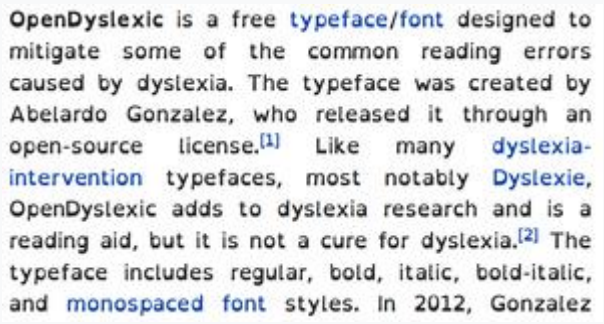
Dyslexia	
Synonyms	Reading disorder, alexia



An example of OpenDyslexic typeface, used to try to help with common reading errors in dyslexia.[1]

Specialty	Neurology, pediatrics
Symptoms	Trouble reading[2]
Usual onset	School age[3]
Causes	Genetic and environmental factors[3]
Risk factors	Family history, attention deficit hyperactivity disorder[4]
Diagnostic method	Series memory, spelling, vision, and reading test[5]
Differential diagnosis	Hearing or vision problems, insufficient teaching[3]
Treatment	Adjusting teaching methods[2]
Frequency	3–7%[3][6]

Dyslexia, also known as **reading disorder**, is characterized by trouble with reading despite normal intelligence.[2][7] Different people are affected to varying degrees.[4] Problems may

include difficulties in spelling words, reading quickly, writing words, "sounding out" words in the head, pronouncing words when reading aloud and understanding what one reads.[4][8] Often these difficulties are first noticed at school.[3] When someone who previously could read loses their ability, it is known as **alexia**.[4] The difficulties are involuntary and people with this disorder have a normal desire to learn.[4]

Dyslexia is believed to be caused by both genetic and environmental factors.[3] Some cases run in families.[4] It often occurs in people with attention deficit hyperactivity disorder (ADHD) and is associated with similar difficulties with numbers.[3] It may begin in adulthood as the result of a traumatic brain injury, stroke, or dementia.[2] The underlying mechanisms of dyslexia are problems within the brain's language processing.[4] Dyslexia is diagnosed through a series of tests of memory, spelling, vision, and reading skills.[5] Dyslexia is separate from reading difficulties caused by hearing or vision problems or by insufficient teaching.[3]

Treatment involves adjusting teaching methods to meet the person's needs.[2] While not curing the underlying problem, it may decrease the degree of symptoms.[9] Treatments targeting vision are not effective.[10] Dyslexia is the most common learning disability and occurs in all areas of the world.[3][11] It affects 3–7% of the population,[3][6] however, up to 20% may have some degree of symptoms.[12] While dyslexia is more often diagnosed in men,[3] it has been suggested that it affects men and women equally.[11] Some believe that dyslexia should be best considered as a different way of learning, with both benefits and downsides.[13][14]

Dyslexia is thought to have two types of cause, one related to language processing and another to visual processing.[15] It is considered a cognitive disorder, not a problem with intelligence. However, emotional problems often arise because of it.[15] Some published definitions are purely descriptive, whereas others propose causes. The latter usually cover a variety of reading skills and deficits, and difficulties with distinct causes rather than a single condition.[16] The National Institute of Neurological Disorders and Stroke definition describes dyslexia as "difficulty with phonological processing (the manipulation of sounds), spelling, and/or rapid visual-verbal responding".[2] The British Dyslexia Association definition describes dyslexia as "a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling" and is characterized by "difficulties in phonological awareness, verbal memory and verbal processing speed".[17]

Acquired dyslexia or alexia may be caused by brain damage due to stroke or atrophy.[18][19] Forms of alexia include pure alexia, surface dyslexia, semantic dyslexia, phonological dyslexia, and deep dyslexia.[20]

Definition

There is some variability in the definition of dyslexia. Some sources, such as the U.S. National Institutes of Health, define it specifically as a learning disorder.[2] Other sources, however, define it simply as an inability to read in the context of normal intelligence, and distinguish between *developmental dyslexia* (a learning disorder) and *acquired dyslexia* (loss of the ability to read caused by brain damage). ICD 10, the manual of medical diagnosis used in much of the world, includes separate diagnoses for "developmental dyslexia" (81.0)[21] and for "dyslexia and alexia" (48.0).[22] DSM 5, the manual of psychiatric diagnosis used in the United States, does not specifically define dyslexia, justifying this decision by stating that "the many definitions of dyslexia and dyscalculia meant those terms would not be useful as disorder names or in the diagnostic criteria". Instead it includes dyslexia in a category called specific learning disorders.[23]

