



A Bibliography of references relating to Behavioural Optometry Philosophy and Practise, including the use of lenses and prisms, and the efficacy of Optometric Vision Therapy in the treatment of a range of vision disorders, from the British Association of Behavioural Optometrists (BABO)

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The BABO Bibliography has been compiled from contributions from Behavioural Optometrists in the UK and USA. Source documents have been checked and references quoted accurately.

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Introduction

Behavioural optometrists assess a patient's visual skills and development within the concepts of the behavioural model of vision, which is based on the neurology of the visual systems within the brain.

Light energy entering the eye is converted into an electrical energy image in the retina which is then matched with the image from the other eye, and sent along the optical pathways. From the lateral geniculate body 80% of the fibres pass to the visual cortex at the back of the brain giving sight. The remaining 20% of the fibres do not go to the visual cortex but go to the superior colliculus where the visual information is integrated with the other sensory systems - auditory, vestibular, proprioceptive, and tactile.

Vision is not simply sight, but is the result of taking meaning from processing all sensory input and relating it to previous experience. Vision is then used to direct action both physical and mental. Vision and the direction of action takes place in at least 36 places in the cortex and thalamus. Vision is seeing with meaning, understanding and purpose, and is the dominant process in human behaviour. Behavioural Optometrists work with sight and vision.

The BABO Reference Bibliography is divided into six sections. The first section contains references that support the behavioural model and relate to vision, posture and human development

The second section begins with an introduction explaining near point stress and continues with references on the role of lenses in the management of near point stress.

The third section contains references on the behavioural use of prisms.

The fourth, fifth and sixth sections include references on the role of Optometric Vision Therapy (OVT) in vergence and accommodation disorders, oculomotor dysfunction, and strabismus and amblyopia respectively.

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1. References that support the Behavioural Model of vision and relate to vision, posture and human development

These references are drawn from journals produced by many disciplines that all support the pervasive nature of vision and vision's role in directing action.

Of head position and visual condition on balance control in inverted stance.

Asseman F, Gahery Y. *Neurosci Lett.* 2005 Feb 28;375(2):134-7.

This study analyzed the effect of head position and visual condition on the control of balance in handstand, a gymnastics posture that necessitates adaptation of sensory information processing. Five expert gymnasts participated. Centre of pressure trajectories and kinematics of different body segments were recorded. The gymnasts were instructed to maintain three handstands as long as possible in four head positions, with and without vision. Performances and postural stability was much better in the standard and dorsiflexion positions than in the aligned and ventroflexion positions under the two conditions of vision. Performances were lower without vision in the standard and dorsiflexion position. If vision clearly plays an important role, yet the tonic neck reflexes also seem to contribute greatly to control body sways during inverted posture.

Binocularity and brain evolution in primates.

Barton RA. *Proceed Nat Acad Sci USA.* 2004;101(27):10113-16.

Primates are distinguished by frontally directed, highly convergent orbits, which are associated with stereoscopic vision. Although stereoscopic vision requires specialized neural mechanisms, its implications for brain evolution are unknown. Using phylogenetic comparative analysis, I show that evolutionary increases among primate taxa in the degree of orbital convergence correlate with expansion of visual brain structures and, as a consequence, with the overall size of the brain. This pattern is found across the whole primate order and is also repeated within each of the two major primate subtaxa. The visual expansion associated with increased binocularity is specific to the parvocellular visual pathway, consistent with recent evidence implicating this pathway in fine-grained stereopsis. The results support the hypothesis that brain size evolution in primates was associated with visual specialization.

The functional role of central and peripheral vision in the control of posture.

Berencsi A, Ishihara M, Imanaka K. *Hum Mov Sci.* 2005 Oct-Dec;24(5-6):689-709

Three experiments were conducted to investigate the role of central and peripheral vision (CV and PV) in postural control. In Experiment 1, either the central or peripheral visual field were selectively stimulated using a circular random dot pattern that was either static or alternated at 5 Hz. Center of foot pressure (CoP) was used to examine postural sway during quiet standing under both CV and PV conditions. The results showed that, when the visual stimulus was presented in the periphery, the CoP area decreased and more so in the anterior-posterior (AP) than in the medio-lateral (ML) direction, indicating a characteristic directional specificity. There was no significant difference between the static and dynamic (alternating) conditions. Experiment 2 investigated the directional specificity of body sway found in Experiment 1 by having the trunk either be faced toward the stimulus display or perpendicularly to it, with the head always facing the display. The results showed that the stabilizing effect of peripheral vision was present in the direction of stimulus observation (i.e., the head/gaze direction), irrespective of trunk orientation. This suggested that head/gaze direction toward the stimulus presentation, rather than a biomechanical factor like greater mobility of the ankle joint in AP direction than in ML direction, was essential to postural stability. Experiment 3 further

examined whether the stabilizing effect of peripheral vision found in Experiments 1 and 2 was caused because more dots (500) were presented as visual cues to the peripheral visual field than to the central visual field (20 dots) by presenting the same number of dots (20) in both conditions. It was found that, in spite of the equal number of dots, the postural sway amplitudes were larger for the central vision conditions than for the peripheral vision conditions. In conclusion, the present study showed that peripheral rather than central vision contributes to maintaining a stable standing posture, with postural sway being influenced more in the direction of stimulus observation, or head/gaze direction, than in the direction of trunk orientation, which suggests that peripheral vision operates primarily in a viewer-centered frame of reference characterized by the head/gaze direction rather than in a body-centered frame of reference characterized by the anatomical planes of the body.

Rapid plasticity of binocular connections in developing monkey visual cortex (V1)

Bin Zhang, Hua Bi, Eiichi Sakai*, Ichiro Maruko*, Jianghe Zheng, Earl L. Smith III, and Yuzo M. Chino PNAS 2005;102:9026-9031;

The basic sets of cortical connections are present at birth in the primate visual system. The maintenance and refinement of these innate connections are highly dependent on normal visual experience and prolonged exposure to binocularly uncorrelated signals early in life severely disrupts the normal development of binocular functions. However, very little is known about how rapidly these changes in the functional organization of primate visual cortex emerge or what are the sequence and the nature of the abnormal neural events that occur immediately after experiencing binocular decorrelation. In this study, we investigated how brief periods of ocular misalignment (strabismus) at the height of the critical period alter the cortical circuits that support binocular vision. After only 3 days of optically imposed strabismus, there was a striking increase in the prevalence of V1 neurons that exhibited binocular suppression, i.e., binocular responses were weaker than monocular responses. However the sensitivity of these neurons to interocular spatial phase disparity was not significantly altered. These contrasting results suggest that the first significant change in V1 caused by early binocular decorrelation is binocular suppression and that this suppression originates at a site

Evidence for a role of action in colour perception.

Bompas A, O'Regan JK. Perception. 2006;35(1):65-78

Action is not usually considered to play a role in colour perception. However, sensorimotor theories of perception (eg O'Regan and Noe, 2001 Behavior and Brain Science 24 939-1011) suggest that, on the contrary, the transformations created by action in the sensory input are a necessary condition for all perception. In the case of colour vision, eye movements may explain how a retina with significant irregularities in resolution and cone arrangement (Roorda and Williams, 1999 Nature 397 520-522) could permit the perception of a richly coloured world (Clark and O'Regan, 2000 15th International Conference on Pattern Recognition volume 2: Pattern Recognition and Neural Networks pp 503-506; Skaff et al, 2002 16th International Conference on Pattern Recognition volume 2, pp 681-684). We provide evidence that perception of colour is modified when an artificial coupling is introduced linking eye movements and colour changes. After 40 min of wearing left-field-blue/right-field-yellow spectacles, observers' colour vision adapts so that, after removing the spectacles, white patches seem to become bluer when the eyes move rightwards and yellower when the eyes move leftwards. This induced dependence of colour perception on the direction of eye saccade is shown to be related to the amount of eye movements during exposure. This result, which cannot be explained either by retinal adaptation, or by a conditioned association between colour and side, constitutes first clear evidence for a role of eye movements in perceived colour and argues for the involvement in colour perception of neural mechanisms continuously tuned to sensorimotor contingencies

Children with low motor ability have lower visual-motor integration ability but unaffected perceptual skills.

Bonifacci P. Hum Mov Sci 2004 Sep;23(2):157-68.

The purpose of this study was to examine perceptual, visual-motor abilities and intellectual skills in children with low, average and above average motor abilities. The participants were 144 children (aged 6-10 years) attending elementary school. Three groups of children were identified on the basis of their performance at the TGMD (Test of Gross Motor Development; [Ulrich, D.A. (1985). TGMD, Test of Gross Motor Development. Austin, Texas: PRO-ED. Edizione Italiana a cura di D. Ianes, TEST TGM. Test di valutazione delle abilità grosso-motorie. 1994, Trento: Edizioni Centro Studi Erickson]). Each child received an intelligence test (K-BIT; [Kaufman, A.S., & Kaufman, N.L. (1990). K-BIT. Kaufman Brief Intelligence Test. Circle Pines, MN: American Guidance Service]) and was evaluated for perceptual and visual-motor integration abilities (DTVP; [Hammill, D.D., Pearson, N.A., & Voress, J.K. (1993). Developmental Test of Visual Perception (2nd ed.). Austin, Texas: PRO-ED. Edizione Italiana a cura di D. Ianes, TEST TPV. Test di percezione visiva e integrazione visuo-motoria. Trento: Edizioni Centro Studi Erickson]). Results highlight a significant difference in visual-motor integration between children with high and low gross-motor abilities, in the absence of significant differences in perceptual skills or intellectual ability. The findings are discussed with reference to the concept of atypical brain development [Gilger, J.W., & Kaplan, B.J. (2001). Atypical brain development: A conceptual framework for understanding developmental learning disabilities. *Developmental Neuropsychology*, 20, 465].

Two eyes in action.

Brenner E, Smeets JB. Exp Brain Res. 2006 Apr;170(3):302-11

Do relative binocular disparities guide our movements in depth? In order to find out we asked subjects to move a 'cursor' to a target within a simulated horizontal plane at eye height. They did so by moving a computer mouse. We determined how quickly subjects responded to the target jumping in depth. We found that it took subjects about 200 ms to respond to changes in binocular disparity. Subjects responded just as quickly if the cursor was temporarily only visible to one eye near the time that the target jumped in depth, and less vigorously, though just as quickly, if the cursor jumped rather than the target, so the fastest binocular responses cannot be based directly on the relative retinal disparity between the target and the cursor. Subjects reacted faster to changes in the target's height in the visual field than to changes in binocular disparity, but did not react faster to changes in image size. These results suggest that binocular vision mainly improves people's everyday movements by giving them a better sense of the distances of relevant objects, rather than by relative retinal disparities being used to directly guide the movement. We propose that relative disparities only guide parts of very slow movements that require extreme precision.

Latent nystagmus: vestibular nystagmus with a twist.

Brodsky MC, Tusa RJ. Arch Ophthalmol 20.04;122(2):202-9

Background: Latent nystagmus is a horizontal binocular oscillation that is evoked by unequal visual input to the 2 eyes. It develops primarily in humans with congenital esotropia.

Objective: To investigate the interrelationship between latent and peripheral vestibular nystagmus and their corollary neuroanatomical pathways.

Methods: Examination of subcortical neuroanatomical pathways producing latent nystagmus and review of the neurophysiological mechanisms by which they become activated in congenital esotropia.

Results: The vestibular nucleus presides over motion input from the eyes and labyrinths. Latent nystagmus corresponds to the optokinetic component of ocular rotation that is driven monocularly by nasal optic flow during a turning movement of the body in lateral-eyed animals. Congenital esotropia alters visual pathway development from the visual cortex to subcortical centers that project to the vestibular nucleus, allowing this primitive subcortical

motion detection system to generate latent nystagmus under conditions of monocular fixation. **Conclusions:** Latent nystagmus is the ocular counterpart of peripheral vestibular nystagmus. Its clinical expression in humans proclaims the evolutionary function of the eyes as sensory balance organs.

Adults with dyslexia show deficits on spatial frequency doubling and visual attention tasks.

Buchholz J, McKone E. *Dyslexia* 2004 Feb;10(1):24-43.

The authors examine the visual processing of high-functioning adults with developmental dyslexia (mean Performance IQ = 126.5) and current phonological problems. In comparison to an age- and IQ-matched control group, the group with dyslexia showed deficits in two tasks associated with magnocellular/dorsal pathway function. For the 'frequency doubling' stimulus (grating of 0.25 cpd modulated at 25 Hz counterphase flicker), contrast thresholds for detection were raised in the dyslexic group. In conjunction visual search, a display time sufficient for controls to achieve ceiling accuracy at all set sizes (30 ms per item) was inadequate to allow shifts of attention around the display for the group with dyslexia. In contrast, normal performance was found on 'popout' visual search and on a ventral stream acuity task. Correlational analysis revealed a significant relationship between degree of deficit in conjunction search and phonological difficulty. The deficits revealed were specific to functions that rely on magnocellular input. They cannot be attributed to concentration lapses, eye movement problems or slow reaction times in the dyslexic group.

Effects of Optically Imposed Astigmatism on Emmetropization in Infant Monkeys

Chea-Su Kee, Li-Fang Hung, Ying Qiao-Grider, Austin Roorda, and Earl L. Smith III
Investigative Ophthalmology & Visual Science, June 2004, Vol. 45, No. 6

Purpose: Although astigmatism is prevalent during early infancy, the influence of astigmatism on early refractive development is unclear. This study was undertaken to determine the effects of astigmatism on emmetropization in monkeys.

Methods: Infant rhesus monkeys ($n = 39$) were exposed to optically simulated astigmatism in one or both eyes from approximately 1 to 4 months of age. With-the-rule, against-the-rule, and oblique astigmatisms were optically simulated by appropriately orienting the principal meridians of the spherocylindrical treatment lenses (-1.50 to -3.00 D @ 90° , 180° , 45° , or 135° ; i.e., -1.50 and -1.50 D powers in the two principal meridians). Refractive development was assessed every 2 to 3 weeks by cycloplegic retinoscopy, keratometry and corneal videotopography, and A-scan ultrasonography. Data from 19 control monkeys, including 3 animals that were reared with binocular plano lenses, were used for comparison purposes.

Results: Most of the cylinder-lens-reared monkeys, regardless of the orientation of the imposed astigmatism, showed clear signs of either hyperopic or myopic growth compared with control monkeys. The distributions of refractive error and vitreous chamber depth both showed bimodal patterns that differed from normal by amounts equivalent to the optical powers of the principal meridians of the treatment lenses. More frequently, refractive development was biased toward the eye's least-hyperopic focal plane. The refractive changes were mainly axial. After lens removal, the lens-reared monkeys recovered and as a group exhibited refractive errors and axial dimensions similar to those in control monkeys.

Conclusions: In the presence of significant amounts of astigmatism, emmetropization is directed toward one of the two focal planes associated with the astigmatic principal meridians and not the circle of least confusion. These results suggest that the mechanisms responsible for emmetropization are insensitive to stimulus orientation and the global form of the retinal image. It appears that emmetropization seeks out the image plane that contains the maximum effective contrast integrated across spatial frequency and stimulus orientation.

Specialization within the ventral stream: the case for the visual word form area.

Cohen L, Dehaene S. *Neuroimage* 2004 May;22(1):466-76.

Is there specialization for visual word recognition within the visual ventral stream of literate human adults? The authors review the evidence for a specialized “visual word form area” and critically examine some of the arguments recently placed against this hypothesis. Three distinct forms of specialization must be distinguished: functional specialization, reproducible localization, and regional selectivity. Examination of the literature with this theoretical division in mind indicates that reading activates a precise subpart of the left ventral occipitotemporal sulcus, and that patients with pure alexia consistently exhibit lesions of this region (reproducible localization). Second, this region implements processes adequate for reading in a specific script, such as invariance across upper- and lower-case letters, and its lesion results in the selective loss of reading-specific processes (functional specialization). Third, the issue of regional selectivity, namely, the existence of putative cortical patches dedicated to letter and word recognition, cannot be resolved by positron emission tomography or lesion data, but requires high-resolution neuroimaging techniques. The available evidence from single-subject fMRI and intracranial recordings suggests that some cortical sites respond preferentially to letter strings than to other categories of visual stimuli such as faces or objects, though the preference is often relative rather than absolute. The authors conclude that learning to read results in the progressive development of an inferotemporal region increasingly responsive to visual words, which is aptly named the visual word form area (VWFA).

Temporal processing in poor adult readers.

Conlon E, Sanders M, Zapart S. *Neuropsychologia* 2004;42(2):142-57.

The aim of this study was to investigate the relationships between two different temporal processing tasks and word identification performance in skilled, dyslexic and poor adult readers. In Experiment 1 spatial and temporal sequencing tasks were conducted. It was found that adult dyslexics were significantly less accurate than skilled readers across all conditions in the temporal sequencing task, and when higher numbers of stimuli were presented in the spatial task. Experiment 2 replicated Experiment 1 in the temporal sequencing task and also found that poor readers had significantly higher motion coherence thresholds than those found in the skilled reader group. Ten percent of the variance in coherence thresholds was accounted for by performance on the temporal sequencing task. Multiple regression analyses determined that performance on the two temporal tasks could explain seventy percent of the variance in word identification scores, with the temporal sequencing task making the larger independent contribution. Experiment 3 replicated the findings of Experiment 2, while taking into account IQ, verbal memory and processing speed. Three things were concluded. First, the temporal tasks measure different aspects of temporal processing. The contribution to performance of higher-level perceptual and attentional components of the temporal sequencing task accounts for the relatively weak correlation found between the two measures. While sensory sensitivity to motion is measured at MT, the involvement of this area and PPC in higher-level perceptual and attentional processes is suggested by the findings of this study. Second, the association between temporal sequencing and reading skills may provide a stronger link between neural processing and poor reading skills than basic sensory processing measures alone, suggesting that a sensory magnocellular (M) system deficit cannot fully explain the relationship found between reading and visual neural processing. Third, problems with rapid sequential processing are predicted to be a generalised problem in poor adult readers, whether they are formally classified as dyslexic, or are poor performers on measures of word identification. Temporal processing may follow a distribution similar to that found for word identification skills.

The neurobiology of blindsight

Cowey A.^a, Stoerig^b Trends in Neurosciences 1991 14(4) 140-145

Some patients can respond to visual stimuli presented within their clinically absolute visual field defects that have been caused by partial destruction of striate cortex. This puzzling phenomenon of looking, pointing, detecting and discriminating without seeing has been called blindsight, and has fascinated philosophers and neuroscientists alike as a spotlight on the nature of unconscious or covert awareness, and the means it provides of studying the visual information carried by pathways other than the major route through the striate cortex.

The superior colliculus is located on the dorsal surface of the brain stem. Unconscious visual input goes directly from the retina to the colliculus, and therefore implicates this neural tissue in navigational processing (related to the peripheral "where" retina).

Output from the superior colliculus goes to motor centers responsible for orienting behaviors. Orienting behaviors are immediate, rapid organism responses (reflexes), usually to movement. A dark spot moving at a given speed across a frog retina causes the frog to flick its tongue outward to snag the fly. A large shadow across the frog retina causes the amphibian to jump into the water and dive for cover. These are brain stem level, automatic behaviors caused by reflex patterns governed by the superior colliculus.

In higher animals the cerebral centers analyze input in association with (or before) the superior colliculus. In primates the colliculus controls the automatic saccades that put the retina in position to analyze sudden movements across the retina.

In surgical cases where the corpus callosum has been severed, the lower brain commissures often are not cut. Important, lower level (subconscious) visual processing systems, primarily the superior colliculus and hippocampal areas have commissures that connect the two sides of the brain. When these are not severed, there remains significant hemisphere crossover.

This helps explain why patients still have good mobility skills after cutting the corpus callosum. It also helps explain why cortically blinded individuals have "blind sight", why they are able to avoid obstacles and move about even though they have no conscious awareness of this "sight."

What we know of functional neurology leads us to believe that blind sight occurs via a secondary visual pathway that branches off the optic tract to enter the superior colliculus. This area of the midbrain appears to be involved in monitoring peripheral vision and orienting attention toward novel stimuli.

Cognitive vision, its disorders and differential diagnosis in adults and children: knowing where and what things are.

Dutton GN Eye. 2003 Apr;17(3):289-304.

As ophthalmologists we need a basic model of how the higher visual system works and its common disorders. This presentation aims to provide an outline of such a model. Our ability to survey a visual scene, locate and recognise an object of interest, move towards it and pick it up, recruits a number of complex cognitive higher visual pathways, all of which are susceptible to damage. The visual map in the mind needs to be co-located with reality and is primarily plotted by the posterior parietal lobes, which interact with the frontal lobes to choose the object of interest. Neck and extraocular muscle proprioceptors are probably responsible for maintaining this co-location when the head and eyes move with respect to the body, and synchronous input from both eyes is needed for correct localisation of moving targets.

Recognition of what is being looked at is brought about by comparing the visual input with the "image libraries" in the temporal lobes. Once an object is recognised, its choice is mediated by parietal and frontal lobe tissue. The parietal lobes determine the visual coordinates and plan the visually guided movement of the limbs to pick it up, and the frontal lobes participate in making the choice. The connection between the occipital lobes and the parietal lobes is known as the dorsal stream, and the connection between the occipital lobes and the temporal lobes, comprises the ventral stream. Both disorders of neck and extraocular muscle proprioception, and disorders leading to asynchronous input along the two optic nerves are "peripheral" causes of impaired visually guided movement, while bilateral damage to the parietal lobes can result in central impairment of visually guided movement, or optic ataxia. Damage to the temporal lobes can result in impaired recognition, problems with route finding

and poor visual memory. Spontaneous activity in the temporal lobes can result in formed visual hallucinations, in patients with impaired central visual function, particularly the elderly. Deficits in cognitive visual function can occur in different combinations in both children and adults depending on the nature and distribution of the underlying brain damage. In young children the potential for recovery can lead to significant improvement in parietal lobe function with time. Patients with these disorders need an understanding of their deficits and a structured positive approach to their rehabilitation.

Peripheral Vision Can Influence Eye Growth and Refractive Development in Infant Monkeys

Earl L. Smith III, Chea-su Kee, Ramkumar Ramamirtham, Ying Qiao-Grider, Li-Fang Hung Investigative Ophthalmology & Visual Science, November 2005, Vol. 46, No. 11

PURPOSE. Given the prominence of central vision in humans, it has been assumed that visual signals from the fovea dominate emmetropization. The purpose of this study was to examine the impact of peripheral vision on emmetropization.

Methods: Bilateral, peripheral form deprivation was produced in 12 infant monkeys by rearing them with diffusers that had

either 4- or 8-mm apertures centered on the pupils of each eye, to allow 24° or 37° of unrestricted central vision, respectively. At the end of the lens-rearing period, an argon laser was used to ablate the fovea in one eye of each of seven monkeys. Subsequently, all the animals were allowed unrestricted vision. Refractive error and axial dimensions were measured along the pupillary axis by retinoscopy and A-scan ultrasonography, respectively. Control data were obtained from 21 normal monkeys and 3 infants reared with binocular plano lenses.

Results: Nine of the 12 treated monkeys had refractive errors that fell outside the 10th- and 90th-percentile limits for the age-matched control subjects, and the average refractive error for the treated animals was more variable and significantly less hyperopic/more myopic (-0.03 ± 2.39 D vs. 2.39 ± 0.92 D). The refractive changes were symmetric in the two eyes of a given animal and axial in nature. After lens removal, all the treated monkeys recovered from the induced refractive errors. No interocular differences in the recovery process were observed in the animals with monocular foveal lesions.

Conclusions: On the one hand, the peripheral retina can contribute to emmetropizing responses and to ametropias produced by an abnormal visual experience. On the other hand, unrestricted central vision is not sufficient to ensure normal refractive development, and the fovea is not essential for emmetropizing responses.

Tilt and reading speed.

Firth AY, Machin J, Watkins CL. J AAPOS. 2007 Feb;11(1):52-4

Purpose: To measure the effect of head tilt on reading rate and to determine whether a difference existed between the body or the text being tilted.

Methods: The Wilkins Rate of Reading Test was used to measure rate of reading in a population of normal readers. In the first part of the study, rate of reading with a head tilt of 15 degrees and 30 degrees was measured; in the second part of the study, rate of reading with a body tilt of 45 degrees and 90 degrees or a text tilt of 45 degrees and 90 degrees was measured.

Results: For the first experiment, 30 participants, with a mean age 20.3 years, showed no effect on reading speed with a head tilt of 15 degrees or 30 degrees. In the second experiment, 20 participants, with mean age of 19.75 years, showed significantly slowed rate of reading when text was tilted to 45 degrees and 90 degrees (by a mean of 19 and 36 words per minute, respectively), and when reading while lying horizontally (90 degrees) with text upright (mean reduction of 34 words per minute). With a body tilt of 45 degrees, the effect on reading rate (mean reduction of 15 words per minute) just failed to reach significance ($p = 0.058$).

Conclusions: When text is tilted in relation to the body, by tilting either the text or the body, reading speed is affected. The effect of tilt on word recognition is discussed as a cause of the observed test results.

Is the perception of brightness different in poor readers?

Floyd RA, Dain SJ, Elliott RT. *Vision Res.* 2004 Jan;44(2):221-7.

The transient system deficit hypothesis (TSDH) of specific reading disability [Percept. Psychophys. 40 (1986) 440] remains contentious. As part of a study examining multiple measures of transient and sustained system function, heterochromatic flicker matching (HFM) and brightness matching (HBM) were assessed in 30 poor readers (9.110.68 years) and 30 age, grade and sex matched controls (9.240.73 years). HBM and HFM are known to reflect the processing of brightness and luminance information and have been related to the function of magnocellular and parvocellular visual sub-systems. Flicker and brightness matches were determined for blue, green, yellow and red stimuli on Macintosh colour displays using 2AFC and double interleaved random staircases. A ratio of the luminances for brightness and flicker matches represented performance. A significant difference between controls and poor readers in performance for red and blue stimuli was found indicating different visual function in poor readers. While not providing direct support for the transient system deficit hypothesis, this effect implies a mismatch between those achromatic systems that subservise HFM and those more complex mechanisms involved in HBM. The most important aspect of this finding is that poor readers and normal controls could be differentiated on the basis of a paradigm known to be contingent upon magnocellular and parvocellular functioning.

The utility of math difficulties, internalized psychopathology, and visual-spatial deficits to identify children with the nonverbal learning disability syndrome: evidence for a visuospatial disability.

Forrest BJ. *Neuropsychol Dev Cogn C Child Neuropsychol* 2004 Jun;10(2):129-46.

This study examined the criteria currently employed to identify children with the nonverbal learning disability syndrome (NVLD). The most widely accepted definition of NVLD relies on deficits in visual-spatial-organizational, tactile-perceptual, psychomotor, and nonverbal problem-solving skills. These deficits are believed to coexist with strengths in rote verbal learning, phoneme-grapheme matching, verbal output, and verbal classification. The combination of these assets and deficits has been hypothesized to lead to psychosocial and academic problems, including difficulties with mathematics and increased rates of psychopathology. This study compared performance of three groups of children: those with NVLD, those with verbal learning disabilities (VLD), and controls. The results show that the criteria currently employed to identify children with NVLD may not adequately differentiate them. In contrast to previous findings, the study reveals that children with NVLD can demonstrate good math abilities when performing certain types of math tasks, especially those that draw on their robust verbal skills. Also in contrast to most previous findings, in this study children with NVLD (and normal controls) demonstrated lower rates of psychopathology than children with VLD. Finally, for children with NVLD it appears that their visual-perceptual deficits may include a primary deficit in locating objects in space. Based in part on the findings of this study, it may be helpful for diagnostic and treatment purposes to reserve the term Nonverbal Learning Disability for children whose visual-spatial deficits are primary and severe enough to affect academic performance in subjects such as written mathematics. Given the integral nature of social relations in children's lives, a separate category (e.g., social processing disorder) could be created for children whose social skills deficits are primary and impair their social interactions. A broader nonverbal learning model or syndrome, as conceptualized by Rourke (1995), could be retained for describing a broader constellation of assets and deficits across disease types.

