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Dyspraxia, Apraxia and Dyslexia

Clinicians and researchers alike have argued about the proper definition of apraxia, dyspraxia, and dyslexia for over three decades. Their disagreements seem to rise out of a certain lack of understanding about how the brain processes sensory information and translates sensory signals into skills like reading and speaking. Fortunately, recent advances in neuroscience have improved our ability to design effective therapies for the wide range of sensory, motor, and cognitive problems associated with these disorders.

There is great confusion about the difference between apraxia and dyspraxia among clinicians and parents alike. Medical dictionaries define *apraxia* as a partial or total inability to make voluntary body movements without losing muscle power or control.¹ Apraxia can affect any number of muscles including those of the face, mouth, eyes, eyelids, trunk, or limbs. Apraxia is a severe condition and it is often associated

1. Definition from the Compact American Medical Dictionary, American Heritage Dictionaries, Boston: Houghton-Mifflin (1998).

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with frank brain damage, as that which occurs after a stroke, seizure, trauma, or infection in the brain.

Dyspraxia, on the other hand, refers to impaired muscle function or control. Because dyspraxia involves motor areas of the brain,² it can affect speech, eating, or the coordinated use of hands, arms or legs, affecting:³

- * chewing and swallowing
- * handwriting and fine motor skills
- * balance or gait
- * learning to walk, skate, ski, or ride a bicycle
- * imitating facial expressions
- * speaking or articulating
- * pointing, reaching or grasping

CAUSES OF APRAXIA AND DYSPRAXIA

A wide range of developmental, neurological and medical events and conditions can result in damage to areas of the brain that control motor actions. Common causes include:

2.For example the vestibular areas, prefrontal cortex, premotor and parietal areas.

3.Maassen (2002).

- * lesions from trauma or toxins⁴
- * lesions from viral infection⁵
- * seizures⁶
- * neuropathy
- * genetic errors⁷
- * metabolic diseases (e.g. galactosemia)⁸
- * sensory deprivation during the critical period

4. Lesions can be detected by testing finger rolling, power, rapid alternating movements, forearm rolling, and pronator drift. Lower limb tests with the greatest sensitivities for detecting focal lesions involved assessment of power (see Anderson et al, 2005).

5. Viral agents include herpes, parvovirus B19, Epstein-Barr, and HIV.

6. This includes pyridoxine dependent seizures (see Baxter, Griffiths, Kelly and Gardner-Medwin; 1996), Worster-Drought syndrome and other pseudo-bulbar palsies (see Clark, Carr, Reilly and Neville; 2000; free article available at <http://brain.oxfordjournals.org/cgi/content/full/123/10/2160>) and rolandic or other forms of epilepsy (see Nabbout and Dulac; 2003, for a review).

7. For example, variants that alter FOXP2 protein sequence (7q31) or mutations in the methyl-CpG binding protein 2 (MECP2) gene with trisomy 21. For more information visit the Online Mendelian Inheritance in Man library at <http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?CMD=search&DB=omim>

8. Galactosemia is genetic error of the GALT enzyme, which oxidizes galactose into CO₂ in expired air. It is unknown why this defect is related to verbal dyspraxia, although some researchers have suggested that it is because it interferes with glycoprotein, glycolipid and glycogen (carbohydrate) synthesis. See Webb, Singh, Kennedy and Elsas (2003).

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TESTING FOR DYSPRAXIA/APRAXIA

Because dyspraxia and apraxia can have highly variable symptoms depending upon the specific areas of the brain that are involved, tests for muscle involvement should include:

- * speech and language (consonant production, vowel production, fluency and pragmatics)
- * grasp and fine motor skills
- * rapid alternating arm and hand movements
- * muscle power
- * finger and forearm rolling
- * vestibular functions
- * gait and balance
- * visual tracking and focus
- * auditory and visual processing
- * motor sequencing and motor imitation
- * problem solving
- * pronator drift⁹
- * self-help skills

TREATING DYSPRAXIA

Traditional therapies for dyspraxia (training and motor drills) typically yield little or no carry-over from trained actions to other skills.¹⁰ As a result there has been a great demand for new ways to treat dyspraxia. Some of these newer therapies have reported good results while others seem to be beneficial only for certain subgroups of patients. Newer treatment techniques include:

- * electropalatography¹¹
- * sign language
- * melodic intonation¹²
- * cueing (to aid initiation or inhibition of movement)
- * sensory feedback (cueing actions with vibration or touch)
- * vestibular exercises (sensory integration)

9. The arms are stretched out, palms up, in front of the body and the eyes are closed. The examiner pushes down hard on one hand at a time and determines whether the hand returned to its original place.

