

Article ▶ Neuro-Developmental Assessment and Treatment for Optomotor Deficits

Graham T. Peachey, B Optom, Wodonga, Victoria, Australia

Paula M. Peachey, Opt Disp COVT, Wodonga, Victoria, Australia

ABSTRACT

Background: Research on optomotor and perceptual developmental deficit diagnosis, treatment, and transfer to improved academic outcomes has gone mostly unnoticed by clinical optometry until recently. The research methodology/technology used has been modified for the clinical application of this research in the assessment and treatment of basic optomotor and perceptual deficits.

Case Reports: Two case studies illustrate the clinical application of precision measurements of performance markers. The first case illustrates that basic 'learning to read' related deficits can be found in children with healthy eyes, clear sight, and no significant refractive problems. Case two highlights that defects, deficits, and dysfunctions can co-exist. Functional visual inefficiency presented in this case with phenomenological symptoms indicative of 'reading to learn' issues. The assessment of basic optomotor and perceptual markers provides an understanding of neuro-circuitry deficits. Treatable deficits and dysfunctions were managed by optometric vision therapy.

Discussion: The neuro-developmental status of basic optomotor and perceptual processes can be objectively assessed, and developmental deficits can be identified and treated, with the transfer of the oculo-visual skills learned that benefit related educational areas. As the more complex schemata needed for efficient visual inspection and engagement with the educational curriculum are built on these basic optomotor and perceptual processes, developmentally, it is desirable that these deficits be treated early in the educational experience.

Research on the basic neuro-developmental deficits that affect functional visual efficiency is now available and applicable. Optometric vision therapy is empowered by the availability of deficit diagnosis and management. This clinical approach is a work in progress but is currently yielding appropriate objective outcomes for a wide variety of deficits.

Keywords: developmental optometry, functional vision, neuroplasticity, optomotor deficits, perceptual deficits.

Introduction

Developmental optometrists have a long history of using performance tests for developmental and perceptual assessments and as a way to identify visual dysfunctions and developmental delay.^{1,2} These procedures allow us to observe behaviour in relation to psychometric tasks as they are performed and graded. No clinical procedure to date has been able to measure saccadic stability, response time, accuracy, and self-correction responses as markers of neural network development.

Three broad groups of functional vision problems can be identified:

- a. Functional vision **defects:** Faults or imperfections in the structure, physiology, neurology, health status, optics, etc., as a result of genetic, traumatic, pathological, toxic factors, abusive use, and/or deprivation
- b. Functional vision **deficits:** Where the neural network for aspects of functional vision is less than required or expected for age because of neuro-developmental delay, or where breakdown of previously available neural networks has occurred
- c. Visual **dysfunctions:** Where the behaviour indicates that some part or relationship with the functional vision

complex does not work properly and is characterised by disorderly function. Visuo-cognitive development may be disturbed by adaptive conditioning, producing distorted organisation that impacts negatively on performance, self-perception thinking, and/or problem solving.³⁻⁸

Optomotor is a new term for many optometrists. It is distinct from oculomotor or ocular-motor in its use in regards to functional visual deficits. When conducting a literature search on ocular-motor and dyslexia, most of the references that result will relate to defects. When you conduct a literature search on optomotor and dyslexia, aspects of developmental delay within the very fine voluntary control of ocular motor application, response times, and accuracy deficits result. In brief, optomotor factors relate to what the person can do with their ocular motor system.

Research tools and a substantial database have been adapted to create tools for clinicians which enable them objectively to assess optomotor and perceptual developmental deficits. Precise psychometric measurements of response times, response accuracy, percentage of errors corrected, and

response time for error correction are examples of the collected data by use of ExpressEye, FixTest, CountFix, FonoFix, FixTrain, CountTrain, and FonoTrain. By adding these new procedures, clinical optometry can expand the assessment of the developmental status of functional vision to include basic optomotor and perceptual neural networks.

Background

A global orientation for neurodevelopment has emerged as the new science of the mind has been detailed. Many disciplines have contributed to the accumulated data.^{3,4,9-29} Neurodevelopment can be simplistically summarised to four points:

1. **Mind emerges from the structures and functions of a living brain.** As the master regulator for neuro-endocrine, autonomic, immune, and neural-integrated circuitry systems, the brain is the key organ of stress reactivity, coping, and recovery processes.
2. **Neural networks are formed into functional circuitry by experience-dependent processes.** Mal-adaptation can result from lack of appropriate and timely experience, toxic stress, and poor social support. On the other hand, beneficial adaptations can result from appropriate, timely experiences and support that directly shapes the genetic expression process. Repetitive experience is needed to maintain, strengthen, refine, and elaborate the neural circuitry on which the mind functions depend.
3. **The mind is enriched by a number of developed processes such as memories, procedural learning, perception, and cognition.** These emerge from complex interactions between the genetic givens and environmental factors.
4. **The mind has a lifelong capacity to reorganise and learn new tasks.** Neuroplasticity refers to the capacity to change the wiring of neural networks in response to maturation and experience. Positive changes in functional neural complexities are more likely to result when the social and task experiences engage attention, operate at an achievable but challenging level of demand, positive reinforcement quickly recognises success, and task delivery motivates repetitive interaction and is sequentially moved in small steps from simple responses to more complex integrative behaviour.

Just as one must learn first to walk before endeavouring to master dance routines, the acquisition of functional vision efficiency is sequential. Each person develops voluntary operational control of the basic optomotor and perceptual processes before they acquire efficient use of more complex functional vision. Developmental milestones are understood to be a reflection of the increasing complexity of the available functional neural networks. The clinical assessment of neural network deficits contributing to efficient functional

vision depends on psychometric procedures designed to measure basic performance markers. Functional MRI and electrophysiological procedures are typically used for defect detection.

Basic optomotor and perceptual assessments are a component of the comprehensive functional vision work-up that must identify and manage defects, deficits, and dysfunctions. A clinician's model of vision is typically a work in progress and is based on best effort to accommodate:

1. The complex molecular neurobiology of neural network development, plasticity, and rehabilitation that is provided by neural science;
2. The global view that is provided by visual science, developmental and cognitive psychology, and cognitive neuroscience;
3. Full-scope optometric education and accumulated clinical experience.

The purpose of functional vision is to enable effective interactions with the environment. Efficient functional vision is the result of a cascading interaction between the visual machinery, the motor and perceptual learned capacities that support visual inspection, and the higher cognitive functions where understanding of the visual experience is achieved.²⁹⁻³¹ The three areas are briefly described in Table 1. The aspects being neuro-developmentally assessable via the procedures being addressed are printed in bolded italics.

Area 1: Health, clarity of sight, integrity of eye structure, ocular motor, neurology, physiology, etc. While assessing Area 1 the clinician considers patient history, symptoms, signs, and assessment results to identify any defect within the visual system.

Area 2: Visual Inspection. Current thinking is that at least three parallel processing streams serve visual inspection and project to multiple areas in the brain. In brief, two cortical systems, the "Where is It" and "What is It" streams, develop in a two way interaction with the sub-cortical orientation "Where am I" system.^{10,25-29,32} These cortical systems show a staged development with the "Where is It" stream being most vulnerable during development.^{25,33} Behavioural milestones depend on the emergence of visuo-motor functional neural networks that are called modules by Atkinson and Braddick,²⁵ who state that these modules first develop as specific networks and then later become coupled for integrated behaviour. The development of spatial attention is considered to be intimately linked with target selection and planning in this visual-motor functional system.^{25,28}

Voluntary control of the processes that are required for efficient visual function are assessed at two different levels:

- a) Neuro-developmental optomotor status is assessed and the deficits in basic processes are identified by the procedures noted in this paper with a developmental aetiology proposed for any optomotor deficits diagnosed.

