Developing of Cognition Skills in Children with learning disabilities by Visual Therapy

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Abstract

Standard binocular vision is contingent upon specific optical and orthoptic factors. The process of visual information assimilation consists of fixations and saccades, which are mediated by several brain functions. These include attention, oculomotor control, and various forms of memory—working, procedural, as well as motor and perceptual learning.

This thesis explores the impact of visual therapy on both orthoptic anomalies and cognitive processes in 558 children aged 6 to 15. The study underscores the integral role of normal binocular vision patterns in cognitive tasks such as reading, memory, and attention.

Through monitored eye movements, the research demonstrates how visual therapy not only corrects eye conditions such as amblyopia but also enhances various cognitive skills. These findings suggest that visual therapy engages multiple brain regions, leading to improvements in visual memory, visual discrimination, and visual span. Furthermore, it significantly boosts reading abilities, attentional control, and overall cognitive skills.

To conclude, this research emphasizes the untapped potential of visual therapy as a multi-faceted tool for advancing both clinical orthoptics and neuroscience, thus offering a comprehensive approach to maximize learning outcomes.

Keywords: *Visual Therapy, Cognition, Memory Therapy, Learning Disabilities, Orthoptics Therapy*

BACKGROUND

The assessment of cognitive development in relation to functional vision is linked to various factors, including refraction correction and binocular disparity. Additionally, orthoptic functions such as accommodation, convergence, divergence, and versions contribute to precise fixations and both pursuit and saccadic eye movements. Owing to the eyes' optical architecture, the variance in cone density across the retina, and the specialized mapping of foveal photoreceptors to visual cortical areas, visual acuity is most pronounced at the fixation point and declines sharply as visual eccentricity increases. Recent studies using functional imaging in healthy individuals have substantiated the strong link between attention and saccadic eye movements within the posterior parietal cortex (PPC). These processes were also shown to activate overlapping cortical networks, including the frontal eye fields (FEF), supplementary eye fields (SEF), PPC, and visual cortex (Konen et al., 2007).

There is a strong relationship between eye movements and cognitive processes. Information gathered from locations that are both attended to and fixated upon is cumulatively stored across eye movements, contributing to both short-term and long-term visual memory (e.g. Melcher & Kowler, 2001; Pertzov et al., 2009). In the field of neuroscience, memory is understood as a reenactment of cortical activities. This involves utilizing fixations and saccades to acquire information through neural pathways responsible for visual stimulation and processing. Recent studies indicate that simultaneous recording of EEG and eye movements is achievable. To minimize the impact of eye movement interference, these experiments were conducted in far fewer complex settings than natural scene exploration, focusing instead on controlled saccade tasks. As far as we are aware, only a pair of studies have specifically examined fixation event-related potentials (fERPs) in the context of freely viewing natural images. This approach offers a straightforward method for contrasting fERPs and ERPs without requiring ocular correction techniques such as Independent Component Analysis.

Establishing objective validation metrics in this experiment poses challenges, given that subjects made saccades in arbitrary directions and of varying magnitudes (Kaunitz et al., 2014). The length of fixations plays a role in how information is processed. Models of attention, which contribute to performance, hint at the involvement of underlying neural mechanisms in both the ventral and dorsal regions of the posterior cortex. Reading engages perceptual representation and eye-movement adaptability, linked with both semantic and syntactic elements, to form a lexical unit. Research indicates that numerous topographic maps related to sensory and motor functions are present in both the cortical and subcortical areas of the brain. Irrespective of the modality, these maps facilitate accurate spatial identification of sensory signals and corresponding motor reactions. Moreover, the superior colliculus (SC) provides an optimal platform for investigating spatial transformations in the oculomotor system. This is due to its role as a hub for sensorimotor integration, featuring a well-characterized topographically organized retinotopic sensorimotor map that has been mathematically delineated (Marino et al., 2008). Reading involves both perceptual interpretation and flexibility in eye movements, which are correlated with semantic and syntactic elements to construct a lexical entry. Research indicates that motion effectively attracts eye movements, a process overseen by the superior colliculus in primates and the optic tectum in less advanced animals, such as toads (Rouinfar et al., 2014).

INTRODUCTION

The research intends to provide evidence-based insights into cognitive advancement through visual therapy, affecting both spatial and neurodevelopmental growth. Visual acuity serves as the metric for evaluating static vision clarity, whereas dynamic vision is regulated by factors such as eye movements, the stability of fixations, and the level of attention. These elements mature as children better integrate visual examination and processing mechanisms. Effective implementation of visual therapy necessitates the identification of visual deficits and malfunctions, enabling tailored interventions that foster the development of essential neural pathways. This enhances functional vision in aspects such as precision, endurance, capacity, and automaticity. The latencies of visual responses in the visual cortex vary significantly from cell to cell and are influenced by factors such as contrast. Additionally, the transient nature of V1 responses means a decrease in activity is not a reliable sign of a fixation's end. Rapid visual processing is critical, as evidenced by studies showing quick behavioural decisions based on visual information. Saccadic eye movements modulate neural activity across multiple brain structures. Lambda waves, first described over half a century ago, are occipital EEG transients linked to saccadic movements during complex image exploration; these waves disappear under certain conditions, such as darkness or prolonged fixation. Various research has documented saccade-related neural activities in metrics such as BOLD signals, local field potentials (LFPs), and spiking activities, particularly in the occipital cortex) (Paradiso et al., 2012).