10. Ballard (2001),

11. In this technique, sensors are placed against the palate to record and send to a computer for visualizing tongue strikes against the palate in consonant production. By comparing the visual feedback between an unimpaired speaker and the electropalate, individuals can adjust tongue placement to form consonants.

12. The therapist intonates or sings the word, then both the patient and the therapist intonate the word, and then the patient alone.

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- * cognitive therapy (attaching meaning to actions)
- * fatty acid supplementation¹³
- * intersystemic reorganization (adding gestures to speech)
- * problem solving

Although it will be many years before researchers can determine the relative effectiveness of these approaches, it does appear clear that any effective treatment program for dyspraxia or apraxia must be comprehensive and involve tasks such as:

- * learning new motor sequences
- * practicing initiating and inhibiting movements
- * practicing rapid motor movements
- * practicing motor sequences involved in specific skills like dressing, handwriting, feeding, opening and closing doors.
- * visual, auditory and tactile perception
- * bilateral coordination
- * independence skills (e.g. toilet use, dressing, feeding)
- * play and cognitive development

13.unproven as yet.

Although many therapists do not consider dyspraxia to be curable at this point in time, significant improvements can be obtained with the right type and degree of intervention. Individual therapy provided daily or nearly daily has been found to be the most effective, while therapy provided in a group setting or therapy that is provided only once or twice a week seems to have little beneficial effect.¹⁴

DYSLEXIA

Dyslexia is defined as difficulty either learning to read or difficulty reading fluently. It is not the result of inadequate teaching, lack of opportunities to read, or an impoverished language environment. Developmental dyslexia refers to an inability to read fluently that is caused by abnormal wiring in areas of the brain that process phonemes, move the eye muscles, process rapid visual or auditory information, or attach meaning to symbols. Acquired dyslexia is the result of injury to one or more of these networks due to stroke, toxins, viral infection, seizures, or trauma.

Dyslexia is one of the most common disorders in childhood,

14. See, for example, Peters, Henderson and Dookun (2004) or Ballard (2001).

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affecting as many as 21% of boys and 11% of girls.¹⁵ The actual nature of dyslexia, as well as its causes, are topics of hot debate among researchers.

In general, dyslexia is believed to be caused by one or more of the following:

- * impaired phoneme recognition¹⁶
- * a visual processing disorder¹⁷
- * slow sensory processing in general¹⁸

Researchers have also found that language impairments and auditory processing disorder are quite common among individuals with dyslexia,¹⁹ as are vestibular and motor coordination disorders.²⁰ An individual with dyslexia will exhibit a unique set of sensory processing problems that are auditory, vestibular and/or visual in nature.

15. Rutter et al (2004). This figure is the average of results reported for four large longitudinal studies in this review. Incidence rates ranged from 17.6%-21.6% for boys and 7.9% - 13% for girls.

16. For example, see Ziegler (2005) or Shaywitz and Shaywitz (2005), Breznitz (2003).

17. For example, see Badian (2005) or Sireteanu, Goertz, Bachert and Wandert (2005).

18. For example see Merzenich et al (1996) or Tallal et al (1996).

19. See Flax et al (2003) and Ramirez and Mann (2005) for examples.

Visual Processing and Dyslexia

As visual signals leave the retina at the back of the eye and course through the brain, they travel along two pathways. The first is the *parvocellular* stream, fed by slow responding *tonic* cells that carry information about color and form to the brain. The second pathway is the *magnocellular* stream, fed by fast responding *phasic* cells, that carry information about contrast, light and movement.