Table 1. Functional Vision – a cascading interaction of 3 areas

Area 1	Visual biology/physics: Defect Management.	Health, clarity of sight, integrity of neurology, structure, physiology, etc.		
Area 2	Visual Inspection Schemata A. Developmental Deficits B. Breakdown Dysfunctions	Visual psycho-physiology; Neural Science Basic optomotor and perceptual developmental status (ExpressEye, FixTest, CountFix) Adverse adaption within motor, sensory, spatial/temporal, endurance and comprehension		
Area 3	Visuo-cognitive Schemata A. Two processing modes B. Three Domains:	Mind Science, (Understanding from visual experience) Linear “sequential” analysis (Hemispheric specialization) Global knowing & linear “sequential” analysis.		
	Domain 1 – Sensorimotor Me/It thinking Visual spatial – laterality/directionality Visual analysis – JND's, sorting, matching, classification Visual motor integration – general/discriminative movement, spatial manipulations and timing, graphic thinking Visual auditory integration – visually directed action to beat, visual/verbal match, RAN, auditory/spatial thinking, FonoFix verbal/spatial thinking	Domain 2- Evolving Self Me thinking Mindful awareness for: Self awareness Body construct Self monitoring Self correction Self planning Self motivating Self talk Self organisation Self confidence Etc.	Domain 3 – Problem Solving It/It thinking Stages 1. Sensorimotor; (Intrinsic Curiosity drives Visuo-Motor Complex) Input – actions, reflexes Output – self discovery, spatial exploration 2. Pre-operational; (mobility) Input – perceptions Output – magical thinking, perceptually bound 3. Concrete; (Intuitive Physics) Input – the “actual” Output – invariance, conservation, logic 4. Formal; (Deductive Reasoning) Input – the “possible” Output – hypothesis testing, creative imagery, thinking about thinking.	Typical for Age (0-2) (2-5) (6-10) (11-adult)

b) The visual inspection operational organisation for required tasks may be dysfunctional even when basic optomotor performance is adequate. Skill dysfunctions seem to have an adverse adaption aetiology, as breakdown of functional visual skills can follow effort to cope with defects and/or deficits. It can also occur independently of pre-existing defects and/or deficits, when the demand becomes excessive for neuro-muscular and/or cognitive capacity.

Area 3: Visuo-Cognitive Operations: In order to accommodate the complexities of higher order thinking into the optometric vision therapy (OVT) clinic, we adopted the use of the Neo-Piagetian three domains construct proposed by Kagen,¹⁸ where biological, psycho-social, and philosophical components interact.

Domain 1: This is called Sensorimotor as it requires “me/it” thinking during the relating of ‘self’ to the environment. This domain is psycho-physiological and essentially the same as the visual information processing.³⁴⁻³⁹

Domain 2: The Evolving Self involves the “me” thinking as it relates self to others. Aspects of this domain are psycho-social and for OVT include self-awareness, self-organisation, self-correction, etc.

Domain 3: Problem Solving involves “it/it” thinking as specific detail is related to other factors. This domain is philosophical and can be assessed clinically by observation of the problem - solving, an inventory of Piaget’s developmental tasks,⁴⁰ and/or a psychometric assessment by pattern matching.⁴¹

Neuro-developmentally, it can be argued that these basic optomotor and perceptual factors are fundamental to the acquisition of more complex visual inspection schemata.

As Fischer states (bolding is the author’s emphasis):

“ ... **it is not the saccade control system as a whole which exhibits developmental deficits in dyslexia.** The eye

muscles and the brainstem mechanisms for saccade generation are usually intact and do not show systematic deficits ...”

“... **It is the frontal lobe component**, which regulates the synchronization of the ongoing reading process and saccade generation that **is not well established**.”⁴²

Other independent researchers have also confirmed this view and report that dyslexic children frequently have immaturity of oculomotor anti-saccade control.⁴³

We view OVT as an opportunity for each patient to explore their self-organisation and visual capacities as they develop functional neural circuitry. The interconnection of simple reflex pathways, motor learning, perceptual learning, cognitive development, and memories into a fast response functional neural network is termed schemata. Schemata development moves from simple, to more advanced, and then finally to where efficient functional vision is integrated into skilled performance on required tasks. The neural network circuitry that supports each schemata is formed by processes that include the formation of cell bodies, selective cell death, and the growth of axons and dendritic processes, as well as the formation of functional synaptic connections and the elimination of unused synapses. Repetitive experience can have the effect of incorporating required synapses into strong functional neural circuits and eliminating the unused connections.^{9,10,12,20,22,23,44}

Our OVT typically follows a five-phase delivery plan:

Phase 1: Establish and Enhance the Basic Visual Inspection Schemata (stability and accuracy)

- a) Orientation & Evolving Self: Optometric vision therapy typically is considered after all defect management approaches have been addressed. At the start of OVT the therapist must establish a working relationship with the patient. They need to know why they are coming to therapy, that they can control much of what their eyes do, and with practice, that we expect them to improve. They explore their self-awareness, self-monitoring, and self-planning while engaged in basic visually-directed orientation activities. Maximising monocular skills and then applying these monocular skills in a binocular field is also addressed. Tasks are then used to develop the awareness of the ability to gain and sustain global stereopsis while stereopsis is used to monitor binocular teaming while engaged in general movements such as walk rail, balance board, and yoked prism.
- b) Basic Optomotor & Perception: We then develop the ability to analyse central detail while holding peripheral stereopsis. To do this we use tasks such as card sorting, Hart chart surrounded by stereo rings, to complement FixTrain, and then later the CountTrain activities.

Phase 2: Develop Advanced Visual Inspection Schemata.

- a) Initially this was done on simple tasks using Computer Orthoptics, vectograms, aperture rule, various stereoscopes, and CountTrain. The cheirosopic tracing sequence was particularly helpful. We started with cheirosopic tracing using peripheral stereoscopic fusion lock and moved eventually to unstructured cheirosopic tracing. Finally, all three visual inspection streams are engaged with tasks such as moving sequentially to a beat clockwise around a balance board while calling letters from a Hart chart and maintaining stereopsis with large peripheral circles. Visuo-spatial attention shifts are now linked with simple auditory and then phonological processing to develop rapid automatic auditory-spatial responses and then naming responses to increasingly more complex material.
- b) Therapy for free space fixation, focus, fusion, and flexibility. Prisms and spherical lenses were used to achieve AC/A changes,^{45,46} perceptual learning,^{9,10,12,16-20,22,24,47} sensory-motor spatial recalibrations,^{26-29,35} and/or the Vaegan isometric prism vergence effects.⁴⁸ The lens therapy was selected to induce selected neuro-muscular and/or perceptual effects during specific procedures. Activities that require accurate visual inspection schemata were introduced and expanded to include involvement with problem solving and basic reading tasks.

Phase 3: Develop Schemata that Integrate Visual Inspection with Spatial-Temporal Processing.

Procedures are now directed to achieve better processing speed and span during advanced dynamic visually-directed performance, while working to:

- a) Refine the stability of the vestibular ocular reflex by integrating stereo visual, auditory/vestibular, and somatosensory during dynamic movement. This advances the schemata that integrate the three visual inspection processing streams with action and manipulation experiences.
- b) Enhance visuomotor timing and prediction via bio-feedback procedures that incorporate ‘soft’ eyes instruction, strobe, multi-tasking, etc. Activities that involve movements of self and/or objects can be used to build awareness and control of many skills during motor loading including spotting - the zoom control of the spotlight of attention for figure-ground analysis and filtering out distractions.

Phase 4: Develop Task Specific Functional Vision Schemata.

