Wick (2014) have suggested that if the AA is below 2D or less than Hofstetter's minimum age-expected amplitude is insufficient accommodation. This suggestion was considered as a primary diagnostic criterion in many clinical trials (Cacho-Martínez *et al*., 2014).

Besides insufficient AA as a preliminary test for AI diagnosis, several studies have used additional tests to support the diagnosis. These tests include a MAF, BAF, PRA, NRA and MEM dynamic retinoscopy (Cacho-Martínez *et al*., 2010). However, some authors consider these additional measures are without homogeneous guidelines for selection and standardised cutoff values (García-Montero *et al*., 2019). As a result, varied prevalence rates, and accurate comparison of treatment outcomes is challenging. However, Scheiman and Wick (2014) reported expected findings for accommodative tests as shown in Table 2.6. It is worth mentioning that it is rare that a patient fails in all measurements or has all these signs (Bartuccio *et al*., 2008).

Table 2. 6 Expected normal Values for accommodative Tests (Scheiman and Wick, 2014)

Test	Age/Method	Expected findings	SD
AA	push-up method	18.5 - 0.3 x age*	±2.0 D
MAF	Children (6-12 years): with ±2.00 on accommodative rock cards	5.5-7.0 cpm	±2.5 cpm
	13-30 years old: ±2.00 flipper lenses, saying now when clear	11.0 cpm	±5.0 cpm

	Adults 30-40 years old	Not available	-
BAF	Children (6-12 years): with ±2.00 on accommodative rock cards	3-5 cpm	±2.5 cpm
	Adults: (based on amplitude scaled testing)	10 cpm	±5.0 cpm
MEM	Children and adults	+0.5	±0.25 D
PRA	Children and adults	−2.37 D	±1.00 D
NRA	Children and adults	+2.00 D	±0.50 D

*Hofstetter's average amplitude of accommodation. AA: amplitude of accommodation; MEM: monocular estimation method retinoscopy; MAF: monocular accommodative facility; BAF: binocular accommodative facility. cpm: cycles per minute; PRA: positive relative accommodation; NRA: negative relative accommodation; SD: standard deviation

A number of authors used a single or multiple signs for AI definition. Different diagnostic criteria of AI and their cutoff values are shown in Table 2.8. To date, there is a disagreement on diagnostic criteria for AI and different definitions have been used throughout the literature. It is noteworthy that accommodative measures should be linked with symptoms to reach the correct diagnosis of the condition (Cacho et al., 2002).

A much debated question among researchers is the effect of diagnostic criteria on the prevalence rate. García-Montero *et al.* (2019) when retrospectively explored the effect of single criterion versus multiple signs on the frequency of AI in 205 clinical records. Interestingly, a single sign of low AA showed an AI prevalence of 41.95% and 6.34% low AA and MAF ≤ 6 cpm were considered. Moreover, the study found using three signs of low AA, MAF ≤ 6 cpm and BAF ≤ 3 cpm resulted in a prevalence of 2.93%. These findings suggest that the prevalence rate might be overestimated when using AA as a single sole criterion. In addition, the prevalence is also directly affected by the number of tests used. Arguably, strict diagnostic criteria could increase the sensitivity of the estimated prevalence rate. However, the disparity in sample size, age, type of population, cutoff values and the number of tests used to reach the diagnosis has led to a wide variation of prevalence rates.

Table 2. 7 Review of previous studies reporting different diagnostic criteria and cutoff values for AI.

Authors/ year of study	Evaluation of symptoms	AA	MAF	BAF	PRA	NRA	MEM
Daum 1983	Reported by the patient	Push-up method < (15-0.25xage)	-	-	-	-	-
Russell and Wick 1993	Not reported	2.5D < Duane's criterion	-	-	-	-	-
Hokoda 1985	Reported by the patient	2D < (15-0.25xage)	-	-	≤ 1.25D	-	-
Scheiman et al. 1996	Not reported	Push-up method 2D < (15-0.25xage)	Can't clear -2.00D	Can't clear -2.00D	≤ 1.25D	-	≥ 1.00D
Porcar et al. 1997	Symptoms questionnaire	Monocular/ Push-up method 2D < (15-0.25xage)*	≤ 6 cpm with ±2D	≤ 3 cpm with ±2D	-	-	≥ +0.75 D
Rouse et al. 1998	Not reported	Monocular/ Push-up method < (15-0.25xage)	-	-	-	-	> +0.75D
Lara et al. 2001	Reported by the patient	Monocular/ Push-up method 2D < (15-0.25xage)	≤ 6 cpm with -2D	≤ 3 cpm with -2D	≤ 1.25D	-	> +0.75D
Borsting et al. (2003)	CISS questionnaire	18.5 - 0.3 x age*	-	-	-	-	-
Marran et al. 2006	CISS questionnaire	Monocular/ Push-up method 2D < (15-0.25xage)	-	-	-	-	-
Sterner et al. 2006	By several questions	Monocular < 8D Binocular < 10D	-	-	-	-	-

Hoseini-Yazdi et al. 2015	Reported by the patient	Push-up method 2D < (15-0.25xage)	≤ 6 cpm with -2D	≤ 3 cpm with -2D	≤ 1.25D	≤ 1.50D	> +0.75D
Ma et al. 2019b	Not reported	Monocular/ Push-up method 2D < (15-0.25xage)	-	-	-	-	-

*Hofstetter's formula for minimum amplitude: 15–0.25×age (in years). AI: accommodative insufficiency; AIF: accommodation infacility; CISS: Convergence Insufficiency Symptoms Survey; AA: amplitude of accommodation; MAF: monocular accommodative facility; BAF: binocular accommodative facility; PRA: positive relative accommodation; NRA: negative relative accommodation; MEM: monocular estimation method; cpm: cycle per minute

2.3.2.2 Prevalence of AI

The prevalence rates of AI in the general population remain uncertain due to the lack of population-based epidemiological studies (Davis *et al.,* 2016). Furthermore, AI rates have been reported by several researchers based on data from clinical practices (Scheiman and Wick, 2014). A wide range of prevalence data been reported considerable diversity of prevalence rates among different ethnicities and age groups (Hussaindeen and Murali, 2020). This great variability in the prevalence of AI were seen in the reported rates which ranged from 0.4% to 61.7% (Cacho-Martínez *et al.,* 2010). It should be noted that the majority of studies have focused on children, and few studies have investigated the prevalence rates after the age of 20 years (García-Muñoz *et al.,* 2016; Hussaindeen and Murali, 2020). In addition, several studies have explored accommodation anomalies but mainly focused on the prevalence of AI (Wajuihian and Hansraj, 2014).

The prevalence of AI in general and clinical populations was ranged between 0.2% to 18.3% (Wajuihian and Hansraj, 2016b). However, several studies reported prevalence based on insufficient AA, which was the primary criterion for diagnosing AI. For example, Sterner *et al.,* (2006) used the AI definition of monocular AA < 8D and binocular AA < 10D among 131 school-age children aged 6-10 years to report a high prevalence of 25%. In comparison, Rouse *et al.* (1999) also chose to define the AI by one sign when insufficient AA or MEM > +1.00 is present. The reported prevalence in 453 (9-13 years) school-age children was relatively lower than in the previous study with 11.5%.

With a different approach, a number of studies chose more than two signs for AI definition. Scheiman *et al*., (1996) used multiple clinical signs to investigate the frequency of AI in 1650 pediatric clinical population aged 6-18 years. The diagnostic criteria were reduced AA need to be present with at least two signs of PRA ≤ 1.25D, MAF (cannot clear -2.00D), BAF (cannot clear -2.00D) and MEM ≥ 1.00D. This strict criterion showed a low prevalence of 2.3%. The different prevalence rates of AI with their diagnostic criteria are shown in Table 2.8.

Table 2. 8 Prevalence rates of AI with different diagnostic criteria and cutoff values

Author/Year/ Country of study	Sample size/and population	Age (years)	Diagnostic criteria of AI	Prevalence rate
Scheiman *et al.* (1996) United States	1650 children Optometry clinic	6-18	AA < 2D from mean (15-0.25xage) Push-up method and at least two signs from: • PRA ≤ 1.25 D • MEM ≥ 1.00 D • BAF can't clear -2.00 D • MAF can't clear -2.00 D	2.3%
Porcar *et al.* (1997) Spain	65 University students	22±3*	• AA < 2D from (15-0.25xage) push-up method • PRA ≤ 1.25 D • MEM ≥ + 0.75D • MAF ≤ 6 cpm and BAF ≤ 3 cpm with -2D • FCC ≥ + 1.00D	10%
Rouse *et al.* (1999) United States	453 school children	9-13	Sign 1 or sign 2: • AA < from mean for age (15-0.25xage) monocular Push-up • MEM >+1.00D	11.5%.
Lara *et al.* (2001) Spain	265 Optometry clinic	10-35	Signs 1-2 are fundamental: (1) AA < 2D from (15-0.25xage) monocular push-up method (2) MAF ≤ 6 cpm with -2D and two signs from 3-5: (3) BAF ≤ 3 cpm with -2D (4) MEM > + 0.75D (5) PRA ≤ 1.25D	3%
Sterner *et al.* (2006) Sweden	131 school children	6-10	• AI definition of monocular AA < 8D and binocular AA < 10D (Push-up method)	25%
Wajuihian *et al.* (2016b) South Africa	1201 school children	13-19	At least two signs 1 and 2 or 1 and 3: 1) AA < 2D from (15-0.25xage) monocular Push-up 2) MEM >+0.75D.	4.5%

			3) failing MAF ≤ 6 cpm with -2D	
Hashemi *et al.* (2019) Iran	726 University students	18-25	• AA < 2D from mean age (18.5-0.3xage) monocular Push-up And at least one sign from: • MAF ≤ 6 cpm with ±2.00D • MEM >+0.75D	4.07%

*Hofstetter's formula for minimum amplitude; Hofstetter's average amplitude of accommodation. AI: accommodative insufficiency; AA: amplitude of accommodation; MAF: monocular accommodative facility; BAF: binocular accommodative facility; cpm: cycle per minute; PRA: positive relative accommodation; MEM: monocular estimation method; FCC: fused cross-cylinder.

2.3.3 CI and AI

CI and AI may share similar symptoms (Marran *et al.,* 2006) and CI can be secondary to AI (Ansons and Davis, 2014; BIOS, 2016). It has been noticed that as the severity of CI increases, the higher comorbidity of AI is found (Marran *et al.,* 2006). In this regard, Rouse *et al.* (1999) examined 453 fifth and sixth grade children for frequency of CI based on the CIRS diagnostic criteria (Rouse *et al*., 1998) (discussed in section 2.2.7). Rouse *et al.* reported a high significant percentage of AI among CI subjects as 21% in low suspect CI, 55% in high suspect CI and 79% in definite CI. Likewise, Borsting *et al.* (2003) screened 392 school-aged children for the frequency of CI and AI. In their study, 17.3% of children were found to have clinically significant CI, whereas 10.5% of them had AI. While the severity of symptoms, interestingly, were similar between CI and AI groups as the CISS score was 6.7 and 6.3, respectively. It has been reported by Daum (1983) that AI and CI are associated with similar symptoms. Daum (1983) reviewed the records of 96 patients with AI and reported that 62 of the patients have CI and the highest incidence of symptoms was a blur, headache, asthenopia and diplopia with 59%, 56%, 45% and 30%, respectively. In another study, Daum (1984) also retrospectively reviewed 110 patients with symptomatic CI. Daum found the incidence of blur, headache, asthenopia and diplopia was 47%, 54%, 36% and 47%, respectively. This observation suggests that the symptoms of CI and AI may overlap and have similar symptomology.

With a different approach, Marran *et al.*, (2006) screened 170 CI school-age children to differentiate CI from CI with AI group. Marran *et al.* adopted the CITT diagnostic criteria for the definition of CI (Scheiman *et al.*, 2008) and defined AI as monocular AA at least 2D below Hofstetter's formula (15 - 0.25 x patient's age in years) by push-up method. The results revealed that 25.9% of children with CI, 8.2% with AI and 5.9% with comorbidity of CI and AI. The results showed that the CI children had mean values of the AA 5.43 D, NPC 6.17 cm and CISS score 12.88; the AI children had AA 12.89 D, NPC 6.0 cm and CISS score 19.69; whilst the CI with AI children had reduced AA 13.1 D, NPC 13.25 cm, and CISS score 22.8. An important finding from the study is that the CISS score was higher in groups of AI and CI with AI, suggesting that AI may present more symptoms than CI and potentially increased symptoms in CI. Another important observation is that children with AI and CI had similar mean NPC values, whereas CI with AI group had more receded NPC. This suggests that NPC measurement can be affected by insufficient accommodation. Thus, evaluating accommodation in CI conditions is important to differentiate between CI alone and CI with AI comorbidity (Marran *et al.,* 2006).

Davis *et al.* (2016) also investigated the frequency of CI and AI in 484 school children and used the CITT protocol (Scheiman *et al.*, 2008) and defined AI as AA of at least 2D below Hofstetter's formula (15 - 0.25 x age) by push-up method. The rate of CI was 16.7%, AI 17.8%, and CI with AI was present in 56.7%. The mean CISS scores were similar for CI (18) and AI (18) but higher for CI with AI (22.7). The results showed a high comorbidity rate, and the associated symptoms are more severe when CI is comorbid with AI. These findings lead to the question of whether AI drove the high CISS score in CI with AI. Data from Davis *et al.* study reinforces the notion that the comorbidity of CI and AI is high, and the elevated CISS score in CI is possibly due to the comorbidity of AI.

2.3.3.1 CI and AI in presbyopia

Presbyopic people, despite having insufficient accommodation at near due to aging, typically do not develop CI. Presbyopia is commonly corrected by reading glasses, bifocals, or progressive lenses, which compensate for the loss of near focusing ability (Mercer *et al*., 2021). These optical aids eliminate the need for accommodation when viewing near objects, so the accommodative-convergence reflex is no longer actively involved. In addition, since presbyopic individuals are using glasses to focus on near objects, their eyes do not rely on accommodation to stimulate convergence. This reduces the chance of developing CI because convergence is no longer as closely linked to accommodation. Moreover, presbyopia develops slowly, giving the visual system time to adjust, unlike AI, which can arise more suddenly and cause strain. This slow progression allows people to adapt to the reduced accommodation without stressing the convergence system. The absence of strong accommodative demands in presbyopia means that CI is less likely to develop, as the system is not stressed in the same way as with AI in younger individuals.

2.4 Treatment of CI

This section introduces the treatment of CI, defining the relevant terminology, available treatments, and types of exercises. Chapter 3 discusses the effectiveness of these treatments in the literature and the variations in their protocols.

The concept of visual training to reduce or eliminate symptoms have attracted researchers and clinicians' interest. This interest led to conduct many studies and clinical trials on CI management in children and adults to determine the most effective and successful treatment regimes. The treatment for CI includes orthoptic exercises, vision therapy, base-in prisms, botulinum toxin injection and surgery. The treatment can be categorised based on its location. It is termed "home-based" when exercises are performed at home and "office-based" when conducted under the supervision of optometrists or vision therapists.

2.4.1 Orthoptic exercises

Von Noorden and Campos (2002) defined orthoptics as all nonsurgical interventions that aim to improve fusional amplitudes and stereopsis, as well as to combat suppression and anomalous retinal correspondence. There are various orthoptic exercises such as smooth convergence (also called pen to nose convergence or pencil push-ups), jump convergence, Dot card and Stereograms. Orthoptists typically prescribe exercises to be performed at home (The Royal College of Ophthalmologists, 2012; BIOS, 2016).

2.4.1.1 Smooth convergence

The exercise is shown in Figure 2.4 and described by Ansons and Davis (2014) as follows:

- The patient is instructed to hold a pen or accommodative target at arm's length

- Then, the target is moved slowly toward the nose.

- If diplopia occurs and is recognised, if fusion cannot be achieved, the target is moved back until it becomes single

- The target is once again moved slowly toward the nose.

- The patient is encouraged to maintain single vision and achieve a NPC of less than 10cm without excessive effort.

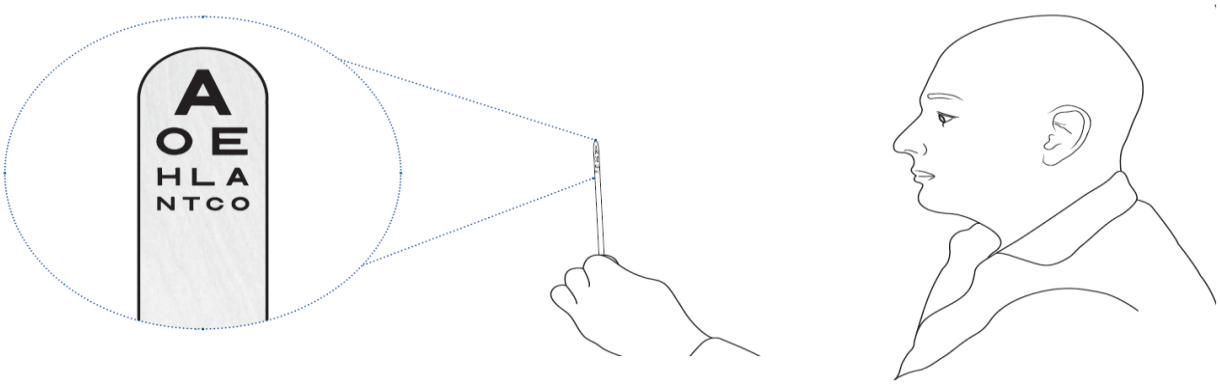


Figure 2. 4 Smooth convergence with an accommodative target Available at: www.uhb.nhs.uk/patient-information-leaflets.htm accessed from: Information for patients doing convergence exercises (Queen Elizabeth Hospital Birmingham,2018) (Free for research use).

2.4.1.2 Jump convergence

The exercise is described by (Evans, 2005) as follows:

- The patient is instructed to look at a distance target and then fixate at near on an accommodative target

- If the target is double, the patient is encouraged to try to make it single

- As soon as the target is single, the patient returns to fixation again at a distance and moves the near target closer a little

- Then the patient looks at the near target, trying to make it single again

- The steps are repeated until the patient is unable to make the near target single

- Then, the patient moves the near target farther until it is single again

- The steps are repeated for the instructed training time

2.4.1.3 Dot card

A narrow-width card with a sequence of circles is centred and positioned on a line drawn along the card (Figure 2.5), approximately 30 cm long (Ansons and Davis, 2014).

The dot card is described by Ansons and Davis (2014) as follow:

- The patient holds the card at end of their nose and looks at the dot furthest from the eyes, resulting in crossed physiological diplopia of the line and the nearer dots.

- The patient attempts to make the furthest dot single (Figure 2.6)

- Then, the patient continues to look sequentially at each dot in turn, keeping the dot they are looking at single. Consequently, the farther dots and line appear as uncrossed diplopia (Figure 2.7).

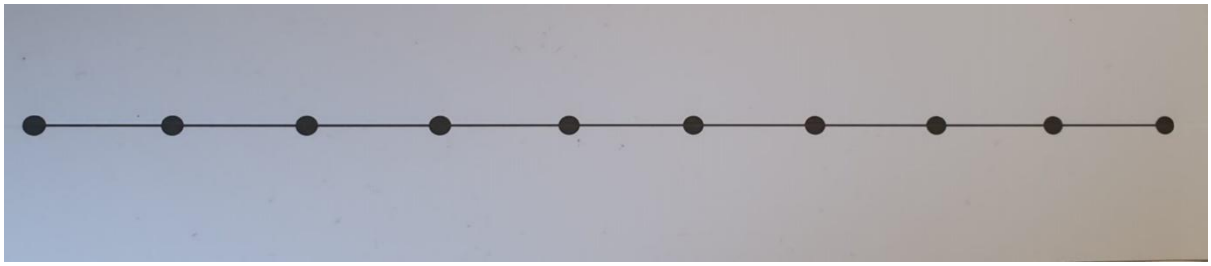


Figure 2. 5 Dot card

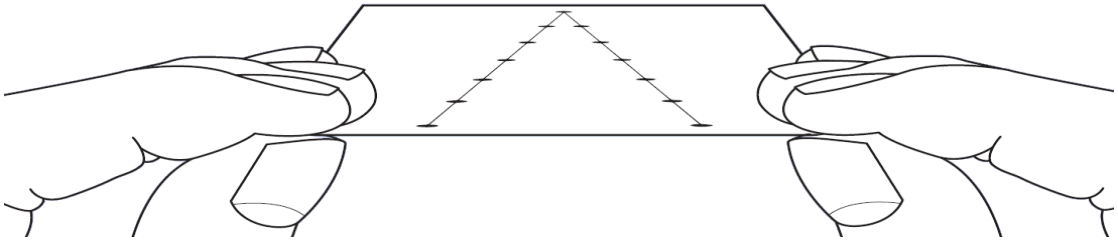


Figure 2. 6 The patient fixates on the furthest dot and when fuses images (lines) to the dot, making this 'ʌ' pattern Available at: https://www.uhb.nhs.uk/patient-information-leaflets.htm accessed from: Information for patients doing convergence exercises, Orthoptics, Queen Elizabeth Hospital Birmingham (Free for research use).

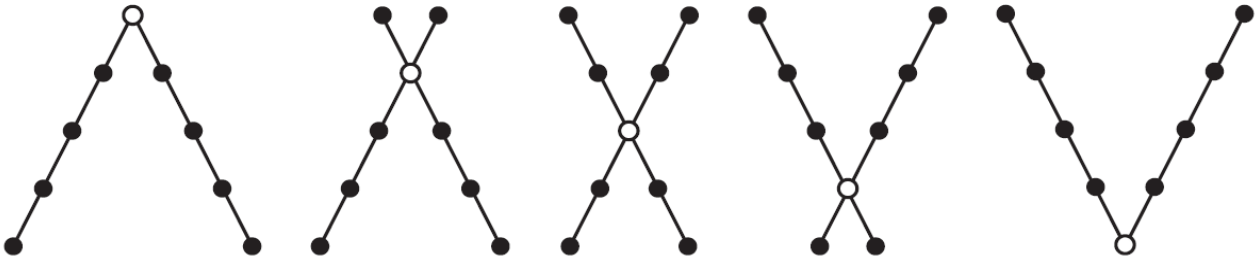


Figure 2. 7 The appearance of shapes when fixating on each dot in turn Available at: https://www.swbh.nhs.uk/wp content/uploads/2012/07/Dot-card-exercise-ML4720.pdf accessed from: Dot card exercises, Information and advice for patients (Sandwell and West Birmingham Hospitals NHS Trust, 2011) (Free for research use).

2.4.1.4 Stereogram

The stereogram has two incomplete figures, usually two-dimensional cats (Figure 2.8). The stereogram is described by Ansons and Davis (2014) as follow:

- The patient holds 2 incomplete figures at about 33cm away

- With the other hand, the patient places an unobtrusive near target such as a pen in front of the card in the centre of the figures

- The patient then focuses on the pen, and without directly looking at the stereogram, should see in the background four figures (uncrossed diplopia)

- The pen is gradually brought closer to the card until the 2 incomplete figures merge into a complete image in the centre (Figure 2.9)

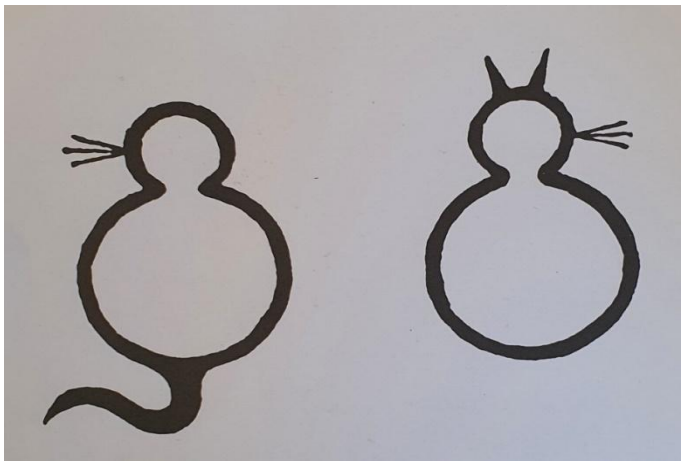


Figure 2. 8 The stereogram cat card

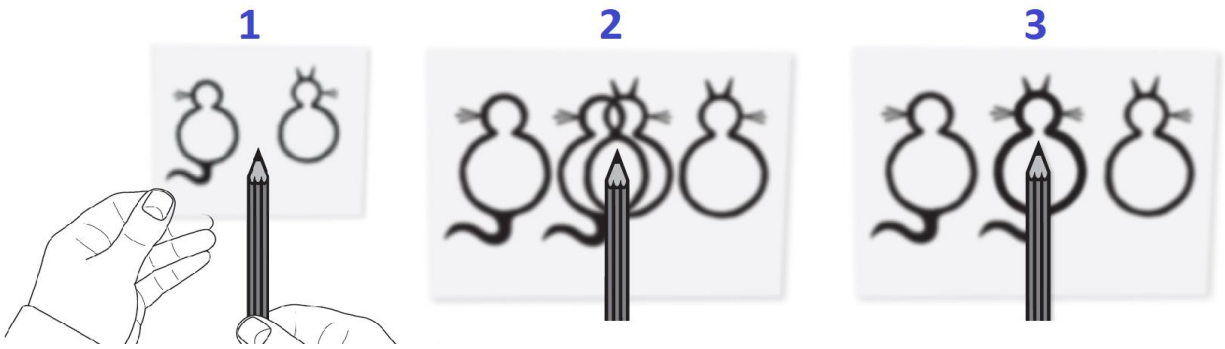


Figure 2. 9 A description of the steps and what the patient sees when performing the stereogram exercise Available at: https://www.uhb.nhs.uk/patient-information-leaflets.htm adapted and accessed from: Information for patients doing convergence exercises (Queen Elizabeth Hospital Birmingham, 2018) (Free for research use).

2.4.1.5 Orthoptic exercises in CI treatment

In dot card and stereogram exercises, the alignment or disparity task specifically challenges the vergence system while keeping accommodation constant, typically at the viewing distance of the stereogram. These exercises intentionally separate accommodation from convergence, training one system while maintaining stability in the other. This approach aims to enhance vergence flexibility and control independently of accommodation. In contrast, natural tasks with target-appropriate balance depend on the inherent coupling of accommodation and convergence, requiring both systems to work together to achieve clear and single binocular vision for objects at specific distances. This distinction is important, as exercises like stereograms are intentionally designed to push the visual system beyond its usual demands in everyday activities.

Orthoptic exercises have been used as the main treatment for CI (Arnoldi and Reynolds, 2007). Moreover, the treatment of CI is the most successful utilisation of orthoptics and is well established in the literature (Von Noorden and Campos, 2002). Orthoptic exercises are the treatment of choice for CI (Arnoldi and Reynolds, 2007) as they successfully reduce CI symptoms (Aziz et al., 2006; Bhutto et al., 2020), and effectively treat CI (Whitecross, 2013; Dawidowsky et al., 2019; Bhutto et al., 2020) and considered the first line of treatment for CI (Adler, 2002).

Despite the agreement on the effectiveness of exercises for treating CI, there still needs to be more agreement about orthoptic exercises protocols in treating CI. For instance, the number of exercises prescribed, training time, and whether prescribing them in the office or at home would give greater successful outcomes have long been questions among researchers. Consequently, there has been inconsistent criteria and great diversity of exercises or treatment protocols which led to variability among eye care practitioners (Piñero, 2016).

2.4.2 Vision therapy

Vision therapy is a specific sequence of neurosensory, perceptual, motor and stimulation activities (Ciuffreda, 2002). Vision therapy programme may include a variety of non-surgical methods and instruments, including vectograms, occluders, loose lenses, and prisms (Wallace,

2008; AOA, 2023) as well as puzzle completion, tracing pictures and video games and penlights and mirrors (Aetna, 2023). Among the goals of various techniques in vision therapy is to enhance convergence and accommodation amplitudes (AOA, 2023; Sinha and Sharma, 2023; Piñero *et al.*, 2023). Additionally, the intervention in vision therapy was reported to enhance perceptual functions (Shandiz *et al.*, 2018; Wang and Kuwera, 2022; Aetna, 2023), and visual skills including change in visual information, visual discrimination, sequential memory, and visual-spatial relationships (AOA, 2023). Vision therapy is used as a treatment for a wide range of visual or non-visual conditions, including CI and AI (Ciuffreda, 2002; AOA, 2023), strabismus (AOA, 2023), nystagmus (Cohen, 1986; Whitecross, 2013), oculomotor dysfunctions (Cohen, 1986; AOA, 2023; Piñero *et al.*, 2023) and learning disabilities (Whitecross, 2013; Sinha and Sharma, 2023). Vision therapy is performed in the clinic under the supervision of the examiner or may be reinforced with home exercises or computer program training done between visits (Aetna, 2023).

2.4.2.1 Vision therapy and orthoptic exercises

One could argue that there is no consistent definition of vision therapy (Piñero, 2016; Rucker and Phillips, 2017; Sinha and Sharma, 2023), and provided with no standard criteria (Chin, 2022). Barrett (2009) indicated that orthoptics and vision therapy share a number of clinical investigations and treatment methods but have distinct underlying rationales. Wang and Kuwera (2022) also supported the idea that vision therapy differs from orthoptics by using techniques beyond traditional optometric or orthoptic practices.

A number of researchers argued that vision therapy can be called orthoptic therapy as they share common features such as same clinical tests, techniques and both are non-invasive (Cohen, 1986; Provda, 1988). In addition, some argue that there are many overlaps between both strategies and the point separating them is indistinct (Barrett, 2009). In contrast, The American Academy of Ophthalmology (AAO) asserts that eye exercises and non-surgical treatment should be distinguished from vision therapy (Aetna, 2023). Furthermore, according to the College of Optometrists in Vision Development (COVD), vision therapy is not

synonymous with orthoptics (COVD, 2008). Barrett (2009) suggested that the term “vision therapy” should be explained and not confused with orthoptics.

For the purposes of the thesis, only studies utilising vision therapy to address CI and/or AI are considered. The term vision therapy will be used when the cited study chooses vision therapy as a treatment and more information be given about what included in therapy.

2.4.3 Prisms

Severe CI or secondary CI may not always improve with orthoptic exercises, making base-in prisms an alternative treatment (Ansons and Davis, 2014; BIOS, 2016). The base-in prisms relieve some of the effort to maintain single vision at near, so they may help improve symptoms. Prisms might be prescribed in elderly patients due to limited accommodation or when the patient is unwilling to undergo orthoptic treatment, if exercises fail to improve CI sufficiently or if the patient declines to undergo orthoptic exercises (Ansons and Davis, 2014). However, prism treatment will not be discussed in the thesis as it is beyond the scope of this research.

2.4.4 Surgery and botulinum toxin interventions

For symptomatic patients with CI, it is often advisable to first try exercises and prisms before considering surgical or botulinum toxin treatments (Rovick, 2022). Surgical and botulinum toxin treatments aimed to reduce exodeviation. Surgical interventions are naturally invasive and carry potential complications, with varying reported outcomes in the literature (Hofsli *et al.,* 2023). Moreover, there is a lack of evidence to support the efficiency of surgery in improving the convergence mechanism in primary CI (Ansons and Davis, 2014). The use of botulinum toxin injection as an alternative to surgery was reported in the literature for CI patients who failed prior treatment and has shown improvement in reading symptoms with the aid of prisms (Saunte and Holmes, 2014). Surgical and botulinum toxin treatments fall outside the scope of the research and will not be discussed in the thesis.

2.5 Video tele-appointments

The NHS Data Model and Dictionary defines telemedicine as "the use of telecommunication and information technology for the purpose of providing remote health assessments and therapeutic interventions" (NHS, 2023). Remote patient monitoring through information and communication technologies is frequently referred to by different names, such as telehealth, telemedicine, and telecare (Johnston, 2011), which usually overlap and might be used interchangeably (Fisk *et al.*, 2020). Tele-appointment is a remote meeting, such as a video or phone appointment between the physician and patient to provide teleconsultation, visual evaluation and follow-up of the patient's condition (Cerqueira *et al.*, 2021).

Telephone calls are occasionally used for tele-appointments (Rowe *et al*, 2021), but this can sometimes lead to confusion. Video and telephone consultations each have unique advantages and limitations, making them suitable for different healthcare scenarios. Video tele-appointments provide visual input, enhancing both accuracy and patient engagement. While both methods aim to facilitate remote patient care, they differ in their applications and potential impact on outcomes. For instance, video tele-appointments create more interaction that closely resembles face-to-face appointments. They enable orthoptists to observe nonverbal cues and assess visual elements, such as guiding orthoptic exercises which can lead to improved patient satisfaction and trust. Additionally, orthoptists can demonstrate exercises or procedures during video tele-appointment, ensuring patients fully understand the instructions. In contrast, telephone consultations may be inadequate for conditions requiring visual assessment, such as orthoptic exercises. Moreover, video tele-appointments can be recorded (with consent), serving as a valuable resource for follow-up care or future analysis. These advantages make video tele-appointments as superior to telephone calls in many contexts in orthoptic practice. For the purposes of thesis, the term tele-appointments refer to video calls, not telephone appointments.

Providing telehealth services is an important strategy and is the future direction of health services in many parts of the world (van Houwelingen *et al.,* 2019; Bouabida *et al.,* 2022) In this regard, the NHS long term plan was to reduce up to 33% of outpatient visits even before Coronavirus COVID-19 (NHS England, 2019). The video teleconsultations have several

advantages such as saving time and travel cost (LeBeau et al., 2023; Rettinger and Kuhn, 2023), reduce hassle of waiting and quick reach to the patient (Sanghera *et al*., 2023).

2.5.1 Video tele-appointments in orthoptic clinics

There can be some key aspects of the utility of video tele-appointment in orthoptic practice. For example, consultation, documenting symptoms, initial assessment, exercises demonstration, monitor progress and discussions of the treatment plan and patient education. Tele-appointments have the potential to provide an excellent opportunity for encouraging compliance and are especially important for disorders such as CI where performing exercises is critical. In addition, one of the advantages that may not be focused on is that tele-appointments are often shorter than face-to-face appointments. Thus, tele-appointments have the potential to free up the orthoptist's appointment slots, as a result, more patients can be served within a clinical session either in-person or virtually. Therefore, this modality might gain prominence in the future due to these advantages.

2.5.2 Video tele-appointments during COVID-19

Teleconsultation have been known for many years, but they became widespread during the COVID-19 pandemic (Sharma *et al*., 2020; Bouabida *et al*., 2022). Following the relaxation of COVID-19 restrictions, clinicians have resumed delivering regular care, but there remain some challenges for patients that still need consideration, for example, self-isolation, fear of COVID-19 transmission (Dantas *et al.*, 2023). Therefore, teleconsultation is beneficial for such difficulties because they reduce the spread of infection (Sharma et al., 2020; Bouabida *et al*., 2022; Rettinger and Kuhn, 2023; Sanghera et al., 2023).

The COVID-19 restrictions and lockdowns have led to major challenges for orthoptists and patients, as a result, clinical visits were rescheduled or cancelled, and video call consultations were one of the alternatives (Rowe *et al.*, 2020).

2.5.3 Patient experience with video appointments

It has been reported that patients express high satisfaction with teleconsultation and their willingness to receive such service (Kruse *et al.*, 2017). This satisfaction is confirmed by a survey of 2,998 patients across outpatient clinics following telehealth care in the University Hospitals Bristol and Weston NHS Foundation Trust (Tyler *et al.*, 2021). The survey showed that patients preferred teleconsultations (36.4%) versus physical appointments (26.9%); also, they found teleconsultations “less stressful” (43.8%) than “more stressful” (6.1%). Most patients felt “listened” (97.5%) and participated in the discussion of the treatment plan (95.9%). Another example, Smith *et al.* (2023) reported high acceptance of video consultation during ophthalmology appointments by 100%. Of the patients who underwent virtual consultation, (96%) showed interest to be seen again remotely. The high satisfaction rates for using tele-appointments during pandemics for the specific purposes are positive and motivating for their implementation within orthoptics and follow-up exercises.

Staffieri *et al.* (2021) surveyed 89 parents for their satisfaction and acceptability of teleconsultation in paediatric ophthalmology. In their study, children with amblyopia, refractive errors and strabismus received teleconsultation services during COVID-19 from the Department of Ophthalmology, Royal Children's Hospital, Australia. The survey showed that 39 (44%) of parents were "satisfied", 34 (38%) "very satisfied", 9 (10%) "neutral", and 7 (8%) were "very unsatisfied" with teleconsultation. Furthermore, 71% of parents were happy to accept teleconsultations for their children in the future. Convenience due to need for travel and absence from work or school might make teleconsultation preferable for patients. In another example of satisfaction, in the UK, 80 phone calls and 40 video calls were given to oculoplastic patients for consultation (Golash *et al.,* 2021). Interestingly, 55% of those receiving phone calls and of those receiving 82.5% video calls, felt similar to the outcome of face-to-face examinations; and the satisfaction level was 10/10 in 71.3% of the phone calls and 72.5% of the tele-consultations. These high satisfaction levels could indicate the potential for a similar positive experience for CI patients.

2.5.3.1 COVID-19 and orthoptic clinics

The COVID-19 pandemic had a huge impact on healthcare services globally and in the UK (Rowe *et al.*, 2020). Tele-appointments have proven to be one of the solutions for continuing service to the challenges that emerged to orthoptic clinics during COVID-19 pandemic. In this regard, Rowe *et al.* (2020) distributed an online survey to orthoptic departments in the UK, Ireland, and the Channel Islands to evaluate services during the first lockdown. In this study, the collected data from 138 orthoptic departments between 31 March 2020 to 27 April 2020 showed up to 90% decrease in capacity and an increase in tele-appointments by 94%. A follow-up survey was conducted in the recovery period after the first lockdown (Fiona *et al.*, 2021). The collected data from 149 hospital trusts and boards indicated continued high use of tele-consultations by 92%. The widespread use of tele-appointments during COVID-19 strongly suggests their viability for ongoing use in orthoptic clinics, particularly for providing treatment and management for conditions such as CI.

As another example of COVID impact, the virtual strabismus services in Sheffield Teaching Hospitals (STH) reported a reduction of face-to-face appointments for non-surgical conditions during COVID-19 from 47.7% to 16.3% and virtual consultation was an alternative (Francis *et al.*, 2022). Francis *et al.* concluded that virtual clinics offered an efficient method with high standards of patient care to manage waiting lists while optimising the use of consultation time and resources. Tele-appointments in CI treatment are discussed in more detail in Chapter 3.

2.6 Chapter 2 summary

This chapter has reviewed the different CI definitions and clinical signs for variability in diagnosis criteria and screening as well as varied prevalence rates. In addition, the accommodation and AI have been explained with evidence reporting the comorbidity of CI and AI. Additionally, the overlap in symptomology between CI and AI, as well as the severity of the CI increases, the possibility of higher comorbidity of AI might be identified. Chapter 3 will comprehensively review the literature on primary CI treatment. These discussions and critical evaluation of the literature will be used to inform studies in Chapter 4 and 5.

Chapter 3 Literature Review of primary CI treatment

This chapter reviews the literature on the assessment of symptoms before and during the treatment of primary CI. It also reviews the evidence for primary CI treatment in adults and children, and their treatment protocols. The chapter also explores the advantages and disadvantages of different primary CI treatment options. Furthermore, it evaluates AI treatment and the effectiveness of the treatments used. Additionally, it discusses the role of tele-appointments in eye care and orthoptic practice, examining their pros, cons, and application in eye care pre- and post-COVID.

3.1 Literature search

A literature search was conducted to identify evidence on the treatment of primary CI. The primary search terms used were "convergence insufficiency" and "orthoptic exercises." The search was broadened to include:

- Convergence insufficiency or insufficiency of convergence
- Convergence insufficiency and/or treatment
- Convergence insufficiency and/or therapy
- Orthoptic exercises or vision therapy
- Vision therapy or orthoptic exercises
- Accommodative insufficiency or insufficiency of accommodation
- Accommodative insufficiency and convenience insufficiency
- Accommodative dysfunction* or dysfunction* of accommodation
- CI or home exercises
- CI or office treatment
- Pencil push-ups
- Smooth vergence
- Jump vergence
- Dot card
- Stereograms

The search was not restricted by a date range and was updated until May 2024. Common databases PubMed, Scopus, Cochrane Library, and Google Scholar, were accessed to search the literature. Boolean operators "AND" and "OR" were used to refine the search. Alongside academic literature, other sources of evidence such as clinical practice guidelines of The British & Irish Orthoptic Society and The Royal College of Ophthalmologists in the UK, were considered. Emphasis was placed on specific study types such as systematic reviews, due to higher levels of evidence. These steps were undertaken to ensure a comprehensive literature search and critical evaluation of the evidence concerning the treatment of primary CI with orthoptic exercises and vision therapy. These steps were undertaken to conduct a comprehensive literature search and critically evaluate the evidence on treating CI with orthoptic exercises and vision therapy.

3.2 Monitoring symptoms in CI treatment

Symptoms associated with CI were discussed in Chapter 2 (section 2.2.1). One method for evaluating the effectiveness of CI treatment is looking at changes in symptoms through visual comfort and post-treatment performance (Rouse *et al.*, 2004). Monitoring CI symptoms is also an important factor in determining whether further treatment is required (Daum, 1988).

3.2.1 Convergence Insufficiency Symptom Survey (CISS)

The CISS survey has been used as the primary outcome measure to evaluate the effectiveness of CI treatments for 4 of the CITT studies (Scheiman *et al.*, 2020). Additionally, the CISS survey has shown to be a reliable tool to quantify presence and frequency of CI symptoms (Borsting *et al.*, 2003). To evaluate the reliability of CISS in young adults, Borsting *et al.* administered the CISS to 46 with CI and 46 without CI. Both groups completed the CISS, but the CI group were given the survey later after 1-2 weeks. There was a significant difference in the mean CISS scores between the two groups. The CI group scored 37.3 and 11.3 for those without CI. Furthermore, the CI group showed a slight mean difference of 0.68 between their initial and later responses. They concluded that the CISS can be used clinically to evaluate CI symptoms and an outcome measure for treatment.

3.3 Treatment of CI

3.3.1 Correction of refractive error

Refractive error should be corrected in CI (Evans and Doshi, 2001; Von Noorden and Campos, 2002; Ansons and Davis, 2014; Scheiman and Wick, 2014), particularly if it is contributing to the patient's symptoms (Ansons and Davis, 2014). In addition, The BIOS (2016) guidelines recommend treating uncorrected or under corrected refractive errors before or in conjunction with CI treatment. Correcting refractive error leads to a clearer image on the retina which enhances fusion (Von Noorden and Campos, 2002; Scheiman and Wick, 2014), restores the appropriate coordination between accommodation and convergence (Von Noorden and Campos, 2002; Ansons and Davis, 2014), making the image or stimulus clearer which can result in enhanced convergence (Ansons and Davis, 2014).

3.3.2 CI treatment with orthoptic exercises

Details of orthoptic exercises that can be used to treat CI were in Chapter 2 (section 2.4.1). Orthoptic exercises are proven to be an effective treatment for primary CI (Lavrich, 2010) and typically shows a good response to orthoptic exercises (Ansons and Davis, 2014; BIOS, 2016). These exercises are primarily aimed to reduce symptoms as well as improving NPC and PFV measures (McCarus and Collins, 2009). Symptoms typically resolve spontaneously once NPC reaches 6 cm without effort and normal PFV becomes attainable (BIOS, 2016). In addition, orthoptic exercises are likely to succeed in treating CI and many cases respond to these exercises with the possibility of returning to a normal state (Rowe, 2012). Additionally, exercises are effective in short periods and showed a long-standing increase in vergence measures in young adults (Daum, 1982).

3.3.2.1 Treatment with a single exercise

Pencil push-ups are usually used as the first choice of treatment for symptomatic CI (Cooper and Duckman, 1978). Furthermore, pencil push-ups were found to be the most recommended and widespread treatment for CI among optometrists and ophthalmologists in the USA (Scheiman and Wick, 2014). Scheiman *et al.* (2002) surveyed 500 optometrists and 196

ophthalmologists about the treatment most commonly prescribed that they believe it is the most effective in treating CI. The survey found that pencil push-ups were the first choice of treatment among optometrists and ophthalmologists by 36% and 50%, respectively. Similarly, (Patwardhan *et al.*, 2008) conducted a survey among ophthalmologists in India regarding the most frequently prescribed CI treatment. The survey revealed that according to 203 ophthalmologists, pencil push-ups were the most commonly recommended first-line treatment, with 30% of them considering it mostly effective. This popularity might be due to the simplicity of the exercise and the low cost.

A number of studies have adopted the use of a single exercise to treat or investigate its effectiveness on CI. Researchers adopted a perspective to determine the effectiveness of pencil push-ups in treating CI solely or compared to other treatment options, such as intensive office-based treatment. Gallaway et al. (2002) in prospective study prescribed 15 minutes of daily home pencil push-ups for 12 CI patients with an average age of 24.5 years. Patients were considered normal if their NPC < 7.5 cm and their near PFV > 15Δ. After 6 weeks of treatment, 4 patients (33%) met the normal criteria, and only one of them reported elimination of symptoms. Similarly, Kim and Chun (2011) in prospective study enrolled 16 patients with symptomatic CI their ages from 7 to 34 years to perform two sets of 20 pencil push-ups/day at home for 12 weeks. The authors defined outcomes into three categories:

- Successful outcome: improvement of NPC < 6 cm and PFV > 15Δ

- Improved outcome, at least one of the following: NPC < 6 cm, an improvement of NPC by more than 4 cm, PFV > 15Δ and an improvement of PFV by more than 10Δ

- Non-responders: patients did not meet any of the criteria.

The results indicated that 10 (62.5%) patients either had successful outcome or improved, and 6 (37.5%) patients were non-responders. The authors did not specify the exact proportion of patients who succeeded or showed improvement. The patients showed greater improvement in NPC from 36.6 to 14.4 cm. This probably because they had a high receded NPC (mean 36.6 cm), so more room for improvement. The improvement of PFV was increased from 11.3 to 19.1Δ.

Another attempt has been made in prospective interventional study by Malli et al. (2013) to find out the efficacy of pencil push-ups alone for a relatively long period. In their study, 62 patients with CI (6-23 years) performed pencil push-ups for 10 minutes/ 3 times a day. The authors used Kim and Chun (2011) criteria (above) to judge outcomes. After 16 weeks of treatment, the outcome showed that 32 patients were cured from symptoms (52%), 12 improved (19.4%) and 14 non-responders (22.6%). There was overall significant improvement in mean values of NPC from 26.1 to 13.8 cm and PFV from 10.1 to 25.3Δ (60%). In a similar approach but with a different exercise, Yi and Shahimin (2018) in prospective study looked at the effectiveness of dot card exercise alone. In their study, they assigned 33 university students aged 18 to 30 years with CI to perform dot card exercise for 4 weeks. The outcomes were based on CISS score, NPC, PFV and exophoria at near. The results also showed improvement with significant improvement in CISS score from 22.3 to 15.3 (31.4%), NPC 11 to 6.5 cm (40.9%), PFV 13.8 to 18.3Δ (24.6%) and insignificant change in exophoria 2.1 to 1.8 Δ (14.3%).

The studies discussed in this section focused solely on evaluating the effectiveness of a single exercise mainly pencil push-ups. Additionally, none of these studies included control groups, potentially allowing placebo effects to influence the results.

3.3.2.2 Treatment with multiple exercises

Kushner (2005) reported that paediatric ophthalmologists and orthoptists prescribe various exercises beyond pencil push-ups, including exercises such as jump convergence exercises, stereograms and additional prisms. Typically, orthoptic treatment plans consist of more than one exercise, and the combination of these exercises have been investigated for their effectiveness in CI treatment. Aziz *et al.*, (2006) investigated the efficacy of orthoptic exercises in improving NPC, fusion amplitudes and alleviating asthenopic symptoms. This study retrospectively analysed the medical records of 28 patients with CI and 50 with decompensating heterophoria who underwent orthoptic exercises. The orthoptic exercises included pen convergence, jump convergence, dot card and stereograms and were performed for 5 minutes, up to 6 times daily. The authors did not distinguish the results of the two groups;

instead, they reported the improvement of CI signs for both groups combined. The findings revealed symptom improvement in 65 (83.3%) patients, with 25 (38.5%) becoming asymptomatic. Moreover, NPC normalisation occurred in 47 (85.5%) out of 55 patients, with a mean improvement from 16.6 to 8.4 cm. The fusion amplitude normalised in 29 (58%) out of 50 patients, improving from 15.4 to 24.9 Δ. Aziz *et al.*, (2006) concluded that orthoptic exercises effectively alleviate symptoms in patients with CI.

Brautaset and Jennings (2006) conducted a prospective study investigating the effectiveness of various orthoptic exercises on 10 symptomatic CI subjects with a mean age of 25.4 years. The patients performed 10 minutes, twice daily of vergence jump, pencil push-ups, prism flippers and accommodative flippers (±1.50 DS). There was no control group or treatment arms in this study. The main outcome criterion was resolution of symptoms. After 12 weeks of treatment, significant improvement was found in NPC 19.5 to 8.4 cm and PFV 18.9 to 24.1Δ as well as all 10 (100%) subjects had symptoms relieved.

Nawrot et al. (2013) conducted a prospective interventional study involving 24 adults with an average age of 25.1 years. In this study, 12 adults with symptomatic CI were assigned to an intensive home vision therapy program, while 12 in the control group received no treatment. Participants in the CI group were instructed to perform exercises for 25–30 minutes daily, 5 days a week. The treatment duration was extended to 24 weeks, which is twice the length of the treatment period used in the study by Brautaset and Jennings. The vision therapy plan included accommodative monocular and binocular letter chart, accommodative rock and binocular accommodative facility; vergence procedures of pencil push-ups and brock strings and fusional vergence procedures of aperture rule, tranaglyphs, vectograms, lifesaver card, eccentric circles. The outcomes measures were CISS score, NPC, PFV. There was significant improvement only in the CI patients' group as the CISS score decreased from 29.5 to 9, NPC 8.0 to 2.5 cm and PFV increased from 12 to 31Δ .

It should be noted that there is a significant difference in the training time between the two reported studies. In Brautaset and Jennings study the total time was 28 hours of training, while in Nawrot *et al*. study, the training time ranged from 50 to 60 hours. The difference of improvement between the studies might be due to training time and intensity of exercises.

Additionally, the improvement of the symptoms was 100% of patients in Brautaset and Jennings, which indicates 28 hours of training might be sufficient. Therefore, based on the results of the two studies, it can be argued that extended periods and intense exercises plans might not be necessary.

3.3.2.3 Efficacy of exercises

The most effective exercises in treating primary CI are still investigated in the literature. Horwood and Toor (2014) have already drawn attention to the efficacy of different eye exercises. In their study, they assessed the effect of different eye exercises through orthoptic testing. In their study, 156 young adults without CI were assigned to different exercises groups and instructed to perform the assigned exercises 3 times daily for 2 weeks. The exercises were directed to targeting convergence only using Gabor image (Figure 3.1), accommodation only, accommodation and convergence in normal relationship, convergence in excess of accommodation, accommodation in excess of convergence and placebo exercises. For convergence exercises the instructions were to emphasise single vision and clear vision for accommodation exercises. Full of exercises regimens, type of targets and end point of exercises are shown in Appendix 1.1. The results showed that exercises targeting convergence-only resulted in improvement followed by exercises targeting accommodation-only. The exercises targeting convergence-only has gained overall improvement across different orthoptic tests by 17.2% and accommodation exercises by 16.1%. An interesting finding in the study was that the effort group showed highest improvement by 27% across all orthoptic measures. Orthoptic tests demonstrated significant improvement in exercises targeting convergence-only, with gains in NPC (1.5 cm), near BO diplopia (10Δ), VF (4.75 cpm), and monocular NPA (0.8 cm). For exercises targeting accommodation-only, significant improvements were observed in NPC (1.5 cm), BAF (1.9 cpm), MAF (5 cpm), and near BO diplopia (9.3Δ). The placebo exercises showed significant improvement in VF (2 cpm) and MAF (3.8 cpm). The effort group demonstrated significant improvement in NPC (2 cm), VF (3.6 cpm), binocular NPA (0.95 cm), monocular NPA (1.57 cm), BAF (3.04 cpm), MAF (2.57 cpm), near BO diplopia (9.76Δ) and distance BO diplopia (6.09Δ).

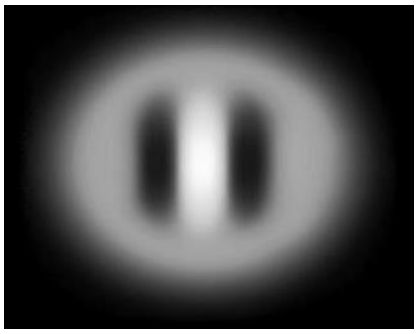


Figure 3. 1 Gabor image

It should be noted that these improvements were in visually normal young adults with ceiling effects. These exercises targeting convergence-only could be investigated on primary CI patients. The higher effectiveness of convergence exercises can be attributed to visual training designed to improve convergence (disparity responses), since disparity is the main drive of both convergence and accommodation (Horwood and Riddell, 2008). Thus, the findings of this study suggested that exercises targeting convergence or accommodation have greater effect and lead to improvement in vergence and accommodation. Additionally, the instruction and effort by clinicians is a major factor in improvement and should be standardised.

3.3.3 Office-based treatment in CI

Several studies have conducted office-based exercises for the treatment of CI (Birnbaum *et al.*, 1999; Adler, 2002; Scheiman *et al.*, 2005b; Revathy, Rizwana *et al.*, 2011; Westman and Liinamaa, 2012; Momeni-Moghaddam *et al.*, 2014; Aletaha *et al.*, 2018; Nehad *et al.*, 2018; Alvarez *et al.*, 2020; Singh *et al.*, 2021; Li *et al.*, 2022). Doyle (2016) suggested the timelines for the office-based therapy as per sample poll of The Australasian College of Behavioural Optometrists (ACBO) fellows in Australia as shown in Table 3.1. It should be noted that a number of clinical trials have added home exercises as a reinforcement to the office-based treatment protocol.

Table 3. 1 Summary of office-based therapy timelines as per the ACBO Survey (adapted from Doyle, 2016)

Description	Recommendation
Average vision therapy program duration	3-4 months (12-24 visits)
Number of exercises per visit	4 to 6
Average time per visit	30 to 45 minutes
Average frequency of office-based vision therapy visits	Twice weekly
Suggested time for home-based vision therapy as part of Office-based vision therapy program	15 to 20 minutes daily, 5 days/week
Number of reviews monitoring progress	6 to 8 visits

3.3.3.1 CITT studies on CI

Some researchers have investigated whether exercising in the clinic might give greater effectiveness than home exercises alone. The CITT study group in the USA conducted two randomised clinical trials in children and young adults to explore the effectiveness of different treatment modalities (Scheiman, 2018). The CITT studies are important because they are the first masked, placebo-controlled, multicentre, randomised clinical trials to investigate primary CI treatment. The studies aimed to compare office-based vision therapy/orthoptics, home pencil push-ups, and placebo office-based vision therapy/orthoptics in treating symptomatic CI (Scheiman *et al.*, 2005a; Scheiman, *et al.*, 2005b). The CITT used three clinical signs for the definition of CI: NPC ≥ 6 cm, exophoria at near at least 4Δ greater than at distance and PFV < 15Δ BO at near or failing Sheard's criterion (Scheiman *et al.*, 2008).

In the first study, the CITT group recruited 47 children ages 9 to 18 years with symptomatic CI to one of three treatment arms: office-based vision therapy/orthoptics (n=17), home pencil push-ups (n=15), and office-based placebo vision therapy/orthoptics (n=15) (Scheiman *et al.*, 2005a). The office-based group performed 60 minutes of various exercises per visit with reinforcement of home exercises for 15 minutes a day, 5 times per week. Full details of

techniques used for 26 office-based vision exercises and 16 home reinforcement exercises are shown in Appendix 1.2. The placebo office-based vision therapy/orthoptics group also performed 60 minutes of weekly office visits with home procedures for 15 minutes, 5 times per week. The placebo protocol included various monocular procedures that simulated real vision therapy/orthoptic exercises without actual effect on vergence and accommodative functions (Scheiman *et al.*, 2005a). Full details of techniques used for office-based placebo vision therapy are shown in Appendix 1.3. The pencil push-ups group performed 15 minutes of pencil push-ups per day, 5 days at home. All the treatment groups were seen at the 4, 8 and 12 weeks of treatment. The primary outcome measure was the change in CISS score, while the secondary outcome measures were NPC and PFV at near. The CITT group set criteria to define the treatment outcomes as follows:

- Cured: CISS score < 16, NPC < 6 cm and near PFV ≥ 15Δ

- Improved: CISS score < 16 and either NPC < 6 cm or near PFV ≥ 15Δ

- Failed: CISS score > 16, or CISS < 16 but NPC > 6 and near PFV ≤ 15Δ

After 12 weeks, only the office-based treatment showed significant improvement in symptoms and CI signs in 80% of patients. In addition, there were significant changes in the CISS score from 32.1 to 9.5, NPC 13.7 to 4.5 cm and PFV 12.5 to 31.8Δ. Eight (53.3%) children in the office-based vision therapy/orthoptics group were considered "cured", while 1 (8.3%) in the placebo group and none in the pencil push-ups group met this criterion. Additionally, 12 (80%) of the office-based vision therapy/orthoptics were considered "improved", while 1 (8.3%) of placebo group and 0 (0%) in the pencil push-ups met this criterion. The placebo group measures were CISS score 30.7 to 24.2, NPC 15.5 to 9.3 cm and PFV 12.1 to 19.8Δ. The pencil push-ups clinical measures were CISS score 29.3 to 25.9, NPC 14.6 to 9.1cm and PFV 12.6 to 14.5Δ. The study concluded that office-based vision therapy/orthoptics effectively improved CI symptoms and signs in children aged 9 to 18 years (Scheiman *et al.*, 2005a).

In the second CITT study, the trial used the treatment protocols and exercises from the previous study (Scheiman *et al.*, 2005a). They recruited 46 young adults ages from 19 to 30 years with symptomatic CI into office-based vision therapy/orthoptics (n=15), home pencil

push-ups (n=17), and office-based placebo vision therapy/orthoptics (n=14) (Scheiman *et al.*, 2005b). The CITT group set criteria to define the treatment outcomes as follows:

- Cured: CISS score < 21, NPC < 6 cm and near PFV ≥ 15Δ

- Improved: CISS score < 21 and either NPC < 6 cm or near PFV ≥ 15Δ

- Failed: CISS score > 21, or CISS < 16 but NPC > 6 and near PFV ≤ 15Δ

The outcomes showed that 3 (25%) in the office-based vision therapy/orthoptics group were considered "cured", whereas none in the placebo group and the pencil push-ups group met this criterion. Additionally, 3 (25%) of the office-based vision therapy/orthoptics were considered "improved", while 2 (15.4%) in the placebo and 2 (13.3%) in the pencil push-ups groups met this criterion. Another notable finding of this study is that, despite improvements in clinical signs, 58% of participants in the office-based vision therapy/orthoptics group, 69% in the placebo group, and 80% in the pencil push-ups group remained symptomatic at the end of the treatment. The outcomes in the office-based vision therapy/orthoptics group significantly improved in CISS from 36.5 to 20.7, NPC 12.8 to 5.3 cm and PFV 11.3 to 29.7Δ. The outcomes of placebo group were CISS from 37.5 to 25.2, NPC 14.5 to 9.6 cm and PFV 11.5 to 17.5Δ.The pencil push-ups and placebo groups showed significant improvement in symptoms but not in clinical signs. The outcomes of pencil push-ups group were CISS from 37.6 to 26.5, NPC 12.5 to 7.8 cm and PFV 13.6 to 24.2Δ. The study concluded that office-based vision therapy/orthoptics, was more effective than pencil push-up or placebo exercises to improve symptoms and CI signs in young adults (Scheiman *et al.*, 2005b). It is important to note that the pencil push-ups outcomes of CITT studies demonstrated low efficacy and produced comparable results to placebo treatments. These CITT findings raise significant concerns and impact the studies discussed in section 3.3.2.1, which focused on single exercises. The placebo effect might confound the improvement rates reported in section 3.3.2.1 because they did not quantify the potential influence of the placebo effect. These conflicting results make the true effect of pencil push-ups remain uncertain.

3.3.3.2 Discussion of CITT studies

The conclusion of the previous CITT trials was office-based treatment is more effective than home-based treatment in children and adults (Scheiman *et al.*, 2005a; 2005b). This conclusion does not reflect a consistent comparison between office-based and home-based treatment. The office-based advantage can be explained in several ways:

Effect of encouragement

Exercising in office has additional benefit of clinician encouragement to the patient through instruction and guidance. For instance, in CITT studies, the patients in office-based groups were given verbal motivation by the therapist for more effort, while the home pencil push-ups group lack this encouragement. Thus, the encouragement might give an additional improvement rather than the effectiveness of the exercise itself.

Horwood and Toor (2014) found the encouragement given to the patient and the level of effort put in by the patient was more effective and led to most significant overall change in clinical tests than any other exercise regime. Moreover, it has been reported that the enthusiasm and instructions of the examiner have a large effect on the outcome of the treatment (Scheiman *et al.*, 2005b). Therefore, there is evidence that instructions and additional effort play a key role in the effectiveness of exercises. It can be argued that the apparent advantage of office-based exercises in CITT studies might be attributed to the additional encouragement provided to patients by vision therapists rather than solely from the effectiveness of the exercises themselves.

Training time

There was an apparent difference in the training time between the office and home groups. The total duration of training in the office-based treatment is 135 minutes for each week as 60 minutes in the office and 75 minutes of home reinforcement, while 75 minutes of weekly training for the home-based group. There is a clear difference in training time, which is reflected in the outcomes and gives preference to office-based groups.

Intensity of training

The intensity of office-based exercises is not comparable with the home exercises where the patients in office-based groups performed 26 exercises each session in addition to 16 exercises as home reinforcement. In contrast, the home treatment was limited to a single and less intense exercise namely pencil push-ups. Consequently, office-based and home-based exercises represent different treatment approaches, making comparisons of their effectiveness inconsistent and inaccurate. Thus, it can be argued that intensive office therapy is not comparable to home exercises with lesser intensity in CI treatment.

AI in CITT studies

It is noteworthy that the CITT studies have not dealt with AI within groups. For example, in the CITT children study, the mean AA in office-based vision therapy/orthoptics group met the minimum AA through Hofstetter's criteria. In comparison, for the pencil push-ups and placebo groups, the AA means were 3.7 D and 4.9 D, which were lower than normal AA for the mean age of the groups. This raises the question of whether the severity of symptoms is due to the accommodation being normal in one treatment group and not in the other. Thus, it can be argued that accommodation measures should be considered to compare the treatment efficacy between groups. Furthermore, in cases of CI with AI, it could be beneficial to consider in future research exercises targeting disparity, which will likely be effective as the disparity is a major drive to both convergence and accommodation (Horwood and Riddle, 2008).

3.3.3.3 Effectiveness of office-based and home-based treatment

Singh *et al.* (2021) compared the effectiveness of 20 min daily/3 days a week of convergence fusional exercises on the synoptophore in office-based therapy versus 15 min/daily of home pencil push-ups in patients with CI for 6 weeks. In their study, they assigned 60 patients aged 9 to 30 years to office-based orthoptic therapy. Additionally, assigned 70 patients with mean age 18.9 ± 5.4 years to home pencil push-ups. The primary and secondary outcomes were improvement in NPC and CISS score, respectively. The study set the following criteria to judge the outcomes as follow:

- Cured: NPC < 6 cm and CISS score < 16

- Improved: reduction of NPC by 4 cm or greater and CISS score by 10 or more points

In the office-based group, 67% of patients achieved NPC < 6 cm and 77% achieved a CISS score < 16. In comparison, in the pencil push-up group, 71% of patients achieved NPC < 6 cm, and 81% of patients scored < 16 in CISS. Both groups achieved improvement in clinical signs and CISS scores with no significant difference between the two groups. It is noteworthy that the results are in contrast to the CITT conclusions in section 3.2.3.1. The training time during treatment in Singh *et al.* study for the office-based group was 360 minutes and 630 minutes for the pencil push-ups group. Thus, the similar results between the two groups may be attributed to the difference in training time for the pencil group.

