Neurocognitive Aspects of Developmental Dyslexia

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Written Language and Brain

Written Language and Brain

- The ability to read and write is essentially a cultural invention
- But this is likely to be derived from a core set of other skills that have developed over the course of evolution.
- These skills include visual recognition,
- manipulation of sounds,
- and learning and memory

Written Language and Brain

- Why is reading so much more difficult than speaking? It is because we speak in syllables,
- but we write in phonemes.
- Phonemes are not physiologically distinct;
- normal speech does not easily break down into individual letter sounds (Liberman, Shankweiler and Studdert-Kennedy, 1967).

Written Language and Brain

- Writing was only invented when it was realized that syllables could be artificially divided into smaller acoustically distinguishable phonemes that could be represented by a very small number of letters.

Written Language and Brain

- Reading requires the integration of two different kinds of analysis (Morton, 1969; Castles and Coltheart, 1993; Ellis, 1993; Seidenburg, 1993; Manis et al., 1997).
- First the visual form of words,
- the shape of letters and their order in words, which is termed their orthography, has to be processed visually.

Written Language and Brain

- Their orthography yields the meaning of familiar words very rapidly without the need to sound them out.
- But for unfamiliar words, the letters have to be translated into the sounds, phonemes, that they stand for,
- then those sounds have to be melded together in inner speech to yield the word and its meaning.

Written Language and Brain

- the brain may acquire, through experience, a dedicated neural structure for literacy,
- but this will be a result of ontogenetic development (of the individual)
- rather than phylogenetic development (of the species).

Cognitive mechanisms of visual word recognition

- reading a long word out aloud will take longer than reading a short word aloud, *(Erikson et al., 1970).*
- However, the actual visual process of recognizing a word as familiar is not strongly affected by word length.
- This suggests a key principle in visual word recognition—namely, that the letter strings are processed in parallel rather than serially one by one.

Cognitive mechanisms of visual word recognition

- If one is asked to detect the presence of a single letter (e.g. R) presented briefly, then performance is enhanced if the letter is presented in the context of a word (e.g. CARPET),
- This is termed the word superiority effect.
- Word superiority effect: It is easier to detect the presence of a single letter presented briefly if the letter is presented in the context of a word