We then go on to develop the capacity to apply efficient functional vision while working under a high cognitive load (e.g. problem solving and reading) sequentially⁴⁴ with:

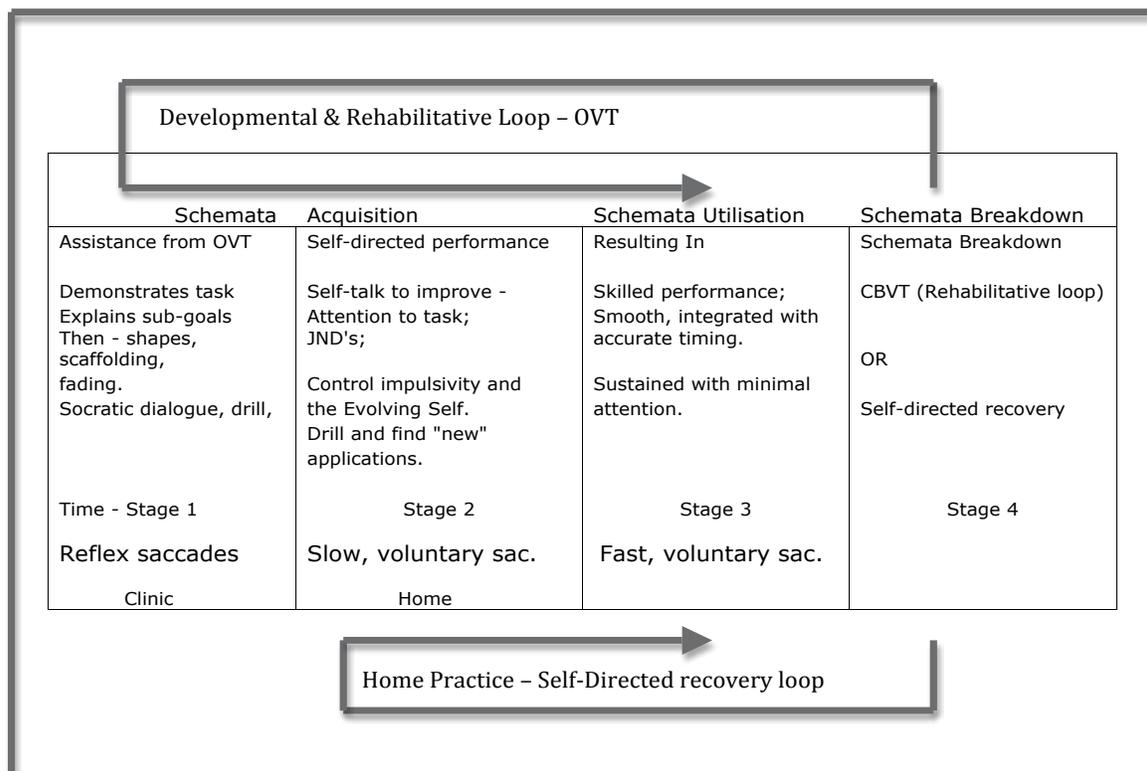


Figure 1: Vygotskyan Concepts Applied to OVT

- a) Application of the newly acquired visual inspection skills to problem solving, which involves vision-language patterns, visualisation patterns, and problem-solving. Accurate visual inspection facilitates visuo-cognitive operational development such as visual analysis schemata, and this in turn fosters problem solving schemata.
- b) Application of the newly acquired visual inspection skills to reading is addressed via the use of tachistoscopic tasks such as: controlled reader, trombone reading, and BIM/BOP flipper reading. These procedures build visual attention, accurate and sustained visual inspection and fast processing speed into usable reading schemata.
- c) Reading Plus⁴⁹⁻⁵¹ type techniques could be considered and used to develop functional vision schemata specifically for reading – with reading eye movement efficiency, attention to task, reading speed, and comprehension improvements being expected outcomes.⁵²

Phase 5: Discharge from Active OVT: Maintenance and Follow-up

A comprehensive review is conducted at the conclusion of the active component of clinic-based OVT. This is done to determine ongoing best prescription support, and maintenance activities and to plan the future review schedule.

To achieve these outcomes, OVT addresses general movement schemata where neural pathway patterns and synaptic inter-connection are built to facilitate visually directed general movements requiring orientation of body, head and eyes, locomotion, and balance. We then move to link the patient's egocentric visual, auditory, and somatosensory spatial maps with the ocular-centric lateral geniculate nucleus stream spatial maps and spatial attention shifts.²⁵⁻²⁷ This involves coaching since activities that require visually directed discriminative movements and dialogue build for the patient their self-awareness, self-organisation, and self-control. This mindful awareness component of OVT is a contemporary application of available neuro-science and developmental psychology. The application of Piagetian schemata concepts^{5,18} and Vygotsky's theory of the Zone of Proximal Development¹⁷ provides a social and motivational context to our neuro-developmental therapy (Figure 1).

Research on basic optomotor factors that underpin the more complex visual inspection operations have been reported.⁵³ Objective assessment of the development of factors includes fixation stability, binocular movement symmetry and stability during saccades, and the pattern of saccadic organisation used during simple eye movements from one spot of light to another. This has resulted in normative data for the general population and profiles of deficit for selected groups. The basic optomotor processes that were researched in laboratory became available for clinical use.⁵⁴ Laboratory studies have also been conducted on two basic perceptual processes. This research also results in

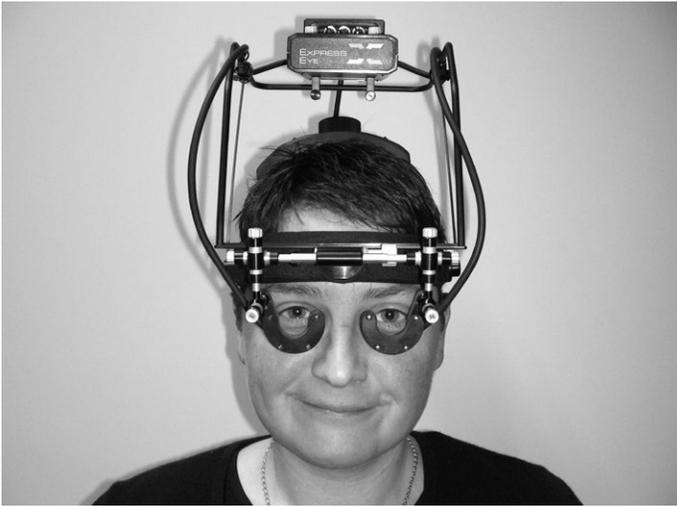


Figure 2: ExpressEye apparatus

developmental milestones for subitizing³³ and basic auditory perception.⁴²

The Neuro-developmental Deficit:

A comprehensive assessment of eyesight and hearing starts with defect detection and management. Thus a detailed study of eye health, clarity of sight, and physical, neurological, and biological integrity precedes tasks that assess the neuro-developmental status of basic and more complex functional vision.

The specific focus of the new assessment procedures is to study in detail aspects of simple optomotor and perceptual factors which are unavailable to direct observation. By electronically recording both right and left eye timing, movement symmetry, and saccadic organisation as they move from light to light, the clinician can study much more basic optomotor operations than those addressed by the Visagraph/ReadAlyzer analysis of fundamental reading eye movements.

Response time, response accuracy, and self-correction responses of basic optomotor and perceptual factors that relate to neuro-development are measured, and then the patient's performance is compared with developmental expected data. The psychometric assessment procedures used with this technology provide key performance markers for neural development.

New Technology for the Clinician:

This technology and the psychometric process have been previously described.⁵⁵⁻⁵⁹ Neural developmental research tools for the diagnosis and treatment related to basic optomotor and perceptual developmental deficits are now clinically available, applicable, and usable.^{33,39,42,50,51,53,54} There are two parts to this system. The hardware consists of four assessment units (ExpressEye, FixTest, CountFix, and FonoFix), and three training units (FixTrain, CountTrain, and FonoTrain). The training equipment units are similar in appearance and operation to the assessment units. They differ in that the

training units provide the therapist greater control over the levels of demand that can be selected and provide feedback to the patient on their performance. The software is the clever part. Stored within the management computer is the research data for the developmental norms of basic reflex and voluntary optomotor control and perceptual factors. This database, established for normal subjects, is used to identify and diagnose specific optomotor deficits where causation can be attributed to delayed neuro-development. The clinician considers all the relevant data before diagnosing a neuro-developmental deficit. These treatable deficits can be co-morbid with other conditions.

Assessment

Express Eye:

Assessment Instrument 1 – ExpressEye

This instrument uses three mini-laser lights to produce fixation targets. The laser lights are positioned in the box above the head (Figure 2). Infrared sensors below each eye measure the position of the eyes with about 1000 readings per second being relayed into the computer. The stability of the projected laser light is dependent on body and head control.