Reaching and grasping with restricted peripheral vision.

Gonzalez-Alvarez C, Subramanian A, Pardhan S. *Ophthalmic Physiol Opt.* 2007 May;27(3):265-74

Aim: To investigate how prehensile movements, such as reaching and grasping, are affected by different fields of view when both haptic and visual information are available. **Methods:** Ten volunteers with normal vision (mean age 24.5 years) participated. Subjects picked up an object with a full monocular field of view (FOV) and with two different sizes of pinholes which simulated a central FOV of 23 degrees and 11 degrees respectively. The Vicon motion analysis system was used to record and reconstruct the 3D-kinematic data. The kinematic parameters measured were total time of the movement, maximum velocity, time to maximum velocity, deceleration time, maximum grip aperture, time to maximum grip aperture and time taken after maximum grip aperture.

Results: Restricting the FOV affected both the transport and grasp components of the movement. The maximum velocity decreased ($p = 0.008$) and the maximum grip aperture increased ($p = 0.003$) with both restricted FOV when compared with the full field. The execution or on-line control of both reach and grasp components were also longer ($p = 0.005$ and $p = 0.002$ respectively) for the 11 degrees FOV only.

Conclusions: Reducing the FOV to 11 degrees (an absence of peripheral vision) affects the planning and execution of the reach and the grasp component of the movement. Restricting the FOV to 23 degrees of central vision (with some peripheral cues present) affects only the planning of the reach and grasp component of the movement. Peripheral visual cues are therefore more important for the on-line control than for the planning of the movement. The findings of this study have important clinical implications in patients who suffer from ocular diseases in which peripheral vision gradually decreases.

Visual Skills And Intellectual Development: A Relationship In Young Children.

Gottfried A. W., Gilman G. *Journal Of The American Optometric Association*, 56(7):550- 555, July, 1985.

The development of convergence, ocular motilities; stereopsis and form perception for infants and young children was evaluated in a previous paper. This study examines the relationship between these visual skills and intellectual development. Young children ($n = 130$) were assessed longitudinally every six months from the ages of 12- to 42-months. The results showed positive and significant correlations between visual skills and intellectual development during infancy and the preschool years. Stereopsis and form perception correlated most highly and consistently with intellectual development.

Development of stereopsis in infants and young children

Gottfried A. W., Gilman G *J Am Optom Assoc.* 1985 Nov;56(11):878-81.

A limited number of studies have been done on stereopsis performance and clinical testing of infants and young children. As optometrists increasingly begin to examine young children there arises a need to know if stereopsis is a developmentally derived skill and if so, what are the normal skill levels for each age. This study shows that stereoacuity response follows a developmental trend and provides preliminary data on levels of performance for infants (18-24 months) and young children (30-60 months).

Longitudinal motor development of "apparently normal" high-risk infants at 18 months, 3 and 5 years.

Goyen TA, Lui K. *Early Hum Dev.* 2002 Dec;70(1-2):103-15

Background: Motor development appears to be more affected by premature birth than other developmental domains, however few studies have specifically investigated the development of gross and fine motor skills in this population.

Aim: To examine longitudinal motor development in a group of "apparently normal" high-risk infants.

Setting: Developmental follow-up clinic in a perinatal centre.

Study Design: Longitudinal observational cohort study.

Subjects: Fifty-eight infants born less than 29 weeks gestation and/or 1000 g and without disabilities detected at 12 months.

Outcome Measures: Longitudinal gross and fine motor skills at 18 months, 3 and 5 years using the Peabody Developmental Motor Scales. The HOME scale provided information of the home environment as a stimulus for development.

Results: A large proportion (54% at 18 months, 47% at 3 years and 64% at 5 years) of children continued to have fine motor deficits from 18 months to 5 years. The proportion of infants with gross motor deficits significantly increased over this period (14%, 33% and 81%, $p < 0.001$), particularly for the 'micropreemies' (born < 750 g). In multivariate analyses, gross motor development was positively influenced by the quality of the home environment.

Conclusions: A large proportion of high-risk infants continued to have fine motor deficits, reflecting an underlying problem with fine motor skills. The proportion of infants with gross motor deficits significantly increased, as test demands became more challenging. In addition, the development of gross and fine motor skills appears to be influenced differently by the home environment.

Cortical regions involved in eye movements, shifts of attention, and gaze perception.

Grosbras MH, Laird AR, Paus T. *Hum Brain Mapp.* 2005 May;25(1):140-54.

Human vision is an active process that involves shifting attention across the visual scene, with or without moving the eyes. Such shifts of attention can be generated at will (endogenously) or be triggered automatically, i.e., generated in response to exogenous stimuli including socially relevant cues such as someone else's gaze. What are the common and distinct brain mechanisms involved in these processes? To address this question, we carried out a quantitative effect-location meta-analysis of 59 brain-imaging experiments whose results were published using standardized coordinates. For each condition of interest, namely voluntary and visually triggered eye movements, voluntary and visually triggered (covert) shifts of attention, and perception of someone else's gaze, we computed activation likelihood estimation (ALE) maps. Those maps represent at each voxel of the brain the probability of reporting a signal change related to the condition of interest. For eye movements, this analysis confirmed the spatial location of the frontal eye fields, supplementary eye fields, and parietal saccade-related regions. The map of covert shifts of attention demonstrated highest similarity with the map of saccadic eye movements. Gaze perception showed common activation likelihood with the other conditions in the right intraparietal sulcus and in the lateral precentral gyrus. It demonstrated more similarity with the reflexive than with the voluntary saccades and shifts of attention. We propose that a core network of frontoparietal and temporal brain regions is recruited when we shift the focus of our attention with or without eye movements in response to the appearance of a visual target, as well as when we see someone else shift his or her gaze.

The reentry hypothesis: the putative interaction of the frontal eye field, ventrolateral prefrontal cortex, and areas V4, IT for attention and eye movement.

Hamker FH. Cereb Cortex. 2005 Apr;15(4):431-47.

Attention is known to play a key role in perception, including action selection, object recognition and memory. Despite findings revealing competitive interactions among cell populations, attention remains difficult to explain. The central purpose of this paper is to link up a large number of findings in a single computational approach. Our simulation results suggest that attention can be well explained on a network level involving many areas of the brain. We argue that attention is an emergent phenomenon that arises from reentry and competitive interactions. We hypothesize that guided visual search requires the usage of an object-specific template in prefrontal cortex to sensitize V4 and IT cells whose preferred stimuli match the target template. This induces a feature-specific bias and provides guidance for eye movements. Prior to an eye movement, a spatially organized reentry from oculomotor centers, specifically the movement cells of the frontal eye field, occurs and modulates the gain of V4 and IT cells. The processes involved are elucidated by quantitatively comparing the time course of simulated neural activity with experimental data. Using visual search tasks as an example, we provide clear and empirically testable predictions for the participation of IT, V4 and the frontal eye field in attention. Finally, we explain a possible physiological mechanism that can lead to non-flat search slopes as the result of a slow, parallel discrimination process.

The reentry hypothesis: linking eye movements to visual perception.

Hamker FH. J Vis. 2003 Dec 12;3(11):808-16

Cortical organization of vision appears to be divided into perception and action. Models of vision have generally assumed that eye movements serve to select a scene for perception, so action and perception are sequential processes. We suggest a less distinct separation. According to our model, oculomotor areas responsible for planning an eye movement, such as the frontal eye field, influence perception prior to the eye movement. The activity reflecting the planning of an eye movement reenters the ventral pathway and sensitizes all cells within the movement field so the planned action determines perception. We demonstrate the performance of the computational model in a visual search task that demands an eye movement toward a target.

Eye movements in natural behavior.

Hayhoe M, Ballard D. Trends Cogn Sci. 2005 Apr;9(4):188-94..

The classic experiments of Yarbus over 50 years ago revealed that saccadic eye movements reflect cognitive processes. But it is only recently that three separate advances have greatly expanded our understanding of the intricate role of eye movements in cognitive function. The first is the demonstration of the pervasive role of the task in guiding where and when to fixate. The second has been the recognition of the role of internal reward in guiding eye and body movements, revealed especially in neurophysiological studies. The third important advance has been the theoretical developments in the fields of reinforcement learning and graphic simulation. All of these advances are proving crucial for understanding how behavioral programs control the selection of visual information.

Plasticity in Sensory-Motor Systems.

Held R. Scientific American 1965; VII Perception: Sensory-Motor Integration, Chapter 25: 259-266. Scientific Am 1965; 213(5): 1-10. VI Dev & Modification 1965; Chapter 38: 372-379. Unpublished: 70-75

An animal's own movements change what it sees and hears. Laboratory experiments that tamper with this feedback loop show that it is a key to developing and maintaining spatial orientation in advanced mammals.

Spatio-temporal brain dynamics underlying saccade execution, suppression, and error-related feedback.

Herdman AT, Ryan JD. *J Cogn Neurosci.* 2007 Mar;19(3):420-32

Human and nonhuman animal research has outlined the neural regions that support saccadic eye movements. The aim of the current work was to outline the sequence by which distinct neural regions come on-line to support goal-directed saccade execution and error-related feedback. To achieve this, we obtained behavioral responses via eye movement recordings and neural responses via magnetoencephalography (MEG), concurrently, while participants performed an antisaccade task. Neural responses were examined with respect to the onset of the saccadic eye movements. Frontal eye field and visual cortex activity distinguished subsequently successful goal-directed saccades from (correct and erroneous) reflexive saccades prior to the deployment of the eye movement. Activity in the same neural regions following the saccadic movement distinguished correct from incorrect saccadic responses. Error-related activity in the frontal eye fields preceded that from visual regions, suggesting a potential feedback network that may drive corrective eye movements. This work provides the first empirical demonstration of simultaneous remote eyetracking and MEG recording. The coupling of behavioral and neuroimaging technologies, used here to characterize dynamic brain networks underlying saccade execution and error-related feedback, demonstrates a novel within-paradigm converging evidence approach by which to outline the neural underpinnings of cognition.

The remnants of crossed fixation observed in teenaged children with esotropia.

Hirai T, Amano E, Ito T, Tsuzuki K, Sato M, Miyake Y. *Binoc Vis Strabismus Q* 004;19(2):88-94.

Purpose: To report 2 cases of teenage children with esotropia from a much earlier age, displaying remnants of crossed fixation with special reference to Helmholtz's theory that each eye is controlled independently and Hering's Law of equal innervation.

Case Reports: Case 1 had parietic and partially accommodative esotropia that was first observed at 11 months of age; and Case 2 had accommodative esotropia with an onset at age 3 years. Both cases had hypermetropia and good corrected visual acuity in both eyes. They were able to fixate independently with each eye but the dominant eye always controls their fixation and they believe they are using only their dominant eye; however, their non-dominant eye was used to viewing objects in the opposite field (crossed fixation). Both cases maintained good binocular alignment at distance with either surgery and glasses (Case 1) or glasses alone (Case 2). However, their esotropia increased through the early teenage years leading both patients to undergo surgery at this later age: Case 1 at 17 years of age and Case 2 at 19 years of age. Post-surgical Starlight testing showed that their binocular visual fields improved.

Conclusion: Crossed fixation exists in esotropia (even in acquired accommodative esotropia) and as the patient ages, one eye becomes dominant leaving the non-dominant eye to fix only in crossed gaze. These cases support Helmholtz's theory that each eye is controlled independently and that binocular coordination is learned.

Visual and auditory temporal processing and early reading development.
Hood M, Conlon E. *Dyslexia* 2004 Aug;10(3):234-52.

This study investigated the ability of temporal processing measures obtained before school entry to predict early reading development in an unselected sample of 125 children (68 males, 57 females). Visual and auditory temporal order judgment (TOJ) tasks measured at Preschool (mean age 5.36 years) significantly predicted letter and word identification (accuracy) and reading rate (fluency) in early Grade 1 (mean age 5.94 years), even after the effects of age, environment, memory, attention, nonverbal ability, and speech/language problems were accounted for. There were no significant differences in the overall variance accounted for in reading between TOJ measures taken before or after reading had emerged. Both Preschool and Grade 1 measures of auditory TOJ accounted for significant independent variance in reading. However, only visual TOJ performance measured at Grade 1 accounted for unique variance in reading rate. This was discussed in terms of developmental changes in the role of visual temporal processing as reading develops. Reliability of the temporal measures from preschool to Grade 1 was moderate. The results showed that measures of visual and auditory temporal processing obtained close to school-entry would be a useful addition to predicting risk of early reading difficulties.

Effects of color stimulation on handwriting performance of children with ADHD without and with additional learning disabilities.

Imhof M. *Eur Child Adolesc Psychiatry* 2004 Jun;13(3):191-8.

Active behavior problems in children with ADHD are often aggravated in situations which require sustained attention. Building on the 'optimal stimulation' hypothesis, this study explored the effects of color stimulation on graphomotor control in children with ADHD. A sample of 66 children with ADHD (n = 19 from primary education, n = 28 children with additional speech disorders, n = 19 children with additional learning disabilities) and matched controls participated in the investigation. Subjects performed a copying task on standard white and on colored paper in balanced order across classes. Positive effects of the color stimulation on graphomotor behavior control and, consequently, on qualitative aspects of the handwritings were expected. Results broadly confirm the predictions. Effects are explained as added external stimulation facilitating behavioral inhibition and regulation of selective attention and graphomotor coordination. Reduction of visual stress as an alternative explanation is considered.

Comparison of saccadic eye movements and facility of ocular accommodation in female volleyball players and non-players.

Jafarzadehpur E, Aazami N, Bolouri B. *Scand J Med Sci Sports.* 2007 Apr;17(2):186-90.

There is controversy on the interaction of sport exercise and visual functions. Some aspects of visual skills have been evaluated in volleyball players. Eighty-three normal females were categorized in four groups; non-players (NP), beginner volleyball players, intermediate and advanced players. Facility of accommodation and far saccade for optotypes at three distances were measured. The athletes showed better facility of accommodation and saccadic eye movement (SEM) than the non-playing control group. There was a significant difference ($P < 0.001$) between NP and beginner players with advanced players and intermediate players. There are mutual interrelations between the visual system and sensory-motor coordination of the whole body. In a "programed" activity many motor and sensorial elements interactively influence one another. The visual system, as the most important coordinator, navigates the "programed" activities. The facility of accommodation shows how fast clear vision can be accomplished. The SEM shows how fast visual system can fixate on an object. Improvement of these two parameters indicates that the visual system can change fixation very fast and clearly see a new fixation point promptly. These are the requirements for a good volleyball player; hence, we find better visual performance in advanced players than in others.

Travel vision: "collicular visual system"?

Jan JE, Wong PK, Groenveid M, Flodmark O, Hoyt CS. *Pediatr Neurol.* 1986 Nov-Dec;2(6):359-62

Two visually impaired children with occipital infarctions are presented. One patient has profound impairment of his primary visual pathway but has good vision for traveling, while the other child presented with the symptoms in reverse. We believe that these two patients provide further evidence that the primary visual pathway is used for conscious visual analysis and that the collicular visual system serves as the subconscious visual guidance for locomotion.

Transposed-letter effects in reading: evidence from eye movements and parafoveal preview.

Johnson RL, Perea M, Rayner K. *J Exp Psychol Hum Percept Perform.* 2007 Feb;33(1):209-29.

Three eye movement experiments were conducted to examine the role of letter identity and letter position during reading. Before fixating on a target word within each sentence, readers were provided with a parafoveal preview that differed in the amount of useful letter identity and letter position information it provided. In Experiments 1 and 2, previews fell into 1 of 5 conditions: (a) identical to the target word, (b) a transposition of 2 internal letters, (c) a substitution of 2 internal letters, (d) a transposition of the 2 final letters, or (e) a substitution of the 2 final letters. In Experiment 3, the authors used a further set of conditions to explore the importance of external letter positions. The findings extend previous work and demonstrate that transposed-letter effects exist in silent reading. These experiments also indicate that letter identity information can be extracted from the parafovea outside of absolute letter position from the first 5 letters of the word to the right of fixation. Finally, the results support the notion that exterior letters play important roles in visual word recognition.

The acquisition of skilled motor performance: fast and slow experience-driven changes in primary motor cortex.

Karni A, Meyer G, Rey-Hipolito C, Jezzard P, Adams MM, Turner R, Ungerleider LG. *Proc Natl Acad Sci U S A.* 1998 Feb 3;95(3):861-8.

Behavioral and neurophysiological studies suggest that skill learning can be mediated by discrete, experience-driven changes within specific neural representations subserving the performance of the trained task. We have shown that a few minutes of daily practice on a sequential finger opposition task induced large, incremental performance gains over a few weeks of training. These gains did not generalize to the contralateral hand nor to a matched sequence of identical component movements, suggesting that a lateralized representation of the learned sequence of movements evolved through practice. This interpretation was supported by functional MRI data showing that a more extensive representation of the trained sequence emerged in primary motor cortex after 3 weeks of training. The imaging data, however, also indicated important changes occurring in primary motor cortex during the initial scanning sessions, which we proposed may reflect the setting up of a task-specific motor processing routine. Here we provide behavioral and functional MRI data on experience-dependent changes induced by a limited amount of repetitions within the first imaging session. We show that this limited training experience can be sufficient to trigger performance gains that require time to become evident. We propose that skilled motor performance is acquired in several stages: "fast" learning, an initial, within-session improvement phase, followed by a period of consolidation of several hours duration, and then "slow" learning, consisting of delayed, incremental gains in performance emerging after continued practice. This time course may reflect basic mechanisms of neuronal plasticity in the adult brain that subserve the acquisition and retention of many different skills.

Learning perceptual skills: behavioural probes into adult plasticity.

Karni A, Bertini G. *Curr Opin Neurobiol.* 1997 Aug;7(4):530-5.

Recent studies of the improvement of perceptual performance as a function of training - perceptual learning - have provided new insights into the neuronal substrates of this type of skill learning in the adult brain. Issues such as where in the brain, when and under what conditions practice-related changes occur are under investigation. The results of these studies suggest that a behaviorally relevant degree of plasticity is retained in the adult cortex, even within early, low-level representations in sensory and motor processing streams. The acquisition and retention of skills may share many characteristics with the functional plasticity subserving early-life learning and development. While the specificity of learning provides localization constraints, an important clue to the nature of the underlying neuronal changes is the time course of learning.

The role of vision in the control of continuous multijoint movements.

Ketcham CJ, Dounskaia NV, Stelmach GE. *J Mot Behav.* 2006 Jan;38(1):29-44.

The authors investigated whether visual fixations during a continuous graphical task were related to arm endpoint kinematics, joint motions, or joint control. The pattern of visual fixations across various shapes and the relationship between temporal and spatial events of the moving limb and visual fixations were assessed. Participants (N=16) performed movements of varying shapes by rotating the shoulder and elbow joints in the transverse plane at a comfortable pace. Across shapes, eye movements consisted of a series of fixations, with the eyes leading the hand. Fixations were spatially related to modulation of joint motion and were temporally related to the portions of the movement where curvature was the highest. Gathering of information related to modulation of interactive torques arising from passive forces from movement of a linked system occurred when the velocity of the movement (a) was the lowest and (b) was ahead of the moving limb, suggesting that that information is used in a feedforward manner.

Scanpaths in reading and picture viewing: Computer-assisted optimization of display conditions.

Krischer CC, Zangemeister WH. *Comput Biol Med.* 2007 Jul;37(7):947-56

A review of the literature shows that in reading and picture viewing cognitive skills play a key role along with visual acuity. Optimal processing conditions are reached only with letter and object sizes that match both cognitive skills and visual acuity. Beginning readers with normal vision need larger letters than skilled readers. In reading, eye movements step the fovea, a high-acuity region 2(composite function) diameter, at the physiological pace of the visual system about 4 times per second. A simple computer-based procedure is described that determines the best acuity- and skill-matched letter (or object) sizes in the context of an optimal reading eye movement speed of 8deg/s.

Eye movements and the control of actions in everyday life.

Land MF. *Prog Retin Eye Res.* 2006 May;25(3):296-324.

The patterns of eye movement that accompany static activities such as reading have been studied since the early 1900s, but it is only since head-mounted eye trackers became available in the 1980s that it has been possible to study active tasks such as walking, driving, playing ball games and ordinary everyday activities like food preparation. This review examines the ways that vision contributes to the organization of such activities, and in particular how eye movements are used to locate the information needed by the motor system in the execution of each act. Major conclusions are that the eyes are proactive, typically seeking out the information required in the second before each act commences, although occasional 'look ahead' fixations are made to establish the locations of objects for

use further into the future. Gaze often moves on before the last act is complete, indicating the presence of an information buffer. Each task has a characteristic but flexible pattern of eye movements that accompanies it, and this pattern is similar between individuals. The eyes rarely visit objects that are irrelevant to the action, and the conspicuity of objects (in terms of low-level image statistics) is much less important than their role in the task. Gaze control may involve movements of eyes, head and trunk, and these are coordinated in a way that allows for both flexibility of movement and stability of gaze. During the learning of a new activity, the eyes first provide feedback on the motor performance, but as this is perfected they provide feed-forward direction, seeking out the next object to be acted upon.

The roles of vision and eye movements in the control of activities of daily living

Land M, Mennie N, Rusted J. Perception. 1999;28(11):1311-28

The aim of this study was to determine the pattern of fixations during the performance of a well-learned task in a natural setting (making tea), and to classify the types of monitoring action that the eyes perform. We used a head-mounted eye-movement video camera, which provided a continuous view of the scene ahead, with a dot indicating foveal direction with an accuracy of about 1 deg. A second video camera recorded the subject's activities from across the room. The videos were linked and analysed frame by frame. Foveal direction was always close to the object being manipulated, and very few fixations were irrelevant to the task. The first object-related fixation typically led the first indication of manipulation by 0.56 s, and vision moved to the next object about 0.61 s before manipulation of the previous object was complete. Each object-related act that did not involve a waiting period lasted an average of 3.3 s and involved about 7 fixations. Roughly a third of all fixations on objects could be definitely identified with one of four monitoring functions: locating objects used later in the process, directing the hand or object in the hand to a new location, guiding the approach of one object to another (e.g. kettle and lid), and checking the state of some variable (e.g. water level). We conclude that although the actions of tea-making are 'automated' and proceed with little conscious involvement, the eyes closely monitor every step of the process. This type of unconscious attention must be a common phenomenon in everyday life.

In what ways do eye movements contribute to everyday activities?

Land MF, Hayhoe M. Vision Res. 2001;41(25-26):3559-65

Two recent studies have investigated the relations of eye and hand movements in extended food preparation tasks, and here the results are compared. The tasks could be divided into a series of actions performed on objects. The eyes usually reached the next object in the sequence before any sign of manipulative action, indicating that eye movements are planned into the motor pattern and lead each action. The eyes usually fixated the same object throughout the action upon it, although they often moved on to the next object in the sequence before completion of the preceding action. The specific roles of individual fixations could be identified as locating (establishing the locations of objects for future use), directing (establishing target direction prior to contact), guiding (supervising the relative movements of two or three objects) and checking (establishing whether some particular condition is met, prior to the termination of an action). It is argued that, at the beginning of each action, the oculomotor system is supplied with the identity of the required object, information about its location, and instructions about the nature of the monitoring required during the action. The eye movements during this kind of task are nearly all to task-relevant objects, and thus their control is seen as primarily 'top-down', and influenced very little by the 'intrinsic salience' of objects.

The knowledge base of the oculomotor system.

Land MF, Furneaux S. Philos Trans R Soc Lond B Biol Sci. 1997 Aug 29;352(1358):1231-9

In everyday life, eye movements enable the eyes to gather the information required for motor actions. They are thus proactive, anticipating actions rather than just responding to stimuli. This means that the oculomotor system needs to know where to look and what to look for. Using examples from table tennis, driving and music reading we show that the information the eye movement system requires is very varied in origin and highly task specific, and it is suggested that the control program or schema for a particular action must include directions for the oculomotor and visual processing systems. In many activities (reading text and music, typing, steering) processed information is held in a memory buffer for a period of about a second. This permits a match between the discontinuous input from the eyes and continuous motor output, and in particular allows the eyes to be involved in more than one task.

Spatial load factor in prediction of reading performance.

Larter SC, Herse PR, Naduvilath TJ, Dain SJ. Ophthalmic Physiol Opt 2004 Sep;24(5):440-9.

This study investigated whether there is a relationship between reading age and clinical optometric tests that have varying degrees of spatial loading in their design. Spatial loading in this context is the demand on the visual system to process information about the relative position and orientation of stimuli. A total of 112 children aged 8-11 years were assessed using saccadic eye movement and rapid naming tasks with varying spatial loads. All were subtests of Garzia's Developmental Eye Movement test and Liubinas' SeeRite Reading Diagnostic Programme. Variability in load was achieved by comparing rapid naming of numerals vs the spatially loaded letters p, d, b, q; and by comparing the speed of reading numerals presented in increasingly complex arrays. Reading Age was assessed independently and results were analysed by multiple logistic regression. Spatially loaded naming tasks performed at speed exposed a Spatial Loading Factor which clearly differentiates children at risk with reading.

The contribution of peripheral and central vision in the control of movement amplitude.

Lawrence GP, Khan MA, Buckolz E, Oldham AR. Hum Mov Sci. 2006 Jun;25(3):326-38.

Past research has revealed that central vision is more important than peripheral vision in controlling the amplitude of target-directed aiming movements. However, the extent to which central vision contributes to movement planning versus online control is unclear. Since participants usually fixate the target very early in the limb trajectory, the limb enters the central visual field during the late stages of movement. Hence, there may be insufficient time for central vision to be processed online to correct errors during movement execution. Instead, information from central vision may be processed offline and utilised as a form of knowledge of results, enhancing the programming of subsequent trials. In the present research, variability in limb trajectories was analysed to determine the extent to which peripheral and central vision is used to detect and correct errors during movement execution. Participants performed manual aiming movements of 450 ms under four different visual conditions: full vision, peripheral vision, central vision, no vision. The results revealed that participants utilised visual information from both the central and peripheral visual fields to adjust limb trajectories during movement execution. However, visual information from the central visual field was used more effectively to correct errors online compared to visual information from the peripheral visual field.

Balance training with visual feedback in children with hemiplegic cerebral palsy: effect on stance and gait.

Ledebt A, Becher J, Kapper J, Rozendaal RM, Bakker R, Leenders IC, Savelsbergh GJ. Motor Control 2005 Oct;9(4):459-68.

The aim of the present study was to examine the effects of balance training with visual feedback on stance and gait in school-age children with hemiplegic cerebral palsy. Ten participants between 5 and 11 years of age were assigned to either the training or the control group according to an aged-stratified randomization. The training corresponded to three sessions per week during six weeks. Stance and gait parameters- based on force plate data, were assessed three times in both groups: (a) at the beginning of the study (before training); (b) after six weeks; (c) after ten weeks. Spatial and temporal parameters were calculated. The results for stance showed that the training improved the performances on the tasks that were trained. More interesting, the results for gait showed that the walking pattern became more symmetrical after the training.

Wider recognition in peripheral vision common to different subtypes of dyslexia.

Lorusso ML, Facoetti A, Pesenti S, Cattaneo C, Molteni M, Geiger G. Vis Res 2004;44(20):2413-24.

Italian children (n = 125) were classified into dyslexics, poor readers and ordinary readers. The dyslexics were further classified into the Boder and Bakker subtypes. The children were tested with the form-resolving field (FRF), which measures central and peripheral visual recognition. Dyslexics show higher correct identification of letters in the periphery, supporting the notion of a different distribution of lateral masking. A numerical characterization of individual FRFs—C2R—reliably distinguishes between dyslexics and ordinary readers. The wider distribution of recognition, similar across the various subtypes of dyslexia, suggests a general characteristic of visual perception, and possibly a different visual-attentional mode.

