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Dedications

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Dedication

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May Allah bless you all and grant you happiness and success

DJAOUI Asma

Dedication

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Abstract

Abstract

Convergence insufficiency is one of the most commonly encountered binocular vision disorders in ophthalmologic consultations. It is characterized by an inability to maintain adequate convergence during near vision tasks, which can disrupt sensory fusion and lead to intermittent diplopia, eyestrain (asthenopia), visual fatigue, headaches, and difficulties with near work.

Rapid screening is possible using simple tests such as the near point of convergence (NPC) test or the Convergence Insufficiency Symptom Survey (CISS). However, a comprehensive binocular vision examination is recommended if convergence insufficiency is suspected. Certain factors, such as traumatic brain injury or other neurological disorders, may be associated with this condition.

The rehabilitation of convergence insufficiency relies on a combination of convergence exercises “both home-based and office-based” that target the eye muscles coordination and strength. These methods improve clinical signs such as NPC and PFV and reduce patient symptoms. Office-based orthoptic therapy, often augmented with prisms and lenses, tends to yield better clinical improvements, though home-based exercises remain valuable, especially when combined with other therapies. The overall goal is to restore comfortable, sustained binocular vision during near tasks, enhancing patients' quality of life and reading performance

As part of this study, several clinical cases were analyzed based on individualized vision therapy programs. The main objective is to observe the progression of clinical signs and symptoms throughout the rehabilitation process and to better understand the potential role of vision therapy in the management of convergence insufficiency. Specifically, four cases were examined: one case of pseudo-convergence insufficiency and three cases of convergence insufficiency associated with accommodative excess. This analysis highlights the diversity of clinical presentations encountered in practice and underscores the value of a personalized approach to vision therapy.

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List of abbreviations

AA: Amplitude of accommodation
AC/A: Accommodative convergence to accommodation ratio
AF: Accommodative facility
CI: Convergence insufficiency
CISS: Convergence insufficiency symptom survey
CITT: Convergence insufficiency treatment trial
cpm: Cycles per minute
D: Diopter
Eso: Esophoria
Exo: Exophoria
Lag/Lead: Accommodative lag or lead
MEM: Monocular estimation method
FV: Negative fusional vergence
NPC: Near point of convergence
OBPT: Office-based placebo therapy
OBVAT: Office-based vergence and accommodative therapy
OD/OS: Right eye/ Left eye
OU: Both eyes
PPA: Near point of accommodation
PFV: Positive fusional vergence
RV: Virtual reality
VA: Visual acuity
VL : Distance vision
VP: Near vision
VT: Vision therapy

General introduction

General introduction:

Binocular vision plays a crucial role in ensuring clear and comfortable vision, especially during near tasks such as reading or using digital devices. Among binocular vision disorders, convergence insufficiency (CI) is one of the most common non-strabismic conditions. It is characterized by a difficulty in maintaining proper eye alignment for near work, often resulting in symptoms such as eye strain, blurred vision, headaches, and difficulty concentrating.

Recent studies estimate that CI affects approximately 3% to 5% of the general population, both children and adults. The condition has gained increasing attention in recent years due to the growing demands of near vision tasks in modern lifestyles, particularly among students and professionals.

Several studies have focused on the diagnosis of convergence insufficiency. However, few studies have explored the therapeutic outcomes of vision rehabilitation, especially in our country. To address this gap, our study aims to investigate the effectiveness of vision therapy in managing convergence insufficiency by analyzing four clinical cases, each following an individualized rehabilitation program.

The objective is to assess both clinical improvements and the reduction of patient-reported symptoms throughout the course of therapy. This research will contribute valuable local data on the benefits of visual rehabilitation for patients with this condition.

This thesis is divided into two main parts:

A theoretical section, which reviews the anatomy and function of convergence, the classification and characteristics of CI, and the principles of vision therapy;

A practical section, which presents and analyzes four clinical cases of CI treated through visual rehabilitation techniques.

THEORETICAL PART

Chapter 1: Binocular vision and its functional mechanisms – Vergence, convergence, accommodation, and their anomalies

I. Introduction:

Binocular vision allows us to perceive a single, three-dimensional image using both eyes. It depends on key mechanisms: vergence, which aligns the eyes on the same target; convergence, a specific type of vergence used for near vision; and accommodation, which sharpens the image by adjusting the lens. These systems work together, especially through the AC/A ratio (accommodative convergence/accommodation), to ensure clear and stable vision. Dysfunction in any of these components can lead to visual issues such as double vision, eye strain, or blurred vision.

II. Physiology of binocular vision:

1. Definition:

The word *binocular* comes from the Latin *bini*, meaning "double," and *oculus*, meaning "eye." Binocular vision is a brain function that allows the perception of two different images one from each eye as a single, unified image. This unity enables binocular fusion and stereoscopic vision, which is the perception of depth or relief. It is a complex sensory process that results in a single image and its accurate localization in space[1].

2. Mechanism of binocular vision:

A. Proper anatomical structure for effective binocular vision, the following conditions must be met:

- The eyeballs, optic nerves, retinas, etc., must be intact
- Monocular visual acuity (in each eye) must be normal and equal
- Any refractive errors must be corrected

B. Normal binocular visual field: in humans, the eyes are positioned at the front of the head, and binocular vision is only possible within a portion of the visual space known as the binocular visual field. This is the overlapping zone of the two monocular visual fields, which reaches a maximum of 130° along the horizontal meridian. On either side, temporal crescents of monocular vision remain, each spanning about 20° to 30°, allowing for panoramic awareness.

C. Normal retinal correspondence: This is a key concept for understanding binocular vision. Corresponding retinal points are homologous points in both eyes. These pairs of

points have the property of producing single vision of an object when they are stimulated simultaneously. At the level of the occipital cortex, images from these corresponding points fuse into a single perception, provided the two transmitted images are identical[1]. The two foveas are corresponding points in individuals with normal binocular vision and define the primary visual direction.

3. Degrees of binocular vision:

Binocular vision has been classified by Worth into three degrees:

A. Simultaneous perception:

Simultaneous perception is based on the principle of confusion, meaning the superimposition of images seen by both maculae. To study this, a different image is presented to each eye using a device called a synoptophore. However, it's important to note that simultaneous perception does not occur in everyday life under normal viewing conditions.

B. Fusion:

Fusion is a physiological mechanism that allows the brain to combine the two images seen by the eyes into a single final perception this is what creates binocular vision. We distinguish between:

- **Sensory fusion:** A cortical process by which two sufficiently similar stimuli are merged into the perception of a single visual object.
- **Motor fusion:** A motor process achieved through vergence movements, allowing sensory fusion to be maintained by keeping stimuli aligned on corresponding retinal points.

C. Stereoscopic vision:

Stereoscopic vision is based on what is called fixation disparity the fact that an object is not seen in exactly the same way by the right eye and the left eye. It is the cortical integration of these two different images that creates the sensation of depth or 3D relief[1].

III. Definition of heterophorias:

Heterophorias are hidden eye misalignments that are kept in check by visual fusion and only appear when that fusion is disrupted. Unlike general binocular imbalances, they involve real oculomotor misalignment and require constant visual effort to stay compensated, especially when sensory or motor challenges exist. Sensory function is usually normal, with proper binocular vision and retinal correspondence. However, if compensation fails, the brain may suppress input from one eye to avoid double vision. Eye movements remain normal in basic heterophorias, but vertical deviations can appear during decompensation. Once fusion is restored, the eyes realign automatically.

The term phoria refers to a latent eye imbalance, as opposed to tropia, a visible deviation that often impairs binocular vision. In heterophorias, binocular functions like stereopsis and retinal correspondence are preserved, setting them apart from intermittent strabismus[2,3].

-The definition given by Lanthony describes:

"A latent strabismic deviation, revealed by sufficient dissociation, followed by sensory and motor recovery upon interruption."

The different types of heterophoria the following distinctions are made:

- **Exophoria:** a divergent deviation.
- **Esophoria:** a convergent deviation of the visual axes.
- **Hyperphoria:** vertical deviation upward.
- **Hypophoria:** vertical deviation downward.
- **Incyclophoria or excyclophoria:** a rotational deviation of the eyeballs.

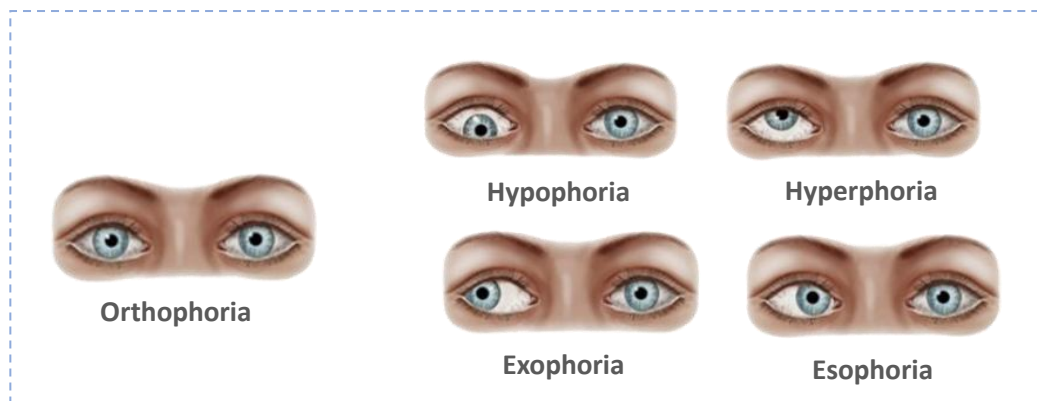


Figure (I-1): Types of heterophoria

IV. Fixation disparity: understanding, influencing factors, and clinical implications:

Fixation disparity is a binocular vision condition in which the two visual axes do not intersect precisely on the fixation point, yet fusion is still maintained. The images of the fixated object do not stimulate exactly corresponding retinal points but still fall within Panum's fusional areas, allowing for a single, fused perception of the object[4].

Several factors influence the measurement of fixation disparity, including accommodation-vergence interaction, perceptual biases (like nonius bias), fusion lock placement, lighting, task demands, test conditions, and resting vergence levels. Clinically, the aim is to reduce stress on the visual system by stabilizing eye alignment using prisms, lenses, or vision therapy. However, evidence supporting treatments based solely on fixation disparity remains limited, so clinicians should interpret results with caution[5].

V. Vergence eye movements and anomalies:

1. Overview of vergence eye movements:

Vergence movements are slow, disjunctive eye movements that align the eyes in opposite directions when focusing along the sagittal plane. There are two types: convergence (eyes move inward) and divergence (eyes move outward). These movements are crucial for the fusion reflex and binocular vision. The vergence reflex appears early in development, detectable by six months, though briefly sustained and reaches full maturity around 12 to 13 years of age[6].

2. Classification of vergence anomalies:

Vergence disorders are abnormalities in the disjunctive eye movements, affecting the eyes' ability to converge or diverge properly. This leads to imprecise fixation and poor image stabilization on the retina. Two main classification systems are used to categorize these disorders: Duane's and Wick's, each with its own strengths and limitations[7].

Functional anomalies:

Disorder	Description
Convergence insufficiency	Excessive exophoria at near, with a receded near point of convergence (NPC).
Divergence insufficiency	Marked esophoria at distance, due to reduced divergence ability.
Convergence excess	Greater esophoria at near than at distance, often causing visual discomfort.
Divergence excess	Intermittent exotropia, primarily noticeable at distance.
Fusional vergence dysfunction	Reduced fusional vergence reserves despite normal phoria levels.
Basic esophoria	Equal esophoria at near and distance, linked to increased tonic vergence.
Basic exophoria	Equal exophoria at near and distance, due to reduced tonic vergence.

Non-functional anomalies:

Disorder	Description
Convergence paralysis	Severe form of convergence insufficiency; diplopia only at near, normal adduction, and inability to converge. Often linked to neurological/systemic causes.
Convergence spasm	Involuntary over-convergence of the eyes, usually accompanied by accommodative spasm.
Divergence paralysis	Marked esophoria at distance with limited divergence ability.

Table (I-1): Vergence anomalies: functional and non-functional

VI. Convergence: mechanism, characteristics and different types of convergence:

Convergence is defined as the alignment of the visual axes so that they intersect at a specific point. It is measured in prism diopters (Δ) or degrees ($^{\circ}$). The point where both axes meet during maximum convergence effort is called the near point of convergence (NPC). The convergence angle depends on the object's distance and the interpupillary distance. The closer the object and the greater the interpupillary distance, the larger the required convergence angle[6].

1. Characteristics of convergence:

Convergence is characterized by several key elements:

- a) Voluntary component:** A healthy individual can initiate the convergence mechanism at any moment. However, this action is difficult to maintain over time, as it demands significant effort from the ocular system. This can quickly lead to fatigue.
- b) Involuntary (or reflex) Component:** When an individual engages in near vision tasks, their convergence system is automatically activated. Without conscious effort, the eyes adjust according to the position required for reading or other near activities. given the daily alternation between near and distant vision, individuals rarely notice when they are actively using their convergence.
- c) Slow process:** according to maddox, vergence movements are the slowest in the oculomotor system, occurring at speeds greater than 20 degrees per second.
- d) Close relationship with accommodation:** convergence is closely linked with accommodation. it is difficult to separate these two mechanisms, as they work in constant complementarity. when convergence is required, accommodation is also necessary[8].

2. Types of convergence:

Convergence can be voluntary (when you choose to focus your eyes) or reflex(automatic).

Reflex types of convergence:

- a) Tonic convergence:** Even when you're not looking at anything, your eyes naturally stay slightly turned in. This helps keep them aligned. It's stronger in babies and can be affected by stress or tiredness.

- b) **Accommodative convergence:** Happens when you focus on something close. Your eyes turn in automatically to keep the image sharp. It works together with focusing (accommodation).
- c) **Fusional convergence:** Helps your eyes fix small misalignments so you see one single image instead of double. It's very important for depth vision.
- d) **Proximal convergence:** Happens when you realize something is near. Your eyes prepare to turn in, even before actually focusing[8].

VII. Accommodation and its relationship with convergence, including the classification of accommodative disorders:

1. Definition:

Accommodation allows the human eye to adjust its focus and see clearly at different distances. This process involves the contraction of the ciliary muscle, which relaxes the suspensory ligament (the zonule), enabling the lens to passively become more convex. This increased curvature provides the necessary vergence for near vision. Presbyopia occurs when accommodation is no longer sufficient to maintain clear focus at close range. Understanding the mechanisms of accommodation helps explain the gradual onset of presbyopia and supports the development of effective surgical correction strategies[9].

2. The structures responsible for accommodation:

Accommodation involves several key structures:

- **Ciliary Muscle:** A ring-shaped muscle that contracts under parasympathetic control. Its contraction reduces tension on the zonular fibers, allowing the lens to become more convex for near vision.
- **Zonule (Suspensory Ligament):** A network of fibers that connects the ciliary muscle to the lens. It transmits tension changes—tightening to flatten the lens for distance vision, and loosening to thicken the lens for near vision.
- **Lens:** A transparent, biconvex structure that changes shape to focus light on the retina. With age, it loses flexibility (causing presbyopia) and can develop cataracts, leading to vision impairment.
- **Nervous System:** The parasympathetic fibers of the oculomotor nerve (cranial nerve III) control the ciliary muscle, initiating accommodation[9].

3. Amplitude of accommodation:

To measure the amplitude of accommodation (AA), the push-up method to the near point (punctum proximum) is recommended. For a given age, there is an expected range of values that are considered normal. Hofstetter's formulas are used to estimate the average, maximum, and minimum amplitude of accommodation based on age.

In practice, a higher-than-average accommodation is not a concern. What is considered abnormal or suspicious is an amplitude that falls below the minimum expected value for the person's age.

Here is Hofstetter's formula to calculate the minimum expected AA:

$$\text{Minimum expected AA (in diopters)} = 15 - 0.25 \times \text{age}$$

For example, for a 30-year-old person:

$$\text{Minimum AA} = 15 - 0.25 \times 30 = 15 - 7.5 = 7.5 \text{ D}$$

Note: In your original example, there was a miscalculation. The formula used "15 - 44 × 20 = 10 D," which appears to be incorrect.

4. Accommodative anomalies: definition and classification:

Accommodative anomalies are neuromuscular dysfunctions of the visual system that affect the eye's ability to focus properly. These conditions are non-refractive and non-age-related but result in blurry retinal images due to inadequate accommodative accuracy, flexibility, and amplitude. Because their boundaries are unclear, classifying these disorders has been challenging. Different authors have proposed various classification systems, categorizing these anomalies into three, five, or six groups, often with slight variations in terminology[7].

The classification of accommodative disorders varies slightly depending on the authors. The following classification is inspired by that of Duke-Elder. Six different anomalies of accommodation can be identified:

Disorder	Definition	Main Symptoms	Key characteristics
Accommodative Excess	Overactive accommodation with difficulty relaxing focus.	Eye strain, headaches, intermittent blurred vision.	The eye stays in near-focus mode even when it's no longer needed.
Accommodative Spasm	Involuntary and continuous contraction of the ciliary muscle.	Blurred distance vision, visual discomfort, pseudo-myopia.	Involuntary and excessive accommodative response.
Accommodative Insufficiency	Reduced ability to focus on near objects compared to age norms.	Difficulty reading, near blur, eye fatigue.	Accommodative amplitude is ≥ 2 diopters below expected (per Hofstetter's formula).
Accommodative Fatigue	Normal accommodation initially, but weakens with prolonged near work.	Fluctuating clarity, discomfort after sustained reading.	Temporary insufficiency that develops with effort or time.
Accommodative Inertia	Delayed or slow change in focus between near and far objects.	Temporary blur when shifting focus, hesitation in clarity adjustment.	Normal strength, but slow to activate or relax.
Accommodative Paralysis / Paresis	Severely reduced or absent accommodative ability.	Persistent near blur, inability to focus at near.	Often due to neurological or pharmacological causes, may affect one or both eyes.

Table (I-2): Accommodative disorders

Accommodative insufficiency, accommodative excess, and accommodative inertia are the most common anomalies. Accommodative paralysis, true accommodative spasm, and accommodative fatigue are rarer and represent only a small percentage of accommodative

5. The relationship between accommodation and convergence:

Relationship accommodation-convergence:

An uncorrected spherical error can lead to an abnormal effort of accommodation. In hypermetropia, accommodation is excessive, while in myopia, accommodation is reduced for near vision. Since accommodation is linked to convergence, abnormal accommodation can place stress on the convergence system. As a general rule, if significant esophoria is found, the practitioner should carefully search for hypermetropia. In young patients, significant esophoria is an indication for cycloplegia (temporary paralysis of accommodation) to accurately measure the necessary correction[10].

VIII. AC/A ratio:

1. Definition:

The AC/A ratio is the relationship between the amount of convergence produced by the stimulus to accommodate (accommodative convergence, measured in prism dioptres) and the amount of accommodation (measured in dioptres) which produces that convergence[11].

2. Measurement of the AC/A Ratio:

The aim is to obtain the relationship between accommodative convergence and accommodation when proximal and fusional convergence are eliminated. Proximal convergence is eliminated using a distant object and fusional convergence by dissociating the eyes., the more common methods for measuring the AC/A ratio used are:

- a) Gradient method with prisms:** the deviation at 6 metres is measured with prisms, using the smallest Snellen's type possible. Measurements are made firstly with glasses if worn, and then with minus spheres (e.g. -3.0 D sph.).

Δ = deviation at 6 m

ΔD = deviation at 6 m. with -3 D sph.

$$AC/A = \frac{\Delta D - \Delta}{D}$$

D = strength of minus lenses used.

Although this method eliminates proximal and fusional convergence it is not as accurate as the graphic method as it is not possible to determine whether the relationship is linear.

- b) Heterophoria method (Burian):** the deviation is measured at 6 metres with 6/6 Snellen's test type and then at 1 metre with 6/6 reduced Snellen's type.

Δn = deviation for near

Δ = deviation for distance

N = accommodation exerted (i.e. 3 dioptres at 1 metre)

$$AC/A = 1 \text{ P.D.} + \frac{(\Delta n - \Delta)}{N}$$

3. Significance of the AC/A Ratio:

If the AC/A ratio is abnormally high, excessive accommodative convergence is exerted on accommodation. A high AC/A ratio is found in patients with accommodative squints of the convergence excess type.

If the AC/A ratio is low, less accommodative convergence takes place on accommodation and the eyes will be relatively divergent. Although the AC/A ratio is an important factor in determining the type of deviation present, its significance in both the aetiology and treatment of squints is debatable. It is believed that the AC/A ratio is inborn and remains constant throughout life[4].

IX. How does binocular vision influence the ability to converge?

Binocular vision depends on the coordinated use of both eyes to merge the images seen by each eye into a single, clear, and three-dimensional perception. A crucial motor mechanism that enables this fusion is “convergence”, which is the inward turning of both eyes to focus on a near object[12].

The ability to converge directly affects the quality of binocular vision. Effective convergence ensures that the images from each eye fall on corresponding retinal points, allowing the brain to fuse them into one clear image with proper depth perception. Conversely, if convergence is insufficient, as in convergence insufficiency, the eyes fail to align properly on near targets. This misalignment disrupts binocular fusion, leading to symptoms such as double vision, eye strain, difficulty maintaining focus, and reduced depth perception.

X. Conclusion:

In summary, convergence is a key motor function that enables the eyes to work together for binocular vision. Without adequate convergence, binocular vision is impaired, highlighting the essential role of convergence in maintaining comfortable and functional binocular vision during near tasks.

Chapter 2: Convergence insufficiency –description and diagnosis

I. Introduction:

Convergence insufficiency (CI), first described in 1855 by Von Graefe [13] and later revisited by Duane, is a binocular vision disorder characterized by inadequate ocular convergence, resulting in difficulty maintaining a single, clear, and comfortable binocular vision at near. CI is particularly relevant in today's digital era, as prolonged near work on mobile devices and computers has increased its prevalence and impact.

Despite its well-documented symptoms, the diagnostic criteria and management of CI remain inconsistent in the literature. Variations in measurement techniques, normative values, and clinical signs often lead to discrepancies in diagnosis [14].

This chapter aims to clarify CI by exploring its definition, classification, contributing factors (heterophorias, AC/A ratio), etiology, clinical symptoms, and diagnostic methods. Emphasis is placed on the importance of standardized diagnostic criteria to ensure consistency in clinical practice and future research.

II. Definition and prevalence of convergence insufficiency:

Convergence insufficiency (CI) is a common non-strabismic binocular vision disorder characterized by an inability to properly converge the eyes when focusing on near objects. It is defined by:

- Exophoria at near
- Orthophoria or low exophoria at distance
- Receded near point of convergence (NPC)
- Reduced positive fusional vergence (PFV)
- Low AC/A ratio

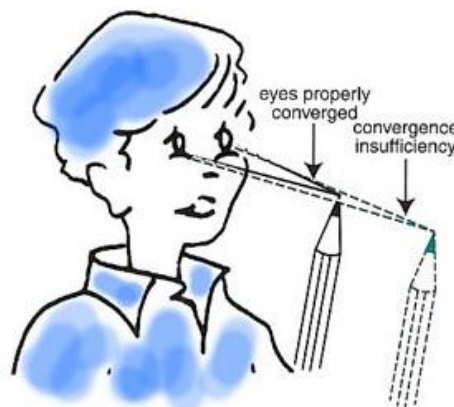


Figure (II-1): Illustration of convergence insufficiency vs. normal convergence

Among non-strabismic binocular vision disorders, CI is the most prevalent, affecting approximately 3% to 5% of the population. Several studies have examined the prevalence of CI in different age groups and settings[12]:

Scheiman et al.