Procedurally, the ExpressEye requires:

1. Calibration.

Calibration: The organisation and control of the body, head, and eyes is typically developed sufficiently by the age of seven to enable calibration. Failure to get calibration with a normal healthy eight-year-old or older is considered to be a marker for a probable orientation developmental deficit.

2. Data collection: fixation stability, pro-saccades, and anti-saccades.

Fixation Stability: The ability to hold steady fixation on a laser light spot projected from the head mount has developmental milestones. This basic fixation task requires functional involvement from magnocellular pathways, parvocellular pathways, and selective visual attention. The marker for a fixation control deficit is the persistence of drift away from the target light. The age-expected fixation stability for this procedure determined by counting the number of error saccades (intrusive saccades) per trial has been established.

Pro-Saccades: These saccade movements are towards the stimulus and make limited demands on voluntary optomotor control. Imagine you are looking at my nose and are aware of the pointer fingers on each hand, held to each side. Notice when one of the fingers moves, then look from the nose to the moving finger. This saccade movement towards the target is the Pro-Saccade.

Anti-Saccades: Now the saccade movements are away from the stimulus, and this imposes a higher

demand on voluntary optomotor control. If we repeat the task, but now ask that instead of looking at the moved finger you look to the finger that did not move, you now have to make a saccade to move fixation away from the moved finger. This consciously controlled eye movement away from a stimulus is an Anti-Saccade.

3. Data analysis: Two eye movement measurement protocols are used.

The measuring of response times, control accuracy, and error profile for both Pro- and Anti-Saccade tasks is new information for the clinical optometrist. Data collection is extensive and takes about 16 minutes. From these recorded responses we can analyse:

1. Fixation Stability: e.g., unstable fixation has frequent intrusive saccades.
2. Binocular motor stability relating to the movements between fixation targets.
3. Saccadic Organisation.

Binocular Stability: Recording the relative velocities and synchrony of actions for each eye as they make saccade movements from one laser light to another enables the assessment of the optomotor aspects of binocularity during saccadic suppression. The symmetry of eye movement actions and timing between fixations to spots of light is a new index of binocular motor stability. It has been called the Bindex and reports the percentage of time that the symmetry of the saccadic eye movements is significantly dissimilar.

Saccadic Organisation: Response times provide markers for saccade responses. There are three saccade groups of interest when assessing neuro-developmental status. Express saccades utilize a reflex pathway without frontal lobe involvement. They are classified by their response which occurs 100msec after the stimulus and is typically accompanied with many errors and poor self-correction. The next are the slow voluntary saccade responses which occur 200msec or more after the stimulus. Finally, fast skilled saccades are marked by their response time of 150–190msec. These saccade response time markers are used to determine the deficit diagnosis and also to monitor optomotor learning during the acquisition of saccade control.

Response Times are used as markers to identify 3 Levels of Motor Control (Figure 1).

- a. Express Saccade – 100msec (Reflex control – Stage 1, Vygotsky Recursive Loop)
- b. Slow Voluntary Saccade – 200msec+ (Unskilled – voluntary –Stage 2, Vygotsky Recursive Loop)

- c. Fast Voluntary Saccade – 150msec (Skilled – voluntary – Stage 3, Vygotsky Recursive Loop)

Self-Correction: The number of errors and response patterns to errors during the simple ExpressEye procedure provides markers that relate to self-correction responses. This data provides a window into an aspect of visuo-cognitive development, the evolving self.

The optomotor developmental changes that are typical as a person progresses from pre-school to advanced “reading to learn” abilities show that the trend is for the developmentally immature to:

1. Start with poor fixation hold, lots of intrusive saccades and/or reflex express saccades with poor accuracy, and limited self-correction.
2. Move to good fixation, hold and release, and use slow voluntary saccades that show improved accuracy and some self-correction.
3. Eventually demonstrate limited express saccades and a mix of fast and slow voluntary saccades with good accuracy and fast, accurate self-correction.
4. Following good saccadic organisation, the next step is to develop attention shifts for form analysis of detail covered by a single fixation. These attention shifts are required for the scanning of short-term memory imagery as with the CountFix procedure.
5. Finally task specific schemata for reading eye movements emerge as is detailed in the developmental table for the averages for measurable components of the fundamental reading skill.^{49,50}

Assessment Instrument 2 – FixTest:

This is a fall back procedure used when ExpressEye cannot be done or used as a performance test to screen for deficits with fixation stability and pro-saccade and anti-saccade organisation. This instrument is further detailed by Fischer and Hartnegg.⁴²

Assessment Instrument 3 – CountFix:

This procedure is a basic tachistoscopic procedure with ‘circles’ presented. The subject must utilise fixation to get visual engagement and short-term memory, and then internal attention shifts can be made to count the circles above the number of four. The computer analyses the subject’s performance and compares this to developmental expected data that covers subjects from seven to 55 years old.

It is a subitizing and count deficits technique using a tachistoscopic “Where Is It” procedure. Clinical treatment of these deficits follows after FixTrain and other procedures have been used. Tachistoscopic performance with circles is typically trained up to age expected levels before numbers, letters, and then words are used. This is a procedure that depends on fixation engagement, short-term memory, and attention shifts to count the number of circles above four. This is considered to be a basic perceptual function where attention shifts facilitate

an internal survey of the perceptual field provided by a single fixation. Covert attention shifts can now replace actual voluntary saccades.

CountFix assesses the ability to respond to briefly flashed circles. This tachistoscopic procedure limits visual inspection to one fixation. Attention shifts around the perceptual field, which facilitates the ability to analyse 'where' and count the number of circles above four. The CountFix assessment is more basic than is typical of the usual perceptual speed and span assessments, as it does not require "What Is It" or form analysis.

Assessment Instrument 4 – FonoFix:⁴²

This is not a hearing or ear health assessment. This procedure requires the subject to listen, to discriminate, to sequentially analyse 'where' each sound is in time, and then to convert this auditory temporal analysis to a spatial "Where Is It" understanding that can be communicated by pressing the appropriate up, down, right, or left arrow. This non-verbal task is viewed clinically as a basic auditory – spatial integration assessment and is a precursor to linear sequential tasks that require 'where and what' analysis of components of speech, as occurs in the Rosner Test of Auditory Analysis Skills (TAAS).

Procedures with the FonoFix require that basic auditory analysis of intensity, tone, sequence, and location be transposed into a spatial construct. To explain this transformation of auditory stimuli into a spatial code, consider the task Side Order. During the instruction for this procedure the patient is told, 'If you were touched on the right shoulder and then a little time after touched on the left shoulder, you could think of the stimuli as an arrow going from the right to the left. An arrow pointing left would represent the direction the stimulus moved.' When the patient demonstrates understanding, the Side Order procedure is explained. In Side Order, the FonoFix presents a sound first to one ear, and then a short time after, another sound to the other ear. The subject then presses the arrow that represents the directional movement sound. Again the subject's response is compared to developmental expected data over the same age spread.

Can the auditory stimuli be sequentially analysed and transposed into a spatial code? When the FonoFix results indicate performance deficits, ensure that a hearing assessment has been done and results are within normal limits. Our current therapy sequence utilises visuo-motor activities and other procedures that build body awareness, spatial constructs, rhythm, and timing before FonoTrain is used to improve auditory-spatial integration.

Training Procedures

Therapy Instrument 1 – FixTrain:

This is the first of the three therapy devices. It is a therapy version of the FixTest that can be adjusted to set the task demand level for each subject. FixTrain is used to treat and monitor progress with three diagnosable deficits and has

treatment protocols for tightening or loosening fixation hold and improving anti-saccade performance.