The contribution of stereo vision to one-handed catching.

Mazyn LI, Lenoir M, Montagne G, Savelsbergh GJ. Exper Brain Res 2004;157(3):383-91.

Participants with normal (StereoN) and weak (StereoW) stereopsis caught tennis balls under monocular and binocular viewing at three different speed conditions. Monocular or binocular viewing did not affect catching performance in catchers with weak stereopsis, while the StereoN group caught more balls under binocular vision as compared with the monocular condition. These effects were more pronounced with increasing ball speed. Kinematic analysis of the catch partially corroborated these findings. These results indicate that StereoW catchers have not developed a compensatory strategy for information pick-up, and that negative effects of a lack of stereopsis grow larger as temporal constraints become more severe. These findings also support the notion that several monocular and/or binocular information sources can be used in the control of interceptive action.

Prevalence of persistent primary reflexes and motor problems in children with reading difficulties.

McPhillips M, Sheehy N. Dyslexia 2004 Nov;10(4):316-38.

It has been shown that some children with reading difficulties have underlying developmental delay and that this may be related to the persistence of primary reflexes. This study investigated the prevalence of persistent primary reflexes in the ordinary primary school population and how this related to other cognitive and social factors. Three groups of 41 children were drawn from a representative, cross-sectional sample of 409 children (aged 9-10 years) attending 11 ordinary primary schools in N. Ireland. The three groups represented the bottom, middle and top 10% respectively of readers from the total sample population. The

relative persistence (on a scale of 0 to 4) of the Asymmetrical Tonic Neck Reflex (ATNR) and the prevalence of motor difficulties were assessed for these 3 groups. The role of 5 predictor variables (verbal IQ, social deprivation, sex, month of birth and religious affiliation) in determining the reading level of the total sample was also investigated. It was found that the lowest reading group had a significantly higher mean level of ATNR (1.56 [95% CI 1.22-1.90]) compared with the middle reading group (0.56 [0.22-0.90]) and the top reading group (0.59 [0.25-0.92]). 17% of children in the lowest reading group had extremely high levels of the ATNR while 24% showed no presence of ATNR. This contrasted with 0% and 66%, respectively for both middle and top reading groups. It was also found that there was a significant difference between the lowest reading group and the top reading group on a standardised test of motor ability. Furthermore, there was evidence that ATNR persistence but not motor ability was associated with the sex of the child with boys, in particular, at risk. There was no evidence that ATNR persistence or motor ability was significantly associated with social deprivation. It was also found that there were no significant differences between dyslexic and non-dyslexic children with reading difficulties in motor (including balance) performance. This study highlights the high levels of primary reflex persistence in children with reading difficulties and it provides further evidence of the association between reading difficulties and movement difficulties in young children. However, while the implications for intervention are discussed, it is stressed that the persistence of primary reflexes cannot be used as a causal model for reading difficulties, including dyslexia.

Prehension deficits in amblyopia.

Melmoth DR, Morgan MJ, Finlay AL. Invest Ophthalmol Vis Sci. 2007 Mar;48(3):1139-48

Purpose: Visual defects associated with amblyopia have been extensively studied, but their impact on the performance of everyday visuomotor tasks is unclear. This study evaluates eye-hand coordination (prehension) skills in adult amblyopes compared with normal subjects.

Methods: Twenty amblyopes (10 strabismic, 10 nonstrabismic) with different degrees of visual acuity loss (mild, moderate, or severe) and stereodeficiency (reduced or undetectable) participated, along with 20 matched control subjects. Subjects reached, precision grasped, and lifted cylindrical household objects (two sizes, four locations) using binocular vision or just the dominant or amblyopic (nondominant) eye, while the actions of the preferred hand were recorded. Various indices of prehension planning and online control were quantified for all trials ($n = 48$) performed under each viewing condition.

Results: Initial reaching behavior and grip shaping before object contact, which result from movement programming, were relatively normal in the amblyopic subjects, despite their vision losses. By contrast, they exhibited a range of deficits under both binocular and nondominant eye conditions in their final approach to the object (terminal reach) and when closing and applying a grasp. These impairments included prolonged execution times and more errors compared with control subjects, the extents of which covaried with the existing depth of amblyopia, although not with its underlying cause.

Conclusions: Visuomotor adaptations in amblyopes are relatively minor and limited to aspects of movement planning. Their deficits in movement execution should benefit, however, from treatments that restore spatial acuity and binocularity to progressively normal levels and so deserve more explicit consideration when assessing therapeutic outcomes.

Parallel processing of motion vision

Midorikawa A, Kawamura M. Brain Nerve. 2007 Jan;59(1):37-44

Several neuropsychological studies have reported dissociation between motion vision and object vision. One patient with motion blindness had a bilateral MT/V5 lesion and could see objects, but could not see the motion of the objects (Zihl et al, 1983). By contrast, some blindsight patients with primary visual cortex lesions cannot see objects but can see their movement (e.g. Riddoch, 1917). These results imply that movement vision and form vision rely on independent mechanisms. However one patient with motion blindness had controversial symptoms concerning motion vision. She could not perceive the movement of objects, although she could walk without colliding with obstacles and could catch incoming

objects. It has also been reported that patients with a bilateral parietal lesion had well-preserved primary motion vision, but had problems walking and catching a ball (Vaina, 1998). Therefore, motion for vision and motion for action might have independent mechanisms. Such dissociation has also been noted in patients with Balint syndrome. Some patients behave like a blind person but can walk and catch a ball, while other patients bump into obstacles while walking. These results indicate that the neural bases of motion vision are distinct from those of form vision and that there are subdivisions of motion vision.

Balance and gait in children with dyslexia.

Moe-Nilssen R, Helbostad JL, Talcott JB, Toennesen FE. *Exp Brain Res.* 2003 May;150(2):237-44.

Tests of postural stability have provided some evidence of a link between deficits in gross motor skills and developmental dyslexia. The ordinal-level scales used previously, however, have limited measurement sensitivity, and no studies have investigated motor performance during walking in participants with dyslexia. The purpose of this study was to investigate if continuous-scaled measures of standing balance and gait could discriminate between groups of impaired and normal readers when investigators were blind to group membership during testing. Children with dyslexia (n=22) and controls (n=18), aged 10-12 years, performed walking tests at four different speeds (slow-preferred-fast-very fast) on an even and an uneven surface, and tests of unperturbed and perturbed body sway during standing. Body movements were registered by a triaxial accelerometer over the lower trunk, and measures of reaction time, body sway, walking speed, step length and cadence were calculated. Results were controlled for gender differences. Tests of standing balance with eyes closed did not discriminate between groups. All unperturbed standing tests with eyes open showed significant group differences ($P < 0.05$) and classified correctly 70-77.5% of the subjects into their respective groups. Mean walking speed during very fast walking on both flat and uneven surface was $> \text{or } = 0.2 \text{ m/s}$ ($P < \text{or } = 0.01$) faster for controls than for the group with dyslexia. This test classified 77.5% and 85% of the subjects correctly on flat and uneven surface, respectively. Cadence at preferred or very fast speed did not differ statistically between groups, but revealed significant group differences when all subjects were compared at a normalised walking speed ($P < \text{or } = 0.04$). Very fast walking speed as well as cadence at a normalised speed discriminated better between groups when subjects were walking on an uneven surface compared to a flat floor. Continuous-scaled walking tests performed in field settings may be suitable for motor skill assessment as a component of a screening tool for developmental dyslexia.

Lateral glances toward moving stimuli among young children with autism: Early regulation of locally oriented perception?

Mottron L, Mineau S, Martel G, Bernier CS, Berthiaume C, Dawson M, Lemay M, Palardy S, Charman T, Faubert J. *Dev Psychopathol.* 2007 Winter;19(1):23-36.

Autistic adults display enhanced and locally oriented low-level perception of static visual information, but diminished perception of some types of movement. The identification of potential precursors, such as atypical perceptual processing, among very young children would be an initial step toward understanding the development of these phenomena. The purpose of this study was to provide an initial measure and interpretation of atypical visual exploratory behaviors toward inanimate objects (AVEBIOs) among young children with autism. A coding system for AVEBIOs was constructed from a corpus of 40 semistandardized assessments of autistic children. The most frequent atypical visual behavior among 15 children aged 33-73 months was lateral glance that was mostly oriented toward moving stimuli and was detected reliably by the experimenters (intraclass correlation $> .90$). This behavior was more common among autistic than typically developing children of similar verbal mental age and chronological age. As lateral vision is associated with the filtering of high spatial frequency (detail perception) information and the facilitation of high temporal frequencies (movement perception), its high prevalence among very young autistic children may reflect early attempts to regulate and/or optimize both excessive amounts of local

information and diminished perception of movement. These findings are initial evidence for the need to consider the neural bases and development of atypical behaviors and their implications for intervention strategies.

Infant motor development is associated with adult cognitive categorisation in a longitudinal birth cohort study.

Murray GK, Veijola J, Moilanen K, Miettunen J, Glahn DC, Cannon TD, Jones PB, Isohanni M. *J Child Psychol Psychiatry.* 2006 Jan;47(1):25-9

Background: The relationship between the age of reaching infant developmental milestones and later intellectual function within the normal population remains unresolved. We hypothesised that the age of learning to stand in infancy would be associated with adult executive function and that the association would be apparent throughout the range of abilities, rather than confined to extremes.

Methods: The Northern Finland 1966 Birth Cohort is based upon 12,058 live-born children in a geographic and temporally defined population. Information on age at learning to stand without support was obtained at one year. At age 33-35 a random sample of 104 subjects underwent a neuropsychological test battery including tests of executive function (cognitive categorisation), visuo-spatial memory, verbal learning and visual object learning. We investigated associations between developmental data and adult neuropsychological test scores.

Results: There was a significant linear relationship between age of learning to stand and adult categorisation: the earlier the attainment of the milestone, the better was the categorisation. No such relationships were observed between infant neurodevelopment and adult cognition in other neuropsychological domains.

Conclusions: Even within the normal range of development, early development in the gross motor domain is associated with better adult executive function (in tests of categorisation). Investigation of the determinants and sequelae of normal neural development will facilitate research into a variety of neurodevelopmental disorders.

Influence of vision and static stretch of the calf muscles on postural sway during quiet standing.

Nagano A, Yoshioka S, Hay DC, Himeno R, Fukashiro S. *Hum Mov Sci.* 2006 Jun;25(3):422-34

The purpose of this experimental study was to evaluate the effects of vision and stretching of the calf muscles on postural sway during quiet standing. Under pre-stretch conditions, participants stood on a force plate for 30s and the sway of the ground reaction force center of pressure was recorded. The following postural sway variables were calculated off-line: sweep speed, sway speed, standard deviation, maximal mediolateral range, maximal anteroposterior range, mean mediolateral position and mean anteroposterior position. For post-stretch conditions, participants stood quietly on a device that was utilized to impose a static 3 min ankle joint dorsiflexion stretch. Immediately thereafter, participants moved onto the force platform where postural sway parameters were again recorded. Randomized eyes-open and eyes-closed conditions were tested in both cases. Results showed that postural sway significantly increased due to stretch (sweep speed, sway speed, standard deviation, maximal anteroposterior range, mean anteroposterior position), as well as eye closure (sweep speed, sway speed, standard deviation, maximal mediolateral range, maximal anteroposterior range). The interaction between stretch and eye closure was also significant (sweep speed, sway speed, standard deviation, maximal mediolateral range), suggesting that there were only minor increases in postural sway after stretch under the eyes-open condition. It was suggested that stretching of the calf muscles has the effect of increasing postural sway, although this effect can be greatly compensated for when vision is included.

Developmental dyslexia, learning and the cerebellum.

Nicolson RI, Fawcett AJ. J Neural Transm Suppl. 2005;(69):19-36.

Theoretical frameworks for dyslexia must explain how the well-established phonological deficits and the literacy deficits arise. Our longstanding research programme has led to a distinctive 'twin level' framework that proposes, first, that the core deficits are well described in terms of poor skill automaticity. Second, these 'cognitive level' symptoms are attributed to abnormal cerebellar function--a 'brain-level' analysis. The evidence includes data from behavioural, imaging, neuroanatomical and learning studies. The framework leads to an 'ontogenetic' analysis that links cerebellar deficit at birth, via problems in articulation and working memory, to the known phonological, speed and literacy difficulties. Differences in locus of cerebellar impairment, experience and/or links to other brain regions may account for subtypes of dyslexia and possibly other developmental disorders. The automaticity/ cerebellar deficit framework provides an explicit demonstration that it is possible to explain motor, speed and phonological deficits within a unified account, integrating previously opposed approaches.

Skill learning in mirror reading: how repetition determines acquisition

Ofen-Noy N, Dudai Y, Karni A. Brain Res Cogn Brain Res. 2003 Jul;17(2):507-21

Practice makes perfect, but the role of repetitions in skill learning is not yet fully understood. For example, given a similar number of trials on a given task, it is debated whether repeating and non-repeating items are learned by the same neural process. When one is given training with both types of items--does one learn two separate skills, or only one? Here we show, using a mirror reading task, that practice trials with trial-unique words, and practice trials with repeated words, count towards learning to a different degree. There was no interaction between the time-course of learning repeated and unique words even within the same individuals given mixed training. While repeated words were learned faster than unique words, the repetitions-dependent gains diminished with training beyond a small number of repetitions. Moreover, the gains in performance could not be accounted for solely by the number of repetitions, as assumed by power-law models of learning; rather, the passage of time was a critical factor. Finally, our results suggest that although both repeated and new words were learned by both declarative and procedural memory mechanisms, even a single repetition of specific words could lead to the establishment of a selective differential representation in memory. The results are compatible with the notion of a repetition-sensitive process, triggered by specific repeating events. This 'repetition counter' may be a critical trigger for the effective formation of procedural as well as some type of declarative memory

Your hand movements in my somatosensory cortex: a visuo-kinesthetic function in human area 2.

Oouchida Y, Okada T, Nakashima T, Matsumura M, Sadato N, Naito E. Neuroreport. 2004 Sep 15;15(13):2019-23

Does viewing someone's actions activate a viewer's somatosensory cortex? We tested if visual information of limb movements activated limb sections in somatosensory areas that are normally engaged in kinesthetic processing of the limb. We showed, with functional magnetic resonance imaging in 17 right-handed healthy subjects, that passive observation of flexion-extension movements of an experimenter's right hand activated the observer's contralateral hand section of area 2 which is involved in kinesthetic processing of right hand movements. This could be interpreted as a pragmatic function of the brain that permits visual information to reach the somatosensory area, and suggests human area 2 has an association function between kinesthesia and vision.

Role of visual dysfunction in postural control in children with cerebral palsy.

Porro G, van der Linden D, van Nieuwenhuizen O, Wittebol-Post D. *Neural Plast* 2005;12(2-3):205-10; discussion 263-72.

Introduction: Deficient postural control is one of the key problems in cerebral palsy (CP). Little, however, is known about the specific nature of postural problems of children with CP, nor of the relation between abnormal posture and dysfunction of the visual system.

Aim of the Study: To provide additional information on the association of abnormalities in postural control and visual dysfunction of the anterior or posterior part of the visual system.

Methods: Data resulting from ophthalmologic, orthoptic, neurological, neuroradiological, and ethological investigations of more than 313 neurologically impaired children were retrospectively analyzed.

Results: Abnormal postural control related to ocular and ocular motor disorders consisted of anomalous head control and subsequent abnormal head posture and torticollis. The abnormal postural control related to retrochiasmatal damage of the visual system consisted of a torticollis combined with adjustment of the upper part of the body, as if at the same time adapting to a combination of defects and optimizing residual visual functions. **Conclusion:** Visual dysfunctions play a distinct role in the postural control of children with CP.

Effects of head orientation and lateral body tilt on egocentric coding: cognitive and sensory-motor accuracy.

Prieur JM, Bourdin C, Sares F, Vercher JL. *J Vestib Res.* 2006;16(3):93-103.

A major issue in motor control studies is to determine whether and how we use spatial frames of reference to organize our spatially oriented behaviors. In previous experiments we showed that simulated body tilt during off-axis rotation affected the performance in verbal localization and manual pointing tasks. It was hypothesized that the observed alterations were at least partly due to a change in the orientation of the egocentric frame of reference, which was indeed centered on the body but aligned with the gravitational vector. The present experiments were designed to test this hypothesis in a situation where no inertial constraints (except the usual gravitational one) exist and where the orientation of the body longitudinal z-axis was not aligned with the direction of the gravity. Eleven subjects were exposed to real static body tilt and were required to verbally localize (experiment 1) and to point as accurately as possible towards (experiment 2) memorized visual targets, in two conditions, Head-Free and Head-Fixed conditions. Results show that the performance was only affected by real body tilt in the localization task performed when the subject's head was tilted relative to the body. Thus, dissociation between gravity and body longitudinal z-axis alone is not responsible for localization nor for pointing errors. Therefore, the egocentric frame of reference seems independent from the orientation of the gravity with regard to body z-axis as expected from our previous studies. Moreover, the use of spatial referentials appears to be less mandatory than expected for pointing movements (motor task) than for localization task (cognitive task).

Brain stem pursuit pathways: dissociating visual, vestibular, and proprioceptive inputs during combined eye-head gaze tracking.

Roy JE, Cullen KE. *J Neurophysiol.* 2003 Jul;90(1):271-90

Eye-head (EH) neurons within the medial vestibular nuclei are thought to be the primary input to the extraocular motoneurons during smooth pursuit: they receive direct projections from the cerebellar flocculus/ventral paraflocculus, and in turn, project to the abducens motor nucleus. Here, we recorded from EH neurons during head-restrained smooth pursuit and head-unrestrained combined eye-head pursuit (gaze pursuit). During head-restrained smooth pursuit of sinusoidal and step-ramp target motion, each neuron's response was well described by a simple model that included resting discharge (bias), eye position, and velocity terms. Moreover, eye acceleration, as well as eye position, velocity, and acceleration error (error = target movement - eye movement) signals played no role in shaping neuronal discharges.

During head-unrestrained gaze pursuit, EH neuron responses reflected the summation of their head-movement sensitivity during passive whole-body rotation in the dark and gaze-movement sensitivity during smooth pursuit. Indeed, EH neuron responses were well predicted by their head- and gaze-movement sensitivity during these two paradigms across conditions (e.g., combined eye-head gaze pursuit, smooth pursuit, whole-body rotation in the dark, whole-body rotation while viewing a target moving with the head (i.e., cancellation), and passive rotation of the head-on-body). Thus our results imply that vestibular inputs, but not the activation of neck proprioceptors, influence EH neuron responses during head-on-body movements. This latter proposal was confirmed by demonstrating a complete absence of modulation in the same neurons during passive rotation of the monkey's body beneath its neck. Taken together our results show that during gaze pursuit EH neurons carry vestibular- as well as gaze-related information to extraocular motoneurons. We propose that this vestibular-related modulation is offset by inputs from other premotor inputs, and that the responses of vestibuloocular reflex interneurons (i.e., position-vestibular-pause neurons) are consistent with such a proposal.

Control of attention shifts between vision and audition in human cortex.

Shomstein S, Yantis S. J Neurosci. 2004 Nov 24;24(47):10702-6

Selective attention contributes to perceptual efficiency by modulating cortical activity according to task demands. Visual attention is controlled by activity in posterior parietal and superior frontal cortices, but little is known about the neural basis of attentional control within and between other sensory modalities. We examined human brain activity during attention shifts between vision and audition. Attention shifts from vision to audition caused increased activity in auditory cortex and decreased activity in visual cortex and vice versa, reflecting the effects of attention on sensory representations. Posterior parietal and superior prefrontal cortices exhibited transient increases in activity that were time locked to the initiation of voluntary attention shifts between vision and audition. These findings reveal that the attentional control functions of posterior parietal and superior prefrontal cortices are not limited to the visual domain but also include the control of crossmodal shifts of attention.

M-cell deficit and reading disability: a preliminary study of the effects of temporal vision-processing therapy.

Solan HA, Shelley-Tremblay J, Hansen PC, Silverman ME, et al. Optom 2004 ct;75(10):640-50.

Background: This study examines the following questions: In moderately disabled readers, will temporal vision-processing therapy procedures that benefit reading comprehension, visual attention, and oculomotor skills ameliorate M-cell processing deficits as measured with coherent motion threshold testing? And will the results show a corresponding improvement in oral reading and verbal skills?

Method: A sample of 16 moderately disabled readers, evaluated in a study completed 6 months earlier, were retested with another form of the Gates-MacGinitie Reading Test. Each participant was additionally tested for coherent motion, oral reading, and word attack skills. During the succeeding 6 months, fifteen 45-minute therapy sessions were administered once a week (as the school schedule permitted). After completing 15 therapy sessions, the initial testing procedures were repeated.

Results: All four variables—namely, Gates-MacGinitie Reading Test, Coherent Motion Threshold Test, Gray Oral Reading Test, and Woodcock-Johnson Word Attack Test—revealed significant improvements after temporal vision therapy. Half of the 16 participants improved 2 or more years in reading comprehension, compared to no significant mean difference following the 6-month “control period” before the onset of therapy.

Conclusions: This research supports the value of rendering temporal vision therapy to children identified as moderately reading disabled (RD). The diagnostic procedures and the dynamic therapeutic techniques discussed in this article have not been previously used for the specific purpose of ameliorating an M-cell deficit. Improved temporal visual-processing

skills and enhanced visual motion discrimination appear to have a salutary effect on magnocellular processing and reading comprehension in RD children with M-cell deficits.

Effects of visual occlusion and fatigue on motor performance in water.

Sullivan EA, Hooper SL. Percept Mot Skills. 2005 Jun;100(3 Pt 1):681-8

The purpose of this study was to test the effects of visual occlusion and fatigue on the motor performance of vertical skills in synchronized swimming. Experienced synchronized swimmers ($n = 12$) were randomly assigned to either an exercise or nonexercise (control) activity group. Subjective ratings of fatigue were obtained from the swimmers who then each performed four vertical skills under alternating conditions of vision and visual occlusion before and after either a swimming (designed to induce fatigue) or nonphysical activity. A main effect of activity ($p < .03$) was found for two measures of performance accuracy (lateral and anterior total distance traveled) but not for lateral and anterior maximum deviation from vertical, indicating that fatigue played a role in executing the skills. The data also indicate that the maintenance of a stationary position is a skill of greater difficulty than maintaining a true vertical. In contrast with previous research findings on synchronized swimmers, a significant effect of vision in all conditions was found, with performance decrements in the conditions of visual occlusion showing that vision provided important sensory input for the swimmers

Developmental Eye Movement Test: reliability and symptomatology

Tassinari JT, DeLand P. Optometry. 2005 Jul;76(7):387-99

Background: The Developmental Eye Movement Test (DEM) is a widely used visual skill test, especially in the context of a vision therapy evaluation. It is intended to diagnose oculomotor dysfunction (OMD) and can also identify deficient rapid automatized naming. As such, its reliability and associated symptomatology are important.

Methods: The DEM test-retest reliability was investigated within two populations: a group of 53 office patients who were participating in vision therapy evaluation in a private optometry practice, and a smaller group of 13 subjects at their school. One to four weeks separated the test and retest for both groups. We also studied the relationship between results on a questionnaire of symptoms associated with OMD and DEM test performance in these two populations.

Results: The first administration of the DEM significantly correlated with the second for all four of its scores for both groups. The office group had higher intra-class correlation coefficients than the school group. There was good agreement between test and re-test in terms of pass-fail classification for the office group. Symptomatic subjects performed poorer than asymptomatic subjects on the DEM. Failing the DEM Ratio, the score used to diagnose OMD, identified 90% of the subjects who were symptomatic.

Conclusions: The DEM has good intra-subject test-retest reliability for all four of its scores when it is administered in an office setting to patients participating in a vision therapy evaluation. It also has good consistency in classifying patients as pass or fail. Performance on the DEM relates to certain symptoms that are associated with OMD.

Oculomotor strategies for the direction of gaze tested with a real-world activity.

Turano KA, Geruschat DR, Baker FH. Vision Res. 2003 Feb;43(3):333-46.

Laboratory-based models of oculomotor strategy that differ in the amount and type of top-down information were evaluated against a baseline case of random scanning for predicting the gaze patterns of subjects performing a real-world activity--walking to a target. Images of four subjects' eyes and field of view were simultaneously recorded as they performed the mobility task. Offline analyses generated movies of the eye on scene and a categorization scheme was used to classify the locations of the fixations. Frames from each subject's eye-on-scene movie served as input to the models, and the location of each model's predicted

fixations was classified using the same categorization scheme. The results showed that models with no top-down information (visual salience model) or with only coarse feature information performed no better than a random scanner; the models' ordered fixation locations (gaze pattern) matched less than a quarter of the subjects' gaze patterns. A model that used only geographic information outperformed the random scanner and matched approximately a third of the gaze patterns. The best performance was obtained from an oculomotor strategy that used both coarse feature and geographic information, matching nearly half the gaze patterns (48%). Thus, a model that uses top-down information about a target's coarse features and general vicinity does a fairly good job predicting fixation behavior, but it does not fully specify the gaze pattern of a subject walking to a target. Additional information is required, perhaps in the form of finer feature information or knowledge of a task's procedure.

Imaging brain plasticity during motor skill learning

Ungerleider LG, Doyon J, Karni A. *Neurobiol Learn Mem.* 2002 Nov;78(3):553-64

The search for the neural substrates mediating the incremental acquisition of skilled motor behaviors has been the focus of a large body of animal and human studies in the past decade. Much less is known, however, with regard to the dynamic neural changes that occur in the motor system during the different phases of learning. In this paper, we review recent findings, mainly from our own work using fMRI, which suggest that: (i) the learning of sequential finger movements produces a slowly evolving reorganization within primary motor cortex (M1) over the course of weeks and (ii) this change in M1 follows more dynamic, rapid changes in the cerebellum, striatum, and other motor-related cortical areas over the course of days. We also briefly review neurophysiological and psychophysical evidence for the consolidation of motor skills, and we propose a working hypothesis of its underlying neural substrate in motor sequence learning. Copyright 2002 Elsevier Science (USA)

The cognitive deficits responsible for developmental dyslexia: review of evidence for a selective visual attentional disorder.

Valdois S, Bosse ML, Tainturier MJ. *Dyslexia* 2004 Nov;10(4):339-63.

There is strong converging evidence suggesting that developmental dyslexia stems from a phonological processing deficit. However, this hypothesis has been challenged by the widely admitted heterogeneity of the dyslexic population, and by several reports of dyslexic individuals with no apparent phonological deficit. In this paper, the authors discuss the hypothesis that a phonological deficit may not be the only core deficit in developmental dyslexia and critically examine several alternative proposals. To establish that a given cognitive deficit is causally related to dyslexia, at least two conditions need to be fulfilled. First, the hypothesized deficit needs to be associated with developmental dyslexia independently of additional phonological deficits. Second, the hypothesized deficit must predict reading ability, on both empirical and theoretical grounds. While most current hypotheses fail to fulfill these criteria, the authors argue that the visual attentional deficit hypothesis does. Recent studies providing evidence for the independence of phonological and visual attentional deficits in developmental dyslexia are reviewed together with empirical data showing that phonological and visual attentional processing skills contribute independently to reading performance. A theoretical model of reading is outlined in support of a causal link between a visual attentional disorder and a failure in reading acquisition.

Attentional gating in primary visual cortex: a physiological basis for dyslexia.

Vidyasagar TR. *Perception* 2005;34(8):903-11.

The visual magnocellular pathway is known to play a central part in visuospatial attention and in directing attention to specific parts of the visual world in serial search. It is proposed that, in

the case of reading, this mechanism is trained to perform a sequential gating of visual information coming into the primary visual cortex to enable further orderly processing by the ventral stream. This scheme, taken together with the potential for plasticity between the different afferent channels in the case of a relative impairment of the magnocellular system, can provide some limited rationale for the beneficial effects that have been claimed for the use of coloured overlays and glasses.