Learning disabilities and dyslexia are often viewed as inherent limitations, leading to subpar language-related processes, including reduced reading speed and visual attention deficits, as well as underdeveloped ocular motor systems. However, these conditions can also co-occur with treatable neurodevelopmental issues affecting optomotor function, perception, and binocular stability.

Children with amblyopia may experience issues such as binocular instability, impaired stereo acuity, and abnormal binocular summation. Challenges with vergence, convergence, and divergence can arise from a variety of causes, including neurodevelopmental shortfalls, fatigue-induced AC/A and CA/C ratios, or a combination of these factors.

Vision is an emergent, constructive process shaped by dynamic feedback and feedforward cycles involving the eye, brain, and oculomotor functions. Reading, as a distinct cognitive ability, benefits from precise saccadic movements. The dorsal visual stream, primarily receiving magnocellular input from the retina, serves a key role in areas such as visuospatial attention and psycholinguistic processing during reading. It also aids attention allocation and enhances neural activities linked to cognitive processes. New approaches for objectively monitoring alertness have emerged, utilizing metrics such as operator behavior, EEG readings, and eye activity. Various eye-related parameters are particularly sensitive to the duration of a task, which is indirectly related to the onset of fatigue in repetitive work environments. Utilizing Electrooculography (EOG) reveals that both blink rate and duration tend to rise, whereas blink amplitude diminished as time spent on a task accumulates. Additionally, other EOG-based studies have indicated that both the frequency and speed of saccades decrease with increasing time on task (Van Orden et al., 2002). Recognizing the visual world necessitates a pace of up to 350 words per minute, engaging perceptual, attentional, and cognitive functions. The influence of word frequency suggests that bottom-up processing takes precedence, with context-related effects manifesting after lexical processing. The area responsible for visual text is connected to visuo-orthographic processing, and it encodes entire word recognition units, signifying the activation of language-related regions. Eye movement (EM) research offers nuanced metrics for tracking the time-course and spatial dynamics of eye control during reading, reflecting both cognitive workload across various psycholinguistic stages and attention distribution.

In these studies, words are generally displayed for a consistent period, ranging from 500 to 1000 ms per word. This duration is an extension of the usual fixation time observed in natural reading, which averages between 200 and 250 ms (Himmelstoss et al., 2019). The enhanced oscillatory activity through visual therapy helps structure information during reading, leading to decreased errors directly related to the severity of dementia and is also associated with cognitive competence. Eye movements not only dictate which portions of a text are processed at given times, but the text itself also influences how the eyes navigate through it. This interplay is expected as the oculomotor system aims to balance the inflow of visual and linguistic information so that it is neither too sparse nor overwhelming, allowing for efficient processing between eye movements. Research has suggested the existence of a global oculomotor program that modulates eye movement planning across an entire line of text. This program results in shorter eye movements at the start and end of lines. There are identified specific patterns in fixation durations across a sentence: an initial surge, known as the "start-up effect," is followed by a stable period and then another spike toward the end (Al-Zanoon et al., 2017).

Consequently, eye movements serve as a reliable indicator of either cognitive advancement or decline, offering avenues for optimizing cognitive functions and boosting educational results. Simulating cognitive deficits is common in forensic environments, and relying solely on clinical assessments is inadequate for identifying such behavior. This has spurred the development of performance validity tests (PVTs), which are crafted to specifically identify feigned cognitive impairments. Currently, these PVTs are viewed as a standard practice in neuropsychological evaluations, with most forensic neuropsychologists incorporating at least one such test into their assessment toolkit (Tomer et al., 2020).

The correlation between ocular dyslexia and linguistic processing opens the door for treating both conditions through visual therapy. This approach enhances information processing via the brain's magnocellular pathway fine-tunes binocular coordination during and post-saccades and rectifies deconjugate stereotyped patterns.

The significance of visual attention is underscored by its involvement with the posterior parietal cortex. Specifically, the lateral intraparietal area within this region functions as a priority map, directing both covert attention and eye movements, also known as overt attention.