- Defined CI as a receded NPC with at least three additional findings (low PFV, exophoria greater at near, or low AC/A ratio).
- Found 5.3% prevalence in 1,650 children (6–18 years old).

Rouse et al.

- Defined "definite CI" as exophoria at near $\geq 4\Delta$ greater than distance, receded NPC, and insufficient PFV.
- 6% prevalence in clinic setting (8–12 years old)
- 4.2% prevalence in school screenings (9–12 years old)

Porcar & Martinez-Palomera.

- Defined CI as exophoria at near $> 6\Delta$, low AC/A ratio, reduced PFV, and receded NPC.
- Found 7.7% prevalence in 65 university students.

III. Classification of convergence insufficiency:

1. Primary and secondary forms of CI:

Convergence insufficiency can be classified into two main categories: primary CI, which results from a fundamental deficit in convergence mechanisms, and secondary CI, which arises from underlying anomalies[10]. The diagram below illustrates this classification:

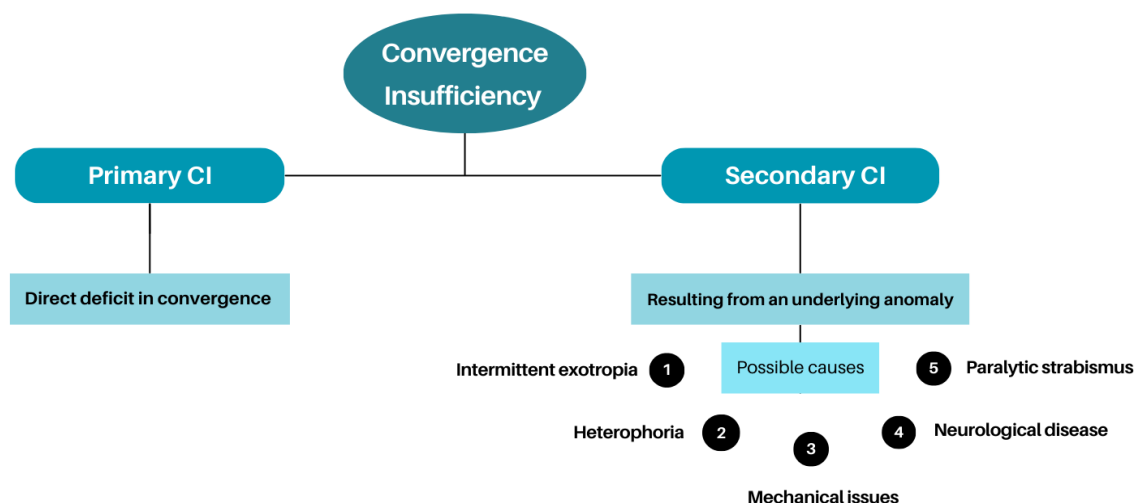


Figure (II-2): Differentiation between primary and secondary CI

2. Convergence insufficiency and decompensated exophoria:

There is a difference in terminology between North America and the UK regarding near exophoria associated with convergence weakness. In North America, convergence insufficiency describes a near exophoria with low positive fusional reserves and a receded near point of convergence, based on criteria like those of Rouse et al., who estimated its prevalence at 18% in optometry clinics and classified subjects as low suspect, high suspect, or definite convergence insufficiency. In contrast, in the UK, similar clinical findings are usually described as decompensated near exophoria or convergence weakness exophoria, while "convergence insufficiency" referring more specifically to a receded near point of convergence, even if it is not always accompanied by exophoria[10].

3. Isolated convergence insufficiency:

Pure convergence insufficiency (also called "true convergence insufficiency") is relatively common in clinical practice. This condition is not strictly a heterophoria but rather a convergence anomaly. A patient may present with strict convergence insufficiency while maintaining a normal, well-compensated exophoria at 40 cm, or even orthophoria[15].

4. Pseudo-convergence insufficiency:

Presents with similar signs to true convergence insufficiency, including significant exophoria at near and/or a remote near point of convergence (NPC). Additionally, it is characterized by reduced accommodative amplitude and an abnormally high accommodative lag. The AC/A ratio appears low because minimal accommodation is engaged during near phoria measurement, resulting in reduced accommodative convergence. A key distinguishing feature is that NPC improves with convex lenses (plus addition), which may seem paradoxical. This improvement is likely due to better focusing accuracy, leading to enhanced fusion stimulation [4].

5. Convergence insufficiency with accommodative insufficiency:

This rare syndrome combines both convergence insufficiency and accommodative insufficiency. Unlike pseudo-convergence insufficiency, the convergence deficit does not improve with convex lens addition. The exact cause of this condition remains uncertain, and patients often show poor response to vision therapy. Initially, plus lenses for near vision and base-in prisms are the primary management options. Over time, optical aids may be gradually reduced, and vision therapy can be considered. Interestingly, many cases resolve spontaneously over a period ranging from several months to years[15].

IV. Heterophorias and the AC/A Ratio in convergence insufficiency:

1. The difference between convergence insufficiency and heterophoria:

According to Professor Hugonnier, a subject can be orthophoric while having convergence insufficiency. Conversely, they can be heterophoric without exhibiting CI.

Convergence insufficiency is a functional disorder, whereas heterophoria is an anomaly of resting position. Hugonnier's definition provides a precise distinction between heterophoria and convergence insufficiency[2].

Heterophoria is an anomaly of the associated position, in which vergence function may remain normal. Convergence insufficiency, on the other hand, is a dysfunction of convergence without any anomaly in the resting position, if it is purely isolated.

2. The AC/A Ratio and its relationship with convergence insufficiency:

The AC/A ratio plays a crucial role in diagnosing and managing nonstrabismic binocular vision disorders, particularly convergence insufficiency (CI). A low AC/A ratio (below 3:1) is commonly associated with CI and is an important factor in treatment decisions[12].

V. Etiology of convergence insufficiency:

- **Historical Perspective:** Convergence insufficiency was initially attributed by von Graefe to a myogenic or psychogenic origin, some ophthalmologists considered it a neuropsychological disorder and believed it to be incurable despite being manageable with orthoptic therapy[16].
- **Current Understanding:** modern research supports an innervational origin, supported by significant improvements in both subjective symptoms and objective clinical measures following treatment[16].

1. General fatigue, psychological, and cognitive factors:

Convergence insufficiency may be associated with general fatigue, reduced psychological adaptability, and exacerbation due to antidepressant use. Psychological conditions such as anxiety, depression, and neurosis can further contribute to its manifestation. Additionally, cognitive factors like concentration difficulties and mental fatigue play a role, with reading inducing more symptoms than other near-vision activities, suggesting that increased cognitive demands may trigger or worsen the condition[8].

2. Accommodation-Convergence disorders:

Reduced use of accommodative convergence can contribute to convergence insufficiency. Individuals with uncorrected myopia, presbyopia using reading glasses, or absolute hyperopia may exert less accommodative effort, leading to inadequate convergence due to the interdependence between accommodation and convergence[10].

3. Accommodative insufficiency:

50% of cases with accommodative insufficiency also have CI. It is often uncertain whether the primary dysfunction lies in accommodation or convergence[10].

4. Prolonged screen uses:

Extended computer use can push the near point of convergence (NPC) and accommodation farther, potentially making a borderline CI symptomatic[10].

5. Anatomical causes:

Anatomical factors contributing to convergence insufficiency include a large interpupillary distance and a naturally divergent resting position [10]. Additionally, paresis or paralysis of extraocular muscles, as seen in certain congenital syndromes, can affect convergence ability. However, these causes remain relatively uncommon[8].

6. Traumatic causes:

Traumatic brain injuries (TBI) can lead to convergence paralysis due to supranuclear damage. A recent meta-analysis reported a 36% prevalence of CI among patients with post-traumatic brain injuries, including both civilians and military personnel. In children, CI is also strongly linked to sports-related head injuries, with nearly 42% of young athletes experiencing CI symptoms following a concussion[17].

7. Strabismus and phoria:

Hyperphoria or cyclophoria can contribute to convergence insufficiency. Additionally, strabismus is a recognized factor in CI. While early-life divergent strabismus has historically been linked to this condition, studies indicate that CI occurs in both convergent and divergent strabismus at rates proportional to their general prevalence[10].

8. Ocular Causes:

High refractive errors (hyperopia, astigmatism, myopia), anisometropia, and uncorrected or poorly corrected hyperopia or excessive minus correction in myopia can contribute to accommodation-convergence dysfunction. Additionally, presbyopia and unilateral amblyopia may also be contributing factors[8].

9. Developmental or phylogenetic factors:

May also contribute to convergence insufficiency. As the most recently evolved function of binocular vision, convergence is particularly susceptible to breakdown under stress.[10] Additionally, delays in visual development may further impact the stability and efficiency of convergence[8].

10. Neurological, systemic, and pathological factors:

CI can be linked to neurological disorders (e.g., Parkinson's disease, multiple sclerosis) and endocrine imbalances (e.g., Graves' disease, myasthenia gravis). Neurodegenerative disorders may lead to complete convergence paralysis[18]. Vestibular dysfunctions, toxic exposures, metabolic conditions, and general health decline are also contributing factors. Additionally, aging and urban living have been associated with a higher prevalence of CI. In rare cases, pineal gland tumors or superior colliculus lesions may be involved[10].

11. Association with Attention Deficit Hyperactivity Disorder (ADHD):

A 2015 meta-analysis found a 7.2% global ADHD prevalence in children under 18, with symptoms often overlapping with convergence insufficiency (CI) [19]. A 2005 study reported that 15.9% of ADHD patients who had an eye exam were diagnosed with CI, nearly three times the national average [20]. While some studies suggest a correlation between ADHD and CI, this association remains controversial and inconclusive. However, CI may exacerbate concentration difficulties already present in children with ADHD, further impacting their academic performance and daily activities [18].

-Identifying the underlying cause is essential for effective management.

VI. Symptoms of convergence insufficiency:

1. Asthenopia:

These symptoms manifest as ocular fatigue, strain, or discomfort during near work. Some patients describe a vague or undefined sensation of visual discomfort, while others report a pulling or pressure-like feeling around the eyes. These complaints stem from the increased convergence and/or accommodative effort required to maintain binocular alignment[16].

2. Headaches:

May arise during or after prolonged reading and, in some cases, even in the absence of specific near tasks. They are often localized in the frontal or periocular region and result from the continuous effort to enhance fusional convergence. Additionally, headaches associated with convergence insufficiency can exacerbate pre-existing conditions such as migraines[16].

3. Challenges with near vision and reading

patients often report:

- Intermittent blurriness of text.
- Difficulty concentrating and slow reading.
- A sensation of words moving, dancing, or floating on the page.
- Frequent loss of place while reading.
- Reduced comprehension and difficulty maintaining focus.
- Eye Strain and stiffness

Sustained near work tends to worsen these symptoms, making prolonged reading challenging. Some patients may not explicitly mention their near vision difficulties, as they instinctively avoid such tasks altogether[8].

4. Diplopia:

May present as two distinct images or overlapping images. In convergence insufficiency, the displacement is horizontal. Many patients struggle to recognize double vision and instead describe their vision as blurry. Some may close one eye while reading to alleviate the diplopia and the discomfort. Appropriate testing can help clarify the complaint, as diplopia typically resolves during monocular acuity assessment. It is usually caused by exodeviation at near, associated with CI [16].

5. Intermittent suppression:

In some patients with more severe convergence insufficiency, intermittent suppression may occur as a sensory adaptation. This mechanism helps reduce symptoms like diplopia and visual discomfort by temporarily suppressing the image from one eye during near tasks. Although suppression was not directly evaluated in the CITT study, the authors suggested that some children may develop suppression or avoid near work to minimize symptoms[21].

VII. Signs of convergence insufficiency:

Diagnosis of convergence insufficiency relies on the identification of several clinical signs. Table 1 provides a summary of these key findings:

Sign	Details
Near exophoria > Distance exophoria	$X' > X$ ($\Delta = 6-8\Delta$)
AC/A ratio	< 3:1 (low ACA ratio)
Near point of convergence (NPC)	Receded > 9 cm
Positive fusional vergence (PFV)	Reduced
Plus lens response	Difficulty adapting to + lenses
Monocular estimation method (MEM) retinoscopy	Low lag measurement

Table (II-1): Clinical signs of convergence insufficiency

-In cases where accommodative anomalies coexist with convergence insufficiency, additional findings may be observed:

- If accommodative excess is present, patients may show difficulty with plus lenses during monocular accommodative facility testing.
- If accommodative insufficiency is present, patients may present difficulty with minus lenses during both monocular and binocular accommodative facility testing, low positive relative accommodation (PRA), and reduced amplitude of accommodation. Improvement in near point of convergence (NPC) testing may also be noted when using plus lenses[12].

VIII. Diagnostic methods :

1. Overview of the convergence insufficiency symptom survey (CISS):

One of the most widely used tools for diagnosing convergence insufficiency is the Convergence Insufficiency Symptom Survey (CISS), a validated questionnaire designed to assess the severity of symptoms associated with this condition.

A. What is the CISS?

The convergence insufficiency symptom survey is a 15-item questionnaire developed to measure the frequency and severity of symptoms related to convergence insufficiency.

Each question on the CISS is rated on a 5-point scale as follows:

0 – Never – 1 – Infrequently – 2 – Sometimes – 3 – Fairly often – 4 – Always

Each item is scored from 0 (never) to 4 (always), giving a total score between 0 and 60.

Higher scores indicate more severe symptoms[23].

B. Interpretation of scores:

-For children aged 9 to 18 years, a score of 16 or higher on the diagnostic test is indicative of symptomatic (CI). This threshold provides high sensitivity (96%) and specificity (88%), distinguishing between children with CI and those with normal binocular vision [24].

-For adults aged 19 to 30 years, a score of 21 or higher is used to identify symptomatic CI. This cut-off demonstrates excellent sensitivity (97.8%) and specificity (87%)[23].

C. Reliability and validity:

The CISS has been validated in both children and adults, demonstrating strong reliability through high intraclass correlation coefficients (ICC). For instance:

→ Children: ICC = 0.77

→ Adults: ICC = 0.885

D. Supporting evidence:

Darko-Takyi et al. (2022) conducted a cross-sectional study involving 300 Ghanaian university students to examine the relationship between Convergence Insufficiency Symptom Survey (CISS) scores and the clinical signs of convergence insufficiency (CI). The study found significant correlations between CISS scores and the severity of clinical signs such as near point of convergence, near exophoria, positive fusional vergence (PFV), and AC/A ratio. A higher CISS score was also associated with a greater number of CI signs. The CISS demonstrated high sensitivity and specificity for detecting convergence insufficiency. It is considered a valuable tool for identifying symptomatic CI in young adults, especially when combined with clinical testing[25].

2. Clinical assessment of vergence and accommodation for CI diagnosis:

-The diagnosis of CI involves a series of clinical tests to assess vergence and accommodation, including[12]:

A. Convergence assessment:

a. Near point of convergence test (NPC Test):

The near point of convergence (NPC) is the closest point to the median plane at which the ocular pair does not experience diplopia.

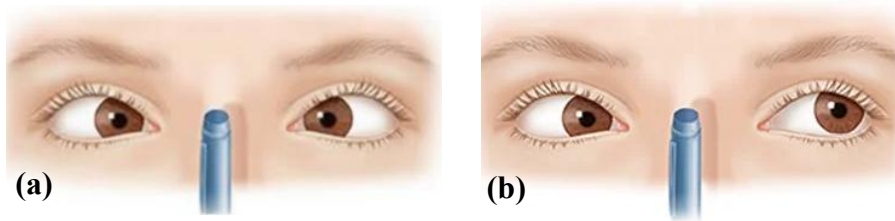


Figure (II-2): NPC test results: (a) Normal convergence; (b) Convergence insufficiency

b. Measurement of phoria:

Subjective method	Objective method
Maddox rod test is based on the principle of diplopia and is commonly used to assess heterophorias. It consists of a red lens made of multiple highly convergent cylinders and can be performed at both near and distance to evaluate the alignment of the visual axes.	Cover test is a method for evaluating binocular motor function by assessing the presence, direction, and magnitude of phoria.

Table (II-2): Comparison of phoria measurement methods

c. Positive and negative fusional vergence amplitudes:

Fusion amplitude refers to the ability to realign the fixated object on both foveae to restore fusion, when retinal disparity is present. Vergence amplitude and recovery measure fusional vergence at different distances and are commonly used to assess positive and negative responses.

- The blur point represents the amount of fusional vergence independent of accommodation.
- The break point indicates the total amount of fusional and accommodative vergence.
- The recovery point assesses the ability to regain single binocular vision after experiencing diplopia.

d. Vergence facility testing:

Vergence facility testing evaluates the dynamics of the fusional vergence system and its ability to adapt over time. It assesses the capacity to make rapid and repetitive vergence adjustments, serving as a clinical measure of stamina. Additionally, this test indirectly examines sustaining ability, which refers to the capacity to maintain vergence at a specific level for an extended period rather than making frequent adjustments.

B. Accommodation assessment:

a. The punctum proximum of accommodation (PPA):

Is the closest point that the eye can focus can see clearly and focus on with maximum accommodation.

b. Accommodative facility testing:

To assess the endurance and dynamics of the accommodative response. The goals of this test are similar to those discussed in relation to fusional facility testing.

c. Negative relative accommodation and positive relative accommodation:

The NRA and PRA tests are integral to evaluating accommodation and binocular vision at near. Their primary objective is to determine whether a patient requires an add for near work. Another key function of NRA and PRA is their use as indirect tools for analyzing both accommodation and vergence.

d. Monocular estimation method retinoscopy:

An objective technique for measuring the precision of the accommodative response.

e. AC/A Ratio:

The AC/A ratio measures the change in accommodative convergence in response to a specific adjustment in accommodation. This finding is essential for establishing a diagnosis and plays a crucial role in determining the appropriate management strategy for a given condition.

There are two approaches to determining a patient's AC/A ratio: the calculated AC/A ratio and the gradient AC/A ratio.

f. CA/C Ratio:

To assess the variation in accommodation that occurs as the patient either increases or decreases convergence by a specific amount.

-These tests help confirm CI and guide appropriate treatment planning.

3. Evaluating stereopsis and suppression:

A. Assessment of stereopsis:

-Evaluating stereopsis is an important part of diagnosing convergence insufficiency, as reduced stereoacuity is one of its objective signs. Stereoacuity depends on precise alignment and coordination of both eyes; when convergence is insufficient, the brain receives mismatched images, impairing depth perception. Several studies have shown that

convergence insufficiency is frequently associated with reduced stereoacuity. Vision therapy has been demonstrated to improve stereoacuity by restoring binocular coordination[26,27].

-Various clinical tests are used to evaluate stereopsis in CI. Among them, the Randotstereotest is widely used.

Randotstereotest:is a subjective near vision test that assesses the presence and degree of stereopsis, using both global and contour targets:

- **Contour (local) stereopsis** is evaluated using laterally displaced targets, such as modified Wirt circles or animal figures. While contour targets are useful for assessing peripheral stereopsis, they may be influenced by monocular cues.
- **Global stereopsis** is assessed using random dot stereograms, which eliminate monocular cues and provide a more accurate measure of true stereoscopic depth perception. The Randot test uses two sets of these patterns for effective assessment[4].

A normal result is typically 20–40 arc seconds. A threshold above 60 arc seconds suggests a binocular vision anomaly.

B. Assessment of suppression:

The assessment of suppression is an important component in diagnosing convergence insufficiency. When a patient presents with CI, suppression phenomena can occur, to avoid diplopia. This suppression can be detected using tests such as:

Worth four-dot test:

The Worth four-dot test is a subjective method used to detect suppression scotomas and assess sensory fusion in binocular vision disorders, such as convergence insufficiency. During the test, patients wear red-green filters, and report how many dots they perceive:

- Two red or three green dots: suppression of the fellow eye.
- Five dots: indicates diplopia.
- Alternating two and three dots: suggests alternating suppression.
- Four dots: normal sensory fusion (no suppression); patients with normal binocular vision should report seeing four dots at both near and far distances[28].

-Scotoma size is assessed by increasing the test distance from 33 cm to 1 m, the angular size of the target decreases. Suppression at further distances indicates a small scotoma, while

suppression at 33 cm suggests a larger one. There is an inverse relationship between the size of the suppression scotoma and the level of stereopsis. The larger the scotoma, the poorer the stereopsis. Suppression intensity is evaluated under both normal and dim lighting, with persistent suppression in low light indicating deeper, more resistant suppression. Even a small suppression scotoma can be more intense and harder to treat than a larger, less intense one[12].

IX. Conclusion:

Convergence insufficiency is a common yet often overlooked binocular vision disorder that significantly affects near vision tasks. Accurate diagnosis is essential for determining the type of CI and selecting the most effective treatment approach. Vision therapy, including vergence and accommodative exercises, plays a key role in rehabilitation by strengthening fusional reserves and improving binocular function. Standardizing diagnostic criteria and treatment protocols will further enhance patient outcomes and ensure more effective clinical management.

Chapter 3: Therapy for convergence insufficiency

I. Introduction:

Vision therapy, also known as orthoptic training, is the primary treatment for convergence insufficiency. Orthoptic exercises have remained the standard therapeutic approach, consisting of specific exercises designed to strengthen the ocular muscles and improve their coordination, enabling effective convergence during near vision tasks.

This chapter will discuss the principles of vision therapy, the different techniques used in the rehabilitation of CI, and the clinical evidence supporting the effectiveness of these treatments. A comparative analysis of various therapeutic approaches, including home-based exercises, in-office therapy, and alternative methods, will also be explored.

II. Physiological basis of accommodation and vergence eye movements:

Although accommodation and vergence are tightly linked and often occur simultaneously during near tasks, their neural control involves overlapping but distinct cortical and subcortical circuits.

1. Cortical and subcortical control of accommodation:

Accommodation begins in the visual cortex where blur is detected. This information is processed in the parietal and temporal cortices, then sent to midbrain centers. The Edinger–Westphal nucleus activates the ciliary muscle via the oculomotor nerve (CN III) to adjust the lens for near focus. The cerebellum modulates the response for precision and adaptation[29].