Yadav *et al.* (2022) used the same previous treatment method in Singh *et al.* study on 80 CI patients (mean age 21.5± 7). They reported no significant differences between the office-based and home pencil push-up groups in terms of NPC and CISS. The symptoms were cured in 80% of office-based and 82% of pencil push-up groups, which are similar to the outcomes of the Singh *et al.* study.

The training time during treatment in Singh *et al.* and Yadav *et al.* studies for the office-based group was 360 minutes and 630 minutes for the pencil push-ups group. Thus, the similar results between the two groups may be attributed to the difference in training time for the pencil group. Considering decrease in symptoms and cure rates in previous studies, provides comparable effectiveness of both treatment modalities in treating CI. It can be argued that home-based treatment can be equally efficacious. Table 3.2 illustrates several CI treatment studies that adopted office-based and/or home exercises, highlighting treatment protocols, outcomes, and mean changes in clinical signs. However, in the UK, The BIOS recommend for CI patients that the exercises should be performed frequently but briefly with a minimum of three times daily, for 2-5 minutes each session, and the follow-up duration during treatment should be at most 4-6 weeks.

Table 3. 2 The efficacy of different treatment regimens for CI patients from several studies in the literature.

Study	Study design	Nonresponse*/ Sample size	Age range	Duration of treatment	Type of treatment	Success rate	Symptoms improvement	Change# in NPC (cm)	Change in PFV at near (△)
Adler 2002	Retrospective	- /92	5-35	2-20 visits	(OB + HB) exercises	80.4%	Not reported	18.3	Not reported
Gallaway et al.,2002	Prospective	13/25	9-51	6 weeks	HB pencil push-ups	58%	91.7%	10.1	11.6
Kim et al. 2011	Prospective	6/16	7-34	12 weeks	HB pencil push-ups	62.5%	Not reported	22.2	7.8
Shin et al. 2011	Prospective	3/57	9-13	12 weeks	(OB+ HB) exercises	61%	61.6%	5.5	12.9
Malli et al. 2012	Prospective	14/62	6-23	16 weeks	HB pencil push-ups	51.61%	Not reported	12.3	15.2
Revathy et al. 2012	Prospective	1/10	9-39	4 months	(OB + HB) exercises	90%	Not reported	6	29
Westman et al. 2012	Retrospective	/135	6-79	Mean 3 months	(OB + HB) exercises	Not reported	55.7%	6.7	18.6
Nawrot et al. 2013	Prospective	4/24	18-35	24 weeks	HB pencil push-ups	83.3%	69.5%	5.5	19
Momeni-Moghaddam et al 2014	Prospective	- /60	21.3 ± 0.9	8 weeks	HB pencil push-ups	Not reported	62.8%	4.5	14.4
Lee et al. 2015	Prospective	-/123	6-12	12 weeks	(OB+ HB) exercises	Not reported	97%	8.7	11.2
PEDIG 2016	Randomised, placebo controlled, masked	- /204	9-18	12 weeks	OB exercises	22%	66.2%	3.6	18.2
					HB computer therapy	23%	60.8%	7.8	1.1
					HB placebo therapy	16%	62.5%	10.7	5.8

Scheiman et al., 2008	Randomized, placebo controlled, masked	3/221	9-17	12 weeks	HB pencil push-ups	43%	47%	6.7	7.8
					HB computer therapy+ HB pencil push-ups	33%	38%	7.6	12.3
					OBVT	73%	73%	9.8	19.7
					OB placebo therapy	35%	43%	4.1	6.8
Jang et al. 2017	Prospective	4/32	8-13	8 weeks	(OB+ HB) exercises	87.5%	Not reported	5.0	3.7
Nehad et al. 2018	Prospective	11/102	7-13	12 weeks	OB exercises + HB HTS	50%	47.3%	4.6	10.8
					OBVT	36.5%	43%	4.9	10.3

*Nonresponse: number of patients who considered failed treatment, the (-) indicates not reported; #Change = mean of (pre-treatment) - mean of (post-treatment). NPC: near point of convergence; PFV: positive fusional vergence; HB: home-based; OB: office-based; (OB+HB): combined treatment of office-based and home-based treatment; VT: vision therapy; HTS: Home Therapy System

3.3.3.4 Office-based or home-based treatment

Several studies considered office-based treatment to provide greater successful outcomes than home-based treatment (Scheiman *et al.*, 2020). This comparison is inconsistent due to intensity of exercises, encouragement and training time factors. Moreover, a number of factors should be taking into account that associated with each office session such as travel costs and inconvenience from missing school and work. For instance, in the USA, the cost of office treatment is approximately $75 per session and the average total cost is from $900 to $1125 per patient for the entire treatment (Scheiman *et al.*, 2005a).

Home-based treatment is considered flexible and less expensive than office-based therapy. For example, the Royal College of Ophthalmologists Guidelines (2012) recommend convergence exercises to be performed at home. However, absence of supervision from the therapist might affect the incompliance of the patient and home exercises success outcome. In addition, most patients lose interest in exercises especially if they do not see rapid improvement and discontinue treatment (Scheiman and Wick, 2014). Therefore, to improve home treatment, the BIOS guidelines (2016) noted that extending follow-up periods beyond 4-6 weeks could result in a loss of motivation, slower progress, or exercises performed incorrectly. There are important considerations that must be taken into account when prescribing home exercises in order to gain effective results and to avoid failure of treatment. According to Cooper (2007), failure of home treatment might be due to one or more of these reasons:

a) The instructions are not fully understood by the patient
b) The training is performed incorrectly
c) The parents were not able to work with the child to carry out the exercises

3.3.4 Compliance

Office training might have greater compliance to treatment than home exercises due to supervision and encouragement factors, but the costs and time commitment remain obstacles to offering office treatment. It is noteworthy, one of the major difficulties limiting the success of home treatment is patient compliance with treatment given. For example, a questionnaire

was distributed in 2007 to 203 ophthalmologists in India about the major reasons for the failure of treatment with pencil push-ups exercises (Patwardhan *et al.*, 2008). Interestingly, 86.7% of ophthalmologists indicated that lack of compliance is the main reason for the failure of treatment. However, the compliance could be challenging to track despite the treatment log and weekly phone calls (Revathy *et al.,* 2011). Furthermore, Horwood *et al.* (2014) reported that it is difficult to prove that patients comply with the exercises, but the absence of systemic differences between treatment groups, for example, in research, might indicate the level of compliance. Therefore, the BIOS (2016) recommends short intervals between follow-ups from 4-6 weeks to enhance the patient's motivation, improve exercise adherence, and consequently increase the possibility of treatment success.

Compliance is also considered an essential determinant of clinical trial outcomes (Pullar *et al.*, 1989). Additionally, failure to follow the treatment protocol in a clinical trial can lead to incomplete or invalid data, subsequently, reducing scientific power. For instance, Gallaway *et al.'s* (2002) study suffered poor compliance with exercises in CI, which significantly affected the outcomes of the study. In their study, a home pencil push-up was prescribed to 25 symptomatic CI patients with a mean age of 24.5 years in clinical practice for 6 weeks. Thirteen patients (52%) did not return for follow-up despite a reminder phone call. Moreover, among the 12 (48%) patients who returned their treatment daily sheet, only 2 (16.7%) reported exact compliance to the treatment protocol. Gallaway *et al.* also indicated that compliance was better in older patients. The CITT group has adopted a method for grading adherence to home-based treatment. The patient was asked about the home exercises, and then the therapist gave a percentage to rate patient adherence from Excellent (75%- 100%), Good (50-74%), Fair (25-49%) and Poor (≤ 25%) (Scheiman*et al.*, 2005a).

The methods for tracking compliance, such as exercise diaries, are prone to inaccuracies, as patients may forget to log their exercises or even fabricate entries. In response, digital solutions, including apps and virtual reality have emerged as promising tools to improve engagement, monitor compliance, and provide feedback. Digital platforms can automatically track patient usage and progress, providing clinicians with objective data on compliance and performance. Real-time feedback helps patients understand their progress, reinforcing adherence to the prescribed treatment. Many digital tools can adapt therapy programs to

individual needs, adjusting difficulty levels based on patient performance to ensure optimal challenge and progress (Cooper, 2007). In addition, digital tools can be used on smartphones, tablets, or other personal devices, allowing patients to complete their exercises anytime and anywhere.

Explaining the expectations of the clinical trial early and what the patient is expecting at each visit will improve adherence and compliance with the treatment protocol (Johnston *et al.*, 2017). In addition, the clinician can suggest solutions that could help better compliance with treatment such as giving a daily sheet to record training times and setting mobile phone notifications, home video recording, and video or phone calls. For the purpose of this research, the term "compliance" will be used instead of adherence.

3.3.5 Treatment of AI

The literature review intended to focus on primary CI treatment, but since CI often coexists with AI and shares similar symptoms, a number of studies have conducted similar treatments for both conditions, which will be discussed in this section. Convergence exercises can improve accommodation (Horwood and Toor, 2014). In this regard, according to the BIOS guidelines (2016), patients with AI can be prescribed convergence exercises, which involve training of accommodation. Therefore, the scope of this research was expanded to include and discuss AI alongside CI. However, despite decades of research, less attention was given to the treatment of accommodation anomalies compared to CI (Barrett, 2009). Some of these concerns were confirmed when Martínez *et al*. (2009) reviewed the literature and reported that apart from CI, there is a lack of rigour evidence for the optimal treatment options for accommodative anomalies. Moreover, previous studies have shown that treatment of accommodative anomalies have been mainly researched in children and with small sample numbers (Sterner *et al*., 2001).

Scheiman and Wick, 2014 reported that a number of clinical trials demonstrated the effectiveness of vision therapy for treating accommodation anomalies with significant success rates (Scheiman and Wick, 2014). In addition, Martínez *et al.* (2009) systematically reviewed the studies between 1986 and 2007 and concluded that the clinical research is not rigorous enough on the best treatment options of accommodation anomalies. Rouse (1987) reviewed

the literature on the role of vision therapy in treating accommodative anomalies and summarised that:

a) The literature supports that vision therapy is an effective treatment for accommodative dysfunctions
b) vision therapy has been shown to improve both signs and symptoms effectively and this improvement is fairly continuing after discontinuation therapy
c) Physiological accommodative responses are modified by vision therapy, thus eliminating the placebo effect

3.3.5.1 Treatment due to psychological factors

Psychological factors can impact accommodation (Pateras and Chrysanthopoulos, 2024) and visual symptoms may worsen due to factors such as anxiety, which could be a sign not the main problem (Horwood and Waite, 2023a). It has been reported there is an association between AI and psychological difficulties (Middleton *et al*., 2008). Blur is a normal part in daily life but many AI patients initially experience mild symptoms but can be triggered by psychological stress (Horwood, 2022). Additionally, Middleton *et al*. (2008) reported that when some AI patients were referred for ophthalmologic investigation, psychosocial difficulties were found as contributing factor to the development of their visual symptoms. Horwood and Waite (2023) suggested that by acknowledging triggers of psychological stress, explanation of the mechanism of their symptoms, psychological support and sometimes simple orthoptic exercises, can provide dramatic improvement.

For example, Middleton et al. (2008) reported a case of a 12-year-old patient who experienced blurring and headaches while reading, despite having no refractive error or ocular pathology. The patient was diagnosed with AI with NPA of 18 cm in each eye and binocularly. Although orthoptic exercises were prescribed, they did not lead to significant improvement. The patient was then referred for a psychiatric consultation where undiagnosed psychiatric problems were found. Following family psychiatry sessions, the patient showed dramatic improvement, and all visual symptoms resolved.

Evaluating potential psychological difficulties affecting visual symptoms is beyond the scope of this PhD research and is not investigated in this thesis.

3.3.5.2 Effectiveness of AI treatment

Daum (1983) retrospectively reviewed 111 subjects with AI with a mean age of 18.5 years. The orthoptic exercises prescribed were daily monocular and binocular push-ups and flipper lenses (±1.50) and training from 5 to 10 minutes per day. After a mean treatment of 3.66 weeks, the accommodative exercises were successful in 43 (53%) and reported total elimination of symptoms. The clinical measures showed a significant improvement as the AA in the AI patients improved from 7.98 to 11.46 D (30.4%).

Theoretically, training with flipper lenses might improve the accommodative facility and AA. In this regard, Brautaset *et al.* (2008) investigated the efficacy of flipper lenses training on 9 children with a mean age of 10.3 years who were diagnosed with AI. The treatment protocol consisted of two sessions of ±1.50D flipper lens training for 9 minutes each day. After 8 weeks of treatment, the participants gained a significant change in AA from 4.25 to 7.82 D while an no significant increase in the accommodative facility from 4.66 to 6.17 cpm. Sterner *et al.* (1999) used the same previous approach with a ±2.00 D flipper on 38 children aged 9 to 13 years old with AI. The children performed flipper lenses training for 3 minutes/5 times a day. After an average treatment period of 8 weeks, all the children reported that their symptoms had resolved. Furthermore, a follow-up conducted two years after stopping the training revealed that none of the children experienced a recurrence of symptoms. This suggests that the treatment not only provided relief of symptoms but also had long-lasting effects, maintaining symptom resolution well after the treatment. The reliability of children at reporting symptoms might be questionable. A set of clinical test results along with symptoms would be an ideal approach.

3.3.5.3 CITT studies on AI

The CITT investigation group conducted two randomised clinical trials in children with symptomatic CI and accommodative anomalies to evaluate the effectiveness of different treatment modalities to improve the AA and accommodative facility. In the first study,

Scheiman *et al.* (2011) evaluated the effectiveness of vision therapy in 164 children aged from 9 to 17 years, where 63 (38.4%) had low AA, 43 (26.2%) had reduced accommodative facility, and 58 (35.4%) had both. The patients assigned to 4 treatment modalities: office-based vergence/accommodative therapy with home reinforcement (n= 36), home-based computer vergence/accommodative therapy group (n= 30), home-based pencil push-up therapy group (n= 27) and office-based placebo therapy group (n= 28). The treatment protocol of the office-based vergence/accommodative therapy, home-based pencil push-ups and office-based placebo therapy was taken from Scheiman *et al.*, (2005a) that was discussed in section 3.2.3.1 and are shown in Appendices 1.2 and 1.3. The office-based group assigned to home-based computer vergence/accommodative therapy supplemented with pencil push-ups for 15 minutes a day/5 days per week. The home-based computer vergence/accommodative therapy group was assigned to perform exercises on Home Therapy System (HTS) to perform fusional vergence and accommodative procedures. These exercises on HTS consisted of vergence (base-in and base-out), autoslide vergence, and jump ductions vergence programs supplemented with pencil push-ups for 15 minutes a day/5 days per week. The AA was measured by the push-up method and accommodative facility through alternating ±2.00 flippers in cycles per minute.

After 12 weeks, all treatment arms showed significant increase in AA than placebo therapy. There was significant improvement in AA in office-based vergence/accommodative therapy 7.7 to 16.9 D, computer vergence/accommodative therapy 6.9 to 13.8 D (50%) and pencil push-ups 7.1 to 13.1 D. The change in placebo group showed no significant change in AA from 7.0 to 9.5 D. The results also demonstrated that only the office-based vergence/accommodative therapy showed a significant improvement in accommodative facility from 2.3 to 12.1 cpm than the placebo group from 2.7 to 8.2 cpm ($p = 0.016$). In the follow-up at 12 months after completion of treatment, regression of the AA among groups was present in 12.5% of patients and reduction of the accommodative facility in 11%.

In the second study, Chen *et al.* (2020) examined 288 symptomatic CI children aged 9 to 14 years were diagnosed with AI (180 children) and decreased accommodative facility (108 children). The children were assigned to 16 weeks of office-based vergence/accommodative therapy or office-based placebo therapy. The accommodation amplitude and facility were

measured as in previous methods as well as the treatment protocol in the first CITT study (Scheiman *et al.*, 2005a) is shown in Appendix 1.2. There was significant improvement in both treatment arms. Children who received vergence/accommodative therapy showed a notable improvement in AA, increasing from 6.1 to 8.6 D (29%), and in accommodative facility, from 5.9 to 13.5 cpm (56.3%). In contrast, the placebo group experienced a smaller, yet significant increase in AA from 3.1 to 5.1 D (39.2%) and in accommodative facility from 4.1 to 7.6 cpm (46%). A higher percentage of participants in the vergence/accommodative therapy group reached normal levels of amplitude and facility—69% and 85%, respectively—compared to 32% and 49% in the placebo group.

Another attempt has been made to improve AA and accommodative facility in a prospective unmasked pilot study by Ming-Leungma *et al.* (2016). In this study, 14 myopic children aged 8 to 12 years were assigned to the CITT 60 minutes office-based accommodative/vergence therapy (Scheiman *et al.,* 2005a) in addition to 15 minutes, 5 days weekly of home reinforcement exercises. There was no placebo group in this study. After 12 weeks, the participants achieved a significant improvement in monocular AA as increased from 16.86 to 20.52 D, MAF from 6.9 to 17.8 cpm.

Although the CITT studies have many strengths such as randomisation, placebo control group, masking of examiners and long-term follow, there are important limitations that should be taken into account. These studies were not designed specifically to treat patients with accommodative anomalies. This raises the question of whether the office and home treatments for CI in this study are effective enough for accommodation anomalies. Arguably, significant success rates have been achieved with non-specific therapy for accommodation alone, so there might be greater potential success with specified accommodative exercises.

3.3.6 Variability in CI treatment

There is a lack of consensus on the most effective treatment of CI (Scheiman *et al.*, 2002, 2009, 2020; Sethi *et al.*, 2006; Patwardhan *et al.*, 2008; Aletaha *et al.*, 2018; Dawidowsky *et al.*, 2019). Several attempts have been made to investigate the ideal treatment protocols for CI using various methods and exercises, but despite the success rates, there is no unified methodology and suggested treatment protocol.

The duration of treatment has varied across studies, with some lasting 6 weeks (Gallaway et al., 2002), while others extended to 16 weeks (Millie et al., 2013) and 24 weeks (Nawrot et al., 2013). Training times also showed significant variation, ranging from 5 minutes of exercises (Aziz et al., 2006) to 25-30 minutes (Nawrot et al., 2013) and up to 75 minutes (Scheiman et al., 2005a; 2005b). Additionally, the number of exercises varied significantly with some researchers used only one exercise (Kim and Chun, 2011; Gallaway, 2002), whereas the CITT studies (Scheiman et al., 2005a; 2005b) included 42 exercises in the office-based treatment protocol.

Different success criteria also contributed to varied results across studies. For example, Gallaway et al. (2002) and Kim and Chen (2011) focused on clinical signs such as NPC and near PFV without considering improvement in symptoms. In contrast, the Brautaset study used symptoms as the sole criterion, and the CITT studies used symptoms as the primary criterion. This inconsistency in success criteria can result in different reported outcomes even for similar treatments. For example, when pencil push-ups were prescribed for 12 weeks, the CITT study reported a 13% improvement, whereas Kim and Chen reported a 62.5% improvement rate, confirming variability even with the same treatment and duration. Such variability in defining success rates makes it challenging to compare outcomes across studies effectively. However, another possible explanation of variability in treatment protocols might be attributed to factors that clinicians take into account, such as prior experience with the efficacy of specific protocol, availability of tools, and the ease of patients performing exercises.

3.3.7 Long term outcomes of CI treatment

It is important for the patient that treatment achieves long-term relief from CI symptoms. To date, the long-term effect of CI treatment has still not been extensively studied. Most reported results focus on outcomes after completion of treatment, not sustained effect over time. Research on the long-term effects of CI treatment has shown the potential of providing longstanding relief of symptoms.

Westman and Liinamaa (2012) conducted a study to assess the efficacy of orthoptic exercises in alleviating associated CI symptoms and their long-term effects on both adults and children. They retrospectively analysed data from 135 CI patients ranging from 6 to 79 years old. The

treatment regimen included office-based orthoptic exercises combined with home pencil push-ups and stereograms. Results revealed that in 66 children below 18 years, their NPC improved from 8.3 to 6.3 cm, while in 69 adults aged 18 and above, NPC improved from 10 to 7.1 cm. Moreover, 59.5% of children and 51.9% of adults reported being symptom-free after completing the exercises. A two-year follow-up period showed that only 5 patients required retreatment with orthoptic exercises. These findings suggest that orthoptic exercises can provide lasting relief from CI symptoms.

The CITT group conducted a study with 221 symptomatic CI children aged 9-17 to examine the effect of CI treatment and changes in symptoms over a year following 12 weeks of therapy (CITT Group, 2009). In their study, the children were divided into four treatment groups, as shown in Table 3.3. The primary outcome measure was the CISS score, which determined if a patient was considered asymptomatic. Results indicated that the office-based therapy group showed the most significant improvement in CISS scores among all groups, as detailed in Table 3.3. After the treatment period, each group was instructed to perform 15 minutes of maintenance therapy once a week for the first 6 months post-treatment. The long-term assessment was based on changes in CISS scores at 6 and 12 months post-treatment. The symptom changes in each group and the proportion of patients who remained asymptomatic are shown in Table 3.3. The study showed that for the majority of participants, CI treatment sustained symptom improvements for at least 12 months after therapy completion.

Table 3. 3 The outcomes of different treatment groups at 12 weeks and the long-term change in symptoms (CITT Group, 2009).

	Treatment group			
	OBVAT (n=60)	HBCVAT+ (n=53)	HBPP (n=54)	OBPT (n=54)
Exercises protocol	APPENDIX 1.2	HTS & CVS computer software +pencil push-up	pencil push-up	APPENDIX 1.3
Training time	60 minutes office therapy + Home exercises 15 minutes a day, 5 days per week	HTS/CVS 15 minutes per day, 5 days per week + Pencil push-ups 5 minutes per day, 5 days per week,	15 minutes per day, 5 days per week	60 minutes office therapy + Home exercises 15 minutes a day, 5 days per week
Outcome measure				
Mean CISS score				
Baseline	30.2	31.7	27.8	29.8
12 weeks	15.1	24.7	21.3	21.9
Change in CISS score after 12 weeks				
6 months	0.2	0.2	-5.8	-2.0
12 months	-0.6*	0.1	-1.9	2.0
Remined asymptomatic at 12 months (%)	84.4	80	66.7	76.9

OBVAT: Office-based vergence/accommodative therapy with home reinforcement; HBCVAT+: Home-based computer vergence/accommodative therapy and pencil push-ups; HBPP: Home-based pencil push-up therapy; OBPT: Office-based placebo therapy with home reinforcement; HTS: Home Therapy System; CVS: Computerized Vergence System; *Negative value indicates deterioration

Following a similar approach, (Shin *et al.,* 2011) divided 57 children, aged 9 to 13 years, into two treatment groups: 27 with symptomatic CI and 30 with symptomatic CI and AI. Both groups underwent 12 weeks of vision therapy, consisting of two weekly office visits of 60 minutes each, supplemented by 15-25 minutes of home exercises (the protocol detailed in Appendix 1.4). The study used the College of Optometrists in Vision Development-the Quality of Life (COVD-QOL) questionnaire (Appendix 1.5) to track symptom changes before and after treatment. A total COVD-QOL score of ≥ 20 was considered abnormal (Maples, 2000), with success defined as scores decreasing to < 20 alongside clinical signs. The children were assessed after 12 weeks and again one-year post-treatment completion. The results of the assessment at 12 weeks and one year are shown in Table 3.4. One-year follow-up showed that 20 (35%) children returned after completing treatment. The assessment revealed that 17 (29.8%) patients remained asymptomatic, while one child of the CI group deteriorated in symptoms and NPC. In addition, symptoms deteriorated in 2 children of the CI and AI group. The study focused on the notation that intensive office-based treatment with home exercises could provide sustain effect for 12 months. The long-term effect of home exercises alone still to be investigated.

Table 3. 4 The outcomes of treatment groups at 12 weeks and the long-term effect in symptoms and clinical signs at 12 months (Shin *et al.,* 2011).

Outcome measure	Treatment group					
	CI			CI with AI		
	Baseline	12 weeks	12 months	Baseline	12 weeks	12 months
COVD-QOL questionnaire	27.1	10.4	12.1	28.5	14.1	14.7
NPC	8.7	3.2	4.2	11.3	4.1	4.7
PFV	13.9	26.8	25.6	13.4	24.3	24.9
MAA	-	-	-	7.5	15.2	14.3
MAF	-	-	-	1.8	16.5	15

COVD-QOL: College of Optometrists in Vision Development-the Quality of Life (COVD-QOL) questionnaire; NPC: near point of convergence (cm); PFV: near positive fusional vergence in (); MAA, monocular accommodative amplitude in (); MAF, monocular accommodative facility in (cpm).

3.3.8 Guidelines or empirical evidence

Evidence-based offers benefits like scientific rigor, transparency, regular updates based on research, and a reduction in treatment variability. However, it also has drawbacks, including reliance on limited available evidence, being time-intensive, and providing generalised recommendations. Filling gaps where evidence is limited, therefore clinical guidelines are important. In many areas of clinical practice, high-quality evidence may be unavailable due to ethical, logistical, or financial constraints. Consensus allows experts to provide guidance based on the best available knowledge, ensuring that clinicians are not left without direction. For instance, rare conditions or some specific conditions may not have robust randomised controlled trials but still require actionable recommendations.

Clinical guidelines play a critical role in standardising care, improving outcomes, and guiding practitioners in managing specific conditions. Many guidelines, such as those from the British and Irish Orthoptic Guidelines, the American Optometric Association, and the Royal College of Ophthalmologists, are often developed based on clinical consensus rather than solely on empirical evidence. This approach involves expert opinions and collective experience when high-quality evidence is lacking. While consensus-based guidelines provide practical value, they also raise important questions about reliability, adaptability, and long-term impact. Additionally, guidelines based on consensus can be developed and updated more quickly than those relying solely on empirical evidence, which often requires years of research. This ensures timely responses to emerging clinical needs or evolving technologies.

Experienced practitioners bring valuable insights gained from years of managing patients, which may not always be captured by clinical trials. This real-world perspective ensures that guidelines are practical and applicable to daily practice. For example, consensus-based recommendations often consider patient variability, resource limitations, or common pitfalls that purely evidence-based guidelines may overlook.

Consensus-based guidelines can identify gaps in evidence, providing a framework for future research. By highlighting areas of uncertainty, they encourage studies to validate or refine the recommendations

3.3.9 Video tele-appointments in CI treatment

Tele-appointments were extensively used during COVID-19, but whether they were used for managing CI cases pre- or post-COVID is unclear. There was an increase in the distribution of leaflets about CI exercises for home use during COVID-19 (Rowe *et a*l., 2021), but it is unclear whether these cases are treated remotely. It has been reported that teleconsultations can safely diagnose and manage conditions such as strabismus and monitor compliance in amblyopia treatment (O'Cathail *et al.*, 2020). On the other hand, there is a lack of literature on using teleconsultations specifically for CI management.

As a result, the lack of tele-appointments in CI has prompted some researchers to suggest its future use in treatment. The American Academy of Ophthalmology (AOA) suggested that future trials could include a group assigned to remote CI management to investigate the effectiveness CI treatment (Chang *et al.*, 2021). Furthermore, in a review meta-analysis on interventions for primary CI, suggested that telemedicine could increase the efficacy of home therapy or replace office-based visits (Scheiman *et al.*, 2020).

The existing literature lacks studies examining the application of tele-appointments in CI management, highlighting a gap in this area. Therefore, introducing tele-appointments for CI management is a preliminary step that could address this current gap in the field. This approach might have the potential to improve or maintain the effectiveness of treatment as well as expand management options. Additionally, it can improve compliance, ensure quick contact, and reduce costs, all of which contribute to greater patient convenience.

3.4 Summary

The review of the literature showed that orthoptic exercises are effective in CI treatment but there is a lack of agreement regarding the most effective exercise protocols. The review of studies discussed in this chapter, showed there is variation in the treatment offered and no apparent most effective or gold standard treatment protocol. Another source of variability is that some researchers used complex regimens with a range of exercises. This variation is noticeable in methods which led to variable success rates. In addition, simple convergence exercises targeting disparity have proven effective in improving convergence and

accommodation responses. The lack of standardisation highlights a gap in CI treatment research, raising questions about the optimal treatment protocols and emphasising the need for research on a standard treatment approach.

There have been several successful examples of tele-appointments in eye care for adults and children. Although orthoptic departments utilised tele-appointments during the COVID-19 pandemic, it is unclear if they were used to manage CI. Moreover, the effectiveness of tele-appointments for treating CI has not yet been evidenced in the literature, making this approach novel. The high levels of satisfaction and acceptance reported for tele-appointments, along with the recommendation to consider them in the future, suggest a positive factor. Thus, the use of tele-appointments in treating CI is promising to be successful. This research aimed to provide frequent tele-appointments to determine their effect on CI management.

In view of all that has been mentioned so far, orthoptic exercises protocols in CI treatment should be investigated. Additionally, simple convergence exercises using Gabor image and tele-appointments might be effective on primary CI patients. It is important to note that the thesis defined primary CI as presence of symptoms and NPC greater than 10 cm from the nose. The success criteria are resolution of symptoms and NPC less than or equal 10 cm.

3.5 Aims of the research

- The primary aim of this research is to investigate the treatment protocols of primary CI and evaluate their effectiveness.

- The secondary research aims were to compare simple exercises to 'standard' exercises when treating primary CI (and/or AI). In addition, to evaluate whether tele-appointments could be used as part of the treatment of primary CI (and/or AI).

3.6 Research questions

<u>The following research questions reflect the updated project plan:</u>

1. What are the most effective orthoptic exercises and their protocols in treating primary CI (and/or AI)?

2. How effective are tele-appointments compared to face-to-face appointments in young adults undergoing orthoptic exercises

4- Are tele-appointments used in CI management among orthoptists and optometrists in the UK

3. Are primary CI numbers changed pre- and post-COVID

3.7 Research Objectives

In order to achieve above aims, the objectives of the research are:

1. Conduct a review of the literature evidence of primary CI treatment with exercises.
2. Gain University of Sheffield ethical approval to undertake a service evaluation in a single NHS site to establish the standard treatment of primary CI as well as evaluate its effectiveness.
3. Gain the HRA and REC approval to undertake the prospective in STH NHS Foundation trust
4. Recruit adult primary CI patients to investigate effectiveness of simple convergence exercises targeting disparity versus standard treatment as well as tele-appointment.
5. Gain University of Sheffield ethical approval to undertake the prospective trial in visually normal young adults.
6. Recruit young adult participants to the prospective trial to investigate effectiveness of tele-appointments and simple convergence exercises targeting disparity.
7. Gain University of Sheffield ethical approval to distribute an online questionnaire in the UK and Saudi Arabia.
8. Investigate the prevalence of primary CI numbers pre- and post-COVID, primary CI treatment protocols and tele-appointments among clinicians.

Chapter 4 Investigating the effectiveness of current treatment protocols for convergence and accommodation insufficiencies

4.1 Introduction

Convergence and accommodation insufficiency treatment protocols were discussed in the literature review chapter 2. Data in the literature showed that orthoptic exercises are often used as the first line of treatment. In the UK, convergence exercises and/or stereograms are most frequently used as first line treatment (Adler, 2002) and more complex cases may need intensive treatment, for example multiple exercises for extended training time (BIOS, 2016). In other parts of the world, pencil push-ups were the most commonly prescribed exercise (Scheiman *et al.*, 2002; Patwardhan *et al.*, 2008). However, it is well documented that clinicians lack agreement on the most effective treatment protocols (Scheiman *et al.*, 2005b), and there is limited research on the effectiveness of these protocols. As a result, the number of the prescribed exercises and the suggested frequency and duration of these exercises vary from clinic to clinic.

Variability in treatment regimens has led to inconsistency in reported outcomes. In this regard, some studies revealing improvements in symptom rates as high as 81.4% (Singh et al., 2021) and 83.3% (Aziz et al., 2006) in some studies, and as low as 29% (Nawrot et al., 2013) and 13.3% (Scheiman et al., 2005b) in other studies.

This variability in success rates is due to the criteria used to judge the treatment outcomes. For example, depending on symptoms only (Scheiman *et al.,* 2005a; 2005b), symptoms and NPC (Singh *et al.,* 2021), improvement in NPC and PFV (Gallaway *et al.,* 2002), improvement in NPC PFV, CISS (Nawrot *et al.,* 2013), and improvement in NPC, near exophoria, PFV and CISS (Aziz *et al.*, 2006; Momeni-Moghaddam *et al*., 2015). Furthermore, there was a considerable difference in the duration of the treatment reported in the literature. A high success rate has been achieved in shorter periods, for example, 81.4% with pencil push-ups in 6 weeks (Singh *et al.*, 2021) and 75.8% with dot card exercises in 4 weeks (Yi and Shahimin, 2018). In comparison, some researchers reported lower rates in longer periods, for example, 13% with pencil push-ups in 12 weeks. This leads to the conclusion that a more extended period does

not necessarily give higher success rates and vice versa. Taken together, these observations and the evidence discussed in the literature (Chapter 3) indicate that there is variation in the treatment provided, and there is no clear gold standard treatment protocol. Exploring the effectiveness of treatment protocols currently used in an orthoptic clinic is essential. In addition, whether the outcomes of current protocols align with what is documented in the literature regarding the variation and extent of the effectiveness.

Service evaluation was designed to evaluate the treatment protocols and outcomes, for patients with convergence and/or accommodative insufficiency from one clinical centre. Additionally, exploring these treatment protocols will determine whether the same variability in this centre is the same as reported in the literature. It will also help to inform the methodology for the CI prospective study.

4.2 Aim

The study retrospectively aimed to examine orthoptic exercises, their protocols, and treatment outcomes.

4.3 Objectives

- Explore the patients notes who diagnosed and treated for convergence and accommodation and/or insufficiencies
- Investigate orthoptic exercises protocols and their outcomes
- The results of retrospective analyses informed standard treatment and the prospective study for primary CI.

4.4 Methodology

This service evaluation was conducted at the Royal Hallamshire Hospital, Sheffield. The study received the necessary NHS approvals from The Clinical Effectiveness Unit, Sheffield Teaching Hospitals NHS Foundation Trust with project number (STH 20426), and also received ethical approval from the University of Sheffield Research Ethics Committee with reference number (052448) (Appendix 2.1). All collected data were anonymised and assigned to a unique anonymous study number. The data were entered on a spreadsheet and then stored in

Microsoft Excel 2016 format and Microsoft Word 2016, and then analysed using IBM SPSS 26.0.

4.4.1 Participants

Patients who had been diagnosed and treated by orthoptic exercises for primary CI, convergence weakness exophoria and/or AI between 10 and 36 years old had their clinical notes reviewed. The age categorisation was defined as children from 10-17 years and adults 18-36 years according to the CITT group criteria (Scheiman et al., 2008). Only patients referred between Jan 2018 and Jan 2021 with distance VA of 0.2 LogMAR or better were included. Patients who were amblyopic (VA ≥ 2 logMAR lines difference between eyes in best-corrected VA (Holmes and Clarke, 2006)), wearing prisms or had strabismus surgery were excluded.

4.4.2 Collected data

The clinical demographic data extracted included gender and age. Clinical data was extracted from the first clinical visit including symptoms, refractive error, distance VA logMAR (ETDRS), CT (33cm and 6m), PFV (33cm and 6m), near stereoacuity (FNS or TNO), PCT (33cm and 6m), NPA with RAF rule binocular and monoocular, NPC (free space or RAF rule push-up method), and diagnosis. The NPC can sometimes be recorded as 'pen to nose' for some patients who had 6 cm or less to indicate reaching normal levels. Therefore, for the purposes of the study, the phrase "pen to nose" will be considered as 6 cm. The treatment given was also recorded, including the type, frequency and duration of exercises to be performed and the follow up period. Final visit included reporting all the previous orthoptic tests, symptoms, and any changes to the treatment plan as well as the treatment outcome, duration of treatment, missed visits, reported compliance by patients or parents and to what extent clinical visits were affected by the COVID-19 pandemic were also recorded.

The orthoptic exercises were performed as home-based treatment for all patients. The study recorded whether patients were carrying out the exercises after being taught by orthoptists and if leaflets were given on how to perform the exercises as well as if there are special instructions for children. The severity of CI was not categorised into mild, moderate, and severe, as the orthoptists' notes lacked clear criteria for such classification. The symptoms

were the main criterion used to judge the treatment outcomes in the final visit. Patients who became asymptomatic were considered "cured", while those who had improvement in symptoms but not cured were considered "improved", and if still symptomatic classified as "failed" (Scheiman *et al.*, 2005b). The results are presented as overall pooled data, dependent on the outcome (cured, improved and failed). The definition of normal NPC and near PFV was unclear in the patients' notes. For the purposes of the study analysis, a receded NPC was considered greater than 10 cm (BIOS, 2016), and insufficient PFV ≤ 15Δ base-out at near was used as a cut-off value based on the CITT group criteria (Scheiman et al., 2008).

4.5 Data Analysis

Descriptive statistics of symptoms, orthoptic exercises and compliance were used to report the first presentation, outcomes, or any change throughout treatment. The mean, standard deviation and range of orthoptic measures were determined and presented as the mean ±SD. Due to the small sample size, the normality of the data was determined by the Shapiro-Wilk test. In addition to the visual indication of normality of the data distribution when plotted on a histogram. Descriptive statistics were also provided for the primary CI, convergence weakness exophoria, and CI with AI as cured, improved and failed groups. Due to the small sample size in these groups, statistical analyses were conducted on the overall data of patients.

There is no difference between adults and children data, so no further break down in results as explained in section 4.5.2.4. The parametric paired t-test analyses were used if data were normally distributed. A non-parametric equivalent Wilcoxon signed-rank test was used to report the statistical difference between pre- and post-treatment. The statistical significance was set as $p < 0.05$ for all tests.

4.6 Results

The notes of 96 patients were reviewed, of which 66 were excluded due to not meeting the inclusion criteria as follows: above the sample age (n =41), treated with prisms (n= 13), referred to strabismus surgery (n= 7), and amblyopia (n= 5). A total of 30 patients were eligible for inclusion in the study, 18 (69.2%) diagnosed with primary CI, 8 (30.8%) convergence

weakness exophoria and 4 (13.3%) comorbidity of CI and AI. Most of the patients were young adults, 83% (n= 25) 18 to 36 years of age, and 17% (n= 5) were under the age of 18 years. Most patients were emmetropic 63% (n= 19), while myopia was found in 20% (n= 6), hyperopia 13% (n= 4) and the refractive status was not recorded for one patient. Table 4.1 provides the study demographics and clinical measures at first visit.

Table 4. 1 Clinical demographic data and measures at baseline.

Characteristic	
Gender (n)	Female (22) Male (8)
Age (years)	**Mean ± SD (minimum - maximum)** 23.2 ±7.4
VA RE	-0.007 ±0.09
VA LE	-0.01 ±0.09
Refractive error (Sphere equivalent)	RE -0.9 ±1.8 LE -0.79 ±1.9
Stereoacuity	64.3" ±40.3

VA: Visual acuity in logMAR; SD: standard deviation; RE: Right eye, LE: Left eye; Stereoacuity in seconds of arc.

4.6.1 Pre-treatment

4.6.1.1 Symptoms

All patients were symptomatic before treatment and verbally reported their symptoms to the orthoptists. The most documented symptoms at the first visit were diplopia in 90% of patients (n= 27), followed by headache 50% (n= 15), eye strain 33% (n= 10) and blurred vision 27% (n= 8). Most patients reported more than one symptom; 11 (36.7%) patients complained of one symptom, 9 (30%) patients had two symptoms, and 10 (33.3%) patients had three or four symptoms.

4.6.1.2 Clinical measures

The overall mean NPC at baseline was 20.3 ± 9.4 cm. Furthermore, 10 patients had NPC greater than 25 cm, mean 31.6 ±4.6 cm. The overall mean PFV at near was 9.5 ± 9.6Δ (0-35), and 23 patients had insufficient PFV mean 5.2 ±4.5Δ. Twenty-two (73.3%) patients had exophoria, with mean distance PCT of 1.18Δ ±0.6Δ and a mean near PCT of 10.4 ±4.5Δ. Convergence weakness exophoria was found in 8 patients where the mean distance and near deviations were 3.12 ±2.9Δ and 20.13 ± 4.9Δ, respectively.

All tests except NPA were performed on all patients during their first visit. NPA was measured in 8 (26.7%) patients. Among these eight patients, four reported blur and were diagnosed with a comorbidity of CI with AI. In contrast, four patients reported blur, but their NPA was not measured.

4.6.1.3 Exercises prescribed

The study found that all the prescribed exercises were demonstrated by the patient at the clinic after being taught by orthoptists, but it was not documented whether leaflets were given to patients on how to perform the exercises.

The exercises given at the beginning of treatment varied among patients. The exercises included smooth vergence with accommodative and non-accommodative targets which was also documented as pen to nose. In addition, included dot card, stereograms, jump convergence. The number of prescribed exercises among patients is shown in Figure 4.1. In regard to stereograms, cat stereograms were given for three patients and a combination of cat and bucket stereograms for 2 patients. The type of stereograms was not specified for 6 patients.

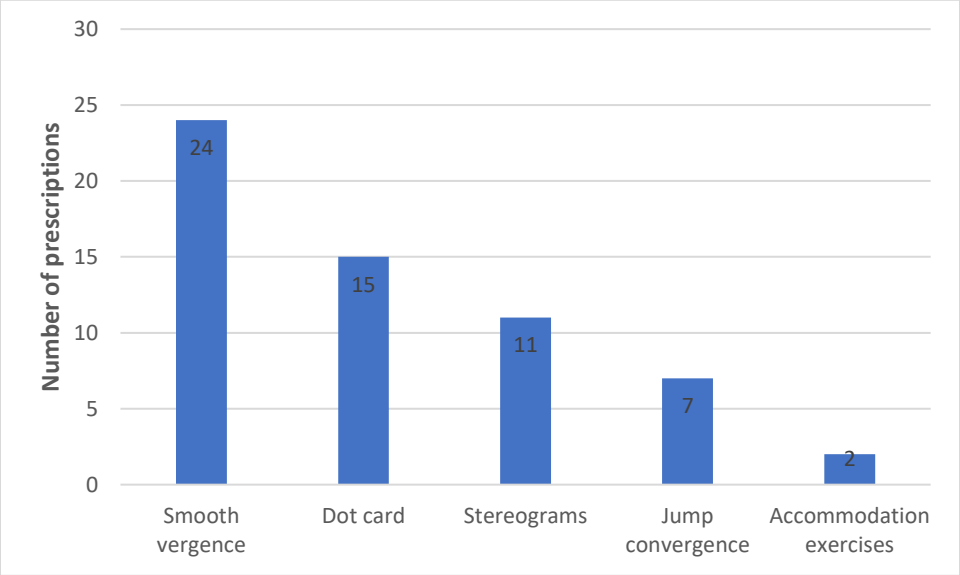


Figure 4. 1 The number of times each type of exercise was prescribed at the first visit

Pen to nose and jump convergence exercises with an accommodative target were prescribed only for the CI with AI patients. Ten (33.3%) patients started the treatment with a single exercise. Specifically, smooth convergence exercises were prescribed eight times and once for each of the jump convergence and stereograms. In addition, 12 (41%) patients were given two exercises, and 8 (28%) patients started with three or four exercises. The first visit revealed that the mean NPC and PFV were notably poorer when only one exercise was prescribed, with NPC at 24.5 ±9.3 cm and PFV at 7.2 ±9.1Δ. In contrast, patients prescribed two exercises had improved mean NPC at 19.7 ±9.8 cm and PFV at 10.3 ±9.5Δ, while those with three exercises showed further improvement with mean NPC at 17.1 ±8.0 cm and PFV at 11.3 ±11.0Δ.

4.6.2 Post treatment outcomes

At the end of the treatment, based on the success criteria, it was found that 12 (40%) patients had a successful outcome. Specifically, six patients were considered cured and six were improved. In addition, 18 (60%) patients were considered to have failed the treatment, as a base-in prism was given to 7 patients, and 11 patients were still symptomatic. Out of these 11 patients, 4 were lost to follow-up, while the remaining 7 were scheduled to resume treatment and encouraged to improve compliance.

4.6.2.1 Exercises prescribed

Figure 4.2 provides the overall number of prescribed exercises at the end of treatment. On the question of the efficacy of a single exercise, the results showed variable outcomes. Five patients achieved improvement while the other five showed no change, which required adding another exercise. Smooth vergence was given in conjunction with other exercises to 22 patients. In addition, smooth vergence exercises were given five times as a single exercise for cases with receded NPC above 25 cm with a minimum frequency of three or four times daily. Out of these five patients, two of them were given smooth vergence exercises only throughout the treatment, one succeeded and one failed. The dot card was given to 14 out of the 23 patients with insufficient PFV. Furthermore, adding the dot card exercise was the most common when changing the treatment, regardless of whether there was progression (5 patients) or no improvement (4 patients). Another important finding is that when stereograms were given to 12 patients, the mean NPC of patients was 16.9 ±9.7 cm and mean PFV 14.2 ±10.9Δ; 8 of them had NPC of 16 cm or better and 6 had PFV greater than 15Δ. This indicates that stereograms were given when the severity was low, or the case was improving. Similarly, jump convergence exercises were given when the severity of CI was low as the mean NPC was 14.2 ± 5.6 cm and mean PFV 12.9 ± 9.6Δ.

The outcomes varied when supplementary exercises were added. An additional exercise was introduced following an improvement in 8 patients, consequently contributing to success in 3 patients. In contrast, a lack of improvement in 5 patients led to adding an exercise, which resulted in success in one case. The number of exercises or protocol remained unchanged, regardless of whether there was a progression (8 patients) or no improvement (9 patients). Additionally, most patients maintained the same number of exercises during the follow-up appointments, and the average remained at two throughout the treatment.

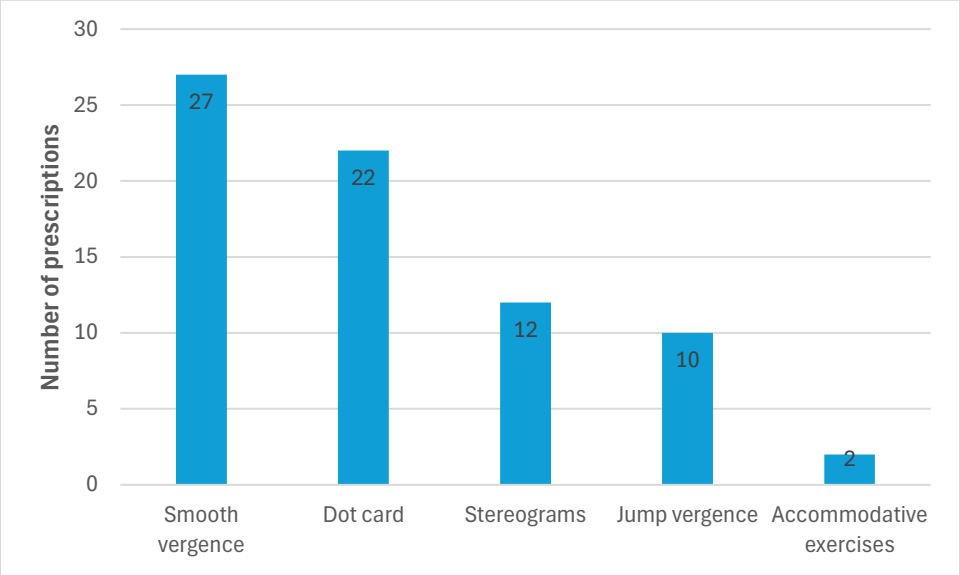


Figure 4. 2 The number of exercises prescribed to patients from the beginning to the end of the treatment

Two exercises only were prescribed to 18 patients throughout the duration of their treatment. This was followed by three exercises and a single exercise, prescribed 15 and 10 times, respectively. The frequency and training time did not always align with the number of exercises prescribed. The number of prescribed exercises also was not linked to the severity of symptoms or targeted one aspect that is poor. There were severe cases for which one exercise was prescribed and moderate cases given two or three exercises.

The exercises' training time and frequency differed between patients and were not followed by standard approach, for example, the training time and frequency not necessarily increased with the number of exercises. The training time was not recorded in 21 visits for 13 patients and frequency in 16 visits for 9 patients. The overall prescribed training time and frequency are shown in Figure 4.3.

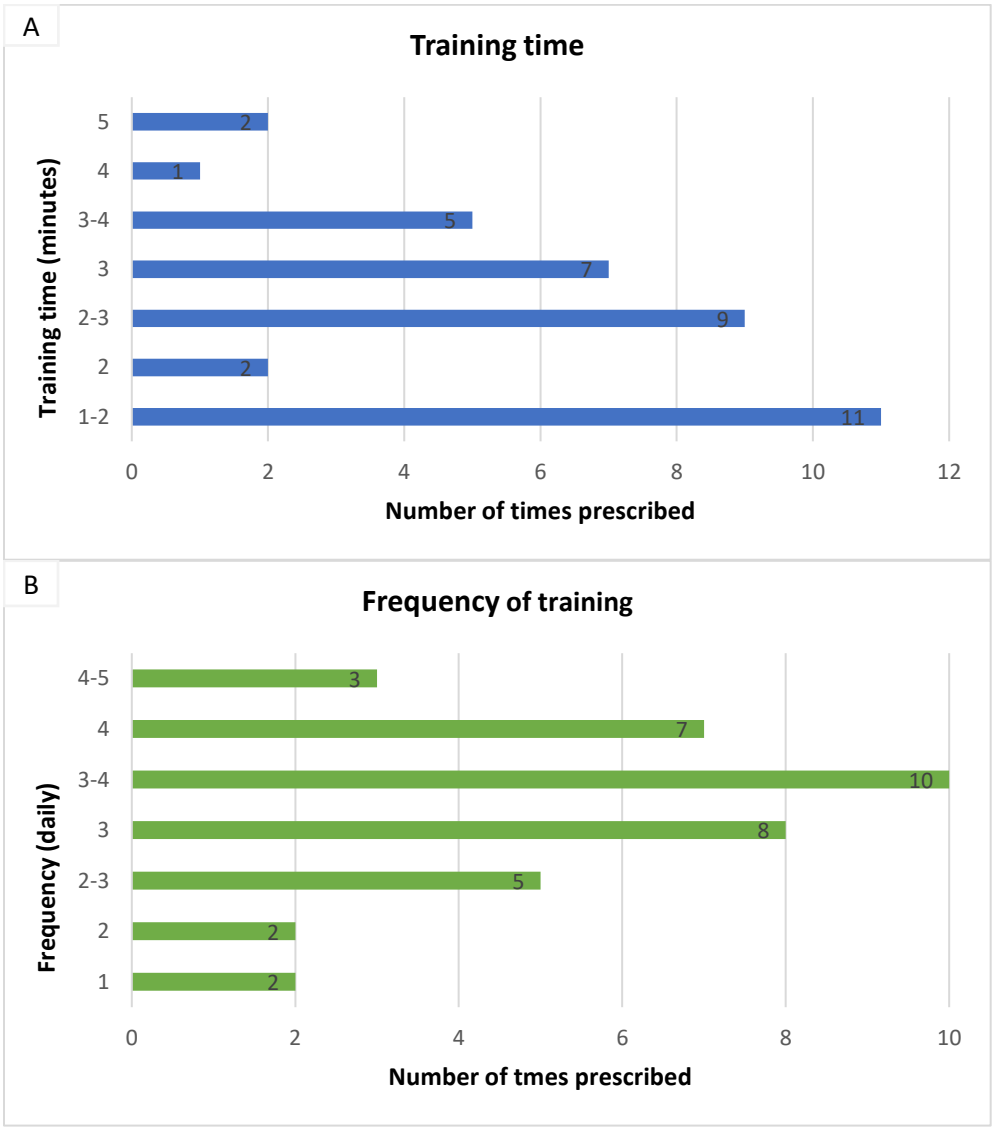


Figure 4. 3 The prescription times of: (A) Training time (B) Frequency of daily training

There was no apparent link between adding exercises based on symptoms or particular sequence. The results also showed inconsistency between the number of exercises, training time and frequency. The patients stopped orthoptic exercises when they became asymptomatic, given prisms or referred to surgery. The summary of protocols of the prescribed exercises for the treatment groups are shown in Table 4.2.

Table 4. 2 Summary of prescribed exercises protocols for cured, improved and failed groups at the end of treatment.

	Treatment groups		
Exercises details	**Cured (n=6)** **Mean ±SD**	**Improved (n=6)** **Mean ±SD**	**Failed (n=18)** **Mean ±SD**
Number of prescribed exercises	2 ±0.6	2.2 ±0.8	2 ±0.9
Training time (minutes)	1.75 ±0.5	2.5 ±1.5	2.3 ±1.0
Frequency (daily)	3.3 ±0.7	3.3 ±0.9	3.0 ±0.6
Type of exercises	**Times prescribed**		
Smooth vergence	6	5	16
Dot card	6	6	10
Stereograms	2	3	7
Jump vergence	1	1	8
Accommodative exercises	-	1	1

SD: Standard deviation

4.6.2.2 Duration, visits and compliance

The mean number of visits was 3.4 ±1.4, and duration of the treatment 17.6 ±8.3 weeks. The COVID-19 pandemic had led to missing clinical visits. Six (20%) patients were impacted by COVID-19, resulting in the rescheduling of 10 clinical visits. Additionally, excluding those affected by COVID-19, 12 patients missed 23 follow-up visits during their treatment, with 3 of them achieved successful outcomes.

Patient compliance with exercises was recorded on the basis of patient reports during the history taking at each visit. The compliance with exercises was not recorded in every visit, where 14 visits were missing this information across 9 patients. Overall, 14 (47%) patients reported poor compliance, of whom, six patients demonstrated consistently poor compliance, and failed the treatment. In addition, out of 14 patients with low compliance, ten were tasked

to perform three to four exercises. Table 4.3 provides the duration, visits number, COVID-19 effect and compliance for cured, improved and failed groups.

Table 4. 3 Outcomes of the treatment groups at the end of the treatment

Treatment group (n)	Duration of treatment (weeks) Mean ±SD	Number of visits Mean ±SD	Patients affected by COVID-19	Missed follow up visits	Compliance
Cured (6)	15.8 ±5.1	3.0 ±0.9	1	2	Full: 2 Good: 4
Improved (6)	17.7 ±10.6	3.2 ±0.8	-	5	Full: 1 Good: 3 Poor: 2
Failed (18)	17.7 ±9.1	3.7 ±1.3	5	16	Full: 1 Good: 5 Poor: 12

SD: Standard deviation

4.6.2.3 Clinical measures

The NPC improved to less than 10 cm in 10 patients (33%), their mean of 19.6 ±9.8 cm significantly improved by 12.6 ±6.9 ($t(9)=4.23$, $p= 0.02$). Out of 23 patients with insufficient PFV (≤ 15Δ) at the start of the treatment, 10 patients achieved significant improvement from baseline measure of 6.5 ± 5.1Δ by 16.4 ± 5.5Δ ($t(9)= -5.42$, $p < 0.001$). There was no significant change in near exophoria after the treatment as the mean 10.5 ± 4.6Δ changed by 1.4 ±4.9 ($Z= -1.952$, $p= 0.051$). The treatment outcomes of clinical signs for overall data, cured, improved and failed patients are shown in Table 4.4.

Table 4. 4 The NPC and PFV measures after orthoptic exercises for all patients and cured, improved and failed groups

		Mean ±SD		
Patient groups	**Clinical sign**	**Baseline**	**Change post-treatment**	**p-value#**
Overall	NPC	20.8 ±9.9	6.3 ±8.3	0.004*
	PFV	9.5 ±9.6	6.9 ±9.4	0.001*
Cured	NPC	23.7 ±10.1	16.9 ±5.2	0.009**
	PFV	11.7 ±10.4	16.3 ±7.6	0.036**
Improved	NPC	13.8 ±7.2	6.6 ±4.8	0.066
	PFV	10.2 ±10.5	6.0 ±8.8	0.121
Failed	NPC	21.4 ±10.3	2.3 ±9.1	0.334
	PFV	8.6 ±9.5	5.2 ±8.9	0.011**

NPC: near point of convergence in cm; PFV: positive fusional vergence in prism dioptre; SD: standard deviation; #Highlighted in blue: data are significant at $p<0.05$; *Wilcoxon signed-rank test; **Paired samples t-test.

4.6.2.4 The CI and AI group

In the comorbidity of CI and AI group, the NPA was not measured monocularly and binocularly at the beginning and at the end of treatment in all patients. Data regarding the measurement of NPA using an RAF ruler was recorded monocularly in 3 patients without measuring it binocularly. Conversely, in two patients, NPA measurements were taken binocularly without monocular measurements being recorded. As a result, it was not possible to perform statistical analysis. However, the mean NPC of comorbidity of CI and AI group improved from baseline 24.5 ±8.3 cm (median 23;16.3 - 35.3) by 13.1 ±5.0 cm as well as mean PFV from 7 ±3.5Δ (6; 4 - 12) by 7.8 ± 9.2Δ. The results for each individual case of the comorbidity of CI and AI groups are shown in Table 4.5.

Table 4. 5 Measurements for each case of the comorbidity of CI and AI group pre-and post-treatment.

	Orthoptic test pre-/post-treatment				
Case number	NPA RE (cm)	NPA LE (cm)	NPA BE (cm)	NPC (cm)	PFV at near (Δ)
1	28/20	14.7/18	24/NM*	16.3/15.3	6/8
2	26/9	16/9	NM/9.7	26.3/8.3	4/20
3	27.3/NM	24/NM	16/10	20/6	12/25
4	15.3/9	12.7/8	14/7.3	35.3/16	6/6

NPA: Amplitude of Accommodation; RE: Right Eye, LE: Left Eye; BE: Both Eyes; NPC: Near Point of Convergence; PFV: Positive Fusional Vergence; *NM: Not Measured

4.6.2.5 Children data

There was no impact of the included children on the overall findings and failure and success rates remained the same. Therefore, the results were not separated between adults and children.

4.7 Discussion

The study aimed to provide a retrospective analysis of treatment outcomes for convergence and accommodation insufficiencies and explore the prescribed orthoptic exercises and their protocols. The current study found that 40% of patients achieved successful outcomes and 60% were considered to have failed the treatment. In addition, there was variability in treatment protocols.

Without debate, alleviation of symptoms is a primary goal for CI treatment. The results revealed that symptoms were cured in 20%, improved in 20% and not changed or worsened in 60%. There are several possible explanations for this result. The improvement of symptoms is slower compared to the changes observed in NPC and PFV (Scheiman *et al.*, 2010). Consequently, while NPC and PFV showed improvement in patients, there might be a delay in

symptom improvement for some patients due to severity of CI, leading to their outcome being considered unsuccessful. This could contribute to the relatively low success rate, suggesting that a more in-depth treatment might improve their symptoms (BIOS, 2016). Another possible explanation for unimproved symptoms rate may be due to the different visual demands among patients. The intense demand for the binocular visual system can exacerbate the symptoms. This could be true as patients in this study are mainly children and young adults who are expected to spend extended time on smart devices and reading (Pillay *et al., 2021*). This result may also be explained by the fact that improvement in symptoms with changes in visual comfort is considered an essential criterion for the success of the treatment. In the present study, the orthoptists documented symptoms with phrases such as feeling the symptoms were reduced, feeling better, little improvement, and slightly better. This subjective assessment of symptoms is a cause for criticism. Symptoms may be overestimated by the patient and have a role in that the recorded symptoms are inaccurate; especially, as it is not necessary that the accompanying symptoms reflect the clinical signs and vice versa (Granet, 2009). Another possible alternative explanation of findings is that evaluating a verbal description of symptoms is prone to interpretation error and clinician bias. In contrast, for example the CISS questionnaire is not affected by the examiner's bias during the questionnaire administration (Scheiman *et al.*, 2005b). Therefore, arguably, if the CISS questionnaire was used, it might give higher accuracy during monitoring symptoms (Nunes *et al.*, 2020), consequently affecting failure rate.

The number of prescribed exercises and their protocols were unclear in all patients, whether in case of progression (8 patients) or lack of improvement (9 patients). It could be argued that these protocols showed consistency when patients improved (as with the stereogram in 8 patients), and when targeted poor fusion (as with the dot card in 5 patients), but this interpretation is taken with caution due to this not applying to all patients. Additional uncertainty arises from the number of prescribed exercises is that continuing with a single exercise without adding a supplementary exercise, whether patients are progressing (5 patients) or not (5 patients). It is possible, therefore, that changing the number of exercises was for variation. Additionally, the training time and frequency did not reflect the number of exercises and the severity of the condition, suggesting variability in treatment protocols. This

variability also may partly be explained by the fact that a big teaching hospital with many orthoptists followed up the patients throughout treatment, which led to different treatment decisions. The department followed a protocol aligned with BIOS guidelines. However, it is unclear if variations in training influenced their approach, as orthoptists may have had the flexibility to make treatment decisions based on the severity of the condition or their level of experience.

The 40% success rate may demonstrate the limited efficacy of this study's treatment protocols; nevertheless, it is not surprising in light of previous studies. Similar to this study, Serna *et al.* (2011) found that 36% of CI patients improved symptoms with normalisation of NPC and PFV after multiple home exercises. Slightly better improvement, Gallaway *et al.* (2002) reported an improvement of symptoms by 58% in 12 CI adults after home pencil push-ups with only one patient's symptoms completely resolved as well as the NPC and PFV improved to normal in 33%. Similar to this study, the CITT group assigned 13 young adults with symptomatic CI to home pencil push-ups treatment (Scheiman *et al.*, 2005b). The NPC and PFV improved to normal, but none of the patients' symptoms resolved, and only 13% of patients achieved some improvement in symptoms which is different from this study. However, severe or non-responsive cases to treatment could contribute to a high failure rate. Additionally, psychological factors that might influence treatment success were not explored during the orthoptic treatment process.

The patient's correct application of exercises may affect the success or failure of orthoptic treatment. It was not documented that patients were given the exercises instructions sheet, which suggests the possibility of performing the exercises incorrectly. It should be noted that Grisham (1988), Cooper (2007) and Momeni-Moghaddam *et al.* (2015) indicated that if home exercises are performed incorrectly, it could fail or impede the treatment's success. Additionally, the patients most likely fully understood the instructions, demonstrated the exercises in front of the orthoptist, but there is doubt about this procedure because it was not recorded for all patients.

It was not surprising that smooth vergence exercises were given as the first line of treatment to 80% of patients. There is general belief among eyecare practitioners that smooth vergence

exercises are the first choice of CI treatment. Additionally, smooth vergence exercises are often the first line of treatment to improve asthenopic symptoms (Aziz *et al.*, 2006). It seems possible that the high rate of smooth vergence exercises in the present study is related to the exercise being appealing because it is an easily taught procedure with minimal cost on the part of the clinicians and patients. The effectiveness of smooth convergence exercises in this study is uncertain. When prescribed alone, they resulted in equal improvement and decline, making it difficult to evaluate their effectiveness.

The dot card was also extensively prescribed in this study, especially at the first visit. The mean NPC at the first visit was 19.6 ± 9.7 cm which is within the furthest dot from the eyes at 28 cm. This link between the mean NPC and the dot card length might explain the use of the dot card as a first line of treatment for half of the patients. In addition, the dot card exercise has been prescribed to patients with the most insufficient PFV to target poor fusion. Moreover, the dot card exercises are believed to treat CI more effectively than pencil push-ups by enabling correct alignment of the eyes (Yi and Shahimin, 2018). This may be one of the reasons why the dot card exercise is the most frequently added exercise during treatment.

A possible reason for failure rate is the fact that CI is often associated with AI. An important point of note in the current study is that the accommodative functions were not measured in 73% of patients. According to Marran and Nguyen (2006) accommodation anomalies cause more symptoms than vergence anomalies, and most of the symptoms found in CI patients result from comorbid AI. In addition, Daum (1984) found the symptoms in CI patients were blur 47%, headaches 54%, asthenopia 36%, and diplopia 47%, while he found similar symptomology in AI patients of blur 59%, headache 56%, asthenopia 45%, and diplopia 30% (Daum, 1983). This confirms that there is an overlap between symptoms of AI and CI. Therefore, it can be argued that this data lacks assessment of accommodation, which possibly leads to missing the accommodative anomalies in those patients, consequently reducing the effectiveness of treatment methods in improving symptoms. This assumption may also explain the unsuccessful outcome of the pencil push-ups and placebo groups in the children's CITT study (Scheiman *et al.*, 2005a). The AA was a confounding factor between treatment groups; the mean AA met Hofstetter's criteria for the office-based group, while the mean AA was lower than normal values of pencil push-ups and placebo groups. Thus, it is possible that the

AI has not been treated in pencil push-ups and placebo exercises, which caused the symptoms and NPC not to be cured. These results provide further support for the importance of accommodation measures for CI patients, which would give a more accurate diagnosis and might enable greater treatment efficacy. It was suggested that such patients who do not respond well to orthoptic exercises might have an abnormality in the mechanism of accommodation (Rouse *et al.*, 1999). Simple convergence exercises targeting disparity could be a potential treatment. These exercises train both vergence and accommodation and have shown improvement in visually normal young adults. (Horwood and Toor, 2014). However, their effectiveness on CI and AI patients has yet to be investigated.