An anatomical link exists between the prefrontal cortex and the superior colliculus, both of which play a role in shaping visual attention. Fixations are governed by a blend of top-down, task-specific elements and bottom-up, stimulus-induced factors. According to (Schwedes, 2012), the work of Ryan et al. (2007) has been instrumental in advancing the domain of indirect memory diagnostics. Their research posits that fixation duration, all else being equal, can serve as an indicator of recognition, essentially providing clues about whether an individual is already familiar with a specific face. This makes it intriguing to compare the methodology of the framework in indirect memory diagnostics: the Concealed Information Test, known as the Guilty Knowledge Test. Visual therapy, interprets the duration spent focusing on an item as indicative of the cognitive effort needed for language processing. In the framework of dynamic reading, eye movement tracking has emerged as a crucial instrument for deducing active visual and linguistic processes, whether to validate particular theories or to establish models for oculomotor behavior during reading. The distribution patterns of initial saccadic landing positions, often termed the "preferred viewing position phenomenon", provide compelling evidence for the word-centric nature of saccade control (Huestegge et al., 2009). In the realm of formulaic language, both lexical context from word combinations and global context guides the selection of semantically compatible lexical items.

Neurophysiological research reinforces the tight relationship between attention and eye movement. Through saccades and fixations, the high-resolution fovea directs its gaze toward specific objects, enabling in-depth visual processing of these gaze-oriented subjects. Such fixations are interspersed with quick eye shifts known as saccades. Therefore, our visual mechanism can be conceptualized as an integration of a high-resolution sensory organ in the eye with a highly accurate motion system the oculomotor system. Studies indicate that theoretical frameworks and computational models have been developed to explain the intricate pattern of eye movements. These models are founded on the notion that a 'focus of attention', not the eye itself, sequentially traverses words and can reprogram saccades based on immediate processing requirements. Another perspective suggests that the apparent randomness of eye movements stems from the parallel processing of multiple words within an attentional window. This complex eye-movement model introduces several novel principles, with the most crucial being the distinction between the timing ('when') and target selection ('where') of saccades, a notion supported by recent neurophysiological research (Engbert et al., 2004). This stored gaze-centered data could subsequently serve multiple functions, including saccade initiation. Therefore, processes such as remapping, spatial memory, and sensorimotor updates may share or intersect in various attributes (Mohsenzadeh et al., 2016). Recognition of the word in focus is a prerequisite for extracting meaningful linguistic information from the subsequent word. In addition to the right visual field (RVF) superiority evident in parafoveal processing, as shown in laterality studies, another form of asymmetry pertinent to this research has been extensively examined in the realm of eye-movement studies. In experiments involving sentence reading where eye movements are captured using eye-tracking technology, there is a tendency for the eye to land at locations just to the left of a word's center. There is evidence that word recognition is affected by where the eye fixates, bolstering the idea of asymmetrical processing in verbal strings.

Specifically, there is evidence that recognition is optimized when forced fixations occur to the left of a word's centre. Research highlights that visual acuity's rapid decline with retinal eccentricity affects eye-fixation behavior during reading. The theory posits that visual fields are divided between the hemispheres based on the fixation point. While most models suggest that readers aim for a word's centre, known as the Optimal Viewing Position (OVP), deviations occur due to inherent visuomotor constraints in the oculomotor system.

The discrepancy between the Optimal Viewing Position (OVP) and the Preferred Viewing Location (PVL) is attributed to basic visuomotor limitations in the oculomotor system. There is a strong link between the Optimal Viewing Position (OVP) and Preferred Viewing Location (PVL), suggesting common mechanisms such as cerebral lateralization of language influence both. They argue that left-of-centre fixations are less detrimental than right-of-centre ones due to reading habits. The PVL predicts the OVP, influenced by perceptual learning and reading direction. The improved reading skill correlates with an increased ability to gather information during a single-eye fixation, particularly to the right of the fixation location. Less-skilled readers have smaller perceptual spans, around 3-4 characters less than experienced readers, due to greater processing resources required for word recognition. This aligns with findings that less-skilled readers make multiple fixations within a single word, highlighting developmental changes in visual information processing. There is evidence of the model of reading acquisition arguing that proficient reading hinges on mastering a left-to-right gradient. Initially, beginners must learn to centre their fixation on a word to establish a locational gradient. This begins with attentional control and eventually becomes a more automatic, bottom-up process to preserve letter sequencing (Ducrot et al., 2013).

Reading is a multifaceted cognitive activity that encompasses various types of processing, such as visual, attentional, lexical-semantic, and eye-movement mechanisms. Binding is considered fundamental to various cognitive functions such as parallel processing, language production, consciousness, self-perception, time perception, memory, and reasoning. It is physiologically thought to occur through conjunctively coded neurons or neural synchrony. These top-down processes mainly stem from Working Memory. Re-entrant brain processes are highlighted as the physiological basis for binding, making it essential for everything from object identification to consciousness (Jaswal, 2009). Cortical activity patterns captured through functional neuroimaging and eye-tracking data facilitate the categorization of viewer cognition and visual stimuli. This signifies a pivotal change in dyslexia intervention, extending beyond merely targeting high-level speech and reading areas. Visual scenes are stored in memory, encompassing both short-term visual recall and advanced semantic data. Memory not only influences our processing of new information and neurophysiological responses but also affects gaze patterns. Recent studies indicate that participants fixate longer on altered regions of a scene and make fewer fixations on previously observed items.