This intricate process highlights the involvement of a complex network of cortical and subcortical structures that integrate both visual processing and the motor control required to focus on near objects. Several key brain areas have been identified through research as central to this coordination:

- **Primary visual cortex (V1) and visual association cortex (Occipital lobe):** these regions process visual input, detect accommodation, and analyze object details for focusing [30].
- **Posterior parietal and temporal cortices:** these areas help coordinate eye movements by analyzing object location and motion[31].
- **Supranuclear areas** around the visual cortex: these structures modulate the near reflex via projections to midbrain centers, such as the superior colliculus and pretectal area[32].
- **Cortical input to brainstem centers:** cortical fibers project to brainstem nuclei, including the Edinger-Westphal nucleus, to control the ciliary muscle for accommodation[31].

- **Cerebellum:**the cerebellum provides subcortical control and contributes to the fine-tuning and stabilization of eye movements during accommodative tasks[33].

2. Cortical and subcortical control of vergence:

Vergence starts with detection of binocular disparity in the visual cortex. Frontal eye fields (FEF) and prearcuate cortex generate motor commands that descend to midbrain vergence centers. The oculomotor nuclei control the medial rectus muscles for convergence. The cerebellum (notably the fastigial and interposed nuclei) fine-tunes vergence for smooth and accurate eye alignment[34]. The control of vergence eye movements involves a network of cortical and subcortical regions that process visual cues, perform sensorimotor transformations, and regulate the motor components of vergence:

- **Frontal cortex (prearcuate region):** located just in front of the frontal eye fields, this area contains neurons that respond to near/far stimuli and visual cues, such as blur and disparity, which are essential for vergence[35].
- **Primary visual cortex (V1) and visual association cortex (Occipital lobe):** involved in visual processing, particularly depth perception and binocular disparity, which guide accurate eye alignment[36].
- **Frontal eye fields (FEF) and prefrontal cortex:** along with anterior frontal areas, play a critical role in both reflexive and voluntary vergence. These regions are responsible for preparing motor commands for vergence eye movements, particularly during near-focus tasks [37].
- **Posterior parietal and temporal cortices:** help coordinate eye movements by analyzing the location and motion of objects[38].
- **Cerebellum:** modulates vergence by connecting with deep cerebellar nuclei (e.g., fastigial and posterior interposed), which influence midbrain centers responsible for eye movement control[34].
- **Pontine nucleus (nucleus reticularis tegmentipontis):** receives input from the frontal cortex and integrates signals for coordinated vergence and accommodation[39].

III. Foundations of vision therapy:

1. Underlying mechanisms and goals of vision therapy:

A. Neural adaptation mechanisms:

-Laboratory studies have shown that training can influence the amplitude and velocity of proximal and tonic vergence. Convergence exercises enhance these components, optimizing their dynamics and adaptability[13].

- **First phase** (fast and reflexive): proximal convergence improves through repetitive, rapid, and large-amplitude shifts at various distances, enhancing the eye's ability to quickly adjust focus.
- **Second phase** (slow and feedback-controlled): tonic convergence strengthens by sustaining convergence over time, improving stability and endurance during near-vision tasks.

B. Enhancements in vergence dynamics:

Increased peak velocity: vergence training enhances the speed of convergence eye movements, which is often reduced in CI patients. Studies found that peak velocities improved after training, bringing them closer to the levels of binocularly normal individuals[40].

Improved functional activity: neuroimaging studies indicate that vergence therapy leads to increased activity in the Frontal Eye Fields, Posterior Parietal Cortex, and Cerebellar Vermis, which are key brain regions involved in controlling vergence movements[40].

Strengthened neural pathways: functional MRI studies show that vision therapy increases neural activity in key areas controlling vergence: the dorsolateral prefrontal cortex, frontal lobe, parietal lobe, cerebellum, and brainstem[41].

The central nervous system (CNS) constantly adapts to maintain precise eye movements, adapting to both physical changes like muscle fatigue or injuries and cognitive influences such as mental exhaustion or attentional fluctuations. While these cognitive factors can impair vergence function, vision therapy strengthens neural pathways to mitigate their impact and preserve visual performance[42].

C. Long-term clinical benefits:

Clinical studies have documented significant improvements in key visual parameters post-therapy, including: near point of convergence (NPC), positive fusional vergence amplitude, near dissociated phoria.

The positive changes in vergence function correlate with a reduction in symptoms such as double vision, eyestrain, and headaches, particularly when performing near-vision tasks[40]. This evidence highlights the long-term efficacy of vision therapy in improving both visual function and overall quality of life.

IV. Management and therapeutic techniques for convergence insufficiency:

1. Management of CI:

In case of IC, several treatment options can be considered:

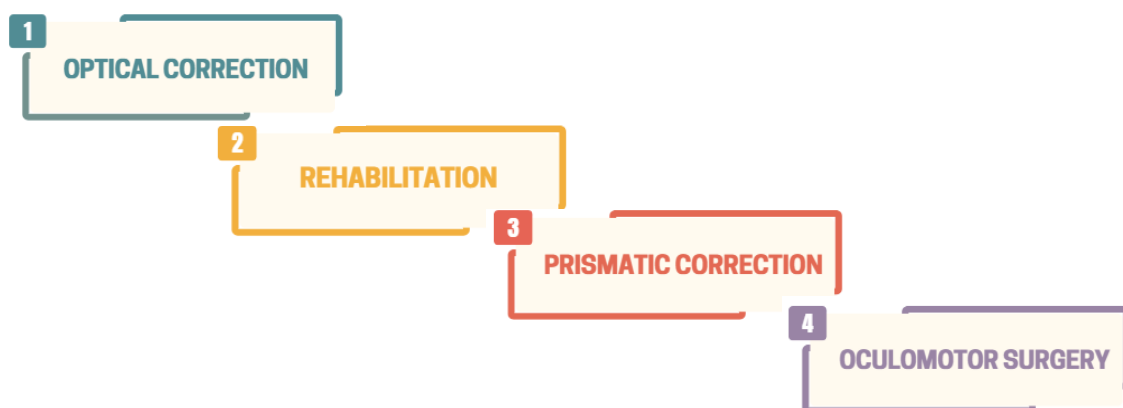


Figure (III-1): Management options for CI

A. Optical correction:

The first step in managing accommodative and binocular vision disorders is correcting any significant refractive error with appropriate optical correction.

Uncorrected refractive errors can lead to several issues, including:

- **Accommodative dysfunction:** Under- or over-accommodation, resulting in accommodative disorders.
- **Binocular vision stress:** Increased phoria and excessive demand on either negative (NFV) or positive (PFV) fusional vergence.

- **Sensory fusion imbalance:** A mismatch between the two eyes, disrupting sensory fusion.
- **Reduced fusion ability:** Blurred retinal images impairing fusion capacity.

A 1995 study conducted on 143 patients with significant ametropia associated with vergence and accommodative disorders found that prescribing optical correction led to an improvement in vergence and accommodation values. In hyperopic-astigmatic patients, this correction resulted in up to 79% normalization of these functions[43].

B. Vision therapy and rehabilitation:

While optical and prismatic corrections provide symptomatic relief, vision therapy remains the most effective approach for improving convergence function in the long term.

A study conducted by Scheiman et al confirms that office-based vergence/accommodative therapy with home reinforcement is the most effective treatment for children with CI. However, the effectiveness of various non-surgical interventions for adults remains uncertain[44].

C. Prismatic correction:

A study published by Scheiman et al. evaluated the effectiveness of base-in prism reading glasses compared to placebo reading glasses for treating symptomatic convergence insufficiency in children aged 9 to 18 years. The results showed that prism glasses were no more effective than placebo glasses in reducing symptoms or improving convergence[45].

Another study on adults aged 18–38 years with convergence insufficiency (CI) found that base-in prism significantly reduced symptoms, as measured by (CISS). However, it did not lead to significant improvements in vergence function, suggesting that while prisms provide short-term symptomatic relief, they do not correct the underlying dysfunction. Further research is needed to evaluate their long-term effectiveness[46].

D. Oculomotor Surgery:

Oculomotor surgery is not a first-line treatment for convergence insufficiency. It should only be considered in severe phoria ($>30\Delta$), extreme anatomical abnormalities, or when other treatments fail. In such situations, bilateral resection or plication of the medial rectus muscles may be proposed[47,48].

2. Rehabilitation plan:

It is essential to tailor the vision therapy program to the patient's abilities and availability to ensure effective rehabilitation, as shown in figure (III-2), the rehabilitation process is divided into three structured phases[12]:

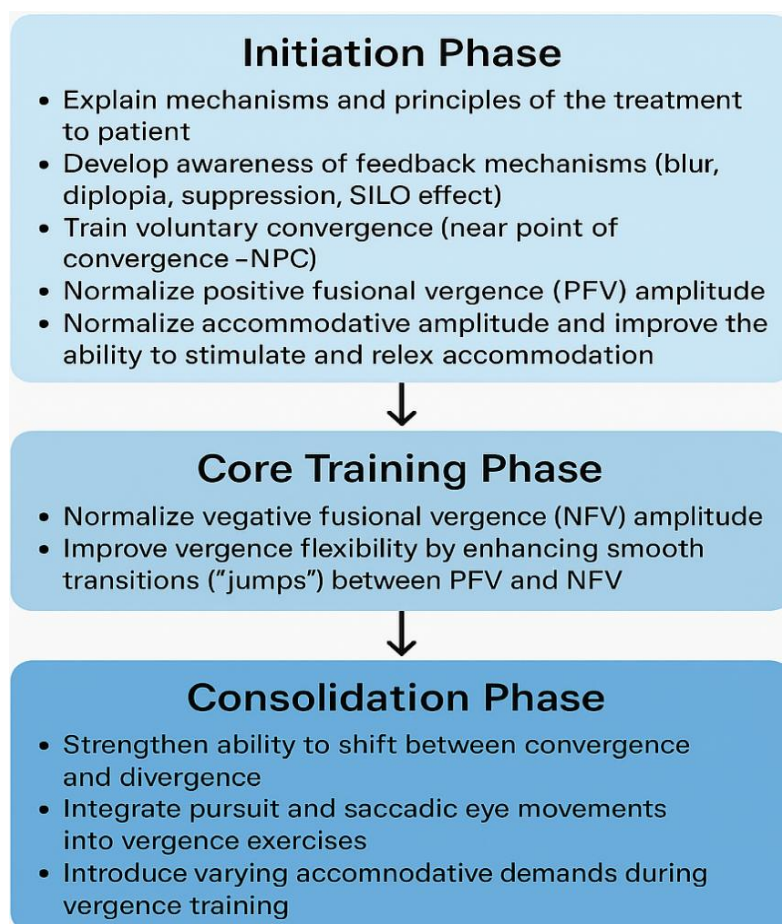


Figure (III-2): Vision therapy rehabilitation phases

3. Categorization of vision therapy:

A. Classification by method:

Binocular vision therapy procedures have traditionally been classified into two main categories:

- **Instrument training**, includes all techniques in which the patient must look directly into a device. In this type of training, the patient's movement is restricted, and it may be difficult to observe their eyes. These conditions are generally considered less natural or more artificial compared to other forms of therapy. The most common example of instrument training is the use of a stereoscopic-type device.

- **Free space training**, consists of techniques that take place in a less restricted environment, allowing for greater movement and easier observation of the patient's eyes. This approach to vision therapy more closely resembles natural viewing conditions and is regarded as less artificial than instrument training[12].

B. Classification by setting of use:

Setting of use	Tools
Office-based tools	Vectograms, tranaglyphs, VR and computerized programs.
Home-based tools	Brock string, lens flippers, hart chart, computer-based home software, fusion cards.
Hybrid use (Home + Office)	Hart chart, lens flippers, jump ductions, portable computer apps or games.

Table (III-1): Vision therapy tools by setting

C. Classification by clinical objective:

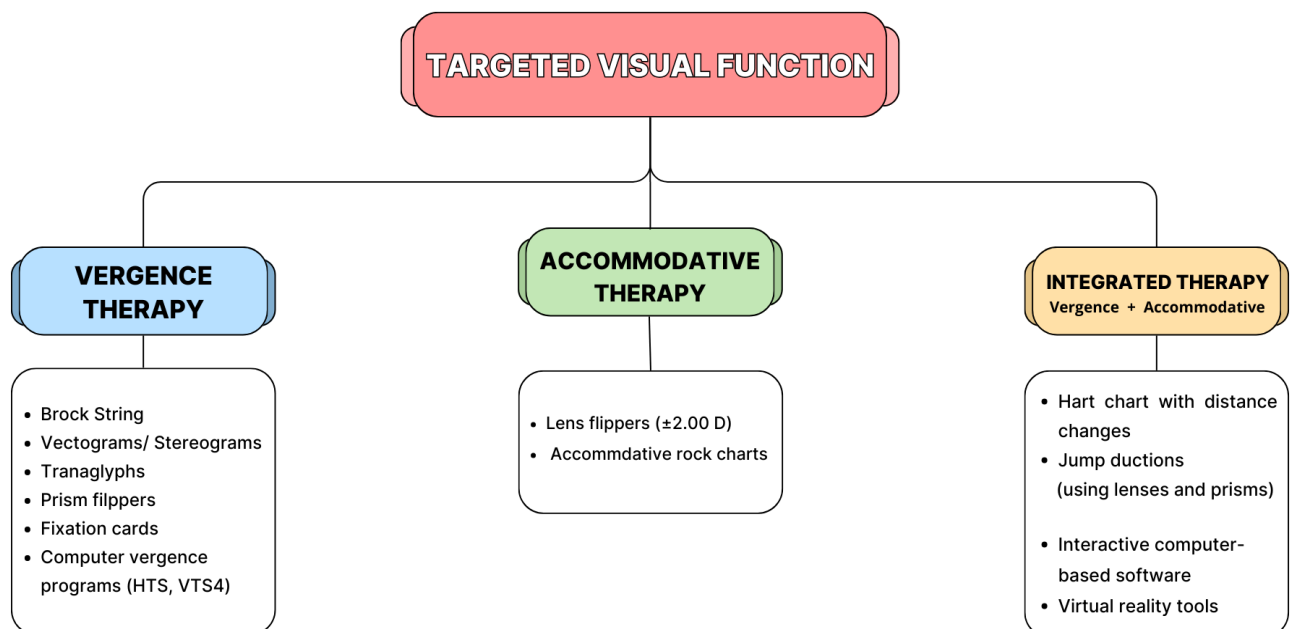


Figure (III-3): Common tools and techniques used in the rehabilitation of CI

4. Management of accommodative and vergence dysfunctions:

The management of patients presenting with accommodative or vergence dysfunction relies on a thorough interpretation and analysis of clinical examination findings. The primary treatment objectives are to enhance the patient's visual efficiency in academic, professional, or athletic settings, and to alleviate associated ocular, physical, and psychological symptoms.

A. Accommodative vision therapy:

Accommodative therapy aims to enhance the amplitude, speed, accuracy, and ease of the accommodative response. Studies have shown that accommodation can be trained and improved through repeated exercises, voluntary control, and biofeedback techniques. Vision therapy effectively treats reduced accommodative amplitude and facility, often resulting in symptom relief and improvements in vergence (PFC, NFV) and stereopsis. Research confirms that accommodative therapy leads to objective changes, including increased response velocity and reduced latency and time constants. In controlled studies, patients who received therapy showed a significant reduction in asthenopic symptoms associated with accommodative anomalies[49].

B. Vergence vision therapy:

Vergence therapy aims to improve fusional vergence, particularly slow vergence, to enhance binocular coordination and influence the AC/A ratio. It supports the balance of multiple vergence and accommodative systems that maintain visual comfort. Research, including the Convergence Insufficiency Treatment Trial (CITT), confirms its effectiveness in reducing symptoms and improving clinical measures such as near point of convergence (NPC) and positive fusional vergence (PFV). Vision therapy has proven highly successful in managing convergence insufficiency, with over 90% of patients responding positively to treatment[49].

C. Accommodative and vergence therapy: timelines and long-term effects

a. Short-term results:

- **Accommodative therapy:** when the visual dysfunction is purely accommodative, accommodative therapy tends to produce faster results. Within the first 4 to 6 weeks of consistent training, patients often show improvements in accommodative response speed, facility, and amplitude. These gains are typically accompanied by a noticeable reduction in symptoms [50,51].
- **Vergence therapy:** In contrast, vergence therapy usually requires more time, with significant gains typically appearing after 4 to 8 weeks of consistent training. During this period, noticeable improvements in binocular coordination are observed, including

enhancements in near point of convergence (NPC) and positive fusional vergence (PFV), along with a reduction in asthenopic symptoms[52].

- **Combined therapy:** When both accommodative and vergence dysfunctions are present, combined therapy is necessary. However, the response may be slower and requires a longer treatment period due to the complexity of addressing multiple visual functions simultaneously. Patients often achieve better functional gains in both vergence ranges and accommodative control, with measurable improvements typically becoming evident within 4 to 6 weeks, and further gains continuing up to 12 to 16 weeks of therapy [53,54].

b. Long-term benefits:

Over the course of 12 weeks, both therapies lead to more substantial and sustained outcomes. Full therapeutic goals may require up to 3 months, depending on the severity of the dysfunction and patient compliance. Accommodative therapy enables patients to reach full therapeutic goals, including increased amplitude and improved accuracy and consistency of accommodative responses. In contrast, the long-term impact of vergence therapy particularly in cases of convergence insufficiency includes marked enhancements in vergence ranges and a deeper reduction in symptoms, often supported by clinically significant changes in vergence amplitudes and fusional vergence at near[52].

c. Persistence of effects:

Improvements achieved through vergence/accommodative therapy, including increased accommodation amplitude, enhanced vergence ability, and symptom relief, are maintained for at least one-year post-therapy, with minimal regression over time[50,55].

-However, long-term success also depends on maintaining good visual hygiene by adopting healthy habits. This includes reducing screen time, encouraging regular visual breaks, and maintaining proper lighting, reading distance, and posture, especially for children. Outdoor activities are also beneficial for promoting balanced visual development. Involving parents in reinforcing these behaviors and providing guidance on sustainable visual habits is crucial. Without these supportive lifestyle adjustments, symptoms may gradually return.

5. Key exercises for convergence insufficiency:

A. Tools used for vergence therapy:

a. Pencil push-ups:

Pencil push-ups are a visual rehabilitation exercise designed to improve how well both eyes work together, especially when focusing on close objects. This exercise is often recommended as part of vestibular rehabilitation to treat binocular vision problems, such as difficulty with eye convergence[56].



Figure (III-4): Pencil push-ups exercise

b. Brock string:

The Brock String is a vision therapy tool designed to train convergence, enhance binocular coordination, and improve the near point of convergence (NPC). It consists of a white cord with three colored beads (typically red, green, and yellow) that can be moved along the string. It helps patients develop awareness and voluntary control of convergence movements while strengthening depth perception and overall vergence function, making it a fundamental exercise for treating convergence insufficiency[12].

c. The aperture rule:

The Aperture Rule is a vergence training tool designed to improve binocular vision by stimulating both convergence and divergence. Unlike other vergence exercises, it does not require red/green or polarized glasses but instead relies on chiasmopic (crossed) and orthopic (uncrossed) fusion to enhance vergence control.

The device uses a ruler-like support with single and double apertures, along with cards showing various disparities (2.5Δ to 30Δ) and suppression controls, to enhance vergence control and monitor binocular alignment [12].

d. BARREL card and 3-DOT card:

The Barrel card and 3-Dot (Albee) card are vergence training tools commonly used to treat convergence insufficiency. Introduced after Brock String exercises, they help improve convergence ability, normalize the near point of convergence (NPC), and develop voluntary control of eye movements [12].

e. Lifesaver cards and free space fusion cardsB:

Lifesaver cards and Free Space Fusion Cards B are binocular vision therapy tools designed to improve vergence flexibility, stereopsis, and fusional reserves. Their preprinted target separations allow precise control over vergence demand without manual adjustment [12].

f. Vectograms and tranaglyphs:

Vectograms and tranaglyphs are widely used tools in vision therapy to improve fusional vergence, particularly in convergence insufficiency. Vectograms use polarized filters, while tranaglyphs rely on red/green anaglyph glasses to dissociate images. Both allow adjustable vergence demand and include suppression controls. They are especially effective in the early stages of therapy for CI, helping patients build accuracy and speed in their vergence responses. Their low cost and ease of use make them ideal for both in-office and home-based therapy programs [12].



Figure (III-5): Tranaglyphs with anaglyph glasses

g. Mawas-Weiss board:

The Mawas-Weiss board is a vision therapy tool used to train vergence, physiological diplopia, and depth perception. It includes fixed targets, movable magnetic elements, and sliding stereograms to simulate various binocular visual tasks. It is especially effective for assessing and treating binocular vision anomalies such as suppression or convergence insufficiency, and can be used in both clinical and home settings.[57].



Figure (III-6): Mawas-Weiss board for vision therapy

B. Tools used for accommodative therapy:

a. Accommodative rock:

The binocular accommodative rock exercise uses flipper lenses (dioptric lenses with alternating powers) to improve accommodative facility and flexibility. These lenses help stimulate and relax accommodation during near tasks, thereby enhancing accommodative function and its interaction with the vergence system.

Objective:

This exercise aims to improve the speed and accuracy of the accommodative response under binocular conditions while helping the patient gain voluntary control over accommodation. By enhancing accommodative flexibility and stability, it supports the vergence system, contributing to better binocular coordination and reducing symptoms of convergence insufficiency.

- Accommodative rock exercises usually produce excellent results. Benefits are often noticeable within the first two weeks. Typical training duration ranges from 2 to 6 weeks. Several studies have shown that the improvements are long-lasting. The exercise is most commonly recommended for individuals aged between 10 and 25 years[4].

b. Hart carts:

A procedure designed to enhance accommodative amplitude and vergence facility by training the eyes to shift focus rapidly and precisely between near and distant targets. It involves a large chart for distance and a small hart chart for near. The goal is to read the near chart at 3 inches and the distance chart at 10 feet (under 20 years), or at half the accommodative amplitude for those over 20 [12].

6. New technologies for CI rehabilitation:

A. Computer programs for office-based therapy in binocular vision rehabilitation:

include tools such as the VTS4 liquid crystal system, which uses high-speed liquid crystal glasses to present vivid binocular targets with minimal ghosting. This system is effective in the early stages of therapy for treating accommodative, vergence, and oculomotor disorders, allowing for independent patient work and automated feedback—especially helpful for young or less verbal patients. The multiple choice vergence program improves fusional vergence by increasing amplitude, reducing latency, and enhancing response speed, adjusting demand based on patient performance. Once a basic level of vergence is achieved (40–50 base-out, 10–15 base-in), more advanced programs like Step-Jump and Jump-Jump vergence are

introduced to alternate convergence and divergence in a structured or random manner. Computer aided vision therapy (CAVT) also targets vergence using red/blue filters and random dot stereograms, adapting stimulus disparity according to the patient's responses. Throughout therapy, key goals include developing the kinesthetic sense of convergence/divergence, maintaining clarity during fusion, and achieving stable, single binocular vision before discontinuing the therapy [12].