- a. Unstable fixation hold (poor magno to parvo switch)
- b. Slow release of fixation (over hold of parvo)
- c. Anti-Saccade deficits (poor frontal lobe control)

The importance of fixation control and saccade organisation for visual engagement should be noted. Fischer's attentional disengagement model for the optomotor cycle³³ suggests that intrusive saccades and express saccades are most likely to occur when attention has disengaged from the locus of fixation. Regular monitoring of the optomotor markers during therapy delivery plots the performance changes that reflect functional neural circuitry organisation. We look for progressive application of improved visual inspection and expect students with learning to read optomotor deficits. Improved attention to small detail and ability to filter out distractions are usual after fixation stability is applied. Later on, better visual analysis of detail, tracking, visual spatial, and visual motor integration skills emerge as skilled saccades with self-directed error correction replace reflex saccades. For the reading to learn deficits, improved capacity to sustain efficient and comfortable visual performance, visual memory, sight word recognition, and reading comprehension are expected to occur as skilled automatic saccades facilitate visual inspection with minimal demand on attention.³¹

We use each of the three training devices as vision therapy stations in the clinic. They are used sequentially and as diagnostically required. These are complimented by suitable home practice procedures. FixTrain procedures can be complimented with other biofeedback procedures such as Haidinger's brush, after-image, head torch, and rotator tasks. Home therapy typically involves simple equipment with straw piercing, prism saccades, and accommodative rock procedures.

Therapy Instrument 2 – CountTrain:

This instrument is used for subitizing and count therapy. Performance on this tachistoscopic procedure is dependent on visual engagement, short-term visual memory, and internal attention shifts to count the circles. This therapy is often started after anti-saccade performance has normalised or reached a plateau.

Therapy Instrument 3 – FonoTrain:

Prior to starting with this device, the patient has organised their personal space construct and has achieved their developmental expected levels or has reached a plateau on CountTrain. This technology can now be viewed as essential for diagnosis and therapy to monitor improvements in basic neural network organisation and to identify when therapy should move to the next level.

Case Examples

Two case reports illustrate neuro-developmental assessment and treatment.

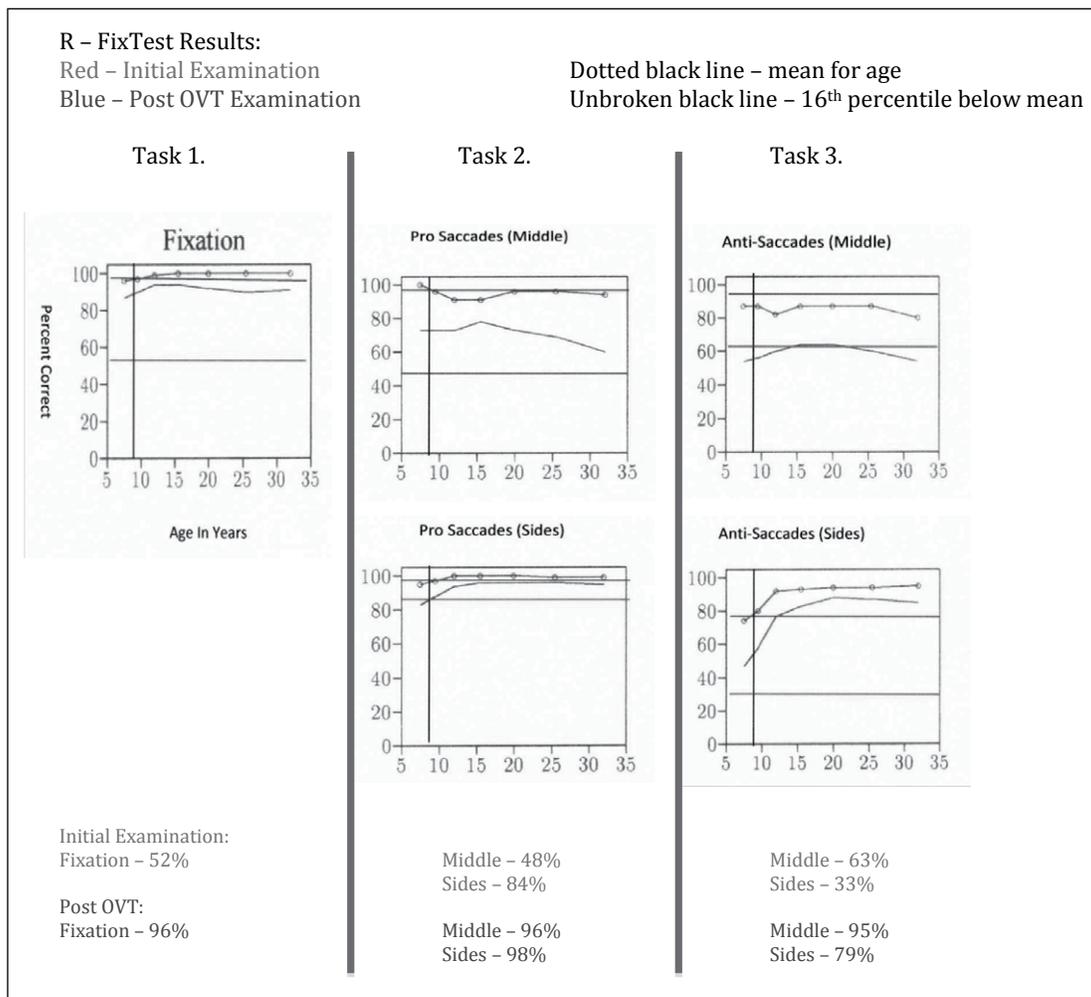


Figure 3: Pre and post OVT FixTest data for patient R

Case 1:

R, an 8.5-year-old male, was selected as a ‘learning to read’ functional vision case where treatable optomotor and perceptual deficits occur without any significant co-morbid functional vision defect. He was referred by his class teacher who reported that his reading progress was below grade expected. Now starting Grade 3, he was confusing word beginnings, slow with handwriting, and had spelling difficulties. Copying from board and tracking were reportedly difficult tasks. His performance was considered to be below potential. His parents confirmed that they had observed similar problems at home. They also reported that R had difficulties staying on task and getting his homework completed. Eye strain was sometimes reported. In summary, R was described as a healthy, happy, and fun-loving lad that was finding school “hard work.”

The initial consult showed that his eyes were healthy, his clarity of sight excellent (6/6+ OD, OS) and revealed no significant refractive anomaly (maximum plus to 6/6 at far was +0.75 OD, OS). Ocular motilities were full and concomitant, and near point of convergence was to 5cms with unstable hold. He could not voluntarily converge without a near target or looking at his nose. Distance and

near heterophorias were 1 exophoria and 4 exophoria, respectively. The near fusion ranges were constricted, and accommodative posture showed lag (BO 12/2: BI 18/12, MEM +1.25 lag). The Developmental Eye Movement (DEM) test and Test of Visual Analysis Skills performances were below age expected normative data (Table 2).

At a follow-up assessment the Express Eye procedure was attempted. R was not able to sustain body, head, and eye coordination sufficiently for calibration of the instrument. We then moved to the FixTest (Figure 3) where the fixation results were well below expected at 52% correct. The pro-saccade scores were 48% correct for middle presentation and 84% correct for side presentation. The anti-saccade scores were 63% correct for middle presentation and 33% correct for side presentation.