Children store essential information in visual short-term memory, which plays a crucial role in standard visual world processing. This acts as a working memory system that supports active vision-related cognitive processes, including arousal, alertness, fatigue, focus and deception. Research suggests that task demands closely guide eye fixations and attentional control, impacting even low-level neural processes. This idea contrasts with the object file theory, which posits that attention creates temporary memory objects. The concept of object-based attention further suggests that focusing on one feature of an object enhances the representation of its other features (Droll et al., 2005). Examining the effects of cognitive development offers insights into the therapeutic potential and applications of visual therapy in both educational and healthcare environments.

METHODS

The study observed 620 children between the ages of 6 and 15 who had orthoptic disorders. Of these, 585 displayed cognitive development and learning challenges. A control group of 27 children was established, as their parents opted out of treatment. Consequently, the study administered treatment to 558 participants.

Eligibility Criteria

Children with orthoptic disorders exhibited reduced cognitive development relative to their age-matched peers.

Exclusion Criteria

Deprivation amblyopia, comitant strabismus, and ocular pathologies such as retinopathy of prematurity, along with mild to severe nystagmus, Duane's syndrome, and Brown syndrome.

Each participant was subjected to both Bruckner and Hirshberg tests, followed by optical correction. Amblyopic children began visual therapy two months post-optical correction. To promote the use of the non-preferred eye, a daily six-hour occlusion of the preferred eye was instituted if fixation was not alternated. Accommodation, vergence, AC/A, and CA/C ratios were assessed at every session. Comprehensive optometric and orthoptic exams were conducted, both with and without cycloplegia. Testing was unbiased by issues such as abnormal direction sense or suppression of the deviated eye, often encountered in cases with eccentric fixation or abnormal retinal correspondence. Both positive and negative vergence fusion tests were completed.

Following a two-month period of accurate optical adjustment and daily partial occlusion for amblyopic cases, the participants engaged in a 16-week orthoptic training program, consisting of one-hour sessions each day. The therapy consisted of accommodative training through reading exercises with progressively stronger minus lenses, first monocularly and then binocularly, followed by computerized accommodative rock exercises. Vergence training involved Base In and Base Out prism therapy and computerized programs focusing on convergence, divergence, and stereo-acuity. FDA-approved computerized programs were used for amblyopic children to enhance eye acuity. Once improvements in motor fusion, fusional reserves, accommodation, and sensory fusion were noted, the children shifted to a two-week saccadic training program via computerized therapy. This phase commenced after achieving specific orthoptic diagnostic criteria for each participant.

Children diagnosed with ocular dyslexia underwent an extra two weeks of therapy to address their elevated symptoms of visual stress and binocular instability. The Dunlop Test, utilized to determine ocular dominance, was particularly relevant for these children with learning challenges.

Eye tracker systems evaluated binocular coordination across different reading distances and lighting conditions. The systems tracked eye orientation and retinal stimulus location, making directional assessments based on gaze points. Phorias were measured in each session using the Maddox method, and disparities were computed. The anti-suppression technique was employed to treat physiological diplopia, using vectograms with color filters tailored to the task. This aided in coordinating eye movements and accurately recalling visual patterns. During each session, binocular disparities were noted and linked to the computational task of resolving depth perception issues through retinal disparities, as explained by Herring's law. Real-time analysis of eye movement data served as a technique for mapping fixation. Post-session, children observed various objects and reported on selected visual characteristics of a randomly picked target. This task gauged their memory of the object's identity and orientation. Consecutive fixations on a word were grouped into gazes, with each gaze's duration marked in milliseconds. Fixation stability was assessed when stimuli appeared consistently on the display. Saccadic control was measured through tasks requiring focal shifts to the stimulus, with stability determined by counting error saccades per trial. Metrics for action velocity and synchrony were recorded before introducing higher cognitive tasks such as reading. Response time functioned as a gauge for saccade responsiveness, which in turn informed assessments of binocular stability and optomotor learning.

To ensure synchronous data collection, coregistration was maintained throughout the recording via split trigger pulses for both eye movement and EEG data. Electrode placements and electro-oculographic (EOG) data were captured above and below the eye orbits and at each eye's outer corner. Saccades were corrected prior to analysis. The children read both syntactically correct and incorrect sentences.