Non-compliance is always a major problem in home-based exercises and the most common cause of treatment failure (Adler, 2002; Cooper and Feldman, 2009), and needs to be followed. Patients' compliance with treatment was not documented at all visits, and some patients did not attend their follow-up visits. These can cause a loss of motivation and patients to perform the exercises incorrectly. Consequently, it affects the effectiveness of treatment and leads to slow progress. However, researchers found a low compliance rate for treatment even for simple exercises such as pencil push-ups. An example of such was (Gallaway *et al.,* 2002) who reported a poor compliance rate of 48% and only 17% followed the exact training protocol. With multiple exercises, the Pediatric Eye Disease Investigator Group (PEDIG) reported moderate compliance rates to the prescribed treatment of 68% in the home-based computer vergence/accommodative therapy group, 55% in the placebo group and 49% in the pencil push-ups group (Scheiman *et al.*, 2016). Unfortunately, in this study, the compliance was in line with previous studies, as found to be poor in 47% of patients, and only 10% claimed full compliance. The data also showed that 6 out of 14 patients constantly reported poor compliance had failed treatment. This could be due to the severity of CI which might preclude improvement. As a result, the patients may observe that their symptoms were not resolving and therefore felt the exercises were boring or they were tired of performing too many exercises. Consequently, some patients might have lost motivation through treatment. There are, however, other possible explanations. It is reported that compliance is affected by the number of doses during treatment (Spilker, 1992). Accordingly, 10 of 14 patients who have

low compliance were required to perform three to four exercises, which may make patients feel that exercises are too many and a burden. Another possible reason is that pencil push-ups were the most prescribed exercises. Pencil push-ups are by nature very repetitive (Gallaway *et al.,* 2002) and, therefore, may lack motivation factors such as improvement to overcome the monotony of the repeated routine. However, the compliance was not tracked by diary notes or phone calls that might motivate patients to perform the exercise. It should be noted that there is no optimal way to measure compliance (Revathy *et al*, 2011) and challenging to prove patients' compliance (Horwood *et al,* 2014). As a result, different methods possibly prone to inaccuracy.

4.8 Limitations

Several limitations to this retrospective study need to be acknowledged. The sample size is small, affecting the accuracy of treatment results; therefore, findings cannot be generalised to children and adults with CI. The study could not obtain a sufficient number of patients with AI to investigate the effectiveness of protocols in treating these anomalies.

The study was limited to a single centre, which impacted its scope. Due to COVID-19 restrictions, it was not possible to involve additional centres, leading to delays in initiating the study. This study was important for informing the cohort study in Chapter 5, meaning any delay would subsequently affect the timeline for the NHS study. Including other centres would have required additional time for obtaining ethics approval, further delaying Chapter 5 and disrupting the overall PhD framework. COVID-19 also influenced the study's start and patient numbers. Many patient appointments were postponed or cancelled, and some patients may have avoided in-person visits to minimise the risk of virus transmission. The ethics approval process prevented conducting a scope study, which in turn delayed subsequent PhD work.

The limited timeframe set by STH (2018–2021) further impacted the sample size; a longer timeframe could have allowed for the collection of more patient data. Finally, the referral pathways for orthoptic patients were not limited to those with unresolved issues previously managed by optometrists. They also included new referrals, such as those from optometrists or general practitioners.

4.9 Conclusion

In summary, there was variability in treatment protocol outcomes, and the most effective remains unclear. Therefore, standardised orthoptic exercise protocols should be applied. Failure to assess accommodative functions may lead to miss comorbidity of CI and AI, affecting the treatment outcome. There were no clear criteria for prescribing specific exercises or the number of exercises together. Ensuring home exercises are performed correctly is essential and motivating compliance remains a challenge.

Chapter 5 Cohort study: investigating tele-appointments in CI treatment on adults undergoing simple convergence exercises

5.1 Introduction

The study was planned before COVID-19, but data collection was scheduled to begin after the lockdowns, which led to recruitment difficulties.

The retrospective service evaluation of patient notes in Chapter 4 revealed 40% achieved successful outcome and 60% failed the treatment. In addition, the service evaluation showed important results of CI treatment protocols. These treatment protocols varied among patients regarding the number of exercises prescribed, changes to treatment, training time and frequency. This variability is consistent with what was reported in the literature (Scheiman et al., 2005b; Lavrich, 2010). In chapter 4, orthoptic exercises such as smooth vergence, dot card, jump vergence and stereograms were the most frequently prescribed. The training time of 1-2 minutes and frequency of 3-4 times daily were most used. These results of the retrospective study have informed the treatment plan to form the 'standard' treatment group. It should be noted that these results are consistent with BIOS recommendations (BIOS, 2016) in terms of convergence exercises and daily training frequency.

Simple convergence exercises were successful in visually normal young adults (Horwood and Toor, 2014; Horwood *et al*., 2014). These studies investigated normal participants and improved vergence and accommodation by 17.2% across orthoptic measures although their visual abilities were considered near ceiling. Simple exercises using Gabor's image were binocular push-ups, jump vergence and vergence facility that targeted convergence only but improved both convergence and accommodation. It is not known how primary CI patients will respond to this type of exercise and whether it will produce improvement as in the case of normal participants.

Orthoptic clinics have utilised tele-appointments during COVID (Rowe *et al.*, 2020; Rowe *et al.*, 2021), and there is ongoing call for their use in managing CI (Chang *et al.*, 2021). In addition, tele-appointments in managing CI patients have not been explored beyond the COVID-19 pandemic. Therefore, the question of whether tele-appointments can replace face-to-face

appointments and give similar results remains. These questions were investigated in this study on CI patients. More recent attention has focused on tele-appointments, which have shown success, effectiveness, and patient satisfaction in eye care during COVID and beyond. However, using tele-appointments in the care of CI patients within or outside the context of the COVID-19 pandemic needs to be clarified and documented.

5.2 Aim

The study aimed to compare simple convergence exercises using Gabor image versus standard convergence exercises for primary CI in adults. Additionally, investigate the long-term outcomes of primary CI treatment.

5.3 objectives

To achieve these aims, the study planned to:

- Recruit 44 patients diagnosed with primary CI attending the orthoptic clinic in STH NHS Foundation Trust.
- Patients underwent orthoptic tests that performed as part of the routine clinical assessment.
- Randomised patients to one of four treatment groups on face-to-face, tele-appointments convergence exercises with a Gabor image or accommodative target:
    - Standard treatment plan using accommodative target and face-to-face appointments
    - Standard treatment plan using accommodative target and tele-appointments
    - Simple treatment plan using Gabor image and face-to-face appointments
    - Simple treatment plan using Gabor image and tele-appointments

5.4 Hypotheses

The study hypothesised that:

- Simple convergence exercises using the Gabor image are more effect than standard treatment in treating CI patients.
- Simple convergence exercises lead to a long-term treatment effect on symptoms and clinical signs

- There is no difference between tele-appointments and face-to-face appointments in CI management.

5.5 Methods

5.5.1 Ethical approval

The study protocol and informed consent (Appendix 3.1) were approved by the Health Research Authority (HRA; IRAS project ID: 305275) and NHS research ethics committee (REC reference: 22/WM/0023) and registered on the University of Sheffield Research Management System (project number: 176246) (Appendix 3.2). The study adhered to the tenets of the Declaration of Helsinki. The study was advertised on NHS Health Research Authority website: https://www.hra.nhs.uk/planning-and-improving-research/application-summaries/research-summaries/current-future-management-of-convergence-and-accommodation-anomalies/.

5.5.2 Study setting

This is a prospective interventional parallel groups study of CI patients. The study was conducted in the orthoptic clinic, Royal Hallamshire Hospital, STH NHS Foundation Trust. Further objective testing of convergence and accommodation using the Plusoptix photorefractor was offered as an optional extra test at the Vision Science Room, Medical School, University of Sheffield. For ethical reasons, Plusoptix test was made optional. Patients who participated in the study attended their appointments in the orthoptic department at the Royal Hallamshire Hospital. However, the Plusoptix lab was situated in a different building separate from the orthoptic clinics, which contributed to the decision to make the test optional.

5.5.3 Sample size

The sample size of 44 patients was selected with 11 patients in each group. The required sample size was calculated by using G power (version 3.1.9), when the effect size, statistical power and significance level were set to 0.35, 0.80, $p < 0.05$, respectively (Appendix 3.3). The improvement of the NPC was calculated by obtaining the mean difference of the NPC between

pre-treatment and post-treatment (Scheiman *et al.* 2005b). The NPC improved by 5.5 cm in the home-based group (n=15), and 6.2 cm in the office-based group (n=15). Therefore, a sample size of 44 participants would be required for the study.

5.5.4 Recruitment

The study aimed to recruit 44 patients diagnosed with primary CI or CI with AI from the orthoptic clinic in the Royal Hallamshire Hospital at STH NHS Foundation Trust. AI was added based on the study results in Chapter 4, which showed that some patients were found to have a comorbidity of CI and AI.

The patients were to be identified by a member of the direct care team when grading referral letters. The grading process was based on the inclusion criteria. The orthoptist was looking for letters that suggested CI and letters that stated signs/symptoms that might indicate the patient has CI. This approach was carefully discussed to ensure that referral letters were appropriately graded to recruit potential participants who met the specified inclusion criteria. Thus, potential participants were referred to possible recruitment. Those potential participants were sent a Participant Information Sheet (PIS) (Appendix 3.4) in the post and seen by a care team member at their first appointment. However, not all new patients requiring convergence and accommodation exercises enter the orthoptic clinic via that route. Therefore, to increase the number of participants in the study, an additional recruitment method was used. This allowed any member of the care team to enrol patients as they came into the clinic. If it was not possible to identify these patients in advance, these patients would not have had 24 hours from reading the PIS to entering the study. However, it would be unethical to delay the start of their treatment. Thus, the patients were given PIS and the opportunity to discuss the study and ask questions before recruitment. The patients enrolled on the clinical trial if written informed consent was obtained by a research team member or the orthoptist from the care team. It was explained for the potential participants that £75 will be awarded at the end of the study as a gesture of thanks for their participation.

5.5.5 Inclusion and exclusion criteria

All Eligible primary CI patients were adults up to pre-presbyopia age between 18 to 35 years (Nawrot *et al*, 2013) with VA at least logMAR 0.2 or better in each eye at distance (Aziz *et al.,* 2006) and had a confirmed diagnosis of primary CI or comorbidity of CI with AI. No patient was wearing prisms, had strabismus, history of strabismus surgery or history of co-existing health condition that affects accommodation or convergence such as nystagmus or amblyopia. The primary CI diagnosis was based on receded NPC ≥ 6 cm break Push-up method of measurement (Scheiman *et al.*, 2008), and symptoms must present at near work (Gallaway *et al.*, 2002; Aletaha *et al.*, 2018). The cut-off value of receded NPC ≥ 6 cm was in agreement with the CITT studies. The AI in this study was identified on the basis of monocular measurement of AA i.e. less than Hofstetter's minimum age formula (15-0.25xage) monocular Push-up method (Hussaindeen and Murali, 2020).

5.5.6 Treatment design

The duration of treatment was 12 weeks, similar to that in the literature (Scheiman *et al.*, 2005b; Kim and Chun, 2011) as well as retrospective the service evaluation which showed that 55% of the patients completed the treatment in less than 16 weeks.

Patients were informed that they would be randomised between standard or simple treatment plans as shown in Figure 5.1. Patients were randomised into one of four groups through random generator application and distributed to four envelopes. Envelopes with all necessary documents for all groups were available. The orthoptist would select an envelope at random which would state the group and contain the documents needed.:

- Standard treatment plan and face-to-face appointments
- Standard treatment plan and tele-appointments
- Simple treatment plan and face-to-face appointments
- Simple treatment plan and tele-appointments

Masking participants from the orthoptists and principal investigator (PI) was not feasible because, during follow-up appointments, it was necessary for them to know the type of exercises prescribed. This ensured they could properly demonstrate the exercises and verify

they were performed correctly. Additionally, the orthoptists and PI needed to be aware of the nature of the appointments. Although masking would have been preferred to minimise bias, it was not possible in this context.

As informed by the retrospective study outcomes, the simple treatment and standard treatment groups always performed two exercises at a time throughout the treatment. For all treatment groups, the exercises were prescribed for the same length of time and the same number of visits. The exercises were home-based for groups at a daily rate of 2 minutes per session/3 times per day based on retrospective study averages. Specifically, the training time was one minute at a time for each exercise.

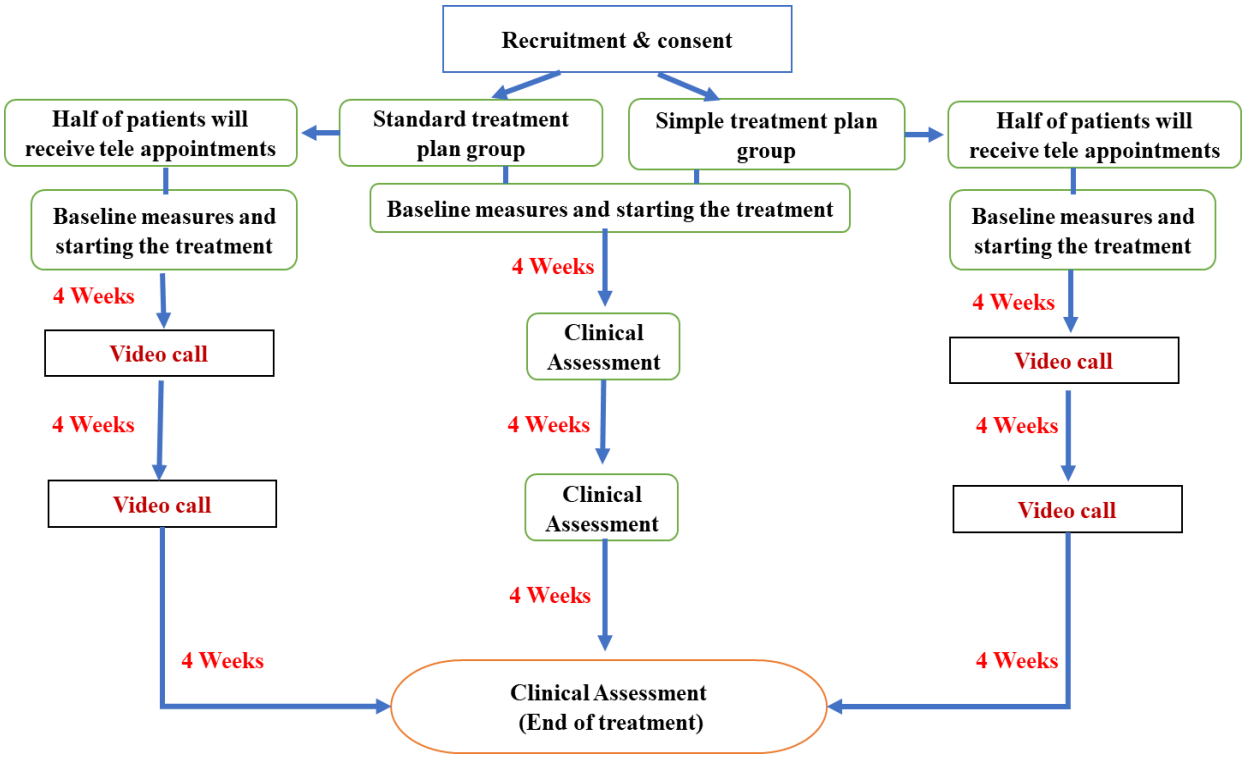


Figure 5. 1 . Flow chart of treatment plan. All patients were randomised to two treatment groups. Half patients of standard care group and simple convergence exercises group will receive 2 weekly tele-appointments to investigate the effect of the treatment.

Simple treatment plan

The simple treatment plan consisted of smooth convergence and jump convergence exercises only (Horwood and Toor, 2014; Horwood *et al*., 2014) throughout the study to match the standard treatment plan. In addition, instead of a detailed target that is typically used to perform these exercises, the patient was given a Gabor patch to use as a fixation target. This minimised blur and therefore emphasised single vision only i.e., targeting convergence, not accommodation. A leaflet with the instructions was provided to explain how each of the exercises are performed in Appendix 3.6. Smooth convergence exercises aimed to focus on a target at an arms-length distance while moving towards the nose and maintaining a single image. The patients were given a printed Gabor patch target close to size of a tongue depressor placed on a grey background as a fixation target. The patients were notified that the image may become blurred, but it should be single. To clarify, the patient held the Gabor patch target at arm's length from the face, below eye level. Then the patient made the target move slowly and smoothly towards the nose. When the target appeared double, the patient held it at that point and tried to make it single again. Then the patient moved the target as close as possible while trying to keep a single image. At the point where the target became double, the exercise stopped and was repeated. On the other hand, jump vergence exercises using a Gabor patch aimed to change the eyes' focus from a near target to a distant target. The patient held the Gabor patch image in front of the face at arm's length and started by looking at a distance target. Then changed the direction of the eyes to the near target. If the Gabor image was single, the patient looked again at the distance target, moved the near target closer to the face, and focused on it. If the near target was still single, the patient looked at the distance again and moved the near target closer. If the target became double, moved the target back until become single and moved the target closer again. This step was repeated until the Gabor image no longer became single.

Standard treatment plan

The standard treatment plan consisted of exercises determined from the BIOS (2016) guidelines for treating CI and AI, and the retrospective service evaluation study. At the first visit, the standard treatment plan started with the two exercises as in the simple treatment

group and used a detailed target of 20/30 letters. These exercises emphasised single and clear vision. The instructions were the same as in the simple treatment plan, but the patient was asked to concentrate on the target being single and clear. For follow-up visits, patients continued with previous exercises and swapped when they met the following criteria:

- Jump vergence was replaced for dot card exercises if the NPC was less than or reached 28 cm
- Smooth vergence was replaced for stereograms when the NPC reached 16 cm, and if the PFV was greater than 15Δ, CITT criteria (Scheiman, 2009).

Adherence with treatment

The patients were taught the exercises at the first visit and demonstrated the exercises immediately after being trained and at each subsequent visit. Patients were given written instructions for each exercise activity. In addition, after exercises, patients were instructed to have ocular relaxation for a few minutes to avoid longer-term discomfort post-exercise. The patient was given a diary to complete, which asked how often and for how long the exercises were completed each day, allowing the researcher to monitor compliance. Additionally, they were encouraged to set mobile phone notifications, set a timer for each exercise, and report any difficulty they might face in follow-up visits.

Trial visits

The duration of treatment was 12 weeks, similar to that in the literature (Scheiman *et al.*, 2005b; Kim and Chun, 2011) as well as retrospective the service evaluation which showed that 55% of the patients completed the treatment in less than 16 weeks. The patients were seen at baseline measurement visit and followed-up after 4 ±1, 8 ±1, 12 ±1 weeks of treatment. Specifically, for the face-to-face appointment groups, patients were attended all four visits. Additionally, the patients were asked to demonstrate how the exercises were performed to ensure these were done correctly. For the tele-appointment groups, patients attended a face-to-face appointment for only the first and last visit. The two visits in between were over video call by the PI (HA) using Microsoft Teams. Each session was planned to last a maximum of 10 minutes for tele-appointments. During the tele-appointment session, the patients were asked

to demonstrate the exercises, asked about compliance, and if there were any difficulties that should be reported. The clinical tests were not repeated in tele-appointment groups until the final face-to-face appointment. It is noteworthy to mention that no orthoptic assessment was conducted for visits 2 and 3 for the participants in the tele-appointment groups because they attended via video calls. Therefore, the participants had an orthoptic assessment at 6 weeks between tele-appointment visits by an orthoptist from the care team for the orthoptic department follow-up purposes. There was no questioning about the exercises, and if the participants had any queries, they were directed to contact the research team.

Patients in the face-to-face appointment groups and in clinical visits for the tele-appointment groups assessed by the direct care team at each visit. An orthoptist at STH carried out all the tests required as instructed by the study protocol and completed the data collection sheet to ensure all necessary data is collected. The patients completed the CISS questionnaire when they were attending the planned appointment in the face-to-face groups. For the tele-appointment groups, the patients were offered the choice to complete the CISS questionnaire on the same day as they were attending the tele-appointment or sent 24 hours before the planned appointment via email.

The patients were invited to attend the remainder of their appointment at the Vision Sciences Room, Medical School, University of Sheffield. This allowed us to assess their accommodation and convergence using the PlusoptiX photorefractor, which is not available in the clinic. The PlusoptiX photorefractor method and measurement is discussed in Chapter 6.

Outcome measures

The outcome measure was determined in final visit based on the CISS score and NPC measurement to evaluate the efficacy of treatment (Nawrot *et al.,* 2013). Successful treatment was defined if CISS score was < 21 and NPC < 6 cm. Patients who did not meet the definition of successful treatment criteria were considered non-responders.

For the face-to-face appointment groups, the patients stopped treatment when achieved successful outcome or if there was no improvement on 2 consecutive visits (Adler, 2002), despite good compliance. For the tele-appointment groups, patients discontinued treatment

with the same previous criteria but on the basis of the CISS questionnaire only because the follow-up visits were conducted via video calls. The patients returned to the routine clinic appointments in these instances or after 12 weeks of treatment have been completed. The patient compliance was evaluated based on how often they did the exercises through their diary. On the other hand, the adherence to the treatment was monitored by the number of patient visits attended

5.5.7 Testing procedures

All patients were assessed by an orthoptist of the care team at each visit with short rest in between to avoid patient fatigue. These tests included VA, Frisby stereoacuity test, cover/uncover Test (CT), Alternative Prism Cover Test (PCT), NPC, PFV, NPA. The orthoptists were taught to perform dynamic retinoscopy. Any clinical tests already completed as part of the standard clinical orthoptic appointment were not repeated for the purposes of the study to avoid fatigue, excessive patient testing burden and unnecessary additional testing time. There was an optional test Plusoptix photorefractor (Plusoptix GmbH, Nuremberg, Germany) to measure vergence and accommodation responses. Patients underwent the same clinical measures pre-treatment, throughout the follow-up, and at the last visit.

5.5.7.1 Visual acuity (VA)

VA was measured monocularly with right eye first and binocularly at distance 6 m using high contrast ETDRS logMAR chart with the patient wore the best refractive correction if required and this was measured using a focimeter and recorded.

5.5.7.2 Stereoacuity

Near stereoacuity was assessed with refractive correction if required using Frisby Stereo test (Clement Clarke, Harlow, UK), consisting of 3 plates of 1.5 mm, 3 mm, and 6 mm thickness. The orthoptist held the test plates at 30 cm, and the patient was asked to identify the target on the plate. The lowest disparity a patient can achieve was recorded as the level of stereoacuity.

5.5.7.3 Cover test and alternative prism cover test

To identify any manifest or latent deviation, a cover-uncover was performed using an 6/9 isolated letter on a tongue depressor at 33 cm and at 6m distance VA chart. The prism was placed over one eye, and the patient was asked to fixate on the 6/9 letter at 33 cm. The orthoptist performed an alternate cover and increased the prism power until the deviation was neutralised and recorded in prism dioptre. The same procedure was repeated at 6 m.

5.5.7.4 Near Point of Convergence (NPC)

The NPC was measured by the push-up method with the RAF rule with refractive correction if required. The NPC measurement used a single line with a dot in the middle at 40 cm. The patients were asked to maintain a single image of the fixation target while it was slowly moved toward the patients' midline at constant speed until the patient reported the dot became double or one eye deviated. The NPC was recorded to the nearest half centimetre from the distance at which the patient confirmed diplopia, or from the point where one eye deviated. The measurement was repeated three times.

5.5.7.5 Positive Fusional Vergence (PFV)

The PFV at near was measured using a Base-out prism bar, and the patient fixated to a single line of 6/9 letters at 33 cm with refractive correction if required. The prism bar was presented over the eye and gradually increased until the patient reported the occurrence of diplopia.

5.5.7.6 Near point of accommodation (NPA)

Binocular NPA was measured with the refractive correction if required using the push-up method with the RAF rule. The patient asked to fixate on N5 print on the RAF rule at 40 cm. The fixation target was slowly moved towards the patient along the ruler until sustained blur was reported. The measurement was repeated three times and recorded in centimetres. The same procedures were repeated for the right eye and then the left eye.

5.5.7.7 CISS questionnaire

The CISS questionnaire was used as a primary outcome to measure and monitor the change in symptoms. The CISS questionnaire was administered to the patients at each visit. Specifically, at the beginning, during and at the end of the treatment. The questions were read to the patient if requested to do so. The symptoms of CI were assessed through a modified CISS questionnaire because five questions of the 15 CISS items might be unrelated to ocular difficulties (Horwood, Toor and Riddell, 2014). Therefore, supplementary questions were added after those five items to ensure that the symptoms were ocular according to the patient. The score of the CISS questionnaire was based on the usual five-point scale where 0 = "never" and 4 = "always", but if the answer to the supplementary questions indicated non-ocular difficulties, a re-score of 0 was considered to the question to give a modified score. The PI (HA) assessed the CISS score for all patients. A CISS score of ≥ 21 was considered to be symptomatic for adults (Scheiman *et al.*, 2008).

5.5.7.8 Plusoptix photorefraction

The PowerRef 3 PlusoptiX R09 is an optical device that objectively measures accommodation and vergence responses. The Plusoptix photorefractor simultaneously captures eye positions and refraction. The specifications and all details of PlusoptiX measurement are discussed in detail in Chapter 6.

5.6 Results

Recruitment opened on 7 February 2022 and was open for 18 months. The study was unable to recruit the required sample size.

5.6.1 Patients recruited

One patient was recruited and randomised to a simple treatment plan using Gabor image and tele-appointments. The patient withdrew from the study after the recruitment visit without giving a reason. The data on recruitment for patients is shown in Table 5.1

Table 5. 1 Assessment of CI patient who withdrew from the study following the recruitment visit

Symptoms	Diplopia
CT	Near slight exophoria Distance ortho
PCT (Δ)	Near 4 Distance ortho
NPC (cm)	18,19,18
NPA (cm)	RE 11, 10, 12 LE 13, 14, 14 BE 14, 12, 14
PFV (Δ)	Near 20Δ Distance 20Δ
CISS score	42
PlusoptiX photorefraction	Not completed

CT: Cover test; PCT: Prism cover test; NPC: near point of convergence in cm; NPA: Near point of accommodation; RE: Right eye, LE: Left eye, BE: Both eyes; PFV: positive fusional vergence in prism dioptre; CISS: Convergence Insufficiency Symptom Survey.

5.6.2 Patients not recruited

The study found potential participants diagnosed with primary CI and PIS were sent in advance when possible. There were referred CI patients, but when it was found that they did not meet inclusion criteria, they were excluded. Table 5.2 shows potential CI participants and the reasons for declining participation.

Table 5. 2 Potential CI participants were found during the study with reasons that led to not participating.

Patient	Diagnosis	Met inclusion criteria Yes / No	Reason for exclusion or declining participation
1	Primary CI	Yes	Previously completed exercises and not happy with the results. Seeking another opinion
2	Reduced fusion range	No	-
3	Normal	No	Previously diagnosed with AI
4	Reduced fusion range	No	-
5	Secondary CI	No	Neurological defect and no convergence

6	Referred with CI	No	Base-in prism in patient's spectacle
7	Primary CI	Yes	Completed exercises before and not interested to participate
8	Referred with CI	No	Base-in prism in patient's spectacle
9	Primary CI	Yes	Too busy to perform exercises, not interested to participate
10	Primary CI	Unsure	Did not attend
11	Primary CI	Yes	Completed exercises before and too busy to perform them. Not interested to participate
12	Referred with CI	No	Base-in prism in patient's spectacle

5.6.3 Recruitment difficulties

There have been numerous attempts to recruit CI patients and innovative ideas to increase the possibility of inviting potential patients.

5.6.3.1 Recruitment considerations during the study design

Before the start of the study, an arrangement was established with the orthoptic clinic at the Royal Hallamshire Hospital to facilitate a recruitment strategy. Referral notes were reviewed weekly to identify any potential CI patients. This process was ongoing throughout the study period. In addition, fast-track patient notes were also examined for potential CI patients in the clinic. The care team was aware of these procedures in order to inform the PI of any eligible participants. Furthermore, the PI (HA) regularly attended the orthoptic clinic on a weekly basis to actively search out potential participants. Academic supervisors also had clinics and actively sought out potential participants to aid in recruitment efforts.

To maintain continuous recruitment efforts, orthoptists were aware of the study's inclusion and exclusion criteria through three presentations conducted before and during the study period. This ensured that orthoptists were well-informed about the research requirements and the ongoing search for eligible patients. Additionally, the PI utilised notice boards in all

clinic channels to provide comprehensive information about the study and guidelines when identifying potential participants. Consequently, orthoptists remained proactive, minimising the possibility of missing primary CI patients.

5.6.3.2 Attempts to improve recruitment during the study

The The PI regularly contacted orthoptists in STH to remind the team about the study. Furthermore, as a result of poor recruitment, 10 months after the start of the study we sought support from a Clinical Trials Assistant for the Ophthalmology department at Sheffield Teaching Hospital, NHS Foundation Trust. The clinical trials assistant sent an email about the study to the ophthalmologists who may have CI cases for additional support for the study. This was done as CI patients may be referred to the orthoptic clinic by a different route, for example, by referral from an ophthalmology consultant. The research clinical trials assistant supported the study by following up with the patients who had PIS sent to them and asking if they had questions about the research. This step was important since a small numbers of primary CIs were coming to the clinic. Therefore, we attempted to maximise all opportunities to recruit those that are suitable.

Due to poor recruitment, the research team amended the ethics to add new sites on board to aid recruitment. Eight months after the start of the study and after approval of the amendments by the ethics committee, the research team started to invite other sites for participation. The research team suggested that the search and invitation circle should be large enough to include far locations, for example, up to 150 miles from Sheffield hospitals. Therefore, invitations were sent to 17 sites, accompanied by an invitation email (Appendix 3.6) and the study protocol. Invitations were sent to sites in the following cities: Newcastle, Middlesbrough, Sunderland, Durham, Bradford, Hull, Harrogate, Leeds, York, Doncaster, Huddersfield, Manchester, Liverpool, Leicester, Derby, Nottingham and London.

One site, the orthoptic clinic in Imperial College Healthcare NHS Trust, accepted the invitation and agreed to participate on 18 October 2022. It was agreed to set up an honorary contract for the PI (HA) after completing the necessary documentation. The agreement was to present the study to the orthoptists and set the necessary preparations to start recruitment. In addition, the orthoptists would assess and follow-up on recruited patients during the study

and the PI collecting necessary data from patient notes. The honorary contract with Imperial College Healthcare NHS Trust was not made until the end of the study due to R&D department delays that made joining the study not of utmost priority. For other sites, the reasons varied and failure to respond to the invitation was the most common reason among the invited hospitals. Below are the anonymised reasons given by hospitals that responded to the invitation email:

- Site 1

"*I don't feel we can offer any input unfortunately, we have an issue with staffing levels and we are needing to give all possible time to clinical demands"*

- Site 2

"Don't offer telephone consultations for this patient group and can't change that".

- Site 3

"That is definitely a challenging group to find, I have just had a quick look through our new case book at the main hospital and did not see one CI recorded since Jan to 12 October 2023. In my experience, optometrists often manage these cases and we only see when all options are exhausted".

- Site 4

"We also only usually utilise 3 visits and the 2nd one is via video and often the 3rd so this would be extending treatment even if one is a longer term outcome visit"

- Site 5

"Staff on sick leave - this is putting us under a lot of stress just keeping our clinic commitment going and managing student placements. I'm sorry to disappoint, but feel that we cannot manage to be involved in the PhD study".

- Site 6

"the PhD student is an optometrist, not an orthoptist".

5.6.3.3 Recruitment discussions with supervisors

The orthoptic team in STH reported that primary CI patients do not always show up in the clinic post COVID, leading to concerns about the low number of participants. Therefore, there were discussions with the supervisory team after 4 months of notable poor recruitment. The

supervisory team and PI (HA) decided that the study would continue to try and recruit patients and discussions for alternative solutions. These solutions included additional studies were planned, and the PhD framework was changed. Despite adding two new studies in Chapters 6 and 7, a close search of CI patients in the clinic continued, and all the methods discussed above to improve recruitment continued.

5.7 Discussion

The study aimed to recruit 44 patients but encountered a low number of primary CI patients. Only one primary CI patient was recruited during the 18-month study period, with 5 potential patients identified. The study seemed feasible during planning stage pre-COVID and clinicians at STH confirmed this but decline in patients possibly post-COVID. The reasons contributing to the decline in CI numbers are unknown, but it may be that patients believe there are long waiting lists or that simple cases are treated through high street optometrists. Investigating the declining numbers of CI patients and the associated factors warrants future research. This raises questions about whether the same decline is happening in other locations or whether additional factors, such as optometrists managing these cases, play a role.

A number of studies investigating CI treatment and reported small sample sizes from clinical settings. For example, Sreenivasan and Bobier (2015) (Canada) reported 6 patients, Gallaway *et al*. (2002) (USA) 12 patients and Kim and Chun (2011) (South Korea) 16 patients, but for how long and without explaining the underlying causes for the low numbers. However, the current prevalence rates for CI in the UK are undetermined. The Royal College of Ophthalmologists (2012) suggested that the prevalence is near 2% on the basis of global literature reports.

In September 2023, the NHS waiting list reached 7.8 million, with increases observed across all regions and areas of England, for instance, by December 2023, the North East & Yorkshire waiting list had risen by 71% compared to January 2020 (Warner and Zaranko, 2024). Such delay may affect the patient's decision, and they may become discouraged from seeking treatment. Consequently, it may lead to a search for other pathways of care, resulting in a possible decrease in the number of primary CI patients in orthoptic clinics.

Recruiting participants poses a significant challenge in clinical trials (Wandile, 2023). For example, in the UK, a survey conducted by Clinical Trials on trial managers, research nurses, statisticians and health researchers indicated that recruitment was the foremost concern (Bower *et al.*, 2014). This study was no exception, as recruitment was the main difficulty, and the potential patients chose not to participate, which led to trial failure. Worldwide, 55% of clinical trials stopped due to poor recruitment, with only 7% of recruited patients completing the trials (Desai, 2020). In the UK, a Harris Interactive Survey of patients regularly informed about clinical trials showed that 71% opted not to participate (Anastasi *et al.*, 2024). In addition, a review found that out of 388 randomised controlled trials funded by the National Institute for Health Research (NIHR) and published in the NIHR Journals Library, 118 encountered recruitment challenges that required adjustments to objectives and recruitment extension, or sample sizes were reduced in 79 trials (Jacques *et al.*, 2022). In this study, measures were taken to improve recruitment by contacting patients in advance, enhancing the commitment of the care team to the study and inviting sites to come on board.

Various factors contributing to poor recruitment, including previous medical experience or a busy lifestyle (Kadam *et al.*, 2016). Among the potential participants were those who had performed exercises before and had an unsuccessful experience. As a result, they had no interest in participating in the study. Furthermore, one participant mentioned the demands of work or academic commitments as a barrier to participation. Additionally, other factors may have influenced participants' decisions, such as concerns about the time required for treatment, with one participant indicating that their study occupied much of their day. Moreover, participants may be hesitant to enrol and perceive the risks of participation over the potential benefits or believe that the trial intervention is not providing the expected benefits or the exercises are ineffective.

Participants may withdraw from the clinical trial for various reasons. Unexpected side effects from the treatment or intervention might lead some participants to withdraw from clinical trials (Anastasi *et al.*, 2024). In this study, orthoptic exercises may cause eyes to feel uncomfortable or exhausted, resulting in participants withdrawing by prioritising their well-being. Additionally, participants may choose to withdraw if they observe no improvement in

their symptoms throughout the study due to a possible lack of the exercises efficacy. Additionally, some participants might lose interest or motivation in the study over time, particularly if they find the protocol is demanding. Participation in this clinical trial requires frequent visits, multiple assessments, and adherence to the treatment protocol, which can be inconvenient, leading some to withdraw from the study. Furthermore, inadequate explanation or difficulties understanding study procedures may lead some participants to withdraw. These reasons and possibilities may have influenced the decision of the patients who declined participation.

Several important strategies are reported in the literature that should be considered to improve recruitment. Key strategies include rewarding participants, research design, collaborative referrals of patients, increasing patient awareness of the research, emphasising the value of clinical research to the care team, the commitment of the care team to the study, and informing senior clinicians who influence research (Adams *et al.,* 2015). The research team considered the importance of expressing gratitude to participants by rewarding them with monetary compensation, acknowledging their time, adherence, and effort. This detail was clearly in the PIS during the study explanation to potential participants. The study design ensured that the treatment plan should simulate standard treatment, for example, the exercises, training time and frequency and the follow-up duration consistent with BIOS guidelines (2016). Furthermore, the research design prioritised close monitoring of patients allocated to tele-appointments by their orthoptist, with reviews scheduled 6 weeks after initiating the treatment plan. It is noteworthy that the patient who dropped out did not attend regular appointments, indicating that the study's design was probably not the reason for their dropout.

Collaborative referrals of CI patients were taken into account through contacts with local sites and informing them about the research. Patient awareness was consistently prioritised by reviewing referral notes and sending the PIS in advance, ensuring patients had better understood the study before their appointments. Furthermore, support was sought from the Clinical Trials Assistant in the Ophthalmology Department to engage with potential patients, provide guidance, and answer any inquiries to enhance awareness of the study.

The value of the research was emphasised to the orthoptists, highlighting the objectives, methodology, and importance through meetings and discussions. The orthoptists were always aware of and committed to the study. This was through presentations, announcing the study in each clinic, conversations, and reminders about the recruitment. Orthoptists remained consistently informed and committed to the study through presentations, announcements in each clinic, discussions, and reminders regarding recruitment. Moreover, efforts were made to inform influential staff about the research, as it informed ophthalmologists through the Clinical Trials Assistant in the Ophthalmology Department.

The responses from invited sites to come on board to aid recruitment have been varied, including issues such as insufficient staff, treatment protocol cannot be implemented, lack of CI patients, and utilisation of tele-appointments is not possible. Insufficient staff is a significant barrier to conducting clinical research (Adams *et al.*, 2015; Johnson *et al.*, 2018), particularly in busy clinical settings. Such shortages might place a heavy burden on staff, leading to a lack of interest or commitment to the study. Furthermore, the lack of agreement on treatment protocols among clinicians, as discussed in Chapter 3 of the literature, contributes to sites' hesitancy to join the study and is understandable, given the variable approaches to CI treatment. Additionally, the observation of one site encounters a lack of CI patients, with optometrists often managing such cases. This raises questions about the numbers of primary CI patients across UK sites and the potential role of optometrists in treating these cases. While orthoptic departments adopted tele-appointments during the COVID-19 pandemic (Rowe *et al.*, 2020), one site reported not using them for CI patient management. This calls into question whether it is happening across other sites and if there are any barriers to utilising tele-appointment.

5.6 Limitations

The study has several limitations. The most significant is the inability to recruit primary CI patients. Securing ethics approval caused delays that impacted the study's timeline. Delays at this stage created a domino effect, pushing back other components of PhD research. In addition, many patient appointments were either canceled or postponed, reducing the pool of potential participants. Additionally, some patients may have been hesitant to attend face-

to-face appointments due to concerns about virus transmission. Moreover, the invitation for potential participants were under COVID restrictions such as wearing a mask and social distancing. Such restrictions most likely made participants reluctant to participate.

As the PI an optometrist, did not perform the orthoptic assessments on the participants; instead, these were carried out by orthoptists which is another limitation. For ethical considerations, an extra visit was scheduled within 6 weeks between the second and third visits for the tele-appointment groups, which represented an additional limitation of the study. The decision to include a 6 week visual assessment was made by the orthoptic team. Orthoptists aim was to ensure that patients remained under the care of the usual orthoptic team and were not isolated from their standard follow-up routine. Therefore, they could not leave the patients for 12 weeks without an assessment. To maintain continuity of care, the orthoptists prioritised integrating the study within their usual protocol. However, this additional visit between study assessments could potentially introduce bias into the results. The 6 week visual assessment could potentially introduce bias into the study results. This interaction could enhance adherence to the prescribed treatment, which might not reflect real-world scenarios where such mid-point follow-ups are not standard. Moreover, the additional visit could create a "monitoring effect," where participants might feel more accountable and motivated to follow the exercise regimen, knowing they would be reviewed midway. This could lead to improved outcomes that are not solely attributable to the intervention itself. The extra visit might provide participants with reassurance or motivation, potentially influencing their perception of symptom improvement. This subjective improvement might inflate the perceived efficacy of the intervention.

A potential limitation of this study is the lack of separation between CI cases with and without coexisting AI. This could have introduced an imbalance in the distribution of AI cases across groups, potentially influencing the outcomes. While randomisation was intended to mitigate such issues, future studies should consider stratified randomisation or separate analysis of these subgroups to control the confounding effects of AI.

However, despite these challenges, the study design was strong and holds potential for further development. Future work could extend the timeframe to recruit more participants.

Moreover, including multiple centers can improve generalisability of outcomes. Furthermore, incorporating psychological assessments to explore their impact on treatment outcomes.

5.7 Conclusion

The number of primary CI patients remains uncertain, and it is unclear if there has been a decline in primary CI cases after COVID-19. Additionally, the effectiveness of simple convergence exercises on primary CI patients has not been definitively established due to challenges in patient recruitment for this study. As a result, there remains a gap in applying this type of exercise to actual patients. Testing these exercises would be crucial to determine their effectiveness compared to conventional orthoptic exercises. The effectiveness of tele-appointments in managing orthoptic exercises also has yet to be investigated.

To address recruitment difficulties in future studies, involving multiple centers could help ensure an adequate sample size. Additionally, conducting clinical trials in countries with higher reported prevalence rates of primary CI could also facilitate recruitment and improve the study's feasibility.

Chapter 6 Tele-appointments compared to face-to-face appointments in typical young adults undergoing orthoptic exercises

6.1 Introduction

As presented in Chapter One, the initial plan was to address the research question through the study detailed in Chapter 5. However, the recruitment challenges for a population group of patients with primary CI led to redesigning the research approach. The inability to recruit this specific patient group demanded the adoption of an alternative methodology to answer the research question. This study aimed to answer the research question using simple convergence exercises through tele-appointments in visually normal young adults. This approach was built upon the foundational work of (Horwood and Toor, 2014; Horwood *et al.*, 2014), who successfully employed simple convergence exercises using Gabor images for a similar population to the one targeted in this study. In their study, the method was designed for face-to-face appointments. Therefore, this chapter presents a modified methodology that employs simple convergence exercises but within the framework of tele-appointments to answer the original research question effectively.

Tele-appointments, as discussed in the literature review Chapter 2 (section 2.5), may offer several benefits for both patients and orthoptists. They can enable faster access to care, reducing travel expenses, waiting times, and the risk of infection. It has been suggested that there is a clear need for remote treatment and follow-up to meet the increasing demand and capacity in orthoptic clinics (Francis et al., 2022).

6.1.1 Tele-appointments in orthoptic clinic

Tele-appointments for orthoptists may face challenges in providing comprehensive orthoptic assessments via video calls. Delivering orthoptic assessment remotely for CI patients might be difficult, given the need for access to orthoptic testing to diagnose and interpret the findings. This may be supported by the return to face to face visits following COVID-19 pandemic. However, despite such difficulty, tele-appointments may offer benefits. To overcome previous limitations, combining both modalities can be a beneficial approach to address this limitation.

For example, in a CI condition, the initial visit can be used for baseline measurements and diagnosis, while follow-up visits can utilise tele-appointments to evaluate symptoms and provide consultations. This approach has the potential to enhance compliance, motivation, exercise demonstrations, and patient education. Combining the advantages of both modalities may be an innovative and appealing approach to orthoptists and patients. Tele-appointments have the potential to increase the effectiveness of treatment and complement CI management.

There is a paucity of literature about the use of tele-appointments in monitoring exercises in orthoptic clinics. The use of tele-appointments within orthoptic practice was not well documented before the rise of COVID-19 pandemic. On the other hand, a number of studies have outlined the use of tele-appointments as a service in orthoptic clinics rather than investigating their validity versus face-to-face appointments in orthoptic management of patient conditions. This warrants further investigation into whether tele-appointments could be effective in monitoring orthoptic exercises and improving compliance.

6.1.2 Tele-appointments for orthoptic exercises

Orthoptic exercises have demonstrated efficacy in relieving CI symptoms (Westman and Liinamaa, 2012). The eye exercises are designed to alleviate symptoms and enhance visual function (Helveston, 2005). In contrast, the placebo effect might also alleviate visual symptoms without changing vergence and accommodation responses (Horwood *et al.*, 2014). The placebo in clinical trials is intended to demonstrate the true effect of the actual treatment compared to an inactive intervention (Cherniack, 2010). In this regard, Horwood and Toor (2014) and Horwood *et al*. (2014), as discussed in Chapter 3 (section 3.3.3.3), investigated the effect of orthoptic exercises on normal subjects. In their study, they found changes in vergence and accommodation responses in young adults after 2 weeks of orthoptic exercises. The simple (disparity) exercises of binocular push-ups, jump vergence and vergence facility using Gabor image as fixation target induced overall improvement in clinical measures by 17.2%. Particularly there was significant improvement in NPC by 1.5 cm, vergence facility 4.75 cpm, monocular NPA 0.8 cm, BO fusion ranges at distance 9.75Δ and near 10.1Δ. In addition, to objective assessment via Plusoptix photorefractor showed improvement in vergence

responses by 12% and accommodation by 9% at 33cm. While placebo exercises such as the snakes illusion and yoked prisms made a small, significant improvement in VF by 2 cpm and MAF by 3.8 cpm. Thus, the simple exercises using a Gabor image made the most improvement and were not explained by the placebo effect.

It is not yet known whether similar improvements of simple exercises can be obtained through orthoptic exercises via tele-appointments in young adults. The participants may not need frequent face to face appointments during exercises if tele-appointments might give the same effectiveness. This study investigated whether video tele-appointments were as effective as in-person orthoptic appointments during orthoptic exercises, in young adults.

6.2 Aim

The study aimed to compare the outcomes of simple eye exercises that were delivered through tele-appointments with face-to-face appointments.

6.3 Hypotheses

- Simple convergence exercises with the Gabor image will result in greater changes in vergence and accommodation responses compared to placebo exercises.

- Tele-appointments and face to face appointments are equally effective in managing orthoptic exercises.

6.4 Objectives

- Recruit 40 young adults with no visual problems

- Randomise participants to one of four treatment groups

- Measure convergence and accommodation at baseline and after treatment

- Deliver orthoptic exercises for 3 weeks

- Monitor participants with face-to-face or tele-appointments

- Analyse changes in convergence and accommodation during treatment and after treatment

- Compare the outcomes of tele-appointments with face to face appointments

- Compare the outcomes of simple convergence exercises with placebo exercises

- Compare the results to the existing evidence

6.5 Methodology

6.5.1 Ethical approval and consent

The study protocol adhered to the Declaration of Helsinki and received ethical approval from the University of Sheffield Research Ethics Committee on 23/11/2022 and application reference number 049079 (Appendix 4.1). The participants were given the PIS (Appendix 4.2) manually or by email and allowed as much time as wished to consider the information before participating. Eligible participants who met the inclusion criteria were given the opportunity to ask questions before obtaining informed consent (participant consent form; Appendix 4.3). The participants were reminded that we are investigating how effective tele-appointments are in comparison to face-to-face appointments when undergoing orthoptic exercises. Half of the participants were assigned placebo exercises, referred to as B exercises in the PIS, without being informed of their true nature, to prevent bias.

The PI (HA) assessed the participants in the Vision Science Room, floor E, Medical School. In addition, the PI used a standard testing protocol for all participants and explained each test, what is required and understand what was expected of them. The participants were offered with a £30 Amazon voucher at the end of their participation as a gesture of thanks.

6.5.2 Sample size calculations

The Gpower version 3.1.9.6 (Faul et al., 2009) was used to determine the number of patients needed for the study. The effect size of 0.3977778 was calculated from published data (Horwood and Toor, 2014). In their study, disparity group had an improvement in binocular NPA 0.6D and the motion (placebo) had an improvement of 0.2D. The power of 0.8, alpha 0.05 gave a total sample size of 40 participants. The sample size of 40 participants was adequate

to achieve statistical significance (Appendix 4.4). The participant was considered dropout if missed one appointment.

6.5.3 Participants

Participants were staff or students recruited from the University of Sheffield (UoS) aged 18-25 years. Participants were recruited through invitation emails and posters using the University volunteers list, internal systems such as Blackboard in the Health Sciences School and Minerva (Managed Learning Environment for the University of Sheffield Medical School) and using advertisements within the UoS Students Union.

6.5.4 Inclusion and exclusion criteria

The inclusion/exclusion criteria matched (Horwood and Toor, 2014; Horwood *et al*., 2014) criteria. All participants were naïve subjects with no prior knowledge about orthoptic exercises. The inclusion criteria included participant's aged 18-25 years, VA of 0.1 logMAR or better in each eye at distance, best corrected refractive errors up to ±4.00 D, TNO stereotest of 60" of arc. The participants were excluded if NPC < 8 cm, exophoria > 6Δ, PFV < 25Δ BO at near, CISS score ≥ 16 on the adjusted CISS questionnaire. In addition, the exclusion criteria included no manifest strabismus, limitations, underaction and overaction, history of past of previous strabismus surgery or took part in previous eye exercises research.

6.5.5 First visit (baseline-measurement)

After the inclusion criteria tests, the eligible participants continued with testing procedures in section 6.5.7 and plusoptix photorefraction in section 6.5.8.

6.5.6 Randomisation to treatment group

At the first visit, after baseline measurements had been taken, the participants were randomised to one of four exercises groups using a random number generator application. The participants randomised into one of 4 groups, as follows:

- Group 1, F2F-S: Simple convergence exercises and face-to-face appointments

- Group 2, Tele-S: Simple convergence exercises and tele-appointments

- Group 3, F2F-P: Placebo exercises and face-to-face appointments

- Group 4, Tele-P: Placebo exercises and tele-appointments

The flow chart of study plan for face-to-face and tele-appointments groups are shown in Figure 6.1. For the tele-appointment groups (Groups 2 and 4), participants attended face-to-face only for the visit 1 and visit 4, while the two appointments in between (visit 2 and 3) were over video call using Google Meet. Testing procedures were not performed during the tele-appointments. The participants had the same number of appointments, testing protocols and tested by the same researcher (HA). The study duration was 3 weeks, with 4 appointments. The participants were reviewed every week for the face to face and tele-appointments groups.

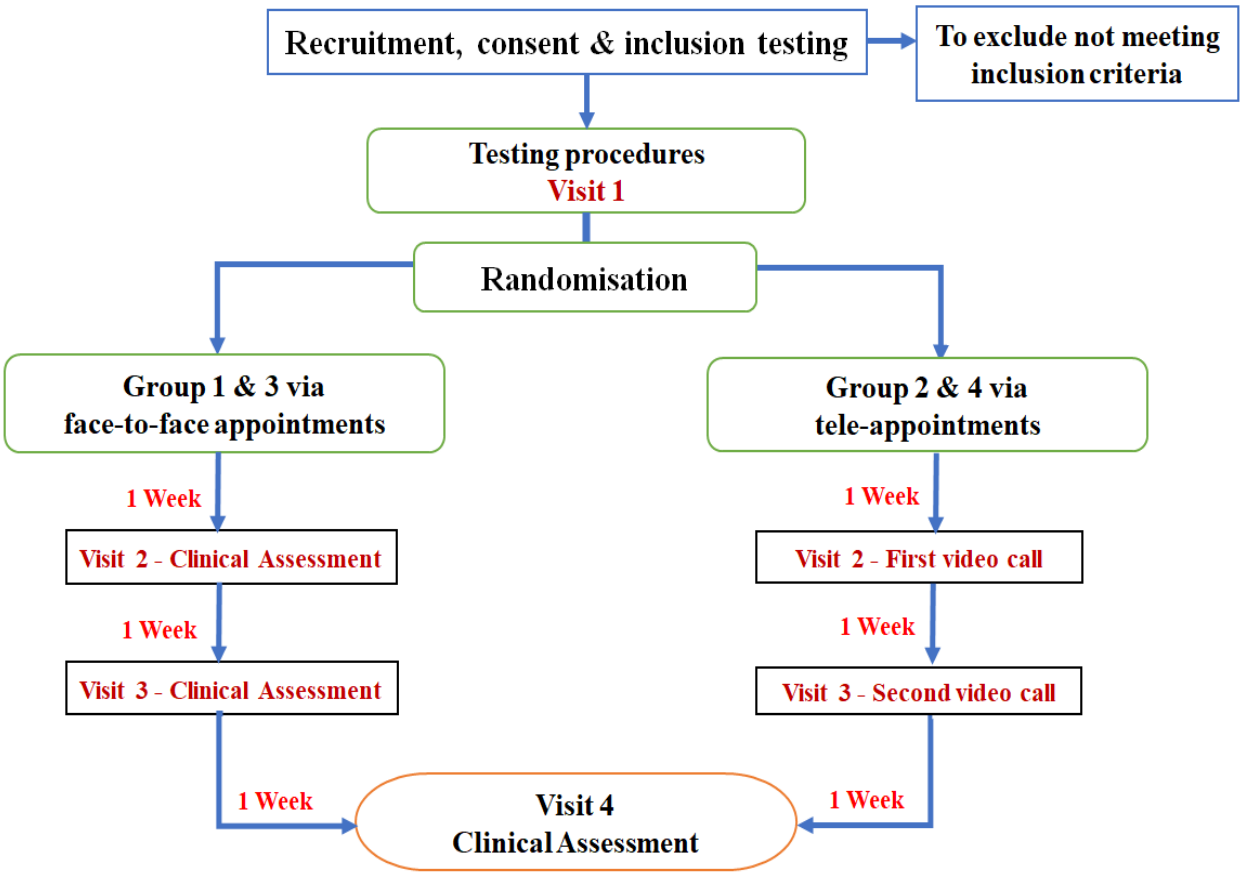


Figure 6. 1 Flow chart illustrates the study plan for the face-to-face and tele-appointments groups.

Masking participants to the PI was not possible. Specifically, in the subsequent appointments, the PI needed to know the type of exercises prescribed to the participant to demonstrate them and ensure they are performed correctly. Despite masking would have been preferred to minimise bias, it was not possible in this study. However, it would affect the more objective Plusoptix results less than the subjective measures. In addition, for the purposes of the study, the participants were less likely to suspect the type of exercises they were in because the simple convergence exercises were referred as type A and placebo exercises as type B in the PIS.

6.5.6.1 Exercises

The exercises performed at home for all groups and prescribed for the same length of time. Participants were asked to complete each exercise session 3 times per day (i.e. 2 exercises of 1 minute 30 seconds each, so a total of 3 minutes, performed 3 times per day). Participants were also shown how to perform the eye exercises that they need to do daily at home to ensure that they are performed correctly and given an instruction sheet (Appendix 4.5 and 4.6) for the exercises. Participants were required to demonstrate the exercises immediately after being taught. Following the exercises, participants were reminded to take breaks and relax their eyes by either looking into the distance or closing their eyes for one minute before performing any other tasks to avoid discomfort. They were also given a diary to record the time of the exercises per day. The participants were also asked to bring the diary on each visit to monitor their compliance.

The participants were given a diary to complete (Appendix 4.7), which asked how many and for how long the exercises were completed each day to allow monitoring compliance. The assessment of compliance was through the CITT group method that was discussed in Chapter 3 (section 3.3.4.1). The diary was reviewed and the participant's compliance with the prescribed exercises was classified as excellent 75–100%, good 50–74%, fair 25–49%, and poor < 25% (Scheiman *et al.*, 2005b). This can be obtained by calculating the percentage of minutes of exercising performed each day that is recorded in the diary compared to the total required exercising time in the study. To clarify, the study duration is 21 days, and the prescribed daily exercise is 3 minutes/3 times per day (total training time in the study is 3x3x21= 189 mins). In

order to improve compliance, the participants were encouraged to set reminders to do the exercises regularly and to complete the diary honestly when recording missed sessions and total training times as well as to bring the diary each visit to take a photo. This encouragement method was used in Horwood and Toor (2014) study and was effective for adhering to the exercises.

Simple convergence exercises (Group 1 and Group 2)

This group of exercises consisted of binocular push-ups (near to nose), and binocular jump vergence (near/distance). Those exercises were referred in the PIS as Group A exercises. The fixation target was a Gabor patch target set on grey background and was used for all near training. Larger distant fixation targets such as a picture or a TV were used for distance fixation. The smooth convergence exercises using Gabor patch was described in Chapter 5 (section 5.5.6.9). The participants were asked to keep the Gabor patch as close as possible, even if it appeared blurred while maintaining a single image. The jump vergence exercises using Gabor patch was described in Chapter 5 (section 5.5.6.9). The participants were asked to keep the Gabor patch as close as possible, even if blurred while maintaining a single image.

Placebo exercises (Group 3 and Group 4)

The placebo exercises consisted of snakes illusion and yoked prisms training that do not exercise the vergence and accommodation systems. Those exercises were referred to in the PIS as Group B exercises and the participants were informed these were motion detection exercises. In the snakes illusion, the participants were asked to look at 16 rotating snakes and within a minute and a half, they record the minimum/maximum number of rotating snakes that have been observed (Figure 6.2). In yoked prisms, the participants used yoked Base-up or Base right prisms while directed to touch a fixation target with their hands. The participants focused on a fixation point at arm's length and then positioned yoked prisms in front of the eyes. While looking through the yoked prisms, they were trying to touch the fixation target with their finger. After that, turned the yoked prism and touched the fixation target again. This procedure was repeated, and the number of flips achieved within one and a half minutes was recorded.

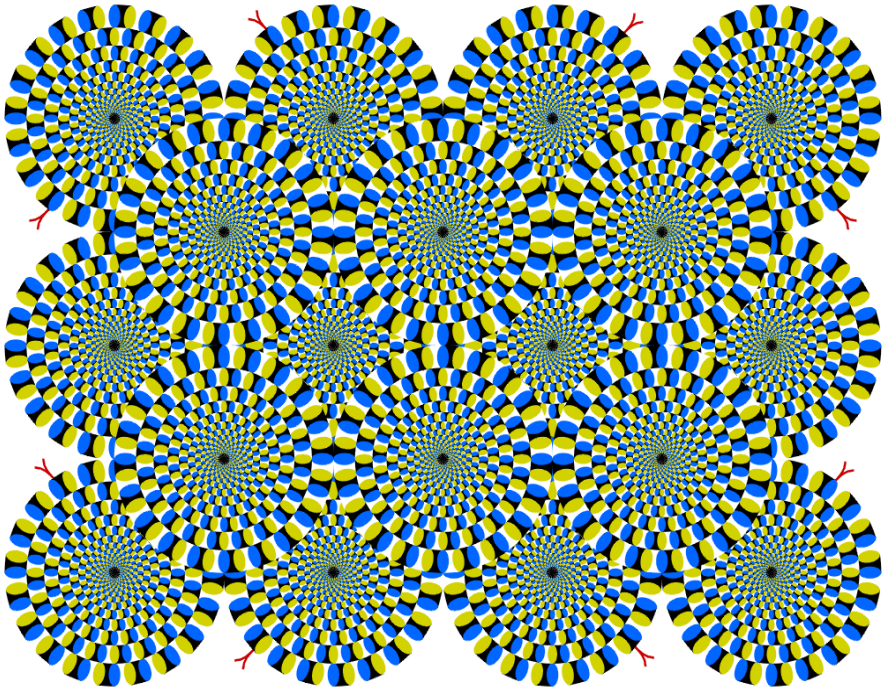


Figure 6. 2 Rotating snakes illusion of placebo exercises group Accessed from: https://www.ritsumei.ac.jp/~akitaoka/index-e.html (free for research use) (Akiyoshi KITAOKA, 2003).

6.5.6.2 Second and third appointments (in between visits)

Face-to-face appointment groups

In face-to-face appointments for Groups 1 and 3, participants completed the CISS questionnaire, testing procedures (NPC, NPA, BAF, VF, PFV and PlusoptiX photorefraction). The face-to-face visit included:

- Participants demonstrated the exercises and presented their diaries for review and copying.

- The participants were asked to demonstrate the exercises and the participant was asked if there is any difficulty in performing them.

- The participant was asked to show the diary and urged to complete the diary and be honest in completing it. The participant was asked about resting eyes after performing the exercises and was reminded to do so.

- The participant was asked if there were any problems or had any questions regarding the study.

- The participant was reminded about the next appointment

Tele-appointment groups

For Groups 2 and 4, tele-appointments via video calls lasted 10 minutes, and the CISS sent on the same day as the tele-appointments or 24 hours in advance. Each tele-appointment included:

- Demonstrating the exercises and the participant was asked if there is any difficulty in performing them

- The participant was asked to show the diary and urged to complete the diary and be honest in completing it

- The participant was asked about resting eyes after performing the exercises and was reminded to do so

- If the CISS is not received before the appointment, the participant is reminded to send it immediately after the appointment

- The participant was asked if there were any problems or had any questions regarding the study

- The participant was reminded about the next appointment

6.5.6.3 The fourth appointment (final visit)

The last visit was face to face for all the treatment groups. The participants completed the CISS questionnaire and underwent testing procedures. The participants asked to return the diary to monitor their compliance and informed that the study visits were completed and offered payment vouchers.

6.5.7 Testing procedure

Tests were performed at the first visit as baseline measures, for any face-to face visits and for the final visit. All tests were carried out using participants' glasses or contact lenses (if any). The PI (HA) maintained a consistent tone of voice during assessment for all participants. The eligible participants underwent the following testing procedures:

6.5.7.1 Near point of convergence (NPC)

The NPC was assessed using the push-up method with the RAF rule. A line with a dot in the middle, positioned at 40 cm, was used for the measurement. The RAF rule was held in slightly depressed position. Patients were instructed to keep the fixation target single while gradually moved towards their nose at a constant speed until they reported seeing double or one eye deviated. The NPC was recorded to the nearest half centimetre. This measurement was repeated three times, and the mean measurement was taken.

6.5.7.2 Near point of accommodation (NPA)

Binocular NPA was measured using the push-up method with the RAF rule, with refractive correction applied if necessary. The patient was asked to focus on N5 letter on the RAF rule at 40 cm. The fixation target was gradually moved towards the patient along the ruler until the target becomes blur. This measurement was repeated three times and recorded to the nearest half centimetre. The same procedure was then performed for the right eye and subsequently the left eye.

6.5.7.3 Binocular accommodative facility (BAF)

The participant was instructed to fixate on 0.2 logMAR letter at 33 cm. A flipper lens with a ±2.00 power was positioned in front of the participant's eyes and asked to say "clear" once the letter became clear. The flipper lens was then quickly flipped to the other side, and the participant again reported when the letter became clear. This process was repeated by alternating the flipper lenses after each clarity confirmation for one minute. Clearing both sides of the flipper lenses constituted one cycle, and the result was recorded in cycles per minute (cpm).

6.5.7.4 Vergence facility (VF)

The participant was instructed to fixate on 0.2 logMar letter at 33 cm. A prism flipper of 8Δ BO/4Δ BI was used for this test. The 4Δ BI side of flipper prisms was placed in front of the participant's eyes and they were asked to report when the letter became single. The flipper prism was then quickly flipped to the other side, and the participant again reported when the letters became single. This process was repeated, alternating the flipper prisms after each confirmation that the letters were single for one minute. One cycle consisted of the participant reporting single with both sides of the flipper prisms, and the result was recorded in cycles per minute (cpm).

6.5.7.5 Positive Fusional Vergence (PFV)

The participant was asked to fixate on 0.1 logMar single letter at 33 cm. A BO prism bar was placed in front of the participant's right eye. The participant was instructed to keep the letter single for as long as possible and to report when they became double. The prism strength was gradually increased until the participant confirmed that the target had become double. The same procedure was repeated at 6 metres with 0.100 logMar letter. If the prism strength reached 40Δ, a loose 20Δ prism was placed over the other eye, and the prism bar was reduced to 20Δ. The prism strength was then gradually increased until the target doubled, and this value was recorded as the break value. The blur point was not assessed as discussed in Chapter 2 (section 2.2.5). In addition, Horwood and Toor (2014) asked the typically normal subjects to report blur when testing PFV, but the majority did not notice this, so they were unable to use the data.