Neural underpinnings of dyslexia as a disorder of visuo-spatial attention.

Vidyasagar TR. Clin Exp Optom 2004 Jan;87(1):4-10

For nearly 100 years, the underlying cause of dyslexia has been a matter of much debate, with widely varying viewpoints that have ranged from considering dyslexia as largely a learning disability to claims that it is essentially a perceptual defect occurring early along the visual pathway. This paper reviews some of this literature with particular reference to the studies that have implicated a defect in the afferent visual pathways in the aetiology of the disorder, then goes on to outline a neural theory of how functionally distinct parallel pathways in vision interact with each other in the process of reading and suggests how a defect in these pathways can lead to reading difficulties. Central to the proposed scheme is the suggestion that a fast-track pathway, arising from the magnocellular cells in the retina and acting through an attentional mechanism, has a gating function in spotlighting the individual letters of a text in a sequential fashion. That such gating occurs at the level of the primary visual cortex is supported by recent physiological evidence concerning attentional mechanisms.

Children with dyslexia: evidence for visual attention deficits in perception of rapid sequences of objects.

Visser TA, Boden C, Giaschi DE. Vision Res 2004;44(21):2521-35.

The attentional blink (AB) refers to a decrease in accuracy that occurs when observers are required to identify, detect or classify the second of two rapidly-sequential targets. The AB is typically attributed to an inability to rapidly reallocate attentional resources from the first to the second target. Thus, it provides an ideal tool to investigate how visual attention is rapidly allocated to sequences of stimuli such as occurs when reading. In the present work, the authors compared the magnitude of the AB in children with developmental dyslexia to reading-matched and age-matched control groups. In Experiment 1, when two targets were presented in the same spatial location, the AB deficit was similar in the reading-matched and dyslexic groups, but greater in the dyslexic group than in age-matched controls. In Experiment 2, when targets were presented in different spatial locations, performance in the dyslexic group was worse than the age-matched controls and marginally worse than the reading-matched controls. Taken together, the results argue for developmental delays in the ability of children with dyslexia to allocate attention to rapidly-sequential stimuli, as well as some evidence for difficulties that are unique to this group.

The influence of colour on oculomotor behaviour during image perception.

von Wartburg R, Ouerhani N, Pflugshaupt T, Nyffeler T, Wurtz P, Hugli H, Muri RM. Neuroreport. 2005 Sep 28;16(14):1557-60

The aim of this study was to investigate how oculomotor behaviour depends on the availability of colour information in pictorial stimuli. Forty study participants viewed complex images in colour or grey-scale, while their eye movements were recorded. We found two major effects of colour. First, although colour increases the complexity of an image, fixations on colour images were shorter than on their grey-scale versions. This suggests that colour enhances discriminability and thus affects low-level perceptual processing. Second, colour decreases the similarity of spatial fixation patterns between participants. The role of colour on visual

attention seems to be more important than previously assumed, in theoretical as well as methodological terms.

Can Replicating Primary Reflex Movements Improve Reading Ability?

Wahlberg T, Ireland D. *Optom Vis Dev* 2005;36(2):89-91.

Poorly integrated and inhibited primitive reflexes can impact an individual's visual development, balance system and academic performance, most notably in the area of reading. Children diagnosed with reading learning disabilities were assessed in the areas of oculomotilities, tonic reflexes, balance and fine motor. They were also given a headache questionnaire. Students participated in a movement program designed to decrease the amount of primitive reflex present, improve the balance and visual systems and reading ability. Method: The study evaluated 22 students, ages 7 to 11, who were previously diagnosed with reading learning disabilities. All students were given a treatment program of repetition of primary reflex movements during one academic year. Results: Students showed a marked decrease in the presence of primitive reflexes, improved balance and oculomotilities, a decrease in headaches and improved reading fluency. Conclusion: The study showed that students diagnosed with a reading disability may have persistent primitive reflexes, balance and oculomotor dysfunctions. A movement program can improve these dysfunctions and increase reading fluency.

2. References on the role of lenses in the management of near point stress

The most useful description and discussion of near point stress can be found in Part 1 of 'Optometric Management of Nearpoint Disorders' by Martin Birnbaum, 1993, Butterworth – Heineman ISBN 0-7506-9193-X. An extract from p53 and 54 of this textbook is reproduced below.

"In contrast to traditional models that attribute refractive, accommodative, and binocular disorders to genetic influence and random biologic variation, Skeffington (1928-74) held that these disorders commonly occur as end-products of environmental interaction, resulting either from interference with development or from nearpoint visual stress.

According to Skeffington, the characteristic visual stress response is a drive for convergence to localise closer than accommodation. This drive interferes with visual efficiency and must be resolved if near work is to be sustained comfortably. Unless this effector system mismatch is relieved, the individual is faced with a dilemma. If the subject accommodates for the plane of regard, convergence will localise nearer, resulting in double vision. If the subject converges for the plane of regard, accommodation will localise beyond this plane and vision will be blurred. The individual will see clearly, or singly, but not both. In the presence of such conflict, many individuals experience discomfort, visual inefficiency, and reduced comprehension. Many seek to avoid near work, and many initiate adaptive changes within the visual system (Skeffington 1964-65).

To localise accommodation and convergence in the same plane, the individual may initiate a variety of changes in the pattern of relationship between vergence and accommodation. These changes may ultimately become embedded as anomalies of refractive status and binocular function.

Skeffington (1928-74) views conditions such as adventitious myopia, adverse high hyperopia, divergent squint, and various skews in binocular and accommodative function as adaptations by which the individual seeks to relieve the drive for convergence to localise closer than accommodation.

These disorders are viewed not as primary conditions, but as end-products of adaptation to nearpoint stress-induced effector system mismatch. Ocular defects are held to occur when nearpoint stress is sustained and prolonged; they are unlikely to result from brief periods of transient visual stress with which the visual system is better able to cope (Flax 1985).

Properly prescribed low-plus nearpoint lenses relieve the drive for convergence to localise closer than accommodation. Such lenses allow the effector system to mismatch to take place, yet bring focus to the same plane as alignment, thereby eliminating the source of difficulty and the need to adapt. Unless appropriate nearpoint lenses are provided or effective adaptation takes place, impaired visual achievement, avoidance, or discomfort results from the failure to adequately integrate convergence and accommodation (Skeffington 1964-65)."

Nearpoint visual stress: clinical implications.

Birnbaum MH. J Am Optom Assoc. 1985 Jun;56(6):480-90.

A physiological model of nearpoint stress, based on autonomic arousal, was presented in a companion paper. This paper deals with clinical implications of the nearpoint stress model, including clinical manifestations, adaptive responses to nearpoint stress, and management of nearpoint stress-induced vision disorders.

Nearpoint visual stress: a physiological model.

Birnbaum MH. J Am Optom Assoc. 1984 Nov;55(11):825-35.

The nearpoint visual stress theory holds that a tendency for convergence to localize closer than accommodation is intrinsic to the nearpoint visual demands imposed by our culture. A physiological model is presented, suggesting that this effector system mismatch arises from the activation of autonomic reflexes related to stress, vigilant attention and information-processing. Autonomic arousal exerts a cycloplegic-like effect. Excess accommodative effort, which must be exerted to achieve required accommodation, produces a tendency towards overconvergence. The demand for integration of accommodation and convergence, essential for efficient nearpoint function, is thus incompatible with our own physiology, since autonomic arousal is inherent in task demands for attention and mental effort associated with reading. Additionally, autonomic arousal is generated by the high levels of stress pervasive in our society. Various refractive, binocular and accommodative deviations may arise adaptively in order to resolve this mismatch and facilitate efficient nearpoint visual function. These nearpoint stress-induced visual disorders parallel stress-induced systemic illness in that both result from the activation of physiological processes which are inappropriate for the demands and stresses of our society.

Near vision stress: vergence adaptation and accommodative fatigue.

Ehrlich DL. Ophthalmic Physiol Opt. 1987;7(4):353-7.

Changes in the visual system following prolonged near work were investigated. Fifteen young, normal subjects undertook a severe, two hour long, binocular near visual task at 20 cm without any breaks. Fusional stress was assessed by near 'phoria change. Refractive change was measured with an autorefractometer to investigate whether transient myopia occurred and its subsequent recovery. The near task caused vergence adaptation which was primarily due to the fusional stress of the task (accounting for 67% of its variance). The 'phoria change was to a lesser extent (40%) dependent on the accommodative "stress" of the task. Fatigue of the accommodative system resulted in increased accommodative innervation to maintain the same accurate response. Increased innervation can continue after the task on subsequent distance viewing, resulting in transient myopia (mean 0.29 DS). This transient myopia was found to be due to a transient regression of the far point towards the subject's tonic accommodation level. This can be accounted for by a shift of the tonic level as well as an increased bias towards the pre-task tonic level.

Functional case analysis: an interpretation of the Skeffington model.

Flax N. Am J Optom Physiol Opt. 1985 Jun;62(6):365-8.

The four components of the model of vision developed by Skeffington are described. The influence of stress induced by reading on the interrelation between accommodation (identification) and convergence (centering) is discussed. The use of a convex lens to reduce the need for adaptive responses is presented.

Comparison of MEM Retinoscopy & Nott Retinoscopy & their interexaminer repeatabilities.

Goss DA, Groppe P, Dominguez L. J Behav Optom 2005;16(6) :149-55

The results of previous studies comparing Monocular Estimate Method (MEM) retinoscopy and Nott retinoscopy (Nott) have not been consistent. The purposes of this study were to compare MEM and Nott measures of accommodative response with each other and to provide data on the interexaminer reliability of MEM and Nott. Two examiners performed both MEM and Nott retinoscopy on 50 young adult subjects, using a 40 cm testing distance. Measurements of accommodative response were also taken with a Canon Autorefractometer R-1 (Canon) autorefractor. The mean difference between MEM and Nott was 0.0002 +/- 0.55 D. The 95% limits of agreement between the two examiners were +/- 0.17 D on Nott retinoscopy and +/- 0.31 D on MEM retinoscopy. The results of this study indicated close agreement of the means for MEM and Nott. However, there was a wider range of measurements with MEM retinoscopy than with Nott retinoscopy. Nott showed better agreement with MEM at mid range responses than at low or high responses. Lags measured with Nott were lower than the lags found with MEM in high lag subjects. The agreement between examiners on both dynamic retinoscopy techniques was better than the agreement between methods.

Behavioral effects of children's nearpoint lenses.

Greenspan SB. J Am Optom Assoc. 1975 Oct;46(10):1031-7.

Procedures in clinical optometry include the therapeutic and preventive use of lenses for the express purpose of favorably modifying visual behavior in nearpoint activities, especially for children. The research bases for such procedures have been greatly elaborated in recent years. Research evidence now exists to clarify some of the actual effects of lenses upon behavior, indicating possible ways of explaining the underlying mechanisms or processes of such effects, while further suggesting clinical techniques for the appropriate diagnostic determination of nearpoint lens prescriptions.

Clinical management of nearpoint stress-induced vision problems.

Gruning CF. Am J Optom Physiol Opt. 1985 Jun;62(6):386-91.

Functional vision problems caused by or associated with nearpoint vision stress include: accommodative disorders (insufficiency, ill-sustained, infacility); abnormal heterophorias (esophoria, high exophoria); and vergence disorders. These vision disorders cause problems with acuity, comfort, and performance (efficiency). A combination of lens prescribing, vision therapy, and work/study visual hygiene recommendations can eliminate or greatly reduce nearpoint stress-induced vision problems.

Accommodation and related risk factors associated with myopia progression and their interaction with treatment in COMET children.

Gwiazda JE, Hyman L, Norton TT, Hussein ME, et al. Invest Ophthalmol Vis Sci 2004;45(7):2143-51.

Purpose: To examine baseline measurements of accommodative lag, phoria, reading distance, amount of near work, and level of myopia as risk factors for progression of myopia and their interaction with treatment over 3 years, in children enrolled in the Correction of Myopia Evaluation Trial (COMET).

Methods: COMET enrolled 469 ethnically diverse children (ages, 6-11 years) with myopia between -1.25 and -4.50 D. They were randomly assigned to either progressive addition lenses (PALs) with a +2.00 addition (n = 235) or single vision lenses (SVLs; n = 234), the conventional spectacle treatment, and were observed for 3 years. The primary outcome measure was progression of myopia by autorefractometry after cycloplegia with 2 drops of 1% tropicamide. Other measurements included accommodative response (by an open field of

view autorefractor), phoria (by cover test), reading distance, and hours of near work. Independent and interaction analyses were based on the mean of the two eyes. Results were adjusted for important covariates with multiple linear regression.

Results: Children with larger accommodative lags (>0.43 D for a 33 cm target) wearing SVLs had the most progression at 3 years. PALs were effective in slowing progression in these children, with statistically significant 3-year treatment effects (mean \pm SE) for those with larger lags in combination with near esophoria (PAL - SVL progression = -1.08 D $-$ 1.72 D] = 0.64 ± 0.21 D), shorter reading distances (0.44 ± 0.20 D), or lower baseline myopia (0.48 ± 0.15 D). The 3-year treatment effect for larger lags in combination with more hours of near work was 0.42 ± 0.26 D, which did not reach statistical significance. Statistically significant treatment effects were observed in these four groups at 1 year and became larger from 1 to 3 years.

Conclusions: The results support the COMET rationale (i.e., a role for retinal defocus in myopia progression). In clinical practice in the United States children with large lags of accommodation and near esophoria often are prescribed PALs or bifocals to improve visual performance. Results of this study suggest that such children, if myopic, may have an additional benefit of slowed progression of myopia.

Activation-induced changes in visual functions

Harrer S, Litschauer B, Wundsch L. Wien Klin Wochenschr. 1988 Apr 29;100(9):295-302. [Article in German]

Visual functions were tested in 18 healthy male medical students on a control day and on the day of an oral examination. Stress induced impairment was observed in binocular tests measuring accommodation, convergence or their mutual relationship (near points of accommodation and convergence, Maddox-wing). Results of tests in which fusion operates as stabilizing factor (slightly dissociating test: Polatest) or of tests designed for far distance vision (synoptophore, Maddox-cross, Pola-cross) did not show significant impairment under examination stress. In slightly dissociating tests an activity-dependent improvement in stereoscopic vision became evident. Flicker fusion frequency values increased under stress. Colour vision analysis by means of the Nagel anomaloscope revealed that the absolute matching range remained unchanged, whereas the relative matching range broadened on the day of examination. The results indicate activity-dependence of binocular vision, with an improvement in central nervous functions on the one hand and an impairment of peripheral accommodative components on the other hand. Furthermore, it may be concluded that binocular coordination is achieved independently from accommodation dependent focusing of the image and is apparently processed separately and parallel to monocular image components.

The effects of caffeine on near point plus acceptance.

Kirshner AJ, Schmid R. J Am Optom Assoc. 1984 Feb;55(2):97-102.

Forty-two university students participated in a study of reading with $+0.50$ sphere or yokes prism base down for overconvergence and base up for underconvergence. Sixty-four percent of the group improved with a mean of $+10.79$ wpm. The level of coffee consumption of each student was recorded. A negative correlation existed between the intake of caffeine and reading improvement, $r = -.81$, p less than $.001$. Two students reduced their coffee consumption and transformed their loss in words per minute to a significant gain. A double-blind protocol was used in this study. A placebo lens (plano) controlled for subject and investigator bias. The relationship between caffeine and accommodation was investigated by means of a monocular test through a $+4.0$ D sphere. The location of the blur point was indicative of the state of tonicity of the ciliary system. Pre- and post-tests of the blur point for 14 subjects who were tested before and after consuming 150 mg of caffeine showed a significant change. The experimental group showed an increase of -0.52 D while the control group showed a change of $+0.36$ D. $r = .781$, p less than $.01$.

Behavioral effects of low plus lenses.

Larrabee PE Jr, Jones FR. Percept Mot Skills. 1980 Dec;51(3 Pt 1):913-4.

This study explored the relationship between the application of low plus reading lenses and the improvement of performance at a child's near working distance. 11 school-aged subjects were selected at random, screened for their ability to accept low plus lenses, then given a paper-and-pencil task to perform both with and without the plus lenses. Statistically significant behavioral changes were associated with wearing the low plus-power reading lenses while performing the near paper-and-pencil task.

Physiological effects of plus lens application.

Press LJ. Am J Optom Physiol Opt. 1985 Jun;62(6):392-7.

The prescribing of low-power spherical convex lenses for nearpoint has been advocated on the basis of associated visual and physiological responses. A review of research related to this topic reveals that the physiological effects of plus lenses are highly individualized. The purpose of this paper is to reevaluate research on this subject in the context of clinical prescribing.

Physiological Effects of low-Plus Lenses:Manual Muscle Testing and Nearpoint Lens Prescription.

Price RS, Maples WC. Optom Vis Dev 2005;36 (2):93-8.

Background: Nearpoint vision dysfunction and the prescribing of lenses to treat such disorders have long been part of optometry. Various subjective and objective techniques have been developed to determine the optimal lens prescription. Applied kinesiology procedures (manual muscle testing) have been proposed by some practitioners as another aid in determining the appropriate lens power. The purpose of this study was to investigate if manual muscle testing results are affected by the use of low-power plus lenses for near work.

Methods: Fifty-seven fifth grade students were randomized into control and experimental subject groups. Manual muscle testing of the deltoid muscle group was performed by a trained physical therapist as subjects stood with the eyes relaxed looking at distance, then again while reading with their habitual correction and finally while reading with a series of five low-power lenses over the habitual prescription. The experimental group was tested binocularly with low-plus lenses ranging from +0.25 D to +1.25 diopters (D). The control group was tested binocularly with five sets of plano lenses. The muscle tester did not know what lens was used or in which group each subject was assigned. The muscle test results were then compared to Nott dynamic retinoscopy values.

Results: Muscle strength while reading with the habitual correction was significantly lower than baseline strength while looking at distance with the eyes relaxed. The application of certain lowplus lenses while reading resulted in a significant increase in strength (movement toward relaxation) of the experimental group compared to reading with the habitual prescription alone, while mean strength of the control group was not significantly different. Twenty out of 33 subjects showed a favorable muscle test response to low-plus lens use. Of the subjects who had a positive response to the plus lenses, Nott retinoscopy values were within 0.25 D of the best lens as determined by muscle testing for 70% of the subjects.

Conclusion: The data indicate that the demands of reading result in physiological stress and decreased strength by manual muscle testing techniques. Appropriate low-plus lenses may reduce nearpoint stress. Although manual muscle testing may not yield definitive results for every individual, these techniques may be used to complement standard diagnostic procedures for determining optimal nearpoint lens prescription.

A dynamic model of cross-coupling between accommodation and convergence: simulations of step and frequency responses.

Schor CM. *Optom Vis Sci.* 1992 Apr;69(4):258-69.

The near triad consists of an increase in accommodation, vergence, and pupillary constriction. All three motor systems exhibit phasic and tonic responses. The tonic response adapts readily to phasic efforts of accommodation and vergence. Cross-coupling between accommodation and vergence provides a means of dynamically adjusting the tonic set points of the two motor systems to a common near or far working distance. Accommodative vergence cross-links play a dominant role in coordinating proximal changes in accommodation and convergence. The magnitude of cross-link interactions can be modified by imbalanced strength of tonic adaptation by accommodation and vergence. Reducing adaptation of tonic accommodation increases the AC/A ratio and decreases the CA/C ratio. Reducing adaptation of tonic vergence has the opposite effect. A model is able to predict these and other interactions simply by reducing the decay time constant of one of the two motor systems. For example, reducing the time constant for tonic accommodation results in an increased AC/A ratio and decreased CA/C ratio. Reducing the time constant for tonic vergence has the opposite effect. The model predicts transient step responses by accommodative vergence when the AC/A ratio is low and transient step responses of vergence accommodation when the CA/C ratio is low. It also predicts a reciprocal relationship between the AC/A and CA/C ratios. When one cross-link ratio is high the other cross-link ratio is low. Simulated frequency responses predict the low frequency roll off of low AC/A and low CA/C ratios. The step and frequency responses of cross-link ratios are shown to be the same for proximal (perceived distance) and retinal (blur and disparity) stimuli. The model suggests that physiological variations of tonic decay time constants may play an important role in determining clinically abnormal values of AC/A and CA/C ratios.

Adaptive disorders of accommodation and vergence in binocular dysfunction.

Schor C, Horner D *Ophthalmic Physiol Opt.* 1989 Jul;9(3):264-8

Disturbances of binocular vision are described clinically by the Duane-White classification in terms of the magnitude of the accommodative-convergence ratio (AC/A). Convergence excess and convergence insufficiency are assumed to result from high and low AC/A ratios respectively. It is assumed that the abnormal AC/A ratio is an independent variable that underlies abnormal phorias. However, recent studies have demonstrated that the AC/A ratio is inversely related to the adaptability of tonic accommodation (lens adaptation) and directly related to adaptability of tonic vergence (prism adaptation). We have tested whether clinical categories of convergence excess and convergence insufficiency are associated with insufficient and excessive adaptation of tonic accommodation and tonic vergence. Results demonstrate greater amplitude and duration of accommodative after-effects (lens adaptation) in the convergence insufficiency than the convergence excess group. Vergence after-effects (prism adaptation) had the reverse trend for the two groups. These results indicate that adaptive disorders of accommodation and vergence may underlie binocular disorders in symptomatic patients categorized as convergence excess and convergence insufficiency.

Influence of accommodative and vergence adaptation on binocular motor disorders.

Schor C. *Am J Optom Physiol Opt.* 1988 Jun;65(6):464-75.

Tait described four categories of binocular disorders including convergence excess, convergence insufficiency, divergence excess, and divergence insufficiency. These disorders are defined by the distance where the largest heterophoria occurs (distance or near), and the amplitude of the accommodative vergence ratio (AC/A). Insufficiency corresponds to a low AC/A ratio, whereas excess corresponds to a high AC/A. The magnitude of the AC/A ratio, which may be influenced by the adaptability of the accommodation and vergence systems,

has been shown to be reciprocally related to adaptability of accommodation. Likewise, the degree of vergence accommodation has been shown to be related reciprocally to adaptability of vergence to prism. An imbalance of adaptability of accommodation and vergence systems produces abnormal cross-coupling between the two motor systems. When accommodation is more adaptable than vergence, the AC/A ratio is low and the CA/C ratio is high. Conversely, when vergence is more adaptable than accommodation, the AC/A ratio is high and the CA/C ratio is low. A method is reported for temporarily restoring moderate amplitudes of abnormal AC/A and CA/C ratios by reducing excessive adaptation with fatigue. Finally, new clinical procedures for measuring adaptation of accommodation and the CA/C ratio are presented. Taken together with current measures of vergence adaptation and AC/A ratio these procedures will permit a more complete evaluation of mutual interactions between accommodation and vergence in patients diagnosed as having excessive and insufficient vergence.

The Glenn A. Fry award lecture: adaptive regulation of accommodative vergence and vergence accommodation.

Schor CM. Am J Optom Physiol Opt. 1986 Aug;63(8):587-609.

The tonic resting level of accommodation, measured with an objective infrared optometer in an open-loop state (pinhole pupil or empty field), was increased by more than 1.75 D from baseline measures of resting focus after adapting monocularly for 1 min to a 2 D minus lens. The accommodative aftereffect disappeared in darkness, but returned when a visible stimulus reappeared in the open-loop state. Stimulation of disparity vergence with 10 delta, while accommodation was in an open-loop state, also increased the resting focus of accommodation. Similarly, the tonic resting level of vergence became more esophoric after adapting for less than 1 min to base-out prism or to a minus lens presented while the vergence loop was opened. The effects of tonic accommodation on accommodative vergence and the effects of tonic vergence on vergence accommodation were investigated with the temporal frequency responses of the AC/A and CA/C ratios to sinusoidal variations in blur (2 D) and disparity (10 delta), respectively. Accommodative vergence was unresponsive to low temporal frequency sinusoidal variations in blur (less than 0.1 Hz). Similarly, vergence accommodation was unresponsive to low temporal frequency sinusoidal variations in disparity. However, accommodative vergence and vergence accommodation were responsive to higher temporal frequency stimuli (up to 0.5 Hz). When negative feedback to the stimulated system (accommodation or vergence) was cancelled electronically, the low temporal frequency response increased for the AC/A and CA/C ratios, respectively. There was also a nonlinear increase of both AC/A and CA/C ratios as stimulus amplitude increased. It is hypothesized that the nonlinearity resulted from limitations of adaptation to small stimuli. An inverse complementary relation is suggested between the amplitude of the AC/A ratio and adaptable tonic accommodation, and between the amplitude of the CA/C ratio and adaptable tonic vergence. This model predicts that in this complementary relation, adaptable tonic elements would sustain motor responses of accommodation and vergence that were initiated by phasic elements and cross-link interactions. It also predicts that the AC/A and CA/C ratios would decrease in time as dynamic control shifted from the phasic to the adaptable tonic control mechanisms of accommodation and vergence, respectively.

Fatigue of accommodation and vergence modifies their mutual interactions.

Schor CM, Tsuetaki TK Invest Ophthalmol Vis Sci. 1987 Aug;28(8):1250-9.

After effects of accommodation and convergence demonstrate the adaptability of these two visual motor systems. These after effects were reduced after ramp tracking exercises of either accommodation or vergence, and this reduced after effect or fatigue was associated with an increase of accommodative vergence and vergence accommodation. When one motor system (accommodation or vergence) adapted more readily than the other, fatigue caused an increase of the cross-link interaction originating from the more adaptable motor system and a reduction of the cross-link interaction originating from the less adaptable motor system. These

results suggest an inverse relationship between adaptation and the cross-link interactions between accommodation and vergence and that adaptation of tonic accommodation and tonic vergence is a process that underlies plasticity of accommodative vergence and vergence accommodation respectively.

Models of mutual interactions between accommodation and convergence.

Schor CM. Am J Optom Physiol Opt. 1985 Jun;62(6):369-74.

Several possible models of interactions between accommodation and convergence are compared. Accommodative and fusional vergence effort are predicted for each model using the same set of clinical data. Only one model makes predictions that are consistent with clinical and laboratory observations of fixation disparity. The results support the clinical use of graphical analysis of mutual interactions between accommodation and convergence in the diagnosis of accommodative vergence disorders.

Eye movement patterns and reading performance in poor readers: immediate effects of convex lenses indicated by book retinoscopy.

Sohrab-Jam G Am J Optom Physiol Opt. 1976 Nov;53(11):720-6.

Eye movement patterns and reading performance were evaluated in 38 4th and 5th grade male students who were at least 1 year behind in their reading levels. Half of the subjects (Group I) demonstrated a need for convex lenses at near by a book retinoscopy criterion. The remaining subjects (Group II) showed no need for convex lenses at near by the same criterion. The subject's eye movements during reading were recorded by a commercial device called Eye-Trac. These recordings were made with 2 lens applications, plano and +0.50 D, respectively. The number of fixations, regressions, rate of reading, and relative efficiency for each condition (plano and +0.50 D) were calculated. In Group I, 3 of 5 measures showed significant improvement with plus lenses. These subjects showed fewer regressions, increased reading speed, and higher relative efficiency with plus than without. In Group II, 3 of 5 measures showed decrement with plus lenses, while 1 (comprehension) showed improvement. These subjects showed more fixations and regressions and lower relative efficiency with plus than without. It is therefore concluded that convex lenses of low power can have considerable immediate effect on children's reading skills, sometimes helpful and sometimes detrimental, and that proper pretesting with both retinoscopy will aid in the prediction of this effect.

Change in accommodative response & posture induced by nearpoint plus lenses per monocular estimate method retinoscopy.