One popular theory suggested that some abnormality in the rapid response pathway might be interfering with the reader's ability to process the movement of the eyes as they move across a page. This theory was later refuted when researchers discovered that the magnocellular pathway is suppressed by the eye movements of reading.²¹

It does appear, however, that some dyslexic readers process sensory information quite slowly, and that this problem is

20. One study reported that 50% of poor readers and dyslexics scored at or below the 5th percentile in tests of motor coordination, particularly in the areas of balance and manual dexterity. See Iversen S, Berg K, Ellertsen B, Tonnessen FE. "Motor coordination difficulties in a municipality group and in a clinical sample of poor readers." *Dyslexia*. 2005 Aug;11(3):217-31.

21. Skottun and Parke (1999).

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related to the difficulty of the sensory signal. Researchers found that dyslexic readers had poor recognition for 4 and 6 digit sequences but not 2 digit sequences.²² Dyslexics are much slower at responding to road signs when driving²³ and take longer to respond to both auditory and visual information than fluent readers.²⁴

If brief auditory signals like voice onset and stop consonants are not processed well (a *phonological deficit*) then it becomes quite difficult to associate letter symbols with these sounds.²⁵ This type of problem impacts not only the ability to read, but also to spell and to write.²⁶ Since practice increases processing speed, words that are frequently encountered and common are less of a problem than words that are novel or unfamiliar.²⁷ Familiarity also allows the brain to process the entire word as a unit rather than decoding it through phonetics.

22.Hawelka and Wimmer (2005).

23. See Sigmundsson (2005).

24.Breznitz and Meyler (2003).

25.See Putter-Katz et al (2005) or Schulte-Korne, Deimel, Bartling and Remschmidt (1998); Breier et al (2001) or Breier, Gray, Fletcher, Foorman and Klaas (2002).

26.Hatcher, Snowling and Griffiths (2002).

27.See, for example, Moll, Hutzler and Wimmer (2005).

When a visual signal is processed too slowly, part of that visual pattern can drop out and create a gap in perception. The brain fills in this missing information automatically, using the context or surroundings as a guide. This *filling-in phenomenon* occurs at a pre-conscious level, which means that the individual is not aware that what they just read may not be correct. This in turn makes comprehension quite difficult, as frequent errors filling in the visual pattern can render a passage bizarre or incomprehensible.

Visual Acquired Dyslexia

Visual forms of dyslexia can also be caused by damage to areas of the brain that recognize visual patterns, process specific areas of the visual field, or integrate parts of visual objects into wholes. In *visual neglect dyslexia*, for example, individuals can have fail to process the initial or final letter in a word (regardless of the direction in which the word is printed), or can fail to process letters located in a particular area of the page (e.g. the final letters of words written top down and the initial letters of words written bottom up).²⁸

Attentional dyslexia produces a somewhat different problem.

28. Nichelli, Venneri, Pentore and Cubelli (1993).

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In this type of dyslexia, areas of the brain that integrate patterns (e.g. letters into words) have been damaged. This makes it difficult to decode words phonetically or to read lines of text. Printing words in different cases or increasing the space between words will improve fluency in cases of attentional dyslexia.²⁹ Individuals with this type of dyslexia should rely on whole word strategies (learning words as units rather than decoding them phonetically) when learning to read.