6.5.8 Plusoptix photorefractor

The PowerRef 3 PlusoptiX R09 (Plusoptix GmbH, Nuremberg, Germany) is an optical measuring device that assesses accommodation and vergence responses objectively. Plusoptix photorefractor works by projecting infrared (IR) light reflected from the retina and returns to the source, in turn, forming a luminance gradient profile for the pupil (Gehring *et al.*, 2022). The Plusoptix photorefractor records continuous data at a speed of 50Hz through a hot mirror set at 45° that reflects the IR light but allows visible light so the participant can see the target

through the mirror. Then the PowerRef 3 collected simultaneous recording of eye positions and refraction in both eyes at the same time (Figure 6.3). The PowerRef 3 can detect a range of refractive errors from +5.00 to -7.00 D in 0.01 D steps in the vertical meridian and pupil size between 3.0 to 8.0 mm in 0.1 mm steps. Additionally, it showed tolerance to eye and head movements as well as variations in background illumination (Wolffsohn, Hunt and Gilmartin, 2002). When considering eye movements, they also reported a minimal accommodation change of -0.50 D at a 25-degree deviation from the optical axis. Moreover, even when the head moves 8 cm towards or 20 cm farther from the correct photorefractor distance, the accommodation change remained < 0.25 DS. These features make the PowerRefractor suitable for accurate assessment of accommodation and vergence. The measurement setup of the Plusoptix photorefractor has been built by STH technicians (Figure 6.4). To prevent interference from peripheral stimuli, the entire setup was encased in matte black shuttering. The measurements were taken in dim light to enable sufficient dilatation of the pupil to collect accurate measurements when the targets reach nearest distance.

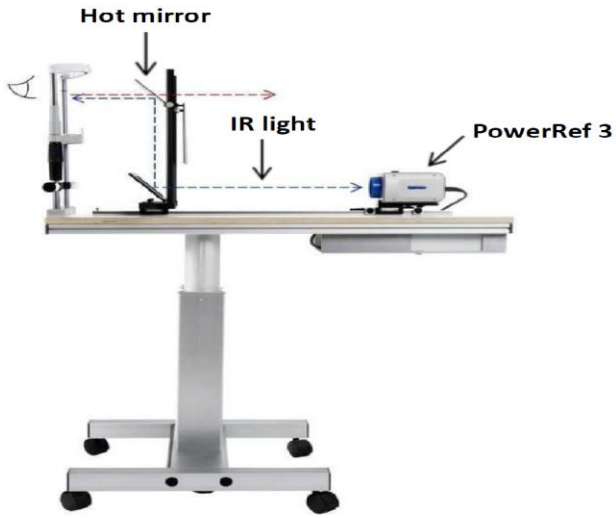


Figure 6. 3 PlusoptiX R09 PowerRef 3 - measurement setup. The hot mirror reflects IR light from the PowerRef 3 while allowing visible light to pass (Adapted from PowerRef 3 - plusoptiX R09 - instruction manual - version 31.07.2019 / 5.0.22.0). Available at: www.plusoptix.com/fileadmin/Downloads/Products /Research_product_models/PowerRef-3_PR09/Plusoptix_PR09_User_manual_Version-5022_english.pdf. Accessed from: https://www.plusoptix.com (Accessed: 24 May 2024).

Figure 6. 4 The experimental custom-built apparatus. Participants watched targets displayed on iPad via motorised beam at 4 fixation distances while the PowerRef 3 recorded eye positions and refraction.

The Gabor target was chosen because it enables binocular fusion with minimal accommodation (Horwood and Riddell, 2008). This can be explained by the fact that fusible elements within the Gabor patch maintain a subjective similarity even when optically blurred, resulting in minimal accommodation (Horwood and Toor, 2014). In addition, Gabor image provides a low spatial frequency as in Horwood and Riddell (2008) to maintain element of attention for participants.

6.5.8.1 PlusoptiX photorefractor measurement

The measurements were taken in dim light to enable sufficient dilatation of the pupil to collect accurate measurements when the targets reach nearest distance. Targets presented on an iPad suspended on a motorised beam that moved and stopped in a pseudorandom order at four fixation distances (2 m, 0.5 m, 1 m and 0.33 m) representing accommodative demands of 0.5 D, 2 D, 1 D and 3 D, respectively. The targets were a Gabor patch image and a horizontal line of English letters which were displayed against a black background (Figure 6.5). The Gabor image subtended a visual angle of 1.52° at 2m and 9.19° at 33 cm. The English letters were Helvetica font style and presented in a size 3.7 cm x 0.5 cm, subtending visual angles 1.06° at

2 m and 6.42° at 33cms. The participants were told to fixate on the target without receiving any additional instructions (Horwood and Toor, 2014).

Figure 6. 5 Fixation targets. English letters (Left), Gabor image (Right).

Disparity was the main cue that drove both convergence and accommodation (Horwood and Riddell, 2008). Disparity was present when viewing the Gabor image binocularly. By occluding the left eye, disparity was eliminated, and the Gabor image minimised accommodation, resulting in a nil condition. This was accomplished using an IR filter placed in front of the left eye, which blocks visible light so the patient cannot see the target with the left eye but allows IR rays through to record data from both eyes. Disparity and blur were achieved by binocularly viewing an accommodative target, and it was changed to blur only by occluding the left eye. Thus, the PlusoptiX photorefractor set-up allowed a range of different cues to be manipulated when presented to the participants, as follows:

- Disparity + Blur: Binocular + letters

- Disparity only: Binocular + Gabor patch

- Blur only: uniocular + letters

- Nil: uniocular + Gabor patch

6.5.8.2 Calibration

Calibration errors can be classified as either absolute or relative. Absolute calibration error refers to the difference between photorefractor measurements and those obtained using gold-standard retinoscopy under identical conditions. The relative calibration method is evaluating the alteration of the photorefractor's refraction estimate with each dioptric change in the focus of the subject's eye.

The responses measured by the PlusoptiX photorefractor were calibrated for accommodation studies by Holly Geraghty (HG) as part of the lab set up. HG used the relative calibration method, with lenses ranging from -2 to +3 D, to determine a group calibration factor (CF) that is applied to the raw data obtained from the PlusoptiX photorefractor. The calibration was conducted on 9 orthoptic students aged 18-25 years who were emmetropic or fully corrected with a VA of 0.1 logMAR or better in each eye at distance and near, and without binocular vision problems. During the calibration procedure, start-stop accommodation measurements, using the PlusoptiX photorefractor, were taken at each distance (2m, 1m, 0.5m and 0.33m) while subjects observed a clown visual target (Horwood and Riddell, 2008) on an iPad. Lenses of known power were then placed in front of the right eye as well as the IR filter, each for 5 seconds. Due to the individual lab design, the PlusoptiX photorefractor was found to underestimates the raw accommodation data. This underestimation requires a CF to be applied to all PlusoptiX photorefractor accommodation measurements. HG determined the CF by analysing the mean group measures of raw data, taking the CF from the slope and intercept of the linear regression trendline. The CF was applied by multiplying the correction value (0.73) and adding the offset value (0.837). This method was standardised as the CF for the PlusoptiX photorefractor and applied to all accommodation measurements in this study. Figure 6.6 presents an example of data from 10 random participants, shown before and after the application of the CF.

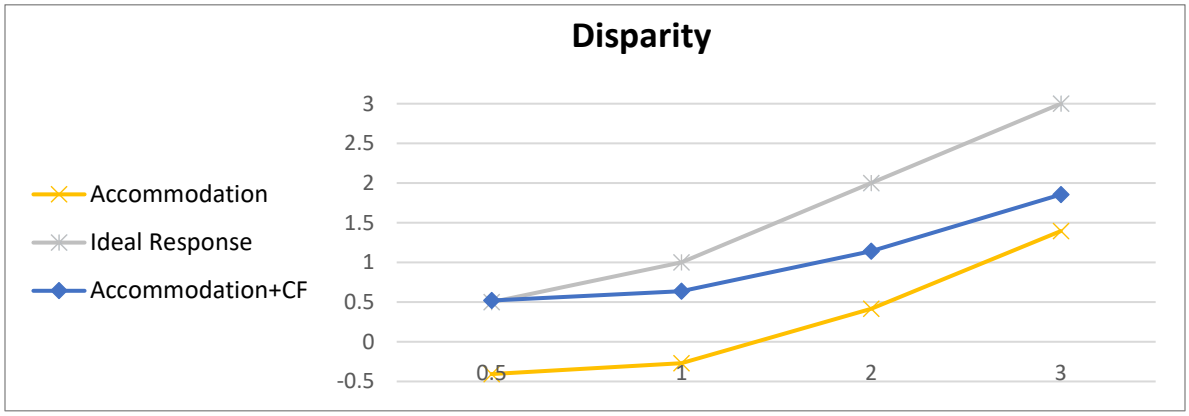


Figure 6. 6 The slope of accommodation responses to target demand (grey line) for 10 participants before (yellow line) and after (blue line) applying CF; CF: calibration factor.

While routine absolute calibration is considered impractical (Bharadwaj et al., 2013). Horwood and Riddell (2008) performed an absolute calibration of the Plusoptix on a sample of 59 adults. In their study, the examiner, blinded to the Plusoptix outputs, conducted MEM dynamic retinoscopy under identical accommodative conditions. Their results showed a strong correlation between MEM retinoscopy and the Plusoptix. However, such detailed calibration procedures are time-intensive and challenging to implement. Given the already lengthy testing protocol, incorporating individual calibration during the study was deemed impractical. Performing calibration at the end of the session risked poor data quality due to participant fatigue. Additionally, including individual calibration at any point would extend the face-to-face visit from 45 minutes to over an hour. This raised ethical concerns regarding participant burden, as longer sessions could violate acceptable visit durations. Consequently, the PhD researcher (HA) decided not to include individual calibration in the study.

6.5.8.3 Data collection

A single run of PowerRef 3 photorefractor involved measurement at each of the four distances under a specific cue condition. For each run, the PowerRef 3 recording was started, stopped, and data automatically saved. Throughout the recording, close observation of the participant's eyes via video output through the monitor screen to ensure at least 3 seconds of recording of

steady fixation at each distance before moving to the next. Thus, ensured the collected data was continuous and reliable. If continuous data was lost due to instances of excessive blinks, too small or large pupils, eyelid fluctuations or spectacle reflections, the recording duration was extended to ensure stable data of at least one second (section of 50 continuous readings) was obtained. The four runs formed a profile for each distinct cue condition.

6.5.8.4 Data processing and analysis

The PlusoptiX photorefractor produced the raw collected data as a Microsoft Excel spreadsheet of refraction and eye positions for both eyes. A macro was purpose-built by the University of Reading lab to process the raw data into accommodation and vergence responses. The refractive errors are converted to accommodation through turning negative data to positive, and vice versa. For instance, -1.0 DS myopic refraction converted to a 1.0 D accommodation. The vergence recordings include adduction in one eye and abduction in the other. To process vergence, the column for one eye data on the spreadsheet is re-signed from minus to plus so the adduction constantly is a positive value. Subsequently, both columns of eye positions are combined to calculate the total vergence and reported in degrees. The vergence data transformed into MA based on individual's interpupillary distance (IPD) and with a correction for angle lambda. The MA is enabling direct comparison with accommodation responses on the same scale in accordance to target demand in diopters. For instance, we need one 1 MA of convergence and 1 D of accommodation at 1 m and 3 MA and 3 D at 0.33 m, as a result can be directly compared.

For the data analysis, the raw data against time were presented in a chart format, enabling the visual identification (vignetting) of 50 data points which is equivalent to 1 sec of stable fixation at each target distance. Once vignettes for each fixation distance were selected, the 50 data points within each vignette were averaged by the macro. It should be noted that the accommodation is calculated via the brightness gradient, making it unaffected by refractive correction. The calculation of vergence is based on the horizontal shift of image in screen pixels, and thus, can be affected by any magnification produced by refractive correction i.e., an adjustment in the right and left gaze is applied according to the power of the refractive correction. In addition, as a result of blinking, spikes appear around blinks in both

accommodation and vergence. Subsequently, the macro identifies and removes data before and after blink-induced spikes, along with any missing data patches. The final stage of the macro is transposing data for the means of 50 data points of total vergence, accommodation, and right and left accommodation from the different fixation target distances. This allowed calculation and compare accommodation and vergence demands with ideal responses on a chart for each cue condition or further statistical analysis. It should be noted that this macro has long been the standard approach for converting Plusoptix refraction data into accommodation measurements, with its process thoroughly tested, validated, and documented by Horwood and Riddell (2008).

An independent scorer (ST) randomly evaluated vergence and accommodation responses for 10 participants to determine interrater reliability. The intra-class correlation coefficient (ICC) analysis was conducted to assess the absolute agreement between vignette data points. The correlation for vergence was r = 0.89, with a mean inter-scorer difference of 0.0097 ± 0.32 MA, while the correlation for accommodation was r = 0.79, with a mean inter-scorer difference of 0.042 ± 0.26 D.

6.6 Data analysis

Data analysis was performed using IBM SPSS Statistics for Windows, Version 28.0 (Armonk, NY: IBM Corp). The distribution of the data was analysed by considering the distribution of the data in a histogram and the Shapiro-Wilk results. The Shapiro-Wilk test for normality was used due to the small sample size.

A three-way mixed ANOVA was performed to determine change of vergence and accommodation responses per- and post-treatment. Levene's test of equality of error variances was examined to assess the assumptions of ANOVA. If Levene's test was significant, an alternative non-parametric test was used unless specified otherwise. A three-way mixed ANOVA was performed to investigate the effect of the appointment and exercise types on orthoptic measures. If the assumptions of sphericity (Mauchly's test) were violated, the degrees of freedom were corrected using Greenhouse-Geisser estimates. All post-hoc tests were adjusted using Bonferroni correction. In cases of significant differences were discovered, paired t-tests were applied to explore changes within face-to-face groups further.

6.7 Results

For the purposes of the study, throughout the results and discussion, the different groups will be referred to as: face-to-face appointments and simple convergence exercises (F2F-S), tele-appointments and simple convergence exercises (Tele-S), face to face appointments and placebo exercises (F2F-P) tele-appointments and placebo exercises (Tele-P).

A total of 48 participants were enrolled in this study. Six participants from the face-to-face groups and 2 from the tele-appointment groups did not attend follow-up sessions and, without providing any reasons, were considered to have withdrawn from the study. Data from 40 participants who met the inclusion criteria was analysed. The mean ±SD age was 21.2±2.3 years (range 18-25 years). Twenty-nine (72.5%) participants were female and 11 were male (27.5%). Age and gender distribution were comparable across the groups. Most participants were emmetropic (70%). There was no significant difference in mean spherical equivalent of refractive errors among groups (F2F-S (2.4D ±1.2), F2F-P (1.1D ±0.5), Tele-S (2.8D ±1.6) and Tele-P (2.3D ±1.5); $F_{3,36} = 0.525$, $p = 0.668$).

Figure 6.7 illustrates compliance rates for each of the participant groups. All groups demonstrated more than 50% of compliance. Excellent compliance was more prevalent in the F2F-S group with 6 participants (60%), the Tele-S group with 5 participants (50%), the F2F-P group with 4 participants (40%), and the Tele-P group with 3 participants (30%). Fair compliance (less than 50%) was present in five participants of the Tele-P group, three in the F2F-P group, and equally by two participants in the F2F S and Tele-S groups. No participants demonstrated poor compliance. There was no significant difference in compliance between groups ($F_{3,36} = 0.976$, $p = 0.415$). Regarding tele-appointments, none of the participants reported any adverse events apart from fatigue or technical difficulties.

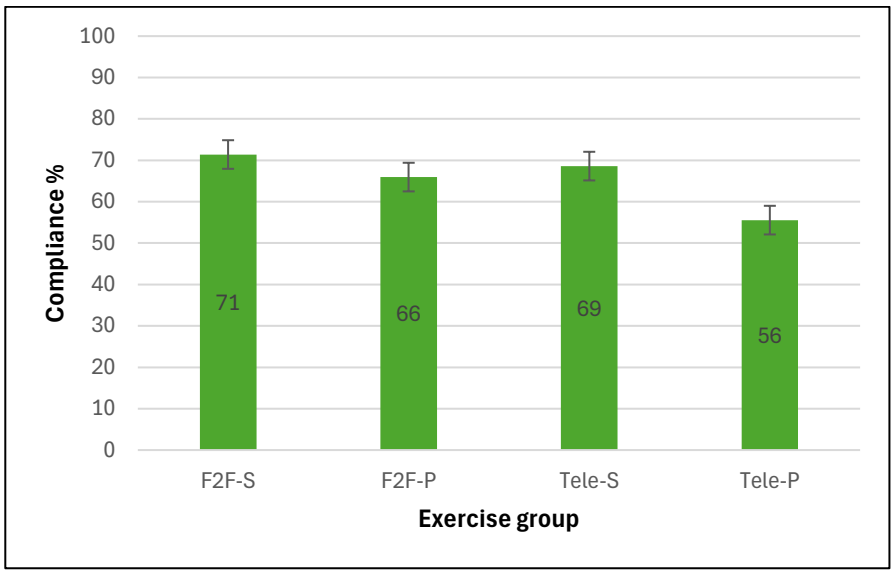


Figure 6. 7 Mean compliance rates achieved by each group of required exercising time during the study. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo. Error bars denote standard deviation.

6.7.1 Analysis by PlusoptiX photorefractor measures

6.7.1.1 Vergence responses

The mean response slope of vergence for each cue condition at baseline for all different groups are shown in Table 6.1 and Figure 6.8. The data fit the expected trend, with disparity-containing cue conditions producing a good vergence response (close to 1) and disparity-absent cue conditions producing a reduced vergence response.

Table 6. 1 mean ±SD response slope of vergence for each cue condition at baseline for all different groups.

Cue condition	F2F-S	F2F-P	Tele-S	Tele-P
BD	0.935±0.06	0.835±0.17	1.01±0.12	0.918±0.11
D	0.935±0.12	0.931±0.09	0.965±0.17	0.984±0.09
B	0.40±0.13	0.419±0.19	0.578±0.33	0.515±0.14
Nil	0.406±0.12	0.326±0.09	0.445±0.21	0.460±0.18

F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; Stimulus: BD, blur+disparity; D, disparity; B, blur; N, nil cue condition; SD: standard deviation

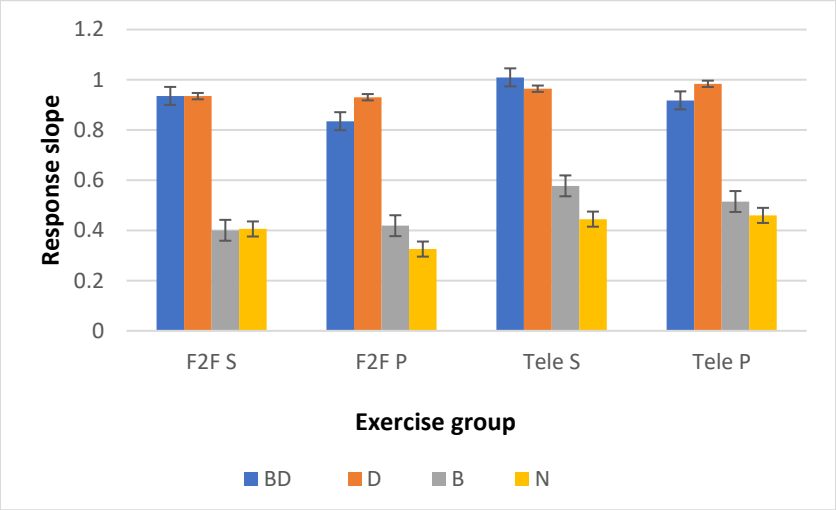


Figure 6. 8 Vergence slope measures at baseline for different cue conditions for all groups. A slope of 1.0 indicates perfect response to target demand. Error bars denote standard error for each condition. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; Stimulus: BD, blur+disparity; D, disparity; B, blur; N, nil cue condition.

Three-way mixed ANOVA was performed to determine change of vergence responses with appointment and exercise types as a between group factors, and cue conditions (BD, D, B and Nil) as within group factors. There was no significant difference between appointment types ($F(1,36)=0.046$, $p=0.831$), exercises type ($F(1,36)=0.844$, $p=0.364$), and no significant interaction between appointment and exercises ($F(1,36)=0.037$, $p=0.849$). This indicates that

participants in the different groups responded similarly regardless of the appointment or exercises type.

The F2F-S group showed the highest mean gain of vergence responses across all cue conditions, with an increase of 0.047 MA, followed by the Tele-S group by 0.04 MA. The F2F-P group achieved slight improvement in vergence by 0.019 MA, whereas the Tele-P group had the lowest improvement by 0.007 MA. Figure 6.9 illustrates the mean gain achieved in vergence responses across all cue conditions for different appointments and exercises groups.

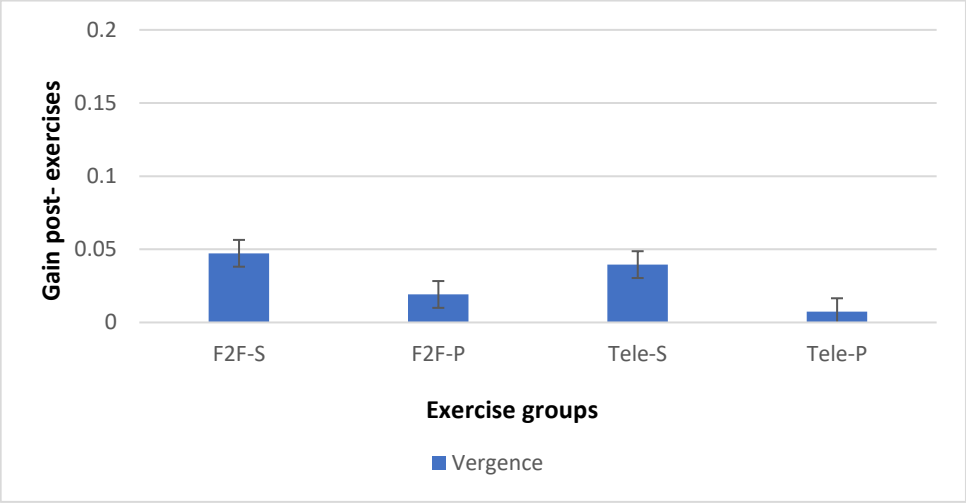


Figure 6. 9 Mean change in vergence gain across all cue conditions after exercises in each treatment group. Error bars denote the standard error of the mean. A change of 0.1 in gain indicates ≈ 0.3 MA at 33 cm. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo.

A Paired t-test analysis showed that all groups demonstrated some level of improvement in vergence responses after exercises in final visit, but these improvements failed to reach statistical significance ($p > 0.05$). Changes in mean responses in convergence gain for all groups following exercises to different cue conditions are illustrated in Table 6.2 and Figure 6.10.

Table 6. 2 Vergence response gain before and following exercises for participants across different cue conditions.

Exercises group	**Vergence (mean ±SD)** **Pre-** **post-exercises** ***Change***			
	Cue condition			
	BD	**D**	**B**	**N**
F2F-S	0.94±0.06 0.95±0.11 *0.01±0.09*	0.93±0.12 0.97±0.14 *0.04±0.13*	0.40±0.13 0.46±0.18 *0.06±0.16*	0.41±0.12 0.46±0.18 *0.05±0.15*
F2F-P	0.84±0.17 0.83±0.16 *-0.01±0.17*	0.93±0.09 0.95±0.10 *0.02±0.10*	0.42±0.19 0.41±0.15 *-0.01±0.17*	0.33±0.09 0.40±0.17 *0.07±0.14*
Tele-S	1.01±0.12 1.00±0.11 *-0.01±0.12*	0.96±0.17 1.03±0.12 *0.07±0.15*	0.58±0.33 0.63±0.20 *0.05±0.28*	0.44±0.21 0.49±0.21 *0.05±0.21*
Tele-P	0.92±0.11 0.94±0.12 *0.02±0.12*	0.98±0.09 1.00±0.06 *0.02±0.08*	0.52±0.14 0.47±0.18 *-0.05±0.16*	0.46±0.18 0.49±0.18 *0.03±0.18*

F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-S: Tele-appointments and placebo; SD: standard deviation; Stimulus: BD, blur+disparity; D, disparity; B, blur removed; N, nil cue condition.

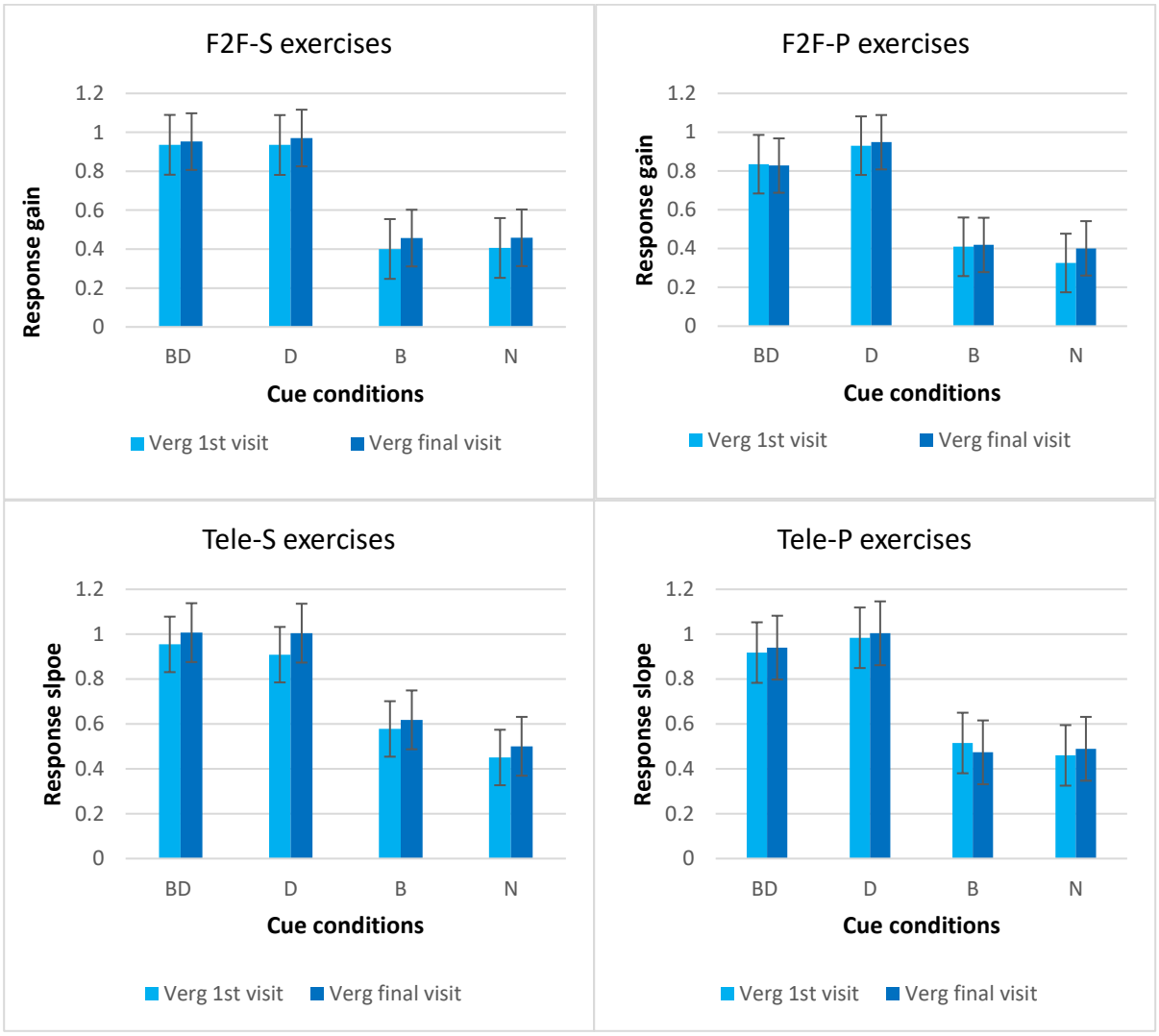


Figure 6. 10 Vergence slope changes of all groups between first and final visits. A slope of 1.0 indicates perfect response to target demand. Error bars denote the standard error for each condition. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; Stimulus: BD, blur+disparity; D, disparity; B, blur removed; N, nil cue condition.

For greater clinical and practical importance, the amount of vergence gain at 33 cm was analysed. Three-way mixed ANOVA was performed to determine change of vergence responses at 33cm with appointment and exercise types as a between group factors, and cue conditions (BD, D, B and Nil) as within group factors. There was no significant main effect of appointment type ($F(1,36)=0.292$, $p=0.592$), exercise type ($F(1,36)=0.583$, $p=0.45$), and no

significant interaction between appointment and exercises (F(1,36)=0.009, p=0.925). In addition, paired t-test analysis showed no significant change in gain for different cue condition at 33 cm (p > 0.05). However, the F2F-S group showed the greatest overall improvement in mean vergence at 33 cm by 0.129 MA followed by Tele-S 0.073 MA, F2F-P 0.053 MA and Tele-P 0.013 MA. The changes in mean vergence at 33 cm with different cue conditions for each group are shown in Figure 6.11.

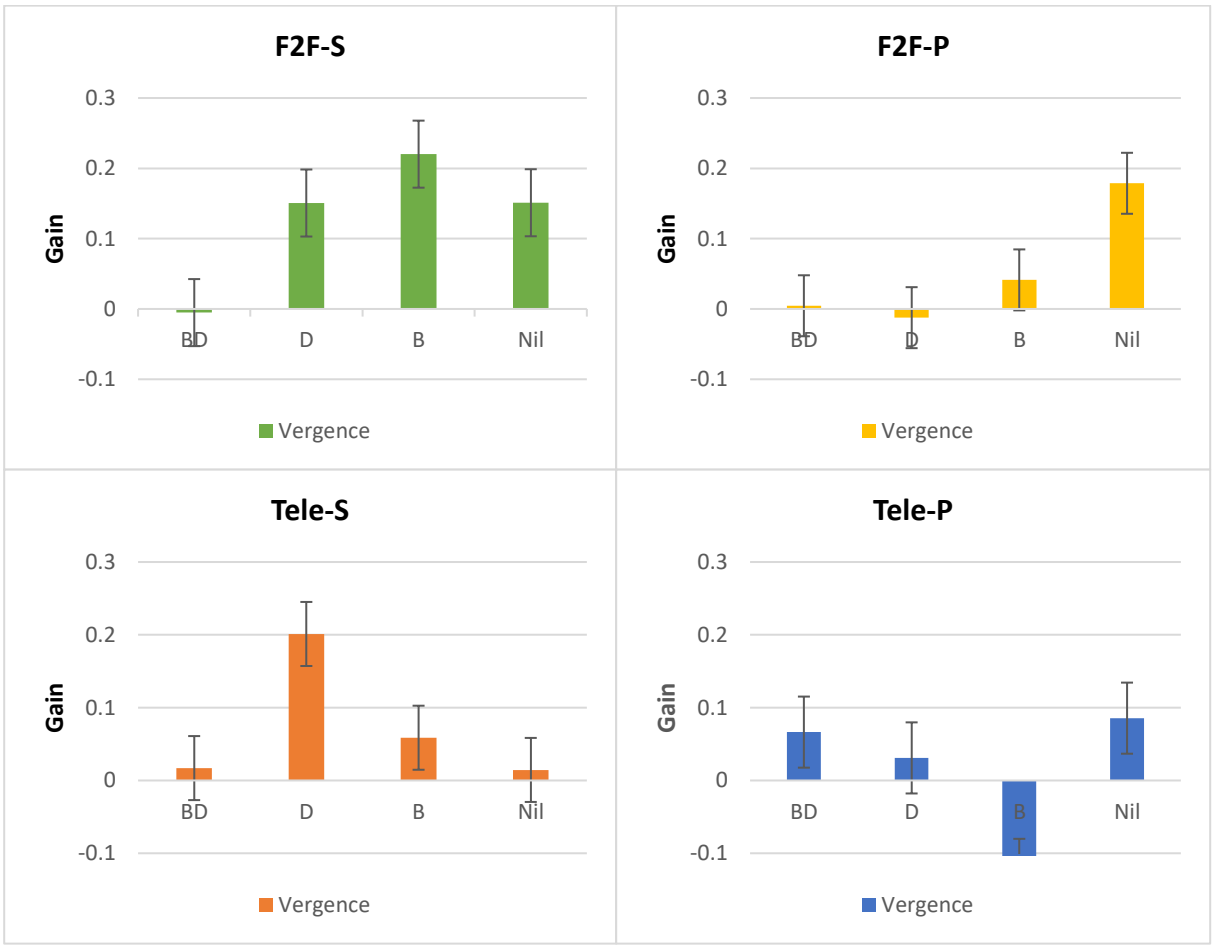


Figure 6. 11 Change in vergence responses at 33 cm after exercises. Vergence in MA (1 ≈ 6Δ for average adults). Error bars denote the standard error. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo. Stimulus: BD, blur+disparity; D, disparity; B, blur removed; N, nil cue condition.

6.7.1.2 Accommodation responses

The mean response slope of accommodation for each cue condition at baseline for all different groups are shown in Table 6.3 and Figure 6.12.

Table 6. 3 Mean ±SD response slope of accommodation for each cue condition at baseline for all different groups

Cue condition	F2F-S	F2F-P	Tele-S	Tele-P
BD	0.622±0.17	0.478±0.12	0.547±0.23	0.542±0.13
D	0.594±0.22	0.463±0.15	0.394±0.11	0.556±0.15
B	0.419±0.27	0.338±0.13	0.383±0.27	0.363±0.15
Nil	0.285±0.23	0.185±0.1	0.143±0.7	0.318±0.2

F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; Stimulus: BD, blur+disparity; D, disparity; B, blur; N, nil cue condition; SD: standard deviation

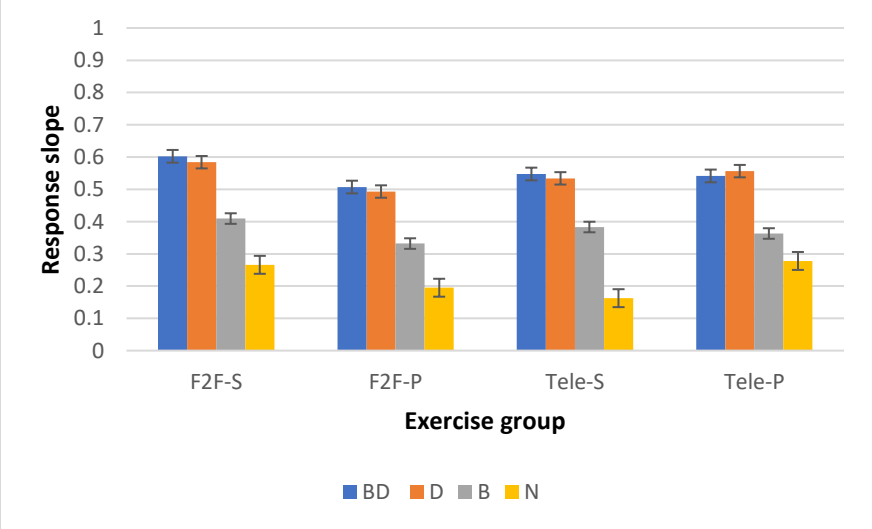


Figure 6. 12 Accommodation slope measure at baseline for different cue conditions for all groups. A slope of 1.0 indicates perfect response to target demand. Error bars denote standard error. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; Stimulus: BD, blur+disparity; D, disparity; B, blur; N, nil cue condition.

Three-way mixed ANOVA was performed to determine change of accommodation responses with appointment and exercise types as a between group factors, and cue conditions (BD, D, B and Nil) as within group factors. There was no significant difference between appointment types ($F(1,36)=1.397$, $p=0.245$), exercises type ($F(1,36)=0.165$, $p=0.67$), and no significant interaction between appointment and exercises ($F(1,36)=0.488$, $p=0.489$).

The F2F-S group showed the highest mean gain in accommodation responses, with an increase of 0.06 D across all cue conditions, followed by the Tele-S group by 0.052 D. The F2F-P group achieved slight improvement in accommodation by 0.03 D, whereas the Tele-P group had the lowest improvement by 0.01 D. In addition, this gain in accommodation was not significantly different from gained vergence (paired t-test [39] = -1.117, P=0.271). Figure 6.13 shows the mean gain achieved in accommodation for different exercise groups.

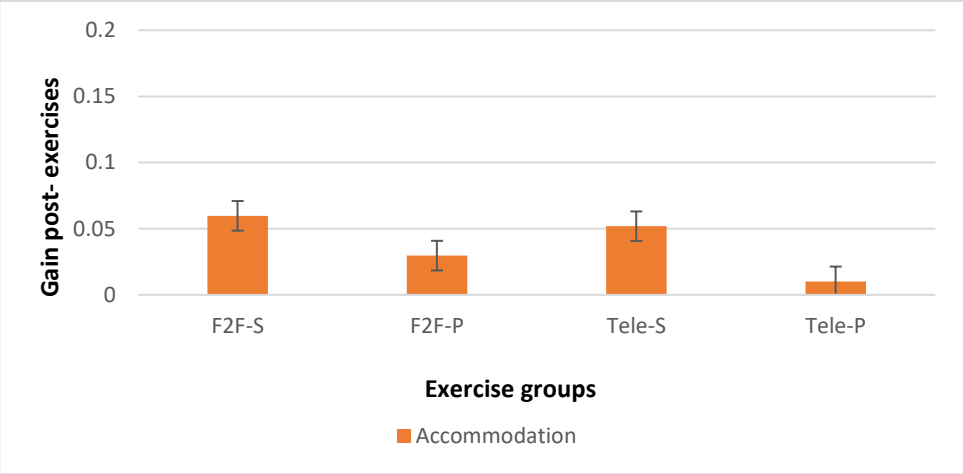


Figure 6. 13 Mean change in accommodation gain according to group. Error bars denote the standard error of the mean. A change of 0.1 in gain indicates ≈ 0.3 MA at 33 cm. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo.

A Paired t-test analysis showed that all groups demonstrated some level of improvement in the accommodation for different cue conditions in final visit, but these improvements failed to reach statistical significance ($p > 0.05$). Changes in mean responses in convergence gain for all groups following exercises to different cue conditions are illustrated in Table 6.4 and Figure 6.14.

Table 6. 4 Accommodation response gain before and after exercises for participants across different cue conditions

Exercises group	**Accommodation (mean ±SD)** **Pre-** **post-exercises** ***Change***			
	Cue condition			
	BD	**D**	**B**	**Nil**
F2F-S	0.62±0.17 0.64±0.18 *0.02±0.18*	0.59±0.22 0.66±0.21 *0.05±0.22*	0.42±0.27 0.52±0.26 *0.1±0.27*	0.29±0.23 0.38±0.27 *0.09±0.25*
F2F-P	0.48±0.12 0.59±0.21 *0.11±0.17*	0.46±0.15 0.52±0.19 *0.06±0.17*	0.33±0.13 0.36±0.10 *0.03±0.12*	0.18±0.10 0.31±0.24 *0.13±0.2*
Tele-S	0.55±0.23 0.52±0.19 *-0.03±0.21*	0.39±0.11 0.49±0.19 *0.1±0.15*	0.38±0.27 0.43±0.24 *0.05±0.26*	0.14±0.07 0.22±0.13 *0.08±0.1*
Tele-P	0.54±0.13 0.57±0.21 *0.03±0.17*	0.56±0.15 0.56±0.25 *0±0.2*	0.36±0.15 0.40±0.22 *0.04±0.19*	0.32±0.20 0.29±0.26 *-0.03±0.23*

F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; SD: standard deviation; Stimulus: BD, blur+disparity; D, disparity; B, blur removed; N, nil cue condition.

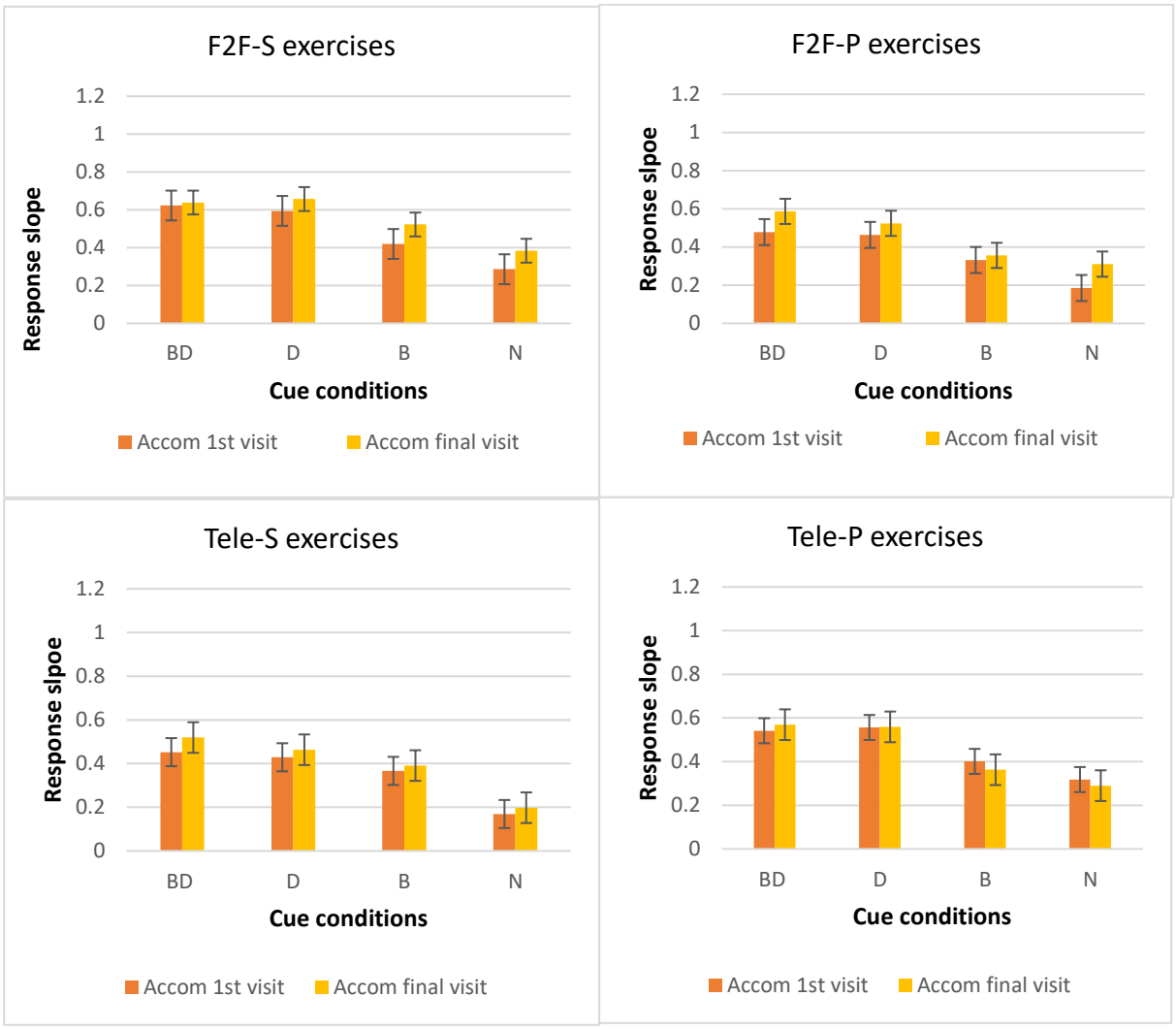


Figure 6. 14 Accommodation slope changes of all groups between first and final visits. A slope of 1.0 indicates perfect response to target demand. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; Stimulus: BD, blur+disparity; D, disparity; B, blur removed; N, nil cue condition.

For greater clinical and practical importance, the amount of accommodation gain at 33 cm was analysed. Three-way mixed ANOVA was performed to determine change of accommodation responses at 33cm with appointment and exercise types as a between group factors, and cue conditions (BD, D, B and Nil) as within group factors. There was no significant main effect of appointment type ($F(1,36)=0.016$, $p=0.899$), exercise type ($F(1,36)=1.68$, $p=0.203$), and no significant interaction between appointment and exercises ($F(1,36)=0.454$, $p=0.505$). In addition, paired t-test analysis showed no significant change in gain for different

cue conditions after exercises at 33 cm ($p > 0.05$). However, the Tele-S group showed the greatest improvement in mean accommodation by 0.257 D, followed by F2F-S 0.195 D, F2F-P 0.126 D and Tele-P 0.036 D. The changes in mean accommodation at 33 cm in different cue conditions for each group are shown in Figure 6.15.

Figure 6. 15 Change in accommodation responses at 33 cm after exercises. Error bars denote the standard error for each condition. F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo. Stimulus: BD, blur+disparity; D, disparity; B, blur removed; N, nil cue condition.

6.7.2 Analysis by orthoptic measures

6.7.2.1 Vergence Facility

The mean VF of groups at baseline was F2F-S 13.2, F2F-P 13.1, Tele-S 14.4 and Tele-P 14.4 cpm. Figure 6.16 illustrates the VF improvement pre/-post exercises for all study groups.

A three-way mixed ANOVA was conducted to investigate the effect of the appointment and exercise types on VF, with appointment and exercise types as a between group factors and change in VF a within-groups factor. There was a significant main effect of exercises on VF ($F_{1,36} = 14.1$, $p < 0.001$) and all groups improved their VF. The main effect of appointment type was found to be not significantly different ($F_{1,36} = 1.11$, $p = 0.3$) as well as appointment type*exercises interaction ($F_{1,36} = 0.203$, $p = 0.655$). The pairwise comparisons corrected by Bonferroni adjustment for multiple comparisons revealed that VF changed in the F2F-S and Tele-S groups by a mean difference (MD) of 1.85 cpm ($p < 0.001$) and in the F2F-P and Tele-P groups by an MD of 0.8 cpm ($p = 0.015$). A one-way repeated measures ANOVA was carried out with the VF as the within subject factor to determine whether there was significant change across appointments. The VF improved significantly in F2F-S, Tele-S groups and F2F-P groups as well as small but significant improvement in F2F-P as shown in Table 6.17.

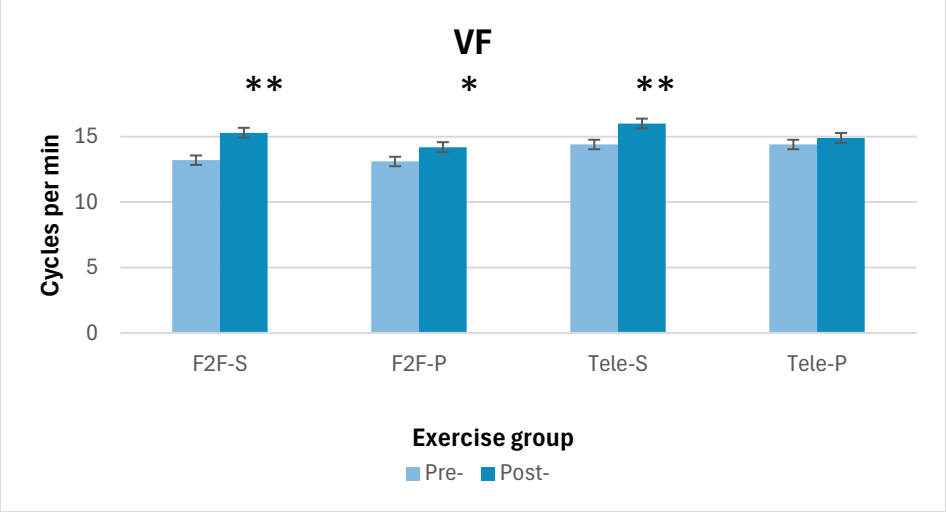


Figure 6. 16 Pre- and post- VF measures for each appointment group. Error bars: Standard error. VF: vergence facility; F2F S: face to face and simple convergence exercises; F2F P: face to face and placebo; Tele S: Tele-appointments and simple convergence exercises; Tele P: Tele-appointments and placebo; *p = 0.01–0.05; **p < 0.001

Table 6. 5 VF changes from baseline to final visit for all groups

Group	VF (mean ±SD)				
	Baseline	1st appointment	2nd appointment	Final visit	Overall change P-value*
F2F-S	13.2±2.0	13.9±2.5	14.6±2.4 (p=0.04)	15.3±2.4	<0.001
F2F-P	13.1±2.2	13.5±2.1	13.7±2.2	14.2±2.3	0.02
Tele-S	14.4±2.2	-	-	16±2.4	<0.001
Tele-P	14.4±2.3	-	-	14.9±1.8	0.244

VF: vergence facility; F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; SD: standard deviation; Shaded cell: significance change between appointments $P < 0.05$ (adjusted for multiple comparisons by Bonferroni correction); *Data are significant at $p < 0.05$.

6.7.2.2 Near Point of Convergence

The mean NPC of groups at baseline was F2F-S 5.3, F2F-P 5.2, Tele-S 5.1 and Tele-P 5.0 cm. Figure 6.17 illustrates the NPC measurement pre/-post exercises for all study groups.

A three-way mixed ANOVA was conducted to investigate the effect of the appointment and exercise types on NPC, with appointment and exercise types as a between group factors and change in NPC as a within-groups factor. There was no significant main effect of exercises on the NPC test ($F_{1,36} = 0.867$, $p = 0.358$). Additionally, no significant main effect of appointments ($F_{1,36} = 1.34$, $p = 0.255$) and interaction between appointment type*exercises ($F_{1,36} = 0.367$, $p = 0.548$) were identified. The NPC improved slightly in the F2F-S and Tele-S groups, while no improvement occurred in the F2F-P Tele-P groups. The mean NPC of groups at final visit was F2F-S 4.9 cm, F2F-P 5.6 cm, Tele-S 4.9 cm and Tele-P 5.2 cm.

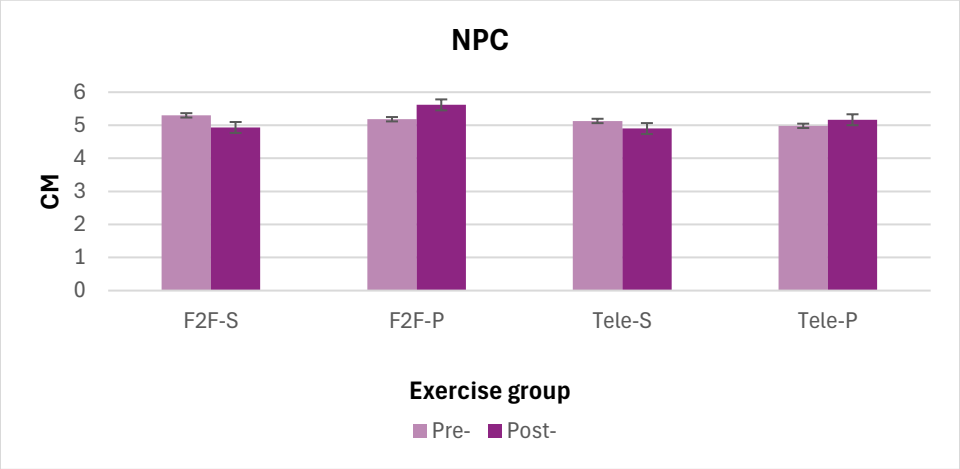


Figure 6. 17 Pre- and post- NPC measures for each appointment group. Error bars: Standard error. NPC: Near Point of Convergence; F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo.

6.7.2.3 Positive Fusional Vergence

The mean near PFV of groups at baseline was F2F-S 36, F2F-P 37, Tele-S 39 and Tele-P 39Δ. Figure 6.18 illustrates the near PFV measurement pre/-post exercises for all study groups.

A three-way mixed ANOVA was conducted to investigate the effect of the appointment and exercise types on near PFV, with appointment and exercise types as a between group factors and change in near PFV change as a within-groups factor. There was no significant main effect of exercises on near PFV ($F_{1,36} = 0.839$, $p = 0.366$). In addition, there was no significant main effect of appointments ($F_{1,36} = 0.34$, $p = 0.856$), and interaction between appointment type*exercises ($F_{1,36} = 0.008$, $p < 0.928$) were identified. The near PFV slightly improved in the F2F-S, Tele-S groups and unchanged in the Tele P group. The mean near PFV of groups at final visit was F2F-S 38Δ, F2F-P 36.5Δ, Tele-S 40.5Δ and Tele-P 39Δ.

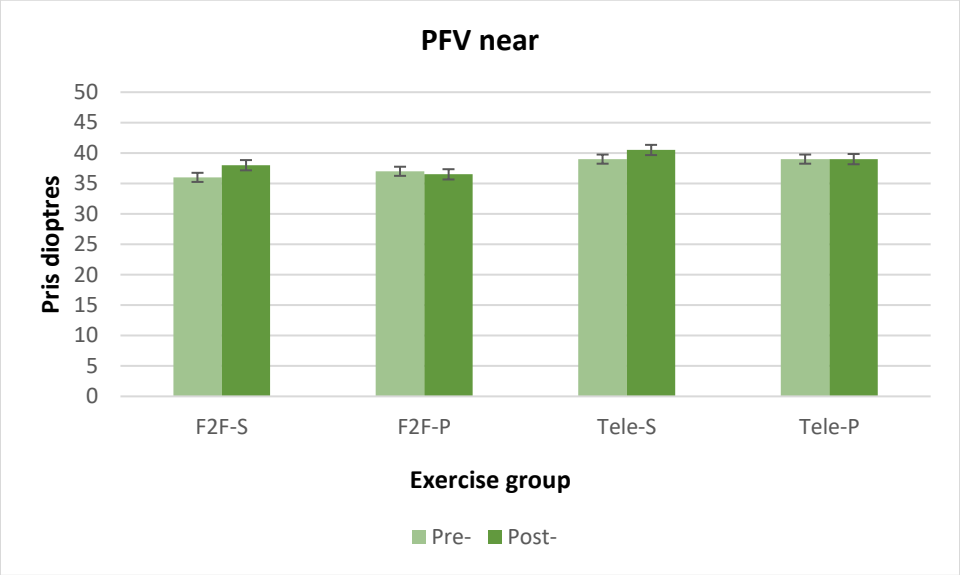


Figure 6. 18 Pre- and post- near PFV measures for each appointment group. Error bars: Standard error. PFV: Positive Fusional Vergence; F2F S: face to face and simple convergence exercises; F2F P: face to face and placebo; Tele S: Tele-appointments and simple convergence exercises; Tele P: Tele-appointments and placebo.

6.7.2.4 Near point of accommodation (NPA)

The mean NPA of groups at baseline was F2F-S 12.1 D, F2F-P 11.4 D, Tele-S 12.5 D and Tele-P 11.1 D. Figure 6.19 illustrates the NPA measurement pre/-post exercises for all study groups.

A three-way mixed ANOVA was conducted to investigate the effect of the appointment and exercise types on NPA, with appointment and exercise types as a between group factors and change in NPA a within-groups factor. There was a significant main effect of exercises on NPA ($F_{1,36} = 5.02$, $p = 0.031$). The main effect of appointment type was found to be not significantly different ($F_{1,36} = 0.65$, $p = 0.8$) as well as appointment type*exercises interaction ($F_{1,36} = 0.527$, $p = 0.473$). The pairwise comparisons corrected by Bonferroni adjustment for multiple comparisons revealed that NPA changed in F2F-S and Tele-S by an MD 1.0 D ($p < 0.001$) and MD -0.08 D in F2F-P and Tele-P groups ($p > 0.05$). The change in F2F-S was 0.1 D greater than Tele-S, and F2F-P changed by 0.33 D greater than Tele-P groups. A one-way repeated measures ANOVA was carried out with the NPA as the within subject factor to determine whether there was significant change across appointments. The NPA improved significantly in

both the F2F-S and Tele-S groups while no significant improvement occurred in the F2F-P group as shown in Table 6.6.

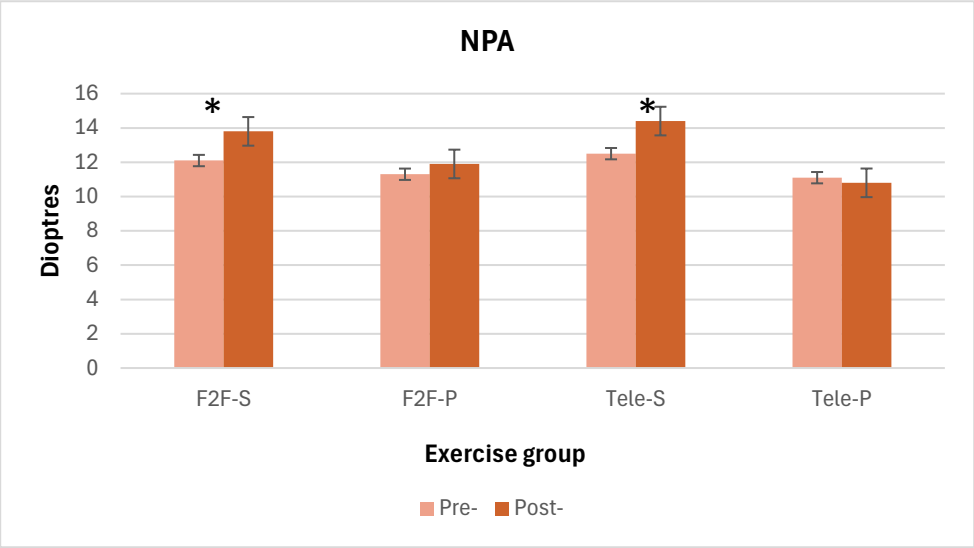


Figure 6. 19 Pre- and post- NPA measures for each appointment group in diopters. Error bars: Standard error. NPA: near point of accommodation; F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; *p = 0.01–0.05

Table 6. 6 NPA changes from baseline to final visit for all groups

Group	NPA (mean ±SD)				
	Baseline	1st appointment	2nd appointment	Final visit	Overall change P-value*
F2F-S	12.1±1.9	12.8±1.8	13.0±1.5	13.7±1.3	0.043
F2F-P	11.4±2.3	10.9±2.4	11.2±2.1	11.9±2.2	0.245
Tele-S	12.5±1.2	-	-	14.3±0.9	<0.01
Tele-P	11.1±2.7	-	-	10.8±2.5	0.394

NPA: near point of accommodation in dioptres (D); F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; SD: standard deviation; *Data are significant at p < 0.05.

6.7.2.5 Binocular Accommodation Facility (BAF)

The mean BAF of groups at baseline was F2F-S 9.5 cpm, F2F-P 8.8 cpm, Tele-S 9.5 cpm and Tele-P 9 cpm. Figure 6.20 illustrates the BAF measurement pre/-post exercises for all study groups.

A three-way mixed ANOVA was conducted to investigate the effect of the appointment and exercise types on BAF, with appointment and exercise types as a between group factors and change in BAF as within-groups factor. There was significant main effect of exercises on BAF test ($F_{1,36} = 9.28$, $p = 0.004$). Additionally, no significant main effect of appointments ($F_{1,36} = 0.158$, $p = 0.693$) and interaction between appointment type*exercises ($F_{1,36} = 0.018$, $p = 0.895$) were identified. The pairwise comparisons corrected by Bonferroni adjustment for multiple comparisons revealed that BAF changed in F2F-S and Tele-S by in MD 1.65 ($p < 0.01$) and in F2F-P and Tele-P by MD 0.5 ($p = 0.069$). The change in Tele-S was 0.5 D, slightly greater than the F2F-S group. A one-way repeated measures ANOVA was carried out with the BAF as the within subject factor to determine whether there was significant change across appointments. The BAF improved significantly in both the F2F-S and Tele-S groups while no significant improvement occurred in the F2F-P and Tele-P groups as shown in Table 6.7.

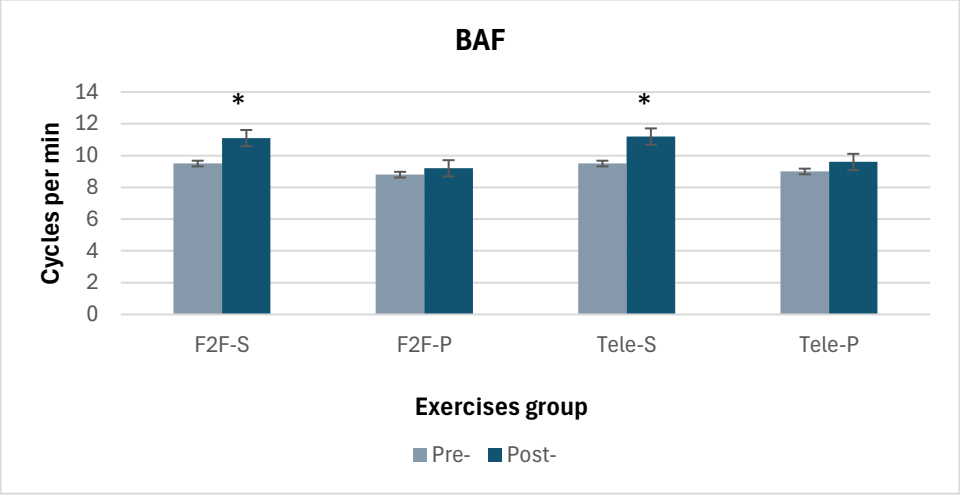


Figure 6. 20 Pre- and post- BAF measures for each appointment group. Error bars: Standard error. VF: vergence facility; F2F S: face to face and simple convergence exercises; F2F P: face to face and placebo; Tele S: Tele-appointments and simple convergence exercises; Tele P: Tele-appointments and placebo; *$p < 0.05$

Table 6. 7 BAF changes from baseline to final visit for all groups

Group	BAF (mean ±SD)				
	Baseline	1st appointment	2nd appointment	Final visit	Overall change P-value*
F2F-S	9.5±1.8	10.6±2.4	10.9±2.2	11.1±2.3	0.007
F2F-P	8.8±1.5	9.6±1.6	8.9±2.0	9.2±2.1	0.72
Tele-S	9.5±2.4	-	-	11.2±2.2	<0.001
Tele-P	9.0±2.7	-	-	9.6±2.7	0.111

BAF: binocular accommodation facility; F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; SD: standard deviation; *Data are significant at $p < 0.05$.

6.7.2.6 Convergence Insufficiency Symptoms Survey

The mean CISS score of groups at baseline was F2F-S 10, F2F-P 9.7, Tele-S 8.5 and Tele-P 8.5. A three-way mixed ANOVA was conducted to investigate the effect of the appointment and exercise types on CISS score, with appointment and exercise types as a between group factors and change in CISS as within-groups factor. There was no significant main effect of exercises on CISS score ($F_{1,36} = 0.993$, $p = 0.326$), appointments ($F_{1,36} = 0.11$, $p = 0.742$) and interaction between appointment type*exercises ($F_{1,36} = 0.151$, $p = 0.7$) were identified.

The CISS showed significant improvement in final visit in the F2F-S and Tele-S groups, while the F2F-P and Tele-P groups showed no significant improvement. The pairwise comparisons corrected by Bonferroni adjustment for multiple comparisons revealed that CISS score improved in F2F-S and Tele-S in MD by 4.35 ($p < 0.001$) and MD by 2.1 in F2F-P and Tele-P groups ($p = 0.117$). A one-way repeated measures ANOVA was carried out with the CISS score as the within subject factor to determine whether there was significant change across appointments. The CISS score improved significantly in F2F-S, Tele-S groups as shown in Table 6.8.

Table 6. 8 The CISS score changes from baseline to final visit for all groups.

Group	CISS score (mean ±SD)				
	Baseline	1st appointment	2nd appointment	Final visit	Overall change P-value*
F2F-S	10±4.9	8.1±4.3	4.8±4.3 P=0.023	5.6±4.1	<0.001
F2F-P	9.7±4.6	8±4.6	7.1±5.9	6.9±6.7	0.099
Tele-S	8.5±4.4	6.1±4.2	5.9±3.8	4.2±3	<0.001
Tele-P	8.5±3.4	8±4.1	8.4±5.3	7.1±4.2	0.439

CISS: convergence insufficiency symptom survey; F2F-S: face to face and simple convergence exercises; F2F-P: face to face and placebo; Tele-S: Tele-appointments and simple convergence exercises; Tele-P: Tele-appointments and placebo; SD: standard deviation; Shaded cell: significance change between appointments $P < 0.05$ (adjusted for multiple comparisons by Bonferroni correction); *Data are significant at $p < 0.05$.