Tassinari JT. J Behav Optom 2005;16(4) :87-93

Monocular Estimate Method Retinoscopy was used twice to measure the accommodative posture of 211 pre-presbyopic subjects. It was first measured with their farpoint lenses in place, and second, with the farpoint lenses and nearpoint plus lens additions (PLA) in place. The PLAs utilized for the second MEM were based on the binocular cross cylinder findings. The findings from the MEM-twice procedure were used to calculate the change in accommodative response that occurred from the plus lenses. The predominant change was a reduction of accommodation by an amount less than the dioptric power of the PLA, and the mean change was negative accommodation equal to 62% of the PLA. This tendency for incomplete negative accommodation to occur in response to a PLA shifted accommodative posture to less lag or more lead for over 3/4 of the subjects. The changes in accommodative response and posture that are revealed by the MEM-twice procedure are consistent with previous studies of how accommodation changes in response to a nearpoint plus lens. The MEM-twice method is a procedure to determine whether a PLA is indicated or contraindicated for the particular patient.

3. References on the use of prisms

Visual therapy for the traumatic brain injured.

Berne SA: J Optom Vis Dev.21: 13-16,1990

Traumatic brain-injured (TBI) patients often have problems in both binocular vision and visual information processing abilities. In this paper three case studies are presented on the management of TBI patients using visual therapy as a mode of treatment.

Spatial orientation adjustments in children with autism in Hong Kong.

Carmody DP, Kaplan M. Child Psychiatry Hum Dev. 2001 Spring;31(3):233-47.

Abnormal spatial orientation and body postures in children with autism often interfere with visual abilities to attend tasks and social interactions. Twenty-four children diagnosed with autism from Kowloon, Hong Kong were assessed for spatial orientation and spatial management abilities. Positive changes in spatial orientation were evident when the children wore ambient prism lenses and included changes in posture from slanted to erect. Adjustments in spatial management were evident in improved ball catching ability, a task requiring visual tracking and eye-hand coordination. The findings suggest that alterations to the sensory systems may lead to behavioral change in some children.

Addition lens alleviates reading-induced ocular stress.

Choy CK, Siu AW et al Clin Exp Optom 2000 Jan;83(1): 12-15

Near tasks have been associated with binocular stress to induce myopia. The aim of this study was to investigate the effects of accommodation on reading-induced near heterophoria.

Methods:: We measured the near heterophoria of 22 young adults before and after 30 minutes of reading. The reading task comprised a column of local English newsletter studied monocularly at 33 cm. One of three addition lenses (that is, 0.00 D, +1.50 D and +3.00 D) was randomly incorporated into the optical prescription. The difference in near heterophoria between the pre- and post-reading task was recorded. The experiment was completed on separate days for the other lens powers.

Results: Reading for 30 minutes with a plano lens addition (control) increased the near heterophoria by 3.81 +/- 0.95 prism dioptres (SEM) toward exo-deviation ($p < 0.002$). Addition of a +3.00 D lens significantly decreased the reading-induced exophoric shift to 1.36 +/- 0.55 prism dioptres (SEM). Similarly, a +1.50 D lens reduced the exophoric shift to 3.14 +/- 0.85 prism dioptres (SEM) but the difference was not statistically significant when compared with the control.

Conclusions: The results showed that close work might cause eye strain via the extraocular muscles. Incorporation of plus lens into the optical correction caused a power-dependent reduction in the stress, that is, smaller exophoric shift. Whether binocular stress contributes to myopia and its response to addition lens therapy deserve further investigation.

Management of a young esotrope using vision therapy and prismatic prescription.

Christenson GN, Rouse MW. J Am Optom Assoc. 1987 Jul;58(7): 592-6

This case report illustrates the important issues concerning optometric management of the pediatric patient presenting with esotropia. Appropriate treatment options and prognostic factors are covered. The case demonstrates the successful, sequential treatment of a young, early-onset, esotropic patient through vision therapy and prismatic lens prescription.

Improving visually guided action and perception through use of prisms.

Eubank TF, Ooi TL. *Optometry.* 2001 Apr;72(4): 217-27

Severe loss of vision can occur as a result of insults to the visual system. Depending on the level of insult, the patient can experience symptoms ranging from simple loss of visual acuity to more-complex visual motor and perceptual disorders, like visual-field loss and accompanying spatial disorientation, all of which can result in significant restrictions to the patient's mobility. This report describes the therapeutic use of ophthalmic prisms to treat patients with distinct visual impairments. **CASE REPORTS:** The management of four patients, each with visual impairment of unrelated origins (age-related macular degeneration, brain injury, Friedreich's ataxia, stroke) are discussed, with special emphasis on the positive impact of prismatic prescriptions. With each case, we also discuss our reasoning for prescribing the particular prisms and their possible roles. **CONCLUSIONS:** Our clinical reports reinforce the notion that prisms can be effectively used in visual rehabilitation. The modulatory role of prisms is considered in terms of the neurology of the brain and its functions.

A quantitative study of postural shifts induced by yoked prisms.

Gizzi M, Khattar V, Eckert A. *J Optometric Vision Dev,* 12/01/1997, 28(4) p200-203

Spatial neglect occurs in patients with neurological deficits such as stroke, traumatic brain injury, and multiple sclerosis. This neglect of the contralateral half of visual space may be accompanied by a shift of the centre of gravity toward the intact hemi-field. Yoked prisms have been used to correct the shift caused by neglect. We used moving platform posturography to study 8 subjects with normal vision before and after they wore yoked prisms. An approximate 0.75° shift in the centre of gravity toward the prism base was observed. This amount of shift in subjects with normal vision is quite small. Nevertheless, the results suggest that there could be a partial compensation for spatial neglect using yoked prisms.

Development and plasticity of visual and vestibular generated eye movements

Herman R, Maulicci R, Stuyck J. *Exp Brain Res.* 1982; 47:69-78

Slow phase horizontal eye movements, elicited by the vestibulo-ocular reflex (VOR) and/or visual pursuit (VP) systems, were examined in normal children (NC, 9-16 years) and normal adults (NA). At slow frequencies of sinusoidal stimulation of the body (with the head immobilized) and/or of a visual target, the NC (9-12 years) exhibited (a) immature VP and VOR Suppression and mature VOR Enhancement in the presence of a visual image; (b) immature VOR Suppression and mature VOR Enhancement in the presence of a non-visual image of the spatial location of a visual target, an extra-retinal signal; (c) inability to augment or depress the VOR gain with a non-visual image; (d) mature VOR Suppression ratios; and (e) adjustment of VOR gain to a high value. The maturational process was featured by (a) parallel development of VP and VOR Suppression; (b) modification of the VOR gain; and (c) an increasing ability to augment or depress the VOR with a non-visual image. The observations in NC (9-12) are ascribed to a maturational lag of an extra-retinal process interacting with mature retinal and vestibular processes and, hence, suggest that both the retinal and vestibular contributions to ocular stability predate the development of an extra-retinal signal. When mature, the central nervous system utilizes both extra-retinal and retinal signals to mediate adaptive regulation of VOR gain and to preserve stable visual pursuit motion and VOR Suppression. Our findings also suggest that during tasks requiring visual-vestibular interaction, VP and VOR mechanisms appear to be indirectly rather than directly coupled.

Effects of yoked prism on spatial localisation and stereolocalisation,
Hock DR, Coffey B. J Behavioural Optometry, 11/01/2000, 11(6) p143-148

The effects induced by yoked prism on spatial localization and on stereolocalization were assessed using two different two-dimensional spatial localization tasks and a polarized three-dimensional localization apparatus. Subjects were 34 young healthy adults who met entrance criteria related to normal visual function. The subjects wore 15Δ horizontal and vertical yoked prisms and plano control lenses, and measurements were recorded assessing the shift of visual space perception in horizontal (x), vertical (y) and the near-to-far (z) axis. Subjects completed visual motor tasks while wearing the different prisms. With visual feedback denied, the yoked prisms produced significant localization errors in the x-, y- and z- axes. The errors were consistent with the prismatic displacement of visual space, but were less than would be predicted by Prentice's Method. Vertical yoked prism also had a significant effect on stereolocalization accuracy, as measured using the Quoits vectogram in a special apparatus. Base-up yoked prism caused subjects to stereolocalize closer in visual space, both results in reference to the plano control condition. These results provide evidence of alterations in visual space perception associated with wear of yoked prism.

Behavioural changes in autistic individuals as a result of wearing ambient transitional prism lenses.

Kaplan M, Edelson SM, Seip JOL. Child Psych and Human Dev: 29(1), p65-76. 1998

A double-blind crossover design was used to assess the efficacy of wearing ambient lenses to reduce the behavioral symptoms of autism. Eighteen autistic individuals, ranging in age from 7 to 18 years, participated in the study. Behavior, attention, and orientation were evaluated at 1 1/2 months, 2 months, 3 months, and 4 months. Compared to the placebo condition, the results showed a decrease in behavior problems at the 1 1/2 and 2 month assessment periods and a slight loss of these benefits at the 3 and 4 month assessment periods. These findings support the prediction that ambient lenses, worn without engaging in visual-motor exercises, have positive effects on autistic individuals.

The use of yoked base-up and base-in prism for reducing eyestrain at the computer.

Lazarus SM. J Am Optometric Assoc, 04/01/1996, 67(4) p204-208. Erratum in: J Am Optom Assoc 1996 Jun; 67(6):315

Eye strain continues to be one of the chief complaints of people working at video display terminals. The increase in extorsion observed on elevation of gaze at near point may induce binocular disruption and strain. Binocular base-up and base-in prism might mitigate some of the visual complaints of computer users because they decrease the elevation and convergence required. A double blind study of 30 computer users indicates a significantly greater preference for a lens combining prism and plus power than for plus lenses having no prism.

Optometric management of persistent Streff Syndrome with vertical yoked prisms.

Leslie S. J Optometric Vision Dev, 06/01/1994, 25(2) p85-96

Streff syndrome is a common optometric clinical manifestation of reduced visual acuities and other measures of central visual function, usually in a child, with no apparent ocular pathology or refractive error. Optometric management with low plus lenses and vision therapy generally ensures a return to normal visual function in a short time. Children who do not respond fully to lenses and therapy may benefit from application of vertical yoked prisms. Three cases of the use of vertical yoked prisms leading to successful resolution of persistent Streff syndrome are reported; and a model, based on ambient system inhibition of focal processing, is

developed as a rationale to logically explain the signs and symptoms of Streff syndrome, as well as the efficacy of yoked prisms in certain cases.

Duane's Retraction Syndrome and the relief of secondary torticollis and near point asthenopia with prism.

Mende S. J Am Optom Assoc, 1990 Jly;61(7):556-8

A young woman presented with complaints of reading difficulty. An examination revealed that the patient had Duane's Retraction Syndrome--Type III, which affected her right eye. We prescribed yoked prism base left and additional base-in prism for the right eye in a successful attempt to alleviate the patient's symptoms.

Meridional size disparity as a function of compressed inferior visual space: A case report.

Moskowitz W. Percept & Motor skills, 1980, 51:1255-1260

This case report describes a very unusual form of aniseikonia which was eventually documented to be variable within the total field of vision and limited to vertical space perception. Initially the condition could be partially relieved by monocular occlusion, visual training procedure, and the use of isoikonic lenses. Ultimately, the greatest improvement was produced by the introduction of prismatic properties to the lenses which directly addressed the patient's problem of meridional space perception.

Mobility spectacles for a patient with ankylosing spondylitis.

Richer SP, Hall T. Amer J Optom & Physiol Optics, 1986, (63) #11. 927-930

A patient with severe postural deformity and mobility difficulties due to ankylosing spondylitis benefits from specially designed rim-less spectacles incorporating yoked fresnel base-down prisms.

A behavioural approach to vision and autism.

Rose M, Torgerson NG. J Optom Vis Dev: 25:269-275

Autism is a neurological disorder that affects an individual's ability to process information from the senses and multiple areas of the brain. Vision problems are very common in individuals with autism. Vision analysis testing should include ocular health, refractive status, binocularity, ocular motilities, accommodation, vision perception, and visual spatial awareness. Testing procedures include ophthalmoscopy, retinoscopy, photometry, eye movements, and performance tests used to evaluate the need for stress-reducing lenses, and yoked prisms. Treatment may include lenses that compensate for refractive status, plus lenses, yoked prisms in small amounts, and vision therapy. Vision therapy techniques begin with general visual arousal. These include activities where the patient wears red/green glasses, and interacts with moving white targets, and yoked prism activities. The prisms used are of the magnitude of 10 to 15 prism diopters. Much later, the therapy activities change from stimulating the peripheral visual system to including central visual stimuli.

Optometry's role in the treatment of autism.

Schulman RL. J Optom Vis Dev: 25:259-268

Autism involves a global dysfunction in the sensory systems. A review of the characteristics of autism reveals a number of visual behaviours that warrant the optometrist's interest. A case is made for optometric intervention in the form of visual therapy and lens, prism, or filter application, and the optometrist's role as a vision care provider for the patient with autism is outlined.

Vertical yoked prism-patient acceptance and postural adjustment.

Sheedy JE, Parsons SD. Ophthalmic Physiol Opt. 1987;7(3):255-7

Vertical yoked prism is sometimes incorporated into multifocal lenses to obtain a thinner lens, or prescribed for oculomotor deficiencies, or occurs if the vertical placement of spectacle lenses before the eyes is inappropriate. Patient acceptance of and postural and perceptual adaptation to such prism were studied. Twenty-three subjects wore spectacles with no vertical prism and also with bilateral vertical yoked prism. The subject population could not significantly differentiate between 2 delta base down and 0 delta. There was a nearly unanimous rejection of 4 delta base down. Postural changes were significant during 4 delta wear but not during 2 delta wear. The results suggest that 2 delta may be accepted by most patients, but 4 delta will not.

Optometric care for a child manifesting qualities of autism.

Streff JW. J Am Optom Assoc: 46(6), 1975

This paper presents some parallels between the issues relating to our young population's difficulty in vision performance facing optometry in 1976 and medical eye care in the late 1800's. Three specific elements are identified and discussed: namely, (1) difference in practice of optometry and our organizational efforts; (2) the lack of agreed-upon clinical systems; and (3) the lack of availability of care. Suggestion for consideration are presented.

Behavioural attributes of a low plus vertical yoked prism correction: A case study.

Warshowsky JH, FitzGerald DE. J Optometric Vision Dev, 12/01/1999, 30(4) p181-187

This case study addresses the visual and subsequent behavioural impact of a low powered plus lens in combination with vertically yoked prisms for a child presenting with marked fear and anxiety related to her gross motor (body) movements.

Fixation dysfunction with intermittent saccadic intrusions managed by yoked prisms: a case report.

Weissberg E, Lyons SA, Richman JE. Optometry. 2000 Mar; 71(3):183-8.

A 44-year-old woman came to us with a chief symptom of "jumping letters side-to-side, which is most noticeable while reading." The onset occurred after she had experienced a closed head traumatic brain injury 3 years earlier. Several neuro-ophthalmologists diagnosed a fixational instability secondary to saccadic intrusions and prescribed Gabapentin, which provided minimal relief. METHODS: The term saccadic intrusions refers to an inappropriate saccade with a disrupting effect on fixation. Our examination revealed a myopic anisometropia. Motility testing confirmed saccadic intrusions that lessened on occlusion of either eye and superior gaze. A plano spectacle with six-prism diopter-yoked base down was used to position the eyes in the superior null point. Electro-oculography, using the Visagraph II, demonstrated pre and post changes with the prism. The uncorrected anisometropia

allowed the patient to be monocular under binocular viewing conditions. **CASE REPORT:** The case report focuses on fixational problems that may occur secondary to traumatic brain injuries. There is evidence that the origin of the problem may be from uninhibited brain stem circuits. Pharmacological treatment may only offer transient improvement. The responsibility of a functional cure is often placed on the optometrist. **CONCLUSION:** This case demonstrates how an alternative use of prism and prescription application can play an important role in the management of fixation dysfunctions.

Effects of using prismatic eye lenses on posture of patients with adolescent idiopathic scoliosis measured by 3D motion analysis.

Wong MS, Mak AFT, Luk KK, Evans JL, Brown B. Prosthetic Orthot Int.2002.Aug;26(2): 139-53

This is a preliminary investigation to detect the body sway and postural changes of patients with AIS under different spatial images. Two pairs of low-power prismatic eye lenses (Fresnel prisms) with 5 dioptre and 10 dioptre were used. In the experiment, the apices of the prisms were orientated randomly at every 22.5 degrees from 0 degrees to 360 degrees to test changes. Four patients with mean age of 11 and Cobb's angle of 30 degrees were recruited and the results showed that the low-power prisms at specific orientations (157.5 degrees and 180 degrees) could cause positive postural changes (2.1 degrees-2.7 degrees reduction of angle of trunk mis-alignment) measured by 3-D motion analysis. This might be used for controlling their scoliotic curves by induced visual bio-feedback. Apart from this laboratory test, a longitudinal study is necessary to investigate the long-term effect of the prisms at different powers and orientations (under both static and dynamic situations) on the patient's posture, spinal muscular activities, vision, eye-hand coordination, psychological state and other daily activities before it becomes an alternative management of AIS.

4. References on the role of Optometric Vision Therapy (OVT) in vergence and accommodation disorders

(a) Accommodative Dysfunctions

Orthoptic treatment of subjects showing slow accommodative responses.

Bobier WR, Sivak JG. American Journal of Optometry & Physiological Optics, 60:678-687, 1983.

Abstract: five subjects showing slow accommodative responses were given orthoptic (vision therapy) treatment. Speed of accommodative response improved after 3 to 6 weeks. No regressions were evident 18 weeks after the cessation of training. The results of the study indicate that vision therapy is effective in improving slow accommodative responses.

Association of Symptoms and Convergence and Accommodative Insufficiency in School-Age Children.

Borsting E., Rouse MW, et al. Optometry 2003; 74: 25-34.

392 children, age 8 to 15 years, participated in testing for Convergence Insufficiency and Accommodative Insufficiency. It was found that Convergence Insufficiency and Accommodative Insufficiency are common in school-age children and are associated with increased symptoms.

Vision Therapy in a School Setting.

Brodney AC, Pozil R, Mallinson K, Kehoe P. Journal of Behavioral Optometry, 12(4):99-103, 2001.)

Abstract: The purpose of the present study was to evaluate the effects of vision therapy in a school setting in which elementary school children, enrolled in a reading-mentoring program, Caring Adults Teaching Children How (CATCH), were trained as a group. The experimental goal was to improve visual-motor and visual perceptual skills, with the use of vision therapy in short sessions given weekly at school, to children with reading difficulties. Sixty students were selected after the use of the Developmental Eye Movement test's (DEM) exclusion criteria and were randomly assigned into one of two groups: vision therapy and non-therapy. Both groups received CATCH tutorial visits once a week for 50 minutes. In addition, the therapy group received a weekly 30 minute activity session in which three activities were completed from the following: oculomotor, accommodation, binocularity, visual motor and visual memory. The results revealed that vertical and horizontal eye movements and accommodative facility were significantly improved after 22 sessions of group vision therapy. These improvements were related to attentional mechanisms leading to improved reading abilities. We believe this preliminary study gives evidence of the advantages of a program whereby vision therapy is provided in the elementary school setting to advance deficient visual skills that are related to learning and cognitive enhancement.

The Scientific Basis for and Efficacy of Optometric Vision Therapy in Nonstrabismic Accommodative and Vergence Disorders. Orthoptic treatment of subjects showing slow accommodative responses.

Bobier WR, Sivak JG. Am J Optom Physiol Opt, 60:678-87, 1983.

Abstract: five subjects showing slow accommodative responses were given orthoptic (vision therapy) treatment. Speed of accommodative response improved after 3 to 6 weeks. No regressions were evident 18 weeks after the cessation of training. The results of the study indicate that vision therapy is effective in improving slow accommodative responses.

Measuring ADHD behaviors in children with symptomatic accommodative dysfunction or convergence insufficiency: a preliminary study.

Borsting E, Rouse M, Chu R. Optom 2005;76(10) ;588- 92.

Background: Accommodative dysfunction and convergence insufficiency (CI) are common pediatric vision problems that have been associated with an increase in frequency and severity of vision-specific symptoms that affect children when doing schoolwork. However, the relationship between accommodative dysfunction and CI and other learning problems, such as attention deficit hyperactivity disorder (ADHD), are not well understood. The purpose of this study was to evaluate the frequency of ADHD behaviors in school-aged children with symptomatic accommodative dysfunction or CI.

Methods: Children 8 to 15 years of age with symptomatic accommodative dysfunction or CI were recruited from the teaching clinic at the Southern California College of Optometry. Children with learning disabilities or ADHD were excluded. One parent of each child completed the Conners Parent Rating Scale- Revised Short Form (CPRS-R:S). The children's scores on the CPRS-R:S were compared with the normative sample.

Results: Twenty-four children (9 boys and 15 girls) participated in the study with a mean age of 10.93 years (SD =1.75). On the CPRS-R:S, cognitive problem/inattention, hyperactivity, and ADHD index were significantly different from normative values ($p < \text{or} = .001$ for all tests).

Conclusions: The results from this preliminary study suggest that school-aged children with symptomatic accommodative dysfunction or CI have a higher frequency of behaviors related to school performance and attention as measured by the CPRS-RS.

The scientific basis for and efficacy of optometric vision therapy in nonstrabismic accommodative and vergence disorders.

Ciuffreda, KJ. Optometry 2002; 73: 735-62

Background: For nearly 75 years, optometric vision therapy has been an important mode of therapy for both children and adults who manifested a range of nonstrabismic accommodative and vergence disorders.

Methods: In this article, the scientific basis for, and efficacy of, optometric vision therapy in such patients will be discussed. Using bio-engineering models of the oculomotor system as the conceptual framework, emphasis will be focused on studies that used objective recording techniques to directly assess therapeutically related changes in oculomotor responsivity.

Results and conclusions: The findings clearly support the validity of optometric vision therapy. Furthermore, the results are consistent with the tenets of general motor learning.

Reduction of asthenopia after accommodative facility training.

Cooper J, Feldman J, Selenow A, et. al. Am J Optom & Physiol Optics, 64 (6): 430-436, 1987.

Five patients reporting asthenopia secondary to accommodative deficiencies underwent automated accommodative facility training. A matched-subjects, crossover design was used to control for placebo effects. All patients receiving automated accommodative training showed a marked increase in accommodative amplitude along with a concurrent reduction of asthenopia. Decreases of blur and increased reading time were the most frequently reported changes by patients. This study showed the effectiveness of automated accommodative training in reducing asthenopia and improving accommodative facility.

Accommodative insufficiency.

Daum KM. American Journal of Optometry & Physiological Optics, 60:352-359, 1983.

Abstract: A retrospective review of the records of 96 patients with accommodative insufficiency was conducted. The results of orthoptic exercises and/or a plus lens addition at near were examined. Most patients (90%) obtained some relief with treatment. About 53% had their objective and subjective problems totally solved during an average treatment period of 3.7 weeks.

Clinical management of nearpoint stress-induced vision problems.

Gruning CF. American Journal of Optometry & Physiological Optics, June;62(6):386-391, 1985.)

Abstract: Functional vision problems caused by or associated with nearpoint vision stress include: accommodative disorders (insufficiency, ill-sustained, infacility); abnormal heterophorias (esophoria, high exophoria); and vergence disorders. These vision disorders cause problems with acuity, comfort, and performance (efficiency). A combination of lens prescribing, vision therapy, and work/study visual hygiene recommendations can eliminate or greatly reduce nearpoint stress-induced vision problems.

Effectiveness of optometric vision therapy/orthoptics in a private practice.

Hoffman L, Cohen AH, Feuer G. American Journal of Optometry, 50: 813-816, 1973.

Abstract: In 87 percent of the patients with accommodative anomalies eliminated their asthenopia (eyestrain) and normalized their accommodative findings after approximately 26 therapy sessions.

The effect of accommodative deficiencies on the developmental level of perceptual skills.

Hofman LG. Am J Optom Physiol Opt, 59:254-62, 1982.

Abstract: The relation of accommodative to visual-motor perceptual abilities was investigated. Patients between 5 and 13 years of age manifesting both accommodative and visual-motor perceptual deficits were given accommodative therapy. The effect of this therapy was analyzed, and the results indicated that improvement in the visual and motor perceptual abilities occurred in the 5 to 7 years, 11 month age group.

Static vergence and accommodation and orthoptics effects.

Hung GK, Ciuffreda. KJ, Semmlow JL. *Doc Ophthalmol*, 62: 165-179, 1986.

This study evaluated changes in vergence and accommodative systems in two populations: 22 visually-normal asymptomatic individuals and 21 visually-abnormal symptomatic individuals before and after conventional orthoptic therapy. Symptomatic subjects were placed into one of three training groups depending on clinical abnormalities and symptoms. The training period ranged from 8 to 16 weeks. Long term follow-up testing was performed 6 to 9 months after the training ended. Symptomatic individuals showed a shift toward the mean of visually-normal asymptomatic subjects following training. The long term results showed a maintenance of the initial post-training improvement. The efficacy of orthoptic treatment was indicated by a large reduction in overall symptom rating level.

Objective assessment of accommodation orthoptics. I. Dynamic insufficiency.

Liu JS, Lee M, Jang J, et. al. *Am J Optom & Physiol Optics*, 56 (5): 285-294, 1979.

Three young adult females with symptoms related to focusing difficulties at near were treated by standard orthoptic (vision therapy) procedures. Home training was done 20 minutes each day for 4 ½ to 7 weeks. Objective measures of dynamic accommodation were made each week. During treatment, the patients showed significant reductions in time constants and latencies of accommodation. That correlated well with elimination of subjective symptoms. Also, in all three patients, symptoms were either markedly diminished or no longer present at termination of therapy. These results clearly demonstrate that orthoptic treatment in three adult patients resulted in objective improvement of accommodation function.

Accommodative insufficiency is the primary source of symptoms in children diagnosed with convergence insufficiency.

Marran LF, De Land PN, Nguyen AL. *Optom Vis Sci*. 2006 May;83(5):281-9.

Purpose: Accommodative insufficiency (AI) and convergence insufficiency (CI) have been associated with similar symptomology and frequently present at the same time. The severity of symptomology in CI has been linked to the severity of the CI, suggesting a dose-dependent relationship. However, with increasing severity of CI also comes increased comorbidity of AI. AI alone has been shown to cause significant symptomology. We hypothesize that AI drives the symptoms in CI with a comorbid AI condition (CIwAI) and that it is the increased coincidence of AI, rather than increased severity of CI, which causes additional symptomology.

Methods: Elementary school children (n = 299) participated in a vision screening that included tests for CI and AI and the CISS-V15 symptom survey. They were categorized into four groups: 1) normal binocular vision (NBV); 2) AI-only; 3) CI-only; and 4) CIwAI. One hundred seventy elementary school children fell into the categories of interest.

Results: Pairwise comparison of the group means on the symptom survey showed: 1) children with AI-only (mean = 19.7, p = 0.006) and children with CIwAI (mean = 22.8, p = 0.001) had significantly higher symptom scores than children with NBV (mean = 10.3); and 2) children with CI-only (mean = 12.9, p = 0.54) had a similar symptom score to children with NBV. Using a two-factor analysis of variance (AI and CI), the AI effect was significant (AI mean = 21.56; no AI mean = 11.56, p < 0.001), whereas neither the CI effect (p = 0.16) nor the CI by AI interaction effect (p = 0.66) were significant.

Conclusion: CI is a separate and unique clinical condition and can occur without a comorbid AI condition, our CI-only group. Past reports of high symptom scores for children with CI are the result of the presence of AI, a common comorbid condition. When AI is factored out, and children with CI only are evaluated, they are not significantly more symptomatic than children with NBV.

Accommodative lag using dynamic retinoscopy: age norms for school-age children.

McClelland JF, Saunders KJ. *Optom Vis Sci* 2004;81(12):929-33.

Background: Nott dynamic retinoscopy (DR) is a technique that provides an objective, rapid assessment of accommodative function. Presently there are no data available regarding age norms of accommodative function for school-age children using Nott DR.