B. Virtual reality:

VR is an emerging tool in healthcare and offers several benefits, including high patient engagement, personalized therapy, and the ability to monitor treatment remotely. In the context of convergence insufficiency rehabilitation, the following exercises are commonly integrated:

- ❖ **Voluntary, proximal convergence, and NPC enhancement:** activities are designed to stimulate voluntary convergence, similar to the use of simultaneous vision targets in traditional synoptophore therapy. Proximal convergence is specifically enhanced through exercises such as the NPC and physiological diplopia training. In the latter, patients alternate fixation between near and distant targets, encouraging vergence movements in three-dimensional space. Additionally, dedicated exercises focus on improving the NPC reflex. Patients practice focusing on a target that gradually approaches them, aiming to maintain single vision for as long as possible.
- ❖ **Fusional and stereoscopic convergence training:** activities simulate synoptophore targets to strengthen voluntary convergence, fusion, and stereoscopic vision. Patients are tasked with maintaining binocular vision while the degree of disparity between images progressively increases[58].

-The exercises have predefined levels of difficulty, with the option for personalized adjustments to suit the patient's progress, from beginners to those at the end of rehabilitation who may need more challenging tasks.

Study results: a study by Li et al. (2022) evaluated the effectiveness of virtual reality-based vision therapy (VR-VT) in comparison to traditional office-based vergence/accommodative therapy (OBVAT) for treating convergence insufficiency (CI) and accommodative dysfunction (AD) in young adults. The study involved 63 participants who were randomly assigned to either the VR-VT or OBVAT group for 12 weeks, with

assessments at baseline, 6 weeks, and 12 weeks. Both therapies showed significant improvements in symptoms of CI and key binocular vision functions, such as near point of convergence (NPC) and positive fusional vergence (PFV), as well as accommodative amplitude and facility [59].

-The results suggest that VR-VT is a viable alternative to traditional office-based therapy for improving binocular vision and alleviating symptoms of CI and AD. Given its flexibility and the possibility for home use, VR-VT could be a promising option for individuals who face barriers to accessing conventional therapy.

V. Effectiveness of vision therapy in the management of CI: clinical evidence and neurophysiological insights:

1. Scheiman et al.: comparative study of CI treatment outcomes in children and young adults:

Two studies were conducted by Scheiman to evaluate the effectiveness of different treatments for symptomatic convergence insufficiency (CI) in two age groups: children (9–18 years) and young adults (19–30 years). Both trials were randomized and controlled, assessing three treatment modalities: office-based vision therapy/orthoptics, home-based pencil push-ups, and office-based placebo therapy. The primary outcome was symptom reduction measured by the Convergence Insufficiency Symptom Survey (CISS), while secondary outcomes included improvements in near point of convergence (NPC) and positive fusional vergence (PFV). Treatments lasted 12 weeks, with the vision therapy group undergoing weekly 60-minute office sessions combined with daily home exercises, whereas the pencil push-ups group followed a self-guided regimen[60,61].The following table provides a comparative overview of the results for each treatment modality in children and young adults:

Treatment	Children (9-18 years)	Young Adults (19-30 years)
Vision therapy/Orthoptics	✅ Most effective treatment	
Symptom Improvement (CISS)	32.1 → 9.5	Only group below symptomatic threshold (<21)
NPC Improvement	13.7 cm → 4.5 cm	12.8 cm → 5.3 cm
PFV Improvement	12.5 → 31.8 Δ	11.3 → 29.7 Δ

Cure Rate (Asymptomatic)	53%	25% cured
Pencil push-ups	✗ Ineffective	
Symptom Improvement (CISS)	29.3 → 25.9	No patients cured, minor changes
NPC/ PFV Improvement	No clinically meaningful changes	
Cure Rate (Asymptomatic)	0 %	
Placebo therapy	✗ Ineffective	
Symptom improvement (CISS)	30.7 → 24.2	Some symptom improvement but not clinically significant
NPC/ PFV improvement	No significant NPC or PFV improvement	

Table (III-2): Comparison of treatment effectiveness for CI in children and adults

Both studies conclude that office-based vision therapy/orthoptics is the most effective treatment for symptomatic CI in both children and young adults, while home-based pencil push-ups and placebo therapy do not produce significant clinical improvements.

2. Effectiveness of different vision therapy approaches for CI:

A study was conducted to compare the effectiveness of three vision therapy approaches in treating convergence insufficiency (CI) in adults. The randomized clinical trial involved 84 participants with an average age of 26.8 years, divided into three treatment groups[26]:

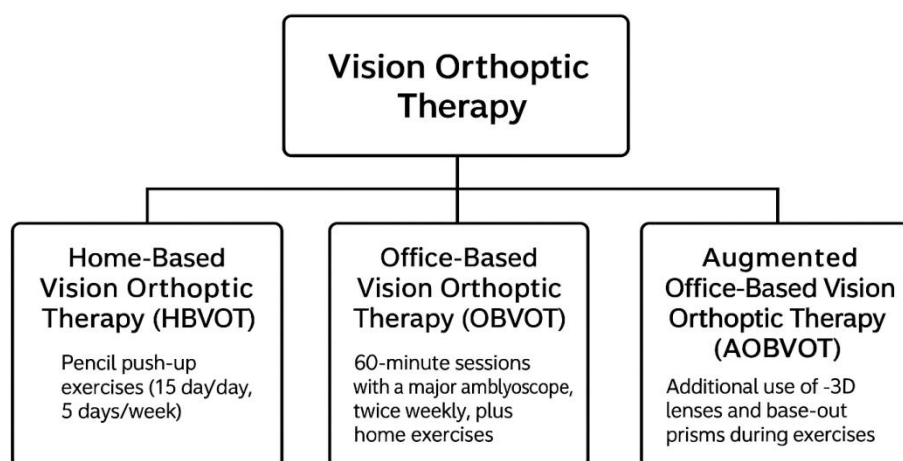


Figure (III-7): Vision orthoptic therapy approaches for CI

Results:

Outcome	HBVOT (%)	OBVOT (%)	AOBVOT (%)
Near exophoria reduction	64	68	85
Positive fusional vergence (PFV) increase	68	100	100
Near point of convergence (NPC) improvement	86	89	96
Symptom score (CISS) reduction	75	96	100

Table (III-3): Effectiveness of different vision therapy approaches for CI

The study found that augmented office-based therapy (AOBVOT) was the most effective in improving convergence and reducing symptoms of CI. Standard office-based therapy (OBVOT) also showed significant results, while home-based therapy (HBVOT) was the least effective.

3. Effectiveness and long-term stability of vision therapy for convergence dysfunctions:

Long-term follow-ups at 6 and 12 months revealed that OBVAT maintained its benefits, whereas home-based therapies had higher relapse rates, indicating that unsupervised treatments may not provide sustained results[62].

The study by Shin et al. (2011) evaluated the effectiveness of vision therapy (VT) in treating convergence insufficiency and combined CI with accommodative insufficiency (AI) in children [63]. After 12 weeks of in-office VT, the treatment group showed significant improvements in symptoms and clinical measures, while the control group exhibited no changes. A one-year follow-up confirmed that most children maintained their progress. These findings demonstrate that VT is an effective and long-lasting treatment for CI and CI with AI, supporting its use as the preferred approach for these binocular dysfunctions.

Key long-term results:The following table presents the key long-term outcomes of various vision therapy approaches for CI, as reported by the CITT study group (2008)[62]:

Treatment type	Long-term outcome (6 & 12 Months)
Office-Based vision therapy (VT)	☑ Best results, sustained improvement over time
Home-Based pencil push-Ups	⚠ Less effective, symptoms often return
Placebo therapy	✗ Little to no long-term benefit

Table (III-4): Long-term effectiveness of vision therapy approaches for CI

4. Brain adaptations to vergence training:

A study using functional MRI (fMRI) examined how vergence training affects brain activity in key eye movement regions, including the Frontal Eye Fields (FEF), Posterior Parietal Cortex, and Cerebellar Vermis. The results showed increased activation in these areas, indicating neuroplasticity and improved vergence eye movement speed[40].

The findings provide neurophysiological evidence that vergence training enhances brain activity and neuroplasticity, particularly in the control of eye coordination. The cerebellar vermis plays a crucial role in vergence adaptation, while the FEF and Posterior Parietal Cortex help regulate voluntary eye movements. This supports the effectiveness of vision therapy for treating convergence insufficiency and binocular vision disorders. fMRI-based neurostimulation could lead to personalized therapy, optimizing vergence training for better treatment outcomes, though more research is needed on long-term neural adaptations[41].

VI. Conclusion:

Advancements in technology are enhancing the treatment of convergence insufficiency. Traditional binocular instruments like stereoscopes and synoptophors have been supplemented by software applications on PCs or tablets, which combine vergence therapy with eye-hand coordination, vestibular information, and proprioceptive stimulation [18]. These innovations offer dynamic and engaging exercises, which can be practiced both in-office and at home. Virtual reality systems promise even better results by providing immersive visual stimuli. In the near future, virtual reality is expected to offer optometrists new and effective tools for treating convergence insufficiency.

Practical section:

Clinical study on the rehabilitation of convergence insufficiency

I. Introduction:

The practical component of this thesis was conducted in the optometry laboratory of institute of science and applied technics at the University of Oran 1 Ahmed Ben Bella, Algeria. Under controlled conditions, to ensure the methodological rigor required for reliable results.

As part of our thesis, we chose to continue a thesis initiated by a previous student pair, whose primary focus was the “screening of convergence insufficiency”. This functional visual disorder, although relatively common, is often underdiagnosed. Patients with convergence insufficiency generally have clear vision sometimes with correction and rarely associate their difficulties, such as visual fatigue, headaches, double vision, or trouble concentrating, with a visual problem. This lack of awareness highlights the importance of systematic “screening by eye care professionals”.

The previous team based their screening protocols particularly those recommended by “the American Optometric Association” provide clinicians with reliable tools to identify CI, using specific clinical tests, building on this initial work, we decided to focus on the therapeutic management of the cases identified with convergence insufficiency. Our aim is to explore various orthoptic and rehabilitative approaches, implement suitable protocols tailored to the profiles of these patients, and assess the effectiveness of these interventions through clinical observation and individual follow-up. This practical section of our thesis is therefore both a continuation and a deepening of the previous work, with a specific emphasis on improving patients’ visual comfort and quality of life.

II. Objective:

The main objectives of this practical project are twofold, reflecting both the continuation of a previously initiated screening process and the extension of that work into therapeutic management:

- 1. To review and analyse the results of convergence insufficiency** screening previously conducted by another student team using the Red/Green Penlight Test (PLRG) and the Convergence Insufficiency Symptom Survey (CISS). This includes identifying individuals who meet the diagnostic criteria for convergence insufficiency.

2. To develop and implement appropriate therapeutic for patients diagnosed with convergence insufficiency, based on current clinical guidelines and best practices in vision therapy.

3. To evaluate the effectiveness of the applied therapy protocols, through follow-up assessments and patient feedback, with the aim of reducing symptoms and improving binocular vision performance.

4. To contribute to the clinical understanding of convergence insufficiency management, by documenting observed outcomes and proposing recommendations for future practice. Through these objectives, our thesis seeks to highlight the importance of early detection and appropriate intervention, and to provide insight into practical, evidence-based solutions for managing this common but often overlooked visual disorder.

III. Materials and methods of vision therapy:

To implement the convergence insufficiency rehabilitation program, various vision therapy tools were employed to stimulate and train vergence and accommodative responses:

1. Vergence therapy:

A. Pencil push-ups:

the procedure consists of the following steps:

Step 1: The patient holds a pencil vertically at arm's length, directly in line with the nose.

Step 2: They are instructed to focus on the tip of the pencil and slowly bring it closer toward the nose, maintaining a single, clear image.

Step 3: When the image becomes double, the pencil is moved back to the starting position, still attempting to regain and maintain binocular single vision

Frequency: This exercise was performed once a day for approximately five minutes per session.

B. Fusion cards (Lifesaver / Free space A and B):

the procedure is as follows:

Step 1: The cards are held approximately 40 cm from the patient, either manually or with appropriate support. The patient is encouraged to try crossing their eyes to experience the sensation of convergence. If needed, a pointer is used to demonstrate the convergence point.

Step 1: The patient is encouraged to try crossing their eyes to experience the sensation of looking closer. If this is not possible voluntarily, a pointer can be used to demonstrate the point where convergence is needed to achieve fusion.

Step 2: Once fusion is achieved, the patient will see three sets of circles and should focus only on the middle set, while ignoring the side images.

Step 3: The patient begins by fusing the bottom target, which has the lowest convergence demand, and holds the fusion for 10 seconds.

Step 4: They should then look away momentarily, look back at the cards, and regain fusion. This process is repeated 10 times before moving to the next, more challenging target with greater separation.

- The exercise continues across all targets for several minutes. With free space fusion cards (A), the cards are initially separated manually by approximately 1 cm. The activity can be stopped once the patient is able to clearly fuse all targets.

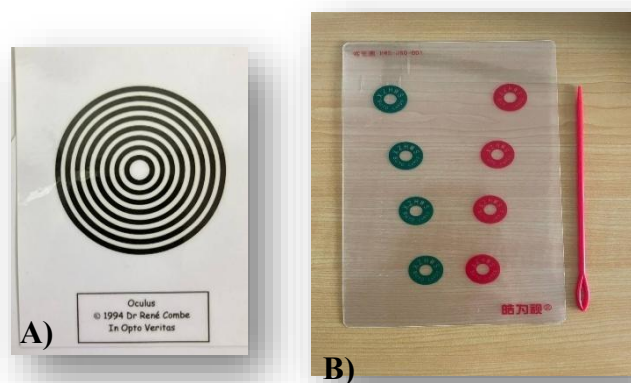


Figure (1): Free-space fusion cards A and B

C. Brock string:

(white cord with three colored beads)

Procedure:

Step 1: The Brock string exercise begins by attaching one end of the string to a fixed point, such as a doorknob, while the other end is held against the bridge of the nose.

Step 2: Initially, the red bead is placed at 2 feet and the green bead at 1 foot, creating an “X” shape with the strings.

Step 3: The patient first fixates on the green bead, aiming to see one single green bead with two red beads doubled behind it, then shifts focus to the red bead, which should appear single with two green beads in front. Proper fixation is confirmed when the strings appear to cross at the bead being fixated, indicating accurate vergence.

Step 4: The near bead is gradually moved closer in 1-inch increments, alternating fixation between near and far beads. The goal is to achieve and maintain convergence as close as 2 inches from the nose.

-The therapy is considered successful when the patient is able to converge to 1 inch from the nose, while demonstrating awareness and voluntary control of vergence movements.



Figure (2): Brock string

D. Aperture rule:

-The therapy setup involves positioning the single-aperture slide at a specific mark on the aperture rule apparatus, with the stimulus cards placed in their designated slots. Training typically begins with card 2, as it is easier to fuse than card 1.

Step 1: The patient places the end of the aperture rule against the bridge of the nose.

Step 2: They view the targets through the aperture, allowing each eye to perceive a separate image.

Step 3: When fusion of the eccentric circles on the cards is achieved, the patient perceives the inner circle as moving forward, which indicates successful convergence.

- After removing monocular occlusion, the patient may experience diplopia, suppression, or successful fusion of the images. The primary objective is to develop clear, single binocular vision through structured vergence training.

With practice, the patient is expected to maintain fusion independently. Once fusion is achieved, the patient should hold it for 10 seconds, look away, and then regain fusion quickly. This sequence is repeated multiple times before progressing to the next card, which increases vergence demand by bringing the aperture closer to the patient, making the exercise progressively more challenging. The exercise is considered successful when the patient can achieve clear, single binocular vision with all 12 cards used in convergence therapy.



Figure (3): Aperture rule

E. Barrel card and 3-DOT card:

These tools are used to improve convergence through controlled fixation changes at near. The procedure is as follows:

Step 1: The patient holds the card against the bridge of the nose and begins fixation on the farthest barrel, aiming to see one fused image (a mix of red and green) while the other two barrels appear doubled.

Step 2: The patient then shifts fixation progressively from the middle to the nearest barrel, holding each for 10 seconds.

Step 3: This sequence is repeated by alternating fixation between the different barrel positions.

-The same procedure applies to the 3-Dot card. Adjustments in difficulty can be made similarly to those used in the Brock string exercise. The exercise is considered successful when the patient is able to fuse targets at 1 inch from the nose, recognize the sensations associated with convergence and divergence, and stable maintenance of convergence.

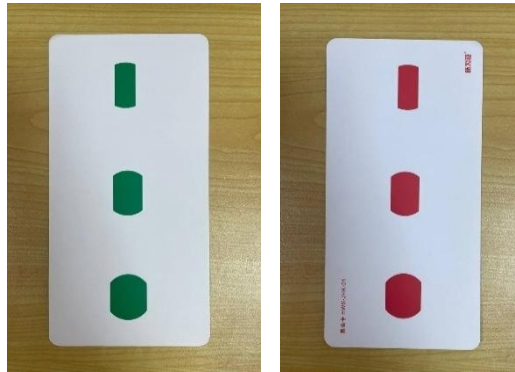


Figure (4): Barrel card

2. Accommodation therapy:

A. Flipper lenses (± 2.00 D):

These lenses are used to stimulate and relax accommodation during near tasks, enhancing accommodative facility and its interaction with vergence. The procedure involves alternating between plus and minus lenses, typically ± 2.00 diopters, while the patient performs near activities such as reading or identifying letters on accommodative charts. The training method is similar to the one used for assessing accommodative facility:

Step 1: The flippers are held at approximately 40 cm from the patient. The patient looks at the target through one side of the flipper ($+2.00$ D) and clears the image.

Step 2: The flipper is then quickly rotated to the opposite lens (-2.00 D), and the patient must clear the image again.

Step 3: This cycle is repeated as quickly and accurately as possible.

-The exercise should be performed daily over several weeks: five minutes monocularly with the right eye (OD), five minutes with the left eye (OS), and five minutes binocularly, for a total of 15 minutes per day.

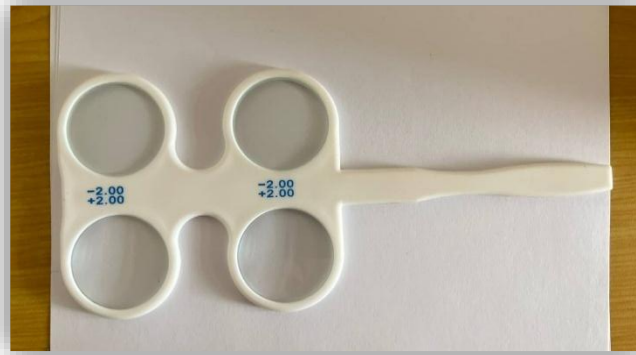


Figure (5): ± 2.00 D flipper lenses

-When the accommodative dysfunction is mild, training can begin directly with ± 2.00 D lenses under binocular conditions, which is the most common case. However, if the patient cannot handle ± 2.00 D binocularly, two alternative strategies are recommended: either start with lenses of lower power (± 1.50 D or ± 1.00 D) binocularly, or begin monocular training with ± 2.00 D or lower, and gradually progress to binocular training. The primary goal is to achieve 20 cycles per minute using ± 2.00 D lenses binocularly.

B. Hart carts:

This exercise trains accommodative flexibility through alternating fixation between near and far targets. Procedure:

1. The patient holds the near chart at approximately 40 cm.
2. They begin by reading the first letter aloud.
3. They then shift their gaze to the distant Hart chart, located about 3 meters away.
4. The patient reads the same letter from the corresponding line on the distant chart.

This near–far alternation continues letter by letter, following the same procedure across all lines on both charts, thereby challenging the accommodative system over several minutes.



Figure (6): Hart charts

IV. Case descriptions:

The diagnosis of convergence insufficiency in all patients was established by another student pair during the initial screening. The following case descriptions include the initial assessment results for each patient, which served as the baseline for the individualized vision therapy programs we designed and implemented.

Type of therapy used:

All four patients included in this study received vision therapy. Three of them followed a fully home-based program, while one underwent a hybrid approach combining home-based exercises with several in-office supervised sessions.

One of the home-based patients attended a single in-office session at the end of the program, but the entirety of their therapeutic follow-up was carried out at home.

Among the four cases, three were diagnosed with convergence insufficiency associated with accommodative excess, and one with pseudo-convergence insufficiency.

Frequency, duration, and follow-up:

The frequency and duration of therapy varied depending on each patient's availability, compliance, and therapeutic response. Most patients performed daily home exercises over a period ranging from 6 to 12 weeks

Follow-up assessments were conducted periodically, most often weekly or every two to three weeks depending on the patient, to monitor progress, measure key visual parameters, and adjust the therapy accordingly. Exercises were modified whenever necessary to ensure continued improvement and to adapt to each patient's evolving condition.

1. Case study 01:

Case 1 – The patient presents with convergence insufficiency accompanied by accommodative excess, as revealed through optometric assessments.

Patient's name: B. A

Age: 22 years

Sex: Male

A. Initial patient profile:

The patient was a young adult with a demanding visual lifestyle, spending long hours working on a computer. Despite not presenting with severe or numerous symptoms initially, their daily activities placed them at risk for visual fatigue and discomfort, especially during near tasks.

A. Established diagnosis and initial assessment:

Parameter	Result			
CISS score:	4			
Refraction (D)	OD: +0.25		OS: +0.25	
Distance visual acuity	OD: 10/10	OS: 10/10	OU: 10/10	
Stereoacuity (arc seconds)	40			
NPC/ Recovery (cm)	12		14	
Distance / Near phoria (Δ)	H: 2 Eso V: ortho		H: 3Exo V: ortho	
AC/A Ratio (Calculated / Gradient)	4.5:1		2.5:1	
Positive fusional vergence at near (Δ)	X / 18 / 10			
Amplitude of accommodation (D)	10			
MEM retinoscopy (D)	-0.25			
Accommodative facility (cmp)	OD: 7	OS: 6.5	OU: 6	

Table 1. Screening summary for convergence insufficiency (CI) – Patient B.A

B. Follow-up and progress monitoring in vision therapy for convergence insufficiency:**a. Therapy schedule and exercises overview:**

- **Start date of therapy:** Thursday, December 18, 2024.

The average duration of vision therapy in this case was 12 weeks. The following table outlines the initial vision therapy exercises, including the type of activity, frequency per day, and duration in minutes.

<i>Period</i>	<i>Exercise</i>	<i>Location</i>	<i>Objective</i>
Week 1	Flipper (± 1.50)	Home	Improve accommodation response
Week 3	Flipper (± 2.00)	Home	Increase accommodative facility
Week 6	Flipper (± 2.00)	Home	Enhance vergence and fusion
	Fusion cards		
End of week 6	Aperture rule	Office	Assess vergence stamina
Week 8	Hart carts	Home	Enhance accommodation and convergence
	Brok string		
Week 9	Aperture rule	Office	Improve fusional reserves
	Barrel card		
Week 10	Hart carts	Home	Integrate vergence and accommodation
	Brok string		
	Flipper (± 2.00)		
End of week 10	Aperture rule	Office	Evaluate binocular coordination
	Fusion cards B		

Week 12	Aperture rule	Office	Final check on convergence
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Table2. Vision therapy home and office exercise schedule– Patient B.A



Figure (7): Illustrates an office-based vision therapy session featuring four exercises: Brock string, and aperture rule and Barrel cards, fusion cards

b. Near point of convergence, recovery point and accommodative facility results:

For each session, three measurements were taken for the near point of convergence (NPC) and the recovery point, using both an accommodative target and a penlight, to ensure reliability. The values presented in the table represent the average of these three attempts.