To evaluate cognitive skills, the participants read timed texts and matched words to images, with non-verbal tasks included to isolate linguistic factors. Eye movements, recorded via synoptophore, were analyzed for lexical dysfunction affecting gaze duration and word skipping. Post-visual therapy metrics were also collected. Various tests assessed cognitive decline during visual searches, scene memorization, and aesthetic choices. Children underwent the FCSRT-IR memory test and an attention-measuring eye movement task with short videos. Control exercises gauged the impact of fixation stimuli on perception. The visual paired comparison task tested episodic memory, measuring the time spent on side-by-side images presented after a delay. The aim was to understand how spatial memory updates after saccades and pursuit movements. Cognitive biases were mapped through questions about the orientation and location of random images, guiding attention and saccade planning.

Linguistic data focused on the lexical processing of sequential words. Sentences featured a critical pre target and target word sequence, altered by inserting a visuospatial and linguistical pseudo-word during fixation on the pre-target word. EEG and eye-tracking recordings were captured concurrently as children read.

Short-term memory was assessed using the Word Memory Test's forced-choice recognition memory paradigm. Children viewed a series of images and later had to identify previously seen images from new options. The forced-choice format yielded objective recognition memory metrics. Throughout this, eye movements were recorded to differentiate genuine cognitive deficits from potential deception. Eye movement analytics covered metrics such as fixation count, duration, regions fixated, region transitions, saccade amplitude, and various entropy measures.

The impact of visual therapy on attention was evaluated using the Attention Battery from the Cognitive Assessment System, complemented by computerized visual attention therapies. Scanning patterns during the initial inspection were compared with those during subsequent recognition tasks.

Visual attention was assessed through cognitive state analyses, employing reading detection and gaze estimation via a wearable augmented reality display. The analysis of eye gaze data was extracted to evaluate attention levels and cognitive processing. Initial cognitive assessments involved a vocabulary test to gauge cognitive state, followed by the use of "brain cards" targeting various cognitive and visual skills ranging from logic and reasoning to sensory-motor integration and comprehension.

Each participant was evaluated for cognitive abilities both before and after the study by a certified clinician or cognitive trainer. The selected psychometric tests, tailored for the children's age group, are widely acknowledged as reliable metrics for assessing cognitive development.

RESULTS

Ninety-eight per cent of the children showed a return to normal accommodative and vergence capabilities post-treatment. Post-treatment measurements indicated a 5-9 Diopter improvement in accommodation for those diagnosed with accommodation insufficiency or ill-sustained accommodation. Children with diminished PVF and NVF gained 30 and 20 prism Diopters Base Out and Base In, respectively.

Participants with amblyopia improved their Snellen acuity scores by 2-4 lines. All the participants demonstrated comparable gains in accommodation, vergence, convergence, and divergence (as shown in Table 2). Children with incomitant strabismus required an additional three weeks of treatment. However, they achieved nearly comparable results, with only minor deviations in prism Diopter values, differing only by 2-4 Base Out prism Diopters in cases of intermittent exotropia or Basic Exo, and 2-4 prism Diopters less in cases of non-accommodative esotropia/esophoria or Basic In diagnosis. Stereopsis enhanced to 40 arcseconds in all participants, while binocular fixation patterns were assessed in 98% of the subjects.

The results demonstrated that all participants exhibited normalized AC/C and CA/C ratios. In 99% of subjects, fusional amplitude normalized, contributing to stable binocular vision. Improvements in both horizontal and vertical saccades facilitated vergence, in a sequence of convergence and divergence. Smooth pursuit abilities showed improvement in 99% of all participants and notably in 85% of those identified with ocular dyslexia. Additionally, significant enhancements were observed in saccadic measurements across all subjects, as evidenced by the DEM test results. High levels of fixation stimulation led to targeted eye movements prior to accurate saccadic frequencies. A strong correlation emerged between optometric parameters and objective fixation disparity as measured by eye-tracking.

Saccade peak velocities ranged between 300-400 degrees per second, with durations reduced to 20-40ms and latencies of 200-250ms. Saccadic amplitude reached between 20-30ms, while fixation durations stabilized at 300-350ms.

Following the completion of the therapy program, participants demonstrated the ability to successfully answer visuospatial questions that had previously posed challenges. Eye movement efficiency was revealed to be instrumental in solving cognitive tasks. Short-term memory scores surged, allowing for the retention of 5-9 words in brief reading passages. Substantial gains were also observed in long-term memory metrics, evidenced by participants accurately answering questions posed at the start of the therapy. Improvements were noted in various types of memory—episodic, semantic, and procedural. Memory performance further enhanced, marked by a reduction in extraneous fixations after last focusing on the target object, making memory more visually rich. The velocity of smooth pursuit movements accelerated to a range of 10-60 degrees. Simultaneously, the amplitude of these movements decreased, aligning with improved saccades at faster target speeds, thereby contributing to significantly higher cognitive task scores.