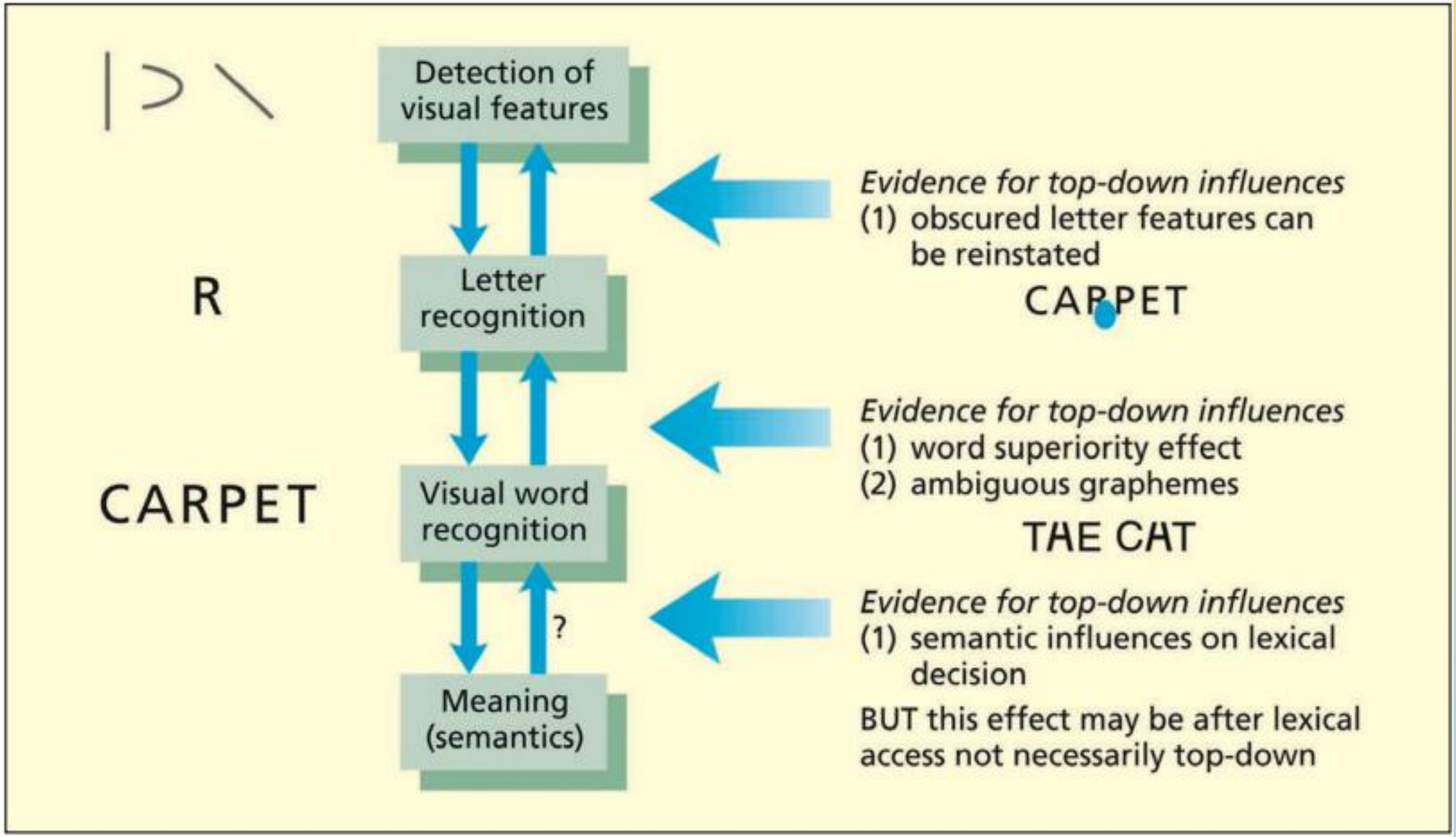


FIGURE 13.3: A basic model of visual word recognition showing evidence in favor of top-down influences.

The visual word form area

- A number of functional imaging studies have reported the existence of a so-called visual word form area, VWFA *(Dehaene & Cohen, 2011; Petersen et al., 1990).*
- This area is located in the left mid occipitotemporal gyrus (also called fusiform gyrus).
- Meaningless shapes that are letter-like do not activate the region.

The visual word form area

- the BOLD activity in the VWFA is unaffected by the length of real words suggesting that the letter pattern might be recognized as a single chunck *(Schurz et al., 2010).*
- The same isn't found for nonwords which implies that their recognition is not holistic.

The visual word form area

- Dehaene et al. (2010) compared three groups of adults using fMRI:
- illiterates,
- those who became literate in childhood,
- and those who became literate in adulthood.
- They were presented with various visual stimuli such as words, faces, houses, and tools.

The visual word form area

- Literacy ability was correlated with increased activity of the left VWFA,
- and there was a tendency for literacy to reduce the responsiveness of this region to faces (which displaced to the right hemisphere).
- The basic pattern was the same if literacy was acquired in childhood or adulthood.

The visual word form area

- In another fMRI study, congenitally blind individuals were found to activate the left VWFA when reading Braille relative to touching other kinds of object *(Reich et al., 2011).*
- Thus the VWFA is not strictly visual but may preferentially process certain types of shape.
- Indeed literates, relative to illiterates, show greater top-down activation of the VWFA in response to processing speech *(Dehaene et al., 2010).*

Pure alexia or "letter-by-letter" reading

- damage to this region produces a specific difficulty with reading—namely, pure alexia or letter-by-letter reading *(Pflugshaupt et al., 2009).*
- When shown the word CAT, the patient spells the letters out "C," "A," "T"
- it was termed pure alexia to emphasize the fact that reading was impaired without impairment of spelling, writing or verbal language *(Dejerine,1892).*