Accommodative facility was assessed using a ± 2.00 diopter flipper lens. Measurements were taken both monocularly (each eye separately) and binocularly, with results expressed in cycles per minute (cpm).

Timeline	NPC (cm)	Recovery point (cm)	Monocular accommodative facility (± 2.00D flipper) (cpm)	Binocular accommodative facility (± 2.00D flipper) (cpm)
Therapy onset	12	14	OD: 7 OS: 6.5	6
Week 1	9.5	11	OD: 14.5 OS: 15.5	11
Week 3	10.5	12	OD: 17.5 OS: 21	15
Week 6	10.5	11.5	OD: 19.5 OS: 20.5	15.5
Week 8	10	11	OD: 25.5 OS: 23.5	17.5
Week 9	6.5	9	OD: 22.5 OS: 23	19
Week 10	5	6	OD: 24.5 OS: 24	24
Week 12	5.5	7	OD: 24.5 OS: 24.5	20

Table 3. NPC, recovery point, and AF results over therapy timeline for patient B.A

c. MEM retinoscopy results:

Stage	Result (D)	Interpretation
Pre-therapy	-0.25 (Lead)	Abnormal – Indicates accommodative excess
Mid-therapy (after week 9)	Plano	Normal response
Post-therapy	+0.50 (Lag)	Within normal range

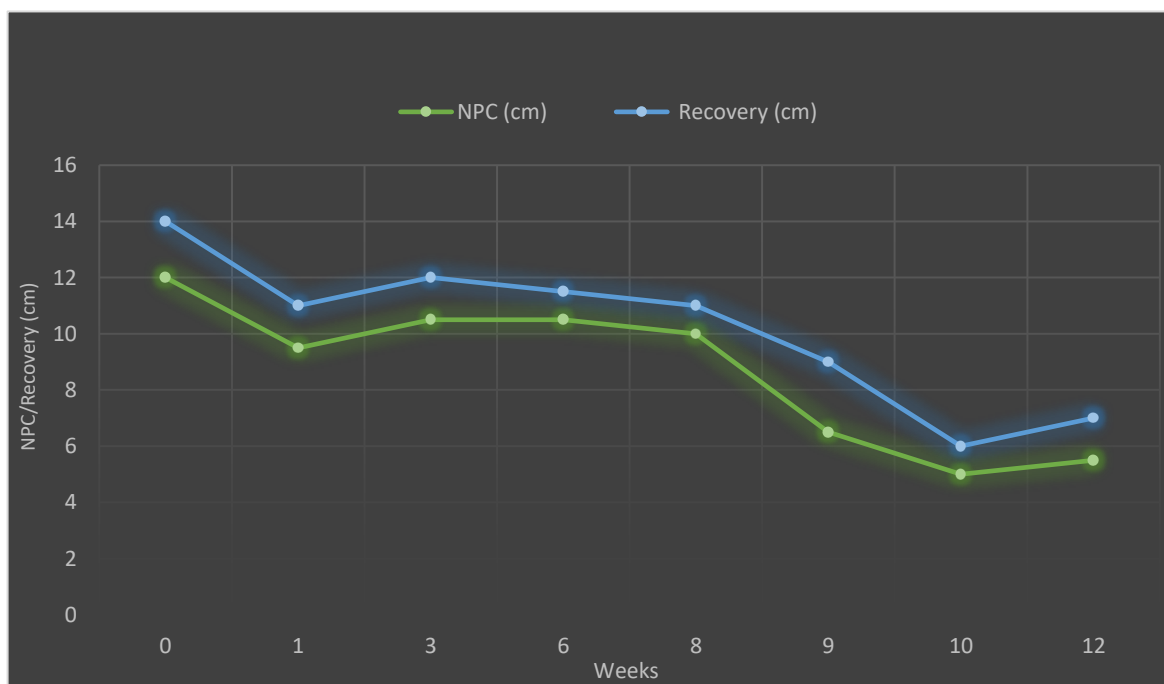
Table 4. MEM retinoscopy results across therapy stages- Patient B.A



Figure (8): Evolution of MEM retinoscopy results throughout the vision therapy sessions

C. Clinical interpretation:

▪ **Near point of convergence and recovery point:**



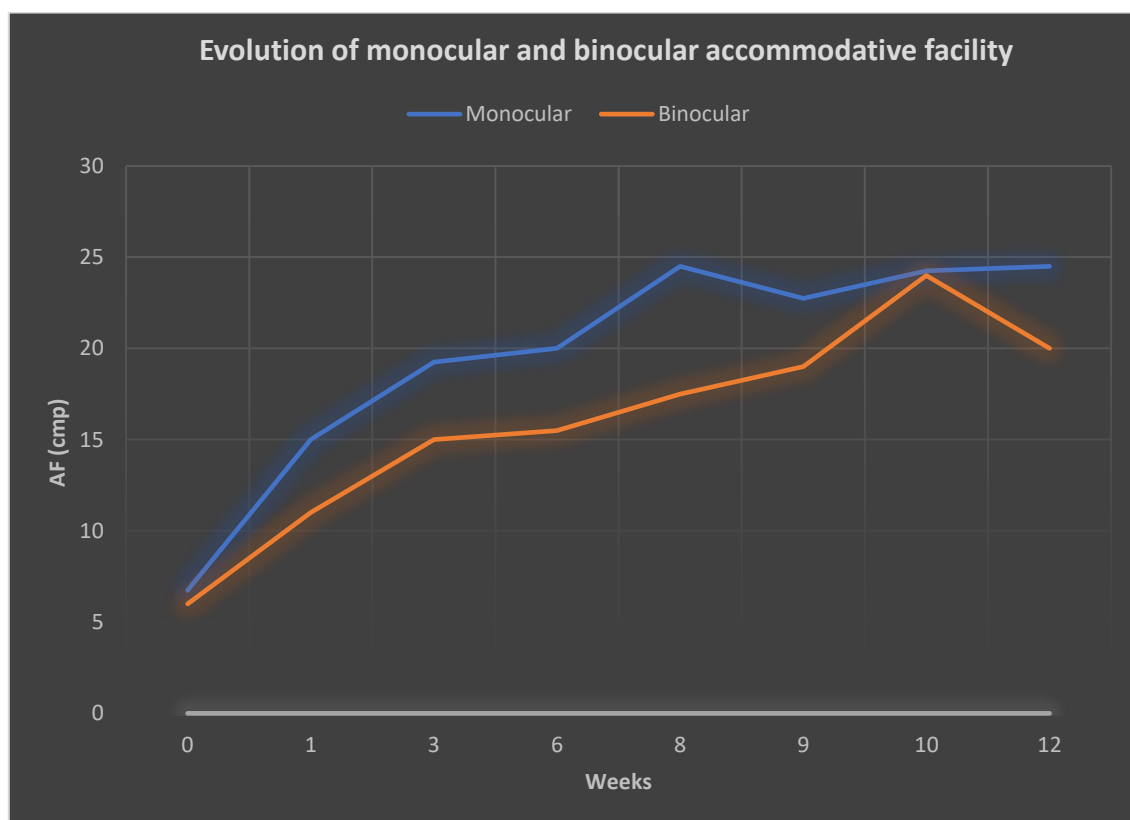
Graph (1): Evolution of NPC and recovery point over for patient B. A

The average initial NPC was 12 cm, which improved to 5.5 cm by the end of therapy, with the best value of 5 cm recorded in week 10. This represents an overall improvement of 6.5 cm, aligning with expected outcomes in the literature.

The recovery point also improved significantly, from 14 cm initially to 7 cm at the end of the program, with a peak performance of 6 cm observed in week 10. While the overall progression was positive, the initial improvement was not stable, likely due to the absence of vergence training in the early sessions.

Moreover, the slight decline between weeks 10 and 12 may be attributed to increased visual demand or fatigue experienced by the patient during that period. These findings suggest a gradual but effective enhancement of convergence ability and recovery stamina over the course of the therapy.

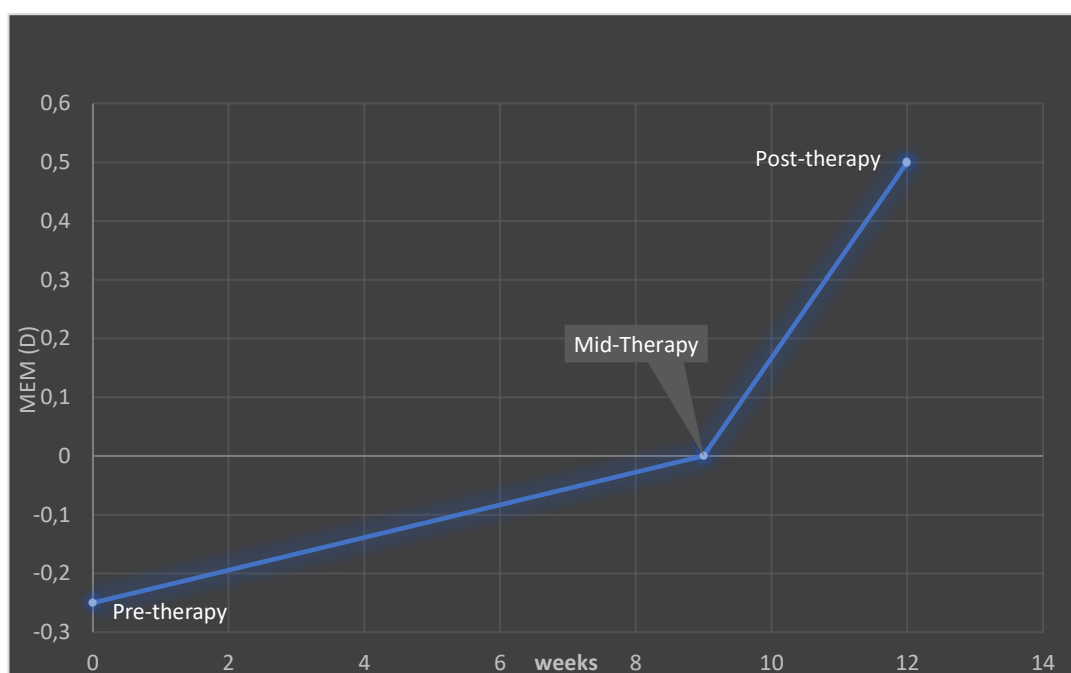
- **Flipper lens facility (cycles per minute):**



Graph (2): Progression of monocular and binocular AF over time for patient B. A

For monocular performance, the average for both eyes (OD and OS) was 6.75 cpm before therapy and increased to 24.5 cpm after therapy. For binocular performance, the average was 6 cpm before therapy and reached 24 cpm in week 10, highlighting a notable enhancement in both monocular and binocular accommodative abilities. However, the binocular facility decreased to 20 cpm by the end of the 12-week program. According to the patient, this decline occurred during a 15-day period of intense academic workload, with increased near tasks and screen time. The final measurement was also taken at the end of the day, which may have contributed to a fatigue-related reduction. Monocular performance, however, remained stable throughout. Despite these factors, the accommodative facility remained significantly higher than at baseline, indicating overall therapy effectiveness.

- **Accommodative response as evidenced by MEM retinoscopy:**



Graph (3): Evolution of MEM retinoscopy result for patient B. A

The patient initially exhibited a lead of accommodation, indicating accommodative excess. By mid-therapy (9 weeks), MEM retinoscopy showed a plano result, reflecting a normalized accommodative response. At the end of therapy, a +0.50 D lag was observed, within the normal range, confirming improved accommodation control and binocular function.

▪ Patient-reported outcomes

Following the vision therapy program, the patient reported a noticeable improvement in visual comfort. They specifically mentioned a significant reduction in eye strain and fatigue during extended computer use. Overall, they felt more comfortable and efficient in their daily visual tasks, particularly during prolonged near work.

D. Short-term follow-up (2 months post-therapy):

Two months after therapy, most visual parameters remained stable or showed slight improvement. Stereoacuity stayed at 20 arc seconds. Positive fusional vergence at near (BO), amplitude of accommodation, and MEM retinoscopy lag also remained stable. Binocular accommodative facility improved slightly from 20 cpm before therapy to 22 cpm at follow-up, indicating maintained progress. NPC and recovery point values showed minor variations but stayed better than baseline. Despite an increased near work load during this period, the patient reported no symptoms. Overall, the patient retained the benefits of therapy with only slight changes after two months.

Parameter	Post-therapy (last session)			After 2 months		
Stereoacuity (arc seconds)	20			20		
NPC (cm)	5.5			6.5		
Recovery point (cm)	7			8		
Positive fusional vergence at near (Δ)	X / 25 / 18			X / 25 / 18		
Amplitude of accommodation (D)	13			12.5		
MEM retinoscopy (D)	+0.50			+0.50		
Binocular accommodative facility (± 2.00 D) (cmp)	OD: 24.5	OS: 24.5	OU: 20	OD: 20.5	OS: 20.5	OU: 22

Table 5. Visual parameter changes after therapy and at 2-month follow-up

2. Case study 02:

Case 2 – The patient presents with pseudo convergence insufficiency.

Patient's name: S. A

Age: 27 years.

Sex: Female.

Initial patient profile:

The patient reported persistent visual discomfort, particularly during sustained near tasks such as reading or computer use. They experienced frequent visual disturbances and occasional episodes of diplopia, occurring two to three times per week. These symptoms significantly impacted visual comfort and functional performance at near. The overall presentation was indicative of a binocular vision anomaly, likely convergence insufficiency, and justified the need for targeted therapeutic intervention.

A. Established diagnosis and initial assessment:

- Given the patient's intensive screen use, two phases of vision therapy were implemented to relieve visual fatigue and improve her convergence abilities.

Parameter	Result		
CISS score	29		
Refraction (D)	OD: -7.00 / -1.50 × 5°	OS: -6.75 / -1.50 × 15°	
Distance visual acuity	OD: 10/10	OS: 10/10	OU: 10/10
Stereoacuity (arc seconds)	70		
NPC /recovery point (cm)	13	20 c	
Distance / Near phoria (Δ)	4 Exo		1 Eso
AC/A Ratio (Calculated / Gradient)	–		–
Positive fusional vergence at near (Δ)	X / 2 / X		
Amplitude of accommodation (D)	6		
MEM retinoscopy (D)	+1.50		
Accommodative facility (cpm)	OD: 7	OS:7	OU:9

Table 6. Screening summary for convergence insufficiency (CI) – Patient S.A

B. Follow-up and progress monitoring in vision therapy for convergence insufficiency:

a. Therapy schedule and exercises overview:

The patient underwent two phases of vision therapy: the first phase lasted 5 weeks, and the second extended over 10 weeks, with the goal of relieving visual fatigue and improving convergence abilities. The following table outlines the initial vision therapy exercises, including the type of activity, frequency per day, and duration in minutes.

❖ **First phase:**

<i>Period</i>	<i>Exercise</i>	<i>Location</i>	<i>Objective</i>
Week 1	Flipper (± 1.00)	Home	Initiate accommodative flexibility using low diopter flipper lenses.
Week 2	Flipper (± 1.00)	Home	Continue flexibility work and add fixation/stamina training with charts.
	Hart charts		
Week 3	Flipper (± 2.00)	Home	Increase difficulty to improve speed and endurance of accommodation.
	Hart charts		
Week 4	Flipper (± 2.00)	Home	Tracking accuracy
	Hart charts		
Week 5	Flipper (± 2.00)	Home	Reinforce accommodative stamina and visual consistency under fatigue.
	Hart charts		

Table 7. Home vision therapy plan for patient S.A (first phase)

❖ **Second phase:**

<i>Period</i>	<i>Exercise</i>	<i>Location</i>	<i>Objective</i>
Week 1	Flipper (± 1.00)	Home	Initiate accommodative flexibility and begin visual reading endurance.
	Hart charts		
Week 6	Flipper (± 1.00)	Home	Resume daily rhythm and reinforce accommodative stability.
	Hart charts		
Week 8	Flipper (± 2.00)	Home	Increase difficulty to enhance speed and accuracy of visual responses.
	Hart charts		
Week 10	Flipper (± 2.00)	Home	Consolidate accommodative control and integrate reading tasks with precision.
	Hart charts		

Table 8. Home vision therapy plan for patient S.A (second phase)



Figure (9): Home-Based vision therapy Setup with Hart chart and flipper lenses

b. Near point of convergence, recovery point and accommodative facility results:

❖ **First phase:**

Timeline	NPC (cm)	Recovery point (cm)	Monocular accommodative facility (cpm)	Monocular accommodative facility (cpm)
Therapy onset	13	20	7	9
Week 1	13	20	7	9
Week 2	10	16	12	11
Week 3	8	10	17	17
Week 5 (final result)	7	9.5	23	34

Table 9. NPC, recovery point, and AF results over therapy timeline for patient S.A (first phase)



Figure (10): Tools for measuring accommodative facility: flipper lenses and cover

❖ **Second phase:**

Timeline	NPC (cm)	Recovery point (cm)	Monocular accommodative facility (cpm)	Monocular accommodative facility (cpm)
Therapy onset	13	18	OD: 6.5	7.5

			OS: 3	
Week 6	8	10	OD: 18 OS: 17	10.5
Week 8	8	10	OD: 21 OS: 25	22
Week 10 (final result)	7.5	9	OD: 23 OS: 23.5	21.5

Table 10. NPC, recovery point, and AF results over therapy timeline for patient S.A (second phase)

c. MEM retinoscopy result:

❖ **Phase one:**

Stage	Result (D)	Interpretation
Pre-therapy	+1.50	High lag of accommodation; indicates underactive accommodative response.
Mid-therapy (after 3 week)	+1.00	Moderate improvement; reduced lag, showing better accommodative engagement.
Post-therapy	+0.50	Near-normal accommodative lag; effective response to therapy

Table 11. MEM retinoscopy result for patient S.A (first phase)

❖ **Phase two:**

Stage	Result (D)	Interpretation
Pre-therapy	+1.25	Reduced accommodative flexibility; initial baseline before training
After 6 weeks	+1.50	Slight increase.
After 8 weeks	+0.50	Marked improvement, indicating increased

		accommodative response efficiency.
Post-therapy	+0.50	Sustained improvement; accommodative function appears stable and more responsive.

Table 12. of MEM retinoscopy resultfor patient S.A (second phase)

d. Amplitude of accommodation results:

❖ **Phase two:**

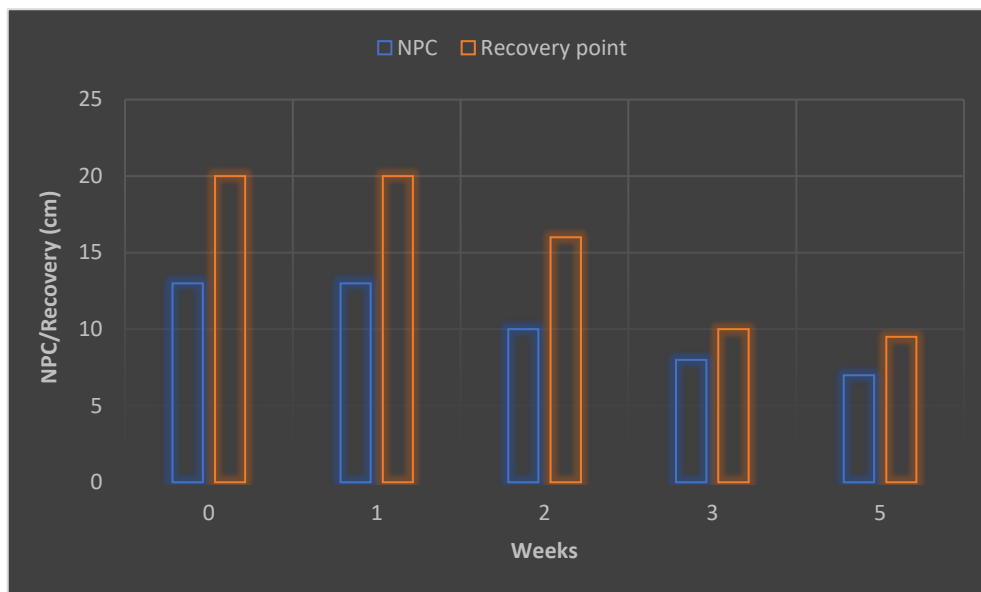
Stage	Result (D)	Interpretation
Pre-therapy	OD: 7 OS: 6 OU: 6	Below age-expected norms (reduced accommodative amplitude)
After 6 weeks	OD:9 OS:10.5 OU: 10	Significant improvement, especially in OS and OU
After 8 weeks	OD: 12.5 OS: 9 OU: 10	OD shows further gain, OS slightly decreased; OU remains stable
Post-therapy	OD: 10 OS: 10 OU: 10	Balanced and stable amplitude in both eyes; functional symmetry achieved

Table 13. Amplitude of accommodation results over the course of therapy for patient S.A

C. Clinical interpretation:

a. Phase one:

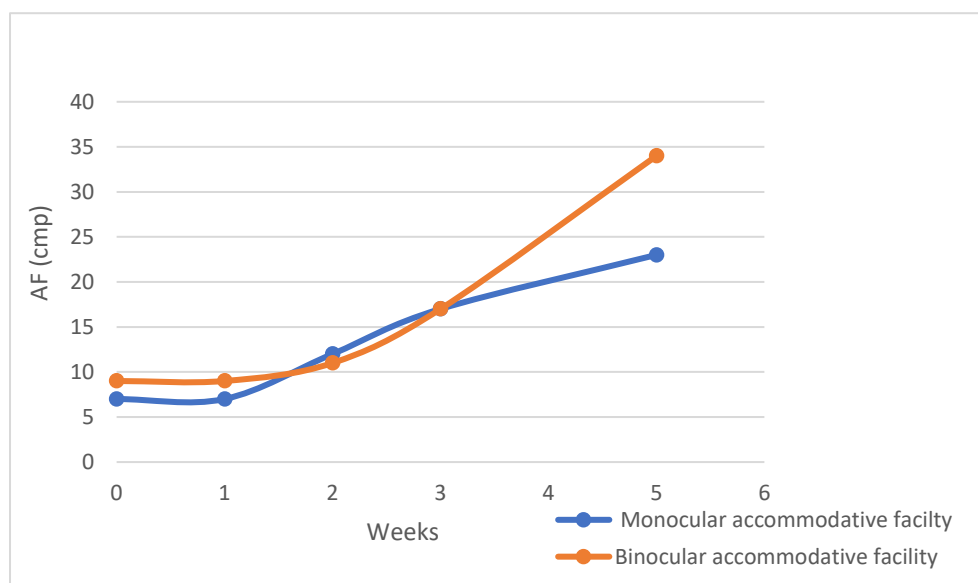
- **NPC and recovery point:**



Graph (4): Evolution of NPC and recovery point over weeks for patient S. A (phase one)

The average initial Near Point of Convergence (NPC) was 10 cm, which improved to 5.5 cm by the end of therapy. This represents an average improvement of 4.5 cm, aligning with expected outcomes reported in the literature. Similarly, the recovery point showed a marked improvement, decreasing from an average of 13 cm to 7 cm post-therapy. These findings reflect enhanced convergence stamina and improved binocular recovery ability.