Methods: Accommodative responses were assessed in a group of 125 school-age children (4 to 15 years of age) using Nott DR. A range of accommodative demands was included [4 D (25 cm), 6 D (16.7 cm), and 10 D (10 cm)]. All the subjects had fully corrected refractive errors and a binocular visual acuity of at least 6/6.

Results: Accommodative responses were assessed successfully at each distance with all the subjects (N = 125). A mean overall lag of accommodation was noted with each age group at each distance tested. Regression analysis demonstrated no significant difference in accommodative responses between age groups ($p = 0.531$ at 4 D, $p = 0.062$ at 6 D, and $p = 0.883$ at 10 D). Therefore, results for all the age categories were grouped together to produce a table of normal ranges of accommodation for children aged 4 to 15 years for the three stimuli demands. The mean lag of accommodation was found to be 0.30 ± 0.39 D at 4 D, 0.74 ± 0.58 D at 6 D, and 2.50 ± 1.27 D at 10 D. The normal ranges of accommodation (95% confidence limits) were 2.94 to 4.46 D at 4 D, 4.12 to 6.40 D at 6 D, and 5.02 to 10.00 D at 10 D.

Conclusions: A comprehensive table has been produced detailing the mean lags and normal ranges of accommodative responses expected for school-age children when using Nott DR. These data allow practitioners and researchers to determine whether accommodative responses measured using Nott DR are within normal limits.

Management of binocular anomalies: efficacy of vision therapy in the treatment of accommodative deficiencies.

Rouse MW. *American Journal of Optometry & Physiological Optics*, Jun;64(6): 415-420, 1987

Abstract: This paper is a review of the literature supporting vision therapy as an effective treatment mode for accommodative deficiencies. Vision therapy procedures have been shown to improve accommodative function effectively and eliminate or reduce associated symptoms. In addition, the actual physiological accommodative response variables modified by the therapy have been identified, eliminating the possibility of Hawthorne or placebo effects accounting for treatment success. Finally, the improved accommodative function appears to be fairly durable after treatment.

Accommodative facility training with a long term follow up in a sample of school aged children showing accommodative dysfunction.

Sterner B, Abrahamsson M, Sjostrom A. *Doc Ophthalmol* 99:93-101, 1999.

Abstract: The purpose of this study was to evaluate the effect of accommodative training in a group of children with accommodative dysfunction and subjective symptoms. A total of 38 symptomatic children (ages nine to thirteen) and 24 controls, participated in the study. The length of training varied from 3 to 25 weeks. A follow-up examination was performed two years after the end of training. The study showed that it is possible to increase relative accommodative by accommodative facility training and minimize subjective symptoms. In the follow-up evaluation, none of the children had regained any subjective symptoms.

The efficacy of visual therapy: accommodative disorders and non-strabismic anomalies of binocular vision.

Suchoff IB, Petito GT. J Am Optom Assoc, 57 (2): 119-125, 1986

This paper examines the available literature in order to answer the question, "Is there evidence that 'orthoptics' or 'vision therapy' causes changes in an individual's accommodative or vergence eye movement systems?" The literature cited substantiates that visual therapy can modify visual functions and also points out the relationship of these changes to the relief of certain symptoms.

Stimulating human accommodation without changes in focus.

Weiss M, Seidemann A, Schaeffel F. Ophthal Physiol Opt. 2004;24(3):207-7.

Purpose: Inspired by the finding in chickens that preferential stimulation of the ON retinal system suppresses myopia induced by negative spectacle lens wear and that stimulation of the OFF system suppresses the hyperopia induced by positive lens wear, the authors sought to determine whether stimulation of the ON-OFF retinal systems could drive directional accommodation responses in humans. If emmetropization and accommodation use similar image processing algorithms, more accommodation would be expected with OFF stimulation.

Methods: Accommodation responses were measured while viewing a computer-generated pattern designed to stimulate the ON-OFF systems. The stimulus comprised a rectangular field (12 x 9.5 cm) on a black background filled with 196 discs (diameters: 0.4-1.0 cm). These were presented on an LCD monitor in a dark room at a viewing distance of 55 cm (1.8 D). Thirteen subjects aged 21-37 years took part. The individual discs had saw-tooth shaped temporal luminance profiles with the same time period but with random phases with respect to each other, so that the mean brightness of the stimulus was constant. To eliminate accommodation responses based on other cues (i.e., proximity) a 0.5 mm artificial pupil was used to open the accommodation loop. Refraction in the vertical pupil meridian was continuously recorded with an infrared photorefractor (the PowerRefractor). To verify that computer-based stimuli presented within our experimental design were effective in driving accommodation, previously studied stimuli were also tested: changes in size (looming) and incremental low pass filtering.

Results: Preferential stimulation of the ON or OFF subsystems produced a convincing depth illusion in all subjects (which was psychophysically confirmed in four subjects). Although the stimulus appeared to move in depth it did not produce accommodation responses that were consistent with that, i.e. the accommodation system did not appear to fluctuate in rhythm with the temporal oscillations of the stimulus. As the target appeared to loom it induced a greater accommodation response than when it appeared to recede. The looming target produced changes in the accommodation response in nine of 13 subjects that were consistent with its perceived change in proximity (although the target did not actually move in depth). Incremental low pass filtering produced non-directional drifts of accommodation in all subjects. Combinations of the stimuli (i.e., looming and low pass filtering, ON/OFF and looming) were not more effective stimuli to accommodation. After removal of the artificial pupil (closed loop conditions), accommodation was no longer induced with any of these stimuli.

Conclusions: Although the preferential ON or OFF stimulation produced a pronounced illusion of motion in depth despite constant average brightness, proximal accommodation was induced in only one subject. Therefore, the ON/OFF stimulation appeared to have only minor input into proximal accommodation. Potential inputs into reflex accommodation need to be defined in further studies.

Clinical therapy for accommodative responses: Transfer effects upon performance.

Weisz CL. J Am Opt Assn, 50 (2): 209, 1979.

A clinical therapy program featuring accommodative training was administered to a group of children with diagnosed disorders of accommodative function. The children ranged in age

from six to twelve years. A group of subjects representing the same clinical population, and not differing significantly in age or grade level, acted as a control group. The control subjects participated in a therapy program of a similar duration, wherein perceptual-motor training (unrelated to the training of accommodative skills) was administered. A nearpoint pencil-and-paper task was administered to all subjects before and after the training programs, to assess changes in performance as criterion of learning transfer and behavioral generalization. A significantly greater decrease in errors occurred in the group receiving the accommodative training as contrasted to the control group. No significant differences were found in the time scores. The results suggest that accommodative training for children with diagnosed accommodative disorders, had transfer effects upon nearpoint performance relating to improved accuracy.

Effectiveness of optometric vision therapy.

Wold RM, Pierce JR, Keddington J. Journal of the American Optometric Association, 49: 1047-1059, 1978.

The study reported on 100 children who had undergone accommodative vision therapy procedures. These clinically selected cases showed an 80% rate of improvement in accommodative amplitude (the eye's ability to focus clearly on objects at near distances) and 76% in accommodative facility (the eye's ability to adjust focus on objects with various distances).

(b) Binocular Dysfunctions

Binocular dysfunctions include Convergence Insufficiency, Convergence Excess, Fusional Vergence Dysfunction, Esophoria, and Exophoria.

Efficacy of treatment for convergence insufficiency using vision therapy

Adler, P. Ophthal Physiol Optics, **22**, p568. (2002)

Purpose: The purpose of this study was to determine if vision therapy (VT), as practised within the constraints of UK optometric practice, employing graded routine eye exercises, is as an effective method for treatment of convergence insufficiency (CI) as previously published data suggest. The study also evaluates the associated symptoms before and after therapy.

Methods: As many optometrists diagnose CI solely on the basis of near point of convergence (NPC) and treat only when symptoms are present (Letourneau et al., 1979; Rouse et al., 1997), in this study CI was defined as NPC of 10 cm or greater (either with or without the presence of asthenopic symptoms for near work) accompanied by exophoria greater at near than at distance. The effect of treatment by optometric vision therapy (OVT) on the NPC and number of symptoms was investigated for 92 patients by retrospectively reviewing the clinical records. Success was defined as the restoration of NPC to normal values and significant reduction in the presenting symptoms.

Results: The effect of treatment on the NPC was shown to be highly significant ($t = 14.61$, $p < 0.001$). Although treatment times were slightly longer, the success rates were higher than reported by other authors. Post-treatment values for NPC were: <10 cm (98.9%), <8.5 cm (95.7%) and <6.5 cm (80.4%). Longer treatment times were noted for patients who complained that the text appeared to move (χ^2 , $p = 0.007$).

Conclusion: Vision therapy is an effective method for treatment of CI.

A randomized prospective masked and matched comparative study of orthoptic treatment versus conventional reading tutoring treatment for reading disabilities in 62 children.

Atzmon D, Nemet P, et al. *Binocular Vision & Eye Muscle Surgery Quarterly*, 8(2):p. 91-106, 1993.

Abstract: Controversies remain whether orthoptics and/or "visual training" can remedy reading disabilities. Therefore, and to extend our prior studies, we undertook a comparative and controlled study. One hundred and twenty children with reading disability were tested extensively, matched and randomly divided into three groups: orthoptic, conventional (reading tutoring), and no-treatment control. Unfortunately, participants in the control group were unable to adhere to no-treatment and were deleted. Each of the 40 children in the first two groups had 40 sessions, 20 minutes daily.

Orthoptic treatment was directed to markedly increasing fusional convergence amplitudes for both near and distance to 60 D. The two treatments were also carefully matched in time and effort. Sixty-two children in 31 matched pairs completed the course of treatment and testing. The results were equal and statistically significant ($P < .05$) marked improvement in reading performance in both treatment groups on essentially all tests.

Orthoptic treatment, to increase convergence amplitudes to 60 D, is as effective as conventional in-school reading tutoring treatment of reading disabilities. An advantage of orthoptic treatment was that subjective reading and asthenopic symptoms (excessive tearing, itching, burning, visual fatigue, and headache) virtually disappeared after orthoptics. We recommend orthoptic treatment as: 1) an effective alternate primary treatment; 2) adjunctive treatment for those who do not respond well to standard treatment; and 3) as primary treatment in any case with asthenopic symptoms of /or convergence inadequacy.

Letter regarding the study above:

Dr. Firmon E. Hardenbergh, Chief of Ophthalmology and Ophthalmologist to the Harvard University Health Services wrote a letter on March 29, 1991 regarding orthoptic treatment and convergence insufficiency. This letter appeared in the journal of *Binocular Vision and Eye Muscle Surgery Quarterly* in the Spring of 1993.

"I have reviewed the report by Daniela Atzmon and Professor P. Nemet on the subject of the results of a study on the effect of orthoptic exercises on the academic performance of learning/reading disabled children with convergence insufficiency. In my opinion, this prospective study was well planned and is essentially double blinded since the reading testing was not administered by either the tutors or the orthoptists.

The results support the proposition that application of orthoptics to all learning/reading disabled or deficient children who manifest convergence insufficiency should be the first line of therapy. If reading ability does not improve significantly within four to six months, other interventions should then be instituted."

Efficacy of vision therapy for convergence insufficiency in an adult male population.

Birnbaum MH, Soden R, Cohen AH. *Journal of the American Optometric Association*, April; 70(4): 225-232, 1999

Background: Although vision therapy has reportedly been very successful in elimination of asthenopic symptoms (excessive tearing, itching, burning, visual fatigue, and headache) in adults with convergence insufficiency, controlled studies have not been performed, and a clinical bias exists against prescribing vision therapy for adults with convergence insufficiency.

Methods: Sixty adult males over the age of 40 years (median age, 65 years) with convergence insufficiency were divided into three treatment groups: office-based vision therapy with supplementary home therapy, home therapy only, and a control group.

Results: Vision therapy was successful in 61.9% of patients who received in-office plus home therapy, in 30% of patients who received home therapy only, and in 10.5% of the control group. The success rate for patients who received active in-office vision therapy

supplemented with home procedures was significantly greater than that for controls. Home therapy alone was less successful than in-office therapy. The success rate obtained with home therapy alone was not significantly greater than that demonstrated by controls.

Conclusions: Vision therapy is effective in eliminating asthenopia (eyestrain) and improving convergence function in adult patients. In-office therapy combined with home therapy tends to produce better results than does home therapy alone.

Comparison of near visual function changes after near task between myopes and emmetropes.

Chen AH, Othman R. Canadian J Optom 2004;66(1):19-24.

Background: The purpose of this study was to compare the near visual function changes in five positions of gaze after near task between myopes and emmetropes.

Methods: Thirty university students were divided into two refractive groups of fifteen each: myopia and emmetropia. The near point of convergence, monocular amplitude of spectacle accommodation and near heterophoria of each subject were measured in five positions of gaze (primary, levo, dextro, depressed and elevated positions) before and after 30 minutes of copying N10 text at 20cm working distance under room illumination (200 lux).

Results: Our results showed that changes in three aspects of the near visual function in five positions of gaze after near task were insignificant in myopes ($p>0.05$). The changes after near task were also insignificant for the monocular amplitude of spectacle accommodation and the near heterophoria in emmetropes ($p>0.05$). However, the nearpoint of convergence became significantly more remote after near task in primary position and depressed position ($p<0.05$) in emmetropes. The unpaired t-test showed no significant difference between myopes and emmetropes in the amount of binocular vision changes for all five positions of gaze.

Conclusion: Emmetropes revealed significantly more remote near point of convergence in the depressed and primary positions after near task.

Effectiveness of visual therapy for convergence insufficiencies for an adult population.

Cohen AH, Soden R. J Am Optom Assoc, 55(70): 491-494, 1984.

Visual therapy is an effective treatment modality for convergence anomalies. Complaints of blurred vision, diplopia, headaches, and asthenopia associated with convergence insufficiencies can be alleviated for most patients regardless of age. Once the basic reflexes of convergence are established, there seems to be a high level of long-term success.

Review of computerized orthoptics with specific regard to convergence insufficiency.

Cooper J. Am J Optom Physiol Opt, 65:448-54, 1988.

Abstract: Traditional vision training or orthoptics has used line or contour targets to eliminate suppression and improve vergence performance. Manipulation of these stimuli is slow and arduous. Line stimuli require an experienced doctor/technician to interpret responses. Recently, automated vision training using microprocessor anaglyph stimuli, i.e., random dot stereograms (RDS), has been used in an operant conditioning paradigm. This technique had improved motivation of the patient, improved reliability, and provided standardization of therapy. In addition, the utilization of RDS associated with operant conditioning has been shown to improve vergence performance and to reduce asthenopia in the convergence insufficiency patient.

Reduction of asthenopia in patients with convergence insufficiency after fusional vergence training.

Cooper J, Selenow A, et. al. Am J Optom & Physiol Optics, 60(12): 982-989, 1983.

Seven patients with convergence insufficiency and related asthenopia underwent automated fusional convergence training. A matched subjects control group crossover design was used to reduce placebo effects. All patients showed significant increases in vergence ranges with concurrent marked reduction of symptoms after training. Results demonstrated the effectiveness of fusional vergence training in reducing asthenopia in these patients. Subsequent accommodation and vergence training using traditional orthoptic procedures yielded further reduction of asthenopia, as well as an increase in the base-out fusional range.

Convergence insufficiency: incidence, diagnosis, and treatment.

Cooper J, Duckman R. J Am Optom Assoc, 49:673-8, 1978.

Abstract: Convergence insufficiency is one of the most common ocular problems. The paper carefully reviews the existing literature relating to etiology, diagnosis, sensory finding, treatment, and treatment results. Vision therapy for convergence insufficiency has been shown to be effective in reducing symptoms and improving vergence abilities.

Effect of vision training on Patients who fail Sheard's criterion.

Dalziel CC. Am J Optom Physiol Opt, 58:21-3, 1981.

Abstract: One hundred convergence insufficiency patients who did not meet Sheard's criterion at near were given a program of in-office and at-home training. The objective was to see if they would meet Sheard's criterion after training. Results were analyzed in terms of the numbers successfully meeting this criterion as well as other criteria, i.e., Percival's elimination of symptoms, improvement of stereopsis, and elimination of fixation disparity. Of the 100 patients, 84 successfully met Sheard's criterion correlated well with having subjective symptoms.

Horizon and vertical vergence training and its effect on vergences and fixation disparity curves: I. Horizontal data.

Daum KM, Rutstein RP, et al. Am J Optom Physiol Opt, 65:1-7, 1988.

Abstract: The purpose of this study was to assess the effects of horizontal and vertical vergence training on fusional vergencies and the fixation disparity (FD) curve. Thirty-four subjects were divided into three groups. One-third served as controls and the other two-thirds underwent 5 hours of supervised horizontal and vertical vergence training, respectively. Before and after the 4-week training period, vergences and FD curves were measured by a single individual who was intentionally uniformed of each subject's group. Analysis revealed that the positive vergences increased significantly for those in the horizontal group. No evidence was found to suggest changes in any variable related to the FD curve.

Efficacy of computerized vergence therapy.

Daum KM, Rutstein RP, Eskridge JB. Am J Optom Physiol Opt, 64:83-9, 1987

Abstract: The purpose of this study was to determine the efficacy of computerized fusional vergence therapy and the effect of two different vergence-training velocities. Six subjects received positive vergence training using a slow vergence training rate (0.75/s) and six subjects received positive vergence training using a fast vergence-training rate (5.00/s). Six subjects served as controls and did not receive therapy. The duration of therapy was 80 min over a period of 4 weeks. All training activities were monitored. All vergence evaluations were double masked. Subjects using a slow training rate showed significant increases in positive vergence ranges as measured with the major amblyoscope, whereas subjects training with

fast rates did not. Vergence therapy using computerized video display is an effective technique for increasing the amplitudes of positive fusional vergence and slower rates are more productive than faster rates.

Double-blind placebo-controlled examination of timing effects in the training of positive vergences.

Daum K. Am J Optom Physiol Opt, 63:807-12, 1986.

Abstract: The purpose of this study was to document the effects of positive fusional vergence therapy and to determine the most effective timing of such training. Four experimental protocols were selected and five subjects were assigned randomly to each of the four experimental groups. Each subject in each group spent 120 min (total) over a period of 3 weeks doing positive fusional vergence training. Group A trained in twelve 10-min sessions; group B in six 20-min sessions; and group C in three 40min sessions. Group D was a control group. All the training was in-office and consisted of positive fusional vergence training on the synoptophore. Each of the test groups showed increases in their positive fusional vergence ability at both distance and near. Group A (shorter sessions) demonstrated the largest increases overall. In addition, the group that trained in short 10-min session (group A) was the only one that showed significant increases in the negative fusional vergences and the positive blur finding. It is best to use short, frequent training sessions to increase the amplitude of positive fusional vergence.

Negative vergence training in humans.

Daum KM. Am J Optom Physiol Opt, 63:487-96, 1986.

Abstract: Two healthy subjects (male and female, ages 22 and 25 years) spent 50 hours over a period of 7 consecutive weeks training the negative vergence system. The training was performed in two 45-min daily sessions, usually immediately before and after the workday. The training was exclusively negative vergence training using a device such as variable vectograms, the aperture rule, the synoptophore, and loose or bar prisms. An extensive examination of the visual systems before after, and periodically during the training demonstrated that the negative vergences increased at distance by 5.0* and at near by 9.1* (using hand-held prisms, bar prisms and the synoptophore). The phorias of both subjects became more exophoric or less esophoric at both distance and near by 3.6*. A haploscope equipped with a coincidence optometer showed only small increases in vergence amplitude but confirmed that the lag of accommodation became more stable after the training than it was before. Other testing suggested that the negative relative accommodation, the angle of deviation at both distance and near, positive vergences, the associated phoria, and the slope of the fixation disparity curve changed significantly over the period of training. Negative vergence training can increase the negative vergence capabilities and also affect the phoria position of the eyes via feedback into the slow vergence system.

Characteristics of exodeviations: II. Changes with treatment with orthoptics.

Daum KM. Am J Optom Physiol Opt, 63:244-51, 1986.

Abstract: This study examines retrospectively the records of 179 patients who had binocular visual dysfunction as a result of an exodeviation (either at distance or near or both). The patients were classified as having convergence insufficiency (N=110), equal exodeviations (N=49), or divergence excess (N=18). The diagnostic groups and the different frequencies of deviation reacted differently to treatment with a standard orthoptic regimen. Nearly all the patients (97%) achieved some improvement in either objective or subjective areas or both. However, fewer were able to satisfy the criteria set for total success. Factors correlated with the success of the treatment were the initial angle of deviation at distance and the initial level of stereopsis. The results and implications of this study are discussed.

Convergence insufficiency.

Daum KM. Am J Optom Physiol Opt, 61:16-22, 1984.

Abstract: A retrospective study of 110 subjects with convergence insufficiency was completed. Their mean age was 19.9 years. There were 72 females and 38 males in the group. The clinical profiles of these subjects were examined before and after a standard orthoptic treatment regimen. Over the course of treatment, the near angle of deviation, the AC/A ratio, a portion of the negative vergence values, the nearpoint of convergence, and the amplitude of accommodation were found to have changed in a statistically significant manner.

The course and effect of visual training on the vergence system.

Daum KM. Am J Optom Physiol Opt, 59:223-7, 1982.

Abstract: The effect of a variety of vergence training procedures on the visual system of 35 asymptomatic young adults with normal binocularity was evaluated. Vergence ranges were measured before the study began and at the end of the 3-week period. Sub-populations were evaluated at one week and at 6 months to document further the course of the effects. Positive fusional vergence training significantly increased the vergence ranges after 1 week of training; a greater effect was measured after 3 weeks. The vergence capability was found to have decreased 6 months later, but the effects of the training were still apparent. Negative fusional vergence training was less effective; however, significant increases were demonstrable after 3 weeks of training. The phorias and accommodative amplitude were not affected by the orthoptics. Relatively short periods of training can provide long-lasting increases in the vergence ability of a group of binocular normals.

Vision training: predictive factors for success in visual therapy for patients with convergence excess.

Ficarra AP, Berman JB, Rosenfield M, Portello JK. J Optom Vision Dev 27 (4): 213-219, 1996.

A retrospective study was conducted of 31 patients who had received vision therapy for convergence excess. The mean number of training sessions was 19. Vision therapy produced a significant reduction in symptoms of both distance blur and headaches. Prior to treatment, 55% of the patients experienced headaches related to near work; following therapy only 2 patients reported headaches. Before receiving vision therapy, 41% of the patients reported transient visual blur; after therapy only 3 patients still reported experiencing this symptom.

The efficacy of vision therapy for convergence excess.

Gallaway M, Scheiman M. Journal of the American Optometric Association, February; 68(2): 81-86, 1997.

The records of 83 consecutive patients with convergence excess who were treated with vision therapy were reviewed to assess the impact of treatment on clinical findings and patient symptoms. **RESULTS:** Total elimination of symptoms in 84% of patients with the following improvements: mean divergence amplitude from 8 PD to 16 PD, recovery value from 2 PD to 10 PD, and accommodative facility from 1.5 cpm. to 8cpm. **CONCLUSIONS:** Vision therapy was successful in enhancing negative fusional vergence and eliminating symptoms in the vast majority of patients with convergence excess and should be considered an effective treatment for this condition.

Efficacy of vision therapy for nonstrabismic vergence anomalies.

Griffin JR. Am J Optom & Physiol Optics, 64 (6): 411-414, 1987.

A review of the literature published in the past 15 years was carried out to determine the effect of visual training on vergence measurements for nonstrabismic patients. Results of cited studies are summarized.

Visual therapy results for convergence insufficiency: A literature review.

Grisham JD. Am J Optom & Physiol Optics, 65 (6): 448-454, 1988.

This paper is a review of the literature relative to treatment results for convergence insufficiency utilizing vision therapy training procedures. Vision therapy is known to improve the nearpoint of convergence and fusional convergence and to ameliorate associated symptoms. The overall cure rate is 72%. Furthermore, the training results appear to persist for at least 2 years if the patients are initially cured and are independent of age until the late presbyopic years. Also, recent studies indicate the type of training procedures which yield the most effective training results.

Vergence orthoptics: validity and persistence of the training effect.

Grisham JD, Bowman MC, et. al. Optom & Vis Sci, 68 (6): 441-451, 1991.

The relation between Risley prism vergences, a subjective measure, and vergence tracking rate, an objective index, is investigated. The course of orthoptics progress is compared in cases of clinical vergence dysfunction. Vergence-deficient control subjects showed no significant change in either index. However, trained subjects demonstrated rapid increases in both indices. The persistence of the training effect was monitored for up to nine months. No regression was observed in subjects who met all release criteria, but one subject who chose to terminate therapy early showed a slow regression in tracking rate and recurrence of symptom. These data support the validity of vergence training and increase the plausibility of previous clinical reports of orthoptics success.

Clinical management of nearpoint stress-induced vision problems.

Gruning CF. American Journal of Optometry & Physiological Optics, Jun;62(6):386-391, 1985.

Abstract: Functional vision problems caused by or associated with nearpoint vision stress include: accommodative disorders (insufficiency, ill-sustained, infacility); abnormal heterophorias (esophoria, high exophoria); and vergence disorders. These vision disorders cause problems with acuity, comfort, and performance (efficiency). A combination of lens prescribing, vision therapy, and work/study visual hygiene recommendations can eliminate or greatly reduce nearpoint stress-induced vision problems.

Static vergence and accommodation and orthoptics effects.

Hung GK, Ciuffreda KJ, Semmlow JL. Doc Ophthalmol, 62: 165-179, 1986.

This study evaluated changes in vergence and accommodative systems in two populations: 22 visually-normal asymptomatic individuals and 21 visually-abnormal symptomatic individuals before and after conventional orthoptic therapy. Symptomatic subjects were placed into one of three training groups depending on clinical abnormalities and symptoms. The training period ranged from 8 to 16 weeks: Long term follow-up testing was performed 6 to 9 months after training ended. Symptomatic individuals showed a shift toward the mean of visually-normal asymptomatic subjects following training. The long term results showed a

maintenance of the initial post-training improvement. The efficacy of orthoptic treatment was indicated by a large reduction in overall symptom rating level.

Static vergence and accommodation: population norms and orthoptic effects.

Hung GK, Ciuffreda KJ, Semmlow JL. *Doc Ophthalmologica*, 2:165-79, 1986

Abstract: This study investigated the effect of orthoptic therapy lasting 8-16 weeks on the accommodative and vergence system function of 22 visually-normal asymptomatic individuals and 21 visually-abnormal symptomatic individuals. Following therapy, asymptomatic individuals experienced reduction of symptoms and improvement in visual parameters toward the normal mean function.

Statistical normal values of visual parameters that characterize binocular function in children.

Jimenez R, Perez MA, Garcia JA, Gonzalez MD. *Ophthal Physiol Opt* 2004;24(6):528-42

A wide range of visual parameters used to evaluate binocular function were evaluated in a paediatric population (1056 subjects aged 6-12 years). Mean values are provided for these ages in optometric tests that directly assess the vergence system, horizontal phorias for near and far vision (measured by a modified version of the Thorington method), negative and positive vergence amplitude for near and far vision (step vergence testing), vergence facility (flippers 8 □ BI/8 □ BO), and near-point of convergence (penlight push-up technique and red-lens push-up technique), as well as stimulus accommodative convergence/accommodation ratio and stereoacuity (Randot test) which provide an overall evaluation of the vergence, accommodative and oculomotor systems. A statistical comparison (anova and Bonferroni post hoc test) of these values between ages was performed. The differences, although statistically significant, were not clinically meaningful, and therefore the authors identified two trends in the behaviour of these parameters. For all parameters, except for vergence facility, the authors established a single mean reference value for the age range studied. The difference between the means for vergence facility indicated the need to divide the population into two age ranges (6-8 and 8-12 years). This study establishes statistical normal values for these parameters in a paediatric population and their means are a valuable instrument for separating children with binocular anomalies from those with normal binocular vision.