Pure alexia or "letter-by-letter" reading

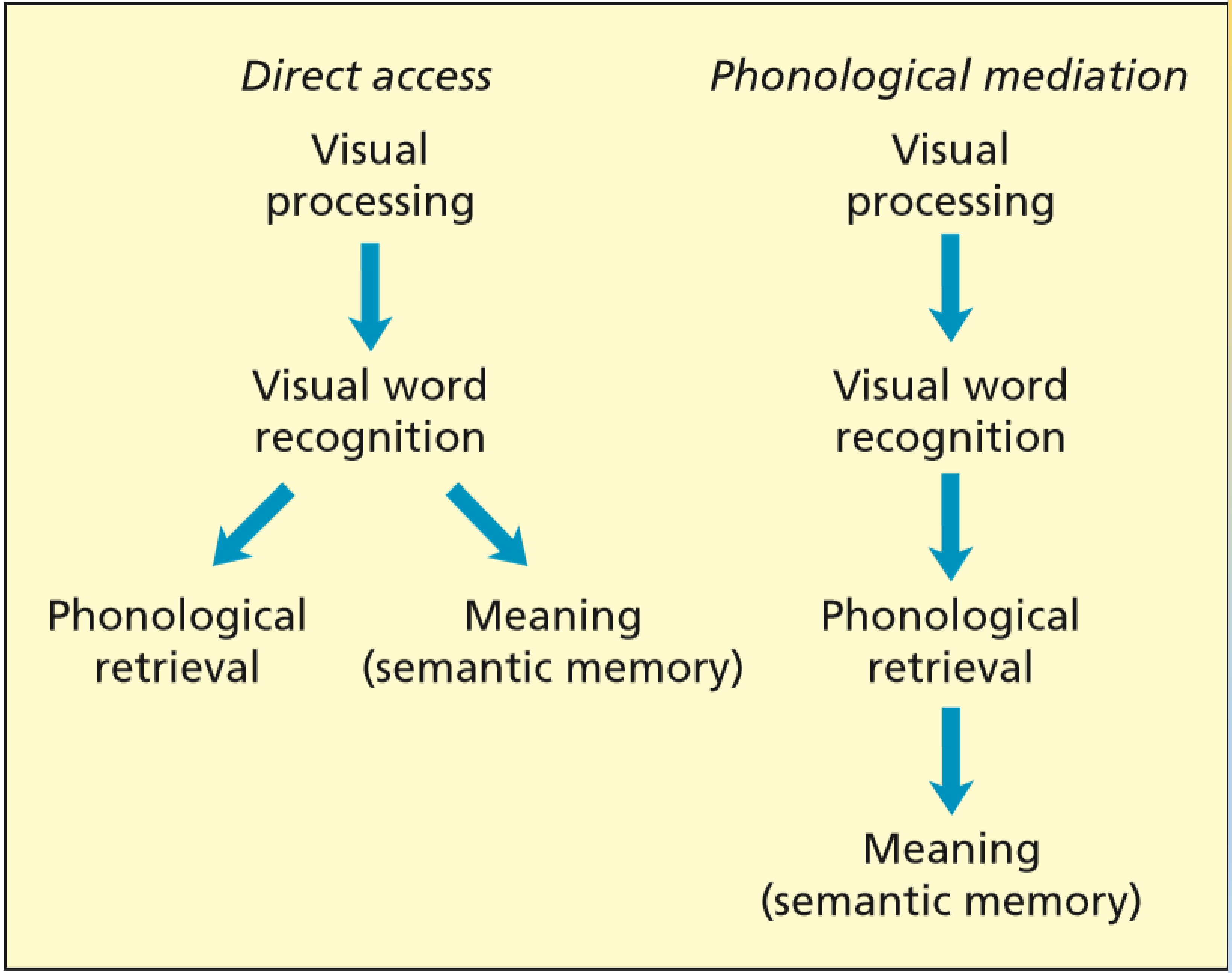
- Many researchers have suggested a hybrid account between visual deficits and orthography-specific deficits.
- These latter models have typically used "interactive activation" accounts
- Many pure alexic patients are able to perform lexical decisions or even semantic categorizations (animal versus object) for briefly presented words that they cannot read *(Bowers et al., 1996; Shallice & Saffran, 1986).*

Routes from spelling to Sound

- There are two things that one may wish to do with a written word:
- understand it (i.e. retrieve its meaning from semantic memory)
- or say it aloud (i.e. convert it to speech).
- does understanding a written word require that it first be translated to speech (i.e. a serial architecture)?
- This possibility has sometimes been termed **phonological mediation**.