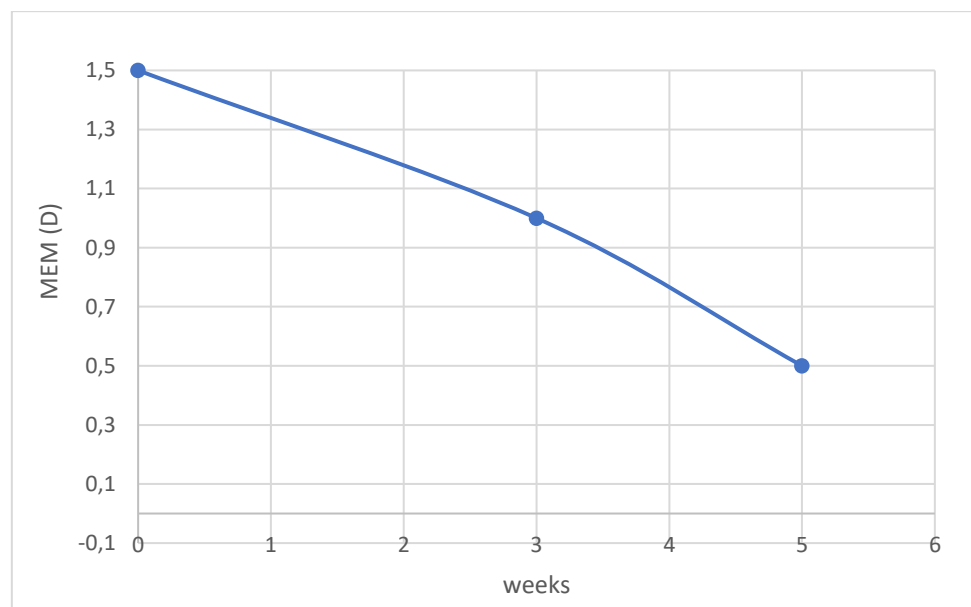
- **Flipper lens facility (cycles per minute):**



Graph (5): Progression of monocular and binocular AF over time for patient S.A(phase one)

Over five weeks of therapy, both monocular and binocular accommodative facility improved markedly. Monocular facility increased from 7 to 23 cycles per minute, while binocular facility progressed from 9 to 34 cpm. These values surpass age-expected norms, indicating excellent gains in accommodative speed and stamina. The improvement reflects enhanced visual efficiency for near tasks and supports a strong therapeutic response consistent with outcomes reported in the literature.

- **Accommodative response as evidenced by MEM retinoscopy**



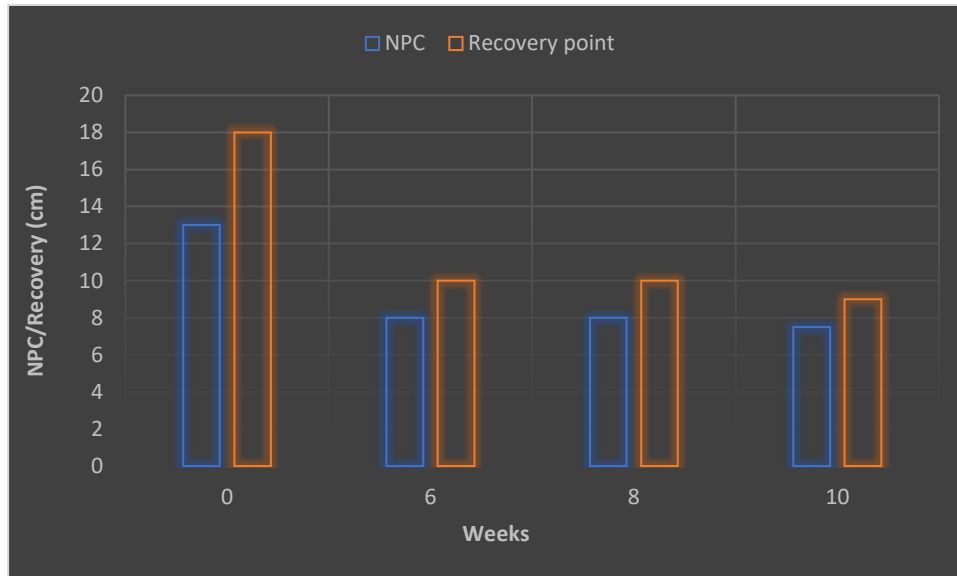
Graph (6): Evolution of MEM retinoscopy result for patient S.A(phase one)

The patient's accommodative response, assessed through MEM retinoscopy, demonstrated consistent improvement over the course of therapy. Initially, a +1.50 D lag was observed, indicating a high lag of accommodation and an underactive accommodative system. After three weeks of therapy, the lag had reduced to +1.00 D, suggesting moderate improvement and better accommodative engagement. By the end of therapy, the lag further decreased to +0.50 D, falling within the normal range. This progression reflects a normalized accommodative response and confirms the effectiveness of the therapeutic intervention.

- **Patient-reported outcomes:**

At the beginning of therapy, the patient reported persistent visual discomfort and no noticeable improvement, especially during near tasks. During the second week, they experienced symptoms of visual disturbances at near and occasional diplopia, occurring two to three times per week. By the third week, symptoms began to diminish, with the patient reporting no significant near vision issues and only isolated diplopia episodes about once a week. By the fifth week, the patient described a marked improvement in overall visual comfort, with no complaints of strain or diplopia, particularly during sustained near activities such as reading or computer use.

- b. Phase two:**
- **NPC and recovery point:**

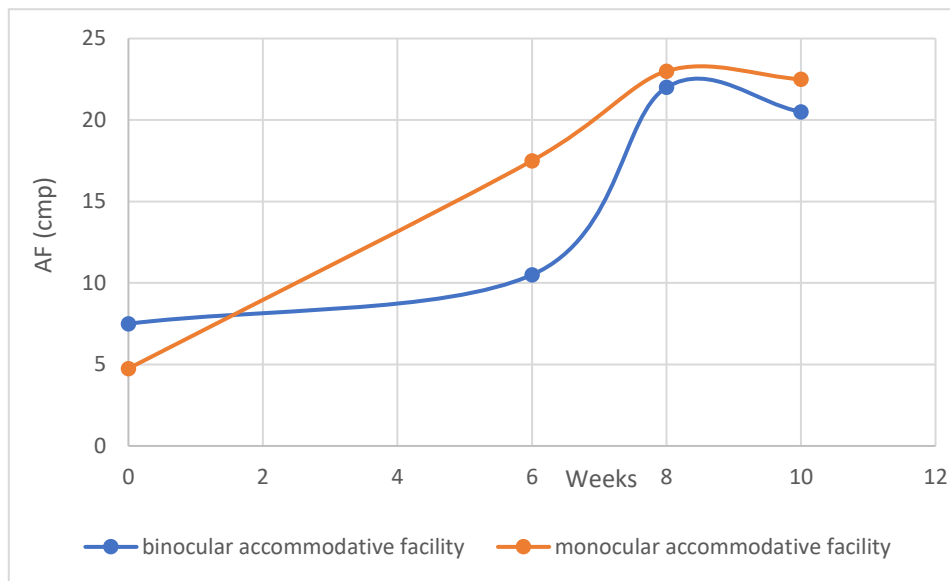


Graph (7): Evolution of NPC and recovery point over weeks for patient S.A(phase two)

The initial Near Point of Convergence (NPC) measured at Week 1 was 13 cm. Over the course of therapy, this value progressively improved, reaching 7.5 cm by Week 10. This represents a total improvement of 5.5 cm, reflecting enhanced convergence ability.

Similarly, the recovery point improved significantly from 18 cm at baseline to 9 cm at the end of therapy a 9 cm improvement. These changes indicate not only a better near point but also increased convergence stamina and faster recovery from fusion break.

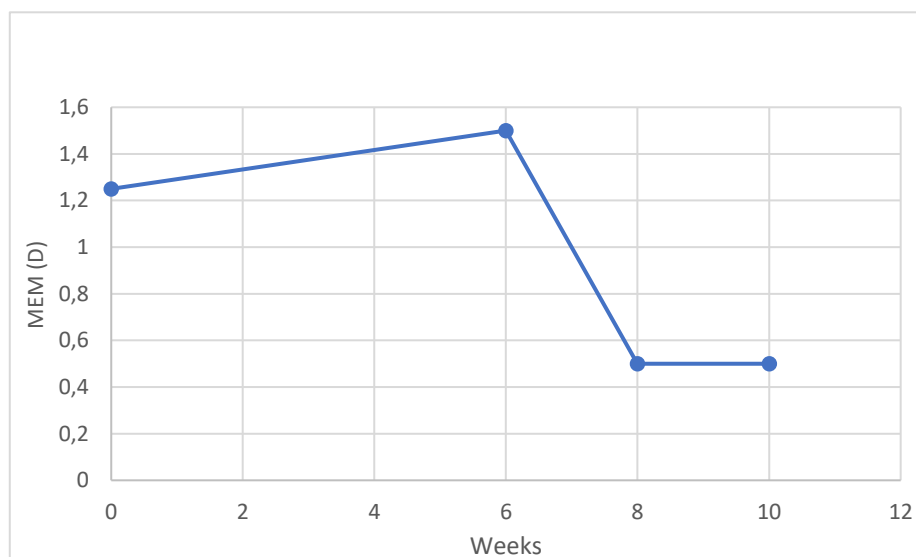
- **Flipper lens facility (cycles per minute):**



Graph (8): Progression of monocular and binocular AF over time for patient S.A (phase two)

Over 10 weeks of therapy, both binocular and monocular accommodative facility improved significantly. Binocular facility increased from 7.5 to 20.5 cpm, and monocular facility from 4.75 to 22.5 cpm. These results exceed age-expected norms and indicate enhanced accommodative flexibility and visual endurance. Such improvement supports better performance in sustained near tasks like reading and studying, and aligns with therapeutic outcomes reported in the literature.

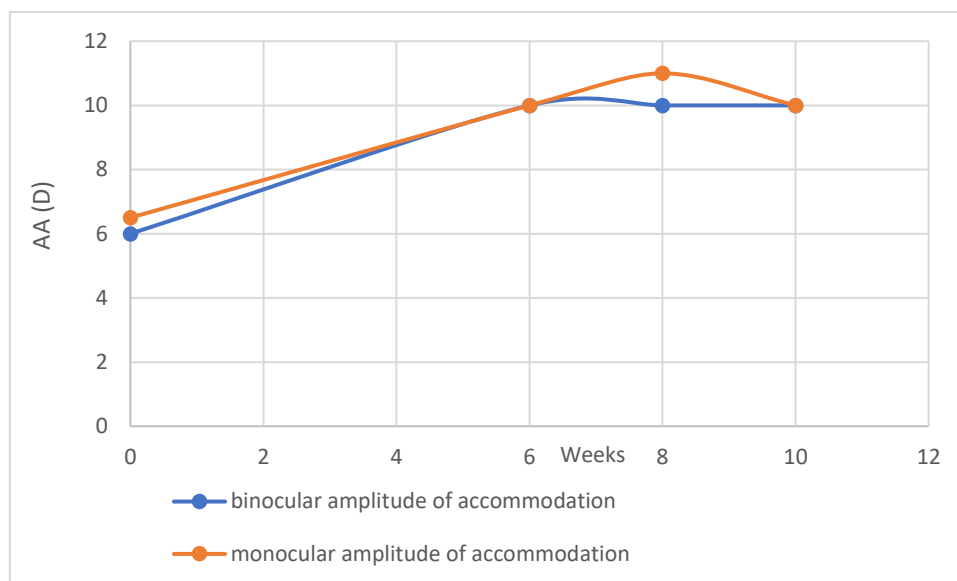
- **Accommodative response as evidenced by MEM retinoscopy**



Graph (9): Evolution of MEM retinoscopy result for patient S.A (phase two)

The patient's accommodative response, as measured by MEM retinoscopy, showed a positive trend over the course of therapy. At baseline, a lag of +1.25 D indicated reduced accommodative flexibility. At Week 6, a slight increase to +1.50 D was noted, possibly reflecting temporary strain or adaptation. By Week 8, the lag reduced markedly to +0.50 D, indicating improved efficiency in the accommodative system. This result was maintained post-therapy, confirming a sustained and stable improvement in accommodative response.

▪ **Amplitude of accommodation:**



Graph (10): Evolution of accommodation amplitude for patient S.A

At baseline, the patient exhibited subnormal accommodative amplitudes in both eyes, falling below age-appropriate norms. Throughout the course of therapy, a marked improvement was observed, with peak amplitudes recorded around Week 8. Final post-therapy measurements indicate functional normalization, with both monocular and binocular amplitudes reaching a stable and balanced level. The alignment of OD and OS values at 10 D post-therapy reflects functional symmetry and enhanced efficiency in the patient's accommodative system.

▪ **Patient-reported outcomes:**

In Week 1, the patient reported frequent visual discomfort, including blur and difficulty focusing during near tasks. By Week 6, symptoms had reduced noticeably, though occasional eye strain and mild blur were still present after prolonged reading. In Week 8, the patient described further improvement, with only minor fatigue during extended near work. By Week 10, the patient reported no visual discomfort, noting clear and comfortable vision during sustained near activities such as reading and screen use. These improvements reflect a positive functional response to therapy.

3. Case study 03:

Case 3 – The patient presents with convergence insufficiency associated with a secondary accommodative excess, as demonstrated by optometric evaluations

Patient's name: M. Y

Age: 22 years.

Sex: female.

Initial patient profile:

For the past two years, the patient has been experiencing unbearable migraines, which she initially neglected. While studying or reading, she noticed that words appeared to move or jump, with letters overlapping or merging with others. She also reported episodes of diplopia and painful eyes, including discomfort in the periocular region. Additionally, she mentioned difficulty keeping her eyes fully open, especially when looking at screens at the end of the day.

A. Established diagnosis

Parameter	Result			
CISS score	35			
Refraction (D)	OD: -0.50		OS: -0.25	
Distance visual acuity	OD: 10/10	OS: 10/10	OU: 12/10	
Stereoacuity (arc seconds)	70			
NPC / Recovery (cm)	17		20	
Distance/ Near phoria (Δ)	H: 5 Exo	V: 0	H: 6 Exo	V: 0
AC/A Ratio (Calculated / Gradient)	3.9:1		3:1	
Positive fusional vergence at near (Δ)	15 / 27 / 19			
Amplitude of accommodation(D)	11			
MEM retinoscopy(D)	-1.25			
Accommodative facility (cpm)	OD: 4	OS: 4	OU: 3	

Table 14. Screening summary for CI – Patient M.Y

B. Follow-up and progress monitoring in vision therapy for CI:**a. Therapy schedule and exercises overview:**

Start date of therapy: Monday, February 24, 2025.

The average duration of vision therapy in this case was 11 weeks. The table below summarizes the activities implemented at different stages, including the type of exercise, duration, frequency, therapeutic objectives, and reported symptom changes throughout the program:

<i>Period</i>	<i>Exercise</i>	<i>Objective</i>	<i>Symptom improvement</i>
Week 6	Flipper (± 1.50)	Improve accommodation	- Improvement, no symptoms reported -Monocular flipper difficulty
Week 8	Flipper	Enhance accommodation and vergence	-Persistent pain -Visual fatigue
	Fusion cards		
	Brock string		
Week 10	Flipper ($\pm 2.00D$)	Integrate accommodation and vergence	-Tolerable headaches
	Hart charts		
	Fusion cards or Brock string (day by day).		
Week 11	Flipper ($\pm 2.00D$)	Focus on vergence improvement and accommodation	-Minor symptoms present -Patient felt normal overall
	Hart charts		
	Fusion cards or Brock string		
End of	Barel card	Final check of	

week 11(in- office)	Fusion cards B	binocular coordination	
	Aperture rule		

Table 15. Vision therapy home and office exercise schedule– Patient M.Y



Figure (11): Hart chart and ± 2.00 flipper lenses used in therapy for patient M. Y



Figure (12): Patient performing office-based therapy with the aperture rule and barrel cards

a) Near point of convergence, recovery point and accommodative facility results:

Timeline	NPC (cm)	Recovery point (cm)	Monocular accommodative facility (cpm)	Binocular accommodative facility (cpm)
Therapy onset	17	20	OD: 4 OS: 4	3
Week 6	14	16	OD: 14 OS: 11 (fails with + lenses)	14
Week 8	6.5	8.5	OD: 12 OS: 8	15
Week 10	12	20	OD: 16.5 OS: 14	15
Week 11	8	11.5	OD: 15.5 OS: 17	15

Table 16. NPC, recovery point, and AF results over therapy timeline for patient M.Y

b) MEM retinoscopy results:

Stage	Result(D)	Interpretation
Pre-therapy	-1.25	Significant accommodative lead
After 6 weeks	- 1.00	Mild improvement, but accommodative lead persists
After 8 weeks	- 1.25	Persistent accommodative lead
After 10 weeks	-1.25	Unchanged accommodative lead
Post-therapy (week 11)	-1.00	Slight reduction in lead, still abnormal

Table 17. MEM retinoscopy results across therapy stages for patient M.Y

c) Amplitude of accommodation results:

Stage	Result (D)	Interpretation
Pre-therapy	11	Stable amplitude, no change observed
Week 6	11	
Week 8	11	
Week 10	11	
Week 11	11	

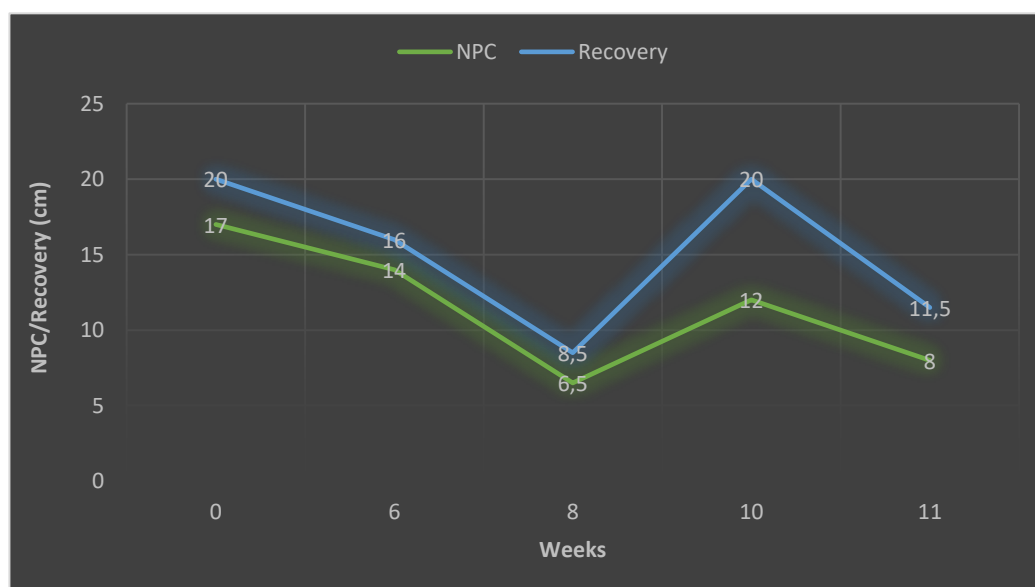
Table 18. Amplitude of accommodation results over the course of therapy for patient M.Y



Figure (13): Measurement of the amplitude of accommodation

C. Clinical interpretation:

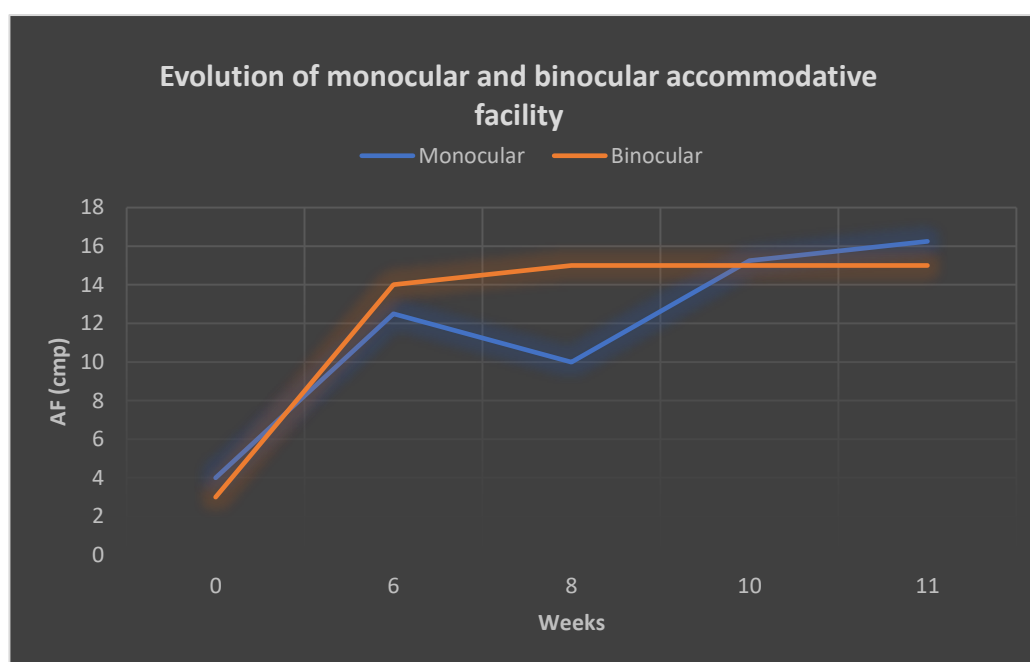
▪ NPC and recovery point:



Graph (11): Evolution of NPC and recovery over weeks for patient M. Y

The graph, showing the progression of NPC and recovery, highlights a clear improvement between weeks 6 and 8, with a significant decrease in NPC distance (from 14 cm to 6.5 cm) and recovery distance (from 16 cm to 8.5 cm). However, a notable regression occurs at week 10, where NPC and recovery distances increase to 12 cm and 20 cm respectively, indicating a deterioration. Finally, an improvement is observed again at week 11, with distances decreasing to 8 cm for NPC and 11.5 cm for recovery.