Signs and symptoms

See also: Characteristics of dyslexia

In early childhood, symptoms that correlate with a later diagnosis of dyslexia include delayed onset of speech and a lack of phonological awareness, as well as being easily distracted by background noise.[10] A common myth closely associates dyslexia with mirror writing and reading letters or words backwards.[24] These behaviors are seen in many children as they learn to read and write, and are not considered to be defining characteristics of dyslexia.[10]

School-age children with dyslexia may exhibit signs of difficulty in identifying or generating rhyming words, or counting the number of syllables in words – both of which depend on phonological awareness.[25] They may also show difficulty in segmenting words into individual sounds or may blend sounds when producing words, indicating reduced phonemic awareness.[26] Difficulties with word retrieval or naming things is also associated with dyslexia.[27]:647 People with dyslexia are commonly poor spellers, a feature sometimes called dysorthographia or dysgraphia, which depends on orthographic coding.[10]

Problems persist into adolescence and adulthood and may accompany difficulties with summarizing stories, memorization, reading aloud, or learning foreign languages. Adults with dyslexia can often read with good comprehension, though they tend to read more slowly than others without a learning difficulty and perform worse in spelling tests or when reading nonsense words – a measure of phonological awareness.[28]

Language

Main article: Orthographies and dyslexia

The orthographic complexity of a language directly impacts how difficult learning to read the language is.[29]:266 English and French have comparatively "deep" phonemic orthographies within the Latin alphabet writing system, with complex structures employing spelling patterns on several levels: letter-sound correspondence, syllables, and morphemes.[30]:421

Languages such as Spanish, Italian and Finnish have mostly alphabetic orthographies, which primarily employ letter-sound correspondence – so-called shallow orthographies – which for dyslexics makes them easier to learn.[29]:266 Logographic writing systems, such as Chinese characters, have extensive symbol use, and pose problems for dyslexic learners.[31]

Associated conditions

Dyslexia is often accompanied by several learning disabilities, but it is unclear whether they share underlying neurological causes.[32] These associated disabilities include:

- Dysgraphia – A disorder which primarily expresses itself through difficulties with writing or typing, but in some cases through difficulties associated with eye–hand coordination and direction or sequence-oriented processes such as tying knots or carrying out repetitive tasks.[33] In dyslexia, dysgraphia is often multifactorial, due to impaired letter-writing automaticity, organizational and elaborative difficulties, and impaired visual word forming which makes it more difficult to retrieve the visual picture of words required for spelling.[33]

- Attention deficit hyperactivity disorder (ADHD) – A disorder characterized by problems paying attention, excessive activity, or taking action without forethought.[34] Dyslexia and ADHD commonly occur together.[6][35][36] Either 15%[10] or 12–24% of people with dyslexia have ADHD.[37] 35% of people with ADHD have dyslexia.[10]

- Auditory processing disorder – A listening disability that affects the ability to process auditory information.[38][39] This can lead to problems with auditory memory and auditory sequencing. Many people with dyslexia have auditory processing problems, and may develop their own logographic cues to compensate for this type of deficit. Some research indicates that auditory processing skills could be the primary shortfall in dyslexia.[40][41]

- Developmental coordination disorder – A neurological condition characterized by marked difficulty in carrying out routine tasks involving balance, fine-motor control, kinesthetic coordination, difficulty in the use of speech sounds, problems with short-term memory, and organization.[42]

Causes

Inferior parietal lobule (superior view). Some dyslexics demonstrate less electrical activation in this area.