6.8 Discussion

The study monitored young adults for 3 weeks through face-to-face or tele-appointments as well as assessed convergence and accommodation measures following their completion of orthoptic exercises.

The key finding of this research study is that there were no significant differences between face-to-face and tele-appointment groups across objective and orthoptic measures. This suggests that tele-appointments can be just as effective as face-to-face appointments for monitoring and managing orthoptic exercises. The ease of tele-appointments in the delivery of orthoptic exercises was reflected in the lack of difficulties reported by both the researcher and participants. The lack of complaints from participants about tele-appointments indicates a high level of satisfaction with this mode of service. Most study participants were university students, they would have demanding academic commitments and extracurricular involvements. Another noteworthy observation is that 75% of the participants who withdrew from the study were those attending face-to-face appointments. This may indicate that they may feel less motivated to commit to this additional responsibility. In contrast, if this study were conducted on patients with primary CI who are experiencing symptoms, showing

improvement, or are motivated to address their symptoms, they would be less likely to discontinue participation. However, Therefore, tele-appointments likely increased convenience and better suited the participants' time preferences, potentially improving adherence to the study. In addition, the tele-appointments focused on discussions and information sharing, which let participants feel free from comprehensive examinations and spare face-to-face when necessary. It could be argued that the positive outcomes of tele-appointments in objective and orthoptic measures contributed to the comparable efficacy observed with face-to-face appointments. However, an interesting observation is that objective and orthoptic measures are comparable for the F2F and Tele simple exercise groups. In contrast, the notable improvement in the placebo groups was only in the F2F group. This result may be explained by the fact that the possible motivational input from seeing the researcher in person improved measures in the F2F placebo group.

The simple convergence exercises using Gabor image in this study aimed to target disparity as the major drive of convergence and accommodation (Horwood and Riddell, 2008), thereby exercising both vergence and accommodation. The orthoptic exercises conducted over three weeks in this study induced changes in vergence and accommodation responses. Although the exercises' effects were small, they did result in a notable overall improvement and at 33 cm. However, to ensure efficiency of results through a standardised protocol, all participants were seen by the same examiner (HA), who maintained a consistent tone of voice. Furthermore, given instructions were minimal to avoid influencing the participants' effort or biasing results, allowing the natural assessment of responses as possible. In addition, despite the participants were typically young adults, considered asymptomatic, and had near-ceiling ocular responses, small exercises' effects were still observed. Placebo effects might alleviate symptoms without altering ocular responses (Horwood *et al*., 2014). The placebo effect is likely related to participants' expectations of benefit from the exercises in this study. Simple convergence exercises significantly improved symptoms and led to objective changes in vergence and accommodation responses. These changes were more than double those seen with the placebo effect. Therefore, these observed differences between simple convergence and placebo exercises are most likely due to the actual exercises effect rather than the placebo effect.

The mean gain from simple convergence exercises was vergence (0.044) and accommodation (0.04), compared to gains at 33 cm in vergence (0.1) and accommodation (0.27). In comparison, with a similar approach, Horwood *et al*. (2014) reported a higher gain of 0.1 in both vergence and accommodation responses, as well as 0.35 MA for vergence and 0.27 D for accommodation at 33 cm after two weeks of similar exercises. These differences may be due to varying levels of compliance with the exercises between the two studies. In this study, the simple exercises groups showed good compliance (mean 70%), whereas the study by Horwood *et al*. reported no systematic differences between groups but did not provide compliance values. The lower gain might be explained by the compliance rates that do not accurately reflect the actual performance of the exercises. There is, however, another possible explanation for this result. Despite similarities in inclusion criteria, population, and exercises between the two studies, group differences in gain were observed. These differences might be attributed to individual response variations between the two studies' groups. Typically, visually normal individuals are expected to show a similar pattern of responses (Horwood and Riddell, 2008). On the other hand, Horwood and Riddell (2014) previous studies revealed an important observation that variability is normal, which could also be the case in this study. Furthermore, the variability could be explained by individual differences in response patterns to cue conditions, even among visually normal populations (Horwood and Riddell, 2008).

The inclusion of placebo exercises helped to distinguish the actual effect of simple convergence exercises from the placebo effect, thereby enhancing the reliability and comparability of the results. The placebo effect found in this study was consistent and comparable with the findings of Horwood *et al*. (2014) study. The placebo groups achieved a mean gain of 0.013 MA in vergence responses and 0.02 D in accommodation. Similarly, the placebo group in Horwood *et al*. (2014) study showed a gain of 0.03 MA and 0.025 D in vergence and accommodation, respectively. The slight differences in gain between the two studies can be attributed to individual differences and expectations among the population of the studies. Additionally, the two studies' similarity in placebo effect rates suggests a consistent placebo effect. It also indicates similarities in contextual factors such as administration methods, instructions, procedures and demonstration of exercises. This also validates the methodology design and gives reliability to the study's results.

The participants were not informed that the study included an investigation of placebo exercises. Efforts were made to ensure that the placebo exercises mimic the required efforts, training time and daily sessions of simple exercises without exercising vergence and accommodation responses. This makes it difficult for participants to speculate whether they were assigned to actual eye exercises or a placebo group. As a result, the study successfully achieved that participants could not distinguish any differences between the exercises groups. If the placebo effect were to influence the outcomes, it would likely be greater among participants who believed they were receiving actual exercises. These placebo exercises resulted in minimal or no improvements in subjective orthoptic measures and CISS scores and led to slight changes in vergence and accommodation responses. Therefore, the placebo protocol was effectively employed as the actual exercises effect was separated from the placebo. Thus, the observed differences between the simple exercises and placebo groups were more likely attributed to exercises' effects rather than explained by the placebo effect.

A good compliance rate was achieved according to the study's criteria, with no significant differences observed between groups. This good complaint rate strengthens the validity of the results and minimises bias. The most notable compliance outcome was the Tele-P group, where half of the participants showed less than 50% compliance. The most minor improvement across all measurements may be attributable to the low compliance observed in this group. When compared with Horwood *et al.* (2014) study, it is unclear whether the low overall gain observed was due to the difference in compliance rates. Proving participants compliance with home exercises is challenging (Horwood *et al*., 2014), and some argue that it cannot be definitively tracked (Revathy *et al*., 2012). In an effort to ensure consistency and meet compliance expectations, all participants were instructed to perform exercises to the best of their ability and meet expectations. The PI (HA) also emphasised the importance of compliance during every face-to-face visit and tele-appointment. Participants were also encouraged to maintain honesty when completing their diaries without attempting to cheat or please the examiner. As with any eye exercises at home, there is a possibility that some participants completed the diary while they were not performing exercises. The close monitoring of diary sheets was intended to encourage participants to comply with the exercises. Nonetheless, it was evident at times that some participants were more diligent in

completing their diaries than others. Most participants in this study were university students, which implies involvement in studying and exams, potentially putting pressure on their compliance. This factor is likely to be related to the most frequently repeated comments in participants' diaries, which included phrases such as "tired", "having exams", or "I skipped the exercises, having a busy day". Still, they achieved good compliance despite the challenges they faced in adhering to the study protocol while managing their academic responsibilities.

Some orthoptic measures showed considerable improvement even though visually normal individuals were expected to perform at or near the ceiling, which could limit the room for improvement. The groups that performed simple exercises demonstrated improvement across orthoptic measures, particularly in VF, NPA, and BAF. Conversely, the placebo groups showed inconsistent improvement across tests, with only significant improvement in the VF test. Additionally, in Horwood's study, the VF test significantly improved in the placebo group and somewhat improved in the control group, suggesting that the VF test is sensitive to the practice effect. However, subjective measurements mainly rely on participants' self-reported responses, which can be influenced by several variations. Examples of such participant response time and perception to report blur, diplopia, and single vision as well as mood, understanding of the test and practice effect. Consequently, subjective responses can vary widely and depend heavily on individual differences in estimation. In contrast, objective measures unaffected by these subjective factors whether before or after the improvement by exercises as well as standardised and can be consistently administered. Thus, changes in vergence and accommodation responses achieved through exercises over a short period in individuals performing near their maximum potential are more accurately reflected by objective measurements.

6.8.1 Limitations

This study has some limitations that should be considered. Firstly, the study recruited visually normal young adults who had no symptoms, limited by ceiling effects, so had limited scope for improvement. However, the data could be used as feasibility and baseline data for future research. Extending the study to include CI patients could provide insights into the convergence exercises' efficacy. It would be important to observe how the same exercises

impact CI patients with varied severity, which are likely to produce different responses. Secondly, the high baseline performance of the young participants was near the ceiling, making improvements less noticeable. Thirdly, the short duration of the study may not be sufficient to observe significant changes in vergence or accommodative responses. Extending the exercise period could potentially produce more observable improvements in both subjective and objective measures. Fourthly, the study utilised tele-appointments for just two appointments. Examining the impact of a longer duration of tele-appointments could reveal the influence on compliance, exercises outcomes, and participant satisfaction. Lastly, the relatively small sample size may not be large enough to generalise the findings to a broader population. A larger sample size would help to clarify the questions raised in this study.

6.9 Conclusion

This study has found that tele-appointments are generally as effective, feasible and complement face-to-face visits in participants undergoing orthoptic exercises with comparable outcomes in compliance, objective and subjective measures. Additionally, the study showed that simple convergence exercises led to noticeable improvements in visually normal young adults. These positive results indicate that such exercises are likely to be efficacious for CI patients, supporting their use as a beneficial intervention in broader clinical settings.

Chapter 7 Questionnaire to investigate the prevalence, investigation and treatment of primary convergence insufficiency

7.1 Introduction

CI is a common binocular vision disorder and is becoming increasingly prevalent among younger generations (Pillay and Munsamy, 2021). There is a lack of information on reported prevalence on a global scale as discussed in more detail in Chapter 2 (section 2.2.8). A recent systematic review by Mohamed and Alrasheed (2023) looked at published prevalence data from 12 countries between 2000-2023. The review reported the overall pooled prevalence rate of CI was 7.98%. However, there is currently a paucity of data on the prevalence rates of CI among general and clinical populations in the UK. A previous study by Stidwill (1997) investigated 60,000 orthoptic examinations to establish the incidence of binocular anomalies across all age groups of patients in Staffordshire, UK. The investigation revealed an incident rate of 207 patients with CI, and an estimated mean prevalence of CI in the general population was 4.05%.

The study in Chapter 5 which was on patients with primary CI in Sheffield Teaching Hospitals. Before the onset of COVID-19, the study plan appeared feasible. Sample size calculations indicated that 44 patients were required and considering the number of CI patients attending the STH clinic at that time, this target seemed achievable. Unfortunately, the study suffered from recruitment difficulties post-COVID as those patients did not frequently appear throughout the duration of the study. Specifically, there were fewer referred cases, but they were either primary or secondary CIs that wore prisms, tried exercises before and failed or interested in other intervention. At STH, clinicians had reported a noticeable reduction in the number of CI cases seen in their clinics and the reasons for this were unclear. Reasons postulated included CI rates being unchanged, but patients were being managed by others for example optometrists and referring only the severe primary and secondary CI to hospitals. Consequently, the number of CI cases reaching hospital settings appeared to have decreased. In this regard, The College of Optometrists journal “Optometry in Practice” (OiP, 2015)

highlighted that CI is frequently encountered within optometric practices in the UK and is often diagnosed and managed within the practice setting. In addition, the journal indicated that referrals to orthoptic clinics may occur when necessary for cases requiring extra care according to the patient's preference. It is worth noting that the NHS key statistics reported that the waiting list for hospitals has risen rapidly since early 2021 i.e., post-COVID (Baker, 2024). Similarly, the number of primary CI cases managed by optometry practices may have increased post-COVID, resulting in fewer referrals to orthoptic clinics. These reasons call to question whether the number of primary CI patients has decreased post-COVID or might be managed by optometrists. In addition, there may be other reasons unknown at the moment that might emerge through the questionnaire.

What remained to be investigated was whether other NHS hospitals were also experiencing a reduction in primary CI cases post-COVID. What may indicate these concerns about CI numbers is one of the responses of NHS hospitals that were invited to participate in the primary CI study in Chapter 5. The invited hospital reported, "That is definitely a challenging group to find...had a quick look through our new case book at the main hospital and did not see one CI recorded since Jan to 12 October 2023. In my experience, optometrists often manage these cases and we only see when all options are exhausted". This hospital's experience aligns with the notion that optometrists manage most CI cases. To understand this trend comprehensively, it is essential to investigate whether other NHS hospitals are experiencing similar reductions in CI cases.

In Chapter 6, the study suggested that tele-appointments were generally as effective and practical as face-to-face visits for participants undergoing orthoptic exercises and monitoring compliance. Therefore, tele-appointments can be complementary to face-to-face visits, providing a convenient and equally beneficial mode of care delivery for CI treatment approach. In addition, tele-appointments were a possible reason for a lack of CI patients in the clinic.

Previous research literature, as discussed in Chapter 3, has documented the variability in the methods used for treating CI. Complementing this, the service evaluation study presented in Chapter 4 confirmed the variability in the treatment protocols utilised in one hospital eye clinic

(STH). It was important to explore opinions regarding CI treatment protocols among clinicians. In addition, investigate the numbers of CI patients before and after COVID and explore possible reasons for primary CI patients being less frequently seen in the orthoptic clinic. Use this opportunity to survey opinions about using tele-appointments pre- and post-COVID for CI patients, and whether there are any barriers to using tele-appointments for primary CI patients.

7.1.1 CI in Saudi Arabia

The study was also conducted in Saudi Arabia to collect preliminary data on primary CI due to the researcher's particular interest in his home country and how it may or may not compare to UK practice observations.

Up to now, far too little research has been paid to investigating the prevalence of CI in Saudi Arabia. A study conducted on 417 children found a prevalence rate of 5.2% (Alghamdi, 2020), while another study found a CI rate of 12.8% in 109 university students (Alghamdi et al., 2021). In addition, primary CI has received less attention as no research focused on its treatment has been identified in the existing literature. To the best of researcher knowledge, no studies showed the treatment protocols and exercises used in Saudi Arabia. Moreover, there are no orthoptists schools or departments in Saudi Arabia. Thus, it is unclear who is responsible for diagnosing CI patients in clinics and treating them, ophthalmologists, optometrists or someone else. Thus, distributing a questionnaire to ophthalmologists and optometrists will provide an important opportunity to advance the understanding of clinic numbers and CI treatment. The questionnaire will be preliminary to establish the initial information about primary CI in Saudi Arabia as well as clarify whether ophthalmologists or optometrists have the most prominent role. Additionally, the questionnaire findings should make a contribution to the field of CI care in Saudi Arabia.

7.2 Aim

The research will compare responses to the questionnaire between different eye care professionals across the UK and Saudi Arabia. In addition, to investigate the low numbers of primary CI patients resulting in poor recruitment on my CI study on Chapter 5. Specifically, the

questionnaire aims to investigate the prevalence and current primary CI treatment as practised in clinics among orthoptists, optometrists in the UK, and optometrists and ophthalmologists in Saudi Arabia pre- and post-COVID. Moreover, to elicit views on the use of video tele-appointments in primary CI care.

7.3 Objectives

- To collect information on primary CI patient numbers pre- and post-COVID
- Investigating whether optometrists diagnose and treat cases of CI or refer them to eye clinics
- To investigate why there were no suitable patients as well as poor recruitment on primary CI study in Chapter 5
- To explore the primary CI treatment protocols used by orthoptists and optometrists in current practice
- To investigate the opinions of orthoptists and optometrists on the most effective and prescribed exercises
- To assess whether orthoptists and optometrists use tele-appointments in primary CI care
- To find out any barriers limiting or preventing the use tele-appointments in primary CI care

7.4 Methodology

Ethical approval for this questionnaire study was received from The University of Sheffield Ethics Committee (Reference Number: 051274) Appendix 5.1. The study adhered to the tenets of the Declaration of Helsinki. There were two versions of the questionnaire:

- First version: Orthoptists and optometrists in the UK (Appendix 5.2)
- Second version: Ophthalmologists and optometrists in Saudi Arabia (Appendix 5.3)

7.4.1 Distribution of the questionnaire

An online questionnaire was distributed to the orthoptists in the UK registered with the British and Irish Orthoptic Society (BIOS), facilitated by academic supervisors who are registered members. For the optometrists, an attempt was made to distribute the questionnaire to registered members of the College of Optometrists. However, The College of Optometrists responded that they could not distribute the questionnaire due to their limited capacity for

surveys. In addition, contacting The Local Optical Committees (LOCs) and Association of Optometrists (AOP) was also attempted several times, but there was no response. Therefore, to reach optometrists, personal efforts were made using social media sites and groups on Facebook, X, WhatsApp, and Instagram. Additionally, the PI (HA) contacted and persuaded The Association for Eye Care Providers (FODO) to announce the questionnaire on their website.

In Saudi Arabia, there are no colleges or institutes graduating orthoptists. Thus, optometrists and ophthalmologists were chosen because they are the only eye care providers. The questionnaire was distributed to ophthalmologists through the Saudi Ophthalmological Society and optometrists via the Saudi Society of Optometry. To enhance distribution, social media groups such as Facebook and WhatsApp were also utilised to maximise distribution as much as possible.

The questionnaire was available for 6 weeks, from 1 August to the deadline of 12 September 2023. However, the deadline was extended to 20 December 2023 due to difficulties in reaching UK optometrists.

7.4.2 Questionnaire design

The questionnaire is an alternative approach to addressing some of the research questions. Particularly those questions about primary CI numbers, treatment and tele-appointments discussed in Chapter 5. The initial creation and development of the questionnaire was following discussion with the academic supervisors, to ensure clarity, clinical relevance and to ensure it was focussed on the questions arising from the earlier elements of the research. In addition, the questionnaire was piloted with three orthoptists and one optometrist in the UK as well as two optometrists in Saudi Arabia to test the time to complete the questions and ensure the questions were easy to understand and answer.

The questionnaire, created using Google Forms, was distributed via a hyperlink leading to the questionnaire's main page. It was designed and tested to be completed in 10 minutes or less. The questionnaire started with a descriptive introduction outlining a background on the research's objectives and a reminder of the primary CI definition. Before completing the

questionnaire, the respondent requested to give informed consent to take part and agreed that their responses be used anonymously for possible publication of the results. It is important to note that participants could only proceed to the questionnaire section after ticking the consent boxes. Taking part was entirely voluntary and anonymous. The questionnaire settings were modified to enable participants to revisit and revise their answers on previous pages. Withdrawal from the questionnaire was permitted at any point, and answers were received if the submit button was clicked.

The questionnaire did not include personally identifiable information but only asked about the profession, which was assigned to both the UK and Saudi Arabia versions. Additionally, asking about the geographical location which was only to the orthoptists and the optometrists in the UK, i.e., England (Northeast, Northwest, Yorkshire and The Humber, East Midlands, West Midlands, East of England, London, South East, and South West), Wales, Scotland and Northern Ireland. In addition, respondents were given an "other" option in multiple choice questions to provide additional information when needed. Additionally, a free-text box was available for them to share their opinions or offer recommendations when more information was requested.

7.4.2.1 Content of questionnaire

The questionnaire started with an invitation to take part in the research. It highlighted that the main focus is on primary CI and emphasised the importance of understanding the research's purpose and details before deciding to participate. The introduction outlined the objectives of the questionnaire, tele-appointments mean video calls and provided an estimate of the time required to complete it. It assured participants of the anonymity of their responses and emphasised that participation is voluntary, with the option to withdraw at any time without the need to provide a reason.

Both versions of the questionnaire began with two questions addressing the diagnosis of primary CI. These questions were tailored specifically for optometrists in the UK and for both ophthalmologists and optometrists in Saudi Arabia to clarify their roles in managing primary CI.

Q) Are you identifying primary CI in any of your patients?

Q) What action would you take if you identified primary CI?

The two questions for optometrists in the UK, aimed to determine if they have a role in reducing the number of CI patients referred to eye clinics, which is why there are no suitable patients for CI study in Chapter 5. Similarly, the two questions for ophthalmologists and optometrists in Saudi Arabia aimed to find out if they diagnose CI, who has the major role in the treatment, and where these patients are referred. If the optometrists in the UK and the ophthalmologists and optometrists in Saudi Arabia diagnose CI, they will complete the questionnaire, but if the answer is "NO", the questionnaire ends. It is expected that all UK orthoptists identify primary CI patients, therefore these two question was not included to orthoptists in the UK.

After that, 19 questions were directed to orthoptists as well as to UK optometrists and Saudi Arabian ophthalmologists and optometrists who proceeded with the questionnaire. The questions were organised into three themes: prevalence (4 questions), treatment protocols (12 questions), and utilisation of video tele-appointments (3 questions).

Prevalence

Q1) Approximately how many patients with primary CI do you currently diagnose per month?

Q2) Is this different to the number of primary CI patients diagnosed pre-COVID?

Q3) Approximately how many patients with primary CI did you diagnose per month pre-COVID?

Q4) In your opinion, why do you think there has been a change in the number of primary CI patients attending?

The questionnaire did not provide prevalence data but instead gathered professional opinions on whether primary CI is occurring more, less, or at the same frequency. The questions (Q1, Q2 and Q3) aimed to ascertain the number of CI cases among optometrists and in orthoptic clinics. Additionally, to examine whether CI numbers had changed pre- and post-COVID, as observed in the orthoptic clinic at Royal Hallamshire Hospital. The final question (Q4) explored possible reasons for any changes in CI numbers, such as optometrists managing simple cases.

Treatment protocol

Q5) What criteria do you use to diagnose primary CI?

Q6) Do you assess the amplitude of accommodation in primary CI patients?

Q7) Which of the following treatment options would you prescribe first in primary CI?

Q8) If the primary CI is improving with this treatment, would you add any of the following treatment options to their management?

Q9) How effective do you consider the following treatment methods for primary CI as either the first or second line of treatment?

Q10) If you prescribe orthoptic exercises for primary CI, what frequency of treatment do you suggest?

Q11) If you give exercises for primary CI - how long do you recommend exercises are performed each time?

Q12) Do you advise a rest period after exercises are performed?

Q13) What is the average follow-up period you prescribe during treatment of primary CIs?

Q14) What outcome measures do you consider as the success criteria of primary CI treatment?

Q15) If you selected 'improved Near Point of Convergence only' in the previous question, please specify the distance.

Q16) In your opinion, what may be the cause(s) of lack of treatment success in patients with primary CI?

The diagnostic criteria (Q5) aimed to compare the respondents' criteria with the variations in the number of signs discussed in the literature in Chapter 2 (section 2.2.7). Question 6 aimed to compare the findings with the Service Evaluation study, which found that most patients' amplitude of accommodation was not assessed. Question 7 aimed to identify the first-line CI treatment methods used by the respondents and to determine if their protocols align with Chapter 3, which reported pen to nose exercises and stereograms as the first line of treatment. Question 8 sought to identify any changes to the treatment plan and determine if they align

with the findings of the Service Evaluation study. Question 9 aimed to determine viewpoints on the efficacy of each treatment option and to compare these findings with the literature discussed in Chapter 3. Questions 10, 11, and 13 aimed to compare the frequency, training duration, and follow up period with the treatment protocols in the Service Evaluation study. Question 12 sought to determine if respondents recommend patients rest their eyes after exercises, as advised by BIOS (2016) guidelines. This question aimed to compare the respondents' definitions of successful treatment and cut-off value of NPC with the definitions discussed in the literature in Chapter 3. Questions 14 and 15 aimed to compare the respondents' definitions of successful treatment and cut-off value of NPC with the definitions discussed in the literature in Chapter 3. Question 16 sought to compare the respondents' views on the causes of unsuccessful treatment with those identified in the Service Evaluation study and discussed in the literature in Chapter 3.

Video tele-appointments

Q17) Do you use video tele-appointments for primary CI patients?

Q 18) Would you recommend video tele-appointments to others treating primary CI and why?

Q19) Are there any barriers to using video tele-appointments for primary CI patients?

Questions 17, 18 and 19 aimed to determine video tele-appointments application in clinical practice, whether respondents recommend them, and any barriers that limit their implementation.

7.5 Data analysis

The responses from the questionnaire were transferred into an Excel spreadsheet. Descriptive data was displayed in a form of (number of respondents, percentage) as well as in tables and charts. For questions that offer to choose more than one answer, since respondents may select multiple answers, response percentages could exceed 100%. To avoid overestimation, results were presented to indicate how many respondents selected each option. Statistical analyses were conducted between groups for these types of questions.

Non-parametric Chi-square was performed when data met the assumptions for the test (Franke *et al.,* 2012). Microsoft Excel 2016 and IBM SPSS 28.0 were used to analyse the data. Fisher's exact test was conducted as an alternative if Chi-square requirements were violated (Cleophas *et al.*, 2016). A significant level of $p < 0.05$ was applied to all statistical analyses. Any free text comments were reviewed and analysed thematically. Example quotations were presented to illustrate the comments made by respondents with taking into account overlapped ideas.

7.6 Results

A total of 275 responses were received between 1 August to 20 December 2023. In the UK, there were 121 responses from 78 orthoptists (64.5%) and 43 optometrists (35.5%). England achieved 103 (85.1%) responses, followed by Scotland 12 (9.9%), Wales 5 (4.1%) and Northern Ireland 1 (0.8%). Figure 7.1 displays the demographic information for orthoptists and optometrists in the UK. In Saudi Arabia, 154 responses were received from 93 (60%) optometrists and 61 (40%) ophthalmologists.

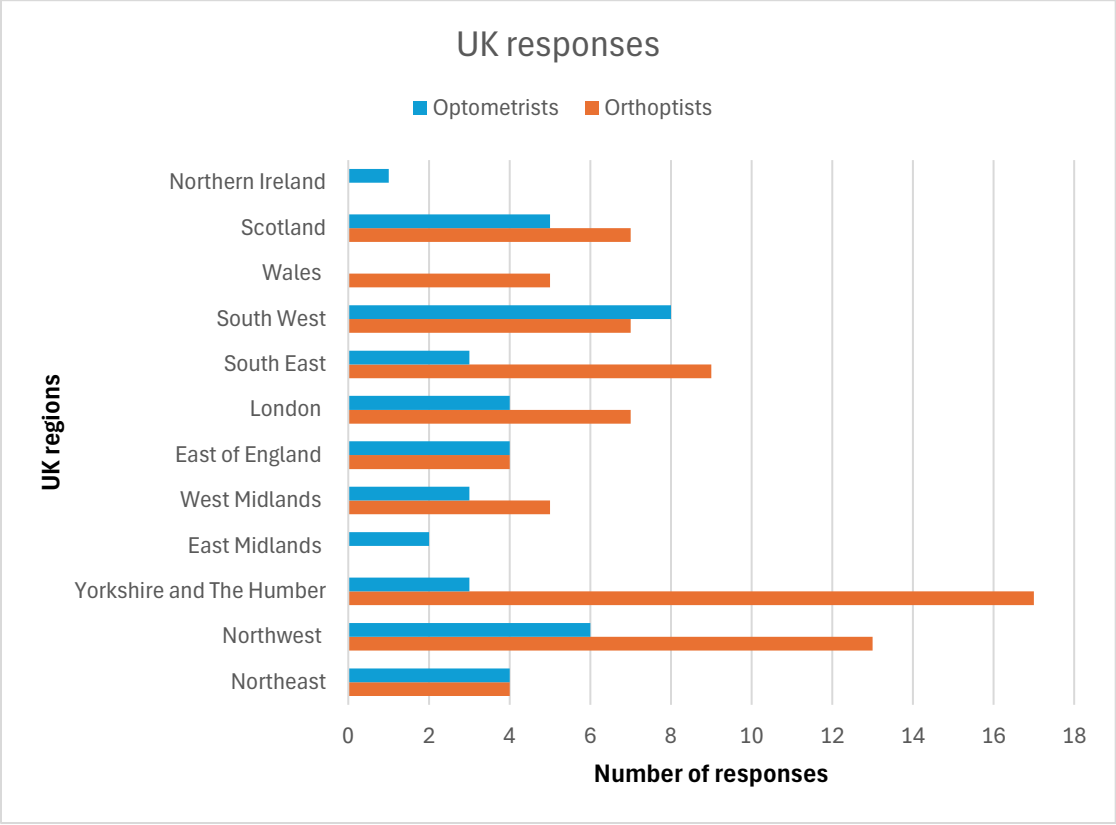


Figure 7. 1 Responses of the UK regions for the orthoptists and optometrists. Numbers in bars indicate the number of responses for each profession in the region.

7.6.1 Identifying primary CI

Q) Are you identifying primary CI in any of your patients?

It was important to determine if UK optometrists were identifying primary CI before moving on to the questionnaire sections. Five (11.6%) out of 43 optometrists indicated they do not identify primary CI in their practice. Thus, the analysis for the UK was performed on all 78 orthoptists and the remaining 38 optometrists, 116 respondents in total.

In Saudi Arabia, 68 (73%) out of 93 optometrists and 39 (63.9%) out of 61 ophthalmologists stated that they do not identify primary CI. There was no statistically significant difference between ratios of optometrists and ophthalmologists identifying primary CI ($\chi 2=1.47$, df=1, p=0.226). The analysis involved 25 optometrists and 22 ophthalmologists, totalling 47 participants.

7.6.1.1 Action in management of primary CI

Q) What action would you take if you identified primary CI?

The findings revealed consistency in primary CI management among optometrists in the UK. Thirty-five out of 38 optometrists recommended primary CI treatment at their practice. None of the optometrists indicated that they would refer all primary CI patients to a hospital eye clinic. Four optometrists reported offering referral to primary CI patients without insisting on it. Additionally, 2 optometrists indicated only referring symptomatic CI patients. At the same time, 2 optometrists also offered referral to other optometrists for treatment.

In Saudi Arabia, 19 optometrists and 16 ophthalmologists recommended primary CI treatment at their practice, while 3 optometrists and one ophthalmologist referred all primary CI cases to a hospital eye clinic. On the other hand, only one optometrist offered a referral to primary CI patients without insisting on it, whereas 5 optometrists and 9 ophthalmologists referred symptomatic primary CI patients. Additionally, 4 optometrists and 7 ophthalmologists recommended referring primary CI patients to another optometrist for treatment. There was

no statistically significant difference in treatment actions between ophthalmologists and optometrists (Fisher's Exact Test, $p > 0.05$).

7.6.2 Prevalence

Q) Approximately how many patients with primary CI do you currently diagnose per month?

In the UK, the number of patients diagnosed with primary CI each month varied among orthoptists and optometrists. The overall primary CI numbers diagnosed monthly by respondents in the UK and Saudi Arabia are shown in Figure 7.2. Fifty-nine orthoptists (75.6%) and 26 (68.4%) of optometrists reported diagnosing 1-5 patients per month, which was the most common range. Slightly higher patient numbers were reported by 11 (14%) of orthoptists and 2 (5.3%) of optometrists, who diagnosed 6-10 patients monthly. Conversely, 5 (6.4%) of orthoptists and 10 (26.3%) of optometrists reported not diagnosing any primary CI patients. Only 2 (1.7%) of orthoptists reported seeing 11-15 patients per month, with no optometrists reporting this range. Additionally, 1 (1.3%) orthoptist reported diagnosing more than 16 patients per month, which might be a potential outlier. These findings from orthoptists and optometrists showed statistically significant differences in monthly primary CI numbers (Fisher's Exact Test, $p=0.019$) with the orthoptists reporting higher monthly primary CI numbers.

In Saudi Arabia, 21 (87.5%) of optometrists and 19 (82.6%) of ophthalmologists reported diagnosing 1-5 patients with primary CI per month. Conversely, 3 (12.5%) of optometrists and 2 (8.7%) of ophthalmologists reported no CI cases in their clinics. Only 1 (4%) optometrist and 1 (4.6%) ophthalmologist indicated managing 6-10 patients monthly. No respondents reported seeing 11-15 or more primary CI patients in their practice. There was no significant difference between optometrists and ophthalmologists monthly primary CI numbers (Fisher's Exact Test, $p > 0.05$).

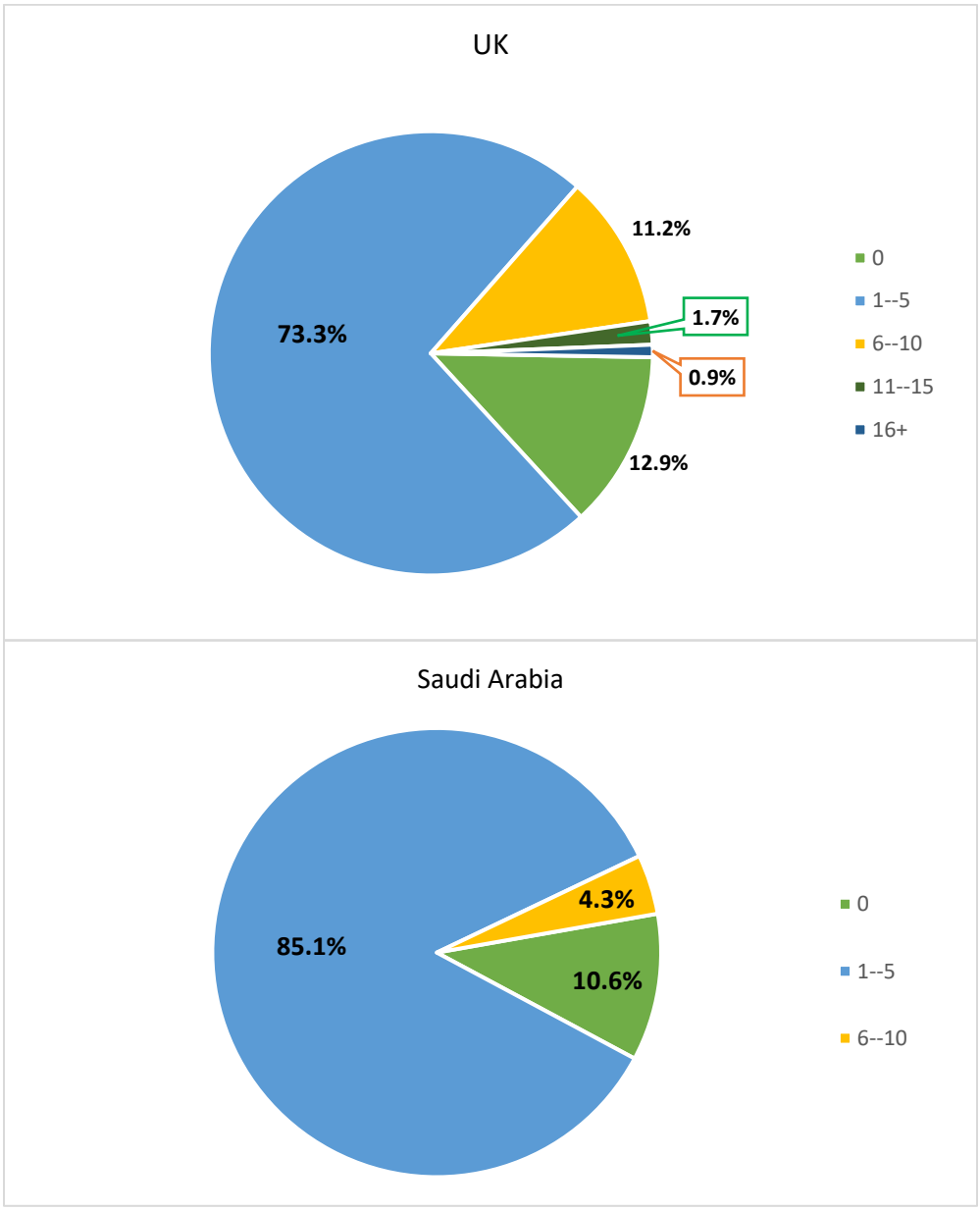


Figure 7. 2 The number of primary CI patients diagnosed monthly by orthoptists and optometrists in the UK (Top), and by ophthalmologists and optometrists in Saudi Arabia (Bottom). Percentages indicates number of respondents.

Q) Is this different to the number of primary CI patients diagnosed pre-COVID?

The details of the primary CI numbers difference pre-COVID and post-COVID for each profession in the UK and Saudi Arabia are shown in Table 7.1. In the UK, 94 (81%) of respondents reported no difference in CI numbers post-COVID compared to pre-COVID, while 22 (19%) observed a difference. Specifically, 15 reported that the numbers had decreased, while 7 responses indicated that the numbers had increased. In Saudi Arabia, 40 (85%) noted no difference post-COVID, while 7 (15%) observed a difference. Specifically, 4 respondents indicated a decrease in CI numbers and 3 an increase.

Table 7. 1 The reported decrease and increase in primary CI numbers pre-COVID and post-COVID by each profession in the UK and Saudi Arabia.

	UK		Saudi Arabia	
Decrease in CI numbers	Orthoptists	Optometrists	Ophthalmologists	Optometrists
1-5 to 0	4	2	2	2
6-10 to 1-5	5	1	-	-
11-15 to 1-5	1	-	-	-
11-15 to 6-10	1	-	-	-
16+ to 11-15	1	-	-	-
Increase in CI numbers			-	-
0 to 1-5	1	1	1	-
1-5 to 6-10	4	1	1	-
6-10 to 11-15	-	-	1	-

CI: Convergence insufficiency, UK: United Kingdom

7.6.2.1 Comments from respondents

Monthly CI numbers:

Q) In your opinion, why do you think there has been a change in the number of primary CI patients attending?

- COVID might increase CI cases:

"Due to the stress of COVID, it also could have had an impact"

"More close work/screen work without breaks. Possibly increased stress especially during lockdown/high COVID time"

- **Fewer patients seek advice, ignoring the problem or optometrists may have a role:**

"COVID restrictions limited footfall through clinics and I believe fewer people are now seeking advice"

"I think more people are expecting to have issues with their eyes with the increase in computer work, so less are seeking advice for it. Or optometrists are happier suggesting alternatives rather than referring to orthoptics"

"Unsure, they have been ignoring the problem, thinking due to covid there is a long wait, and now are all being referred in"

7.6.3 Treatment

7.6.3.1 Diagnostic criteria of CI

Q) What criteria do you use to diagnose primary CI?

The number of responses for each profession of respondents in the UK and Saudi Arabia is shown in Figure 7.3. In the UK, 51 (44%) of respondents showed a high emphasis on symptoms with a receded NPC, relying on this combination to diagnose primary CI. Conversely, 18 (15.5%) of respondents would diagnose based on reduced NPC even without symptoms but

might not treat if asymptomatic. On the other hand, 4 (3.5%) of optometrists would diagnose CI solely based on a receded NPC and none of orthoptists do so. However, 38 (32.7%) of orthoptics and optometrists used symptoms, receded NPC and reduced PFV for primary CI diagnosis. Moreover, 5 (4.3%) of respondents indicated that considering symptoms, reduced NPC and exophoria < 10x at near as diagnostic criteria. The differences in responses between orthoptists and optometrists in diagnosing primary CI were significantly different ($\chi 2=17.98$, df=4, $p< 0.001$), with orthoptists using multiple sings for diagnosis than optometrists.

In Saudi Arabia, 20 (42.5%) of respondents diagnosing CI with more strict criteria based on symptoms, receded NPC, reduced PFV, cover test findings at near and distance, refraction and accommodation. Seventeen (36.2%) of respondents used the symptoms and receded NPC, while 4 (8.5%) relied solely on the NPC. Additionally, 6 (12.8%) of respondents would diagnose based on symptoms, receded NPC and reduced PFV. The responses between optometrists and ophthalmologists in diagnosing primary CI were not significantly different ($\chi 2=5.97$, df=3, $p=0.113$).

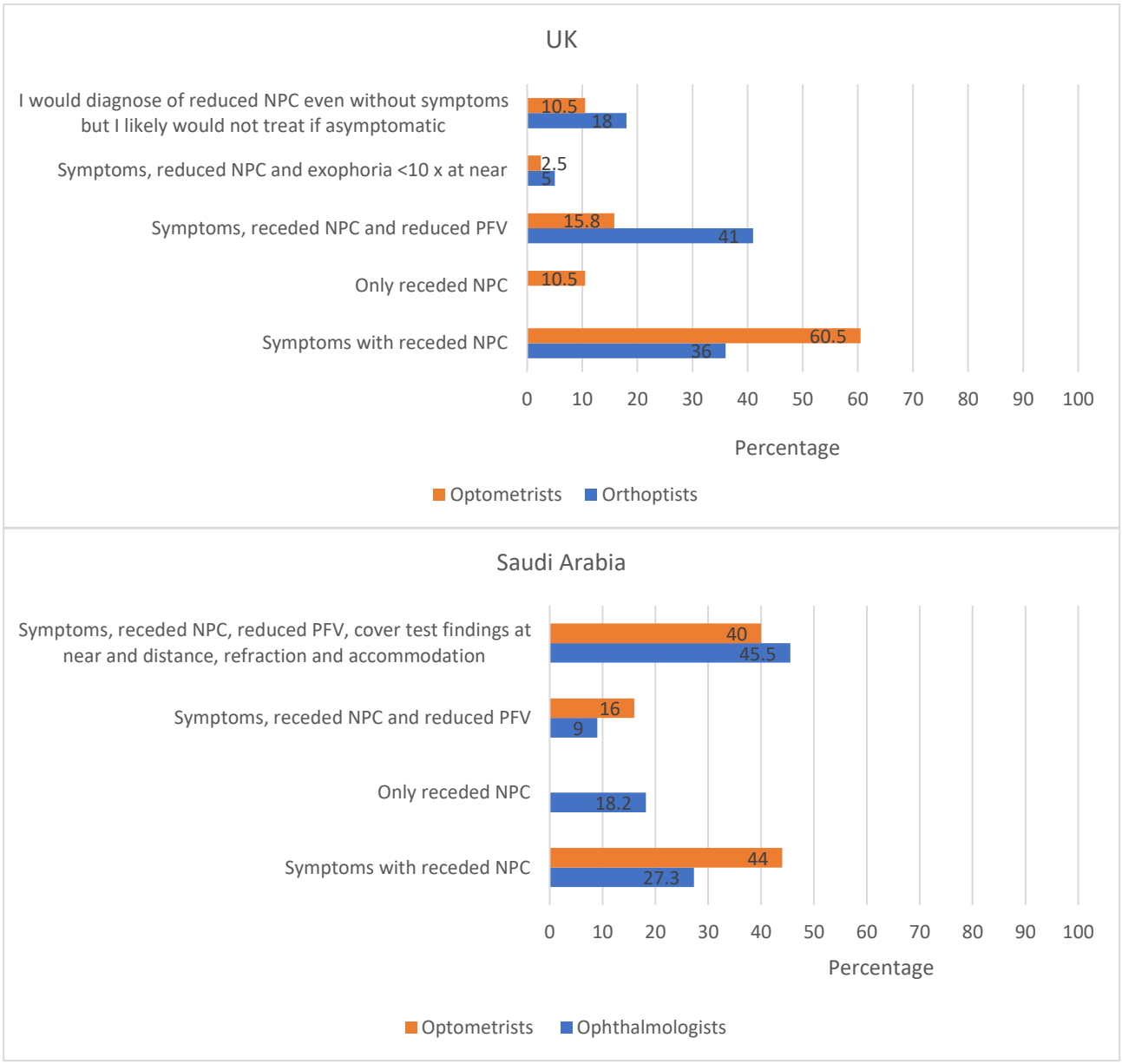


Figure 7. 3 The diagnostic criteria of primary CI used by orthoptists and optometrists in the UK (Top) and Saudi Arabia (Bottom). Numbers in bars indicate percentages for each profession.

7.6.3.2 Assessment of amplitude of accommodation

Q) Do you assess the amplitude of accommodation in primary CI patients?

The number of responses for each group of respondents in the UK and Saudi Arabia is shown in Figure 7.4. In the UK, 32 (27.6%) of respondents indicated a routine assessment of the AA and 28 (24.1%) not doing the assessment. While 40 (34.5%) did an assessment if patients

complained of a blur. Additionally, 16 (13.8%) of respondents reported assessing accommodation when patients were referred with accommodation dysfunction. There was no significant difference in AA assessment responses between orthoptists and optometrists ($\chi 2=4.99$, df=3, $p > 0.05$).

In Saudi Arabia, 36.2% (17) of respondents reported not assessing the AA. In contrast, 21.3% (10) assessed the AA in primary CI patients, with the same percentage assessing it in patients referred for accommodation dysfunction or who complained of blur. There was no significant difference in AA assessment responses between optometrists and ophthalmologists ($\chi 2=0.268$, df=3, $p > 0.05$).

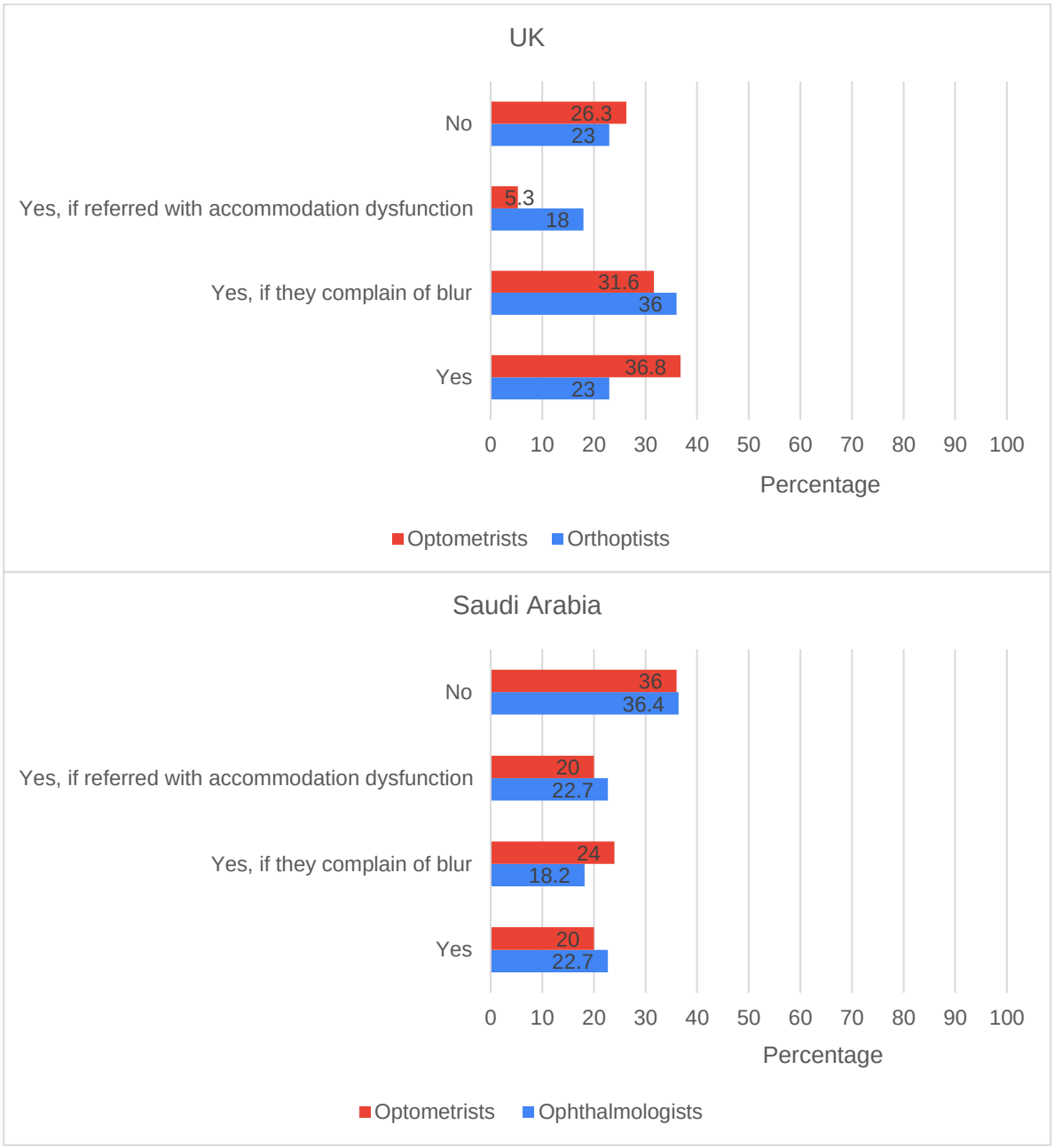


Figure 7. 4 The assessment of AA by each profession in the UK (Top) and Saudi Arabia (Bottom). Numbers in bars indicate percentages for each profession.

7.6.3.3 Treatment options

Q) Which of the following treatment options would you prescribe first in primary CI?

The details of the respondents' first treatment choices and changes/additions to treatment options are illustrated in Table 7.2. In the UK, smooth/pen convergence exercises were the most prescribed treatment by 106 respondents. This was followed by dot card and jump convergence exercises by 70 and 52 respondents, respectively. There was a significant difference between orthoptists and optometrists' first treatment options ($\chi2=37.55$, df=9, $p < 0.0001$), with the orthoptists using wider variation of treatment options than optometrists.

In Saudi Arabia, smooth convergence were the most prescribed exercises by 39 respondents. This followed by accommodative exercises and spectacles by 20 and 11 responses, respectively. There was significant difference between optometrists and ophthalmologists' first treatment options ($\chi2=3.49$, df=8, $p > 0.05$), with the optometrists using wider variation of treatment options than ophthalmologists.

Q) If the primary CI is improving with this treatment, would you add any of the following treatment options to their management?

In the UK, if the primary CI is improving with the prescribed treatment, the majority of orthoptists and optometrists will keep the same treatment with 62 responses. This was followed by stereograms by 43 responses. There was a significant difference between orthoptists and optometrists' responses in changing treatment options the UK (Fisher's Exact Test, $p < 0.001$), with the orthoptists tend to change treatment options than optometrists.

In Saudi Arabia, most of optometrists and ophthalmologists will keep the same treatment if the primary CI is improving with the prescribed treatment with 34 responses. This followed by prescribing Base-in prism by 10 responses. There was no significant different in between optometrists and ophthalmologists' in changing treatment options in Saudi Arabia (Fisher's Exact Test, $p > 0.05$).

Table 7. 2 Number of responses by each profession regarding the first treatment options of primary CI and change to the management in case of improvement (Respondents can choose more than one answer).

Treatment	UK orthoptists/optometrists In percentages %*		Saudi Arabia optometrists/ophthalmologists In percentages %	
	First treatment	Change or added to treatment	First treatment	Change or added to treatment
Smooth convergence	94/87	5/0	84/18	20/18
Dot card	79/21	27/10	4/5	16/-
Jump vergence	46/42	24/10	8/14	12/14
Stereograms	10/16	51/8	12/5	-/15
Brock string	3/16	3/2	8/-	-
Accommodation exercises	4/21	8/10	40/46	20/9
Base-in prism	9/10	19/8	16/14	20/23
No treatment, monitor	4/5	3/10	4/9	12/5
Vision therapy	-/4	-/5	-	-
Spectacles	-	-	24/23	-
Home use Base-in prism bar exercises	-	2/-	-	-
Depends on severity of CI	8/13	5/8	-	-
Keep the same treatment		53/55		68/77

CI: Convergence insufficiency, UK: United Kingdom* Respondents may select multiple answers, so percentages could exceed 100%

7.6.3.4 Effectiveness of treatment

Q) How effective do you consider the following treatment methods for primary CI as either the first or second line of treatment?

The responses of effectiveness for each treatment option with statistical significance between respondent groups in the UK and Saudi Arabia are shown in Table 7.3 and overall number of responses for the effectiveness of primary CI treatment options are shown in Figures 7.4

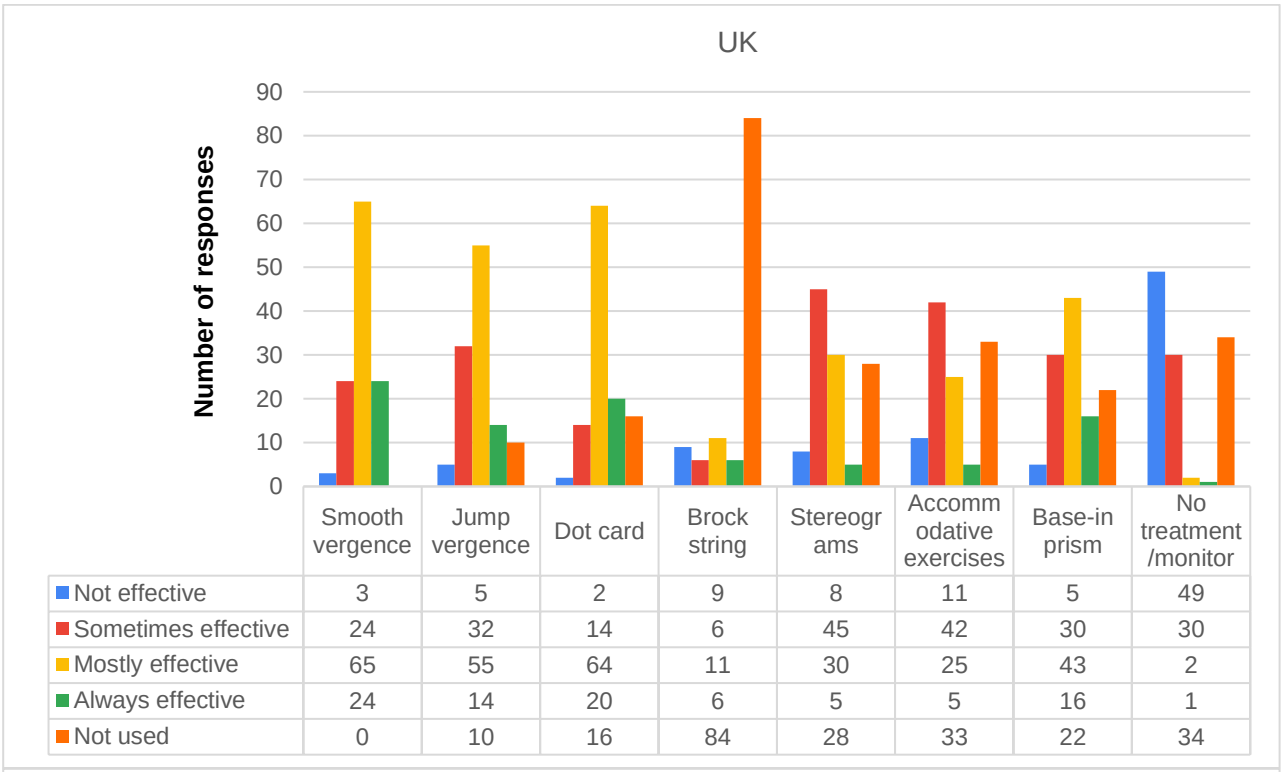
In the UK, most responses indicated that smooth/pen convergence, dot card, and jump convergence exercises were considered mostly effective. Furthermore, respondents indicated that stereograms, accommodation exercises, and no treatment/monitoring CI cases were sometimes effective. In addition, the Brock string was infrequently used.

In Saudi Arabia, smooth/pen convergence, dot card, and jump convergence exercises were considered sometimes effective treatments. Additionally, the respondents observed that accommodative exercises are mostly effective. Moreover, the strategy of no treatment/monitor is not effective management. As well as the Brock string, the dot card, jump convergence and stereograms were considered infrequently used.

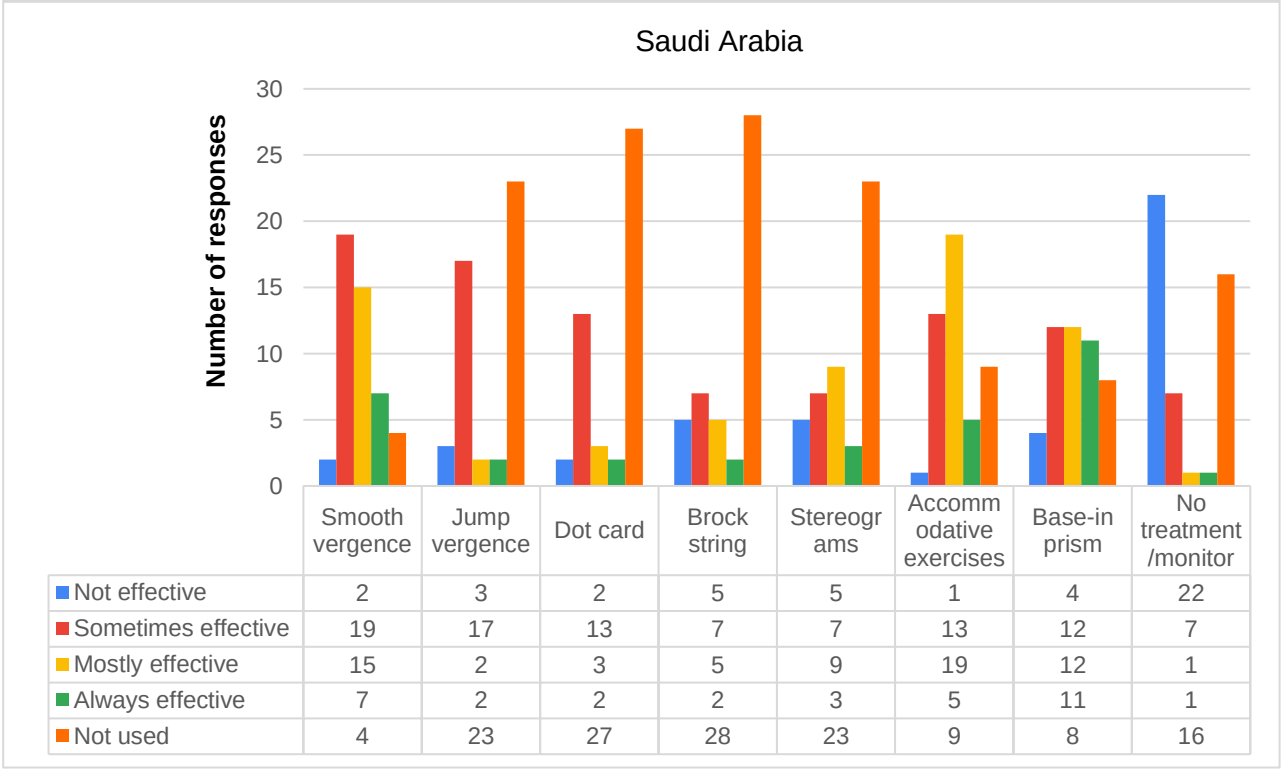
Table 7. 3 The effectiveness of treatment options by number of responses for each profession in the UK and Saudi Arabia.

Treatment	Always effective	Mostly effective	Sometimes effective	Not effective	Not used	P-value*	Always effective	Mostly effective	Sometimes effective	Not effective	Not used	P-value*
	UK orthoptists/optometrists In percentages %						Saudi Arabia optometrists/ophthalmologists In percentages %					
Smooth vergence	19/24	56/55	24/13	-/8	-	P<0.05[C]	20/9	36/27	28/55	-/9	8/9	p>0.05[C]
Jump vergence	9/18	52/37	27/29	5/3	5/5	P>0.05[C]	4/5	4/5	44/27	8/5	44/55	p >0.05[F]
Dot Card	19/13	69/26	8/21	2/3	2/14	p<0.05[F]	8/-	12/-	32/23	-/9	56/5	p >0.05[F]
Brock string	4/8	4/21	4/8	9/5	63/21	P<0.05[C]	8/-	20/-	16/14	8/14	48/73	p>0.05[C]
Stereograms	4/5	31/16	50/16	9/3	6/22	p<0.001[C]	12/-	28/9	12/18	16/5	36/64	p>0.05[C]
Accommodative exercises	2/10	23/18	40/29	11/5	19/14	p>0.05[C]	20/-	40/41	20/36	4/-	16/23	p >0.05[F]
Base-in prism	11/9	33/18	33/10	3/8	15/7	p>0.05[C]	28/18	28/23	24/27	16/-	16/18	p> 0.05[C]
No treatment, monitor	2/-	2/5	28/21	42/42	22/12	p >0.05[F]	4/-	-/5	12/82	56/36	36/32	p >0.05[F]

UK: United Kingdom; C: Chi-square test; F: Fisher Exact test; *Data are significant at p <0.05, * Respondents may select multiple answers, so percentages could exceed 100%



	Smooth vergence	Jump vergence	Dot card	Brock string	Stereograms	Accommodative exercises	Base-in prism	No treatment /monitor
Not effective	3	5	2	9	8	11	5	49
Sometimes effective	24	32	14	6	45	42	30	30
Mostly effective	65	55	64	11	30	25	43	2
Always effective	24	14	20	6	5	5	16	1
Not used	0	10	16	84	28	33	22	34



	Smooth vergence	Jump vergence	Dot card	Brock string	Stereograms	Accommodative exercises	Base-in prism	No treatment /monitor
Not effective	2	3	2	5	5	1	4	22
Sometimes effective	19	17	13	7	7	13	12	7
Mostly effective	15	2	3	5	9	19	12	1
Always effective	7	2	2	2	3	5	11	1
Not used	4	23	27	28	23	9	8	16

Figure 7. 5 The overall number of responses for the effectiveness of primary CI treatment options in the UK (Top) and Saudi Arabia (Bottom). The numbers in the table indicate the overall number of both professions.

7.6.3.5 Frequency of treatment

Q) If you prescribe orthoptic exercises for primary CI, what frequency of treatment do you suggest?

Figure 7.5 shows overall respondents' recommendation rates of treatment frequency in the UK and Saudi Arabia. In the UK, 27 (34.6%) of orthoptists recommended a frequency of 4-5 times daily. This followed closely by 25 (32.1%) recommending 2-3 times daily depending on patient compliance and severity, and 17 (21.8%) recommending 3 times daily. Three times daily was the most recommended frequency by 14 (36.8%) optometrists, followed by twice daily 10 (26.3%) and once daily 6 (15.8%). There was a significant difference between orthoptists and optometrists' frequencies ($\chi 2=34.4$, df=4, $p< 0.0001$), with orthoptists using higher frequency times than optometrists.

In Saudi Arabia, 9 (36%) of optometrists recommended a frequency of 3 times daily, followed by 6 (24%) recommending twice daily. Ophthalmologists showed different preferences, where recommended equally 4-5 times daily and once daily by 6 (27.3%). The responses from optometrists and ophthalmologists did not show a statistical difference in prescribed frequency ($\chi 2=6.23$, df=4, $p > 0.05$).

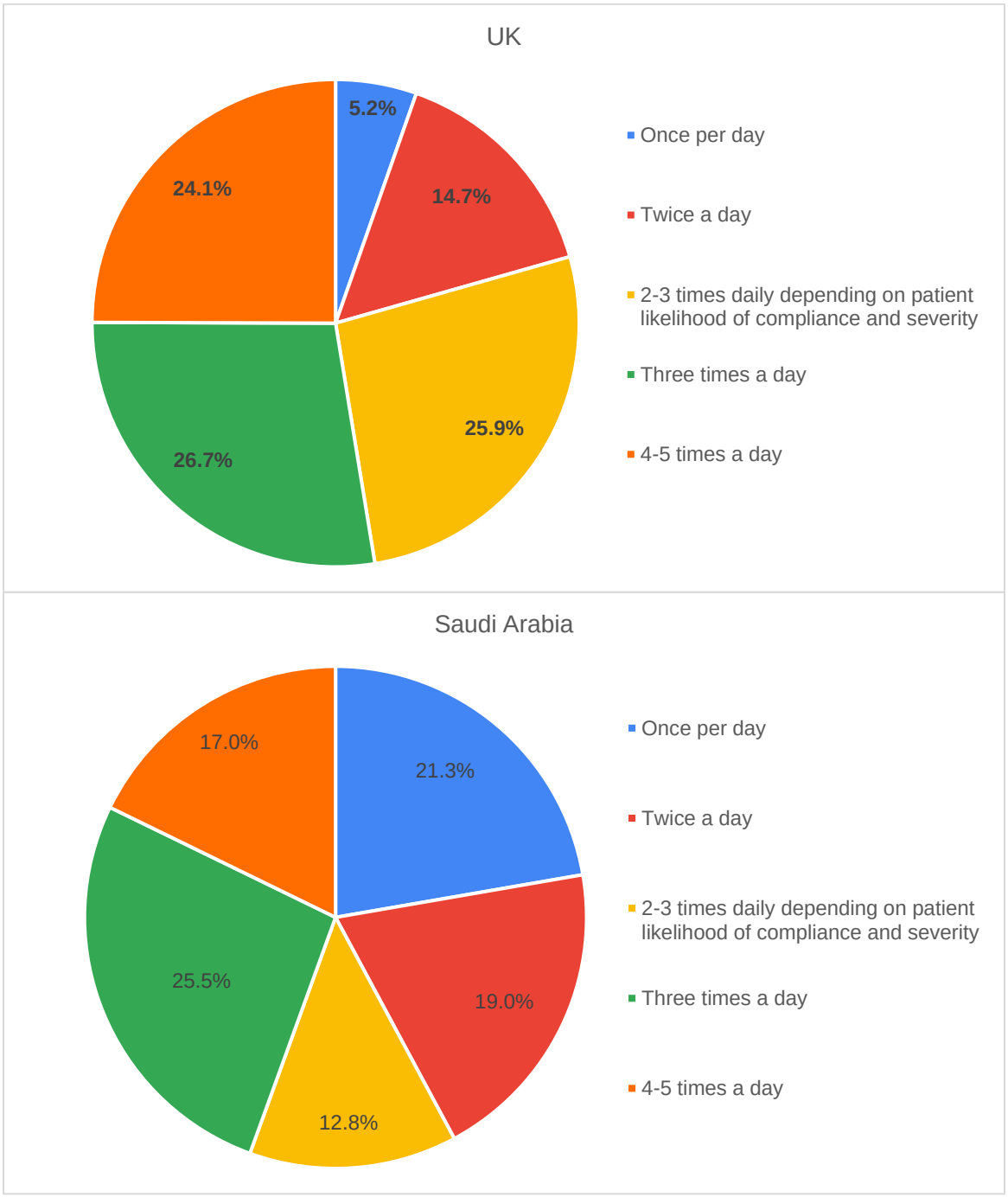


Figure 7. 6 Suggested frequency of exercises by both professions in the UK (Top) and in Saudi Arabia (Bottom)

7.6.3.6 Training time

Q11) If you give exercises for primary CI - how long do you recommend exercises are performed each time?