Reading in the Brain

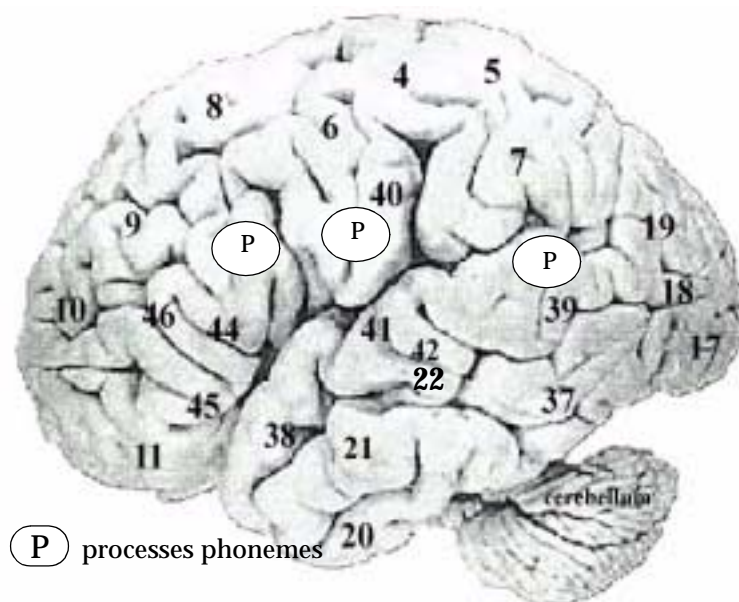
A vast number of networks in the brain are necessary for both reading and comprehension of written language.³⁰ In inexperienced readers (6-7 year olds), Brodmann's areas 37, 21 and 22 (this is Wernicke's area, which processes meaning and syntax) as well as areas 44 (this is Broca's area, which processes face, mouth and hand movements), 7, 9, 10, 40, 41 and 42 (which processes word meaning) become active

29. See Mayall and Humphreys (2002). Individuals with Balint's Syndrome experience this type of dyslexia. See Baylis, Driver, Baylis and Rafal (1994).

30. Left hemisphere dominance for word comprehension occurs at the level of semantic processing (see Zahn, Huber, Drews, Erberich, Krings, Willmes, and Schwarz, 2000).

when reading.³¹ Visual areas of the brain that process binocular vision include Brodmann areas 17,18, and 19.

Figure 3: Brodmann Areas of the Brain



Brain function studies of dyslexia suggest that areas that process phonemes (Brodmann areas 37, 39 and 6) and areas that process rapid auditory information (Brodmann areas 46, 10 and 9) are less active in dyslexics when reading than in other individuals.³² These results are difficult to inter-

31. Gaillard, Balsamo, Ibrahim, Sachs and Xu (2003).

32. See Brunswick, McCrory, Price, Frith and Frith (1999) and Temple (2002).

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pret, however, since learning affects how sensory events are processed. Intervention programs that improve the ability to discriminate rapid auditory signals and phonemes increase activation in these areas, which appears to also result in improved fluency and comprehension.³³

Brain activation studies suggest that in general, dyslexic readers have less activation in areas of the brain involved in: watching moving objects (ocular-vestibular disorder)³⁴ processing rapid auditory or visual information³⁵ naming common objects (lexical access)³⁶

How these problems affect the ability to read, however, remains a topic of hot debate among researchers.

Genetic Candidates for Dyslexia

The field of genetics has made dramatic leaps in the past ten years, stimulating a fervor among researchers for finding ways to link genetic errors on chromosomes with various disabilities or diseases.³⁷ A search of the OMIM produced a

33. See Shaywitz et al (1998) or Temple (2002) or Temple et al (2003).

34. Eden et al (1996).

35. See Temple et al (2000) and Putter-Katz et al (2005).

36. See McCrory, Mechelli, Frith and Price (2005).

variety of candidate genes for dyslexia in regions:³⁸ 1p36-p34, 2p16-p15,³⁹ 3p12-q13, 6p21.3-22.2,⁴⁰ 15q21, 18p11.2, and Xq27.3.

The region on chromosome 1 appears to be linked to phonologic awareness, spelling, and rapid naming.⁴¹ The region on chromosome 3 was also linked to phonologic awareness, naming speed, and verbal short-term memory.⁴² Phoneme awareness and single word reading ability were linked to 18p11.2⁴³ while a genome wide linkage analysis of a large Dutch family reported dyslexia susceptibility on Xq27.3.⁴⁴

37. This fervor prompted Dr. Victor McKusick and his colleagues to create a large database of all studies on human genes and genetic disorders. This database, the Online Mendelian Inheritance in Man (OMIM) (www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=OMIM) was placed online by the National Center for Biotechnology Information (NCBI) and can be accessed by anyone.