Main article: Theories of dyslexia

Researchers have been trying to find the neurobiological basis of dyslexia since the condition was first identified in 1881.[43][44] For example, some have tried to associate the common problem among dyslexics of not being able to see letters clearly to abnormal development of their visual nerve cells.[45]

Neuroanatomy

Main article: Neurological research into dyslexia

Modern neuroimaging techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have shown a correlation between both functional and structural differences in the brains of children with reading difficulties.[46] Some dyslexics show less electrical activation in parts of the left hemisphere of the brain involved with reading, such as the inferior frontal gyrus, inferior parietal lobule, and the middle and ventral temporal cortex.[40] Over the past decade, brain activation studies using PET to study language have produced a breakthrough in the understanding of the neural basis of language. Neural bases for the visual lexicon and for auditory verbal short-term memory components have been proposed,[47] with some implication that the observed neural manifestation of developmental dyslexia is task-specific (i.e. functional rather than structural). fMRIs in dyslexics have provided important data which point to the interactive role of the cerebellum and cerebral cortex as well as other brain structures.[48][49]

The cerebellar theory of dyslexia proposes that impairment of cerebellum-controlled muscle movement affects the formation of words by the tongue and facial muscles, resulting in the fluency problems that are characteristic of some dyslexics. The cerebellum is also involved in

the automatization of some tasks, such as reading.[50] The fact that some dyslexic children have motor task and balance impairments has been used as evidence for a cerebellar role in their reading difficulties. However, the cerebellar theory is not supported by controlled research studies.[51]

Genetics

Main article: Genetic research into dyslexia

Research into potential genetic causes of dyslexia has its roots in post-autopsy examination of the brains of people with dyslexia.[45] Observed anatomical differences in the language centers of such brains include microscopic cortical malformations known as ectopias, more rarely, vascular micro-malformations, and microgyrus.[52] The previously cited studies and others[53] suggest that abnormal cortical development presumed to occur before or during the sixth month of fetal brain development was the cause of the abnormalities. Abnormal cell formations in dyslexics have also been reported in non-language cerebral and subcortical brain structures.[54] Several genes have been associated with dyslexia, including DCDC2 and KIAA0319 on chromosome 6,[55] and DYX1C1 on chromosome 15.[56]

Gene–environment interaction

Main article: Gene–environment interaction

The contribution of gene–environment interaction to reading disability has been intensely studied using twin studies, which estimate the proportion of variance associated with a person's environment and the proportion associated with their genes. Studies examining the influence of environmental factors such as parental education[57] and teacher quality[58] have determined that genetics have greater influence in supportive, rather than less optimal, environments.[59] However, more optimal conditions may just allow those genetic risk factors to account for more of the variance in outcome because the environmental risk factors have been minimized.[59] As environment plays a large role in learning and memory, it is likely that epigenetic modifications play an important role in reading ability. Animal experiments and measures of gene expression and methylation in the human periphery are used to study epigenetic processes; however, both types of study have many limitations in the extrapolation of results for application to the human brain.[60]

Mechanisms

Main article: Dual-route hypothesis to reading aloud

The dual-route theory of reading aloud was first described in the early 1970s.[61] This theory suggests that two separate mental mechanisms, or cognitive routes, are involved in reading aloud.[62] One mechanism is the lexical route, which is the process whereby skilled readers can recognize known words by sight alone, through a "dictionary" lookup procedure.[63] The other mechanism is the nonlexical or sublexical route, which is the process whereby the

reader can "sound out" a written word.[63][64] This is done by identifying the word's constituent parts (letters, phonemes, graphemes) and applying knowledge of how these parts are associated with each other, for example, how a string of neighboring letters sound together.[61] The dual-route system could explain the different rates of dyslexia occurrence between different languages (e.g. the Spanish language dependence on phonological rules accounts for the fact that Spanish-speaking children show a higher level of performance in non-word reading, when compared to English-speakers).[29][65]

Dyslexia disorder is not caused by mutation in one gene; in fact, it appears to involve the combined effects of several genes. Studying the cognitive problems associated with other disorders helps to better understand the genotype-phenotype link of dyslexia.[66] Neurophysiological and imaging procedures are being used to ascertain phenotypic characteristics in dyslexics, thus identifying the effects of certain genes.[67]

Diagnosis

There are tests that can indicate with high probability whether a person is a dyslexic.[68] If diagnostic testing indicates that a person may be dyslexic, such tests are often followed up with a full diagnostic assessment to determine the extent and nature of the disorder.[69] Tests can be administered by a teacher or computer.[70] Some test results indicate how to carry out teaching strategies.[70][71]

Central dyslexias

Central dyslexias include surface dyslexia, semantic dyslexia, phonological dyslexia, and deep dyslexia.[18][72] ICD-10 reclassified the previous distinction between dyslexia (315.02 in ICD-9) and alexia (315.01 in ICD-9) into a single classification as R48.0. The terms are applied to developmental dyslexia and inherited dyslexia along with developmental aphasia and inherited alexia, which are considered synonymous.[73]