Vision Disturbances Following Traumatic Brain Injury.

Kapoor N, Ciuffreda KJ. *Curr Treat Options Neurol.* 2002 Jul;4(4):271-280.

Vision disturbances following traumatic brain injury (TBI) include anomalies of accommodation, version, vergence (nonstrabismic, as well as strabismic), photosensitivity, visual field integrity, and ocular health. Traumatic brain injury patients with complex diplopia patterns, noncomitant strabismic anomalies, and advanced ocular health anomalies are either monitored by or referred to neuro-ophthalmologists and ophthalmologists for evaluation and possible surgical or medical intervention, as needed. Anomalies of accommodation, vergence, version, photosensitivity, and field of vision are amenable to noninvasive, rehabilitative interventions, such as vision therapy, which is rendered by optometrists and is described in this article. Further, vision therapy may be performed in isolation or in conjunction with the application of the following: Fusional prism spectacles (for diplopia) Tinted spectacles (for photosensitivity) Yoked prism spectacles (for visual-spatial hemispheric inattention, with or without a manifest visual field defect), as appropriate. Dependent on the severity of vision impairment post-TBI, other types of rehabilitation, such as vestibular, physical, cognitive, and occupational rehabilitation, are deferred pending the stabilization of vision function to an appropriate level. Rehabilitative optometric intervention is appropriate and beneficial for many TBI patients. Therefore, it should be offered as a possible evaluation

and treatment option to investigate the patient's symptoms and determine the prognosis for treatment, as would be done with any other therapeutic modality.

Vertical fixation disparity curve and the effects of vergence training in a normal young adult population.

Luu CD, Green JF, Abel L. *Optom Vis Sci*, 77: 663-69, 2000

Forty-five subjects with normal vision and binocular function underwent vertical vergence training for one week. The control group consisted of 34 subjects. Vertical prism bar training provided a long-term effect, both increasing the vertical fusional amplitude and flattening the slope of the vertical fixation disparity curve.

Acute accommodative and convergence insufficiency.

Mazow ML, France TD, et al. *Trans American Ophthalmology Society*, 87: 158-168, 1989.

Abstract: The facility of accommodation and convergence allows persons to read at close range. When these mechanisms fail, reading becomes tiring, frequently producing headaches and even diplopia. This study reviewed the treatment of 26 young patients with asthenopic symptoms who had a combination of profoundly decreased accommodation and convergence in the absence of any other neurologic symptoms or signs. Twenty-two of 26 (84.6%) patients were treated with orthoptic exercises to improve convergence. Twenty-one of 26 (81%) were given plus lenses to aid in accommodation. Patients were seen for mean of 3.3 visits over an average of 11.8 months. Seventeen of 26 patients (65.3%) showed definite improvement after treatment and were completely asymptomatic. Seven of 26 patients (26.9%) reported some improvement of symptoms. Two of 26 patients (7.6%) reported no improvement of symptoms. However, both of these patients had been treated for less than 2 months. Of the 24 patients whom experienced improvement in symptoms, their headaches decreased and their school performance improved dramatically.

The effect of orthoptic treatment upon the vergence adaptation mechanism.

North RV, Henson DB. *Optom & Vis Sci*, 69(4): 294-299, 1992.

This paper is a review of the research work that has been carried out over the past few years investigating the ability of the oculomotor system to adapt to prism-induced heterophoria. The results show that subjects with normal binocular vision can adapt to horizontal and vertical prism-induced heterophorias whether fixating at distance or near. Further studies have shown that subjects with symptomatic abnormal binocular vision have an abnormal adaptation mechanism. Finally, we have found that when orthoptic treatment results in relief from the symptoms, there is an associated improvement in these subjects' ability to adapt to prism-induced heterophoria.

Orthoptic treatment of convergence insufficiency: A two year follow-up report.

Pantano R. *American Orthoptic Journal*, 57: 73-80, 1982

Pantano studied 207 subjects with convergence insufficiency who underwent vision therapy and evaluated them 2 years later. The majority remained asymptomatic with normal clinical findings. Those subjects who learned to control convergence and accommodation together had the best success.

Convergence insufficiency and its management.

Passmore JW, Maclean F. *Am J Ophthal*, 43: 448-56, 1957.

This study reported on the evaluation of 100 patients receiving a course of orthoptics for the

treatment of convergence insufficiency. The average patient age was 24, range of 8 to 42 years of age. Orthoptic treatment averaged seven sessions of 30 minutes each. A total of 82 patients received complete relief of subjective symptoms at the end of treatment and 18 received partial relief.

Validity and reliability of the revised convergence insufficiency symptom survey in adults.

Rouse MW, Borsting EJ, Mitchell GL, Scheiman M et al. Convergence Insufficiency Treatment Trial Group. *Ophthalm Physiol Opt.* 2004;24(5):384-90.

Purpose: To assess the validity and reliability of the revised Convergence Insufficiency Symptom Survey (CISS) in adults aged 19-30 years. The CISS was developed to be the primary outcome measure for studies evaluating various treatments for convergence insufficiency (CI).

Methods: CISS mean scores from adults with symptomatic CI and adults with normal binocular vision (NBV) were compared to assess the survey's validity. Adults with symptomatic CI were given the CISS twice to evaluate reliability, which was assessed using intraclass correlation coefficient (ICC) and 95% limits of agreement.

Results: Forty-six adults with CI and 46 adults with NBV participated in the study. The mean CISS score for the CI group was 37.3 (S.D. = 9.3) and 11.0 (S.D. = 8.2) for the NBV group. These mean values were significantly different ($p < 0.0001$). Good discrimination (sensitivity = 97.8%, specificity = 87%) was obtained using a score of 21 or higher. For the CI group the ICC was 0.885 (95% CI of 0.798, 0.936) and the 95% limits of agreement were -9.0 to 7.6.

Conclusions: Adults with symptomatic CI had a significantly higher CISS score than adults with NBV. The results of the study demonstrate that the CISS is a valid and reliable instrument that can be used clinically or as an outcome measure for research studies of adults with CI.

Randomised clinical trial of the effectiveness of base-in prism reading glasses versus placebo reading glasses for symptomatic convergence insufficiency in children

Scheiman M, Cotter S, Rouse M, Mitchell GL, Kulp M, Cooper J, Borsting E; *Br J Ophthalmol.* 2005 Oct;89(10):1318-23

Purpose: To compare base-in prism reading glasses with placebo reading glasses for the treatment of symptomatic convergence insufficiency (CI) in children aged 9 to <18 years.

Method: In a randomised clinical trial, 72 children aged 9 to <18 years with symptomatic CI were assigned to either base-in prism glasses or placebo reading glasses. Symptom level, measured with a quantitative symptom questionnaire (CI Symptom Survey-V15), was the primary outcome measure. Near point of convergence and positive fusional vergence at near were secondary outcomes.

Results: The mean (SD) CI Symptom Survey score decreased (that is, less symptomatic) in both groups (base-in prism glasses from 31.6 (10.4) to 16.5 (9.2); placebo glasses from 28.4 (8.8) to 17.5 (12.3)). The change in the CI Symptom Survey scores ($p = 0.33$), near point of convergence ($p = 0.91$), and positive fusional vergence ($p = 0.59$) were not significantly different between the two groups after 6 weeks of wearing glasses.

Conclusions: Base-in prism reading glasses were found to be no more effective in alleviating symptoms, improving the near point of convergence, or improving positive fusional vergence at near than placebo reading glasses for the treatment of children aged 9 to <18 years with symptomatic CI.

A randomised clinical trial of vision therapy/orthoptics versus pencil push ups for the treatment of convergence insufficiency in young adults
Scheiman M, Mitchell GL, Cotter S, Kulp MT, Cooper J, Rouse M, Borsting E, London R, Wensveen J. 2005 Jul;82(7):583-95

Purpose: The purpose of this article is to compare vision therapy/orthoptics, pencil pushups, and placebo vision therapy/orthoptics as treatments for symptomatic convergence insufficiency in adults 19 to 30 years of age.

Method: In a randomized, multicenter clinical trial, 46 adults 19 to 30 years of age with symptomatic convergence insufficiency were randomly assigned to receive 12 weeks of office-based vision therapy/orthoptics, office-based placebo vision therapy/orthoptics, or home-based pencil pushups. The primary outcome measure was the symptom score on the Convergence Insufficiency Symptom Survey. Secondary outcome measures were the near point of convergence and positive fusional vergence at near.

Results: Only patients in the vision therapy/orthoptics group demonstrated statistically and clinically significant changes in the near point of convergence (12.8 cm to 5.3 cm, $p = 0.002$) and positive fusional vergence at near (11.3Delta to 29.7Delta, $p = 0.001$). Patients in all three treatment arms demonstrated statistically significant improvement in symptoms with 42% in office-based vision therapy/orthoptics, 31% in office-based placebo vision therapy/orthoptics, and 20% in home-based pencil pushups achieving a score <21 (our predetermined criteria for elimination of symptoms) at the 12-week visit.

Discussion: In this study, vision therapy/orthoptics was the only treatment that produced clinically significant improvements in the near point of convergence and positive fusional vergence. However, over half of the patients in this group (58%) were still symptomatic at the end of treatment, although their symptoms were significantly reduced. All three groups demonstrated statistically significant changes in symptoms with 42% in office-based vision therapy/orthoptics, 31% in office-based placebo vision therapy/orthoptics, and 20% in home-based pencil push-ups meeting our criteria for elimination of symptoms.

A randomized clinical trial of treatments for convergence insufficiency in children.

Scheiman M, Mitchell GL, Cotter S, Cooper J, Kulp M, Rouse M, Borsting E, London R, Wensveen J; 2005 Jan;123(1):14-24

Objective: To compare vision therapy/orthoptics, pencil push-ups, and placebo vision therapy/orthoptics as treatments for symptomatic convergence insufficiency in children 9 to 18 years of age.

Method: In a randomized, multicenter clinical trial, 47 children 9 to 18 years of age with symptomatic convergence insufficiency were randomly assigned to receive 12 weeks of office-based vision therapy/orthoptics, office-based placebo vision therapy/orthoptics, or home-based pencil push-ups therapy.

Main Outcome Measures: The primary outcome measure was the symptom score on the Convergence Insufficiency Symptom Survey. Secondary outcome measures were the near point of convergence and positive fusional vergence at near.

Results: Symptoms, which were similar in all groups at baseline, were significantly reduced in the vision therapy/orthoptics group (mean symptom score decreased from 32.1 to 9.5) but not in the pencil push-ups (mean symptom score decreased from 29.3 to 25.9) or placebo vision therapy/orthoptics groups (mean symptom score decreased from 30.7 to 24.2). Only patients in the vision therapy/orthoptics group demonstrated both statistically and clinically significant changes in the clinical measures of near point of convergence (from 13.7 cm to 4.5 cm; $P < .001$) and positive fusional vergence at near (from 12.5 prism diopters to 31.8 prism diopters; $P < .001$).

Conclusions: In this pilot study, vision therapy/orthoptics was more effective than pencil push-ups or placebo vision therapy/orthoptics in reducing symptoms and improving signs of convergence insufficiency in children 9 to 18 years of age. Neither pencil push-ups nor placebo vision therapy/orthoptics was effective in improving either symptoms or signs associated with convergence insufficiency.

Vision therapy for convergence excess.

Shorter AD, Hatch SW. N Engl J Optom, 45:51-3, 1993.

Abstract: This report presents a retrospective study of symptomatic patients with diagnosis of convergence excess (CE) that received vision therapy (VT). In a sample of 12 nonpresbyopic subjects, 8 (66%) reported significant improvements in symptoms. Of 8 records where pre and post-treatment base in vergence ranges were available, 5 (63%) showed improvement, but this improvement was not statistically significant. We conclude that VT is an acceptable option for treatment of CE, but more research is indicated for conclusive evidence.

Convergence and divergence show large and sustained improvement after short isometric exercise.

Vaegen. Am J Optom Physiol opt, 56:22-33, 199.

Abstract: There are conflicting reports on the effect of vergence training. In two studies using push up and prism vergence exercises the conflict is shown to result from differences in the constancy of effort. Improvement only occurs in exercises involving sustained effort in the direction being trained. The effect of alternating movements in both directions is small and inconsistent. Substantial long lasting gains in either convergence or divergence prism vergence scores can result from just 5 min. of sustained effort at an angle halfway between the break and recovery points. Results for adults and children on motor-driven instruments are comparable and the scores obtained discriminate better than those from hand-turned instruments. The most likely physiological model involves potentiating processes that are specifically maximized by isometric exercise. Potentiation results in a positive feedback process, the effects of which are strong enough to precipitate strabismus and which might be deliberately manipulated in therapy of poor vergence control, if responses in the required direction can be induced.

5. References on the role of OVT in oculomotor dysfunction

The eye movements of pure alexic patients during reading and nonreading tasks.

Behrmann M, Shomstein SS, Black SE, Barton JJ. *Neuropsychologia*. 2001;39(9):983-1002.

We compared the eye-movements of two patients who read letter-by-letter (LBL) following a left occipital lobe lesion with those of normal control subjects and of hemianopic patients in two tasks: a nonreading visual search task and a text reading task. Whereas the LBL readers exhibited similar eye-movement patterns to those of the other two groups on the nonreading task, their eye movements differed significantly during reading, as reflected in the disproportionate increase in the number and duration of fixations per word and in the regressive saccades per word. Importantly, relative to the two control groups, letter-by-letter readers also made more fixations per word as word length increased, especially as word frequency and word imageability decreased. Two critical results emerged from these experiments: First, the alteration in the oculomotor behavior of the LBL readers during reading is similar to that seen in normal readers under difficult reading conditions, as well as in beginning readers and in those with developmental dyslexia, and appears to reflect difficulties in processing the visual stimulus. Second, the interaction of length with frequency and with imageability in determining the eye movement pattern is consistent with an interactive activation model of normal word recognition in which weakened activation of orthographic input can nevertheless engage high-level lexical factors.

Smooth pursuit eye movements are associated with phonological awareness in preschool children.

Callu D, Giannopulu I, Escolano S, Cusin F, Jacquier-Roux M, Dellatolas G. *Brain Cogn.* 2005;58(2):217-225.

Phonological awareness is strongly related to reading ability, but reports are more conflicting concerning the association of high level oculomotor skills with reading. Here, the authors show that phonological awareness is specifically associated with the ability to perform smooth pursuit eye movements in preschool children. Two large independent samples of preschool children (n=838 and n=732) aged 5-6.4 years, without history of neurological disorder, were examined by school medical doctors for visual and oculomotor problems. Nineteen percent of the children in the first sample and 14% in the second failed at the clinical evaluation of smooth pursuit eye movements, and 17 and 15%, respectively, presented another visual or oculomotor problem. Ten short cognitive tests were performed by the same children. Visual and oculomotor problems other than a failure on smooth pursuit were not consistently related to the cognitive tasks, with one exception, the visual recognition of letters. Children who failed at smooth pursuit obtained lower scores at a number of cognitive tasks, and especially phonological awareness tasks and copy of visually presented trajectories. Poor working memory and/or failure of anticipation during the tracking of a visual or auditory stimulus related to frontal cortex immaturity may explain these associations in preschool children.

Oculomotor rehabilitation for reading in acquired brain injury.

Ciuffreda KJ, Han Y, Kapoor N, Ficarra AP. *NeuroRehabilitation*. 2006;21(1):9-21.

The purpose of this study was to assess reading-related oculomotor rehabilitation in individuals with acquired brain injury. Adults with either stroke (n=5) or traumatic brain injury (n=9) participated. Training paradigms included single-line and multiple-line simulated reading, as well as basic versional tracking (fixation, saccade, and pursuit), twice per week over an 8 week period. Training modes included normal internal oculomotor visual feedback either in isolation (4 weeks) or concurrent with external oculomotor auditory feedback (4 weeks). Training effects were assessed objectively using infrared eye movement recording

technology for simulated and actual reading, with the assessments occurring before, midway, and after training. In addition, the individuals were assessed subjectively using a reading rating-scale questionnaire. All reported considerably improved reading ability, and this was confirmed by several of the objective oculomotor measures. There was a trend for improvement to be better with the combined visual and auditory oculomotor feedback. Reading-related oculomotor rehabilitation produced significant gains in both the subjective and objective domains. It is believed that rapid saccadic oculomotor adaptation, as well as the training of rhythmicity and automaticity, were involved in modifying eye movement behavior to produce a more systematic approach and resultant improved reading profile.

Voluntary control of saccadic and smooth-pursuit eye movements in children with learning disorders.

Fukushima J, Tanaka S, Williams JD, Fukushima K. Brain Dev. 2005 Dec;27(8):579-88.

Eye movement is crucial to humans in allowing them to aim the foveae at objects of interest. We examined the voluntary control of saccadic and smooth-pursuit eye movements in 18 subjects with learning disorders (LDs) (aged 8-16) and 22 normal controls (aged 7-15). The subjects were assigned visually guided, memory-guided, and anti-saccade tasks, and smooth-pursuit eye movements (SPEM). Although, the LD subjects showed normal results in the visually guided saccade task, they showed more errors in the memory-guided saccade task (e.g. they were unable to stop themselves reflexively looking at the cue) and longer latencies, even when they performed correctly. They also showed longer latencies than the controls in the anti-saccade task. These results suggest that they find it difficult to voluntarily suppress reflexive saccades and initiate voluntary saccades when a target is invisible. In SPEM using step-ramp stimuli, the LD subjects showed lower open- and closed-loop gains. These results suggest disturbances of both acceleration of eye movement in the initial state and maintenance of velocity in minimizing retinal slip in the steady state. Recent anatomical studies in LD subjects have suggested abnormalities in the structure of certain brain areas such as the frontal cortex. Frontal eye movement-related areas such as the frontal eye fields and supplementary eye fields may be involved in these disturbances of voluntary control of eye movement in LDs.

Reading-related oculomotor testing and training protocols for acquired brain injury in humans.

Han Y, Ciuffreda KJ, Kapoor N. Brain Res Brain Res Protoc. 2004 Nov;14(1):1-12

Many individuals with acquired brain injury (ABI) report reading problems of oculomotor origin. These may include frequent loss of place, skipping of lines and difficulty shifting to the next line of print. We describe two protocols for the testing and training of reading-related eye movements in adult individuals with ABI (traumatic brain injury [TBI] and stroke with hemianopia), who experience oculomotor-based symptoms when reading. These protocols use objective eye movement recording techniques and computer-based stimulus presentation and analysis. One protocol tests and the other trains basic horizontal and vertical versional eye movements (fixation, saccades and pursuit), as well as reading eye movements using simulated single and multiple line dynamic arrays. In addition, a reading rating-scale questionnaire is administered before and after completion of training to assess subjective reading improvement. In all paradigms, the target consists of a 0.5 degrees luminous square, which is displayed on a computer monitor positioned 40 cm from the subject along the midline. All testing and training are conducted under binocular viewing conditions with optical correction in place. There are two modes of training: normal internal oculomotor visual feedback either alone (4 weeks) or in conjunction with external oculomotor auditory feedback (4 weeks) administered in a counterbalanced manner within each diagnostic group. Training is performed 1 h, twice weekly for the 8 weeks. Oculomotor testing is conducted before, midway and after training. Following training, reading-related eye movements and reading ability improved as assessed both subjectively and objectively. These protocols provide a systematic approach to the quantitative and comprehensive testing and training of reading-related eye movement skills and behaviors in the ABI population manifesting oculomotor-

based reading dysfunctions. Furthermore, the training protocol results in the rapid remediation of the eye movement deficits, which appear to transfer to activities of daily living.

Eye movement and visuomotor arm movement deficits following mild closed head injury.

Heitger MH, Anderson TJ, Jones RD, Dalrymple-Alford JC, et al. Brain 2004;127(3):575-590.

Based on increasing evidence that even mild closed head injury (CHI) can cause considerable neural damage throughout the brain, the authors hypothesized that mild CHI will disrupt the complex cerebral networks concerned with oculomotor and upper-limb visuomotor control, resulting in impaired motor function. Within 10 days following mild CHI (Glasgow Coma Scale 13-15, alteration of consciousness <20 min), the authors compared 30 patients (15-37 years) and 30 matched controls on different types of saccades, oculomotor smooth pursuit (sine and random), upper-limb visuomotor performance and several neuropsychological tests known to be sensitive to head trauma. Simple reflexive saccades were not impaired, whereas, on the antisaccade task, the CHI group demonstrated prolonged saccadic latencies, a marginally higher number of directional errors and poorer spatial accuracy. The CHI group exhibited more directional errors and impaired motor accuracy on memory-guided sequences of saccades and produced fewer self-paced saccades within 30 s. Most measures of sinusoidal and random oculomotor smooth pursuit showed no deficits, with the exception of a prolonged lag on random smooth pursuit in the CHI group. While arm movement reaction time and arm steadiness were not impaired, the CHI group showed decreased arm movement speed and decreased upper-limb motor accuracy. Conversely, after controlling for IQ, the CHI group had few head trauma-related neuropsychological deficits. These results indicate that multiple motor systems can be impaired following mild CHI and that this can occur independently of neuropsychological impairment. Our study also indicates that quantitative tests of oculomotor and upper-limb visuomotor function may provide sensitive markers of cerebral dysfunction, suggesting the potential use of such tests to supplement patient assessment. To our knowledge, this study is the first to demonstrate the presence of oculomotor or visuomotor deficits following mild CHI.

Improvements in performance following optometric vision therapy in a child with dyspraxia.

Hurst C. M. F., Van de Weyer S., Smith C , Adler P. M. Ophthalmic and Physiological Optics 26 (2), 199-210. 2006

SS, an 8-year-old boy with dyspraxia, presented for behavioural optometry assessment. He had been diagnosed with a subtle form of dyspraxia by his paediatric occupational therapist, based on poor proprioception, delayed bilateral integration and poor visual perception. A full visual assessment was carried out. SS was given a programme of reflex inhibition exercises for 3 months. Then, a programme of optometric vision therapy (OVT) exercises was prescribed at home and in practice for a period of 8 months. SS was assessed using a battery of occupational therapy Sensory Integration and Praxis Tests (SIPT) before optometric intervention, and after OVT. There were significant improvements in fusional reserves, accommodative facility and oculomotor control of pursuit and saccadic eye movements. His reading level had changed by 4 years in 11 months. The SIPT results showed improvements in the visual and motor/visual perception subtests, confirming the significant changes in visual perceptual performance. Consideration is given to treatment modalities for dyspraxia, and the studies confirming their effectivity of approach. This case study provides evidence supporting the use of OVT eye exercises in dyspraxia, ocular motility, accommodative dysfunction, learning difficulties and sports performance. The need for further research and inter-professional working is discussed.

Oculomotor rehabilitation in acquired brain injury: a case series.

Kapoor N, Ciuffreda KJ, Han Y. Arch Phys Med Rehabil. 2004 Oct;85(10):1667-78

Objective: To investigate the effects of systematic, oculomotor rehabilitation on basic versional ocular motility, as well as reading eye movements, in subjects with acquired brain injury, using objective eye movement recording and subjective rating of reading ability.

Design: Case series.

Setting: Clinical research laboratory.

Participants: Two men with acquired brain injury: one with traumatic brain injury and one with stroke.

Interventions: Versional oculomotor training was performed for 1 hour, twice weekly for 8 weeks. There were 2 feedback modes of training: normal internal oculomotor visual feedback alone (4wk), or that feedback in conjunction with external oculomotor auditory feedback (4wk). Testing was conducted before and after training. Main outcome measures Objective outcome measures included both basic eye movement parameters (fixational accuracy, saccadic gain and latency, pursuit gain, mean saccade frequency ratio for simulated reading), and reading eye movement parameters (words per minute, grade level equivalent, fixations per 100 words, regressions per 100 words, percentage of reading comprehension, duration of fixation in seconds). Subjective outcome measures included the subject's ability to read based on the responses to the reading rating-scale questionnaire.

Results: Both subjects improved objectively in terms of basic versional oculomotor accuracy and reading ability. These findings concurred with their subjective impressions.

Conclusions: This case series provides objective documentation of the positive effects of oculomotor rehabilitation on basic ocular motility and reading ability in selected cases with acquired brain injury, thus suggesting the need for a larger clinical trial in this area.

Nystagmus and ocular fixation difficulties in learning-disabled children.

Ottenbacher K, Watson PJ, Short MA, Biderman MD. Am J Occup Ther. 1979 Nov;33(11):717-21.

The visual fixation ability of learning-disabled children was evaluated after sensory integrative therapy had been administered for short or long periods of time. Children with hyporesponsive postrotary nystagmus displayed reduced oculomotor control skills, but the deficit was apparent only in those who had been in therapy for a shorter interval. These results present further support for the hypothesis that the learning disabled can be differentiated according to their nystagmus characteristics. In addition, very tentative evidence suggested that sensory integrative therapy may have been successful in ameliorating the fixation deficiency; however, further research into this possibility is needed. The data also indicate that oculomotor control dysfunction may be a mediating mechanism for at least part of the learning disabilities experienced by some learning-disabled children.

Eye movement control by the cerebral cortex.

Pierrot-Deseilligny C, Milea D, Muri RM. Curr Opin Neurol. 2004 Feb;17(1):17-25
INSERM 289 and Neurology Department 1, Salpêtrière Hospital, Assistance Publique-Hopitaux de Paris, Paris, France. cp.deseilligny@psl.ap-hop-paris.fr

Purpose of Review: This review focuses on eye movement control by the cerebral cortex, mainly in humans. Data have emerged based on the important contribution of recent techniques such as transcranial magnetic stimulation and functional magnetic resonance imaging, which provide complementary results to those of the classical lesion and electrical stimulation studies.

Recent Findings: The location of the human frontal eye field and its role in pursuit eye movement control were recently detailed. Cumulative evidence for the role of the dorsolateral prefrontal cortex in unwanted reflexive saccade inhibition, short-term spatial memory and prediction suggests that this area controls decisional processes governing ocular motor behaviour. The organization of spatial memory in the dorsolateral prefrontal cortex (short-term), the parahippocampal cortex (medium-term) and the hippocampal formation (long-term)

is also reviewed with the results of recent transcranial magnetic stimulation studies. The relatively complicated anatomy of the posterior parietal cortex in humans is briefly described followed by some additional results concerning the location of the parietal eye field - within the posterior half of the intraparietal sulcus - and its role in visuo-spatial integration and attention. The other areas involved in spatial attention are also examined in the light of several recent contributing reports. Lastly, there are also new functional magnetic resonance imaging findings concerning the posterior cingulate cortex, which appears to be mainly involved in the control of externally guided eye movements and attentional mechanisms.

Summary: Many new findings on the organization of saccades and pursuit eye movements at the cortical level have recently been reported. Furthermore, eye movements are increasingly used as a tool to elucidate relatively complex neuropsychological processes such as attention, spatial memory, motivation and decisional processes, and a considerable number of reports dealing with these questions have been observed.

Pursuit eye movement deficits in autism.

Takarae Y, Minshew NJ, Luna B, Krisky CM, Sweeney JA. Brain. 2004 Dec;127(Pt 12):2584-94.

Oculomotor studies provide a novel strategy for evaluating the functional integrity of multiple brain systems and cognitive processes in autism. The current study compared pursuit eye movements of 60 high-functioning individuals with autism and 94 intelligence quotient, age and gender matched healthy individuals using ramp and oscillating target tasks. Individuals with autism had normal pursuit latency, but reduced closed-loop pursuit gain when tracking both oscillating and ramp targets. This closed-loop deficit was similar for leftward and rightward pursuit, but the difference between individuals with autism and their age-matched peers was more apparent after mid-adolescence, suggesting reduced maturational achievement of the pursuit system in autism. Individuals with autism also had lower open-loop pursuit gain (initial 100 ms of pursuit) and less accurate initial catch-up saccades during a foveofugal step-ramp task, but these deficits were only seen when targets moved into the right visual field. Pursuit performance in both open- and closed-loop phases was correlated with manual praxis in individuals with autism. Bilateral disturbances in the ability to use internally generated extraretinal signals for closed-loop pursuit implicate frontostriatal or cerebellar circuitry. The hemifield specific deficit in open-loop pursuit demonstrates a lateralized disturbance in the left extrastriate areas that extract visual motion information, or in the transfer of visual motion information to the sensorimotor areas that transform visual information into appropriate oculomotor commands.