- **Flipper lens facility (cycles per minute):**

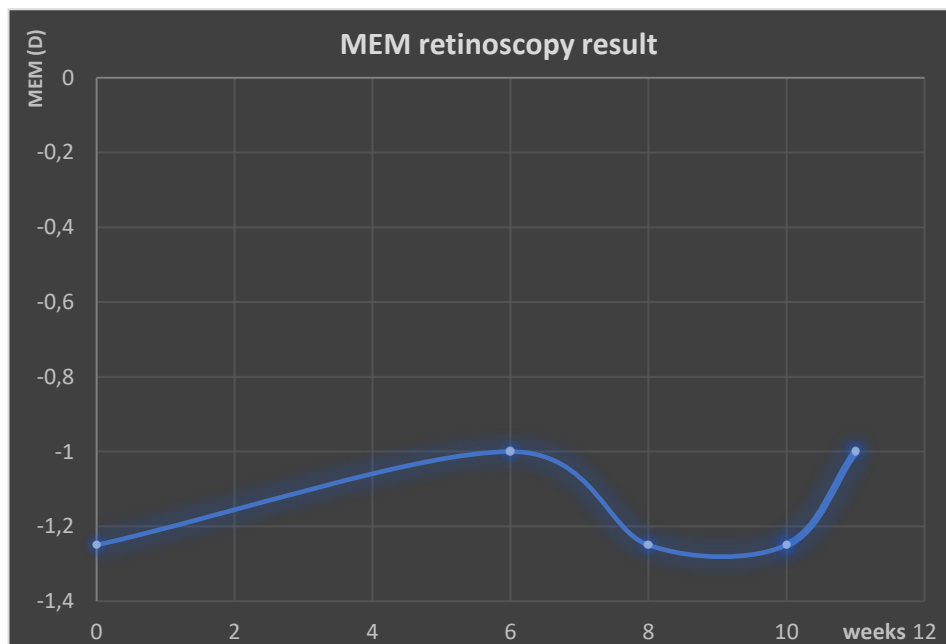


Graph (12): Progression of monocular and binocular AF over time for patient M. Y

The graph demonstrates a clear improvement in both monocular and binocular AF over the course of the therapy. Both measures increase rapidly in the initial weeks, with binocular accommodative facility reaching a plateau around week 8 and remaining stable thereafter. Monocular accommodative facility shows a slight dip around week 8, due to visual fatigue but continues to improve, surpassing binocular facility by week 11.

This fluctuation in progress may be explained by inconsistent adherence to home-based exercises and visual fatigue. A temporary decline in NPC improvement was noted before the final session, which the patient attributed to skipping vergence training, including the Brock string and fusion cards. In contrast, accommodative facility continued to improve, as the patient remained consistent with accommodation therapy using tools such as the Hart chart and flipper.

- **Accommodative response as evidenced by MEM retinoscopy:**



Graph (13): Evolution of MEM retinoscopy result for patient M. Y

The MEM retinoscopy results indicate a significant accommodative lead at baseline (-1.25 D), which shows a mild improvement at week 6 (-1.00 D). However, the lead returns to -1.25 D by week 8 and remains unchanged through week 10. By the end of therapy (week 11), the lead slightly decreases to -1.00 D, suggesting a trend toward normalization. However, the persistence of this lead may reflect accommodative stress or a compensatory strategy for the convergence insufficiency being treated, as the visual system attempts to manage an ongoing imbalance between the accommodation and vergence systems.

Therefore, continuing therapy or scheduling follow-up sessions is recommended to ensure full stabilization of the accommodative system and restore a proper accommodation-vergence relationship.

- **Patient-reported outcomes:**

The best symptom improvement was reported after 6 weeks of therapy, when the patient experienced no symptoms such as headaches, diplopia, or eye pain. However, during the course of the study, due to the intense work at near and occasional illness, the patient sometimes found the exercises difficult to perform and had poor sleep. As a result, some symptoms recurred intermittently. Despite this, no severe or significant issues were reported by the end of the therapy.

4. Case study 04:

Case 4 – The patient presents with convergence insufficiency accompanied by accommodative excess, according to optometric findings.

Patient's name: L.R

Age: 23 years.

Sex: Male.

Initial patient profile:

The patient reports symptoms like eye strain, double vision, and difficulty concentrating during near tasks, with a total score of 8. Although the form was not completed for a specific concern, the results suggest possible convergence insufficiency and warrant further evaluation.

A. Established diagnosis and initial assessment:

Parameter	Result		
CISS score	8		
Refraction (D)	OD: Plano / -0.75 × 90		OS: Plano
Distance visual acuity	OD: 12/10	OS: 12/10	OU: 12/10
Stereoacuity (arc seconds)	20		
NPC/ Recovery point	10	11	
Distance / Near phoria (Δ)	Ortho		7 Exo
AC/A Ratio (Calculated / Gradient)	4 :1		2: 1
Amplitude of accommodation (D)	10		
MEM retinoscopy (D)	+ 0.25		
Accommodative facility (cpm)	Fails with + lenses		

Table 19. Screening summary for convergence insufficiency (CI) – Patient L.R

B. Follow-up and progress monitoring in vision therapy for CI:**a. Therapy schedule and exercises overview:**

The average duration of vision therapy in this case was 6 weeks. The following table outlines the initial vision therapy exercises, including the type of activity, frequency per day, and duration in minutes.

Period	Exercise	Location	Objective
Week 1	Flipper (± 1.50)	Home	Stimulate accommodation and fusion skills
	Brock string		
	Fusion cards		
Week 3	Flipper (± 1.50)	Home	Improve eye-hand coordination and binocular fusion
	Brock string		
	Fusion cards		
Week 5	Flipper (± 1.50)	Home	Consolidate accommodative flexibility and binocular fusion
	Brock string		
	Fusion cards		
Week 6	Flipper (± 1.50)	Home	Prepare for the generalization of visual skills to real-life tasks (reading, sports, screens)
	Brock string		
	Fusion cards		

Table 20. Home vision therapy plan for patient L.R

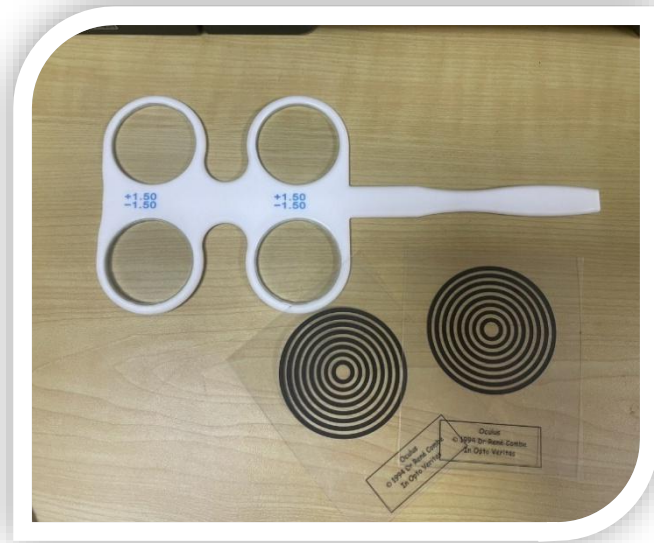


Figure (14): ± 1.50 Flipper and Fusion Card A used during therapy with patient L.R

a) Near point of convergence, recovery point and accommodative facility results:

Timeline	NPC (cm)	Recovery point (cm)	Monocular accommodative facility (cpm)	Binocular accommodative facility (cpm)
Therapy onset	10	11	Fails with + lenses	Fails with + lenses
Week 3	9	11	OD: 7 OS: 5	9
Week 5	8.5	12.5	OD: 6 OS: 4	6.5
Week 6 (final result)	6	7	OD: 6.5 OS: 6.5	11

Table 21. NPC, recovery point, and AF results over therapy timeline for patient L.R.

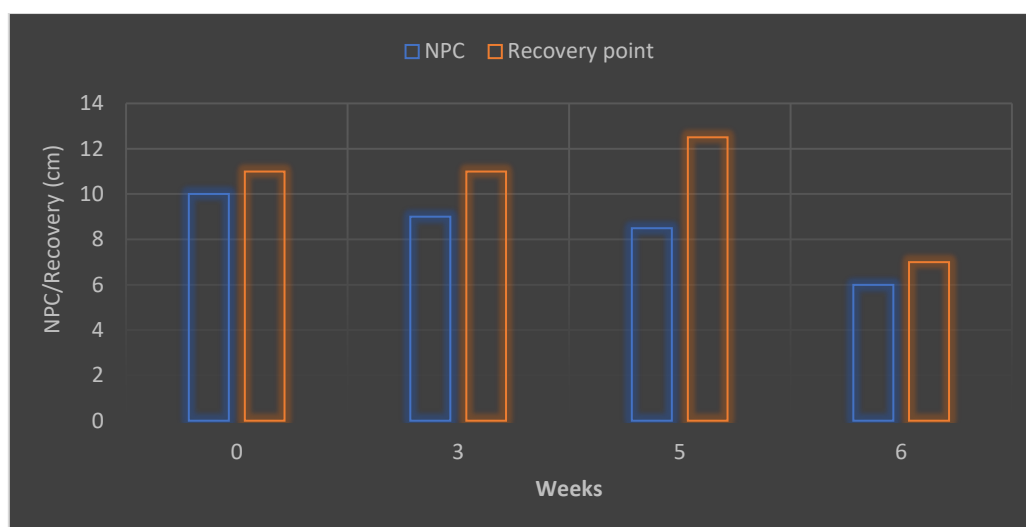
b. MEM retinoscopy results:

Stage	Result (D)	Interpretation
Pre-therapy	+0.25	Mild lag of accommodation; indicative of reduced accommodative response.
After 5 weeks	Plan	Normal response; accommodative lag has decreased significantly.
After 6 weeks	-0.25	Lead of accommodation; may suggest overcompensation or increased accommodative effort.

Table 22. MEM retinoscopy results across therapy stages- Patient L.R

C. Clinical interpretation

▪ **NPC and recovery point:**

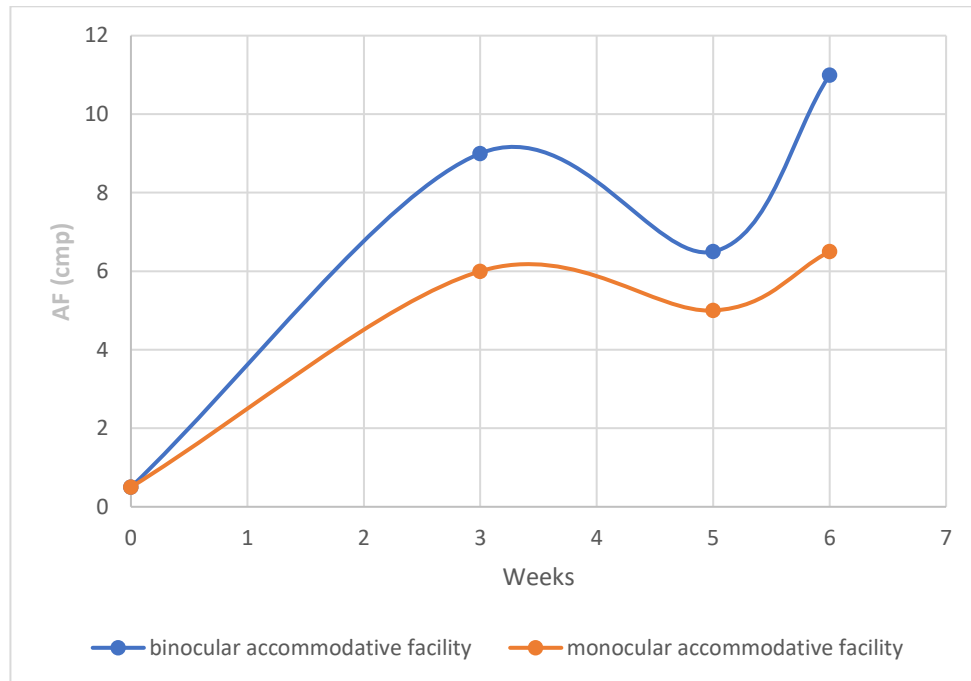


Graph (14): Evolution of NPC and recovery point over for patient L.R

The initial result of NPC was 10 cm, which progressed to 6 cm at the completion of therapy, representing a 4 cm increase in convergence ability. The recovery point was also favorable, from 11 to 7 cm. Although with minor oscillations in middle of the therapy, the general trend

seems to show that better convergence stamina and more efficient binocular recovery is in accordance with both the therapeutic purpose and data present in literature.

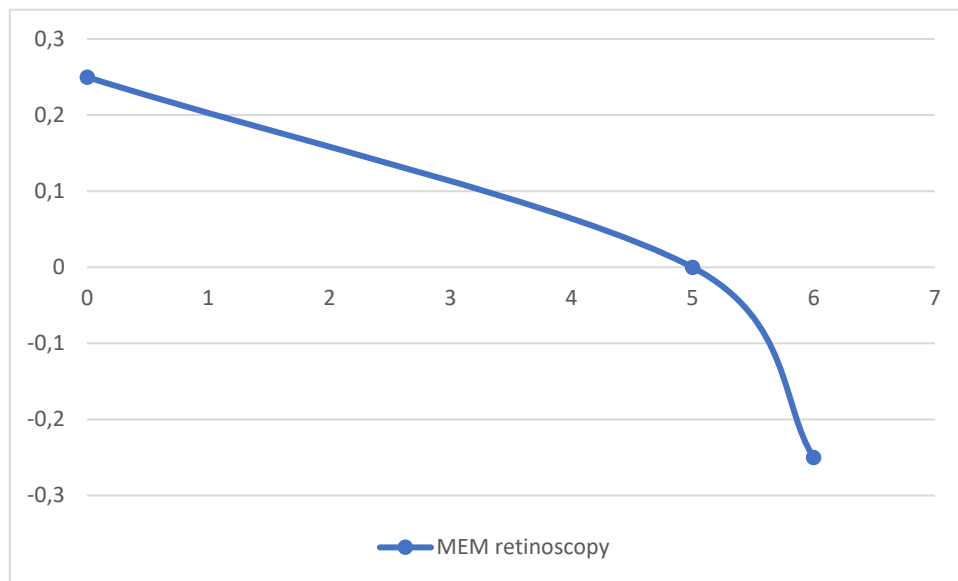
- **Flipper lens facility (cycles per minute):**



Graph (15): Progression of monocular and binocular AF over time for patient L.R

Over six weeks of therapy, both monocular and binocular accommodative facility showed significant improvement. Starting at just 0.5 cycles per minute (cpm), monocular facility increased to 6.5 cpm, and binocular facility rose to 11 cpm by Week 6. A temporary decline at Week 5 was noted, which coincided with the patient not performing home exercises and experiencing increased visual strain due to intensive thesis work. Despite this setback, the overall progression reflects improved accommodative flexibility and visual stamina, aligning with expected outcomes in accommodative therapy.

- **Accommodative response as evidenced by MEM retinoscopy**



Graph (16): Evolution of MEM retinoscopy result for patient L. R

Initially, the patient presented with a +0.25 D lag, suggesting an accommodative response below the demand, consistent with a mild lag of accommodation. By week 5, the response measured plano, showing no lag. Although this is slightly below the expected normative range. At week 6, a slight lead of -0.25 D was noted, which may be interpreted as overcompensation or an increased accommodative effort, this may be explained by irregular performance of vision therapy exercises and the patient's intensive near work while writing his thesis.

- **Patient-reported outcomes:**

The patient initially reported frequent visual discomfort, headaches, and difficulty concentrating during near tasks. Symptoms included occasional double vision and blurred vision. Over the following weeks, these symptoms gradually decreased. By the fifth week, the patient reported marked improvement in visual comfort with no diplopia or strain during near work.

V. Overall results and comparative analysis of vision therapy cases:

1. Individual clinical outcomes pre- and post-therapy:

Case 01:

<i>Measure</i>	<i>Pre-therapy</i>	<i>Post-therapy</i>
NPC (cm)	12	5.5
Recovery point (cm)	14	7
Monocular Flipper rate (cpm)	7	24.5
Binocular flipper rate (cpm)	6	20
MEM retinoscopy (D)	-0.25 (Lead)	+0.50 (Lag)
Stereoacuity (arc seconds)	40	20
Amplitude of accommodation (D)	10 D	13 D
Positive fusional vergence at near (Δ)	X / 18 / 10	X / 25 / 18
CISS	4	0

Case 02:

<i>Measure</i>	<i>Pre-therapy</i>	<i>Post-therapy</i>
NPC (cm)	13	7.5
Recovery point (cm)	20	9
Monocular flipper rate (cpm)	7	23
Binocular flipper rate (cpm)	9	21,5
Stereoacuity (arc seconds)	70	50
MEM (D)	+1.50	+0.50 D
Amplitude of accommodation (D)	6	10
Positive fusional vergence at near (Δ)	X / 2 / X	X / 25 / 20
CISS	29	21

Case 03:

<i>Measure</i>	<i>Pre-therapy</i>	<i>Post-therapy</i>
NPC (cm)	17	8
Recovery point (cm)	20	11.5
Monocular flipper rate (cpm)	4	16.25
Binocular flipper rate (cpm)	3	15
MEM retinoscopy(D)	+0.25	-1.00
Stereoacuity (arc seconds)	70	20
Amplitude of accommodation (D)	12.5	10
CISS	35	17

Case 04:

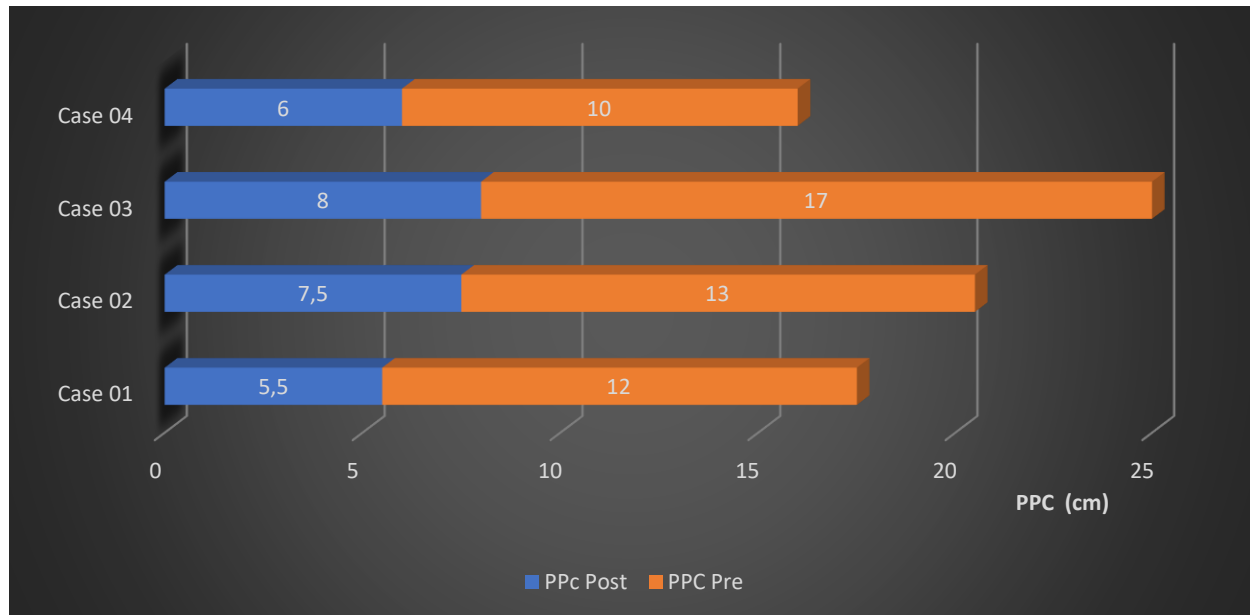
<i>Measure</i>	<i>Pre-therapy</i>	<i>Post-therapy</i>
NPC (cm)	10	6
Recovery point (cm)	11	7
Monocular flipper rate (cpm)	Fails with + lenses	6.5
Binocular flipper rate (cpm)	Fails with + lenses	11
MEM retinoscopy (D)	+0.25	-0.25
Stereoacuity (arc seconds)	20	20
Amplitude of accommodation (D)	10	10.5
CISS	9	8

Table23. Comparison of clinical measures pre- and post-vision therapy across four cases

2. Comparative results and graphs for all cases:

- In all four cases, each patient showed significant improvement in the primary clinical markers of convergence insufficiency following vision therapy:

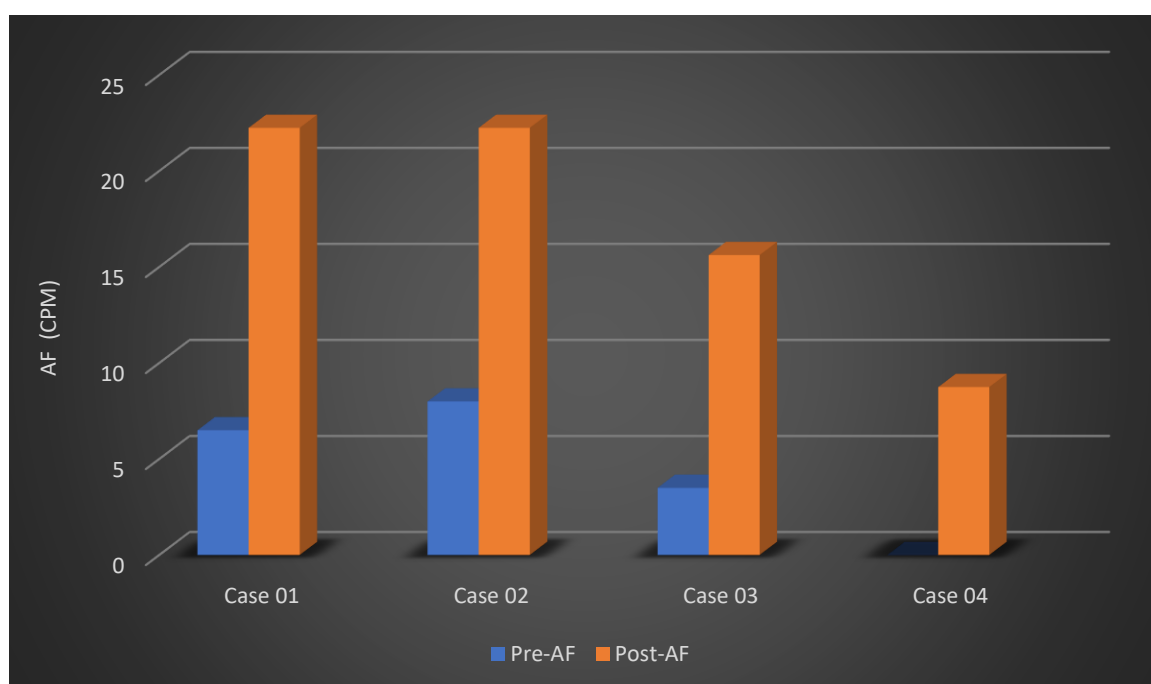
A. Near point of convergence and recovery point changes:



Graph (17): Comparison of NPC Pre- and Post-therapy for 4 patients

- ➔ The near point of convergence improved significantly across all cases, with the average NPC decreasing from 13.75 cm at baseline to 6.75 cm post-therapy.
- ➔ Recovery points also showed significant improvements, with the mean value decreasing from 16.25 cm pre-therapy to 8 cm post-therapy. This represents a 50% reduction in recovery distance