Figure 7.6 shows respondents' recommendation rates for training time per session in the UK and Saudi Arabia. In the UK, 47 (60.3%) of orthoptists and 20 (52.6%) of optometrists recommend a training time of 1-3 minutes, followed by 4-5 minutes suggested by 25 (32.5%) of orthoptists and 11 (29%) of optometrists. Training less than one minute was suggested only by 6 (7.7%) of orthoptists. There was a significant difference between orthoptists and optometrists' training times ($\chi2=12.3$, df=3, $p< 0.001$), with orthoptists using longer training times than optometrists.

In Saudi Arabia, 9 (36%) optometrists and 10 (45.5%) ophthalmologists suggested 1-3 minutes. In addition, 4–5 minutes was suggested by 10 (52%) of optometrists and 5 (22.7%) of ophthalmologists. Additionally, (6) 27.2% of ophthalmologists and 2 (8%) optometrists tend towards longer training sessions with more than 5 minutes. There was no significant difference between optometrists and ophthalmologists' training times ($\chi2=5.44$, df=3, $p> 0.05$).

Q) Do you advise a rest period after exercises are performed?

In the UK, 77 (98.7%) of orthoptists advised their patients to rest their eyes after exercises. On the other hand, 24 (63.2%) of optometrists advise rest after exercises. There was significant difference between orthoptists and optometrists' responses in prescribing resting period ($\chi2=28.7$, df=1, $p< 0.0001$). In Saudi Arabia, 17 (68%) of optometrists and 10 (45.5%) of ophthalmologists advised a rest after exercises, while 8 (32%) of optometrists and 12 (54.5%) of ophthalmologists do not recommend such rest. There was no significant difference between optometrists and ophthalmologists' in prescribing resting period ($\chi2=2.34$, df=1, $p> 0.05$).

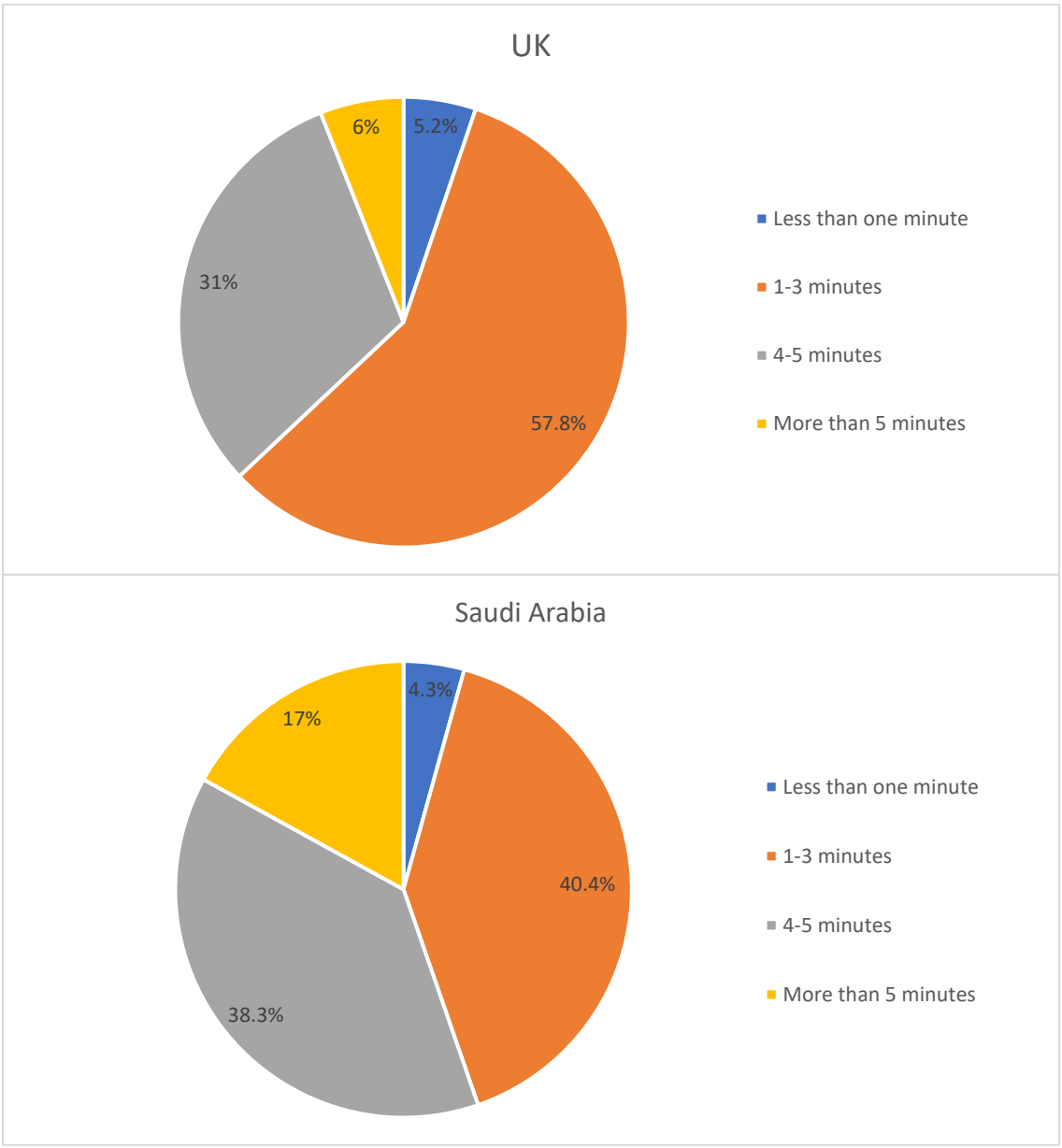


Figure 7. 7 Suggested frequency of training time for exercises per session for both professions in the UK (Top) and Saudi Arabia (Bottom).

7.6.3.7 Duration of follow-up

Q) What is the average follow-up period you prescribe during treatment of primary CIs?

Figure 7.7 provides the recommended follow-up period during treatment among respondents in the UK and Saudi Arabia. In the UK, 53 (68%) of orthoptists and 11 (29%) of optometrists recommending a follow-up period of 4 to 6 weeks. Additionally, 12 (15.4%) orthoptists and 13 (34.2%) optometrists suggested 7 to 9 weeks. In addition, 9 (23.7%) of optometrists suggested 10 to 12 weeks. There was a significant difference between orthoptists and optometrists' duration of follow-ups ($\chi 2=25.67$, df=3, $p< 0.001$), with orthoptists using longer follow-up periods than optometrists.

In Saudi Arabia, 12 (48%) of optometrists and 5 (22.7%) of ophthalmologists suggested to 4 to 6 weeks. Additionally, 4 (16%) of optometrists and 13 (59%) of ophthalmologists suggested a longer follow-up duration of 10 to 12 weeks, while 4 (16%) of optometrists recommended a short follow-up of 1-3 weeks. There was a significant difference between optometrists and ophthalmologists' duration of follow-ups ($\chi 2=13.12$, df=3, $p< 0.01$), with optometrists using shorter follow-up periods than ophthalmologists.

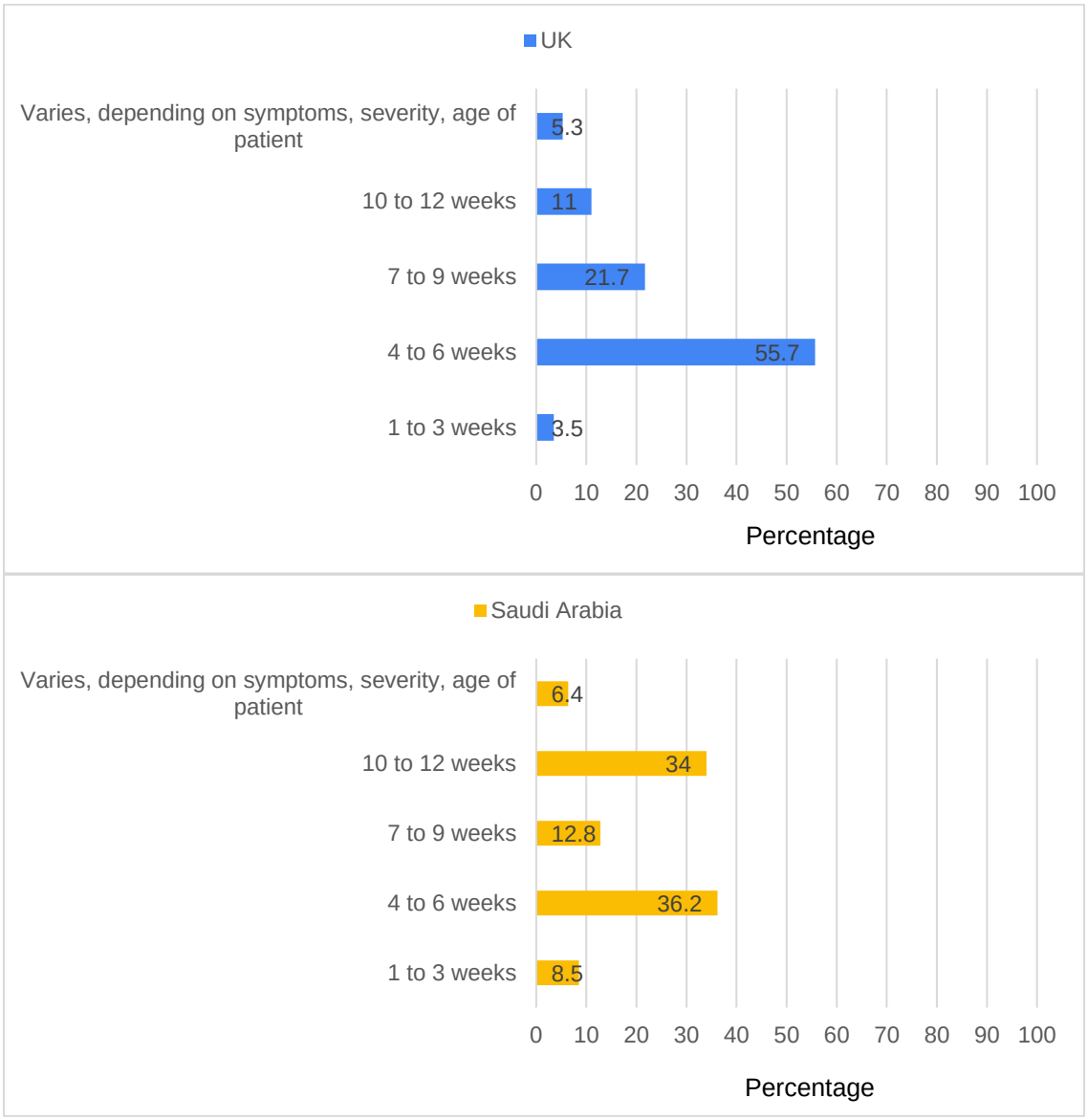


Figure 7. 8 Suggested follow-up period during treatment in the UK (Top) and Saudi Arabia (Bottom). Numbers in bars indicate percentages for both professions.

7.6.3.8 Success of treatment

Q) What outcome measures do you consider as the success criteria of primary CI treatment?

Figure 7.8 shows the respondents' responses to primary CI treatment's success criteria in the UK and Saudi Arabia. In the UK, 38 (48.7%) of orthoptists suggested criteria for success are the improvement in symptoms and NPC. This was followed by improvement in symptoms, NPC, and PFV by 25 (32%) and resolution of symptoms 15 (19.3%). For optometrists, most

optometrists suggested resolution of symptoms 47.4% (18), followed by improvement of symptoms and NPC 16 (42%). There was a significant difference between orthoptists and optometrists' successful outcome measures ($\chi 2=11.63$, df=4, $p< 0.01$), with orthoptists using more sings to evaluate the outcomes than optometrists.

In Saudi Arabia, 13 (52%) optometrists and 6 (27.2%) of ophthalmologists considered improvement of symptoms and NPC criteria of success. Additionally, 5 (20%) of optometrists and 7 (31.8%) of ophthalmologists suggested improvement in symptoms, NPC, and PFV. In addition, 6 (27.2%) of ophthalmologists and 6 (24%) of optometrists suggested resolution of symptoms. On the other hand, 1 (4%) of optometrists and 3 (13.6%) of orthoptists relied on improvement of NPC to 10 cm or less. There was no significant difference between optometrists and ophthalmologists' successful outcome measures ($\chi 2=3.74$, df=4, $p > 0.05$).

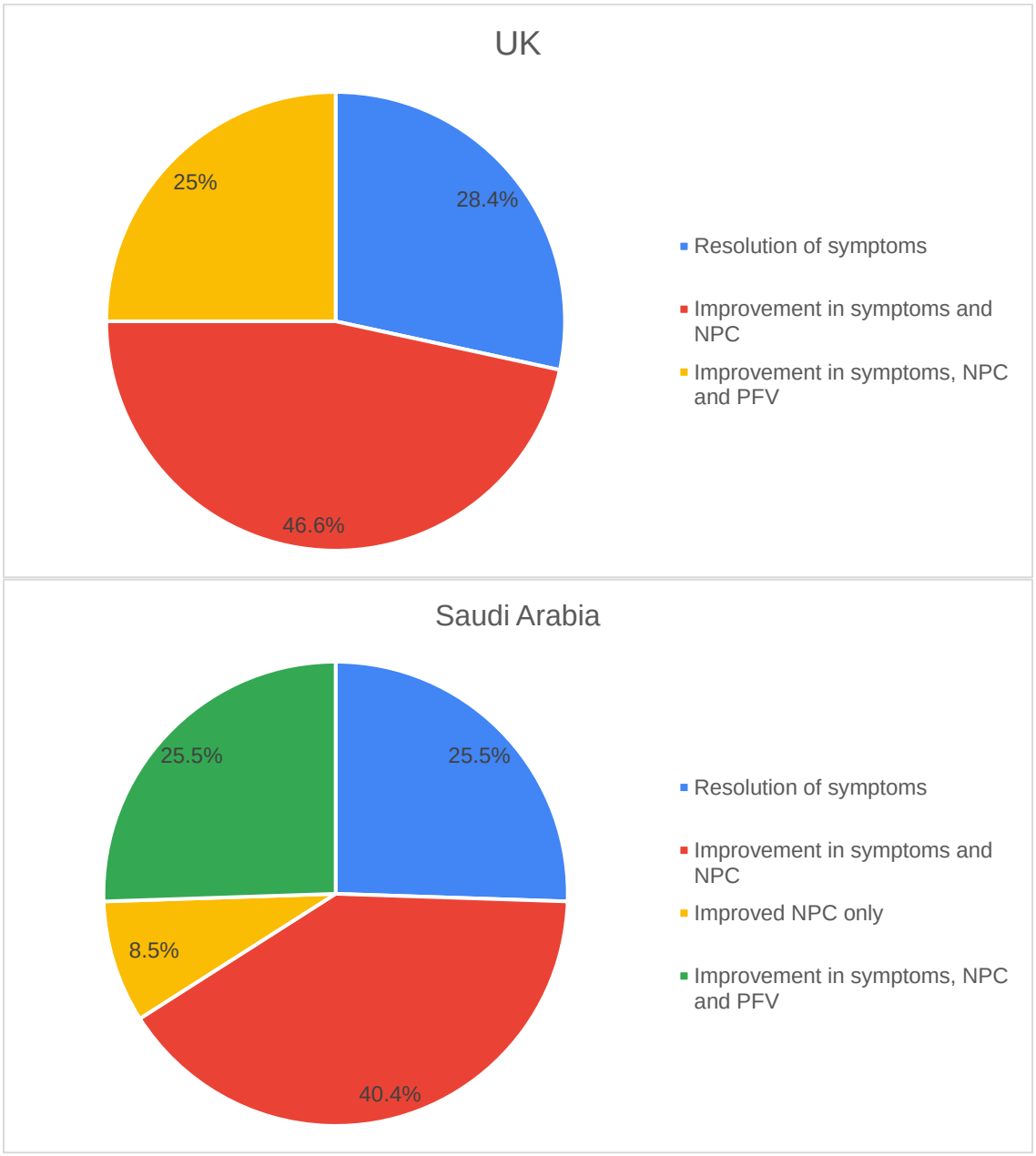


Figure 7. 9 Suggested success criteria of primary CI treatment for both professions in the UK (Top) and Saudi Arabia (Bottom).

7.6.3.9 Lack of treatment success

Q) In your opinion, what may be the cause(s) of lack of treatment success in patients with primary CI?

Table 7.4 provides respondents' responses in the UK and Saudi Arabia regarding the causes of the lack of treatment success. In the UK, 75 orthoptists and 30 optometrists reported that poor compliance is the most crucial cause attributing to lack of success. There were concerns over poor exercise techniques used by the patient was reported by 64 orthoptists and 23 optometrists. Additionally, 51 orthoptists and 9 optometrists outlined that poor follow-up attendance as an affecting factor. The lack of demonstration of exercises by clinicians was reported by 31 orthoptists and 12 optometrists. There was no significant difference between orthoptists and optometrists' opinions on causes of treatment failure (Fisher's Exact Test, $p > 0.05$).

In Saudi Arabia, 23 optometrists and 16 ophthalmologists reported that poor compliance is the most attributing factor to lack of success of treatment. Furthermore, 16 optometrists and 11 ophthalmologists suggested that poor follow-up attendance as an affecting factor. This followed by poor exercise techniques used by the patient by 13 optometrists and 11 ophthalmologists, and lack of demonstration of exercises by clinicians by 10 optometrists and 8 ophthalmologists. There was no significant difference between optometrists and ophthalmologists' opinions on causes of treatment failure (Fisher's Exact Test, $p > 0.05$).

Table 7. 4 The overall number of responses for both professions on various factors that affect treatment success in the UK and Saudi Arabia.

Reasons of lack of treatment success	UK	Saudi Arabia
Exercises for primary CI are not effective	11	7
Poor compliance with exercises	105	39
Exercises are effective, but the effect is not maintained	16	12
Severity of primary CI symptoms	33	17
Very poor (receded) near point of convergence	36	14

Size of the deviation (for example heterophoria)	46	18
Lack of demonstration of the exercises by clinician	43	18
Poor exercise technique used by the patient	87	24
Poor attendance for follow up after exercises have been given	60	27
Would like to see patients more regularly but not an option with such a backlog	15	-
Poor understanding of the problem and misdiagnosis	3	6

UK: United Kingdom; CI: Convergence insufficiency

7.6.4 Video tele-appointments

Q) Do you use video tele-appointments for primary CI patients?

Figure 7.10 shows respondents' responses on using video tele-appointments in primary CI management in the UK and Saudi Arabia. In the UK, 49 (62.8%) orthoptists and 36 (94.7%) optometrists indicated not using video tele-appointments for primary CI patients. Additionally, 15 (19.2%) of orthoptists and 2 (5.3%) of optometrists reported that they employed video appointments during the COVID-19 pandemic but returned to face-to-face appointments. Ten (12.8%) of orthoptists reported that using video tele-appointments for follow-up only in primary CI patients. There was a significant difference between orthoptists and optometrists' utilisation of video tele-appointments in the UK (Fisher's Exact Test, $p < 0.01$).

In Saudi Arabia, 19 (76%) optometrists and 18 (81.8%) ophthalmologists reported that not using video tele-appointments for primary CI patients. In addition, 3 (12%) of optometrists and 3 (13.6%) of ophthalmologists indicated that they employed video appointments during the COVID-19 pandemic but returned to face-to-face appointments. One optometrist and one ophthalmologist reported that using video tele-appointments for follow-up only in primary CI patients. There was no significant difference between optometrists and ophthalmologists' utilisation of video tele-appointments in Saudi Arabia ($\chi 2=1.84$, $df=3$, $p > 0.05$).

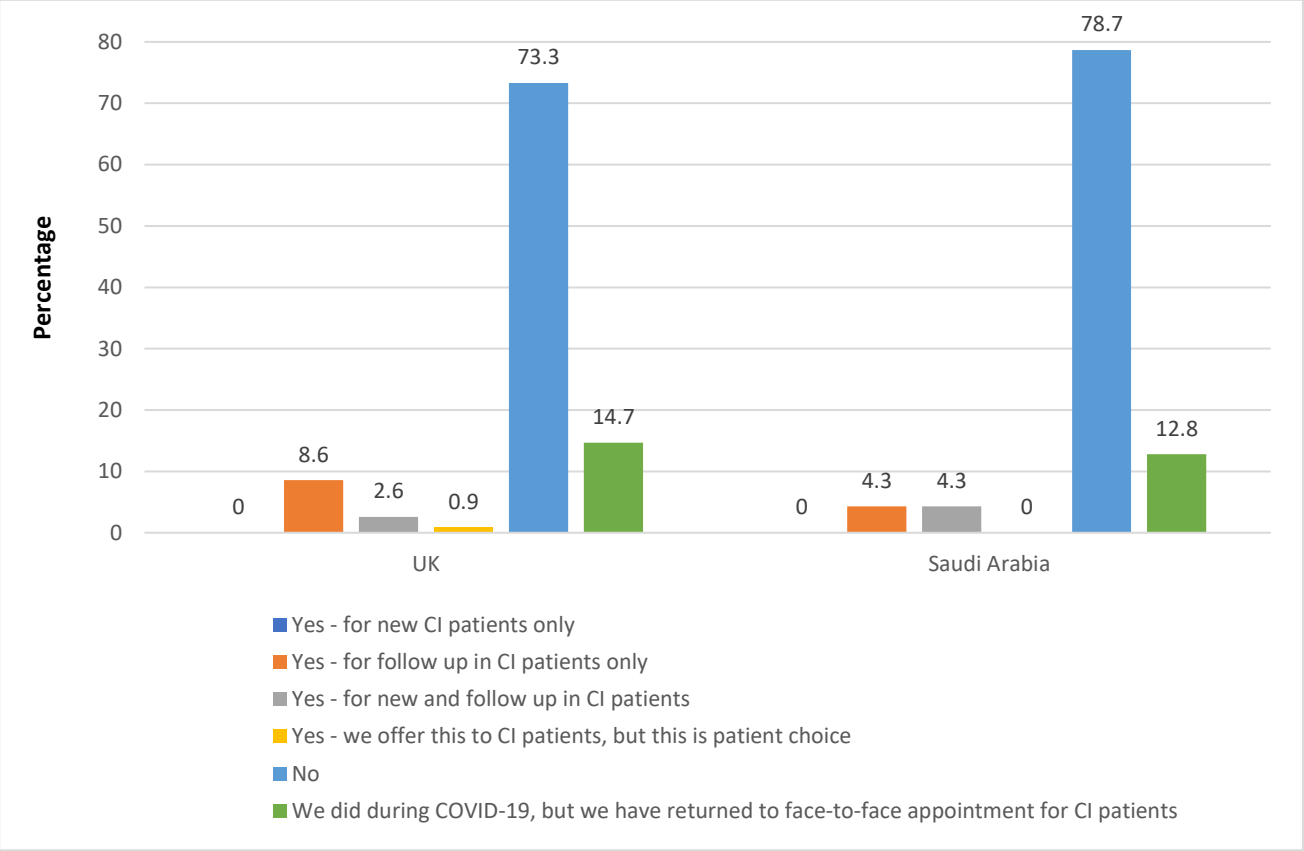


Figure 7. 10 Responses of using video tele-appointments in primary CI management in the UK and Saudi Arabia. Numbers above bars indicate percentages of both professions.

7.6.4.1 Views about Tele-appointments

<u>Positive views on video tele-appointments</u>

Q) Would you recommend video tele-appointments to others treating primary CI and why?

- From the UK: Can be effective, convenient, well accepted and reduce waiting times:

"It is effective and reduces the hassle of waiting"

"Tele Appointments are more convenient and reduce stress but I wonder if they can increase patient satisfaction"

"Yes - it works effectively and is well received by patients and parents"

- **Accessible and helpful during COVID and some concerns about long term benefits:**

"Yes, easier to get a short term video appointment than face to face"

"Yes, It was useful during COVID, but difficult to tell exact distances achieved via video"

From Saudi Arabia: *"For uncooperative, vulnerable, unmovable"*

- From the UK: Assess symptoms and compliance but not measurement:

"Yes, for following up on symptoms and treatment compliance, doesn't always need face to face"

"Yes, as primarily guided by symptoms, not measurements"

"Patients feel its a hassle to come in every 2-4 weeks, so a video appointment in between is useful to check exercises but hard to determine improvement in convergence and PFV"

- From the UK: Concerns about compliance via video appointments

"Can be very effective with a motivated patient but not as good when compliance is less than hoped for"

"Yes, as it saves an unnecessary face to face appointment if improving"

"Possibly because only with patients who have a good understanding of the condition and exercises"

"Dependent on patient symptoms, compliance and clinical capacity"

"Yes, if your Trust has a system in place. More patients can generally be assessed in each session"

"would consider video or tele appointments for suitable patients in the future"

From Saudi Arabia*: "Tele-appointments depend on whether these facilities are available in the hospital or not. So, it is difficult to recommend it to colleagues"*

- Helpful tools to monitor progress and demonstration of exercises:

"Yes, if able to use a camera so you could check they are doing the exercises correctly and whether they are improving"

"Yes, can still get the patient to demonstrate how they do the exercises and if symptoms are resolving. If they are not resolving, could bring back to face to face appointment"

"Can be used to aid motivation and check on progress with exercises in between face to face appointments"

"Yes, we have found it a good way to ensure exercises are being carried out correctly and it reduces physical attendance in overcrowded clinic"

- From the UK: Lack of *comprehensive assessment and technical difficulties:*

"No, I find it easier to demonstrate and correct patients face to face"

"No, not easy to assess patients"

"Not normally as you need to observe patients"

"Most need face to face to maintain compliance"

"I won't recommend them. I think we need measurements at every visit, and this is not possible with tele appointments"

"No, technical issues"

"No, too complicated"

From Saudi Arabia: *"No, not effective"*

- From the UK: Patients choose face to face over video appointments:

"No, Patients prefer face to face appointments"

"Generally, finding with CI patients face to face is preferable as it is ideally good to compare actual measurements, i.e. with the RAF rule. Also, CI patients often need that extra reassurance"

From Saudi Arabia:

"I don't like it much because not all patients prefer it!"

"It is on the patient choice"

7.6.4.2 Barriers using tele-appointments

Q) Are there any barriers to using video tele-appointments for primary CI patients?

Figure 7.11 shows video tele-appointments using rates and barriers preventing their use in the UK and Saudi Arabia. In the UK, 32 orthoptists and 18 optometrists reported that not using tele-appointments even if there were no barriers. Out of them, 24 orthoptists and 7 optometrists reported difficulties in accurately assessing patients remotely. In comparison, 23 orthoptists and 16 optometrists indicated they had no barriers but did not use them. Additionally, only 6 orthoptists using video tele-appointments without any barriers. There were no significant differences between orthoptists and optometrists' of existing barriers in the UK (Fisher's Exact Test, $p > 0.05$).

In Saudi Arabia, 13 optometrists and 7 ophthalmologists indicated they had no barriers but did not use them. Moreover, 8 optometrists and 8 ophthalmologists reported not using tele-appointments even if there were no barriers. In addition, 4 optometrists and 2 ophthalmologists highlighted difficulties in accurately assessing patients remotely. None of the respondents in Saudi Arabia reported using video tele-appointments without any barriers. There were no significant differences between optometrists and ophthalmologists' of existing barriers in Saudi Arabia (Fisher's Exact Test, $p > 0.05$).

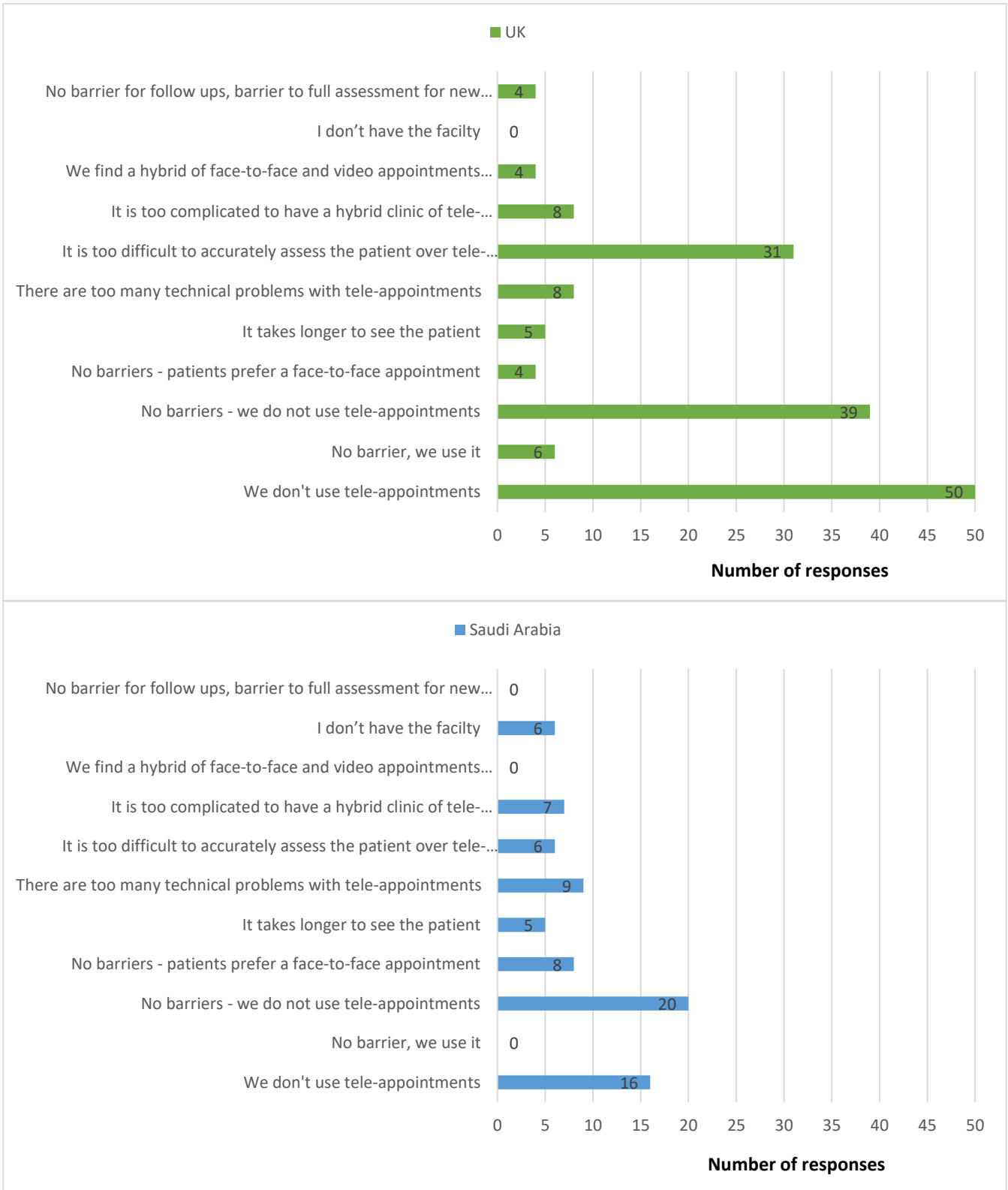


Figure 7. 11 Number of responses of using video tele-appointments for both professions and the barriers in the UK (Top) and Saudi Arabia (Bottom). Numbers in bars indicate the number of responses for both professions.

7.7 Discussion

The aim of this questionnaire was to investigate the primary CI numbers pre- and post-COVID among orthoptists and optometrists in the UK. This was done in response to unexpected poor recruitment and lower numbers of patients with primary CI post-COVID in Chapter 5. In addition, to explore current treatment protocols and the use of video tele-appointments in primary CI management. The results indicated that most respondents suggested the number of patients with primary CI has remained consistent before and after COVID-19, with low counts of 1-5 being the most common in hospitals and optometric practice. The results also showed variability in treatment protocols and the effectiveness of exercises among the respondents. Moreover, most respondents do not utilise video tele-appointments to manage primary CI.

The practice of orthoptists and optometrists varies widely across countries due to differences in professional training, diagnostic criteria, clinical guidelines, and referral pathways. Diagnostic criteria and guidelines for eye care professionals can vary internationally, for example between the UK and Saudi Arabia. In some healthcare systems, patients may be able to directly access orthoptists or optometrists. While in others, these professionals may only see patients through secondary referrals from general practitioners or ophthalmologists like Saudi Arabia. In the UK, patients can directly access optometrists, but orthoptists and ophthalmologists are through referrals from optometrists or GPs. In secondary referrals system, clinicians are more likely to encounter patients with clearly defined or complex conditions, necessitating a more specialised approach. Thus, the referral system plays a crucial role in shaping practice patterns.

The use of evidence-based practice is essential for eye care professionals to continually update their knowledge and skills based on the latest research, rather than relying solely on what they learned during their initial training. On the other hand, orthoptists and optometrists may follow clinical guidelines which vary internationally, shaping how practitioners' approach specific conditions. Guidelines for managing common conditions may be evidence-based, but their implementation can depend on accessibility and awareness. For example, while orthoptic exercises or vision therapy are widely recognised as effective for primary CI, some

clinicians may still prefer older, less evidence-based approaches due to familiarity or resource limitations. On the other hand, in some cases, clinicians may be more comfortable adhering to familiar methods, even if newer evidence suggests alternative approaches. Therefore, the professional training, diagnostic criteria, clinical guidelines, and referral pathways might have influenced the views of respondents in this questionnaire.

7.7.1 Numbers of primary CI

7.7.1.2 The UK

The questionnaire showed that most optometrists identified primary CI, indicating that they encountered primary CI and often frequently managed these cases. This finding aligns with the traditional role of optometrists in the UK as the first line of eye care (Dabasia *et al.*, 2014), and supported by majority of optometrists offered treatment at their practice. This suggests wide acceptance of optometric intervention for primary CI independently over external referrals. Additionally, the option to refer cases to the hospital shows some optometrists' flexibility in managing these cases. This finding also could be explained by the fact that there were no optometrists in the questionnaire referring primary CI patients to hospital eye clinics. This may explain the fact that optometrists carry out the treatment in the first place, which in turn results in 1-5 monthly primary CI cases being the most common trend among orthoptists. Consequently, this may explain the relationship to the low numbers observed in the primary CI study discussed in Chapter 5.

The prevalence of primary CI in the UK remains uncertain, with no recent studies addressing this issue. The Royal College of Ophthalmologists (2012) suggested that the prevalence of primary CI in the UK is close to the 2% rate reported in the literature. According to responses in this questionnaire, the majority reported diagnosing 1-5 monthly primary CI patients, with these numbers remaining same or slightly decreased post-COVID. Respondents related these low numbers to the fact that patients did not pay attention to the problem, the belief in long waiting lists, or patients seeking alternative care pathways through optometrists. This further indicates the possibility of optometrists' role in managing primary CI cases and potentially lowering hospital CI numbers. Consequently, affected referred primary CI patients as in

primary CI study in Chapter 5. However, with a small sample size, it may not be generalisable to a broader range of practices. The question whether these numbers can be generalised requires further research.

7.7.1.3 Saudi Arabia

The primary focus for most optometrists and ophthalmologists is on ocular conditions like glaucoma, diabetic retinopathy, corneal diseases, cataracts, and refractive errors, and don't specifically identify other disorders despite their role in providing primary eye care (Al Motowa *et al*., 2014). This might be attributed to inadequate training for certain conditions like primary CI, the high patient volume in clinics, or a tendency to refer patients to specialists. A smaller percentage of respondents identified primary CI and most provided treatment in their practices.

The reported primary CI numbers from respondents seem to be lower than the rates mentioned in introduction (Section 7.1.1), despite the participants being from clinical settings where symptomatic conditions are likely to be encountered. However, the literature lacks clarity on the diagnosis and treatment role, but results suggested that both optometrists and ophthalmologists may play comparable roles in managing primary CI. To the best of the researcher's knowledge, the findings establish preliminary data for primary CI management in Saudi Arabia.

7.7.2 Treatment

7.7.2.1 Diagnostic criteria

In the UK, most optometrists emphasised on the significance of symptom severity alongside a receded NPC. This is most often used in optometric practice within the UK (Adler, 2002). This approach has been documented in existing literature. For example, Abdi *et al.* (2008) applied these criteria to 120 schoolchildren aged 6–16 years. The diagnostic criteria included the presence of asthenopic symptoms and an NPC > 9 cm. As a result, 22 children were diagnosed with CI and referred for treatment. This criterion may be subject to criticism for its reliance on reported symptoms rather than combined to set of objective measures. Such dependence on

symptoms could be influenced by varied patient-reported experiences, potentially impacting the accuracy of diagnosis and treatment decisions. Furthermore, similar symptoms of CI and other complex conditions emphasise the need for careful orthoptic investigation, as recommended by the BIOS guidelines (BIOS,2016), to ensure accurate management. On the other hand, orthoptists may have more specialised training in accurately diagnosing primary CI, as they consider additional clinical signs.

In Saudi Arabia, almost half of optometrists and ophthalmologists used multiple signs for primary CI diagnoses. This result may be explained by the fact that respondents follow how the term is used in the USA, such as by the CITT group (Schieman *et al*., 2009). Additionally, multiple signs diagnoses might be based on different primary CI definitions found in the literature, which argue that CI is a syndrome characterised by a set of signs (Rouse *et al.*, 1997). Moreover, some respondents included refractive errors in the diagnostic criteria. This is likely to address them to reduce symptoms before initiating any treatment, as recommended by (Ansons and Davis, 2014; Scheiman and Wick, 2014). However, this inconsistency in diagnostic criteria confirms the lack of agreement on the primary CI definition documented in the literature discussed in (Section 2.2.7) as well as among respondents in this questionnaire.

7.7.2.2 First line of treatment

In the UK, smooth/pen convergence by far were the most common prescribed exercises, followed by dot card and jump vergence exercises. These exercises are aligned with suggested exercises among primary CI treatment (Ansons and Davis, 2014; BIOS, 2016). Furthermore, Aziz et al. (2006) reported in retrospective study that treatment for 27 primary CI patients included pen convergence, dot card, and jump convergence exercises. The study found that most patients experienced improvement in symptoms.

The results indicated that orthoptists and optometrists share some common first line treatment preferences, such as smooth/pen convergence exercises, but differ in other options, like dot card and jump convergence exercises. Optometrists were less likely to prescribe dot card and jump exercises compared to orthoptists, possibly because these exercises require clinical training and demonstrate the techniques in front of the examiner.

The time needed for training and demonstration may be an additional burden for optometrists, leading to less frequent prescriptions of these exercises.

Pencil push-up exercises were found as the most prescribed exercise in surveys conducted in the USA (Scheiman et al., 2002) and India (Patwardhan et al., 2008). Thus, this similarity may not be surprising among respondents in this questionnaire. It was also the most prescribed to patients in service evaluation study (Chapter 4), to 90% of patients. Additionally, Adler (2002) noted that smooth vergence usually the first line of treatment in UK hospitals. Therefore, the popularity of smooth/pen exercises is not surprising and consistent with previous findings in service evaluation as well as existing literature. Respondents' choices suggest a possible preference for simple, easy-to-implement exercises over more comprehensive interventions such as stereogram exercises. In addition, factors such as patient compliance possibly influence respondents' choices. In Saudi Arabia, pencil push-up exercises are similarly popular among optometrists and ophthalmologists, likely because of the exercise's simplicity and their popularity in the literature.

7.7.2.3 Change to treatment

In the UK, over half of the orthoptists and optometrists and most of optometrists and ophthalmologists preferred to keep the same treatment if the primary CI is improving. Clinicians might often prefer to keep the same treatment option since they work effectively. Changing treatments unnecessarily could disrupt or stop progress. Additionally, it may be due to minimising patient discomfort. For example, if the exercises are well-tolerated by the patient, consequently maintaining or even improving compliance. Another possible explanation is the potential burden on patients if additional exercises are added while improvement is already occurring, which could impact compliance due to increased time and effort demands. This should be considered, especially if the patient is satisfied with the current treatment plan and experiencing improvement. When respondents indicated that they wanted to change the treatment, adding stereograms was the most common among all the exercise options. This aligns with findings from the service evaluation study (Chapter 3), where the addition of stereograms was associated with improvements in NPC and PFV. This aims to

exercise vergence via base-out and base-in fusion ranges to improve NPC and prism fusion ranges, subsequently resolving symptoms.

7.7.2.4 Effectiveness of treatment

In the UK, while most orthoptists and fewer optometrists consider smooth vergence, dot card, and jump vergence exercises to be mostly effective, while some optometrists believe that dot card and jump vergence exercises are only sometimes effective. The optometrists prescribe these exercises less frequently which suggests that opinions on their effectiveness may be less accurate. However, the effectiveness of the previous exercises is consistent with BIOS (2016) recommendations, which support the efficacy of simple orthoptic exercises, and with The Royal College of Ophthalmologists (2012) of smooth vergence exercises efficacy.

The variation in respondents' opinions on efficacy aligns with the differing effectiveness of exercises reported in the literature. For example, orthoptists believe that smooth/pen convergence exercises are always, mostly, or sometimes effective, with none considering them ineffective. The CITT study (Schieman, 2005b) reported limited efficacy of pencil push-ups among 17 CI patients, with only 2 (13.3%) experienced improvement in symptoms and clinical signs. Conversely, Kim and Chun (2011) found far higher efficacy with pencil push-ups, with 10 out of 16 CI patients (62.5%) achieving successful outcomes.

Dot card and jump vergence exercises are also considered mostly effective, although they may be more challenging for the patient and require more effort. The percentage of respondents rating these exercises as "always effective" was lower compared to smooth vergence, possibly due to a potentially higher difficulty level. Previous research has shown that office-based vision therapy, which includes dot card and jump vergence exercises, was an effective treatment for CI (Scheiman *et al.*, 2020). This might support respondents' views that these exercises are effective. Additionally, several orthoptists indicated that stereograms are only sometimes effective, likely due to the exercise's complexity and the need for patient training.

Another notable finding is the consensus among orthoptists that accommodation exercises are not always effective. This could be because exercises targeting accommodation are less effective than those focusing on convergence (Horwood and Toor, 2014) that discussed in

Chapter 3 (Section 3.2.2.3). As a result, orthoptists may have observed that accommodation exercises do not consistently provide successful outcomes. However, responses about the effectiveness of treatment varied due to lack of standardised protocols. This can be explained due to factors such as patient compliance, severity of symptoms, and clinician judgement.

In Saudi Arabia, optometrists and ophthalmologists are divided in their opinions on the effectiveness of smooth/pen exercises, with some considering them mostly effective and others finding them only sometimes effective. Conversely, most opinions suggest dot card and jumping exercises are sometimes effective, while accommodation exercises are considered mostly effective. This division in opinions might stem from clinical experience, as it is unclear whether any specific clinical guidelines are being followed.

7.7.2.5 Frequency of treatment

In both the UK and Saudi Arabia, exercise frequency recommendations generally emphasise performing exercises multiple times throughout the day. In the UK, 41% of optometrists typically recommend exercises once or twice daily, which is more frequent than the standard preferences of orthoptists. This could indicate that optometrists often manage milder cases of primary CI, requiring less intensive treatment.

The literature shows variability in treatment frequency. For example, Aziz *et al*. (2006) and Hamed Momeni-Moghaddam *et al*. (2015) recommended exercises 6 and 3 times daily, respectively, whereas the CITT trials instructions were performing pencil push-ups once daily (Scheiman *et al.*, 2005a; Scheiman *et al.*, 2005b). Diversity in the recommended frequency of orthoptic exercises among respondents might be due to the lack of consensus on primary CI treatment protocols. The respondents' decisions may be related to available evidence, guidelines, clinical experience and severity of the case. Nevertheless, more than 75% of responses were within BIOS (2016) recommendations, at least 3 times a day. The optimal frequency of exercises to improve remains unclear, but accommodating patients' needs and compliance is critical to success.

7.7.2.6 Training time

The BIOS guidelines recommended training times ranging from 2-5 minutes. The majority of respondents in the UK recommend performing exercises for 1-3 minutes and 4-5 minutes each time, indicating a preference for shorter sessions. This may reflect avoidance of longer and potentially more fatiguing sessions. Additionally, shorter durations could be preferred to maintain patient engagement and compliance, especially in cases where effort and time availability may be challenging. In Saudi Arabia, the criteria for training time are unclear. Respondents' choices may be influenced by factors such as the severity of the condition, patient compliance, and clinical experience.

Similar to variability in respondents' opinions, the literature showed variability in training time, even with a multiple number of exercises. For example, Aziz et al. and Hamed Momeni-Moghaddam et al. reported daily training sessions of 5 minutes. In contrast, the CITT trials allocated 15 minutes daily solely for pencil push-ups (Scheiman *et al.*, 2005a; Scheiman *et al.*, 2005b).

7.7.2.7 Duration of follow-up

The majority of respondents in the UK and Saudi Arabia suggested a follow-up period of 4-6 weeks which aligns with BIOS (2016) guidelines. Respondents' choice of 4-6 weeks reflects the aim to avoid leaving the patient for an extended period, which could lead to loss of motivation or performing exercises incorrectly. Additionally, regular monitoring of progress, compliance and patient needs. The literature aligns with the preferences of the majority of participants. For example, follow-up every 4 weeks was the chosen duration in both the CITT trials (Scheiman *et al.*, 2005a; Scheiman *et al.*, 2005b) and Momeni-Moghaddam *et al.* (2015). Moreover, a 6-week follow-up was reported by Gallaway *et al.* (2002) and Singh *et al.* (2021).

A small percentage suggested a longer follow-up of 7-9 weeks, which might be suitable for well-responding cases and requiring less frequent monitoring. Conversely, a shorter follow-up interval of 1-3 weeks received fewer recommendations from respondents but may be needed in some conditions, such as the early stage of treatment, to closely monitor progress or modify the treatment plan.

7.7.2.8 Success of treatment

Nearly half of the respondents in the UK and Saudi Arabia identified the resolution of symptoms and NPC as the success criteria for primary CI treatment. A possible explanation for this finding is that alleviation of symptoms is crucial to present patients' visual comfort, while NPC provides important indicator of changes in the vergence system. Adler (2002) employed this approach, using on symptoms and NPC as outcome measure of treatment effectiveness. The reported success rate was high, with significant improvement in symptoms and NPC improving to < 10 cm in 98.9% of CI patients.

Resolution of symptoms was reported by a considerable portion of respondents as a sole criterion for treatment success because it represents an essential indication of treatment efficacy. This criterion suggests that, despite improvements in clinical signs, prioritise overall outcomes by looking into the complete picture by improvement of symptoms, which is reflected in patient satisfaction. This approach was employed in the CITT trials (Scheiman *et al.*, 2005a; Scheiman *et al.*, 2005b) and (Nawrot *et al*., 2013). The primary outcome measure for treatment effectiveness was the assessment of symptoms through CISS.

Respondents also included additional measures such as NPC and PFV, along with symptoms, as criteria for determining the success of treatment. This approach is supported by the literature (Gallaway et al., 2002; Kim and Chun, 2011; Aletaha et al., 2018). In addition, it aligns with the definition of CI, which emphasises that it is a disorder characterised by multiple signs (Rouse et al., 1997). In addition, it could be argued that adding clinical signs with symptoms provide a comprehensive evaluation, guide treatment decisions and monitoring progress. However, these results highlight the lack of consensus among respondents regarding the optimal outcome measures for success of primary CI treatment.

7.7.2.9 Lack of treatment success

Respondents in the UK and Saudi Arabia addressed challenges related to the causes of lack of treatment success in patients with primary CI. Non-compliance is a major problem in home-based exercises and the most common cause of treatment failure (Adler, 2002; Cooper and Feldman, 2009). In this regard, a number of clinical trials have reported poor compliance with

treatment. For example, Gallaway et al. (2002) reported that out of 25 CI patients, only 12 (48%) returned for follow-up, and of those, just 2 (16.7%) reported full compliance to the prescribed exercise protocol. Another example is the reported compliance rates by the PEDIG to the prescribed treatment. The compliance rates were 68% in the home-based computer vergence/accommodative therapy group, 55% in the placebo group and 49% in the pencil push-ups group (Scheiman et al., 2016). The agreement on poor compliance with exercises reflects the high awareness of respondents on the critical role of patient adherence in achieving successful outcomes. This might explain respondents' experience with factors contributing to poor compliance, such as loss of motivation, lack of improvement and difficulty scheduling exercises into a daily routine. It can also reflect the need of respondents to address barriers to compliance through patient education and motivational strategies. Improving compliance with home exercises can be investigated by comparing traditional approaches like verbal instructions with enhanced strategies such as providing digital exercise platforms, instructional videos, or interactive apps.

Poor exercise technique used by the patient was a concern to respondents. This highlights the importance of the respondents' role in providing clear and complete exercise instructions. Cooper (2007) indicated that if training is performed incorrectly, it could fail home-based treatment. Factors such as incorrect gaze direction and insufficient effort can be avoided by demonstrating exercises at the first visit and each return visit to guide patients on proper exercise techniques. In addition, providing printed instruction materials is required to ensure prescribed exercises are performed correctly and increase self-efficacy in patients. Lack of instruction materials was a concern in service evaluation results in Chapter 4 as not recorded in patient notes and might contributed to failure rate. Clinicians or future studies can evaluate the impact of different modes of instruction, for example in-person demonstrations, tele-appointment sessions, printed materials, or video tutorials on patients' ability to correctly perform orthoptic exercises. In addition, consideration of observational studies to assess the long-term outcomes of patients who receive enhanced instruction, for instance, step-by-step demonstrations at each visit compared to those who do not.

Severe primary CI condition as a barrier to the success of treatment may indicate the need for respondents to adopt an intensive treatment plan. Specifically, more significant symptoms

and poorer convergence ability may be more resistant to simple treatment and require more intensive intervention. The BIOS (2016) guidelines emphasise that more complex conditions may need in-depth investigation and treatment through intensive exercises to control the severity of CI. It should be noted that the variations between orthoptists and optometrists in the UK should be considered cautiously as CI cases referred to orthoptists are likely to involve more severe conditions. Conducting prospective cohort studies can examine outcomes in patients with severe primary CI who are treated with varying levels of intensity might give evidence-based basis.

Poor attendance and adherence to follow-up appointments were a main concern for respondents. Regular monitoring and adjusting treatment plans based on patient progress are crucial in primary CI management. Missed follow-up appointments can limit assessment of progress, treatment adjustment and patient engagement. Loss to follow-up can limit the significance of research outcomes and introduce bias. For example, the PEDIG study experienced dropout rates of 8% in the home-based computer vergence/accommodative therapy group, 30% in the placebo group, and 19% in the pencil push-ups group (Scheiman et al., 2016). This loss of follow-up prevented the study from drawing any definitive conclusions about the comparative effectiveness of the treatment groups. Investigating the effectiveness of strategies like tele-appointments, automated reminders or mobile applications in reducing missed follow-up appointments and dropout rates might improve adherence to treatment. These strategies can encourage patients' adherence and regular monitoring to increase treatment success.

7.7.3 Video tele-appointments

Most respondents in the UK and Saudi Arabia do not use video tele-appointments, while a small percentage do use them for treatment follow-up. Tele-appointments have been utilised in orthoptic practice and have been reported in STH's adoption of virtual clinics in The Adult Strabismus service since 2015 (Choi & Rossiter, 2016). However, their application in managing primary CI remains unclear in the literature.

Some respondents reported using video tele-appointments during COVID-19. For example, during COVID-19, orthoptic clinics in the UK primarily conducted patient consultations mainly

through telephone rather than video appointments (Rowe *et al*, 2021). However, respondents noted a return to face-to-face appointments after the pandemic, highlighting the continued reliance on in-person consultations for comprehensive examination and treatment of this condition. It cannot be stated with certainty that practices have changed since the COVID period due to a lack of supporting literature. However, the questionnaire results suggest that most participants have returned to conducting face-to-face appointments. In addition, respondents indicated that they do not currently use video tele-appointments despite acknowledging the lack of barriers. A possible explanation might be that this group of respondents have a previous unsuccessful experience or are influenced by a negative idea about video tele-appointments. On the other hand, this suggests the possibility of adopting video tele-appointments among this group in the future.

Respondents reported difficulties in accurately assessing patients remotely as a barrier. Orthoptic clinics reported challenges with teleconsultation during COVID-19. For example, Rowe *et al.* (2020) reported difficulties such as gathering clinical information, making treatment decisions, assessing patient compliance and IT issues. Thus, tele-appointments can be used on follow-up for non-examination purposes, such as assessing symptoms and compliance, demonstrating exercises, and increasing motivation. Some respondents found that technical issues such as poor internet connectivity and video/audio quality are barriers to effective tele-appointments. These issues should be avoided as much as possible because they can disrupt treatment outcomes and impact the patient's experience. A few respondents noted that some patients may prefer traditional face-to-face over tele-appointments, which could limit the adoption of tele-appointments. Despite the potential benefits, some patients may prefer personal rapport with the clinician or feeling receive greater quality of care.

7.7.4 Limitations

This study had several limitations. Firstly, the questionnaire was distributed to members registered in the membership databases of orthoptists' societies in the UK and optometrists and ophthalmologists in Saudi Arabia. The number of responses from certain groups, such as UK optometrists and ophthalmologists in Saudi Arabia was low, but the study provided insight into the current practices of the participants. However, this limits the generalisability and

conclusion of findings on the prevalence and management of primary CI. Secondly, there were no previously published questionnaires regarding the numbers and management of primary CI in both countries, making the findings comparable. Thirdly, the questionnaire used closed-end questions with predetermined options, which limited respondents to provide additional insights to their responses. Fourthly, another possible limitation of the questionnaire is the response bias (Dabasia *et al.*, 2014), as the respondents might be influenced by personal interests, such as an orthoptic exercise, potentially skewing their responses. Fifth, the questionnaire mainly reflects respondents' opinions, not necessarily reflect actual practice.

Lastly, developing a high-quality questionnaire requires a systematic approach informed by qualitative research, thoughtful design, and rigorous validation (Boone *et al*., 2013). Techniques such as focus groups, content analysis, and RASCH analysis represent gold standard in questionnaire development (Boone *et al*., 2013). Rasch analysis used the following steps: dimensionality, response ordering, local dependence, infit and outfit analyses, differential item functioning, subject targeting, and confirmatory dimensionality (Leske *et al*., 2012). While time constraints limited their application in this study, understanding and discussing these methods can enhance the credibility of the research and provide a framework for future work. By incorporating these principles, researchers can ensure their questionnaires are reliable, valid, and capable of generating meaningful insights.

7.7.5 Conclusion

The questionnaire indicated that optometrists in the UK frequently encounter and manage primary CI in their practice. Reported monthly CI numbers most likely unchanged before and after the COVID-19 and tend to be low. The questionnaire also confirmed variation among respondents in diagnostic criteria for primary CI, as well as in treatment protocols. Smooth/pen convergence, dot card and jump convergence exercises are the most commonly recommended treatment and are believed to be mostly effective. Most respondents reported that poor compliance with treatment is the most contributing factor to treatment failure. Despite the absence of barriers, the utilisation of video tele-appointments in primary CI management is limited.

Chapter 8 General discussion

Although orthoptic exercises are the treatment of choice for primary CI, it would be logical to have their protocols standardised and clearly defined. Until recently, literature has emphasised considerable variability in the treatment protocols, with conflicting outcomes. Consequently, the most effective exercises or their protocols are still unclear. This variability is concerning as it can lead to inconsistent treatment outcomes, making it challenging to determine the most effective protocols and comparison of results. The lack of standardised protocols means that patients might receive varied exercises, treatment frequencies, and intensities, depending on the clinician's preferences and experiences. Establishing standardised protocols would improve the effectiveness of treatment, shortening the treatment period, which is reflected in the well-being of patients as well as facilitating more reliable comparisons of treatment outcomes.

The primary purpose of the thesis was to investigate the treatment protocols of primary CI and evaluate their effectiveness. To address the previous aim, specific research questions were formulated to guide investigation. The first question focused on identifying the most effective orthoptic exercises and their protocols for treating symptomatic CI and/or AI. The second significant question involved comparing simple convergence exercises to standard orthoptic exercises. The third critical question was comparison effectiveness of tele-appointments compared to face-to-face appointments. Four studies in thesis were conducted to answer these questions.

The first step in this thesis involved evaluating the effectiveness of CI treatment by conducting a service evaluation in an orthoptic clinic to assess and determine the efficacy of standard CI treatment with orthoptic exercises in current practice. Understanding what the ‘standard treatment’ is for CI was a crucial part to compare them to simple convergence exercises that target disparity. This aim was planned through a prospective study that tested simple exercises on primary CI patients as well as incorporating tele-appointments for their management. This innovative approach drew inspiration from the practices adopted during the COVID-19 pandemic but extended the concept beyond the pandemic era.

However, the prospective study faced challenges in recruiting primary CI patients at the NHS site and did not meet its planned objectives. To address this, two additional studies were conducted to achieve the previous aims. Simple convergence exercises were tested on visually normal young adults using tele-appointments. Additionally, clinicians were surveyed to gather their opinions on the effectiveness of standard treatment in their practice and the use of tele-appointments for managing primary CI.

8.1 Key findings

Orthoptic exercises and their protocols for CI have shown variation among clinicians through their utilisation and surveyed opinions. The criteria for prescribing orthoptic exercises and identifying the most effective protocol are not well-defined. There was variability on the number of exercises prescribed, training time, frequency and the change on the treatment. Compliance with home exercises was the most impactful factor for treatment success, and it remains challenging. Patient compliance is crucial and one of the essential components of effective orthoptic treatment as well as improved adherence to treatment plan.

Simple convergence exercises can lead to noticeable improvements in visually normal young adults. There were improvements in vergence and accommodation responses with objective and subjective measures after short-term of training. Tele- appointments have shown similar outcomes to face-to-face appointments while performing orthoptist exercises. Thus, tele-appointments can be a supportive element to compliance, motivation, and increase treatment effectiveness.

8.2 Summary of key findings

- The service evaluation in Chapter 4 and questionnaire in Chapter 7 revealed that smooth/pen convergence exercises are the most commonly prescribed treatment. Furthermore, there was variability in CI treatment protocols among clinicians. The variability was observed in number of exercises, training time, frequency and change in treatment plan. Thus, the criteria for prescribing orthoptic exercises and identifying the most effective protocol are not well-

defined. Additionally, compliance with home exercises was the most impactful factor for treatment success, and improving it remains challenging.

- The study in Chapter 4 revealed that tele-appointments were found to be as effective and feasible as face-to-face visits for young adults undergoing orthoptic exercises, with comparable outcomes in objective and subjective measures. Moreover, simple convergence exercises resulted in noticeable improvements in vergence and accommodation responses in visually normal young adults.
- The questionnaire in Chapter 7 showed that optometrists in the UK are likely to encounter and manage primary CI cases. Furthermore, the number of primary CI cases seen monthly in clinics likely remained consistent before and after COVID-19, though clinicians reported mostly seeing only 1-5 patients each month. Despite the lack of barriers, the use of video tele-appointments in managing primary CI was limited, both during and after the COVID-19.

8.3 The effectiveness of 'standard treatment' for treating primary CI

The effectiveness of clinical treatment for primary CI is evaluated through the established treatment protocols and the prescribed exercises used in current practice. A key question is whether these treatments are sufficiently effective or must be accompanied by a specific protocol to succeed. The results from the service evaluation study (Chapter 4) highlighted significant variability in the effectiveness of the most commonly prescribed exercises and their associated protocols. This variability confirmed what has been evident in the literature: treatment efficacy varies between researchers, and there is a lack of consensus on an effective treatment protocol. From a clinical standpoint, the service evaluation's conclusion of a 40% success rate was not satisfactory. The poor 40% success rate might be because only severe cases get referred to orthoptic clinic in STH with referral information could be gathered for future studies. However, the study aimed to establish a clear, effective protocol, and doing so was challenging due to the inconsistent results. For instance, when prescribed solely, smooth vergence exercises succeeded in some cases but failed in others, preventing a definitive assessment of their overall efficacy.

The findings of the service evaluation study do not align with those reported by Aziz et al. (2006), who found a high effectiveness rate of 83.3% for orthoptic exercises. In Aziz's study, patients performed exercises up to 6 times daily, each lasting 5 minutes. This frequency and duration are significantly higher than the most prescribed in the service evaluation of 1–2-minute sessions, twice daily. This large difference in exercise regimen likely accounts for the disparity in success rates between the two studies, making direct comparisons between their outcomes inconsistent. Another example of efficacy of orthoptic exercises come from Westman's study, which reported a success rate of 51.9%. However, lacking details on exercises, training time and frequency in Westman's study were not included, making a thorough comparison difficult. Therefore, the low success rate observed in the service evaluation can be attributed to the fact that the effectiveness of the exercises cannot be isolated from the prescribed protocol, compliance and severity of conditions.

Despite this, the exercises prescribed in the Service Evaluation likely followed generally recommended protocols, such as those outlined in the BIOS 2016 guidelines. These protocols emphasised the importance of appreciating diplopia and incorporating fusion exercises. However, it remains unclear whether these methods alone are sufficient to alter vergence behaviour in all CI cases. Considering that the cases studied were from an orthoptic clinic, they likely involved more severe CI, requiring more in-depth treatment. The poor patient compliance likely reduced the overall effectiveness observed in the Service Evaluation. Consequently, it is challenging to confirm the efficacy of a specific protocol.

A key strength in addressing this research question on effectiveness of treatment is the inclusion of opinions from various clinicians who manage primary CI conditions, as discussed in Chapter 7. The literature review highlighted that variability in CI management is an international issue. The questionnaire results confirmed this global lack of consensus exists within the UK and even in countries like Saudi Arabia. In Chapter 7, clinicians' responses provided valuable insights. While there was general agreement among respondents on the specific exercises considered most effective for treating CI, such as smooth vergence, jump vergence and dot card activities, there remained disagreement on the optimal protocols for administering these exercises. This aligns with the findings of the Service Evaluation, which also identified smooth vergence and dot card exercises as the most commonly prescribed but

highlighted the variability in their effectiveness due to differences in protocols. The clinicians' input reinforced the Service Evaluation study's results, emphasising that while certain exercises might be effective, the lack of a standardised protocol contributes to inconsistent outcomes. Additionally, the questionnaire's findings strongly support existing literature, which identifies poor compliance as a major factor impacting the effectiveness of CI treatments. The clinicians' perspectives offered additional qualitative context to the thesis, with necessity for a more standardised approach to CI treatment protocols. Moreover, it emphasised the need to address patient compliance to enhance the overall effectiveness of CI treatment.

The findings of Chapters 4 and 7 confirmed the variability in CI treatment protocols but also reinforced the critical role of patient compliance in treatment success. The findings also suggested that simple convergence and dot card exercises are mostly used as the first lines of treatment, and, most likely, they are effective in treating primary CI.