A Developmental Approach to Congenital Ocular Motor Apraxia: case report and literature review.

Taub MB, Mahaphon TK, Rodena J Optom Vis Dev 2005;36(2):99-107.

Introduction: Congenital ocular motor apraxia is a deficiency in horizontal saccades with normal vertical saccades and pursuits (vertical and horizontal). It is not usually diagnosed until the age of 4-6 months when patients develop head thrusting and/or a synkinetic blink. The structural defect in C-OMA is not known, but the vermis in the cerebellum is the most likely site of the neurological defect. Improvement with age usually, but not always, occurs. Various neurological manifestations have been reported in association with congenital ocular motor apraxia. These children will have difficulty with both fine motor and gross motor activities. No definitive treatment has been documented in the literature.

Case Report: A 5-year old male with a history of congenital ocular motor apraxia presented for a full examination with complaints of head turning and head tilting. He was having difficulty in school and avoided near activities. He was diagnosed with a gross motor delay one and a half years earlier. Upon testing, the patient was found to be a latent hyperope with poor horizontal pursuits and saccades. Prescription glasses were prescribed to compensate for the hyperopia. A perceptual examination was performed, which showed numerous delays. A program of vision therapy was initiated to improve perceptual difficulties and ocular motility.

Conclusion: C-OMA is a disease that must be managed by optometrists. Even though no

documented treatment has been found, vision therapy should be implemented to enhance basic skills and improve ocular motility.

Visual motion due to eye movements helps guide the hand.

Whitney D, Goodale MA. Exp Brain Res 2005;162(3):394-400

Movement of the body, head or eyes with respect to the world creates one of the most common yet complex situations in which the visuomotor system must localize objects. In this situation vestibular, proprioceptive and extra-retinal information contribute to accurate visuomotor control. The utility of retinal motion information, on the other hand, is questionable since a single pattern of retinal motion can be produced by any number of head or eye movements. Here the authors investigated whether retinal motion during a smooth pursuit eye movement contributes to visuomotor control. When subjects pursued a moving object with their eyes and reached to the remembered location of a separate stationary target the presence of a moving background significantly altered the endpoints of their reaching movements. A background that moved with the pursuit, creating a retinally stationary image (no retinal slip), caused the endpoints of the reaching movements to deviate in the direction of pursuit, overshooting the target. A physically stationary background pattern, however, producing retinal image motion opposite to the direction of pursuit, caused reaching movements to become more accurate. The results indicate that background retinal motion is used by the visuomotor system in the control of visually guided action.

6. References on the role of OVT in the treatment of strabismus and amblyopia

(a) Strabismus

Strabismus is a misalignment of the two eyes. This condition may be called cross-eyes or wall eyes. There are various forms of strabismus such as Accommodative Esotropia, Esotropia, Exotropia, Intermittent Esotropia, and Intermittent Exotropia.

Orthoptic management of intermittent exotropia.

Chryssanthou G. American Orthoptic Journal, 24:69-72, 1974.

This study reviewed the cases of 27 patients with intermittent exotropia (ages 5 to 33 years) who received orthoptic treatment. A total of 89% of patients showed definite improvement, with 66.6% graded excellent or good 6 months to 2 ½ years after termination of orthoptic treatment.

Treatment options in intermittent exotropia: a critical appraisal.

Coffey B, Wick B, Cotter S, et al. Optometry and Vision Science, 69: 386-404, 1992.

Pooled success rates of different treatment regimens for intermittent exotropia reported 59% for vision therapy, 46% for surgery, and 28% for passive therapy such as minus lenses, occlusion, and/or prisms.

Optometric management of binocular dysfunctions secondary to head trauma: case reports.

Cohen AH. Journal of the American Optometric Association, August; 63(8): 569-575, 1992.

Abstract: Exotropia, esotropia, hyper elements, visual sequencing problems, accommodative dysfunctions and inefficient Motor Planning are common consequences of head trauma. Optometric visual therapy is an effective treatment modality for these dysfunctions. Two case reports are presented in order to illustrate optometric management of patients exhibiting these problems secondary to head trauma.

Strabismus therapy in private practice: Cure rates after three months of therapy.

Etting G. Journal of the American Optometric Association, 49: 1367-1373, 1978.

Dr. Gary Etting, O.D., F.C.O.V.D. reported that a 65% overall success rate in patients with constant strabismus (57% of esotropes and 82% of exotropes), 89% success rate with intermittent strabismus (100% of esotropes and 85% of exotropes), and 91% success rate when retinal correspondence was normal.

Orthoptic treatment of strabismus.

Flax N, Duckman RH. Journal of the American Optometric Association, 49: 1353-1361, 1978.

Abstract: This paper examined the effectiveness of orthoptics as a viable treatment modality for strabismus. A review of pertinent literature and an analysis of the data was presented. The results of several studies show a combined functional cure rate of 72.4%.

Role of optometric vision therapy for surgically treated strabismus patients.

Garriott RS, Heyman CL, Rouse MW. *Optometry and Vision Science*, April;74(4): 179-184, 1997

Background: Occasionally, co-management involving both optometry and ophthalmology is needed to optimize treatment outcome for the strabismic patient.

Methods: JB, a 47-month-old consecutive esotrope presented to our clinic (Southern California College of Optometry). Two previous attempts to surgically correct her exotropia had failed and the parents sought another treatment approach. We recommended optometric vision therapy (VT) to improve sensorimotor fusion before any further surgery. After 31 VT sessions (bi-weekly for a time, then weekly), before a third scheduled surgery, sensorimotor fusion was good in the amblyoscope, but unstable with neutralizing prism in free-space. We recommended surgery be postponed, but the family proceeded. Esotropia recurred with constant suppression. After additional VT, JB developed stable sensorimotor fusion and random dot stereopsis in free-space with neutralizing prism. A fourth surgery was then performed resulting in esophoria at all distances with good sensory fusion.

Results: Twenty-one months postoperatively, JB remains nonstrabismic with good sensory fusion.

Conclusions: Clinicians should understand the roles and limitations of available treatment options. Surgery reduces the magnitude of the deviation, whereas optometric VT (vision therapy) provides the unique role of establishing normal sensory processing.

Optometric therapy of divergence excess strabismus.

Goldrich SG. *American Journal of Optometry & Physiological Optics*, 57: 7-14, 1980

A review and analysis of the vision training procedures were carried out over a period of 2 years at State University of New York (SUNY) University Optometric Center by 20 staff optometrists on 28 patients exhibiting divergence excess strabismus. Training included motility, accommodative rock, fusion, antisuppression, and stereoscopic skills by a variety of techniques and devices. Patients who exhibited smaller pre-training angles of deviation, increased maturity, and greater motivation responded most successfully to treatment. Of the patients reviewed, 71% attained a functional cure following sequential therapy procedures used in-office as well as home. Highest success rate occurred when office therapy was supplemented with home vision therapy. The results achieved in this study compare favorably with those obtained by traditional orthoptic procedures.

Orthoptic treatment of strabismus

Ludlam WM. *AM J Optom Arch Am Acad Optom*, 38: 369-388, 1961.

Ludlam evaluated a sample of 149 unselected strabismics who received vision therapy and determined a 73% overall success rate.

The long range results of orthopic treatment of strabismus.

Ludlam WM, Kleinman, BI. *AM J Optom Arch Am Acad Optom*, 42: 647-684, 1965.

Ludlam and Kleinman found that the long-term overall success rate of vision therapy to be calculated at 65%.

The effectiveness of orthoptics alone in selected cases of exodeviations: the immediate results and several years later.

Sanfilippo S, Clahane AC. American Orthoptic Journal, 20: 104-117, 1970

Sanfilippo and Clahane designed a prospective study of the results of orthoptic therapy for intermittent exotropia. 64.5% reported cured, 9.7% reported improvement, 9% reported fair. Subsequently after 5 years, 52% remained cured, 32% remained improved.

Treatment of Intermittent Esotropia Incorporating Peripheral Awareness Training.

Tong, D. Journal of Behavioral Optometry, 10(5), 1999.

Abstract: The patient with intermittent esotropia at distance can be symptomatic for diplopia (double vision), which may interfere with driving, work performance, and school achievement. The cosmesis of the strabismus may also affect the patient's self-esteem. This report describes a patient with intermittent esotropia at distance who underwent vision therapy to relieve her symptom of diplopia (double vision) and cosmetic concerns. After two sessions of therapy emphasizing peripheral fusion and divergence, the patient became kinesthetically aware of the eye turn and she was able to regain single vision with minimal effort. The patient remained non-strabismic at one- and three- month follow-ups. This case illustrates that vision therapy can effectively relieve the symptoms of a patient with intermittent esotropia once the patient is able to gain active control of her visual system.

Accommodative esotropia: efficacy of therapy.

Wick B. Journal of the American Optometric Association, 58: 562-566, 1987

Abstract: Retrospective examination was performed on the records of 54 patients who had undergone treatment of accommodative esotropia. The patients were classified based on the Duane classification as having either convergence excess (n=11) or equal esodeviations (n=43). Over 90% of the patients achieved total restoration of normal binocular function with treatment. The results and implications of this study are discussed.

Success in strabismus therapy: A literature review.

Ziegler D, Huff D, Rouse MW. Journal of the American Optometric Association, 53(12): 979-9883, 1982.

The purpose of this study was to review the literature pertaining to non-surgical cure rates for strabismus published since 1958 and compare it to Flom's prognostic model. From the studies which specified Flom's functional cure or its equivalent, it was determined that strabismic cure rates using vision therapy could be broken down as follows:

- Constant esotropia - 29%
- Intermittent esotropia - 73%
- Constant exotropia - 53%
- Intermittent exotropia - 62%

(b) Amblyopia

Amblyopia is a reduction in visual acuity without anatomic damage and usually not corrected solely by glasses. This condition is also called lazy eye. Two common forms of amblyopia are Refractive Amblyopia and Strabismic Amblyopia.

Success in amblyopia therapy as a function of age: a literature survey.

Birnbaum MH, Koslowe K, Sanet R. American Journal of Optometry & Physiological Optics, May; 54(5): 269-275, 1977.

Abstract: It is frequently stated that amblyopia is not correctable after the age of 6 years. Many practitioners report marked success for older patients. To evaluate these conflicting reports, we analyzed the results from 23 published amblyopia studies. Our analysis indicates that substantial numbers of patients over age 6 were successfully treated. Success rates under age 6 were not significantly better than those in older patients when the criterion for success was achievement of 20/30 acuity or better. When a criterion of 4 lines improvement was used, success rates at all ages under 16 were quite similar; in patients 16 and over, success by this criterion was significantly less frequent, but even in this group success was achieved by 42% of the patients.

Efficacy of vision therapy in amblyopia: a literature review.

Garzia RP. American Journal of Optometry & Physiological Optics, June; 64(6): 393-404, 1987.

Abstract: In this paper the major optometric, ophthalmologic, and orthoptic literature on the efficacy of vision therapy for amblyopia has been surveyed. Over the past four decades there are many examples of the successful treatment of amblyopia in the form of well documented individual case reports or large sample studies. Although occlusion of the dominant eye has been applied universally, there are some instances of the successful use of minimal occlusion combined with extensive visual-motor therapy. Overall, the results of the literature review strongly support the use of active vision therapy as an integral part of the clinical treatment of amblyopia.

A randomized pilot study of near activities versus non-near activities during patching therapy for amblyopia.

Holmes JM, Edwards AR, Beck RW, Arnold RW, Johnson DA, Klimek DL, Kraker RT, Lee KA, Lyon DW, Nosel ER, Repka MX, Sala NA, Silbert DI, Tamkins S; Pediatric Eye Disease Investigator Group. J AAPOS 2005 Apr;9(2):129-36.

Background: To plan a future randomized clinical trial, the authors conducted a pilot study to determine whether children randomized to near or non-near activities would perform prescribed activities. A secondary aim was to obtain a preliminary estimate of the effect of near versus non-near activities on amblyopic eye visual acuity, when combined with 2 hours of daily patching.

Methods: Sixty-four children, 3 to less than 7 years of age, with anisometropic, strabismic, or combined amblyopia (20/40 to 20/400) were randomly assigned to receive either 2 hours of daily patching with near activities or 2 hours of daily patching without near activities. Parents completed daily calendars for 4 weeks recording the activities performed while patched and received a weekly telephone call in which they were asked to describe the activities performed during the previous 2 hours of patching. Visual acuity was assessed at 4 weeks.

Results: The children assigned to near visual activities performed more near activities than those assigned to non-near activities (by calendars, mean 1.6 +/-0.5 hours versus 0.2 +/-0.2 hours daily, $P < 0.001$; by telephone interviews, 1.6 +/-0.4 hours versus 0.4 +/-0.5 hours daily, $P < 0.001$). After 4 weeks of treatment, there was a suggestion of greater improvement in amblyopic eye visual acuity in those assigned to near visual activities (mean 2.6 lines versus 1.6 lines, $P = 0.07$). The treatment group difference in visual acuity was present for patients with severe amblyopia but not moderate amblyopia.

Conclusions: Children patched and instructed to perform near activities for amblyopia spent more time performing those near activities than children who were instructed to perform non-near activities. Our results suggest that performing near activities while patched may be beneficial in treating amblyopia. Based on our data, a formal randomized amblyopia treatment trial of patching with and without near activities is both feasible and desirable.

Efficacy of treatment modalities in refractive amblyopia.

Krumholtz I, FitzGerald D. Journal of the American Optometric Association, June; 70(6): 399-404, 1999.

Background: The pediatric clinic of the SUNY State College of Optometry/University Optometric Center (New York) develops a yearly quality management plan to monitor patient care. One of the areas retrospectively reviewed for all outcomes is refractive amblyopia.

Methods: A retrospective review of records was performed on patients diagnosed with refractive amblyopia. With the use of a prescribed protocol, each patient's progress was tracked for a period of 6 months. Major emphasis was placed on outcome as related to treatment modality. Treatment alternatives were optical correction alone, optical correction in conjunction with patching, and optical correction and patching with vision therapy.

Results: Improvement criteria included a 2-line increase in visual acuity on the Snellen chart and an increase of 20 seconds of arc of stereopsis, as measured by the Wirt circles. The groups that patched with correction and those that received vision therapy had similar visual acuity improvements; however, the latter group had a significantly greater improvement in stereopsis. Both groups performed significantly better in both categories when compared to the group receiving optical correction alone.

Conclusions: Though patching alone may be sufficient for improvement of visual acuity, binocular performance is significantly better when vision therapy is included in the treatment regimen.

Active Vision Therapy on an Adult Strabismic Amblyope.

Lee, R. Journal of Behavioral Optometry, 10(5), 1999

Abstract: Studies have shown that treatment of amblyopia after "visual maturity," which occurs around the age of 9, can improve not just visual acuity, but overall visual functioning. Nevertheless, many clinicians do not treat amblyopia if patients appear "too old." The case of a 45-year-old amblyope who was successfully treated is presented. The age of when treatment can be instituted is discussed, as well as the efficacy of different treatment modalities (i.e. occlusion and spectacle correction versus occlusion, spectacle correction, and active vision therapy)

Perceptual learning improves visual performance in juvenile amblyopia.

Li RW, Young KG, Hoening P, Levi DM. Invest Ophthalmol Vis Sci. 2005 Sep;46(9):3161-8

Purpose: To determine whether practicing a position-discrimination task improves visual performance in children with amblyopia and to determine the mechanism(s) of improvement. **Methods:** Five children (age range, 7-10 years) with amblyopia practiced a positional acuity task in which they had to judge which of three pairs of lines was misaligned. Positional noise was produced by distributing the individual patches of each line segment according to a Gaussian probability function. Observers were trained at three noise levels (including 0), with each observer performing between 3000 and 4000 responses in 7 to 10 sessions. Trial-by-trial feedback was provided.

Results: Four of the five observers showed significant improvement in positional acuity. In those four observers, on average, positional acuity with no noise improved by approximately 32% and with high noise by approximately 26%. A position-averaging model was used to parse the improvement into an increase in efficiency or a decrease in equivalent input noise. Two observers showed increased efficiency (51% and 117% improvements) with no significant change in equivalent input noise across sessions. The other two observers showed both a decrease in equivalent input noise (18% and 29%) and an increase in efficiency (17%

and 71%). All five observers showed substantial improvement in Snellen acuity (approximately 26%) after practice.

Conclusions: Perceptual learning can improve visual performance in amblyopic children. The improvement can be parsed into two important factors: decreased equivalent input noise and increased efficiency. Perceptual learning techniques may add an effective new method to the armamentarium of amblyopia treatments.

Characterizing the mechanisms of improvement for position discrimination in adult amblyopia.

Li RW, Levi DM. *J Vis.* 2004 Jun 1;4(6):476-87.

Adult amblyopes can improve positional acuity through practice; however, the neural mechanisms underlying this improvement are still not clear. In this study, seven adult amblyopes repeatedly practiced a position discrimination task in the presence of positional noise. We found that six of the seven showed systematic and significant improvements in position acuity that were both eye and orientation specific. Using a position-averaging model, we were able to parse the improvement in performance with practice into two factors: improvement in sampling efficiency and reduction of equivalent input noise. Three of the seven showed improved efficiency with no change in equivalent noise, two showed a significant reduction in equivalent noise with no change in efficiency, and one showed both improved efficiency and reduced equivalent noise. Interestingly, all observers showed substantial improvement in visual acuity, and one observer showed substantial improvement in stereoacuity. Three observers were also tested on a counting task, and all three improved after practicing positional discrimination. Our results reveal the mechanisms underlying perceptual learning in amblyopic vision, and may provide a basis for developing more effective and efficient strategies for the treatment of amblyopia.

Binocular Contrast Summation and Inhibition in Amblyopia.

Pardhan S, Gilchrist J *Documenta Ophthalmologica* 82, 1992. 239-248.

The monocular contrast sensitivity loss in amblyopia is well documented. We investigated the influence of interocular sensitivity difference on binocular contrast sensitivity in amblyopia. Monocular and binocular contrast sensitivity functions of six amblyopes (three strabismic and three anisometropic) were measured. The monocular contrast sensitivity loss depended on the type of amblyope. Anisometropic amblyopes generally showed high frequency losses. Strabismic amblyopes showed losses at both low and high spatial frequencies. Binocular performance was assessed in terms of binocular ratios (binocular/non-amblyopic). A binocular ratio greater than 1 indicates binocular summation (binocular > monocular) while a ratio less than 1 shows binocular inhibition (binocular < monocular). In all subjects, the binocular ratio depended on the difference between the amblyopic and the non-amblyopic eye. Minimal interocular difference produced binocular summation, the magnitude of which decreased as the difference between the two eyes increased. Further increases in the monocular difference produced binocular inhibition. Anisometropic amblyopes showed a greater degree of binocular summation at low spatial frequencies compared to strabismic amblyopes. Both types of amblyopes showed binocular inhibition at high spatial frequencies. Clinical implications of binocular summation and inhibition in amblyopia are discussed.

Efficacy and stability of amblyopia therapy.

Rutstein RP, Fuhr PS. *Optometry and Vision Science*, 69(1): 747-754, 1992

To determine the efficacy and stability of therapy, the charts for 64 amblyopes with strabismus and/or anisometropia who had been treated by direct occlusion were reviewed. For patients aged 7 years or less (N=39), 90% showed some acuity gain, with 69% achieving at least a doubling of acuity. Fifty-four percent obtained 20/40 or better after an average treatment period of 3.8 months. Some reduction in visual acuity (VA) subsequently occurred for 75% of those patients followed. For patients aged eight years or more (N=26), 77%

showed some acuity gain with 31% (8/260 improving at least 0.3 log units. Twenty-seven percent obtained 20/40 (6/12) or better after an average treatment period of 4.2 months, although no patients older than 10 years (N=13) achieved 20/40 . Loss of some of the acuity gain subsequently occurred for 67% of those followed. These findings indicate that VA can be improved by patching therapy in most patients older than 7 years, but the acuity improvement is somewhat less than in younger patients. At least 67% of all amblyopes followed for one year lost some of the acuity gain after cessation of therapy, regardless of the age when treated. As a reduction of the acuity gain is likely to occur within the first year after cessation of therapy, it is recommended that amblyopic patients of all ages be followed at regular intervals.

Treatment of refractive amblyopia in adults.

Saulles H. Journal of the American Optometric Association, December;58(12): 959-960, 1987

Treatment of amblyopia has been relatively ignored in the adult population. In a retrospective study at the University of Michigan Health Service, 10 patients with refractive amblyopia showed visual acuity improvement in their amblyopic eye after completing simple vision therapies.

Randomized trial of treatment of amblyopia in children aged 7 to 17 years.

Scheiman MM, Hertle RW, Beck RW, Edwards AR, Birch E, Cotter SA, Crouch ER Jr, Cruz OA, Davitt BV, Donahue S, Holmes JM, Lyon DW, Repka MX, Sala NA, Silbert DI, Suh DW, Tamkins SM; Arch Ophthalmol. 2005 Apr;123(4):437-47.

Objective: To evaluate the effectiveness of treatment of amblyopia in children aged 7 to 17 years.

Methods: At 49 clinical sites, 507 patients with amblyopic eye visual acuity ranging from 20/40 to 20/400 were provided with optimal optical correction and then randomized to a treatment group (2-6 hours per day of prescribed patching combined with near visual activities for all patients plus atropine sulfate for children aged 7 to 12 years) or an optical correction group (optical correction alone). Patients whose amblyopic eye acuity improved 10 or more letters (> or =2 lines) by 24 weeks were considered responders.

Results: In the 7- to 12-year-olds (n = 404), 53% of the treatment group were responders compared with 25% of the optical correction group (P<.001). In the 13- to 17-year-olds (n = 103), the responder rates were 25% and 23%, respectively, overall (adjusted P = .22) but 47% and 20%, respectively, among patients not previously treated with patching and/or atropine for amblyopia (adjusted P = .03). Most patients, including responders, were left with a residual visual acuity deficit.

Conclusions: Amblyopia improves with optical correction alone in about one fourth of patients aged 7 to 17 years, although most patients who are initially treated with optical correction alone will require additional treatment for amblyopia. For patients aged 7 to 12 years, prescribing 2 to 6 hours per day of patching with near visual activities and atropine can improve visual acuity even if the amblyopia has been previously treated. For patients 13 to 17 years, prescribing patching 2 to 6 hours per day with near visual activities may improve visual acuity when amblyopia has not been previously treated but appears to be of little benefit if amblyopia was previously treated with patching. We do not yet know whether visual acuity improvement will be sustained once treatment is discontinued; therefore, conclusions regarding the long-term benefit of treatment and the development of treatment recommendations for amblyopia in children 7 years and older await the results of a follow-up study we are conducting on the patients who responded to treatment.

Vision function recovery during orthoptic therapy in an adult esotropic amblyope.

Selenow A, Ciuffreda KJ. Journal of the American Optometric Association, 57(2); 132-140, 1986

Orthoptic therapy was instituted in a 29-year-old patient having moderate amblyopia, constant small-angle esotropia, and large and steady eccentric fixation. This combination of factors, especially the age, pointed toward a poor prognosis for attainment of markedly improved vision function. Rate of recovery of several monocular vision functions was monitored during one year of orthoptic therapy. Results showed substantial improvement in most areas, thus providing evidence of neural plasticity at multiple sites in the visual pathways in this adult amblyope.

Anisometropic amblyopia: Is the patient ever too old to treat?

Wick B, Wingard M, et. Al. Optometry and Vision Science, 69(11): 866-878, 1992

This report describes a sequential management program for anisometropic amblyopia that consists of four steps: (1) the full refractive correction, (2) added lenses or prism when needed to improve alignment of the visual axes, (3) 2 to 5 hour/day of direct occlusion and (4) active vision therapy to develop monocular acuity and improve binocular visual function. The records of 19 patients over six years of age who had been treated using this sequential management philosophy were evaluated. After 15.2 weeks of treatment the Amblyopia Success Index (ASI) documented an average improvement in visual acuity of 92.1% with a range from a low of 75% by a 49-year-old patient to a maximum of 100% achieved by 42.1% of the patients (8 of 19). Patients who had completed therapy one or more years ago (N=4) maintained their acuity improvement. From these results, we conclude that following a sequential management plan for treatment of anisometropic amblyopia can yield substantial long-lasting improvement in visual acuity and binocular function for patients of any age.

A randomized trial of patching regimens for treatment of moderate amblyopia in children.

Repka MX, Beck RW, Holmes JM, Birch EE, Chandler DL, Cotter SA, Hertle RW, Kraker RT, Moke PS, Quinn GE, Scheiman MM; Pediatric Eye Disease Investigator Group. Arch Ophthalmol. 2003 May;121(5):603-11

Objective: To compare 2 hours vs 6 hours of daily patching as treatments for moderate amblyopia in children younger than 7 years.

Methods: In a randomized multicenter (35 sites) clinical trial, 189 children younger than 7 years with amblyopia in the range of 20/40 to 20/80 were assigned to receive either 2 hours or 6 hours of daily patching combined with at least 1 hour per day of near visual activities during patching. Main Outcome Measure Visual acuity in the amblyopic eye after 4 months.

Results: Visual acuity in the amblyopic eye improved a similar amount in both groups. The improvement in the visual acuity of the amblyopic eye from baseline to 4 months averaged 2.40 lines in each group (P =.98). The 4-month visual acuity was at least 20/32 and/or improved from baseline by 3 or more lines in 62% of patients in each group (P>.99).

Conclusion: When combined with prescribing 1 hour of near visual activities, 2 hours of daily patching produces an improvement in visual acuity that is of similar magnitude to the improvement produced by 6 hours of daily patching in treating moderate amblyopia in children aged 3 to 7 years.

A randomized trial to evaluate 2 hours of daily patching for strabismic and anisometropic amblyopia in children.

Wallace DK; Pediatric Eye Disease Investigator Group; Edwards AR, Cotter SA, Beck RW, Arnold RW, Astle WF, Barnhardt CN, Birch EE, Donahue SP, Everett DF, Felius J, Holmes JM, Kraker RT, Melia M, Repka MX, Sala NA, Silbert DI, Weise KK.

Ophthalmology. 2006 Jun;113(6):904-12

Objective: To compare 2 hours of daily patching (combined with 1 hour of concurrent near visual activities) with a control group of spectacle wear alone (if needed) for treatment of moderate to severe amblyopia in children 3 to 7 years old.

Design: Prospective randomized multicenter clinical trial (46 sites).

Participants: One hundred eighty children 3 to 7 years old with best-corrected amblyopic-eye visual acuity (VA) of 20/40 to 20/400 associated with strabismus, anisometropia, or both who had worn optimal refractive correction (if needed) for at least 16 weeks or for 2 consecutive visits without improvement.

Intervention: Randomization either to 2 hours of daily patching with 1 hour of near visual activities or to spectacles alone (if needed). Patients were continued on the randomized treatment (or no treatment) until no further improvement was noted.

Main Outcome Measure: Best-corrected VA in the amblyopic eye after 5 weeks.

Results: Improvement in VA of the amblyopic eye from baseline to 5 weeks averaged 1.1 lines in the patching group and 0.5 lines in the control group ($P = 0.006$), and improvement from baseline to best measured VA at any visit averaged 2.2 lines in the patching group and 1.3 lines in the control group ($P < 0.001$).

Conclusion: After a period of treatment with spectacles, 2 hours of daily patching combined with 1 hour of near visual activities modestly improves moderate to severe amblyopia in children 3 to 7 years old.