The CountFix and Fonofix assessments were conducted and deficit performances were apparent with subitizing. The Wold Sentence Copy assessment confirmed a slow and poorly organised approach to this handwriting task. On the Gardner Reversal Frequency assessment, completion was slow, but error-free. In summary, the assessments disclosed that R had:

Table 2: Significant clinical findings for patient R

Significant Clinical Findings:		Date of Exam: 20/2/2009	
1. Eye health:	All Ok.		
2. Functional vision:	Unaided V.A	OD 6/6	OS 6/6
	#4	R. +0.50	L. +0.50
	#7	R. +0.50	L. +0.50
	#14	R. +0.75	L. +0.75
	#16	x/12/2	
	#17	x/18/12	
	#20	-3	
	#21	OU +1.75	
3. NPC	14cms		
4. Brock string:	Exo posture - 8cms behind bead.		
5. Keystone FVP:	Excellent stereopsis.		Poor JND's
Supplementary Assessments:		Date of Exam: 26/2/2009	
1. TVPS:	Above expected results for age - skilled performance.		
2. Express Eye:	Could not do.		
3. FixTest:	Well below expected abilities demonstrated.		
4. Wold Sentence Copy:	Slow to complete task.		
5. Gardner Reversal Test:	At age expected.		
Diagnosis - Case 1 R			
1. Healthy eyes, clear sight and no significant refractive defect.			
2. Neuro-developmental, visual inspection deficits;			
	A. Unstable fixation.		
	B. Unstable near binocularity (Convergence Insufficiency)		
	C. Poor subitizing and count ability.		
3. Visuo-cognitive operations below age expected;			
	A. Visual-spatial schemata.		
	B. Visual analysis - poor JND's noted.		
	C. Visual-motor integration.		
	D. Evolving self - poor self-awareness, no "voluntary" convergence.		
	E. Problem solving style - reflective, lacking visual"trust".		
Recommendations & Treatment:			
1. Spectacles for VT tasks and near work during VT delivery.			
2. VT, with good gains expected after 15 clinic based visits, to conclude after 24 visits.			
Outcome:			
1. Parents "self-discharged" after 15 clinic based sessions, with the comments that the "problems are now resolved - R now reads books by the chapter; at or above expected class performance".			
Post VT:			
1. Optomotor and perceptual KPI status at or above expected.			
2. Binocular fusion ranges and operational organisation better, but potential not yet realised.			
3. VMI, improved, but still below age expected.			

1. Healthy eyes, no significant refractive anomaly, excellent clarity of sight, and no identifiable defect.
2. Basic optomotor and perceptual deficits with fixation stability, saccadic organisation, and subitizing
3. Accommodative insufficiency and convergence insufficiency dysfunctional traits
4. Visuo-cognitive operations: The areas of visual spatial skills were within normal limits, visual analysis tasks demonstrated slow processing speed and constricted perceptual span, visual motor integration was unskilled, and visual auditory integration was border-line.

Diagnosis: The basic optomotor and perceptual developmental deficits are seen as aetiological markers to R's functional vision difficulties.

Treatment: Recommended management was OVT with a support near prescription of +1.00 OD, OS.

The clinical assessment disclosed no functional vision defect.

At the conclusion of active OVT, the markers were at or better than expected. Prognosis for fixation instability to

be improved with monocular OVT on treatment procedures has been reported to be only 20%.⁵⁹ Our experience from this case and others similar is that optometry adds value to treatment technology via our holistic perspective. Additionally, diagnosis without the use of new technology would probably have led to treatment focused on a phenomenological diagnosis, i.e., convergence insufficiency, slow processing speed, and visual-motor integration dysfunction. This would have missed the basic underlying deficit in optomotor function, fixation instability.

Experience with this and similar cases has indicated that the prognosis for fixation instability significantly improves from the 20% improvement reported by Fischer⁵⁸⁻⁶⁰ when a monocular OVT approach has been used. The Getman Vision Developmental Sequence⁶¹ has yielded our best results as it initially addresses the "Where Am I" processes. Special movement pattern activities are used before the visual inspection schemata are addressed.

The calibration and recalibration of the egocentric spatial "Where Am I" maps follow specific rules.^{26,27,29,33,45-48} Repetitive self-directed visual engagement with a specific task that provides for the subject multi-sensory feedback that is fun and achievable but challenging sets the stage for

what would now be argued as diagnostically driven, sequenced therapeutic interactions.^{29, 44} To achieve these outcomes, OVT addressed a therapeutic sequence as detailed above.

Case 2:

C was a 12.7-year-old male when initially seen. His case represents a complex of defects, deficits, and dysfunctions contributing to 'reading to learn' difficulties. History revealed that C had been treated for visual difficulties from around the age of three. He was found to have myelinated nerve fibres and a visual field defect. At about age five, an intermittent right eye exotropia was noted and treated by patching the left eye. Right eye blur was apparent at the age of eight and spectacles (R -1.50, L Plano) were then introduced and the patching continued with less intensity. Ten months prior to his first interaction, C was seen for a full examination at another office. The prescription was found to be unchanged, patching was discontinued, and the lad and his parents were advised that glasses were the only treatment required. Rapid growth had made the current spectacles too small. The parents sought another opinion, new spectacles, and were concerned that the right eye was turning out more frequently and that the child

Table 3: Significant clinical findings for patient C

Significant Clinical Findings:		Date of Exam: 14/1/2009
1. Defects:	Myelinated nerve fibres = field defect. Refractive defect - R -1.25 (6/12), L +0.50 (6/6) Right amblyopia???	
2. Functional vision:	ExpressEye -	Fixation stability - ok. Binocular stability - fail. Saccadic organisation - fail.
	CountFix	Fail
	FonoFix	Intensity & Gap detection, below 50%
3. Operational organisation:	Keystone Functional Vision Profile (FVP)	
Distance	1. Vertical	Ortho
	2. Horizontal	11 Exo
	3. Flat fusion	2 balls/sometimes 4. Suppression R eye.
	4. Gross stereo	5-2
	5. Fine stereo	9 of 12
	6. Randot	positive
	7. Colour vision	- within normal limits
Near	1. Simult. Macular Percep. -	Suppress R eye
	2. Stereo	2 of 6
	3. Horizontal	Suppress (11-19 Exo with pointer)
	4. Flat fusion	2 balls (4 balls with pointer) (Sensory preferred eye - Left)

At the OVT work –up the ExpressEye procedures (Figure 5) determined that the fixation stability was within normal limits. The binocular stability was poor, and 61% of the time it was the left eye vergence posture which was off task. Saccadic organisation was poor for both pro-saccade and anti-saccade procedures. The CountFix performance was well below age expected. Two of the five procedures with the FonoFix were also below expected.

In summary, the assessment disclosed that C had defects, deficits, and dysfunctions. These were:

1. Visual field defect due to persistent myelinated nerve fibres OD
2. A basic exophoria ocular motor defect that resulted in frequent near exotropia and suppression OD

3. Anisometropia
4. Amblyopia OD
5. Optomotor and perceptual deficits were identified with binocular stability (61% BIndex), saccadic organisation in both pro-saccade and anti-saccade areas, and the subitizing performance
6. Sensory/motor binocular dysfunction where splintering had resulted in his right eye being motor preferred and the left eye sensorially preferred.

The case presentation discussed the previous treatment approaches that emphasized refractive management and passive patching or penalization of the non-amblyopic eye before 12 years of age.⁶² Two recommendations were now made regarding refractive management and OVT.⁶³⁻⁶⁶ The management of the refractive anisometropia required spectacles and contact lenses for sports. A 10-week trial of active optomotor and perceptual therapy was recommended. If the expected functional vision responses were made, then reading tasks should be more comfortable. A further 15 to 20 weeks of OVT could be expected to achieve optimal visual potential.

Post OVT: After 25 OVT sessions the selected performance markers had plateaued. At the discharge from therapy his distance visual acuity was 6/9 OD, 6/5-1 OS. The refractive and eye health status was unchanged. Prolonged cover test demonstrated that the basic exophoria was unchanged. The improved optomotor functions were objectively confirmed by Express Eye (Figure 5). The ability to compensate for the binocular defect resulted in an improved functional performance at both distance and near. We find that stereoscopic virtual space tasks provide performance assessments that are sensitive to “top down” self-organisation of functional vision capacity

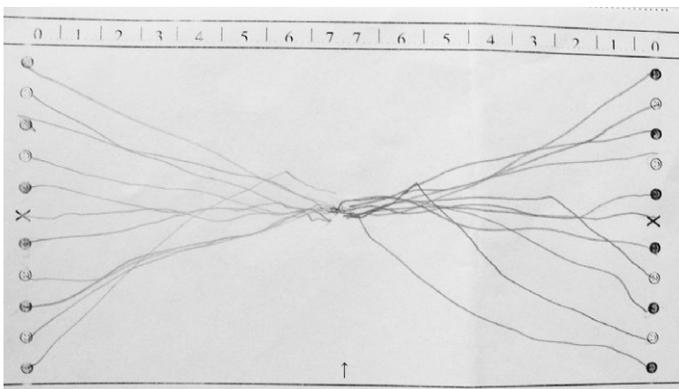


Figure 4: Intake VO Star for patient C

suffered from glare difficulties. His teacher was concerned that C was working below potential. Discussion with the child revealed that he regularly experienced eye strain and discomfort after about 10 minutes or more of reading. He tended to avoid close tasks and typically held the book close to the face when he did read. I was a third opinion and followed a traditional optometrist and an ophthalmologist.