When every word in a text was fixated upon, the overall time spent on comprehension, as measured by gaze duration per word, decreased. Extended, stable fixations led to more efficient information processing, influenced by the word's rarity and thematic relevance. Pauses at sentence ends were eliminated or significantly reduced in dyslexic children, facilitating a more unified visual-cognitive and neurodevelopmental information processing system. The fusion of binocular images contributed directly to the perception of three-dimensional depth. Stereopsis improved across the board, including in amblyopic children, reaching a measure of 40”. Enhanced optomotor responses laid the groundwork for effective visual examination, entrusting control to newly developed neural networks. This resulted in advances in both optomotor and perceptual memory, which in turn led to improvements in both conscious and selective attention, effectively linking perceptual experience to cognitive function. Consequently, the enhancement in perceptual abilities correlated positively with learning capabilities.

Significant gains in short-term memory, as evidenced by cognitive testing, demonstrated the interplay between central executive control and both linguistic and visual- spatial domains, pointing to an overall enhancement in working memory.

During diverse cognitive activities—including perception, learning, cognition, action, memory, and knowledge acquisition—changes in neural organization were observed, enriching the functionality of the central executive system. Adaptive neural adjustments were noted in response to yoked prism tasks, AC/A variations, and motivational stimuli, reflecting recalibrations based on expected postural memory. Enhanced orthoptic capabilities had a significantly favorable impact on learning skills.

The study found that better attention focus was linked with stronger visual signals in the brain. This improvement was consistent among all participants. Visual therapy significantly enhanced both cognition and attention. Brain scans indicated heightened activity in regions linked to reading abilities. Enhanced eye movement correlated with positive brain activity during reading. The study also revealed an uptick in unexpected word usage in complex sentences, indicating better cognitive control. These results were confirmed through EEG brain scans, suggesting a deeper understanding of language.

The study revealed that faster eye movements improved mental focus and workload in risky settings. Longer gaze durations were linked to better memory recall. This eye movement improvement also suggested lasting changes in oculomotor behaviour. Our data showed a strong connection between where people fixated and where they focused their attention. Children with dyslexia showed better word recognition when their eye movements were effectively aligned. This led to a boost in recognizing entire words based on their visual representation (see Table 1).

Automated word recognition improved overall language function and data processing. Our findings also suggest that focused visual attention plays a role in actively storing information in working memory. Word processing started even before finishing the previous word, indicating that attention is continuously shifted to gathering useful language information. Participants also showed better focus in language comprehension, with longer gazes during visual scenarios. This finding backs up theories about how language processing is linked to physical experience and is further supported by neuroimaging data and the interplay between language and vision. All participants showed notable gains in cognitive test performance.

Table 1. *Cognition scores before and after visual therapy*

	Before visual therapy	After visual therapy
Short memory scores (immediate recognition)	1-3 words in small paragraph	5-9 words in small paragraph
Verbal memory scores	1-9 words in small paragraph	10-30 words in small paragraph
Number memory scores	1-3 numbers per line	6-8 numbers per line
World Memory Test Scores	2-9 percentiles	18-30 percentiles

Table 2. *Orthoptics corrections after visual therapy*

Scores After Visual Therapy	Scores Before Visual Therapy	Orthoptic Disfunction
6D-10D	0.25D-1.0D	Accommodative Insufficiency
6D-10D per 10cycles	1.5D-2.0D decreased per each cycle	Accommodative Infacility
15pd bo- 25pd bo	2pd bo- 4pd bo	Convergence Insufficiency
4pd bi- 10pd bi	1pd bi- 2 pd bi	Divergence Insufficiency
5pd bi- 12pd bi	1pd bi- 2pd bi	Basic eso
12pd bo- 22pd bo	3pd bo- 5pd bo	Basic exo
Pvf10-18bo, nvf 5- 12bi Vertical 2-3bu/bd	Pvf 2-4bo, nvf 0-3bi vertical 0bu/bd	Fusional Reserves Disorders
40”	70”-140”	Stereopsis
300msec-350msec	150msec-200msec	Fixation Duration
300-400degrees	100-150degrees	Peak velocity of saccadic latency
10-60 degrees	5-25 degrees	Velocity of smooth pursuit movements
20msec-40msec	50msec-70msec	Saccadic Duration
20msec-30msec	100msec-150msec	Saccadic Amplitude
200msec-250msec	400msec-500msec	Saccadic Latency

DISCUSSION

The visuomotor system demonstrates considerable adaptability in reconciling sensory input with necessary output. Vergence cells, which modulate in direct relation to the vergence angle, share attributes with motoneurons. This suggests they serve as the vergence integrator, reflecting the afferent qualities relayed to the oculomotor nuclei. The superior colliculus governs gaze shifts using dynamic motor errors, consistent with its known functions in saccadic movement, pursuit control, and gaze repositioning.

The synchronization of eye movements is crucial for effective reading and visual comprehension, underscoring the impact of optometric variable vergence facility on eye fixations. These results carry substantial neurophysiological significance, demonstrating notable oculomotor adaptability in children. Such findings are consistent with the foundational concepts of perceptual and motor/oculomotor learning that inform all vision therapy methods (Hollingworth, 2006).