38. The first number refers to the chromosome and the p or q refers to the short (petite) or long (q) arm of the chromosome.

39. Fagerheim et al (1999).

40. Cardon et al (1994).

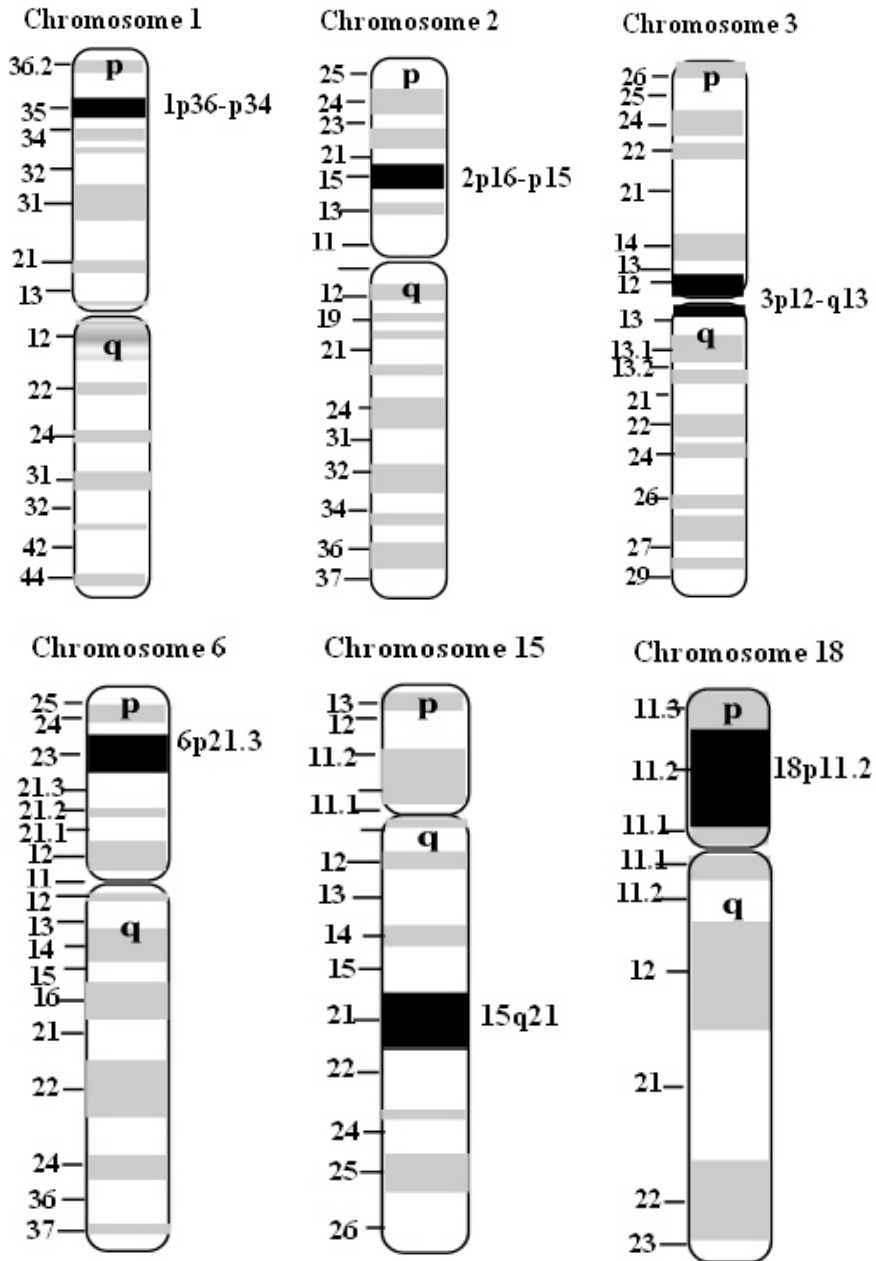
41. Tzenova, Kaplan, Petryshen and Field (2004).