The initial consultation (Table 3) confirmed the myelinated nerve fibres and a related field defect. The refraction showed low myopia OD with best corrected visual acuity at 6/12 and sight hyperopia OS with 6/6 visual acuity.

Diplopia was not reported when the right eye drifted. The alternating cover test disclosed 10 exophoria at distance and 18 exophoria at near. With the Sterescope far point assessment, C could achieve gross stereopsis, fine stereopsis with 9 correct, and randot stereopsis. Right eye suppression occurred with flat fusion task at both far and near. The intake VO Star (Figure 4) showed right eye was the most stable during this hand/eye task.

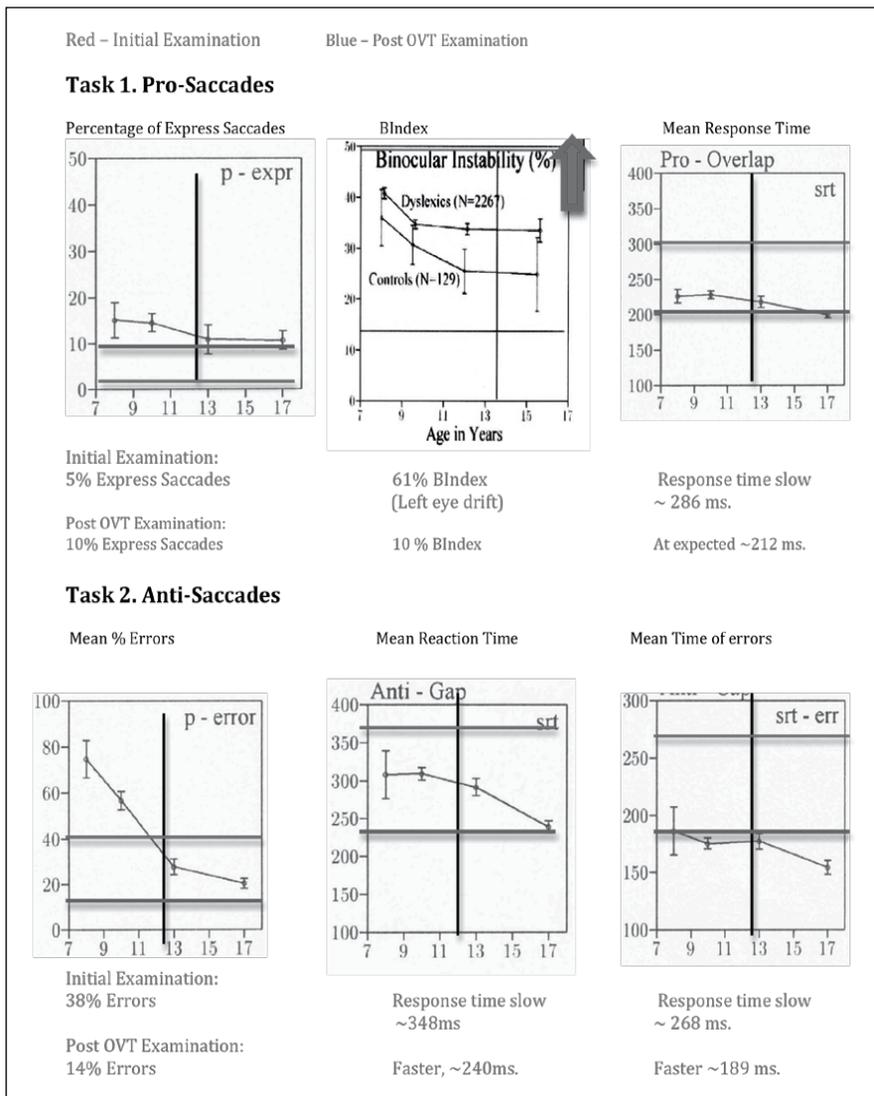


Figure 5: Before and After ExpressEye Results for patient C

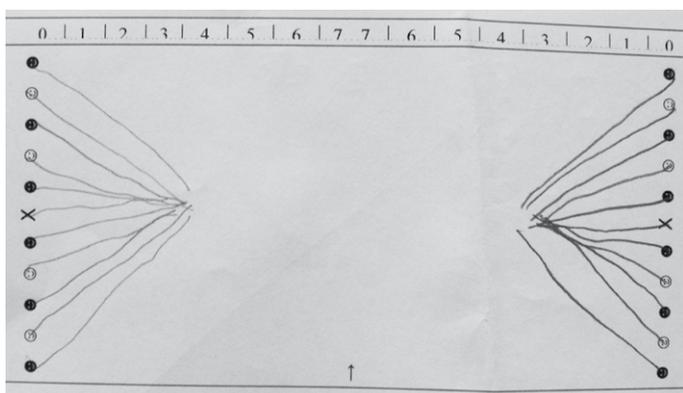


Figure 6: Discharge VO Star for patient C.

and dysfunction modification. Developmental milestones on these tasks, called visual projection, were reported by Gesell et al.⁶⁷ The series of cards^b that previously elicited right eye suppression responses was repeated. The patient was now able to be binocularly analysed and inspect cards that were previously beyond his ability. The fixation disparity card resulted in a horizontal and vertical ortho posture at distance

and near. Flat fusion was achieved with the orthophoric three ball response to the four-ball target at both distance and near. Self-generated fusional ranges were measured with three trials for convergence and divergence at both far and near. The distance convergence fusional ranges were: a) 0 – 5; b) 0 – 24; c) 0 – 24. The distance divergence fusional ranges were: a) 0 – 12; b) 0 – 12; c) 0 – 12. The response to the fine stereopsis distance card improved from 9 correct to now getting all 12 correct. The distance VO Star improvement is shown in figure 6.

Stereoscopic assessment of self-generated near convergence fusional ranges gave: a) 0-24, b) 0-24, c) 0-24 results. The near divergence fusional ranges were: a) 0-10, b) 0-14, c) 0-24. The near fixational disparity test demonstrated a central horizontal posture to be at ortho, and the vertical posture also at ortho, whilst he was experiencing peripheral 3D on the stereo circles and blocks.

Our patient was an enthusiastic participant during his OVT delivery and a pleasure to assist. Attitudes that would contribute to his eventual success were reflected while conducting his therapy. These included a high motivation to succeed and to continually meet or better a previous personal best. He demonstrated quick up-take on motor learning tasks and willingness to comply with recommendations and to engage in regular practice. Maintenance activities were assigned for twice weekly practice and included

chiastopic (crossed) fusion tasks, with and without stereopsis, to retain his capacity to compensate for the high exophoria. Future follow-up evaluations will determine the stability and endurance of his new level of voluntary binocular motor control.

This case has been selected to represent the reading to learn/binocular instability group. It demonstrates the benefits of deficit analysis in the diagnostic work-up and with aspects of the treatment. The limits of a monocular OVT strategy and with addressing only the markers of basic optomotor and perception with such cases should be noted.

This case illustrates the limitations of using only monocular occlusion and refractive compensation. Active care for the treatable binocular coordination and optomotor deficits was apparently not considered because this was not discussed. Objective assessment shows that optometric binocular vision therapy moved this case from a BIndex of 61% to 10% at discharge, a level that is better than normally expected for his age-matched peers.

The quality of life questionnaire and performance assessments support the contention that the functional vision improvements have been transferred to general operations. The

OVT was systematically delivered to C and his individualised curriculum-incorporated multiple biofeedback opportunities, routine self-analysis of his own performance, and self-correction. Improved performance was recognised and measured achievement beyond his previous personal best was celebrated.