Optometric visual therapy and rehabilitation have shown efficacy in addressing a range of visual disorders. It is plausible to hypothesis that such therapy techniques fortify synaptic connections via learning processes and trigger cortical restructuring to optimize visual effectiveness. This lends credence to the idea that vision therapy can foster neural adaptability and improve visual performance in individuals facing visual impairments.

Consequently, visual training has demonstrated its efficacy in remedying a wide array of visual impairments, such as amblyopia, oculomotor issues, accommodative dysfunctions, both strabismic and non-strabismic binocular conditions, and challenges in visual information processing. The approach has also successfully alleviated symptoms linked to visual impairments stemming from prenatal and acquired brain injuries.

A transformative shift has occurred in the field of neurorehabilitation, propelled by enhanced insights into the brain’s exceptional potential for structural and functional recuperation. This shows the acknowledgement that sensory, motor, and cognitive deficits can be targeted to induce brain reorganization, resulting in functional improvement. The key elements highlighted in effective visual training mirror those employed in various other rehabilitation disciplines aimed at stimulating neuroplasticity. These elements comprise motivation, multisensory coordination, repetition, task intensity and feedback.

Specifically targeting amblyopia, active therapy has demonstrated enhancements in oculomotor, binocular, accommodative and perceptual capabilities, pointing to remaining plasticity in the visual cortex. These observations accentuate the efficacy of visual training as a potent means for bolstering visual abilities and stimulating brain neuroplasticity to elevate overall visual performance. Various topographic maps related to sensory and motor functions have been discovered in both the cortical and subcortical areas of the brain. A universal advantage of these maps, irrespective of their sensory modality, is their capacity to enable precise spatial pinpointing of sensory input signals and to generate corresponding motor responses. By repeatedly performing visual tasks and employing specialized therapeutic methods, considerable improvements have been observed in children’s visual clarity and binocular vision. Furthermore, visual therapy has facilitated the development of stereoscopic depth perception in children post-strabismus surgery for the first time.

By diversifying therapeutic methods and escalating the level of challenge, the brain's focus can be optimally engaged. This leads to fortified synaptic connections and yields superior therapeutic outcomes. Disruption of the Frontal Eye Fields (FEF), as evidenced in humans, has a significant impact on the direction of spatial attention. The Ira parietal Sulcus (IPS) neurons are pivotal in creating action-focused spatial representations and are central to endogenous (top-down) regulation of spatial attention (Casarotti et al., 2012). Activity in the Lateral Intraparietal Area (LIP) is influenced by the dynamics of spatial and temporal attention and is geared towards highlighting only relevant targets, indicating that LIP neurons construct a saliency map of the visual landscape. Neuroimaging research shows that the cortical network activated during human top-down spatial attention control encompasses both the IPS and FEF. Essentially, the brain regions facilitating endogenous orientation of spatial attention largely coincide with those involved in sensorimotor transformations for saccadic eye movements.

The ability to synchronize binocular saccades is not an inborn trait but emerges through visual exposure and learning experiences. Post-therapy, children may achieve a level of autonomous control over both eyes, enabling them to fine-tune their fixation disparity to enhance reading performance.

For successful binocular perception, the cortex must align disparate image elements on both retinas, which can appear in either crossed or uncrossed reading disparities. The visual system is tasked with harmonizing non-matching images from each retina, which often involves a critical directional discrepancy. This misalignment can be rectified through targeted visual training. The visual system adeptly leverages the high-resolution quality of the fovea by intentionally adjusting the foveal fixation point. Moreover, the gaze is generally sustained near the locus of active information extraction, thereby maximizing the high acuity advantages of the fovea (Kuhn et al., 2008).

During the recollection of a visual scene, the brain reactivates the same visual processes employed at the time of initial encoding. This implies that the benefits of visual training extend beyond immediate visual tasks to also affect memory-associated processes related to visual scenarios. Collectively, visual therapy has demonstrated significant potential in augmenting diverse visual functions and inducing neuroplastic alterations in the brain for optimized visual perception and performance.

The most compelling support for a two-way relationship between eye movements and cognitive processes is derived from studies focusing on attention-related outcomes. In contemporary scholarship, there is a growing consensus that vision is not passive but active. This perspective is crucial, as our visual experiences are shaped not just by external stimuli but also by internal cognitive mechanisms. One key feature of this active vision is selective attention, which allows us to process only a limited subset of the available visual information to guide actions and perceptions. Unattended information is typically filtered out during the initial stages of visual processing. By directing our covert attention toward a specific stimulus, we can perceive it with greater clarity than if our attention were dispersed. Indeed, advancements in perceptual abilities can be quantified through enhanced sensitivity to faint stimuli, increased perceived contrast and decreased reaction times to stimuli that are the focus of attention. Additionally, visual attention demonstrates a phenomenon known as "inhibitory surround", wherein stimuli located close to but not within the focal point of attention are actively inhibited. Similar results are echoed in neurophysiological research, indicating that visual attention amplifies neural selectivity and responsiveness. When a child aims to focus on a spatial location or specific object, their eyes move to fixate on that point, signaling a corresponding shift in attention. There is evidence of performance in Ternus apparent movement tasks, which assess the functions of the M system, correlated with nonword reading skills but not with the ability to read irregular words. Interpreting this data leads to the position that the act of reading nonwords demands a sequential allocation of covert attention from left to right across the series of letters.