B. Accommodative facility progression:



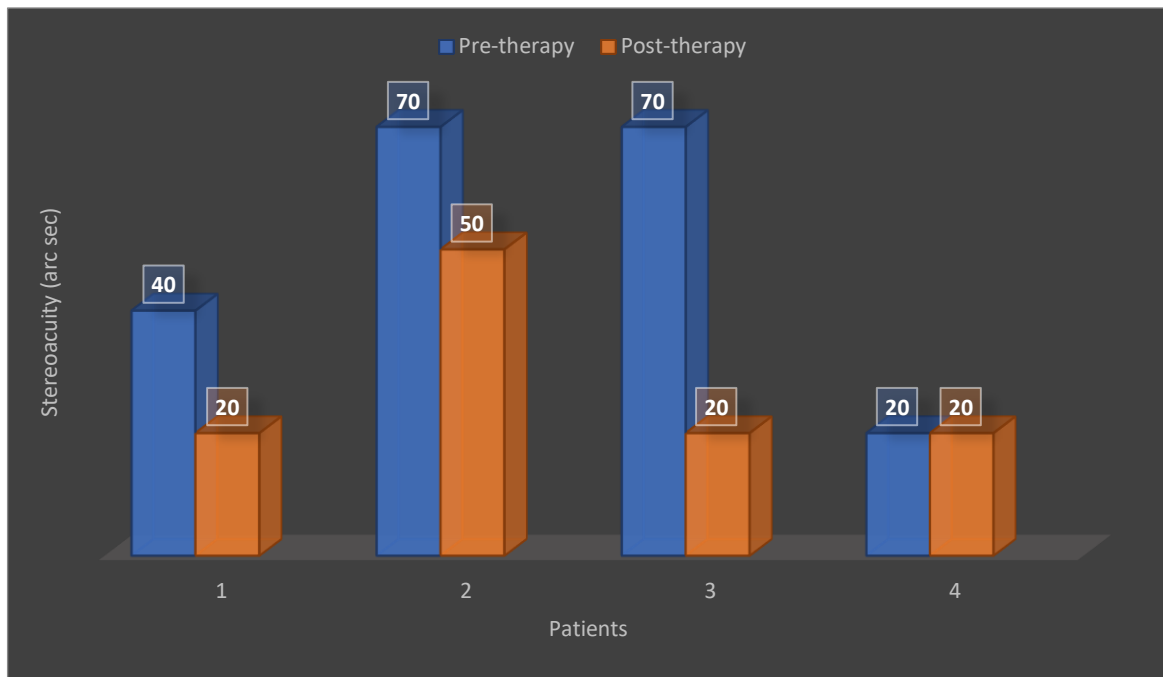
Graph (18): Accommodative facility before and after therapy in 4 patients

→ The flipper rate (± 2.00 D) showed a remarkable improvement. The monocular accommodative facility increased from an average of 6.0 cycles per minute at baseline to 17.6 cpm post-therapy. Likewise, the binocular flipper improved from 6.0 cpm to 16.9 cpm,

C. Stereoacuity evolution:

Patient	Initial stereoacuity (arc seconds)	Final stereoacuity (arc seconds)	Improvement
1	40	20	Improved
2	70	50	Improved
3	70	20	Markedly improved
4	20	20	Stable (normal from baseline)

Table 24. Stereoacuity changes before and after vision therapy in four patients



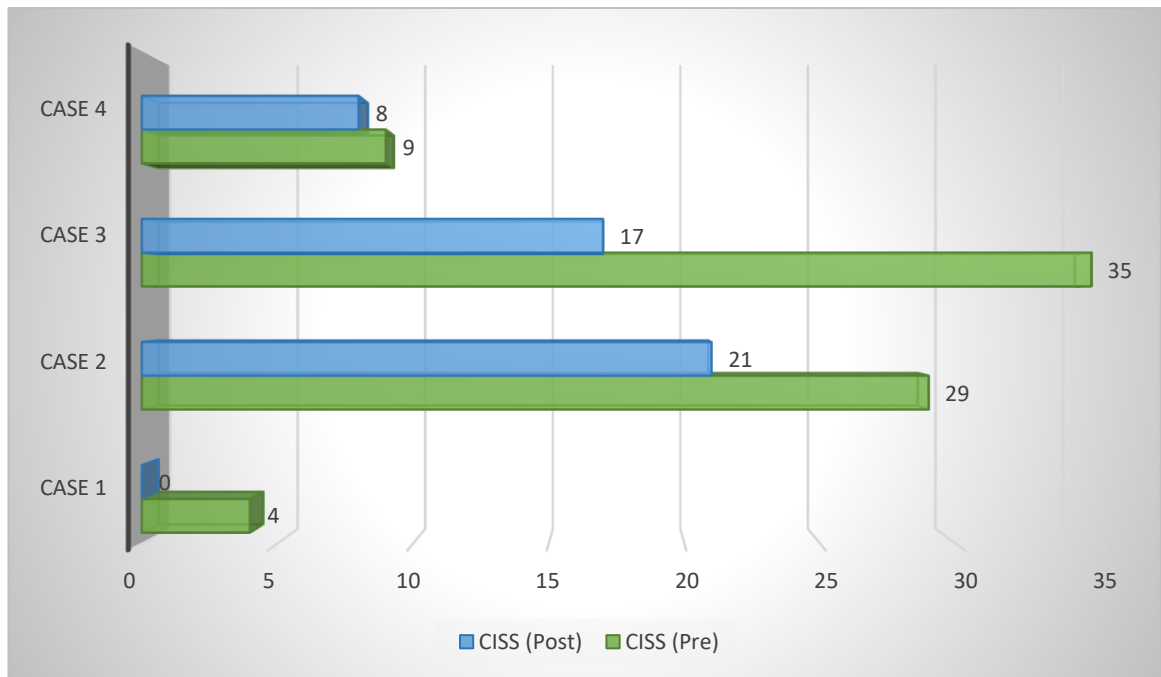
Graph (19): Evolution of stereoacuity before and after vision therapy in four patients

→ Stereoacuity was evaluated pre- and post-therapy using a standardized random dot stereotest. A significant improvement was observed, with patients progressing from coarse to finer levels of stereoacuity, indicating enhanced binocular integration and depth perception. Stereoacuity also improved, with mean values decreasing from 50 arc seconds to 27.5 arc seconds, a 45% improvement in binocular depth perception. Overall, three out of four patients demonstrated measurable improvement in stereoacuity, while one patient maintained an already normal level throughout the therapy.

D. CISS score reduction and symptom relief:

Patient	CISS Pre	CISS Post
1	4	0
2	29	21
3	35	17
4	9	8

Table 25. CISS Score Changes Pre- and Post-therapy in four patients



Graph (20): CISS scores before and after therapy for 4 patients

- There was a notable decrease in CISS scores, with an estimated average reduction of approximately 18 points, reflecting a meaningful reduction in symptoms and visual discomfort.
- Patients also reported a general reduction in subjective symptoms such as eyestrain, blurred vision, and difficulty maintaining near tasks.



Figure (15): Patient completing the CISS post-therapy

E. MEM, amplitude of accommodation, and positive fusional vergence results:

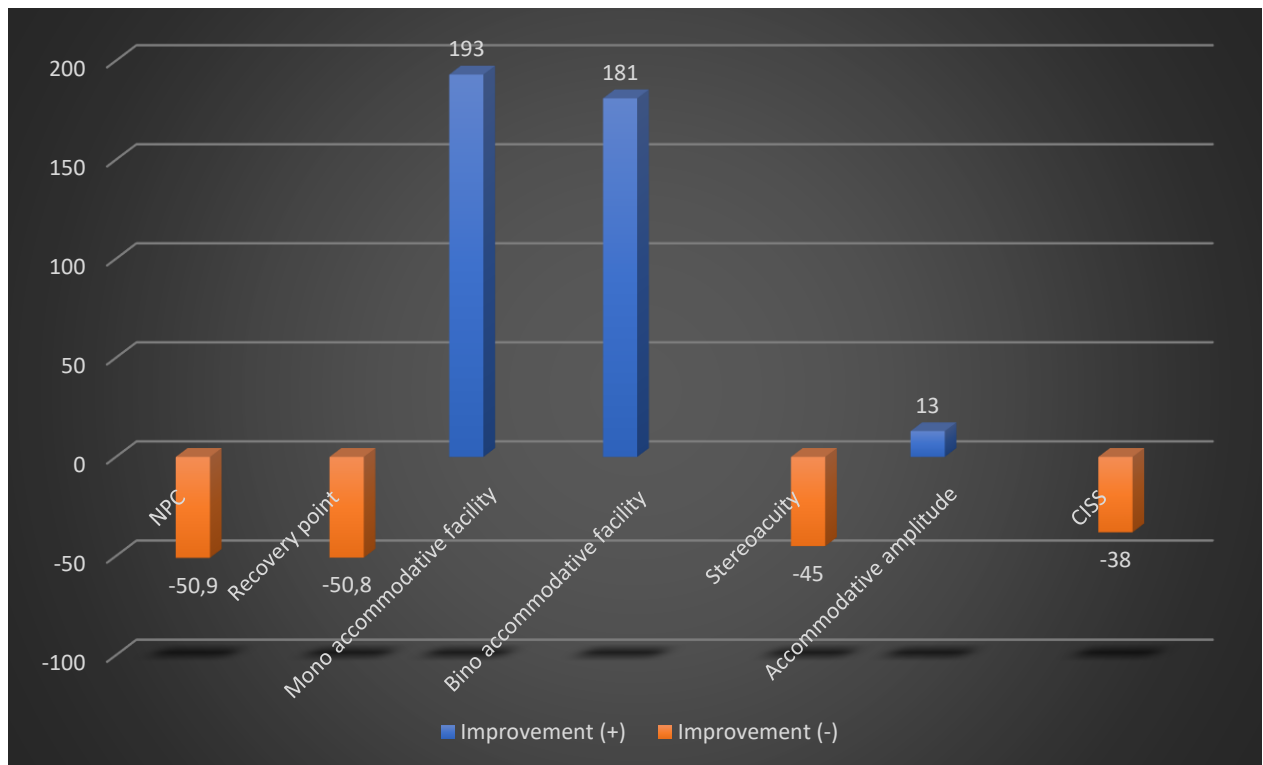
- Out of four patients, three had accommodative excess at the start. After therapy, one normalized while two showed only slight improvement. The fourth patient, who presented pseudo-CI with an accommodative lag, normalized their accommodative response after treatment.
- The average amplitude of accommodation increased from 9.63 D before therapy to 10.88 diopters after rehabilitation, corresponding to an improvement of approximately 13%.
- Positive fusional vergence (PFV) at near improved noticeably in two out of three evaluated patients following vision therapy. PFV increased from 18Δ to 25Δ (+39%) in case 1 and from 2Δ to 25Δ in case 2. However, case 3 showed a decrease from 27Δ to 18Δ (-33%). PFV was not measured in case 4 and was excluded from this analysis.

3. Summary and visual representation of results:

- To better visualize the global improvement across all cases, a comparative table summarizing key clinical parameters is presented below:

Parameter	Mean pre-therapy	Mean post-therapy	Improvement
NPC (cm)	13.75	6.75	↓ - 50.9%
Recovery point (cm)	16.25	8	↓ - 50.8%
Monocular flipper rate (cpm)	6.0	17.6	↑ +193%
Binocular flipper rate (cpm)	6.0	16.9	↑ +181%
Stereoacuity (arc seconds)	50	27.5	↓ -45%
Amplitude of Accommodation (D)	9.63	10.88	↑ +13%
CISS Score	19	11.75	↓ - 38%

Table 26. Summary of average clinical outcomes before and after vision therapy in four cases



Graph (21): Clinical improvements following vision therapy

4. Factors influencing outcomes:

Multiple factors contributed to the therapy outcomes reported in the study. Patient adherence was crucial-irregular participation often resulted in slower progress or less stable gains. The starting severity of convergence insufficiency and any related accommodative issues also influenced the rate and extent of improvement. Outcomes varied depending on the therapy approach: combined in-office and home-based sessions typically produced better results than home-based therapy alone. Additional influences included the total duration of therapy, the amount of screen time, levels of visual fatigue, and aspects of the patient's daily routine, such as academic demands and lifestyle.

VI. Discussion:

1. Clinical validation of vision therapy for convergence insufficiency in young adults:

-The findings of our study align closely with those reported in the literature, particularly Aletaha et al. (2018), who compared three different vision therapy protocols for managing convergence insufficiency. All patients in our study demonstrated meaningful improvements in both subjective symptoms and objective clinical markers, including near point of convergence (NPC), positive fusional vergence (PFV), and Convergence Insufficiency Symptom Survey (CISS) scores. These outcomes are also consistent with those described by Cooper et al. (2012), who emphasized vision therapy as the most effective intervention for CI, particularly in young adults.

-Although the therapy in our study was primarily conducted at home, it incorporated nearly all the tools typically used in office-based protocols, except for the aperture rule. The program combined vergence and accommodative training, included a comprehensive set of exercises such as pencil push-ups, fusion cards, Brock string, barrel cards, Hart chart and accommodative flippers. This decision was made due to the limited availability of our participants, many of whom were students with demanding schedules and lived far from the practice. Consequently, despite being implemented at home, our protocol closely mirrors a combined home-office therapy model as described in previous literature.

-Aletaha et al. reported better outcomes with office-based therapy supplemented by home reinforcement, a structure similar to ours, where consistency and diversity of the therapeutic tools played a central role in achieving positive results. The following section reviews each clinical outcome in light of previous studies to assess the relevance of the observed improvements:

2. Near point of convergence (NPC) and recovery improvements:

In our study, a complete improvement including NPC and recovery point were found in all cases after vision therapy. The mean NPC reduced from 13.75 cm at baseline to 6.75 cm following therapy, with an average improvement of about 51%. This is indicative of a significant improvement in convergence performance for all cases. Recovery points improved in the same way, with mean values shifting from pre-therapy (16.25) to post-therapy (8 cm). This reflects greater fusional reserves and greater ability to maintain single binocular vision after convergence disruption.

These results are compatible with those reported in the literature. Scheiman et al. (2005) reported that office-based vision therapy reduced the mean NPC from 12.8 cm to 5.3 cm over 12 weeks, while no significant changes were observed in the pencil push-up or placebo groups. Likewise, Aletaha et al. (2018) observed NPC improvements ranging from 86% to 96% across all therapy modalities, with the greatest gains in the augmented office-based group.

3. Positive fusional vergence (PFV) improvement:

Our study demonstrated a noticeable improvement in positive fusional vergence (PFV) at near in two out of three evaluated patients following vision therapy. One of them, however, didn't show improvement. We think it's because they didn't do the exercises regularly. On average, there was a 45% increase in PFV, which seems promising.

This result is similar to what was found in the study by Scheiman et al. (2005). They saw PFV get better after 12 weeks of office-based therapy. On the other hand, the group performing only home-based pencil push-ups did not show clinically meaningful changes in PFV.

Similarly, Aletaha et al. (2018) observed PFV improvements ranging from 68% in home-based therapy to 100% in office-based and augmented office-based groups, with greater long-term stability noted in the latter.

4. Accommodative facility gains:

In our study, all patients showed a remarkable improvement with the flipper (± 2.00 D). The monocular accommodative facility went up from about 6 cpm at the start to 17.6 cpm after therapy. For binocular accommodative facility, it increased from 6 to 16.9 cpm, indicating enhanced accommodative flexibility and better coordination between accommodation and vergence mechanisms.

When we compare this to Scheiman et al. (2005), they found that their office-based therapy group improved from 6.4 to 11.9 cpm for monocular facility. Their pencil push-up group improved less (6.2 to 7.6 cpm), and the placebo group didn't improve at all. Our results show even greater improvement than Scheiman's study, which suggests that our therapy method can be as effective as, or even better than, office-based therapy.

5. MEM retinoscopy changes:

Our results show that vision therapy can help normalize accommodation in some patients with accommodative excess. However, two patients still had some lead after therapy, possibly because they do a lot of near work and sometimes skip exercises. The patient with pseudo convergence insufficiency also showed significant improvement in high accommodative lag.

These findings align with previous studies by Scheiman et al. (2005) and Cooper et al. (2012), who reported improvements in accommodative responses measured by MEM retinoscopy in patients undergoing office-based vision therapy for CI. Scheiman et al. found that participants in the office-based group showed normalized accommodative responses, with their lag shifting closer to the typical range of +0.25 to +0.50 D. Cooper et al. reported similar findings, noting that MEM values normalized, moving from high lead or lag toward a typical response, with the best outcomes seen in office-based or hybrid therapy programs.

6. Progression of accommodative amplitude after therapy:

In our study, we noticed a moderate increase in accommodative amplitude after vision therapy, with an average increase of 1.25 diopters (approximately 13%) across the cases. Before therapy, the average was about 9.63 D, and after therapy, it reached 10.88 D.

These findings are consistent with those of Alvarez et al. (2010), where adults with CI showed a significant increase in accommodative amplitude about 6.75 D to 9.67 D after doing both office and home-based therapy for 12 weeks. These observations reinforce the hypothesis that structured vision therapy can improve accommodative function in adults as well as children. This improvement reflects a stronger accommodative system, which likely enhances near vision performance and helps reduce related symptoms.

7. Improvement of stereoacuity:

In our study, we saw a really noticeable jump in stereoacuity after therapy. Before treatment, only 25% of patients had what's considered normal stereo vision (≤ 40 arc seconds). But after therapy, that number shot up to 75%. That tells us there's a strong connection between better convergence and sharper depth perception.

This isn't just something we saw in our data it lines up with another research too. For example, there was a big pediatric study with over 2200 kids where the percentage of children with normal stereoacuity went from 29% to 76% after doing vision therapy. Pretty similar trend. Also, another study that looked at different types of therapy (at-home, in-office, and enhanced in-office programs) found solid improvements in stereoacuity across all methods. Basically, no matter the setting, structured therapy helped the eyes work better together and

made it easier for the brain to process 3D images. So overall, vision therapy doesn't just help with convergence it actually helps the whole system click into place.

8. CISS score reductions:

When treating convergence insufficiency, symptom relief is just as important as what we see in the clinical tests. That's why we use the CISS questionnaire, it gives us a better idea of how patients are actually feeling in their daily life. According to Cooper and others, a drop of 10 points or more is a good sign that the treatment is working. In our group, every single patient had a noticeable drop in their CISS scores. On average, the score went down from 19 to 11.75 that's around a 38% reduction in symptoms. That kind of drop definitely crosses the line for clinical improvement. Other studies back this up too. For example, Aletaha et al. (2018) reported symptom reductions ranging from 75% with at-home therapy to 100% in enhanced in-office programs. And compared to Scheiman's 2005 study, where only 20% of patients doing at-home pencil push-ups got their CISS score under 21, our results look even stronger. It just shows how much more effective structured therapy can be when it's done right.

9. Short-term follow-up:

Our results are consistent with the findings of Shin et al. (2011), as patients who received structured office-based therapy combined with home reinforcement showed lasting improvements, whereas those with poor compliance had partial or regressed outcomes.

For patient B.A., who followed a home-based vision therapy program supplemented by occasional in-office sessions, a follow-up evaluation conducted two months after the completion of therapy showed that the clinical improvements were maintained and the symptoms had completely resolved.

VII. Study limitations and future directions:

1. Limitations:

- First, the vision therapy was not always consistent, with some irregularities in patient compliance and frequent use of digital screens in daily activities, which could have influenced the outcomes. The study also relied on self-reported compliance for home-based exercises, which might be subject to reporting bias.
- The short duration of follow-up, limited by the academic timeline for thesis completion, restricts the ability to fully evaluate long-term treatment efficacy and potential relapse rates.

2. Future perspectives:

- Long-term, multicenter studies with standardized follow-up at six months and one year would be valuable to assess the stability and generalizability of the therapy's improvements.
- Including a randomized control group to better isolate the effects of the therapy.
- Exploring the impact of different therapy protocols (e.g., home-based vs. office-based) through comparative studies.
- Utilizing objective compliance monitoring tools (e.g., digital logs or wearables) to improve data accuracy.
- Investigating new technologies such as virtual reality and computer programs in CI rehabilitation to enhance patient engagement and treatment effectiveness.
- Examining neurophysiological changes associated with therapy using imaging or electrophysiological techniques.

VIII. Conclusion:

The clinical cases presented involved three patients with convergence insufficiency associated with accommodative excess and one with pseudo-convergence insufficiency. Each patient followed an individualized vision therapy program based on their symptoms, initial evaluation results, and therapeutic goals.

All patients showed significant improvements in key clinical parameters, including near point of convergence (NPC) which is increasing more than 50 %, monocular and binocular accommodative facility, amplitude of accommodation, accommodative response (MEM retinoscopy), also stereoacuity and CISS score. These objective gains were consistently accompanied by a reduction in visual symptoms such as eyestrain, blurred vision, and difficulty with near tasks, confirming the effectiveness of the prescribed therapy.

This experience allowed us, as a clinical team, to strengthen our skills in evaluating and managing binocular vision disorders. We also learned how to adjust therapeutic protocols based on each patient's progress and to emphasize the importance of regular follow-up and patient motivation. Overall, these cases illustrate the benefits of a structured, personalized, and progressive vision therapy approach carried out both in-office and at home for improving binocular function and visual comfort.

General conclusion:

General conclusion:

This practical study has served as a critical continuation and expansion of the work initiated by a previous research team on the screening of convergence insufficiency (CI). Conducted in the controlled environment of the optometry laboratory at the University of Oran 1 Ahmed Ben Bella, this project adhered to rigorous methodological standards, allowing for the collection of reliable clinical data and meaningful patient outcomes.

By first revisiting the screening results obtained through validated tools such as the Red/Green Penlight Test, NPC and the Convergence Insufficiency Symptom Survey (CISS), we were able to identify individuals presenting with clinically significant symptoms of CI. The comprehensive analysis of these screening data provided a clear foundation for selecting appropriate candidates for therapeutic intervention.

The core of study was centered on the development, application, and evaluation of vision therapy protocols specifically tailored to the needs of patients diagnosed with convergence insufficiency. These protocols drew from contemporary clinical guidelines and evidence-based practices in orthoptic rehabilitation. Through individualized follow-up and regular reassessment, we observed a consistent reduction in patient-reported symptoms including visual fatigue, headaches, difficulty concentrating, and diplopia alongside improvements in binocular function and reading performance.

Our findings affirm the efficacy of structured vision therapy in addressing the functional deficits associated with CI. The improvement in patients' quality of life, particularly in tasks requiring sustained near vision, underlines the clinical relevance of early detection combined with targeted intervention. Moreover, the use of standardized patient feedback instruments has proven to be a valuable tool in monitoring therapeutic progress and adjusting care as needed.

In conclusion, this practical study demonstrates the tangible benefits of appropriate therapeutic management. It contributes to the growing body of optometric literature advocating for the integration of rehabilitative strategies in routine clinical care. Future research should aim to expand the sample size and explore long-term outcomes, with the goal of optimizing treatment protocols and promoting greater awareness among both professionals and the public regarding this often-overlooked visual disorder.

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