Discussion

New technology provides quantitative data on fixation accuracy and stability, binocular stability, saccadic response time to stimuli, motor control accuracy during saccadic movements, and the self-correction patterns that have not been readily available in the past. Data analysis of key performance markers reflects on the neural network organisation available for each of these processes. We now have the capacity to objectively diagnose neuro-developmental deficits in basic optomotor and perceptual abilities.

As we gain experience with the applications of these procedures, greater respect for the basic developmental aspects of visual inspection has occurred. This technology has extensive laboratory research to support it and is often used in Europe. It should not be considered experimental for this population. Basic optomotor and perceptual processes can now be regularly monitored during the early stages of therapy delivery. If a patient fails to improve as expected, this can be recognised early and the possibility of an undetected defect considered. For the greatest majority we need to know when they have improved to meet age expected performance or have reached a plateau so the task demand level can be reset or another more appropriate task assigned. Additionally, with the management of functional vision problems that affect when we read to learn, we now initially establish that the adequacy of basic optomotor and perceptual factors are appropriate before addressing higher order visual inspection and visuo-cognitive operations.

Paradigm Shifts

Research has advanced on the visual aspects of dyslexia, basic optomotor and perceptual developmental milestones, the diagnosis of deficits, treatment efficacy, and the transfer of functional vision improvement to related educational areas.⁵⁰ This provides a game changer for all who work in this area. The traditional healthy eyes, clear sight, no defect perspective is an appropriate and necessary beginning but is no longer sufficient. The public and professionals alike need a paradigm shift to move from the defect model of vision to a vision function/functional vision model.⁶⁸⁻⁷¹

With the realisation that efficient functional vision depends on assessment and management of defects, deficits, and dysfunctions, there will come the understanding that the neuro-developmental status can be as critical to successful patient outcomes as are healthy eyes and clear sight. To know how well the person can use their vision for various aspects of their perceptual and cognitive operations must also be considered.

Behavioural optometry grew from the defect orientation to include a behaviourist approach where the clinical focus was extended to observed aspects of visually-directed behaviour. The brain, at that time, was poorly understood and thus treated as a black box. This resulted in a 'symptoms/performance' perspective for the diagnosis of visual dysfunction. Until recently, the basic optomotor and perceptual deficits were not able to be diagnosed clinically. Indeed the express saccade in man was not noted until 1984.^{72,73} A shift in perspective and assessment strategies is required to accommodate the clinical opportunities that neuroscience now provides. The evidence-based diagnosis of any basic deficit present provides an understanding of the neuro-developmental status so that a rehabilitative approach can be planned with due consideration of neuroplasticity principles. We can then sequentially deliver approaches to address any defects, deficits, and dysfunctions. Research supports diagnosis and treatment of functional vision disorders by OVT. Best outcome results are typically achieved when therapy is provided by a skilled therapist in the context of an in-office program. A home-based vision therapy approach, computer aided home therapy, or a combination of both has not been shown to be as efficacious.^{74,75}

Co-morbidity

Conditions that exist simultaneously with, but are independent of, basic optomotor and perceptual deficits, are referred to as co-morbid. Visual, neurological, and genetic defects that affect performance, learning, and self-concepts become risk factors for the neuro-development of efficient functional vision. Defects, however, may be associated with, but independent of, functional vision deficits and dysfunctions.

The clinical management of basic neuro-developmental deficits in functional vision is complicated when they are co-morbid with other performance-limiting conditions. Research has shown that basic optomotor and perceptual deficits are able to be objectively diagnosed and can be successfully treated even when co-morbid with dyslexia, attention deficit disorder/attention deficit hyperactivity disorder (ADHD), or general learning difficulties, and that successful treatment outcomes transfer to related educational quality of life outcomes. While the neural basis of reading⁷⁶ and visual aspects that are commonly associated with dyslexia have been progressively detailed,⁵³ the precise biological causes of Specific Learning Disability (SLD) – Dyslexia are complex and evade consensus. Current information supports a multidisciplinary approach where:

- A. Early pre-school neuro-developmental guidance reduces the impact as environmental factors can influence genetic expression and performance outcomes. School readiness emerges from the acquisition of many basic schemata. The visual aspects of school readiness are too important to be left to chance.

- B. Intensive schooling must be the basis of any care for the child with SLD – Dyslexia. Educational outcomes are typically most effective when a specialised, highly structured, multi-sensory language therapy, such as the Orton-Gillingham program, is used.
- C. Factors limiting access to the curriculum are improved. Research shows that treatable functional vision deficits can co-exist with other defects such as SLD – Dyslexia. Indeed about 40% of children with dyslexia have been found to exhibit treatable developmental optomotor and/or perceptual deficits.^{33,42} Most functional vision deficits can be effectively diagnosed and then usually successfully treated with up to 86% of subjects responding positively.³³

The visual aspects that are commonly associated with dyslexia have been detailed⁵³ and about 40% of children with dyslexia could be expected to exhibit treatable, developmental optomotor and/or perceptual deficits.^{33,53} OVT for basic optomotor and perceptual deficits and functional vision dysfunctions must not be considered as treatment for any co-existing defect conditions, however.

A neuro-developmental perspective assists the understanding of how vision therapy can be an applicable treatment for a child presenting with a defect diagnosis such as dyslexia, ADHD, cerebral palsy, and fragile X syndrome. Subjects with visual defects such as a significant refractive anomaly often require management that includes spectacles, but this in and of itself would not be considered as treatment for coexisting defects. Similarly, OVT can be recommended for individuals with treatable optomotor and perceptual deficits and/or vision dysfunctions when they are co-occurring with a defect diagnosis.

Neural network building and rehabilitation treatment uses regular progress measurements to verify progress and as a strategy that fosters self-directed engagement. An appropriate, personalised sequence of instruction and Socratic-like questioning supports treatment delivery. OVT delivery is individually planned for each subject to include both bottom-up and top-down factors. The therapist guides the subject as they explore and reflect upon self-guided, visually directed experiences, response analysis of these experiences, purposeful self-correction, and problem solving to develop the synaptic organisation required to improve functional vision efficiency.

Conclusions

Research supports the efficacy of the objective assessment of key performance markers for identifying and diagnosing basic optomotor and perceptual developmental deficits. Neuro-developmental milestones for these basic processes have been established, and clinical procedures, based on this research, are used to identify responses that are developmentally atypical. Objective measurement of fixation stability, saccadic organisation, subitizing, and the auditory

spatial analysis test responses can now be completed. When the neuro-developmental status of optomotor and perceptual processes has been assessed, the clinician gains information that has previously not been available. Basic deficits can then usually be improved with functional vision efficiency becoming more comfortable.

Successful treatment of learning related functional vision deficits can be expected to improve accessibility to the educational experiences offered to the patient. With more time on task, better attention to detail, and visual engagement, the patient is able to be involved in visually demanding tasks. The improvements in reading, spelling, arithmetic, and handwriting are changes that come after the acquisition of efficient functional vision.

The integration of neuro-developmental optomotor and perceptual assessment into a vision therapy practice is an initial challenge, but worthy of the effort. With this technology, optometry moves into measuring mind processes backed by research. These are first generation, objective neuro-developmental tools for the vision therapy practice that connect us to contemporary neural science.

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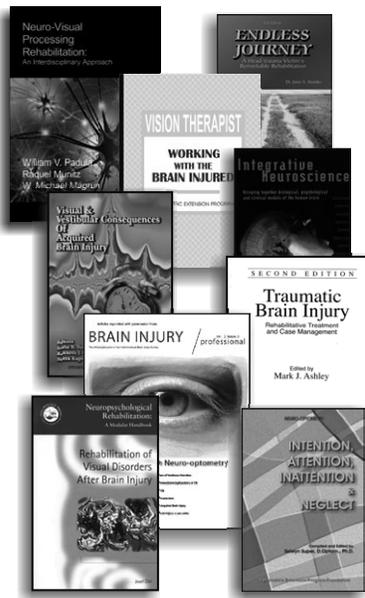
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