8.4 Simple convergence exercises

Evaluating the effectiveness of simple exercises compared to standard exercises for treating primary CI was an important aspect of this research. The aim of Chapter 5 was to answer the research question by evaluating the effectiveness of simple convergence exercises compared to standard treatment in primary CI patients. In addition, to manage these exercises through tele-appointments. However, since this study could not answer the question, Chapter 6 focused on testing the effectiveness of simple convergence exercises versus placebo through both tele-appointments and face-to-face appointments.

The results from Chapter 6 showed noticeable improvement in vergence and accommodation responses. These results provide further evidence supporting the findings by (Horwood and Toor, 2014; Horwood *et al.*, 2014) that pure simple convergence exercises elicit more immediate improvements in vergence and accommodative responses. The key advantage of these simple convergence exercises is that they may increase the efficiency of treatment plans for CI by producing more rapid gains over a shorter period of time. However, this promising initial concept has yet to be directly applied to a clinical population of primary CI patients. The

low number of CI patients in the study discussed in Chapter 5 precluded the ability to formally investigate the potential benefits of this type of exercise in that population.

The improvement achieved in Chapter 6 was assessed by objective and subjective measures. Additionally, there was a significant improvement in CISS scores, even though the participants did not initially complain of visual symptoms. This strengthens the results by demonstrating that the observed effects of these exercises are real and not merely due to a placebo effect. Moreover, the improvements observed in the clinical set of orthoptic tests further strengthen the efficacy of these simple exercises. Notably, the improvements were also confirmed through objective tests, which are considered more accurate and reliable. While the improvements might not seem as expected due to the participants' high baseline visual abilities and compliance, they still indicate a positive indicator of improved convergence and accommodation responses. This improvement in young adults suggests a strong foundation for applying these simple exercises to CI patients. Given that the vergence abilities of CI patients are significantly lower compared to those studied in this thesis. Thus, it provides an encouraging basis to hypothesise that similar simple convergence exercises may also lead to improvements when administered to CI patients.

The fact that notable improvements were observed within a short duration of three weeks in this study, and even in just two weeks Horwood and Toor (2014) and Horwood *et al.* (2014) studies. The immediate effects observed in young adults with normal vision suggest that primary CI patients could benefit similarly or significantly from these exercises. The potential for these simple exercises to shorten the treatment duration is particularly motivating. Current literature recommends a treatment period of around 12 weeks for primary CI, but the observed quick improvements suggest that this period could be reduced. Therefore, implementing these exercises could reduce treatment times and improve compliance, as patients are likely to be more motivated by faster progress.

By focusing on disparity and providing a more direct stimulus to vergence and accommodation, these exercises might offer quicker and more robust results. Positive results in such trials would not only confirm the initial findings but also revolutionise primary CI treatment by providing a solid evidence-based foundation for integrating this treatment

approach into standardised primary CI protocols. Additionally, by applying these simple convergence exercises to actual primary CI patients, the exercises' validity and reliability can be more rigorously tested and established.

8.5 Video tele-appointments compared to face-to-face appointments in management of primary CI

The study in Chapter 6 showed important results as there were no significant differences between face-to-face and tele-appointments groups when undergoing orthoptic exercises. This indicates that tele-appointments can adequately support the clinical assessment and undergoing orthoptic exercises. This is a novel and essential finding about tele-appointments in orthoptic exercises and a feasibility study that could be undertaken for patients with primary CI.

Tele-appointments succeeded in Chapter 6 in several ways. The most notable aspect is the lack of significant differences in measurements and the CISS questionnaire between face-to-face appointments and tele-appointments. Tele-appointments demonstrated good compliance rates, meaning participants adhered well to the prescribed exercise plans and follow-up schedules. This suggests that tele-appointments can engage patients effectively and encourage them to stick to their treatment regimens. Moreover, this gives an important indication that the tele-appointments served the same purpose of motivation, aid compliance and monitoring exercises without compromising participants' outcomes. Additionally, what gives importance to the results is that no complaints were reported in terms of dissatisfaction, technical problems, difficulty in demonstrating the exercises, or choosing times for the video appointments. Therefore, these findings suggest that tele-appointments were as effective as face-to-face visits and led to similar outcomes.

The questionnaire study in Chapter 7 provided valuable insights into the perception of tele-appointments from the clinicians’ perspective. The findings revealed that 19.2% of orthoptists and 5.3% of optometrists utilised video appointments during the COVID-19 pandemic but later returned to face-to-face appointments. Additionally, 12.8% of orthoptists used video tele-appointments only for follow-up in primary CI patients. These results represent basic

information on tele-appointments from orthoptists and optometrists who have used them previously, for example, during COVID-19 or have consideration for using them in the future.

Tele-appointments can benefit mobility disabled or those unable to attend regular clinic visits. In addition, can a solution to accommodate busy clinics with high patient volumes. The results indicated positive indicators for the future use of tele-appointments by clinicians. Some believe they will allow more frequent check-ins between face-to-face visits, facilitating better compliance, progress monitoring and support for primary CI patients. Tele-appointments also provide convenience for both patients and clinicians, reducing the need for face-to-face visits and potentially increasing patient satisfaction, and this has been reported in the literature from other specialities (Roe *et al.*, 2020; Gerbutavicius *et al.*, 2021; Pardhan and Vaughan, 2021; Morettin *et al.*, 2023; Smith *et al*., 2023) Moreover, tele-appointments have been well-received by both patients and their parents. Children may feel less anxious during tele-appointments compared to face-to-face visits. The findings also suggested they are appropriate for patients whose conditions are improving and may require less intensive monitoring.

Previous experience of clinicians showed that it is particularly suitable for motivated patients who have a good understanding of their treatment plan and who adhere to the required exercises. This point, in particular, may be an important option because such CI patients will benefit from them to the fullest extent. The previous results also showed that tele-appointments are practical and feasible in orthoptic or optometric practices. The decision to utilise tele-appointments can be guided by a careful consideration of individual patient needs, preferences, and clinical requirements.

The results provide several practical applications that have been used for tele-appointments and initiative suggestions. Tele-appointments enable clinicians to ensure that patients perform exercises correctly. It can be argued that face-to-face visits are seen as more accurate and effective for clinical examinations and patient observations. Therefore, as was used in Chapter 6, combining the two appointment methods would give the best outcomes in such cases of CI. Thus, tele-appointments can be helpful between face-to-face visits to monitor progress and maintain treatment momentum.

The combined findings from the thesis suggest tele-appointments have potential clinical viability and provide supportive, valuable insights into their practical application. The thesis also suggests that clinicians are open to incorporating tele-appointments into the future of CI management. By addressing the identified challenges and leveraging the advantages, tele-appointments can be effectively integrated into CI care practices, enhancing CI efficiency of treatment outcomes.

8.6 Limitations

The research faced several limitations:

- The main limitation of the research was the difficulty in recruiting primary CI patients to address the research question, which aimed to test the effectiveness of simple convergence exercises compared to standard exercises while monitoring patients' progress through tele-appointments. Despite efforts such as reviewing CI referrals in the orthoptic clinic and inviting 18 hospitals to assist with recruitment, the study could not recruit the required sample size.

- Another limitation was the retrospective review of notes in the service evaluation (Chapter 4). Missing information for some patients such as training time, frequency, and compliance limited the ability to fully assess the treatment protocol, making it difficult to draw conclusions on success. Additionally, patients were treated by different orthoptists, resulting in variations in their treatment plans.

- Since the PhD student is an optometrist, it was not possible for him to assess patients in the primary CI study (Chapter 5). It was planned for orthoptists to perform the assessments, which may have led to the same limitations encountered in the service evaluation study (Chapter 4), where different orthoptists might have performed the tests slightly differently or provided varying levels of encouragement, potentially affecting the results.

- The small sample size of UK optometrists in questionnaire study (Chapter 7), which affected the generalisability of the findings. FODO’s announcement of the questionnaire was posted on their website rather than being sent to registered members, limiting the reach to optometrists. Moreover, access to some large optometrist groups on Facebook required

membership verification, such as being a practicing optometrist with a GOC registration number, further restricting the reach.

- A further limitation of the Service Evaluation study was the small sample size, primarily due to the limited timeframe permitted by SHT. This was from 2018 to 2021 for regulatory reasons, which restricted the search period. Extending the search period for patient records would have increased the number of patients. Moreover, some patients were impacted by COVID-19, leading to rescheduled appointments or extended follow-up periods, which influenced the actual treatment protocol.

- The participant's satisfaction level and experience with tele-appointments, discussed in Chapter 6, were not evaluated through a questionnaire, which constitutes another limitation.

8.7 Future work

The research aimed to evaluate the efficacy of primary CI treatment protocols. The service evaluation was conducted in a single orthoptic clinic, reviewing the records of 30 patients, which is a relatively small sample size. Future research could use the findings of this study for comparison in terms of success rate, treatment protocols and most prescribed exercises. The next step would be a larger-scale investigation of treatment protocols for CI. A multicentre trial would allow for reviewing a larger number of patients' records, increasing the sample size and accounting for potential variations in treatment practices across different clinics. A larger number of patients involved in the study would increase statistical power and provide more reliable and generalisable results. Additionally, this approach would allow researchers to standardise the treatment protocols and outcome measures.

Simple convergence exercises have demonstrated improvement in vergence and accommodation responses in visually normal young adults. In addition, the outcomes of tele-appointments on orthoptic exercises were successful. However, the effectiveness of this type of exercises and tele-appointments on actual CI patients remains an open question. The poor recruitment of primary CI patients after the COVID-19 has hindered answering the question: How effective are simple exercises compared to standard exercises as well as tele-appointments in primary CI management? To address the need for CI patients, future studies

should establish partnerships with multiple hospitals and clinics early in the study design phase to ensure broader recruitment opportunities. By tackling the challenges encountered in this study, future research can enhance the likelihood of successful patient recruitment, data collection, and testing of these simple exercises and appointment modalities in patients with primary CI.

Investigating the long-term effect of simple convergence exercises and tele-appointments would be valuable. Following patients for an extended period, post-treatment could assess if outcomes are truly equivalent in the long run. Orthoptists frequently rely on telephone calls for tele-appointments, as highlighted by Rowe et al. (2021), while video tele-appointments are less commonly used, as indicated by the questionnaire results in Chapter 7. Future research could focus on comparing the effectiveness of video and telephone consultations in primary CI management. For example, studies could examine whether patient outcomes differ significantly between the two approaches for specific treatments and management strategies, such as orthoptic exercises, symptom relief, and compliance. Additionally, future research could explore the preferences of both patients and orthoptists, investigating factors like convenience, satisfaction, motivation and perceived quality of care in managing primary CI beyond COVID-19 era.

8.8 Conclusion

The primary goal of the thesis was to investigate the effectiveness of primary CI treatment. The findings highlighted a consensus in the literature indicating variability in the protocols used by clinicians to treat primary CI. Despite this variability, the results suggested that smooth vergence and dot card exercises are the most commonly prescribed and serve as the first line of treatment for primary CI. The low numbers of primary CI patients post-COVID-19 led to poor recruitment of clinical trial in this thesis.

The thesis demonstrated that simple convergence exercises could improve vergence and accommodation responses on objective and subjective measures over a short period of time, even in visually normal young adults. These promising results underscore the effectiveness of these exercises, showing notable improvements even when participants' abilities are at the ceiling. This supports the hypothesis that such exercises could be highly beneficial for primary

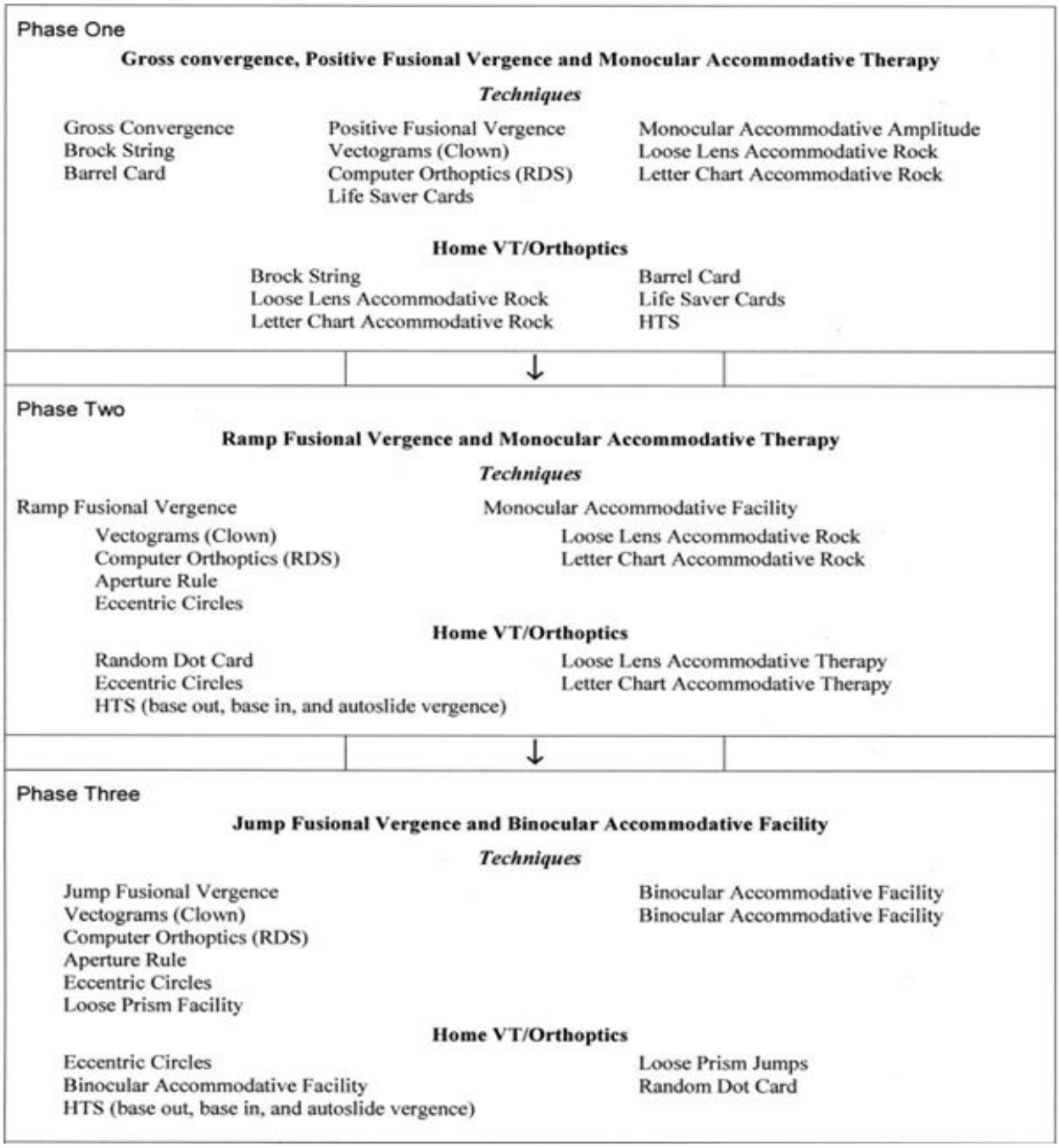
CI patients. Further research involving primary CI patients will be crucial to confirm these findings and establish these exercises as a standard treatment protocol for CI. A novel aspect of the research was the successful implementation of tele-appointments for administering orthoptic exercises. The use of tele-appointments was not only feasible but also effective in maintaining patient compliance. The results obtained from tele-appointments were comparable to those from face-to-face visits, indicating that tele-appointments can be a viable intervention for CI treatment without compromising the quality of care.

Appendices

Appendix 1.1 Exercises regimes in Horwood and Toor (2014) study.

Group	Skill manipulated	Exercise
Blur	Accommodation only; blur independent of disparity	Monocular push-ups Monocular near /distance "jump" accommodation Monocular accommodation facility (+2/-2D [near], 0/-2D [distance] lens flippers)
Both	Accommodation and convergence in normal relationship	Binocular push-ups Binocular "jump" vergence/accommodation Near/distance physiological diplopia
Disparity	Vergence independent of accommodation	Binocular push-ups Binocular "jump" vergence Near & distance vergence facility (12D BO/4D BI prism flippers)
Conv+	Convergence in excess of accommodation	Binocular push-ups (+2.0 D or 12D BO) Binocular near accommodation facility (0/+2.0 D) Binocular near & distance vergence facility (0/12D BO)
Accom+	Accommodation in excess of convergence	Binocular push-ups (-2.0 D or 12D BI) Binocular near and distance accommodation facility (0/-2.0 D) Binocular near (and distance if possible) vergence facility (0/12D BI)
Placebo	Attention, motion detection, proprioception	"Snakes illusion": max/ min moving Necker cube: perceptual shift Yoked prisms: visually directed reach with / without prisms
Nil	Practice, test–retest	None
Effort	Effort Tester, instruction set, effort	None

Appendix 1.2 Vision therapy/orthoptics protocol for office-based group with reinforcement of home exercises **(Scheiman *et al.*, 2005b)**



*HTS: Home Therapy System; RST: Random Dot Stereogram

Appendix 1.3 CITT Office-based Placebo Vision Therapy/Orthoptics Treatment Sequence Available at https://clinicaltrials.gov/study/NCT00338611#study-overview

Initial Training Visit

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
Ductions	4 minutes	Equalize monocular inputs
Monocular Brock String – level one	6 minutes	Equalize monocular inputs
Visual Closure – Lines and Boxes	10 minutes	Eye teaming
At Home		
Monocular Brock String and TV Trainer	15 minutes	

Week 1

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
Ductions	4 minutes	Equalize monocular inputs
Monocular Brock String –level two	6 minutes	Equalize monocular inputs
Visual Closure – Lines and Boxes	10 minutes	Eye teaming
At Home		
Monocular Brock String and TV Trainer	15 minutes	

Week 2

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
Bailey-Lovie Acuity	4 minutes	Equalize monocular inputs
Monocular Brock String-level two	6 minutes	Equalize monocular inputs
Visual Closure – Closing on Center	10 minutes	Eye teaming
At Home		
Monocular Brock String and TV Trainer	15 minutes	

Week 3

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
Bailey-Lovie Acuity	4 minutes	Equalize monocular inputs
Monocular Brock String – level three	6 minutes	Equalize monocular inputs
Visual Closure – Closing on Center	10 minutes	Eye teaming
At Home		
Monocular Brock String and TV Trainer	15 minutes	

Weeks 4 & 5

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Accommodation	8 minutes	Improve focusing and speed of response
After Image	4 minutes	Equalize monocular inputs
Red/Red Activities	6 minutes	Eye teaming
Visual Figure Ground – Hidden Characters (level 1)	10 minutes	Eye teaming
At Home		
HTS Vergence/Accommodation (or Red Lens Activities) and TV Trainer	15 minutes	

Weeks 6 & 7

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo vergence	8 minutes	Improve eye teaming and speed of response
Strobismo Trainer	4 minutes	Eye teaming
Yoked Prism Flippers	6 minutes	Eye teaming
Visual Figure Ground – Figuring Words (level 2)	10 minutes	Eye teaming
At Home		
HTS Vergence/Accommodation (or Red Lens Activities) and Polaroid Playing Cards	15 minutes	

Weeks 8 & 9

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Vergence	8 minutes	Improve eye teaming and speed of response
Modified Thorington	4 minutes	Eye teaming
Bernell-o-scope level 1	6 minutes	Eye teaming
Visual Spatial Skills	10 minutes	Eye teaming
At Home		
HTS Vergence/Accommodation (or Red Lens Activities) and Polaroid Playing Cards	15 minutes	

Weeks 10 & 11

Technique	Time	Goal
In Office		
Necker Cube	12 minutes	
HTS - Placebo Vergence	8 minutes	Improve eye teaming and speed of response
Double Maddox Rod	4 minutes	Eye teaming
Bernell-o-scope level 2	6 minutes	Eye teaming
Visual Spatial Skills	10 minutes	Eye teaming
At Home		
HTS Vergence/Accommodation (or Red Lens Activities) and Polaroid Playing Cards	15 minutes	

Maintenance Therapy

Technique	Time	Goal
At Home		
TV Trainer	10 minutes	To improve eye teaming ability by using visual and motor inputs.
Polaroid Playing Cards	5 minutes	

Appendix 1.4 Vision Therapy protocol (Shin et al., 2011)

Phase 1		
Gross convergence	PFV	MAF
At school		
Brock String then Barrel Card	Vectograms (Quoits, Clown, Fusion) Then Tranaglyphs (Bunny, Plane)	±1.50 D Lens Flipper
At home		
Brock String then Barrel Card	HTS† Both Base In and Out	±1.50 D Lens Flipper, HTS† Accommodative Rock
Phase 2		
Ramp Fusional Vergence	MAF	
At school		
Vectograms (Quoits, Clown, Basic Fusion) Then Tranaglyphs (Bunny, Plane) Then Prism Flippers Then Synoptophore Both Base In and Out Then Aperture Rule	±2.50 D Lens Flippers	
At home		
Prism Flippers, HTS†Autoslide Vergence	±2.50 D Lens Flippers, HTS† Accommodative Rock	
Phase 3		
Jump Fusional Vergence	BAF	
At school		
Prism Flippers Then Aperture Rule Then Life Saver Card Then Eccentric Circles	±2.50 D Lens Flippers	
At home		
Life Saver Card Then Eccentric Circles, HTS† Jump Ductions	±2.50 D Lens Flippers, HTS† Accommodative Rock	

†Home Therapy System (HTS) procedures were performed before the conventional procedures at home training.

Appendix 1.5 The 19 Item COVD-QOL Checklist Questionnaire (Maples 2010)

19 Item COVD-QOL Checklist Questionnaire

Check the column which best represents the occurrence of each symptom.

		NEVER	SELDOM	OCCASIONAL	FREQUENTLY	ALWAYS
1. Headaches with near work	A					
2. Words run together reading	B					
3. Burn, itch, watery eyes	A					
4. Skips/repeats lines reading	OM					
5. Head tilt/close one eye when reading	B					
6. Difficulty copying from chalkboard	A					
7. Avoids near work/reading	B					
8. Omits small words when reading	OM					
9. Writes up/down hill	O					
10. Misaligns digits/columns of numbers	OM					
11. Reading comprehension down	P					
12. Holds reading too close	A					
13. Trouble keeping attention on reading	B					
14. Difficulty completing assignments on time	P					
15. Always says *I can't* before trying	P					
16. Clumsy, knocks things over	O					
17. Does not use his/her time well	P					
18. Loses belongings/things	P					
19. Forgetful/poor memory	P					

A=Accommodation; B=Binocularity; O=Orientation; OM=Ocularmotor; P=Perception

Appendix 2.1 Ethical approval of Service Evaluation study (Chapter 3)

The University Of Sheffield.

Downloaded: 11/07/2023
Approved: 07/06/2023

Hani Alrehaily
Registration number: 200252157
Orthoptics and Ophthalmology
Programme: PhD Full Time

Dear Hani

PROJECT TITLE: Investigating the effectiveness of current treatment protocols for convergence and accommodation insufficiencies
APPLICATION: Reference Number 052448

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 07/06/2023 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 052448 (form submission date: 05/06/2023); (expected project end date: 31/01/2024).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Kate Chadwick
Ethics Administrator
Health Sciences School

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy: https://www.sheffield.ac.uk/research-services/ethics-integrity/policy
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

Appendix 3.1 Informed consent (Chapter 5)

Hani Alrehaily
Consent form v1.2
19/01/2022
IRAS Project ID: 305275

The University Of Sheffield.

Participant Identification Number:

Consent Form

Current and future management of convergence and accommodation anomalies

Name of Researcher: Hani Alrehaily

Please initial each box:

1. I confirm that I have read the information sheet dated __/__/20__ (version__) and have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. ☐
3. I understand that relevant sections of my medical notes may be looked at by individuals from the University of Sheffield or from Sheffield Teaching Hospitals NHS Foundation Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records. ☐
4. I understand the information I provide, as part of this study, will only be accessed by members of the research team. ☐
5. I understand that the study will collect the minimum personally identifiable information needed. ☐
6. I understand that if I withdraw from the study, information that has already been obtained will be kept. To safeguard your rights, we will use the minimum personally identifiable information possible. ☐
7. I understand that my information, as part of this study, will be used to support other research in the future, and may be shared anonymously with other researchers. ☐
8. I understand that I can receive information about the progress of the study if I wish, and this will require me to provide the researcher with my preferred postal or email address. ☐
9. All study information will be stored securely at the University of Sheffield. Following the University of Sheffield policy, we will keep identifiable information about you for 10 years after the study has finished. ☐
10. I agree to take part in the above study. ☐

IRAS ID:
Study Number:

Original Copy to: patient
investigator site file
medical notes

Name of Participant	Date	Signature

Name of Person taking consent	Date	Signature

*An original copy of the completed informed consent form and PIS is given to the participant.

IRAS ID:
Study Number:

Original Copy to: patient
investigator site file
medical notes

Appendix 3.2 Ethical approval of Cohort study: investigating tele-appointments in CI treatment on adults undergoing simple convergence exercises (Chapter 5)

Ymchwil Iechyd a Gofal Cymru
Health and Care Research Wales

NHS
Health Research Authority

Dr Sonia Toor
Floor E, Medical School
Beech Hill Road
University of Sheffield
S10 2RXN/A

Email: approvals@hra.nhs.uk
HCRW.approvals@wales.nhs.uk

07 February 2022

Dear Dr Toor

HRA and Health and Care Research Wales (HCRW) Approval Letter

Study title:	**Current and future management of convergence and accommodation anomalies**
IRAS project ID:	**305275**
Protocol number:	**NCT 21/08**
REC reference:	**22/WM/0023**
Sponsor	**University of Sheffield**

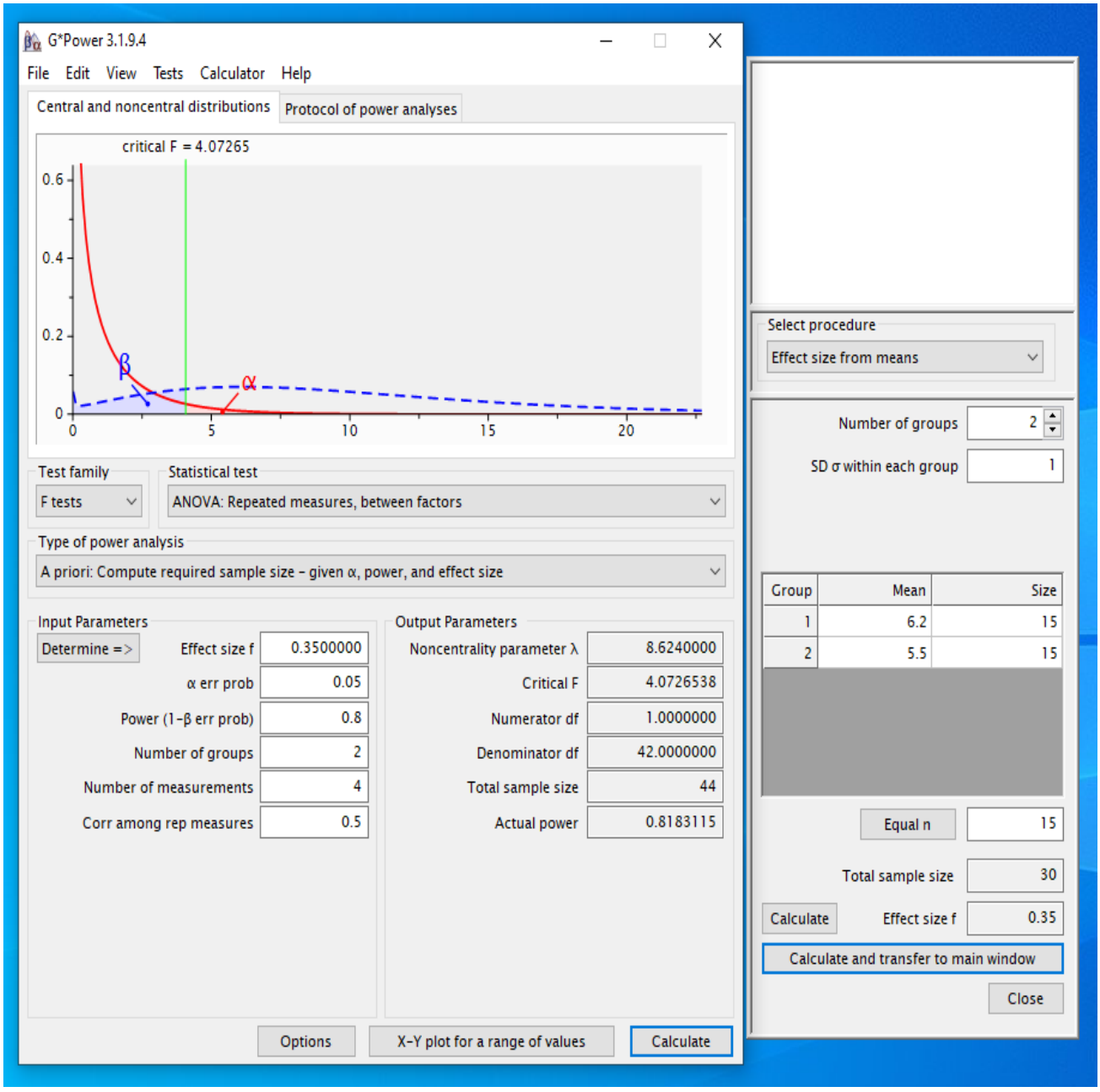
I am pleased to confirm that **HRA and Health and Care Research Wales (HCRW) Approval** has been given for the above referenced study, on the basis described in the application form, protocol, supporting documentation and any clarifications received. You should not expect to receive anything further relating to this application.

Please now work with participating NHS organisations to confirm capacity and capability, in line with the instructions provided in the "Information to support study set up" section towards the end of this letter.

How should I work with participating NHS/HSC organisations in Northern Ireland and Scotland?
HRA and HCRW Approval does not apply to NHS/HSC organisations within Northern Ireland and Scotland.

If you indicated in your IRAS form that you do have participating organisations in either of these devolved administrations, the final document set and the study wide governance report (including this letter) have been sent to the coordinating centre of each participating nation. The relevant national coordinating function/s will contact you as appropriate.

Appendix 3.3 Sample size calculations of Cohort study: investigating tele-appointments in CI treatment on adults undergoing simple convergence exercises (Chapter 5)



Appendix 3.4 Invitation email to NHS Hospitals for participation in Cohort study (Chapter 5)

Dear All,

I'm getting in touch about research rather than placements – I hope that is ok!

I have a PhD student who is looking at the effectiveness of convergence and accommodation exercises and the effectiveness of tele-appointments during treatment. He has received ethics approval and has started recruiting patients from the Royal Hallamshire Hospital in Sheffield. However, we are really struggling to recruit (where have all the primary CI's gone?!). Would you be interested in getting involved?

As a quick overview, this is the project plan:
- Aim 1 is to compare simple convergence exercises (smooth vergence and jump vergence only using a gabor patch target - as suggested by Horwood et al 2014) to standard treatment protocols (as determined by a Service Evaluation at RHH for an earlier study).
- Aim 2 is to compare standard face-to-face appointments with tele-appointments.
- Adult patients will be randomised into one of 4 groups (simple or standard exercises AND face-to-face or tele-appointments).
- There are 4 visits in total. For those in the tele-appointment group, there would only be 2 face-to-face visits (at the start and end of treatment) with the other 2 being held online (using MS Teams/Attend Anywhere or any other platform that your Trust has approved).
- The patients will be tested by you as normal and the student will attend to extract the data collected.

Please let me know your thoughts. If you are happy to be involved or just want more information then it would be great to discuss the project in more detail over phone/video call.

Thank you,

Sonia

--
Dr Sonia Toor
Lecturer in Orthoptics

Health Sciences School
Division of Ophthalmology & Orthoptics
The University of Sheffield
Medical School
Floor E, Beech Hill Road
Sheffield S10 2RX
Telephone: (0114) 2159064
Email: sonia.toor@sheffield.ac.uk
https://www.sheffield.ac.uk/health-sciences

Appendix 3.5 Patient Information Sheet (Chapter 5)

The University Of Sheffield.

Current and future management of convergence and accommodation anomalies

You are being invited to take part in a research study

- Before you decide whether to take part, it is important for you to understand why the research in being done and what it will involve.
- Please take time to read the following information carefully. Discuss it with friends and relatives if you wish.
- You are free to decide whether or not to take part in this study. If you choose not to take part, this will not affect your clinical care in any way.
- Ask us if there is anything that is not clear or if would like more information, please contact the study researcher: Hani Alrehaily via email (hadalrehaily1@sheffield.ac.uk) or contact the lead supervisor: Dr Sonia Toor via phone (01142159064) or email (sonia.toor@sheffield.ac.uk).
- Thank you for taking the time to consider taking part in this study.

Why have I been invited?

- You are being invited to take part in this study as you have a convergence and/or accommodation anomaly. This is where the eyes do not turn inwards and/or focus appropriately when looking at objects at near, resulting in symptoms such as double vision and/or blurred vision.

Hani Alrehaily
Participant Information Sheet v1.4
18/01/2022
IRAS Project ID: 305275

Why is the study needed?

Convergence and accommodation anomalies are common, with a prevalence of approximately 23%. Eye exercises, known as orthoptic exercises, are prescribed to treat accommodation and convergence anomalies. Standard treatment consists of a number of different eye exercises that vary in complexity and emphasise the need to maintain clear and/or single vision. Recent research has found that making the treatment simpler, with only the simpler eye exercises and only emphasising the need to maintain single vision, is more effective. However, this research was done on those with normal eyes and needs to be investigated in patients with accommodation and convergence anomalies. Therefore, we are carrying out a study using 44 symptomatic participants to investigate the efficacy of standard exercises versus simple exercises on convergence and accommodation anomalies. If the simple exercises are just as effective or more effective, we would not need to teach patients all the different exercises and possibly complete treatment quicker.

Patients undergoing orthoptic exercises are monitored every few weeks to check the progress of treatment. Due to COVID-19, tele-appointments have been used frequently by clinicians and these could be continued in the future to monitor patients who are undergoing orthoptic exercises Tele-appointments are beneficial as they are inexpensive, easy to use, reduce the spread of infection, reduce travel costs, reduce waiting times and absence from school or work. Moreover, tele-appointments come in line with the NHS long-term plan to minimise in-person clinic visits. Thus, we are investigating whether tele-appointments are just as effective as face-to-face clinic appointments in the treatment of convergence and accommodation anomalies.

What does taking part in the study involve?

- You will be recruited to the study after you have signed the consent form.

At your first eye clinic appointment, you will be required to undergo measurements of your convergence and accommodation. You will also be shown how to perform some eye exercises that you will need to perform daily at home. This appointment will take up to 45 minutes.

- You will be randomised into one of four groups*

1) Standard treatment plan and clinic appointments

You will be given all the eye exercises that would usually be prescribed in clinic for convergence and accommodation anomalies. You will attend another 3 face-to-face appointments, each lasting up to 45 minutes.

2) Standard treatment plan and tele-appointments
You will be given the eye exercises that would usually be prescribed in clinic for convergence and accommodation anomalies. You will have another 2 tele-appointments via video call (10 minutes each) and a final face-to-face appointment (up to 45 minutes).

3) Simple treatment plan and clinic appointments
You will only be given the simple exercises that are used to treat convergence and accommodation anomalies. You will attend another 3 face-to-face appointments, each lasting up to 45 minutes.

4) Simple treatment plan and tele-appointments
You will only be given the simple exercises that are used to treat convergence and accommodation anomalies. You will have another 2 tele-appointments via video call (10 minutes each) and a final face-to-face appointment (up to 45 minutes).

*Randomisation means you will have an equal chance of being allocated to any one of four treatment groups. You will not be able to choose the treatment group you prefer.

- You will perform the prescribed eye exercises at home for 2 minutes, 3 times a day.
- Each appointment (tele-appointments and/or face-to-face) will take place every 4 weeks +/-1 week (as typically done in clinics) to check there are no problems and to ensure the eye exercises are being performed correctly. At face-to-face appointments, eye tests will also be performed to monitor the effects of the exercises.
- Face-to-face appointments will take place in the Eye Clinic on A Floor of the Royal Hallamshire Hospital.
- Tele-appointments will take place by video call using Microsoft Teams.
- During the face-to-face appointments, a range of different tests will measure your vision, convergence and accommodation. These are all non-invasive common clinical eye tests that are routinely performed at an orthoptic appointment. Examples of the tests include:
    - Reading aloud different letters from a chart.
    - Watching a target move closer to you and letting us know when this becomes blurred or double.
    - Looking at a target through prisms and letting us know when this becomes blurred or double.
    - Looking at a target whilst a light is shone in your eyes.

Hani Alrehaily
Participant Information Sheet v1.4
18/01/2022
IRAS Project ID: 305275

- You will be asked to complete a CISS questionnaire about your eye symptoms at each appointment (face-to-face and tele-appointments).
- You will complete a diary of how frequently you performed the prescribed exercises.
- The treatment will stop when your symptoms are resolved and reach normal clinical measures OR if there is no improvement in symptoms and clinical measures after 2 sessions (8 weeks of exercises).
- You are also being invited to take part in an optional extra part of the study where your convergence and accommodation is tested with a non-contact and non-invasive automated device (Plusoptix photorefractor). This will take up to 10 minutes at each face-to-face appointment.
- If you choose to take part in the study, you do not have to take part in the extra Plusoptix test. The choice is yours.

Do I have to take part?

- No, it is completely up to you.
- Only eligible subjects will be enrolled.
- If you decide to take part, you will be asked to sign a consent form at the end of your eye clinic appointment.
- You are free to withdraw at any time, without giving a reason.
- Withdrawing from the study will not affect your clinical care.

Are there any risks for me in joining the study?

- All the tests are non-invasive and there is very little risk involved in taking part in this study. However, it is expected to take up to 45 minutes to complete all the tasks and this may make your eyes tired.

- You may also experience tired eyes and fatigue after performing the exercises at home, but these are commonly prescribed eye exercises that will be prescribed following typical guidelines on duration and frequency.

- You will be advised to rest your eyes following a session of exercises by closing your eyes or looking into the distance to minimise the risk of fatigue.

Are there any benefits for me in joining the study?

- There will be no immediate direct benefit to you should you participate.

- There should be benefits to future convergence and accommodation patients receiving treatment because the study results will recommend the most effective exercises.

- As a gesture of thanks, you will be offered a £15 shopping voucher for each appointment. This means a maximum of £75 in shopping vouchers are available to you if you participate in the study.

- Reimbursements for travel costs are not available. However, study visits will be in place of your routine eye clinic appointments so there are no extra appointments for you to attend. Appointments will be planned around your availability where possible.

How do I withdraw if I want to do so?

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

- Withdrawing from the study will not affect your clinical care.

- You can withdraw by calling Hani Alrehaily or Dr Sonia Toor on 0114 215 9064 Mon to Fri: 9:00 - 17:00 or by emailing hadalrehaily1@sheffield.ac.uk or sonia.toor@sheffield.ac.uk

- If you withdraw from the study, we will keep the information about you that we have already obtained. To safeguard your rights, we will use the minimum personally-identifiable information possible.

Hani Alrehaily
Participant Information Sheet v1.4
18/01/2022
IRAS Project ID: 305275

Can I know the results obtained from the study?

- You can choose whether you would like to receive information about the progress of the study. If you would, please let the study researcher Hani Alrehaily know your preferred postal or email address.

Who has approved the study?

- All research in the NHS is reviewed by an independent group of people, called a Research Ethics Committee which is there to protect your safety, rights, wellbeing and dignity.

- This study has been reviewed and approved by the NHS Health Research Authority (HRA).

Who is organising this study?

- The University of Sheffield is the sponsor for this study.

- The research is being done as part of a PhD research study.

How will information about me be kept confidential?

- We will protect your privacy at all times.

- All study data will be stored with restricted access. Access to the study database will be password protected and will be used only by named researchers working on this study under the direct supervision of the academic supervisors.

- We will be using information from you and your medical records in order to undertake this study.

- We will collect the minimum personally identifiable information needed for the purposes of the study.

- All study information will be stored securely at the University of Sheffield. The University of Sheffield will keep identifiable information about you for 10 years after

the study has finished. For more information about The University of Sheffield records retention schedule: https://www.sheffield.ac.uk/uso/records-management-policy-and-guidance

- STH will use your name, NHS number and contact details to contact you about the research study, and make sure that relevant information about the study is recorded for your care, and to oversee the quality of the study. Individuals from STH and regulatory organisations may look at your medical and research records to check the accuracy of the research study. The only people in STH who will have access to information that identifies you will be people who need to contact you to arrange appointments or audit the data collection process.

- You can find out more about how we use your information at https://www.sheffieldclinicalresearch.org/

General Data Protection Regulation (GDPR):

- We will act as the data controller for this study. This means that we are responsible for looking after the participants' information and using it properly.

- The study will collect the minimum personally identifiable information needed for the purposes of the research project. Any non-anonymised data which is patient-identifiable will not be shared unless the participant provides explicit consent.

- Anonymity, confidentiality and data protection are covered in the University's 'Ethics Policy Governing'.

Who will be able to use my information and results?

- Your anonymous information will be available only to researchers who have relevant scientific and ethics approvals for their planned research.

- The research is being done as part of a PhD and the data collected will be used anonymously for articles, conferences, and other ways of sharing research evidence.

- Data will remain accessible for authorised people throughout the study conduct, and until the final publication of results (if applicable).

- Data collected through this study will be suitable to share in an anonymised format for other interested researchers.

Hani Alrehaily
Participant Information Sheet v1.4
18/01/2022
IRAS Project ID: 305275

- Any non-anonymised data which is patient-identifiable will not be shared unless explicit consent is provided by the participant.

- The University of Sheffield's Good Research and Innovation Practice (GRIP) Policy follows RCUK principles for data sharing: http://www.rcuk.ac.uk/research/datapolicy/

What will be stored of the research database?

- Your anonymised data and definitive project documentation will be stored on centrally provisioned University of Sheffield virtual servers and research storage infrastructure throughout the lifetime of the project.
- Consent forms will be kept in a locked filing cabinet in the chief investigator's locked office.
- The link to the university research storage is: https://students.sheffield.ac.uk/it-services/research/storage/standard

Gesture of thanks

- As a gesture of thanks, you will be offered a £15 shopping voucher for each appointment. This means a maximum of £75 in shopping vouchers are available for taking part in the study.

What if something goes wrong?

- If you have a concern or complaint about the study or would like to speak to someone from outside the research team, you can contact the Patient Services Team at Sheffield Teaching Hospitals NHS Foundation Trust (previously known as PALS).

- The independent Patient Services Team can be contacted via:

Telephone: 0114 2712400
Email: PST@sth.nhs.uk
In person: between 8am – 5pm at the Patient Partnership Department, B Floor, Royal Hallamshire Hospital.

- If you remain unhappy and wish to complain formally, you can contact the Research Manager at Sheffield Teaching Hospitals NHS Foundation Trust.

Dr Dipak Patel, Research Manager,
Clinical Research Office,
Sheffield Teaching Hospitals NHS Foundation Trust,
D49, D Floor,
Royal Hallamshire Hospital,
Glossop Road,
Sheffield.
S10 2JF

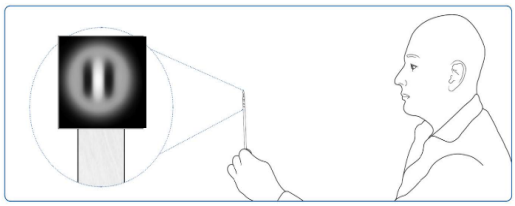
Appendix 3.6 Instructions of simple exercises (Chapter 5)

Information for patients doing pen to nose exercises using a Gabor patch

- This information sheet is a reminder of the exercises you were given at your orthoptic appointment and not a substitute for appointment attendance.
- Your orthoptist will give you a small picture 'Gabor patch' on which you can attach to small fixation stick.
- It is important to remember to practice your exercises as instructed by the orthoptist.
- Initially it is not uncommon for you to feel some discomfort, as you exercise your eye muscles for the first few times. This is normal but it is important to persevere, as improvement will not happen without practice. If you need further guidance regarding your exercises, please contact the research team or orthoptic department.

➢ **Instructions**

1) Hold the Gabor patch target at arm's length from face at eye level, then slowly and gradually bring the target towards your nose watching the picture carefully to see at which point double vision occurs



2) Once the target appears double, hold it at that point and try to make it single again by blinking and focusing your eyes as much as possible. Aim to get it as close as possible to your nose without it appearing double
3) If unable to maintain a single image, take the target back a little until it is single then try again
4) Repeat the exercise for 1 minute
5) This exercise may take some effort, but try to get the picture closer each time.

Information for patients doing jump vergence exercises using a Gabor patch

- This information sheet is a reminder of the exercises you were given at your orthoptic appointment and not a substitute for appointment attendance.
- Your orthoptist will give you a small picture 'Gabor patch' on which you can attach to small fixation stick.
- It is important to remember to practice your exercises as instructed by the orthoptist.
- Initially it is not uncommon for you to feel some discomfort, as you exercise your eye muscles for the first few times. This is normal but it is important to persevere, as improvement will not happen without practice. If you need further guidance regarding your exercises, please contact the research team or orthoptic department.

➢ **Instructions**

1) Hold the Gabor Patch picture in front of your face, at arm's length
2) Look at the target "make sure that it is single"
3) Then look into the distance at an object e.g., a point on the wall 3 meters away, or more
4) While you are looking in the distance, move the Gabor picture a little closer to your face
5) Then look at the Gabor picture, keeping it single for a few seconds
6) Look into the distance again while moving the Gabor picture a little closer to you again
7) Repeat steps until the Gabor picture is double and you cannot make it single

Appendix 4.1 Ethical approval of prospective study: Tele-appointments compared to face-to-face appointments in typical young adults undergoing orthoptic exercises (Chapter 6)

The University Of Sheffield.

Downloaded: 23/11/2022
Approved: 23/11/2022

Hani Alrehaily
Registration number: 200252157
Orthoptics and Ophthalmology
Programme: PhD Full Time

Dear Hani

PROJECT TITLE: Is a short tele-appointment equally effective as a comprehensive orthoptic assessment in young adults undergoing orthoptic exercises?
APPLICATION: Reference Number 049079

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 23/11/2022 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 049079 (form submission date: 21/11/2022); (expected project end date: 28/11/2023).
- Participant information sheet 1111407 version 5 (21/11/2022).
- Participant consent form 1111408 version 3 (19/11/2022).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Kate Chadwick
Ethics Administrator
Health Sciences School

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy:https://www.sheffield.ac.uk/research-services/ethics-integrity/policy
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

Appendix 4.2 Patient information Sheet (Chapter 6)

The University Of Sheffield.

Is a short tele-appointment equally effective as a comprehensive orthoptic assessment in young adults undergoing orthoptic exercises?

You are being invited to take part in a research study

- Before you decide whether to take part, 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. Discuss it with friends and relatives if you wish.
- You are free to decide whether or not to take part in this study.
- If there is anything that is not clear or if would like more information, please contact the study researcher: Hani Alrehaily via email (hadalrehaily1@sheffield.ac.uk) or contact the lead supervisor: Dr Sonia Toor via phone (01142159064) or email (sonia.toor@sheffield.ac.uk).
- Thank you for taking the time to consider taking part in this study.

Why have I been invited?

Convergence is the ability of the two eyes to move inwards to view a near object and accommodation is the ability to make near objects clear. Convergence and accommodation are essential for sustained comfortable clear vision. You are invited to participate in this study as you have normal eyes. You will perform specific visual exercises at home to investigate the efficacy of exercises via tele-appointments versus face-to-face appointments among young adults.

Why is the study needed?

Lots of people have difficulties at one time or another with converging their eyes and maintaining very good close vision. These patients are prescribed eye (orthoptic) exercises and are monitored frequently by an Orthoptist in the hospital eye clinic. However, due to COVID-19, tele-appointments have been used frequently by clinicians and these could be continued in the future to monitor patients who are undergoing eye exercises. Tele-appointments are beneficial as they are inexpensive and easy to use. Additionally reducing the spread of infection, travel costs, waiting times and hassle of being absent from school or work. Moreover, tele-appointments come in line with the NHS long-term plan to minimise in-person clinic visits. Thus, we are investigating if a short tele-appointment equally effective as a comprehensive orthoptic assessment, in young adults undergoing orthoptic exercises? We are carrying out a study using 40 normal participants. If tele-appointments are effective, they will facilitate access to the treatment for the patient and the clinician as well as save expenses for the NHS.

What does taking part in the study involve?

- The study duration will be 3 weeks and you will be completing eye exercises on a daily basis
- You will be reviewed every week, either face-to-face or via video call.
- At your first visit, you will be recruited to the study after you have signed the consent form. You will undergo the inclusion criteria tests, and if you are eligible, will continue with a full eye assessment for baseline measurements of your vision as well as convergence and accommodation functions. See below for further information on the tests performed at the face-to-face visit. You will also complete a questionnaire and be shown how to perform some eye exercises that you will need to do daily at home. Thus, this appointment will take up to 45 minutes.
- We will be comparing two different types of exercises. You will be allocated either to Group A or to Group B and these two groups will complete different types of exercises. You will also be allocated to either the face-to-face appointments group or the tele-appointments group. Therefore, you will be randomised into one of four groups*

1) Group 1: face-to-face appointments and Group A exercises
- You will have the first face to-face visit, then you will attend another 3 face-to-face appointments each lasting up to 30 minutes
- You will be asked to carry out two Group A exercises at home for 3 minutes/ 3 times a day
- You will perform each exercise for 1 minute 30 seconds/ 3 times per day

2) Group 2: tele-appointments and Group A exercises
- You will have the first face to-face visit, then you will attend 2 tele-appointments via video call (10 minutes each) and a final face-to-face appointment (up to 30 minutes)
- You will be asked to carry out two Group A exercises at home for 3 minutes/ 3 times a day
- You will perform each exercise for 1 minute 30 seconds/ 3 times per day.

3) Group 3: face-to-face appointments and Group B exercises

- You will have the first face to-face visit, then you will attend another 3 face-to-face appointments each lasting up to 30 minutes
- You will be asked to carry out two Group B exercises at home for 3 minutes/ 3 times a day
- You will perform each exercise for 1 minute 30 seconds/ 3 times per day

4) Group 4: tele-appointments and Group B exercises

- You will have the first face to-face visit, then you will attend 2 tele-appointments via video call (10 minutes each) and a final face-to-face appointment (up to 30 minutes)
- You will be asked to carry out two Group B exercises at home for 3 minutes/ 3 times a day
- You will perform each exercise for 1 minute 30 seconds/ 3 times per day

*Randomisation means you will have a chance of being allocated to any one of four exercises groups. You will not be able to choose the treatment group you prefer.

- You will need to complete a diary of your exercises to show the researchers which exercises where completed and for how long each day

- Face-to-face appointments will take place in vision science room, Orthoptic Department, E floor in the Medical School, University of Sheffield.

- During the face-to-face appointments, a range of different tests will measure your vision, convergence and accommodation. These are all non-invasive common clinical eye tests that are routinely performed at an orthoptic appointment. Examples of the tests include:

    - Reading aloud different letters from a chart.
    - Watching a target move closer to you and letting us know when this becomes blurred or double.
    - Looking at a target through prisms and letting us know when this becomes blurred or double.

- You will also have your accommodation and convergence tested with a non-contact and non-invasive automated device (Plusoptix photorefractor). This will take up to 10 minutes at each face-to-face appointment.

- Tele-appointments will take place by video call using Google Meet. At each tele-appointment we will check there are no problems and ensure the eye exercises are being performed correctly

Hani Alrehaily
Study ID: 049079
Participant Information Sheet v5.0
21/11/2022

- You will be asked to complete a Convergence Insufficiency Symptom Survey questionnaire about your eye symptoms at each appointment (face-to-face and tele-appointments).

* An overview showing the duration, number of exercise groups, types of appointments, and what is required during the study

Study duration	21 days				
First appointment (45 minutes)	Inclusion, consent and recruitment				
	Face-to face - All tests				
	Randomisation to one of four groups	***Group 1***	***Group 2***	***Group 3***	***Group 4***
	Prescription of the exercises	Group A exercises 3 minutes/3 times per day	Group A exercises 3 minutes/3 times per day	Group B exercises 3 minutes/3 times per day	Group B exercises 3 minutes/3 times per day
	1 week of exercises				
Second appointment		Face-to-face (30 minutes)	Tele-appointment (10 minutes)	Face-to-face (30 minutes)	Tele-appointment (10 minutes)
	1 week of exercises				
Third appointment		Face-to-face (30 minutes)	Tele-appointment (10 minutes)	Face-to-face (30 minutes)	Tele-appointment (10 minutes)
	1 week of exercises				
Fourth appointment		Face-to-face (30 minutes)	Face-to-face (30 minutes)	Face-to-face (30 minutes)	Face-to-face (30 minutes)
	End of study				

Do I have to take part?

- No, it is completely up to you.

- Only eligible participants will be enrolled.

- If you decide to take part, you will be asked to sign a consent form.
- You are free to withdraw at any time, without giving a reason.

Are there any risks for me in joining the study?

- All the tests are non-invasive and there is very little risk involved in taking part in this study. However, it is expected to take up to 45 minutes at first visit to complete all the tasks and this may make your eyes tired.
- You may experience tired eyes and fatigue after performing the exercises at home, but these are commonly prescribed eye exercises that will be prescribed following typical guidelines on duration and frequency.
- You will be advised to rest your eyes following a session of exercises by closing your eyes or looking into the distance to minimise the risk of fatigue.
- The face-to-face appointments will pose a risk of COVID. Please see the University of Sheffield Safety guidance.
  https://www.sheffield.ac.uk/coronavirus/safety-guidance

Are there any benefits for me in joining the study?

- There will be no immediate direct benefit to you should you participate.
- There should be benefits to future convergence and accommodation patients receiving treatment because the study results will indicate the effectiveness of tele-appointments versus face-to-face appointments.
- As a gesture of thanks, you will be offered £30 shopping voucher when returning the exercise tools at the end of the study.
- If we discover an abnormality in the eye, we will provide you with advice and ask you to seek care.

How do I withdraw if I want to do so?

- You are free to withdraw at any time, without giving a reason.
- You can withdraw by emailing hadalrehaily1@sheffield.ac.uk or sonia.toor@sheffield.ac.uk

Hani Alrehaily
Study ID: 049079
Participant Information Sheet v5.0
21/11/2022

- If you withdraw from the study, we will keep the information about you that we have already obtained. To safeguard your rights, we will use the minimum personally identifiable information possible.

Can I know the results obtained from the study?

- You can choose whether you would like to receive information about the progress of the study. If you would, please let the study researcher Hani Alrehaily know your preferred postal or email address.

Who has approved the study?

- All research in the University of Sheffield is in accordance with the University's Research Ethics Policy to protect your safety, rights, wellbeing and dignity.

Who is organising this study?

- The University of Sheffield is the sponsor for this study.
- The research is being done as part of a PhD research study.

How will information about me be kept confidential?

- We will protect your privacy at all times.
- All study data will be stored with restricted access. Access to the study database will be password protected and will be used only by named researchers working on this study under the direct supervision of the academic supervisors.
- We will collect the minimum personally identifiable information needed for the purposes of the study.
- All study information will be stored securely at the University of Sheffield. The University of Sheffield will keep identifiable information about you for 10 years after the study has finished. For more information about The University of Sheffield records retention schedule: https://www.sheffield.ac.uk/uso/records-management-policy-and-guidance

- You can find out more about how we use your information at https://www.sheffieldclinicalresearch.org/

General Data Protection Regulation (GDPR):

- We will act as the data controller for this study. This means that we are responsible for looking after the participants' information and using it properly.
- The study will collect the minimum personally identifiable information needed for the purposes of the research project. Any non-anonymised data which is patient-identifiable will not be shared unless the participant provides explicit consent.
- Anonymity, confidentiality and data protection are covered in the University's 'Ethics Policy Governing'.

Who will be able to use my information and results?

- Your anonymous information will be available only to researchers who have relevant scientific and ethics approvals for their planned research.
- The research is being done as part of a PhD and the data collected will be used anonymously for articles, conferences, and other ways of sharing research evidence.
- Data will remain accessible for authorised people throughout the study conduct, and until the final publication of results (if applicable).
- Data collected through this study will be suitable to share in an anonymised format for other interested researchers.
- Any non-anonymised data which is patient-identifiable will not be shared unless explicit consent is provided by the participant.
- The University of Sheffield's Good Research and Innovation Practice (GRIP) Policy follows RCUK principles for data sharing: http://www.rcuk.ac.uk/research/datapolicy/

Hani Alrehaily
Study ID: 049079
Participant Information Sheet v5.0
21/11/2022

What will be stored of the research database?

- Your anonymised data and definitive project documentation will be stored on centrally provisioned University of Sheffield virtual servers and research storage infrastructure throughout the lifetime of the project.
- Consent forms will be kept in a locked filing cabinet in the chief investigator's locked office.
- The link to the university research storage is: https://students.sheffield.ac.uk/it-services/research/storage/standard

What if something goes wrong?

- If you have a concern or complaint about the study, you can contact Head of Division of Ophthalmology & Orthoptics Professor Helen Davis

h.davis@sheffield.ac.uk
+44 114 215 9005
The Medical School
University of Sheffield

Appendix 4.3 Participant consent form for participating in "Is a short tele-appointment equally effective as a comperhinsive orthoptic assessment in young adults undergoing orthoptic exercises" (Chapter 6)

Name of Researcher: Hani Alrehaily
Study ID: 049079
Consent form v3.0
19/11/2022

The University Of Sheffield.

Participant Number:

Consent Form

Is a short tele-appointment equally effective as a comprehensive orthoptic assessment in young adults undergoing orthoptic exercises?

Please initial each box:

1. I confirm that I have read the participant information sheet dated / /2022 (version 2.0) and have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. ☐
3. I understand the information I provide, as part of this study, will only be accessed by members of the research team. ☐
4. I understand that the study will collect the minimum personally identifiable information needed. ☐
5. I understand that if I withdraw from the study, information that has already been obtained will be kept. To safeguard your rights, we will use the minimum personally identifiable information possible. ☐
6. I understand that my information, as part of this study, will be used to support other research in the future, and may be shared anonymously with other researchers. ☐
7. I understand that I can receive information about the progress of the study if I wish, and this will require me to provide the researcher with my preferred postal or email address. ☐
8. All study information will be stored securely at the University of Sheffield. Following the University of Sheffield policy, we will keep identifiable information about you for 10 years after the study has finished. ☐
9. I understand that I will attend four appointments during the study, whether face-to-face or tele-appointments via Google meet. ☐
10. I understand that an eye assessment will take place at each face-to-face visit. ☐
11. I will do 2 eye exercises at home for 3 minutes/3 times a day for 3 weeks and record completion in the diary. ☐

Original Copy to: participant
investigator site file

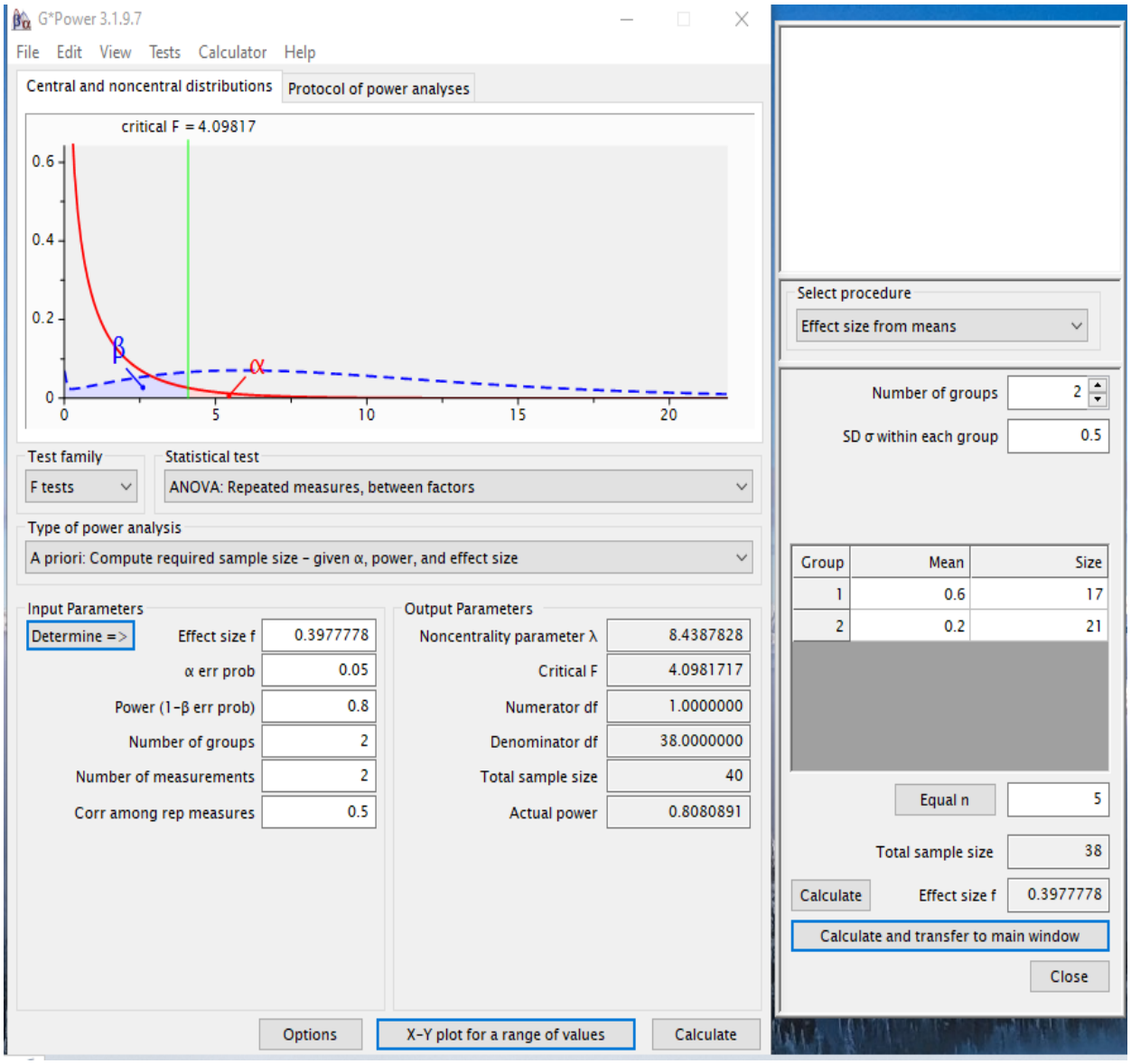
12. I understand that I will be asked to complete a symptom questionnaire at each appointment. ☐

13. I agree to take part in the above study. ☐

Name of Participant	Date	Signature
Name of Person taking consent	Date	Signature

*An original copy of the completed informed consent form and PIS is given to the participant.