Surface dyslexia

Main article: Surface dyslexia

In surface dyslexia, words with regular pronunciations (highly consistent with their spelling, e.g. *mint*) are read more accurately than words with irregular pronunciation, such as *colonel*.[74] Difficulty distinguishing homophones is a diagnostic used for some forms of surface dyslexia. This disorder is usually accompanied by surface agraphia and fluent aphasia.[75] Acquired surface dyslexia arises when a previously literate person experiences brain damage, which results in pronunciation errors that indicate impairment of the lexical route.[18][76][77]

Phonological dyslexia

Broca's area – (lateral view) dyslexics overuse this area which is associated with speech.[78]

Main article: Phonological dyslexia

In phonological dyslexia, sufferers can read familiar words but have difficulty with unfamiliar words, such as invented pseudo-words.[79] Phonological dyslexia is associated with lesions in the parts of the brain supplied with blood by the middle cerebral artery. The superior temporal lobe is often also involved. Furthermore, dyslexics compensate by overusing a front-brain region called Broca's area, which is associated with aspects of language and speech.[80] The Lindamood Phoneme Sequencing Program (LiPS) is used to treat phonological dyslexia.[81] This system is based on a three-way sensory feedback process, using auditory, visual, and oral skills to learn to recognize words and word patterns. Case studies with a total of three patients found a significant improvement in spelling and reading ability after using LiPS.[82]

Deep dyslexia

See also: Deep dyslexia

Individuals with deep dyslexia experience both semantic paralexia (para-dyslexia) and phonological dyslexia, causing the person to read a word and then say a related meaning instead of the denoted meaning.[83] Deep dyslexia is associated with clear phonological processing impairments.[18] Deep dyslexia is caused by widespread damage to the brain that often includes the left hemisphere.[84] The "continuum" hypothesis claims that deep dyslexia develops from phonological dyslexia.[85]

Peripheral dyslexias

Peripheral dyslexias have been described as affecting the visual analysis of letters as a result of brain injury.[86] Hemianopsia, a visual field loss on the left/right side of the vertical midline, is associated with this condition.[87][88]

Pure dyslexia

Main article: Pure alexia

Pure, or phonologically-based,[89] dyslexia, also known as agnosic dyslexia, dyslexia without agraphia, and pure word blindness, is dyslexia due to difficulty in recognizing written sequences of letters (such as words), or sometimes even letters. It is considered '"pure" because it is not accompanied by other significant language-related impairments. Pure dyslexia does not affect speech, handwriting style, language or comprehension impairments.[90] Pure dyslexia is caused by lesions on the visual word form area (VWFA). The VWFA is composed of the left lateral occipital sulcus and is activated during reading. A lesion in the VWFA stops transmission between the visual cortex and the left angular gyrus. It can also be caused by a lesion involving the left occipital lobe or the splenium. It is usually accompanied by a homonymous hemianopsia in the right side of the visual field.[86] Multiple oral re-reading (MOR) is a treatment for pure dyslexia.[91] It is considered a top-down processing technique in which affected individuals read and reread texts a predetermined number of times or until reading speed or accuracy improves a predetermined amount.[92]

Hemianopic dyslexia

Hemianopic dyslexia is commonly considered to derive from visual field loss due to damage to the primary visual cortex.[93] Sufferers may complain of abnormally slow reading but are able to read individual words normally. This is the most common form of peripheral alexia, and the form with the best evidence of effective treatments.[94]

Neglect dyslexia

In neglect dyslexia, some letters, most commonly those at the beginning or left side of a word, are skipped or misread during reading.[95] This alexia is associated with right parietal lesions. The use of prism glasses has been shown to mitigate this condition substantially.[96]

Attentional dyslexia

People with attentional dyslexia complain of letter-crowding or migration, sometimes blending elements of two words into one.[97] Sufferers read better when words are presented in isolation rather than flanked by other words and letters. Using a large magnifying glass may help mitigate this condition by reducing the effects of flanking from nearby words; however, no trials of this or indeed any other therapy for left parietal syndromes have been published as of 2014.[98]