This process either necessitates an operational M-system or some variant of visual-spatial attention linked to Ternus motion perception. Further supporting this, other studies highlight the pivotal role of the M system in attention focusing (Facoetti et al., 2006). Even in connectionist reading models, a preprocessing phase is assumed, where letters or graphemes are organized into specific slots based on a grapho-syllabic template. Therefore, effective phonological assembly relies not just on adequate phonological abilities but also on accurate visuospatial processing mechanisms. Numerous research efforts have highlighted visuospatial attention deficits in individuals with developmental dyslexia (DD). Compared to typical readers, individuals with reading difficulties struggled to quickly focus their visuospatial attention. There is a great investigation to show asymmetrical focusing in children with dyslexia, impacting the automatic regulation of their visuospatial attention. Attention serves as a pivotal element in both perceptual and advanced cognitive activities, including creativity. The intimate connection between attention and eye movements is highlighted through the pre-motor processes governing attention. This demonstrates a strong correlation between both overt and covert attentional orientation and the intentional programming of eye movements.

Eye movements act as a navigational mechanism for attention regulation, facilitating the effective processing of the copious information in one's environment. Pre-motor indicators of attention reveal that both eye movements and shifts in attention are orchestrated by the exact underlying mechanisms, chiefly overseen by the superior colliculus. The superior colliculus (SC) serves as a critical hub for converting incoming sensory data into outgoing motor commands, specifically for the regulation of saccadic eye movements.

The results emphasize the interrelationship between eye movements and attention in visual exploration and cognition. They spotlight the superior colliculus as a key neural center governing both oculomotor control and attention, illustrating the integrated character of visual perception and cognitive performance (Hannula et al., 2010).

The study confirms that factors such as working memory, short-term active storage, and information processing play a critical role in visual reading activities. Understanding the mechanics and physiology of eye movements is key to advancing vision and related neural processes, which also impact attention and neural adaptation. Visual therapy enhances various aspects, including working memory, perception, and neural activity, specifically during visual stimulus encoding and recognition. Words that are focused upon are translated into a semantic format and stored in working memory. This activates a comprehensive representation of the word, encompassing its meaning, semantic and syntactic traits, eye movement skills, perceptual abilities, and contextual information.

Patterns of eye movements and their links to cognitive functions are crucial for visual perception, attention systems, reading activities, and cognitive tasks.

Visual therapy can effectively enhance functional vision efficiency. Fields such as cognitive science, visual studies, cognitive growth, neuroplasticity, perceptual learning, and educational psychology offer frameworks that bolster a neuro-developmental and rehabilitative approach to visual therapy. Sensory and motor data are interpreted as unique experiential features. The brain then orchestrates this visual information, starting from visual inspection to form a stable image, thereby ameliorating visuo-cognitive challenges, and fostering the growth of visual processing skills.

Co-registration, combining eye tracking and EEG neuroimaging, allows for a synchronized analysis of eye movements and brain activity, offering crucial insights into the neural basis of visual processing and cognitive functions during reading. EEG stands out as a dependable measure for capturing the timing of cognitive processes due to its high spatial resolution and the stability it provides in identifying specific brain areas linked to language processing. Fixation-related brain oscillations serve as a tool for studying real-time language comprehension and attention distribution during reading. Information gathered in the parafoveal zone during fixations aids in quicker word recognition, enhancing overall reading efficiency. This sheds light on the cognitive mechanisms at play in visual word identification and its role in language processing. These findings deepen our understanding of the neural operations involved in recognizing written words, with broader implications for the fields of education, language processing, and cognitive neuroscience.

The study establishes a significant relationship between cognitive well-being and eye movement patterns during visual tasks, underscoring their vital role in visual interpretation and perception. The intricate relationship between neural resets in perception and varied neural activities during fixations and saccades showcases the complexity of how the brain processes visual information. Eye movement characteristics are associated with children’s cognitive abilities and are predictive of memory functions. The enhancement in visual directionality and spatial focus, stemming from corrected fixation disparity, positively influences reading proficiency. The formation of a normalized spatial map via visual therapy, along with its beneficial effects on attentional filtering abilities, underscores the potential of visual therapy as an instrument for cognitive growth.

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