Appendix 4.4 Sample size calculations for Chapter 6



Appendix 4.5 Information for Group A (Chapter 6)

"Exercise 1"

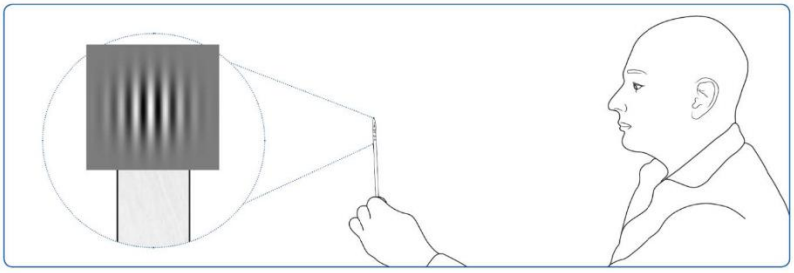
Hani Alrehaily
Study ID: 049079
Group A exercise (#1) instructions v3.0
21/11/2022

Information for Group A exercise (#1)

- This information sheet is a reminder of the exercises you were given at your appointment and not a substitute for appointment attendance.
- You will be given you a small picture 'Gabor patch' as a fixation target
- It is important to remember to practice your exercises as per instructions sheet

➢ **Instructions**

1) Hold the Gabor patch target at arm's length from your face at eye level, then slowly and gradually bring the target towards your nose watching the picture carefully to see at which point double vision occurs



2) Once the target appears double, hold it at that point and try to make it single again by blinking and focusing your eyes as much as possible. Aim to get it as close as possible to your nose without it appearing double
3) If unable to maintain a single image, take the target back a little until it is single then try again
4) Repeat the exercise for 1:30 minutes
5) Record how close you managed to get the target from your nose (estimation)

"Exercise 2"

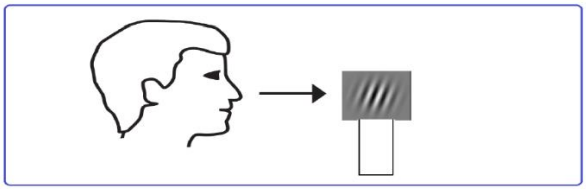
Hani Alrehaily
Study ID: 049079
Group A exercise (#2) instructions v3.0
21/11/2022

Information for Group A exercise (#2)

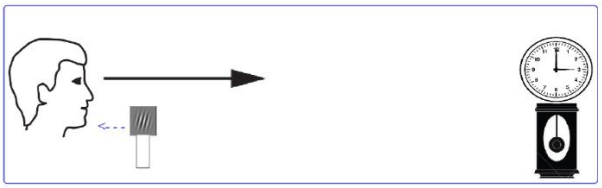
- This information sheet is a reminder of the exercises you were given at your appointment and not a substitute for appointment attendance.
- You will be given you a small picture 'Gabor patch' as a fixation target
- It is important to remember to practice your exercises as per instructions sheet

➢ **Instructions**

1) Hold the Gabor Patch picture in front of your face, at arm's length
2) Look at the target "make sure that it is single"



3) Then look into the distance at an object e.g., a point on the wall 3 meters away, or more
4) While you are looking in the distance, move the Gabor picture a little closer to your face



5) Then look at the Gabor picture, keeping it single for a few seconds

Hani Alrehaily
Study ID: 049079
Group A exercise (#2) instructions v3.0
21/11/2022

6) Look into the distance again while moving the Gabor picture a little closer to you again
7) If the Gabor picture becomes double, try your best to make this single. If you cannot make it single move it back slightly until it becomes single before looking at the distance target again.
8) Repeat this for 1.5 minutes
9) Record how close you managed to get the target from your nose (estimation) and how many jumps you achieved in 1:30 minutes.

Appendix 4.6 Information for Group B (Chapter 6)

"Exercise 1"

Hani Alrehaily
Study ID: 049079
Group B exercise (#1) instructions v3.0
21/11/2022

Information for Group B exercise (#1)

- This information sheet is a reminder of the exercises you were given at your appointment and not a substitute for appointment attendance.
- It is important to remember to practice your exercises as per instructions sheet

Instructions

1) Focus on a fixation point at arm's length
2) Position the prism flippers in front of the eyes
3) While looking through the prism flipper, touch the fixation target with your finger
4) After that, flip the prism flipper to look through the other set of prisms and touch the fixation target again
5) Repeat the procedure for 1:30 minutes.
6) Record the how many flips you achieved within 1:30 minutes

"Exercise 2"

Hani Alrehaily
Study ID: 049079
Group B exercise (#2) instructions v3.0
21/11/2022

Information for Group B exercise (#2)

- This information sheet is a reminder of the exercises you were given at your appointment and not a substitute for appointment attendance.
- It is important to remember to practice your exercises as per instructions sheet

Instructions

1) Hold the Snakes target at an arm's length from your face
2) Maintain fixation on the rotating snakes for 1:30 minutes whilst alternating between trying to get all the snakes rotating at once and then trying to stop all the snakes from rotating.
3) Record the maximum and the minimum number of snakes you have seen rotating during 1:30 minutes

Appendix 4.7 Diary of exercises (Chapter 6)

Group A exercises

Hani Alrehaily
Study ID: 049079
Diary of Group A exercises v3.0
18/11/2022

Diary of Group A exercises (1 & 2)

Participant Number: _____

Training period: _____ TO _____

* **Please remember:**

- Do your best to do the exercises for 1 minute 30 seconds/3 times per day

- Please record when the exercises were done, for how long and how well you did.

- Remember to relax your eyes following exercising. This is done by looking into the distance or by closing them for approximately 1 minute. This should be done before performing any other activity.

- Be honest in your responses

- If you miss any sessions, it is important that this is also recorded below

- Set mobile phone alarms to remind yourself to do the exercises

- Complete the diary and bring the diary to each visit

- Please use additional paper if you run out of space

- If there are any difficulties or if you have any questions, please contact the primary researcher Hani Alrehaily (hadalrehaily1@sheffield.ac.uk)

Date	Time	Training Time	Exercise (#1) - Estimated maximum distance of target from nose	Exercise (#2) – Estimated distance of target from the nose Number of jumps	Any comments
e.g. 21/10/22	e.g. 2pm	e.g. 3 mins	e.g. 8 cm	e.g. 10 cm - 25 jumps	e.g. feeling very tired today

Group B exercises

Hani Alrehaily
Study ID: 049079
Diary of Group B exercises v3.0
21/11/2022

Diary of Group B exercises

Participant Number: _____

Training period: _____ TO _____

* **Please remember:**

- Do your best to do the exercises for 3 minutes/3 times per day (1.5 minutes for each exercise)

- Please record when the exercises were done, for how long and how well you did.

- Remember to relax your eyes following exercising. This is done by looking into the distance or by closing them for approximately 1 minute. This should be done before performing any other activity.

- Be honest in your responses

- If you miss any sessions, it is important that this is also recorded below

- Set mobile phone alarms to remind yourself to do the exercises

- Complete the diary and bring the diary to each visit

- Please use additional paper if you run out of space

- If there are any difficulties or if you have any questions, please contact the primary researcher Hani Alrehaily (hadalrehaily1@sheffield.ac.uk)

Date	Time	Training Time	Number of prism flips	Min moving snakes	Max moving snakes	Any comments
e.g. 21/10/22	e.g. 2pm	e.g. 3 mins	e.g. 10	e.g. 5	e.g. 7	e.g. feeling very tired today

Appendix 5.1 Ethical approval of Questionnaire to investigate the prevalence, investigation and treatment of primary convergence insufficiency (Chapter 7)

The University Of Sheffield.

Downloaded: 10/07/2023
Approved: 10/07/2023

Hani Alrehaily
Registration number: 200252157
Orthoptics and Ophthalmology
Programme: PhD Full Time

Dear Hani

PROJECT TITLE: Questionnaire to investigate the prevalence, investigation and treatment of primary convergence insufficiency
APPLICATION: Reference Number 051274

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 10/07/2023 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 051274 (form submission date: 05/07/2023); (expected project end date: 30/05/2024).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Sophie Tomlinson
Ethics Administrator
Health Sciences School

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy: https://www.sheffield.ac.uk/research-services/ethics-integrity/policy
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

Appendix 5.2 Orthoptists and optometrists questionnaire in the UK (Chapter 7)

Questionnaire to investigate the prevalence, investigation and treatment of primary convergence insufficiency

You are being invited to take part in research at The University of Sheffield by completing a questionnaire. Before you decide whether or not to participate, it is important that you understand why the research is being done and what it will involve. Please take time to read the following information carefully. You can contact us if anything is unclear or if you would like more information.

The main focus of this research is primary convergence insufficiency (CI). The research will compare responses to the questionnaire between different eye care professionals across the UK.

The questionnaire aims to investigate the:
- Prevalence and investigation of primary CI in adults
- Current treatment of primary CI in adults
- Use of tele-appointments to monitor treatment of CI in adults

You have been invited to complete the questionnaire because you are an Orthoptist or Optometrist. The questionnaire should take approximately 10 minutes to complete, and your responses will be anonymous.

It is up to you to decide whether or not to take part in this research project. If you decide to take part, you can proceed to the next section of this questionnaire where you will be asked to give your consent. Your responses will only be used if you click the 'submit' button at the end of the questionnaire. Until that point, you may withdraw from the research project at any time without any negative consequences. After you click the 'submit' button we will be unable to withdraw your data from the study as all data is received anonymously.

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5. Are you identifying primary CI in any of your patients? *

Mark only one oval.

- Yes *Skip to question 6*
- No

6. What action would you take if you identified primary CI? (You can choose more than one answer) *

Tick all that apply.

- [ ] Recommend primary CI treatment at my practice
- [ ] Refer all patients with primary CI to a hospital eye clinic
- [ ] Offer referral to primary CI patients, but not insist on it
- [ ] Refer only patients with primary CI if they are symptomatic
- [ ] Recommend referral to another optometrist for primary CI treatment
- [ ] Orthoptic exercises and review
- [ ] Optometric vision therapy
- [ ] Other: _____

Prevalence

7. Approximately how many patients with primary CI do you currently diagnose per month? *

Mark only one oval.

- 0
- 1-5
- 6-10
- 11-15
- 16+

8. Is this different to the number of primary CI patients diagnosed pre-COVID? *

Mark only one oval.

- Yes *Skip to question 9*
- No *Skip to question 11*

Prevalence

9. Approximately how many patients with primary CI did you diagnose per month pre-COVID? *

Mark only one oval.

- 0
- 1-5
- 6-10
- 11-15
- 16+

10. In your opinion, why do you think there has been a change in the number of primary CI patients attending?

_____
_____
_____
_____
_____

11. What criteria do you use to diagnose primary CI? *

Mark only one oval.

- Only symptoms
- Symptoms with receded Near Point of Convergence
- Only receded Near Point of Convergence
- Symptoms, receded Near Point of Convergence and reduced Prism Fusion Range
- Symptoms, reduced NPC and exophoria <10 x at near
- I would diagnose off reduced near point of convergence even without symptoms but I likely would not treat if asymptomatic
- Other: _____

12. Which of the following treatment options would you prescribe first in primary CI? * (You can choose more than one answer)

Tick all that apply.

- [ ] Smooth/pen convergence
- [ ] Jump vergence
- [ ] Dot card
- [ ] Brock string
- [ ] Stereograms
- [ ] Accommodation exercises
- [ ] Base-in prism
- [ ] No treatment, monitor
- [ ] Vision therapy
- [ ] Depends on severity of CI
- [ ] Other: _____

13. If the primary CI is improving with this treatment, would you add any of the following treatment options to their management? (You can choose more than one answer) *

Tick all that apply.

- [ ] Keep the same treatment
- [ ] Smooth/pen convergence
- [ ] Jump vergence
- [ ] Dot card
- [ ] Brock string
- [ ] Stereograms
- [ ] Accommodation exercises
- [ ] Base-in prism
- [ ] No treatment, monitor
- [ ] Home use Base-in prism bar exercises (made with Fresnel Prisms)
- [ ] Vision therapy
- [ ] Bar reading
- [ ] Depends on severity and patients individual needs
- [ ] I would give out base in prism bar if this was the primary issue or if the CI was not improving despite good compliance with exercises
- [ ] Other: _____

14. How effective do you consider the following treatment methods for primary CI as either the 1st or 2nd line of treatment? *

Mark only one oval per row.

	Not effective	Sometimes effective	Mostly effective	Always effective	Not used
Smooth vergence	◯	◯	◯	◯	◯
Jump vergence	◯	◯	◯	◯	◯
Dot card	◯	◯	◯	◯	◯
Brock string	◯	◯	◯	◯	◯
Stereograms	◯	◯	◯	◯	◯
Accommodative exercises	◯	◯	◯	◯	◯
Base-in prism	◯	◯	◯	◯	◯
No treatment, monitor	◯	◯	◯	◯	◯

15. If you prescribe orthoptic exercises for primary CI, what frequency of treatment do you suggest? *

Mark only one oval.

- ◯ Less than once per day
- ◯ Daily (once per day)
- ◯ Twice a day
- ◯ 2-3 times daily depending on patient likelihood of compliance and severity
- ◯ Three times a day
- ◯ 4-5 times a day
- ◯ 5 mins per day 5 days out of 7
- ◯ 6 or 7 times a day
- ◯ Other: _____

16. If you give exercises for primary CI - how long do you recommend exercises are performed each time? *

Mark only one oval.

- ◯ Less than one minute
- ◯ 1-3 minutes
- ◯ 4-5 minutes
- ◯ More than 5 minutes

17. Do you advise a rest period after exercises are performed? *

Mark only one oval.

- ◯ Yes
- ◯ No

18. What is the average follow-up period you prescribe during treatment of primary CIs? *

Mark only one oval.

- ◯ 1 to 3 weeks
- ◯ 4 to 6 weeks
- ◯ 7 to 9 weeks
- ◯ 10 to 12 weeks
- ◯ More than 12 weeks
- ◯ Varies, depending on symptoms, severity, age of patient
- ◯ Other: _____

19. What outcome measures do you consider as the success criteria of primary CI treatment? *

Mark only one oval.

- ◯ Resolution of symptoms *Skip to question 21*
- ◯ Improvement in symptoms and Near Point of Convergence *Skip to question 21*
- ◯ Improved Near Point of Convergence only *Skip to question 20*
- ◯ Improvement in symptoms, Near Point of Convergence and Positive Fusion Range *Skip to question 21*
- ◯ Other: _____

20. If you selected 'improved Near Point of Convergence only' in the previous question, please specify the distance. *

Mark only one oval.

- ◯ Improved Near Point of Convergence to 6 cm or to nose
- ◯ Improved Near Point of Convergence to 10 cm or less
- ◯ Other: _____

Treatment

21. In your opinion, what may be the cause(s) of lack of treatment success in patients with primary CI? (Please select all that apply) *

Tick all that apply.

- ☐ Exercises for primary CI are not effective
- ☐ Poor compliance with exercises
- ☐ Exercises are effective, but the effect is not maintained
- ☐ Severity of primary CI symptoms
- ☐ Very poor (receded) near point of convergence
- ☐ Size of the deviation (for example heterophoria)
- ☐ Lack of demonstration of the exercises by clinician
- ☐ Poor exercise technique used by the patient
- ☐ Poor attendance for follow up after exercises have been given
- ☐ Would like to see patients more regularly but not an option with such a backlog
- ☐ It is really important to establish a rapport with the patient and engage them with the exercse programme
- ☐ Poor understanding by optoms on CI and using techniques that Scheimann identified as no better than placebo
- ☐ Age of patient
- ☐ Other: _____

22. Do you assess the amplitude of accommodation in primary CI patients? *

Mark only one oval.

- ◯ Yes
- ◯ Yes, if they complain of blur
- ◯ Yes, if referred with accommodation dysfunction
- ◯ No

Video tele-appointments

23. Do you use video tele-appointments for primary CI patients? *

Mark only one oval.

- ◯ Yes - for new CI patients only
- ◯ Yes - for follow up in CI patients only
- ◯ Yes - for new and follow up in CI patients
- ◯ Yes - we offer this to CI patients, but this is patient choice
- ◯ No *Skip to question 25*
- ◯ We did during COVID-19, but we have returned to face-to-face appointments for CI patients
- ◯ Other: _____

Video tele-appointments

24. Would you recommend video tele-appointments to others treating primary CI and why? *

_____

25. Are there any barriers to using video tele-appointments for primary CI patients? (Select all that apply) *

Tick all that apply.

- ☐ No barriers - we do not use tele-appointments
- ☐ No barriers - patients prefer a face-to-face appointment
- ☐ Yes, barrier - it takes longer to see the patient
- ☐ Yes, barrier - there are too many technical problems with tele-appointments
- ☐ Yes, barrier - it is too difficult to accurately assess the patient over tele-appointments
- ☐ Yes, barrier - it is too complicated to have a hybrid clinic of tele-appointments and face-to-face appointments
- ☐ Don't use
- ☐ We find a hybrid of face-to-face and video appointments effective (usually alternate)
- ☐ We are hoping to implement! sorting IT
- ☐ No barrier, we use it
- ☐ I don't believe a tele appt is useful in these situations as you need to be able to assess the patient clinically to for a diagnosis /ongoing treatment plan
- ☐ No barrier for follow ups, barrier to full assessment for new patients
- ☐ We were able to to do it during Covid but not ideal, Zoom kept breaking down
- ☐ Other: _____

Appendix 5.3 Optometrists and ophthalmologists questionnaire in Saudi Arabia (Chapter 7)

Questionnaire to investigate the prevalence, investigation and treatment of primary convergence insufficiency

You are being invited to take part in research at The University of Sheffield by completing a questionnaire. Before you decide whether or not to participate, it is important that you understand why the research is being done and what it will involve. Please take time to read the following information carefully. You can contact us if anything is unclear or if you would like more information.

The main focus of this research is primary convergence insufficiency (CI). The research will compare responses to the questionnaire between different eye care professionals across Saudi Arabia.

The questionnaire aims to investigate the:
- Prevalence and investigation of primary CI in adults
- Current treatment of primary CI in adults
- Use of video-appointments to monitor treatment of CI in adults

You have been invited to complete the questionnaire because you are an Optometrist or ophthalmologist. The questionnaire should take approximately 10 minutes to complete, and your responses will be anonymous.

It is up to you to decide whether or not to take part in this research project. If you decide to take part, you can proceed to the next section of this questionnaire where you will be asked to give your consent. Your responses will only be used if you click the 'submit' button at the end of the questionnaire. Until that point, you may withdraw from the research project at any time without any negative consequences. After you click the 'submit' button we will be unable to withdraw your data from the study as all data is received anonymously.

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3. Are you identifying primary CI any of your patients? *

Mark only one oval.

- ◯ Yes *Skip to question 4*
- ◯ No

4. What action would you take if you identified primary CI? (You can choose more than one answer) *

Tick all that apply.

- ☐ Recommend primary CI treatment at my practice
- ☐ Refer all patients with primary CI to a hospital eye clinic
- ☐ Offer referral to primary CI patients, but not insist on it
- ☐ Refer only patients with primary CI if they are symptomatic
- ☐ Recommend referral to another optometrist for primary CI treatment
- ☐ Other: _____

5. Approximately how many patients with primary CI do you currently diagnose per month? *

Mark only one oval.

- ◯ 0
- ◯ 1-5
- ◯ 6-10
- ◯ 11-15
- ◯ 16+

6. Is this different to the number of primary CI patients diagnosed pre-COVID? *

Mark only one oval.

- ◯ Yes *Skip to question 7*
- ◯ No *Skip to question 9*

Prevalence

7. Approximately how many patients with primary CI did you diagnose per month pre-COVID? *

Mark only one oval.

- ◯ 0
- ◯ 1-5
- ◯ 6-10
- ◯ 11-15
- ◯ 16+

8. In your opinion, why do you think there has been a change in the number of primary CI patients attending?

_____
_____
_____
_____
_____

Treatment

9. What criteria do you use to diagnose primary CI? *

Mark only one oval.

- ◯ Only symptoms
- ◯ Symptoms with receded Near Point of Convergence
- ◯ Only receded Near Point of Convergence
- ◯ Symptoms, receded Near Point of Convergence and reduced Prism Fusion Range
- ◯ Symptoms, receded NPC, reduced fusional range, cover test findings at near and distance, refraction and accommodation
- ◯ NPC only because symptoms can mix with other disorders
- ◯ Other: _____

10. Which of the following treatment options would you prescribe first in primary CI? (You can choose more than one answer) *

Tick all that apply.

- [ ] Smooth/pen convergence
- [ ] Jump vergence
- [ ] Dot card
- [ ] Brock string
- [ ] Stereograms
- [ ] Accommodation exercises
- [ ] Base-in prism
- [ ] No treatment, monitor
- [ ] Spectacles
- [ ] If the patient is symptomatic I will refer and give pen exercises
- [ ] Other: _____

11. If the primary CI is improving with this treatment, would you add any of the following treatment options to their management? (You can choose more than one answer) *

Tick all that apply.

- [ ] Keep the same treatment
- [ ] Smooth/pen convergence
- [ ] Jump vergence
- [ ] Dot card
- [ ] Brock string
- [ ] Stereograms
- [ ] Accommodation exercises
- [ ] Base-in prism
- [ ] No treatment, monitor
- [ ] Refer to our orthoptist
- [ ] Refer to our optometrist
- [ ] Other: _____

12. How effective do you consider the following treatment methods for primary CI as either the 1st or 2nd line of treatment? *

Mark only one oval per row.

	Not effective	Sometimes effective	Mostly effective	Always effective	Not used
Smooth vergence	◯	◯	◯	◯	◯
Jump vergence	◯	◯	◯	◯	◯
Dot card	◯	◯	◯	◯	◯
Brock string	◯	◯	◯	◯	◯
Stereograms	◯	◯	◯	◯	◯
Accommodative exercises	◯	◯	◯	◯	◯
Base-in prism	◯	◯	◯	◯	◯
No treatment, monitor	◯	◯	◯	◯	◯

13. If you prescribe orthoptic exercises for primary CI, what frequency of treatment do you suggest? *

Mark only one oval.

- ◯ Less than once per day
- ◯ Daily (once per day)
- ◯ Twice a day
- ◯ 2-3 times daily depending on patient likelihood of compliance and severity
- ◯ Three times a day
- ◯ 4-5 times a day
- ◯ Other: _____

14. If you give exercises for primary CI - how long do you recommend exercises are performed each time? *

Mark only one oval.

- ◯ Less than one minute
- ◯ 1-3 minutes
- ◯ 4-5 minutes
- ◯ More than 5 minutes

15. Do you advise a rest period after exercises are performed? *

Mark only one oval.

- ◯ Yes
- ◯ No

16. What is the average follow-up period you prescribe during treatment of primary CIs?

Mark only one oval.

- ◯ 1 to 3 weeks
- ◯ 4 to 6 weeks
- ◯ 7 to 9 weeks
- ◯ 10 to 12 weeks
- ◯ More than 12 weeks
- ◯ Not regular
- ◯ Other: _____

17. What outcome measures do you consider as the success criteria of primary CI treatment? *

Mark only one oval.

- ◯ Resolution of symptoms *Skip to question 19*
- ◯ Improvement in symptoms and Near Point of Convergence *Skip to question 19*
- ◯ Improved Near Point of Convergence only *Skip to question 18*
- ◯ Improvement in symptoms, Near Point of Convergence and Positive Fusion Range *Skip to question 19*
- ◯ Other: _____

Skip to question 19

Treatment

18. If you selected 'improved Near Point of Convergence only' in the previous question, please specify the distance. *

Mark only one oval.

- ◯ Improved Near Point of Convergence to 6 cm or to nose
- ◯ Improved Near Point of Convergence to 10 cm or less
- ◯ Other: _____

19. In your opinion, what may be the cause(s) of lack of treatment success in patients with primary CI? (Please select all that apply) *

Tick all that apply.

- [ ] Exercises for primary CI are not effective
- [ ] Poor compliance with exercises
- [ ] Exercises are effective, but the effect is not maintained
- [ ] Severity of primary CI symptoms
- [ ] Very poor (receded) near point of convergence
- [ ] Size of the deviation (for example heterophoria)
- [ ] Lack of demonstration of the exercises by clinician
- [ ] Poor exercise technique used by the patient
- [ ] Poor attendance for follow up after exercises have been given
- [ ] Poor understanding of the problem and misdiagnosis.
- [ ] Other: _____

20. Do you assess the amplitude of accommodation in primary CI patients? *

Mark only one oval.

- ◯ Yes
- ◯ Yes, if they complain of blur
- ◯ Yes, if referred with accommodation dysfunction
- ◯ No

21. Do you use video tele-appointments for primary CI patients? *

Mark only one oval.

- ◯ Yes - for new CI patients only
- ◯ Yes - for follow up in CI patients only
- ◯ Yes - for new and follow up in CI patients
- ◯ Yes - we offer this to CI patients, but this is patient choice
- ◯ No *Skip to question 23*
- ◯ We did during COVID-19, but we have returned to face-to-face appointments for CI patients
- ◯ Other: _____

Video tele-appointments

22. Would you recommend video tele-appointments to others treating primary CI and why?

_____

23. Are there any barriers to using video tele-appointments for primary CI patients? * (Select all that apply)

Tick all that apply.

- [ ] No barriers - we do not use tele-appointments
- [ ] No barriers - patients prefer a face-to-face appointment
- [ ] Yes, barrier - it takes longer to see the patient
- [ ] Yes, barrier - there are too many technical problems with tele-appointments
- [ ] Yes, barrier - it is too difficult to accurately assess the patient over tele-appointments
- [ ] Yes, barrier - it is too complicated to have a hybrid clinic of tele-appointments and face-to-face appointments
- [ ] Don't use
- [ ] We find a hybrid of face-to-face and video appointments effective (usually alternate)
- [ ] We are hoping to implement! sorting IT
- [ ] I don't have the facilty
- [ ] Other: _____

References

Adler, P. M. *et al.* (2007) 'Influence of target type and RAF rule on the measurement of near point of convergence', *Ophthalmic and Physiological Optics*, 27(1), pp. 22–30. doi: 10.1111/j.1475-1313.2006.00418.x.

Aletaha, M. *et al.* (2018) 'Comparison of three vision therapy approaches for convergence insufficiency', *Journal of Ophthalmic and Vision Research*, 13(3), pp. 307–314. doi: 10.4103/jovr.jovr_99_17.

Alghamdi, W. (2020) 'Refractive Errors and Binocular Anomalies in Primary Schools in Uyoun Aljawa: A Small Urban Town in Saudi Arabia', *Global Journal of Health Science*, 12(10), p. 116. doi: 10.5539/gjhs.v12n10p116.

Alghamdi, W. M. *et al.* (2021) 'Refractive Errors and Binocular Vision Anomalies among Young University Students', *Global Journal of Health Science*, 14(1), p. 23. doi: 10.5539/gjhs.v14n1p23.

Alvarez, T. L. *et al.* (2020) 'The Convergence Insufficiency Neuro-mechanism in Adult Population Study (CINAPS) Randomized Clinical Trial: Design, Methods, and Clinical Data', *Ophthalmic Epidemiology*, 27(1), pp. 52–72. doi: 10.1080/09286586.2019.1679192.

American Optometric Association (2011) 'Optometric Clinical Practice Guideline: Care of the pation with Accommodative and Vergence Dysfunction', *American Optometric Association*, p. 107.

Amiebenomo, O., Ovenseri-Ogbomo, G. and Nwacheli, C. (2018) 'Comparing measurement techniques of accommodative amplitude among school children', *Optometry and Visual Performance*, 6(5), pp. 181–186.

Ansons, A. M. and Davis, H. (2014) *Diagnosis and Management of Ocular Motility Disorders*. 4th edn. John Wiley & Sons, Ltd. doi: 10.1002/9781118712368.

Atowa, U. C., Hansraj, R. and Wajuihian, S. O. (2019) 'Accommodative anomalies among school children in Abia State, Nigeria', *African Vision and Eye Health*, 78(1). doi: 10.4102/aveh.v78i1.465.

Aziz, S. *et al.* (2006) 'Are orthoptic exercises an effective treatment for convergence and fusion deficiencies?', *Strabismus*, 14(4), pp. 183–189. doi: 10.1080/09273970601026185.

Baker, C. (2024) *NHS key statistics: England*, *Commons Library Research Briefing*. Available

at: commonslibrary.parliament.uk.
Barrett, B. T. (2009) 'A critical evaluation of the evidence supporting the practice of behavioural vision therapy', *Ophthalmic and Physiological Optics*, 29(1), pp. 4–25. doi: 10.1111/j.1475-1313.2008.00607.x.
Bartuccio, M. (2009) 'THE TREATMENT OF CONVERGENCE INSUFFICIENCY: A HISTORICAL OVERVIEW OF THE LITERATURE.', *Journal of Behavioral Optometry*, 20(1).
Bhutto, Israr A. *et al.* (2020) 'Does orthoptic exercise improve convergence insufficiency? a prospective study at al-ibrahim eye hospital', *Medical Forum Monthly*, 31(12), pp. 132–134.
Birnbaum, M. H. (2008) *Optometric management of nearpoint vision disorders*. Optometric Extension Program Foundation.
Birnbaum, M. H., Soden, R. and Cohen, A. H. (1999) 'Efficacy of vision therapy for convergence insufficiency in an adult male population.', *Journal of the American Optometric Association*, 70(4), p. 225.
Borsting, E. *et al.* (2003) 'Association of symptoms and convergence and accommodative insufficiency in school-age children.', *Optometry (St. Louis, Mo.)*, 74(1), p. 25.
Borsting, E. J. *et al.* (2003) 'Validity and reliability of the revised convergence insufficiency symptom survey in children aged 9 to 18 years', *Optometry and Vision Science*, 80(12), pp. 832–838.
Borsting, E., Rouse, M. W. and De, P. N. L. (1999) 'Prospective comparison of convergence insufficiency and normal binocular children on CIRS symptom surveys. Convergence Insufficiency and Reading Study (CIRS) group.', *Optometry and vision science: official publication of the American Academy of Optometry*, 76(4), pp. 221–228.
Brautaset, R. *et al.* (2008) 'Accommodation insufficiency in children: Are exercises better than reading glasses?', *Strabismus*, 16(2), pp. 65–69. doi: 10.1080/09273970802039763.
Cacho-Martínez, P., García-Muñoz, Á. and Ruiz-Cantero, M. T. (2010) 'Do we really know the prevalence of accomodative and nonstrabismic binocular dysfunctions?', *Journal of Optometry*, 3(4), pp. 185–197. doi: 10.1016/S1888-4296(10)70028-5.
Cacho, P. *et al.* (2002) 'Diagnostic signs of accommodative insufficiency', *Optometry and Vision Science*, 79(9), pp. 614–620. doi: 10.1097/00006324-200209000-00013.
Carvelho, T. *et al.* (2008) 'Computer gaming for vision therapy', *2008 Virtual Rehabilitation,*

IWVR, pp. 198–204. doi: 10.1109/ICVR.2008.4625160.

Chang, M. Y. *et al.* (2021) 'Home- and Office-Based Vergence and Accommodative Therapies for Treatment of Convergence Insufficiency in Children and Young Adults: A Report by the American Academy of Ophthalmology', *Ophthalmology*, 128(12), pp. 1756–1765. doi: 10.1016/j.ophtha.2021.05.017.

Chen, A. M. *et al.* (2020) 'Effectiveness of vergence/accommodative therapy for accommodative dysfunction in children with convergence insufficiency', *Ophthalmic and Physiological Optics*, pp. 1–12. doi: 10.1111/opo.12747.

Chen, D. L. (2013) 'Treatment of convergence insufficiency', *American Orthoptic Journal*.

Ciuffreda, K. J. (2002) 'The scientific basis for and efficacy of optometric vision therapy in nonstrabismic accommodative and vergence disorders', *Optometry*, 73(12), pp. 735–762.

Ciuffreda, K. J. *et al.* (2016) 'Does Vision Therapy Work? The Wrong Question: A Perspective "the power of a lollipop"', *PERSPECTIVE Vision Development & Rehabilitation Vision Dev & Rehab*, 22(22), pp. 101–4.

Ciuffreda, K. J. *et al.* (2020) 'Evaluation and treatment of visual dysfunction', *Brain Injury Medicine. Zasler N, Katz D, Zafonte R.(). Springer/Demos, NY, USA*.

Cooper, J. (1988) 'Accommodative dysfunction', *Diagnosis and management in vision care*, pp. 431–454.

Cooper, J. and Jamal, N. (2012) 'Convergence insufficiency-a major review.', *Optometry (St. Louis, Mo.)*, 83(4), pp. 137–158.

Cooper, J. S. (2007) 'Computerized Vision Therapy For Home And Office Treatment of Accommodative & Vergence Disorders & Amblyopia', *Journal of Behavioral Optometry*, pp. 88–93.

Darko-Takyi, C., Khan, N. E. and Nirghini, U. (2016) 'Symptomatic accommodative disorders and asthenopia: Prevalence and association in Ghanaian children', *African Vision and Eye Health*, 75(1), pp. 1–8. doi: 10.4102/aveh.v75i1.343.

Daum, K. M. (1983) 'Accommodative dysfunction', *Documenta Ophthalmologica*, 55(3), pp. 177–198. doi: 10.1007/BF00140808.

Daum, KENT M (1983) 'Accommodative insufficiency.', *American journal of optometry and physiological optics*, 60(5), pp. 352–359.

Daum, K. M. (1988) 'Characteristics of convergence insufficiency.', *American journal of optometry and physiological optics*, 65(6), pp. 426–438.

DAUM, K. M. (1984) 'Convergence insufficiency', *Optometry and Vision Science*, 61(1), pp. 16–22.

Davis, A. L. *et al.* (2016) 'Convergence Insufficiency, Accommodative Insufficiency, Visual Symptoms, and Astigmatism in Tohono O'odham Students', *Journal of Ophthalmology*, 2016. doi: 10.1155/2016/6963976.

Dawidowsky, B. *et al.* (2019) 'Do Orthoptic Exercises Have Any Influence on Children and Adolescents Diagnosed With Convergence Insufficiency and Attention Deficit/Hyperactivity Disorder?', *Acta clinica Croatica*, 58(4), pp. 662–671. doi: 10.20471/acc.2019.58.04.14.

Dwyer, P. and Wick, B. (1995) 'The influence of refractive correction upon disorders of vergence and accommodation.', *Optometry and vision science: official publication of the American Academy of Optometry*, 72(4), pp. 224–232.

Elsayed, D. A. and Abdou, R. M. (2015) 'The study of convergence insufficiency in children with attention deficit hyperactivity disorder', *The Egyptian Journal of Otolaryngology*, 31(4), pp. 250–253. doi: 10.4103/1012-5574.168361.

Esmail, H. and Arblaster, G. (2016) 'A comparison of the conventional and modified push-up methods of measuring the near point of accommodation', *British and Irish Orthoptic Journal*, 13(0), p. 35. doi: 10.22599/bioj.100.

Evans, B. J. W. (2002) *Pickwell's binocular vision anomalies: investigation and treatment*. Elsevier Health Sciences.

Evans, B. J. W. (2005) *Binocular Vision*. Elsevier/Butterworth-Heinemann (Eye essentials). Available at: https://books.google.co.uk/books?id=yYxsAAAAMAAJ.

Evans, B. J. W. (2007) *Pickwell's Binocular Vision Anomalies*. 5th ed, *USA: Elsevier*. 5th ed.

Fortenbacher, D. L. *et al.* (2018) 'Vision Therapy and Virtual Reality Applications', *Advances in Ophthalmology and Optometry*, 3(1), pp. 39–59. doi: 10.1016/j.yaoo.2018.04.002.

Francis, J. E. *et al.* (2022) 'Utilising Virtual Clinics and Orthoptists to Aid COVID-19 Service Recovery in Adult Strabismus', *British and Irish Orthoptic Journal*, 18(1), pp. 144–151. doi: 10.22599/bioj.273.

Gallaway, M., Scheiman, M. and Malhotra, K. (2002) 'The effectiveness of pencil pushups

treatment for convergence insufficiency: A pilot study', *Optometry and Vision Science*, 79(4), pp. 265–267. doi: 10.1097/00006324-200204000-00013.
Gantz, L. and Stiebel-kalish, H. (2022) 'Convergence insuf fi ciency : Review of clinical diagnostic signs', 15.
García-Muñoz, Á. *et al.* (2016) 'Accommodative and binocular dysfunctions: prevalence in a randomised sample of university students', *Clinical and Experimental Optometry*, 99(4), pp. 313–321. doi: 10.1111/cxo.12376.
García-Muñoz, Á., Carbonell-Bonete, S. and Cacho-Martínez, P. (2014) 'Symptomatology associated with accommodative and binocular vision anomalies', *Journal of Optometry*, 7(4), pp. 178–192. doi: 10.1016/j.optom.2014.06.005.
Garcia, A., Cacho, P. and Lara, F. (2002) 'Evaluating Relative Accommodations in General', *Optometry and Vision Science*, 79(12), pp. 779–787.
Gerbutavicius, R. *et al.* (2021) 'Evaluierung der Patientenzufriedenheit mit einer augenärztlichen Videosprechstunde während der COVID-19-Pandemie', *Der Ophthalmologe : Zeitschrift der Deutschen Ophthalmologischen Gesellschaft*, 118(December 2020), pp. 89–95. doi: 10.1007/s00347-020-01286-0.
Golash, V., Athwal, S. and Khandwala, M. (2021) 'Teleophthalmology and COVID-19: the patient perspective', *Future Healthcare Journal*, 8(1), pp. e54–e59. doi: 10.7861/fhj.2020-0139.
Goss, D. A. (2001) 'The relation between accommodative facility and general binocular dysfunction', *Ophthalmic and Physiological Optics*, 21(6), pp. 484–485. doi: 10.1016/S0275-5408(01)00015-1.
Gwiazda, J. *et al.* (1995) 'Shifts in tonic accommodation after near work are related to refractive errors in children', *Ophthalmic and Physiological Optics*, 15(2), pp. 93–97. doi: 10.1016/0275-5408(95)98238-I.
Hashemi, H. *et al.* (2018) 'Global and regional estimates of prevalence of amblyopia: A systematic review and meta-analysis', *Strabismus*, 26(4), pp. 168–183. doi: 10.1080/09273972.2018.1500618.
Hashemi, H., Khabazkhoob, M., *et al.* (2019) 'Accommodative insufficiency in a student population in Iran', *Journal of Optometry*, 12(3), pp. 161–167. doi:

10.1016/j.optom.2018.03.006.

Hashemi, H., Pakbin, M., *et al.* (2019) 'Near points of convergence and accommodation in a population of university students in Iran', *Journal of ophthalmic & vision research*, 14(3), p. 306.

Hayes, G. J. *et al.* (1998) 'Normative values for the nearpoint of convergence of elementary schoolchildren.', *Optometry and vision science: official publication of the American Academy of Optometry*, 75(7), pp. 506–512.

Helveston, E. M. (2005) 'Visual training: Current status in ophthalmology', *American Journal of Ophthalmology*, 140(5), pp. 903–910. doi: 10.1016/j.ajo.2005.06.003.

Hofsli, M. *et al.* (2023) 'Botulinum Toxin A Injection for Convergence Insufficiency', *Journal of Pediatric Ophthalmology & Strabismus*, 60(2), pp. 108–113.

Hofstetter, H. W. (1950) 'Useful age-amplitude formula', *Optom World*, 38(12), pp. 42–45.

Hokoda, S. C. (1985) 'General binocular dysfunctions in an urban optometry clinic.', *Journal of the American Optometric Association*, 56(7), pp. 560–562.

Horwood, A. M. (2022) 'When Does Blur Matter? A Narrative Review and Commentary', *Journal of Binocular Vision and Ocular Motility*, 72(2), pp. 57–68. doi: 10.1080/2576117X.2022.2033588.

Horwood, A. M. and Riddell, P. M. (2008) 'The use of cues to convergence and accommodation in naïve, uninstructed participants', *Vision Research*, 48(15), pp. 1613–1624. doi: 10.1016/j.visres.2008.04.023.

Horwood, Anna M and Riddell, P. M. (2009) 'A novel experimental method for measuring vergence and accommodation responses to the main near visual cues in typical and atypical groups', *Strabismus*, 17(1), pp. 9–15.

Horwood, A. M. and Riddell, P. M. (2014) 'Disparity-driven vs blur-driven models of accommodation and convergence in binocular vision and intermittent strabismus', *Journal of AAPOS*, 18(6), pp. 576–583. doi: 10.1016/j.jaapos.2014.08.009.

Horwood, A. M., Toor, S. and Riddell, P. M. (2014) 'Screening for convergence insufficiency using the CISS is not indicated in young adults', *British Journal of Ophthalmology*, 98(5), pp. 679–683. doi: 10.1136/bjophthalmol-2013-304533.

Horwood, A. M., Toor, S. S. and Riddell, P. M. (2014) 'Change in convergence and

accommodation after two weeks of eye exercises in typical young adults', *Journal of AAPOS*, 18(2), pp. 162–168. doi: 10.1016/j.jaapos.2013.11.008.
Horwood, A. M. and Waite, P. (2023b) 'Using evidence-based psychological approaches to accommodation anomalies', *Strabismus*, 31(1), pp. 45–54. doi: 10.1080/09273972.2023.2171070.
Horwood, A. and Toor, S. (2014) 'Clinical test responses to different orthoptic exercise regimes in typical young adults', *Ophthalmic and Physiological Optics*, 34(2), pp. 250–262. doi: 10.1111/opo.12109.
Hoseini-Yazdi, S. H. *et al.* (2015) 'Frequency of convergence and accommodative disorders in a clinical population of Mashhad, Iran', *Strabismus*, 23(1), pp. 22–29. doi: 10.3109/09273972.2014.1002622.
Hussaindeen, J. R. and Murali, A. (2020) 'Accommodative insufficiency: Prevalence, impact and treatment options', *Clinical Optometry*, 12, pp. 135–149. doi: 10.2147/OPTO.S224216.
Jang, J., Tai-Hyung, K. and Moon, H. (2017) 'Effectiveness of vision therapy in school children with symptomatic convergence insufficiency', *Journal of Ophthalmic and Vision Research*, 12(2), pp. 187–192. doi: 10.4103/jovr.jovr_249_15.
Jang, J. U. and Park, I. J. (2015) 'Prevalence of general binocular dysfunctions among rural schoolchildren in South Korea', *Taiwan Journal of Ophthalmology*, 5(4), pp. 177–181. doi: 10.1016/j.tjo.2015.07.005.
Jenkins, R. H. (1999) 'Characteristics and diagnosis of convergence insufficiency', *American Orthoptic Journal*, 49(1), pp. 7–11.
Johnston, B. (2011) 'UK telehealth initiatives in palliative care: A review', *International Journal of Palliative Nursing*, 17(6), pp. 301–308. doi: 10.12968/ijpn.2011.17.6.301.
Kim, K. M. and Chun, B. Y. (2011) 'Effectiveness of home-based pencil push-ups (HBPP) for patients with symptomatic convergence insufficiency.', *Korean journal of ophthalmology : KJO*, 25(3), pp. 185–188. doi: 10.3341/kjo.2011.25.3.185.
Lambert, J. (2013) 'Vision therapy and computer orthoptics: Evidence- based approach to use in your practice', *American Orthoptic Journal*, 63(1), pp. 32–35. doi: 10.3368/aoj.63.1.32.
Laria, C. and Piñero, D. P. (2013) 'Evaluation of binocular vision therapy efficacy by 3D video-oculography measurement of binocular alignment and motility', *Binocular Vision and*

Strabology Quarterly, 28(3), pp. 136–145.

Lavrich, J. B. (2010) 'Convergence insufficiency and its current treatment', *Current Opinion in Ophthalmology*, 21(5), pp. 356–360. doi: 10.1097/ICU.0b013e32833cf03a.

Lavrich, J. B. *et al.* (2019) 'Inconsistent diagnostic criteria for convergence insufficiency', *Journal of AAPOS*, 23(1), pp. 1–32. doi: 10.1016/j.jaapos.2018.09.008.

Lee, S. H. *et al.* (2015) 'Effectiveness of Vision Therapy for Children With Symptomatic Convergence Insufficiency With or Without Attention Deficit Hyperactivity Disorder', *Vision Development & Rehabilitation*, 1(3), pp. 229–239. doi: 10.31707/vdr2015.1.3.p229.

Letourneau, J. E. and Ducic, S. (1988) 'Prevalence of convergence insufficiency among elementary school children', *Can J Optom*, 50, pp. 194–197.

Li, S. *et al.* (2022) 'Virtual reality-based vision therapy versus OBVAT in the treatment of convergence insufficiency, accommodative dysfunction: a pilot randomized controlled trial', *BMC Ophthalmology*, 22(1), pp. 1–12. doi: 10.1186/s12886-022-02393-z.

De Lott, L. B. *et al.* (2021) 'Change in ophthalmic clinicians' attitudes toward telemedicine during the coronavirus 2019 pandemic', *Telemedicine and e-Health*, 27(2), pp. 231–235.

Ludden, S. N. M. and Codina, C. J. (2012) 'Is there an ideal speed for the prism fusion range?', *British and Irish Orthoptic Journal*, 10(0), p. 51. doi: 10.22599/bioj.73.

Ma, M. M.-L. *et al.* (2019) 'Vergence and Accommodative Dysfunctions in Emmetropic and Myopic Chinese Young Adults', *Journal of Ophthalmology*, 2019, pp. 1–8. doi: 10.1155/2019/5904903.

Malli, S. S. *et al.* (2013) 'Pencil push-up "The economical and easy answer to symptomatic convergence insufficiency"', *Indian Journal of Applied Basic Medical Sciences*, 15(20), pp. 90–96.

Maples, W. C. (2000) 'Test-retest reliability of the College of Optometrists in Vision Development Quality of Life Outcomes Assessment.', *Optometry (St. Louis, Mo.)*, 71(9), pp. 579–585.

Maples, W. C. and Hoenes, R. (2007) 'Near point of convergence norms measured in elementary school children', *Optometry and Vision Science*, 84(3), pp. 224–228.

Marran, L. F., De Land, P. N. and Nguyen, A. L. (2006) 'Accommodative insufficiency is the primary source of symptoms in children diagnosed with convergence insufficiency',

Optometry and Vision Science, 83(5), pp. 281–289.
Martínez, P. C., Muñoz, Á. G. and Ruiz-Cantero, M. T. (2009) 'Treatment of accommodative and nonstrabismic binocular dysfunctions: A systematic review', *Optometry*, pp. 702–716. doi: 10.1016/j.optm.2009.06.011.
Mary Bartuccio, O., Mary Bartuccio, F. and Jennifer Kieser, B. (2008) 'Accommodative Insufficiency: A Literature and Record Review', *Optometry & Vision Development*, (June).
Matsuo, T. and Ohtsuki, H. (1992) 'Follow-up results of a combination of accommodation and convergence insufficiency in school-age children and adolescents', *Graefe's archive for clinical and experimental ophthalmology*, 230(2), pp. 166–170.
McFarland, S., Coufopolous, A. and Lycett, D. (2021) 'The effect of telehealth versus usual care for home-care patients with long-term conditions: A systematic review, meta-analysis and qualitative synthesis', *Journal of Telemedicine and Telecare*, 27(2), pp. 69–87. doi: 10.1177/1357633X19862956.
McGregor, M. Lou (2014) 'Convergence insufficiency and vision therapy', *Pediatric Clinics of North America*, 61(3), pp. 621–630. doi: 10.1016/j.pcl.2014.03.010.
Middleton, E. M., Sinason, M. D. A. and Davids, Z. (2008) 'Blurred vision due to psychosocial difficulties: A case series', *Eye*, 22(2), pp. 316–317. doi: 10.1038/sj.eye.6703009.
Ming-Leungma, M. *et al.* (2016) 'Effect of vision therapy on accommodation in myopic Chinese children', *Journal of Ophthalmology*, 2016(December). doi: 10.1155/2016/1202469.
Mohamed, Z. and Alrasheed, S. H. (2023) 'A Systematic Review and Meta-analysis of Convergence Insufficiency Prevalence and Management Options', *The Open Ophthalmology Journal*, 17(1), pp. 1–8. doi: 10.2174/18743641-v17-20230712-2023-8.
Momeni-Moghaddam, H. *et al.* (2014) 'Effect of target distance on accommodative amplitude measured using the minus lens technique', *Clinical and Experimental Optometry*, 97(1), pp. 62–65. doi: 10.1111/cxo.12090.
Moon, B. Y., Kim, S. Y. and Yu, D. S. (2020) 'Receiver operating characteristic curve analysis of clinical signs for screening of convergence insufficiency in young adults', *PLoS ONE*, 15(1), pp. 1–14. doi: 10.1371/journal.pone.0228313.
Morettin, C. E. *et al.* (2023) 'Refraction in the Tele-Optometric Examination Compared to Traditional In-Person Refraction in an Adult Population.', *Optometry & Visual Performance*,

11(1), pp. 30–38. Available at: https://search.ebscohost.com/login.aspx?direct=true&db=cul&AN=163152873&site=ehost-live&scope=site.

Al Motowa, S., Khandekar, R. and Al-Towerki, A. (2014a) 'Resources for eye care at secondary and tertiary level government institutions in Saudi Arabia', *Middle East African Journal of Ophthalmology*, 21(2), pp. 142–146. doi: 10.4103/0974-9233.129761.

Al Motowa, S., Khandekar, R. and Al-Towerki, A. (2014b) 'Resources for eye care at secondary and tertiary level government institutions in Saudi Arabia', *Middle East African Journal of Ophthalmology*, 21(2), pp. 142–146.

Nabovati, P. *et al.* (2020) 'The effect of base-in prism on vision-related symptoms and clinical characteristics of young adults with convergence insufficiency; a placebo-controlled randomised clinical trial', *Ophthalmic and Physiological Optics*, pp. 8–16. doi: 10.1111/opo.12654.

Nawrot, P., Michalak, K. P. and Przekoracka-Krawczyk, A. (2013) 'Does home-based vision therapy affect symptoms in young adults with convergence insufficiency', *Optica Applicata*, 43(3), pp. 551–566. doi: 10.5277/oa130314.

NHS (2020) *NHS Improvement 2020 objectives*. Available at: https://www.england.nhs.uk/publication/nhs-improvement-2020-objectives/ (Accessed: 24 October 2023).

NHS (2023) *NHS Data Model and Dictionary*. Available at: https://www.datadictionary.nhs.uk/nhs_business_definitions/telemedicine.html (Accessed: 22 October 2023).

NHS England (2019) *The NHS Long Term Plan. 2019*. Available at: https://www.longtermplan.nhs.uk/ (Accessed: 5 March 2024).

Von Noorden, G. K., & Campos, E. C. (2002) *Binocular Vision and Ocular Motility: Theory and Management of Strabismus*. 6th edn. Mosby- A Harcout Health Science Company.

Nunes, A. F., Monteiro, P. L. and Nunes, A. S. (2020) 'Factor structure of the convergence insufficiency symptom survey questionnaire', *PLoS ONE*, 15(2), pp. 1–9. doi: 10.1371/journal.pone.0229511.

Pang, Y. *et al.* (2010) 'A prospective study of different test targets for the near point of

convergence', *Ophthalmic and Physiological Optics*, 30(3), pp. 298–303. doi: 10.1111/j.1475-1313.2010.00731.x.

Pardhan, S. and Vaughan, M. (2021) 'COVID-19 and its impact on eye care: a review Optometry in Practice (Optometry in Practice COVID-19 and its impact on eye care: a review Background', (April), pp. 1–9.

Parikh, D. *et al.* (2020) 'Advances in Telemedicine in Ophthalmology', *Seminars in Ophthalmology*, pp. 210–215. doi: 10.1080/08820538.2020.1789675.

Pateras, E. and Chrysanthopoulos, A. (2024) 'Amplitude of Accommodation in Young Caucasian Adults in Greece', *Ophthalmology Research: An International Journal*, 19(4), pp. 22–31. doi: 10.9734/or/2024/v19i4429.

Patwardhan, S. *et al.* (2008) 'Preferred clinical practice in convergence insufficiency in India: A survey', *Indian Journal of Ophthalmology*, 56(4), pp. 303–306. doi: 10.4103/0301-4738.39661.

Pickwell, L. D., Viggars, M. A. and Jenkins, T. C. A. (1986) 'Convergence insufficiency in a rural population.', *Ophthalmic & physiological optics*, 6(3).

Pillay, R. and Munsamy, A. J. (2021) 'A review exploring convergence insufficiency in younger populations and e-devices in the digital era', *African Vision and Eye Health*, 80(1), pp. 1–12. doi: 10.4102/AVEH.V80I1.623.

Piñero, D. P. (2016) 'Science Based Vision Therapy', *Journal of Optometry*, 9(4), pp. 203–204. doi: 10.1016/j.optom.2016.07.001.

Press, L. J., Overton, M. and Leslie, S. (2016) 'A Discussion and Analysis, in the context of current research to May 2016, of: A critical evaluation of the evidence supporting the practice of behavioural vision therapy', *Australasian College of Behavioural Optometrists*, (June), pp. 1–53.

Rawstron, J. A., Burley, C. D. and Elder, M. J. (2005) 'A systematic review of the applicability and efficacy of eye exercises', *Journal of Pediatric Ophthalmology and Strabismus*, 42(2), pp. 82–88. doi: 10.3928/01913913-20050301-02.

Revathy, M., Rizwana, H. J. and Kumar, R. K. (2012) 'Effectiveness of Vision Therapy in the Treatment of Symptomatic Convergence Effectiveness of Vision Therapy in the Treatment of Symptomatic Convergence', *Scientific Journal of Medical & Vision Research Foundations*, (2),

pp. 29–32.
Roe, M. *et al.* (2020) 'Implementation of Telehealth for Vision Therapy in an Academic Setting', *Vision Development & Rehabilitation*, 6(2), pp. 173–181. doi: 10.31707/vdr2020.6.2.p173.
Rouse, M. W. (1987) 'Management of binocular anomalies: efficacy of vision therapy in the treatment of accommodative deficiencies.', *American journal of optometry and physiological optics*, 64(6), pp. 415–420.
Rouse, M. W. *et al.* (1998a) 'Frequency of convergence insufficiency in optometry clinic settings. Convergence Insufficiency and Reading Study (CIRS) Group.', *Optometry and vision science: official publication of the American Academy of Optometry*, 75(2), pp. 88–96.
Rouse, M. W. *et al.* (1998b) 'Frequency of convergence insufficiency in optometry clinic settings', *Optometry and Vision Science*, 75(2), pp. 88–96.
Rouse, M. W. *et al.* (1999) 'Frequency of convergence insufficiency among fifth and sixth graders. The Convergence Insufficiency and Reading Study (CIRS) group.', *Optometry and vision science: official publication of the American Academy of Optometry*, 76(9), pp. 643–649.
Rouse, M. W. *et al.* (2004) 'Validity and reliability of the revised convergence insufficiency symptom survey in adults', *Ophthalmic and Physiological Optics*, 24(5), pp. 384–390.
Rowe, F. (2012) *Clinical Orthoptics*. 3rd ed, *UK:Wiley-Blackwell*. 3rd ed. John Wiley & Sons.
Rowe, F. *et al.* (2020) 'Orthoptic services in the UK and Ireland during the covid-19 pandemic', *British and Irish Orthoptic Journal*, 16(June), pp. 29–37. doi: 10.22599/bioj.153.
Rowe, F. J., Hepworth, L. R. and Howard, C. (2021) 'Orthoptic service survey in the UK and Ireland during the interim recovery period (summer 2020) of the COVID-19 pandemic', *Strabismus*, 29(4), pp. 252–266. doi: 10.1080/09273972.2021.1987929.
Russell, G. E. and Wick, B. (1993) 'A prospective study of treatment of accommodative insufficiency.', *Optometry and vision science: official publication of the American Academy of Optometry*, 70(2), pp. 131–135.
Scheiman and Wick, B. (2014) *Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye movement Disorders*. 4th edn. USA: Lippincott Williams & Wilkins.
Scheiman, M. *et al.* (1988) 'Normative study of accommodative facility in elementary

schoolchildren', *Optometry and Vision Science*, pp. 127–134. doi: 10.1097/00006324-198802000-00009.

Scheiman, M. *et al.* (1996) 'Prevalence of vision and ocular disease conditions in a clinical pediatric population.', *Journal of the American Optometric Association*, 67(4), pp. 193–202.

Scheiman, M. *et al.* (2003) 'Nearpoint of convergence: test procedure, target selection, and normative data', *Optometry and Vision Science*, 80(3), pp. 214–225.

Scheiman, M., Mitchell, G. L., Cotter, S., Cooper, J., *et al.* (2005a) 'A randomized clinical trial of treatments for convergence insufficiency in children', *Archives of ophthalmology*, 123(1), pp. 14–24.

Scheiman, M., Mitchell, G. L., Cotter, S., Kulp, M. T., *et al.* (2005b) 'A randomized clinical trial of vision therapy/orthoptics versus pencil pushups for the treatment of convergence insufficiency in young adults', *Optometry and Vision Science*, 82(7), pp. E583–E595.

Scheiman, M. *et al.* (2006) 'Accommodative insufficiency is the primary source of symptoms in children diagnosed with convergence insufficiency [1]', *Optometry and Vision Science*, pp. 857–858. doi: 10.1097/01.opx.0000245513.51878.26.

Scheiman, M. *et al.* (2008) 'Randomized clinical trial of treatments for symptomatic convergence insufficiency in children', *Archives of Ophthalmology*, 126(10), pp. 1336–1349. doi: 10.1001/archopht.126.10.1336.

Scheiman, M. *et al.* (2009) 'Treatment of convergence insufficiency in childhood: a current perspective', *Optometry and vision science: official publication of the American Academy of Optometry*, 86(5), p. 420.

Scheiman, M. *et al.* (2011) 'Treatment of accommodative dysfunction in children: Results from a randomized clinical trial', *Optometry and Vision Science*, 88(11), pp. 1343–1352. doi: 10.1097/OPX.0b013e31822f4d7c.

Scheiman, M. *et al.* (2020) 'Interventions for convergence insufficiency: a network meta-analysis', *Cochrane Database of Systematic Reviews*, (12), p. 73.

Scheiman, M., Gwiazda, J. and Li, T. (2007) 'Non-surgical interventions for convergence insufficiency', *Cochrane Database of Systematic Reviews*, (4). doi: 10.1002/14651858.CD006768.

Scheiman, M., Gwiazda, J. and Li, T. (2011) 'Non-surgical interventions for convergence

insufficiency', *Cochrane Database of Systematic Reviews*. doi: 10.1002/14651858.cd006768.pub2.
Scheiman, M. M. *et al.* (2016) 'Home-based therapy for symptomatic convergence insufficiency in children: a randomized clinical trial', *Optometry and vision science: official publication of the American Academy of Optometry*, 93(12), p. 1457.
Scheiman, M. M. (2018) '2017 Glenn A. Fry Award lecture: Establishing an evidence-based literature for vision therapy-A 25-year journey', *Optometry and Vision Science*, 95(8), pp. 632–642. doi: 10.1097/OPX.0000000000001257.
Sethi, H. S. *et al.* (2006) 'Home Exercises for Convergence Insufficiency in Children', *Archives of Ophthalmology*, 124(2), p. 287. doi: 10.1001/archopht.124.2.287-a.
Sharma, I. P. (2018) 'RAF near point rule for near point of convergence—a short review', *Annals of Eye Science*, 2, pp. 16–16. doi: 10.21037/aes.2017.02.05.
Sharma, M. *et al.* (2020) 'Tele-ophthalmology: Need of the hour', *Indian Journal of Ophthalmology*, 68(7), p. 1328.
Sheedy, J. E. and Saladin, J. J. (1983) 'Validity of diagnostic criteria and case analysis in binocular vision disorders', *Vergence eye movements: basic and clinical aspects. Boston: Butterworths*, pp. 517–540.
Shin, H. S., Park, S. C. and Maples, W. C. (2011) 'Effectiveness of vision therapy for convergence dysfunctions and long-term stability after vision therapy', *Ophthalmic and Physiological Optics*, 31(2), pp. 180–189. doi: 10.1111/j.1475-1313.2011.00821.x.
Shukla, Y. (2020) 'Accommodative anomalies in children', *Indian Journal of Ophthalmology*, 68(8), p. 1520.
Singh, S., Kishor, K. and Kesavan, R. (2020) 'Prevalence of Accommodative Anomaly in High School Children Age from 13 to 17 Year in Clinical Population', *International Journal of Innovative Science and Research Technology*, 5(3), pp. 1–13.
Smith, J., Hirst, N. and Yagan, A. (2023) 'A Quality Assurance Audit of an Orthoptic-Led Virtual Neuro-Ophthalmology Clinic', *British and Irish Orthoptic Journal*, 19(1), pp. 7–14. doi: 10.22599/bioj.289.
Starr, N. B. (2000) 'Vision therapy for learning disabilities and dyslexia.', *Journal of pediatric health care : official publication of National Association of Pediatric Nurse Associates &*

Practitioners, 14(1), pp. 32–33. doi: 10.1016/S0891-5245(00)70042-3.
Sterner, B., Abrahamsson, M. and SjoÈstroÈm, A. (2001) 'The effects of accommodative facility training on a group of children with impaired relative accommodation—a comparison between dioptric treatment and sham treatment', *Ophthalmic and Physiological Optics*, 21(6), pp. 470–476.
Sterner, B., Abrahamsson, M. and Sjostrom, A. (1999) 'Accomodative facility training with a long term follow up in a sample of school aged children showing accomodative dysfunction', *Documenta Ophthalmologica*, 99(1), pp. 93–101. doi: 10.1023/A:1002623107251.
Stidwill, D. (1997) 'Epidemiology of strabismus', *Ophthalmic and Physiological Optics*, 17(6), pp. 536–539. doi: 10.1111/j.1475-1313.1997.tb00094.x.
The British and Irish Orthoptic Society BIOS (2016) 'Guidelines for Convergence and Accommodation Anomalies', 44(0), p. 13. Available at: https://www.orthoptics.org.uk/.
The Royal College of Ophthalmologists (2012) *Guidelines for the Management of Strabismus in Childhood*. London, UK. Available at: https://www.rcophth.ac.uk/resources-listing/guidelines-for-the-management-of-strabismus-in-childhood/.
Tyler, J. M. B. *et al.* (2021) 'The impact of increased outpatient telehealth during COVID-19: Retrospective analysis of patient survey and routine activity data from a major healthcare system in England', *International Journal of Health Planning and Management*, 36(4), pp. 1338–1345. doi: 10.1002/hpm.3185.
Wade, V. A., Eliott, J. A. and Hiller, J. E. (2014) 'Clinician acceptance is the key factor for sustainable telehealth services', *Qualitative health research*, 24(5), pp. 682–694.
Wahlberg, M., Abdi, S. and Brautaset, R. (2010) 'Treatment of accommodative insufficiency with plus lens reading addition: Is +1.00 D better than +2.00 D?', *Strabismus*, 18(2), pp. 67–71. doi: 10.3109/09273972.2010.485243.
Wajuihian, S. O. (2019) 'Normative values for clinical measures used to classify accommodative and vergence anomalies in a sample of high school children in South Africa', *Journal of Optometry*, pp. 143–160. doi: 10.1016/j.optom.2018.03.005.
Wajuihian, S. O. and Hansraj, R. (2014) 'Near vision anomalies in Black high school children in Empangeni, South Africa: A pilot study', *African Vision and Eye Health*, 73(1). doi: 10.4102/aveh.v73i1.4.

Wajuihian, S. O. and Hansraj, R. (2015) ‘A review of non-strabismic accommodative and vergence anomalies in school-age children. Part 2: Accommodative anomalies’, *African Vision and Eye Health*. doi: 10.4102/aveh.v74i1.33.
Wajuihian, S. O. and Hansraj, R. (2016a) ‘Accommodative Anomalies in a Sample of Black High School Students in South Africa’, *Ophthalmic Epidemiology*, 23(5), pp. 316–323. doi: 10.3109/09286586.2016.1155715.
Wajuihian, S. O. and Hansraj, R. (2016b) ‘Accommodative Anomalies in a Sample of Black High School Students in South Africa’, *Ophthalmic Epidemiology*, 23(5), pp. 316–323. doi: 10.3109/09286586.2016.1155715.
Wandile, P. M. (2023) ‘Patient Recruitment in Clinical Trials: Areas of Challenges and Success, a Practical Aspect at the Private Research Site’, *Journal of Biosciences and Medicines*, 11(10), pp. 103–113. doi: 10.4236/jbm.2023.1110010.
Ward, M. K. *et al.* (2015) ‘Mapping the macaque superior temporal sulcus: Functional delineation of vergence and version eye-movement-related activity’, *Journal of Neuroscience*, 35(19), pp. 7428–7442. doi: 10.1523/JNEUROSCI.4203-14.2015.
Warner, M and Zaranko, B. (2022) *The NHS needs to ramp up treatment volumes if waiting lists are to start falling any time soon [Comment] Institute for Fiscal Studies*, *Institute for Fiscal Studies*. Available at: https://ifs.org.uk/articles/nhs-needs-ramp-treatment-volumes-if-waiting-lists-are-start-falling-any-time-soon (Accessed: 29 October 2023).
Warner, M. and Zaranko, B. (2024) ‘The past and future of NHS waiting lists in England’, *The Institute for Fiscal Studies*, (978-1-80103-169–1), p. 29.
Weissberg, E. M. (2004) *Essentials of clinical binocular vision*. Butterworth-Heinemann Medical.
Westman, M. and Liinamaa, M. J. (2012) ‘Relief of asthenopic symptoms with orthoptic exercises in convergence insufficiency is achieved in both adults and children’, *Journal of Optometry*, 5(2), pp. 62–67. doi: 10.1016/j.optom.2012.03.002.
Whitecross, S. (2013) ‘Vision therapy: Are you kidding me? Problems with current studies’, *American Orthoptic Journal*, 63(1), pp. 36–40. doi: 10.3368/aoj.63.1.36.
Wick, B. and Hall, P. (1987) ‘Relation among accommodative facility, lag, and amplitude in elementary school children.’, *American journal of optometry and physiological optics*, 64(8),

pp. 593–598.