Management

Main article: Management of dyslexia

Through the use of compensation strategies, therapy and educational support, dyslexic individuals can learn to read and write.[99] There are techniques and technical aids which help to manage or conceal symptoms of the disorder.[100] Removing stress and anxiety alone can sometimes improve written comprehension.[101] For dyslexia intervention with alphabet-writing systems, the fundamental aim is to increase a child's awareness of correspondences between graphemes (letters) and phonemes (sounds), and to relate these to reading and spelling by teaching how sounds blend into words. It has been found that reinforced collateral training focused on reading and spelling yields longer-lasting gains than oral phonological training alone.[102] Early intervention that is done for children at a young age can be successful in reducing reading failure.[103]

There is some evidence that the use of specially-tailored fonts may help with dyslexia.[1] These fonts, which include Dyslexie, OpenDyslexic, and Lexie Readable, were created based on the idea that many of the letters of the Latin alphabet are visually similar and may, therefore, confuse people with dyslexia. Dyslexie and OpenDyslexic both put emphasis on making each letter more distinctive in order to be more easily identified.[104] The benefits, however, might simply be due to the added spacing between words.[105]

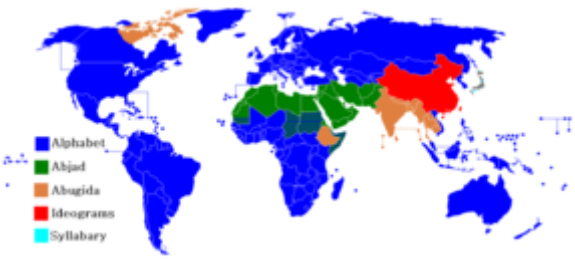
There have been many studies conducted regarding intervention in dyslexia. Among these studies one meta-analysis found that there was functional activation as a result.[106]

There is no evidence demonstrating that the use of music education is effective in improving dyslexic adolescents' reading skills.[107]

Prognosis

Dyslexic children require special instruction for word analysis and spelling from an early age.[108] While there are fonts that may help people with dyslexia better understand writing, this might simply be due to the added spacing between words.[1][105] The prognosis, generally speaking, is positive for individuals who are identified in childhood and receive support from friends and family.[2]

Epidemiology



Map showing predominant forms of writing systems by country and what their characters represent:[109]

Alphabet (consonants and vowels)

Abjad (only consonants)

Abugida (family-related syllables)

Logograms

Syllabary (isolated syllables)

The percentage of people with dyslexia is unknown, but it has been estimated to be as low as 5% and as high as 17% of the population.[110] While it is diagnosed more often in males,[3] some believe that it affects males and females equally.

There are different definitions of dyslexia used throughout the world, but despite significant differences in writing systems, dyslexia occurs in different populations.[111] Dyslexia is not limited to difficulty in converting letters to sounds, and Chinese dyslexics may have difficulty converting Chinese characters into their meanings.[112][113] The Chinese vocabulary uses logographic, monographic, non-alphabet writing where one character can represent an individual phoneme.[114]

The phonological-processing hypothesis attempts to explain why dyslexia occurs in a wide variety of languages. Furthermore, the relationship between phonological capacity and reading appears to be influenced by orthography.[115]

History

Main article: History of developmental dyslexia

Dyslexia was identified by Oswald Berkhan in 1881,[43] but the term *dyslexia* was coined in 1887 by Rudolf Berlin, an ophthalmologist in Stuttgart.[116] He used the term to refer to the case of a young boy who had a severe impairment in learning to read and write, despite showing typical intelligence and physical abilities in all other respects.[117] In 1896, W. Pringle Morgan, a British physician from Seaford, East Sussex, published a description of a reading-specific learning disorder in a report to the *British Medical Journal* titled "Congenital Word Blindness".[118] The distinction between phonological and surface types of dyslexia is only descriptive, and without any etiological assumption as to the underlying brain mechanisms. However, studies have alluded to potential differences due to variation in performance.[119]

Research and society

Main article: Dyslexia research

See also: International Dyslexia Association

The majority of currently available dyslexia research relates to alphabetic writing systems, and especially to European languages.[120] However, substantial research is also available regarding dyslexics who speak Arabic, Chinese, Hebrew, or other languages.[121]

As is the case with any disorder, society often makes an assessment based on incomplete information. Before the 1980s, dyslexia was thought to be a consequence of education, rather than a basic disability. As a result, society often misjudges those with the disorder.[101] There is also sometimes a workplace stigma and negative attitude towards those with dyslexia.[122] If a dyslexic's instructors lack the necessary training to support a child with the condition, there is often a negative effect on the student's learning participation.[123]