42. Nopola-Hemmi et al (2001).

43. Fisher et al (2002).

44. de Kovel (2004).

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Figure 4: Six Candidates for Dyslexia (regions in bold)

Treating Dyslexia

A wide variety of treatments for dyslexia have been developed over the past thirty years that have reported to benefit dyslexic readers. Since the causes of dyslexia are still being actively debated among researchers and there have been few comparative studies of treatments, it is up to the clinician to identify a given individual's sensory processing deficits and to design a comprehensive intervention program to address these deficits.

Visual Therapies

Researchers have yet to agree upon which visual processing problems occur in visual dyslexia. In part this is due to the fact that researchers study groups rather than individuals; any group may contain individuals that have very different combinations of sensory processing problems. There is also a great deal of variability in research design and a lack of standards for identifying visual processing disorders. This makes interpretation of research results quite difficult, although some general guidelines can be proposed.⁴⁵

45. Methods used to identify common visual processing problems are described in Chapter One.

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Colored filters or lenses have been used for over 20 years as a treatment for dyslexia. Their use was first proposed by H. Irlen, an educational psychologist, in a presentation to the annual meeting of the American Psychological Association in 1983.

Irlen noticed that some individuals with reading problems could read well but reported frequent headaches and eye fatigue when reading. Irlen theorized that these individuals had a hypersensitivity to certain wavelengths of light and that using colored filters designed specifically to address an individual's color sensitivity would reduce reading fatigue. The use of colored filters became wildly popular after 60 Minutes Australia aired a program on Irlen's work in 1985 and 60 Minutes America aired a similar program in 1988.

Although research on the use of colored filters or lenses does not appear to support Irlen's theory of color sensitivity the use of colored lenses has been shown to be effective in treating some cases of convergence dysfunction and may help hypersensitivity to pattern glare (visual fatigue created by viewing repeated patterns like lines of text) for some readers.⁴⁶

Convergence disorders appear to occur in about 20% of the cases of dyslexia.⁴⁷ In cases of convergence dysfunction, letters can appear to blur, move around on the page or waver. In addition, visual fatigue occurs when reading.

One group of researchers addressed convergence problems in a group of dyslexic children by giving them yellow tinted glasses to use when reading or writing.⁴⁸ Half of the group were given glasses with the left lens covered, which meant that only one eye had to focus during reading.

In this study, all of the children wore the glasses for three months. At the end of the three month period, 54% of the children who did not use the occluded lenses and 64% of the children who did exhibited an improved ability to focus with both eyes. Those who improved their ability to focus gained 9.4 months in reading skills compared with a gain of 3.9 months for those who did not acquire accurate focusing skills.⁴⁹ Abnormal convergence is often treated with prism

46. Increased pattern glare and flicker sensitivity were reported in a group of dyslexic readers (Evans, Cook, Richards and Drasdo, 1994).

47. Stein, Richardson and Fowler (2000).

48. Yellow was chosen because the magnocellular system peaks in the yellow wavelength range of light.

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lenses or orthoptics; while research suggests that prism lenses can be effective for cases of neglect dyslexia,⁵⁰ the effectiveness of prism lenses for improving eye muscle control remains controversial. A recent paper reported that orthoptics (exercises designed to improve eye muscle control) were effective at improving convergence and visual focusing skills while prism lenses (used over a 6 week period) were not.⁵¹

Abnormal saccadic control (the ability to move the eyes back and forth accurately) can also make reading difficult. One study reported that 50% of a group of poor readers and 20% of a group of average readers exhibited poor saccadic eye movement control.⁵² Saccadic eye control can be improved through practice; in one study, daily exercises to improve saccadic control resulted in a normalization of visual control within 8 weeks.⁵³ Simple puzzles like word

49. Stein, Richardson and Fowler (2000).

50. Angeli, Benassi and Ladavas (2004).

51. Schieman, Mitchell et al (2005) reported that the use of prism lenses for 6 weeks were no better than placebo reading glasses at alleviating symptoms, improving the near point of convergence, or improving positive fusional vergence in children with convergence insufficiency. These same authors did find that orthoptic exercises (but not pencil push-ups) were effective at improving convergence skills (Schieman, Mitchell et al 2005)

52. See Biscaldi, Gezeck and Stuhr (1998).

searches or Sudoku, or games like MahJongg solitaire (all of which require the player to make saccadic eye movements) can also be used for this purpose.

Visual pursuit (tracking a moving target or maintaining visual stability when the body is in motion) is an ocular-vestibular skill that is often impaired in dyslexic readers. In one study, 25% of poor readers could not smoothly track a slowly moving target.⁵⁴ Visual pursuit skills can be improved through exercises that require visual pursuit, such as watching video games in which you are moving through an environment or in which things are moving toward you, playing tennis or softball, playing computer games in which you must click on moving objects, etc.⁵⁵

Phoneme Discrimination Training

Phonological awareness is believed to play a major role in both reading and spelling, and daily exercises that require making judgements about whether two phonemes are the

53.Fischer and Hartegg (2000).

54.Black, Collins, DeRoach and Zubrick (1984).

55.See Reynolds, Nicolson and Hambly (2000) reported improved reading fluency and phonological skill in dyslexic children after an exercise based intervention of vestibular activities.

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same or different can improve reading and spelling skills.⁵⁶ As a result, exercises designed to improve phonological awareness or the ability to discriminate between phonemes has been a cornerstone of many popular treatments for dyslexia. Some of the more popular of these include *Orton-Gillingham*,⁵⁷ *Lindamood Bell*,⁵⁸ *Earobics*⁵⁹ and *FastForWord*.⁶⁰ The Orton-Gillingham program focuses on teaching the rules of phonetics and syntax while the Lindamood Bell program focuses on associating oral-motor movements with speech sounds. Earobics and FastForWord are computer games involving practice with phoneme discrimination, auditory memory, word segmentation, rhyming, and other auditory skills.

Abnormal vestibular functions are common among dyslexic individuals; one study reported that 94% of a large group of dyslexic children and adults exhibited abnormal vestibular responses.⁶¹ Because the auditory nerve and the vestibular

56. See Schaffler, Sonntag, Hartnegg and Fischer (2004) or Moore, Rosenberg and Coleman (2005).

57. More information is available at www.orton-gillingham.com

58. More information is available at www.lindamoodbell.com

59. Available from Cognitive Concepts at www.earobics.com or www.cogcon.com/aboutus

60. Available from Scientific Learning Corp. at www.scilearn.com

nerve join to become the 8th cranial nerve in the brain, anything that damages this nerve or the areas of the brain that it innervates will be affected. Therefore it is common to find both auditory perception and vestibular problems together. In these cases, interventions must include both vestibular activities as well as activities to improve the perception of speech sounds. In addition to the techniques mentioned above, options include:

- * training in word identification strategies⁶²
- * daily practice reading short, simple texts out loud
- * comprehension training (e.g. semantics, pragmatics)

Slow speed of processing problems can be improved with daily practice learning new motor sequences. This type of activity stimulates neural development in motor sequencing and motor planning areas of the brain (e.g. premotor cortex and frontal lobe) and improves response times. Interventions that improve speed of processing include:

- * FastForWord
- * learning a *new* dance, song or sport

61. Levinson (1988).

62. See Lovett, Lacerenza and Borden (2000).

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- * fencing (sabre, foil, etc.)
- * novel video games
- * learning a new fine motor skill (e.g. tying shoes, knitting, beading, sewing, braiding).

Like apraxia and dyspraxia, developmental dyslexia is not considered fully reversible at this time. Acquired apraxia or dyspraxia and dyslexia (e.g. from injuries to the brain) are often reversible, depending upon the degree and location of the damage and the type of intervention provided.⁶³ As we continue to advance our knowledge about how the brain processes sensory information and how different forms of sensory processing disorders affect the ability to speak or to read, we will improve our ability to effectively treat these disorders.

63. In one case, removal of a tumor damaged BA 37 and created severe dyslexia. Reading skills gradually improved over the next year and eventually the patient recovered. See Kamada et al (2004).