Routes from spelling to Sound

- The alternative proposal is that understanding written words
- and transcoding text into speech
- are two largely separate, but interacting, parallel processes.
- The evidence largely supports the latter view and has given rise to so-called dual route architectures for reading


Direct access
Visual processing
Visual word recognition
Phonological retrieval
Meaning (semantic memory)
Phonological mediation
Visual processing
Visual word recognition
Phonological retrieval
Meaning (semantic memory)

Routes from spelling to Sound

- In the traditional model, the phono- logically based route is called grapheme– phoneme conversion, in which letter patterns are mapped onto corresponding phonemes.
- This may be essential for reading nonwords, which do not have meaning or a stored lexical representation.
- Known words, by contrast, do have a meaning and can be read via direct access to the semantic system and via the stored spoken forms of words.

Routes from spelling to Sound

- the direct semantic access route is generally considered faster.
- This is because it processes whole words, whereas the grapheme–phoneme conversion route processes them bit-by-bit.
- The semantic route is also sensitive to word frequency
- High-frequency words are fast to read, irrespective of the sound–spelling regularity.
- For low-frequency words, regular words are read faster than irregular ones (*Seidenberg et al., 1984*).

Developmental Dyslexia

Developmental dyslexia

- Developmental dyslexia is defined as problems in literacy acquisition (reading and/or spelling) that cannot be attributed to lack of opportunity or other known causes (e.g., deafness, brain injury).
- there is heterogeneity in what can be accurately read.

DEFINITION OF DYSLEXIA

- Individuals with dyslexia have difficulties with accurate or fluent word recognition and spelling despite adequate instruction and intelligence and intact sensory abilities (Lyon et al. 2003).
- The ultimate goal of reading is comprehension, which is a function of both decoding ability
- and oral language comprehension (Hoover & Gough 1990).

SPECIFIC LEARNING DISORDER WITH IMPAIRMENT IN READING

- Reading impairment is characterized by difficulty in
- recognizing words,
- slow and inaccurate reading,
- poor comprehension,
- and difficulties with spelling.

SPECIFIC LEARNING DISORDER WITH IMPAIRMENT IN READING

- **Clinical Features**
- Children with reading impairment make many errors in their oral reading.
- The errors include omissions, additions, and distortions of words.
- Such children have difficulty in distinguishing between printed letter characters and sizes,

Visual Processing

- the core cognitive deficits in developmental dyslexia have been linked to problems in either the visual domain
- or the auditory domain, with the latter being the dominant view (Goswami, 2015).
- people with developmental dyslexia do not present with overt problems in hearing or seeing (e.g., due to difficulties with the eyes or ears).

Visual Processing

- one theory states that developmental dyslexia reflects a deficit of the magnocellular visual pathway *(e.g., Stein & Walsh, 1997).*
- this pathway, originating subcortically, is involved in the fast detection of visual information (including motion) and low-resolution visual information.
- It has been implicated in reading because of its role in the allocation of visuo-spatial attention including eye movements (via the visual dorsal stream)

Visual Processing

- Development of the magnocellular layers of the dyslexic lateral geniculate nucleus (LGN) is abnormal;
- their motion sensitivity is reduced;
- many dyslexics show unsteady binocular fixation; hence poor visual localization, particularly on the left side (left neglect) (Stein 2001).

Visual Processing

- Dyslexics' binocular instability and visual perceptual instability, therefore, can cause the letters they are trying to read to appear to move around and cross over each other
- Hence, blanking one eye (monocular occlusion) can improve reading (Stein 2001).

Visual Processing

- The cerebellum is the head ganglion of magnocellular systems;
- it contributes to binocular fixation and to inner speech for sounding out words, and it is clearly defective in dyslexics.
- Thus, there is evidence that most reading problems have a fundamental sensorimotor cause.

Visual Processing

- how the visual magnocellular system contributes to reading, however, since print is usually stationary, not moving
- Breitmeyer (1993) suggested that magnocellular activity during each saccade is necessary to erase the previous fixation;
- hence weak magnocellular responses might fail to do so and the letters seen on the previous fixation might superimpose on those derived from the next fixation.

Visual Processing

- children tend to confuse neighbouring letters, not those separated by 6 or 7 mm, which is the distance covered by reading saccades.
- children with low magnocellular function, as evidenced by reduced visual motion sensitivity, are slower
- and make more errors in judging the correct order of letters (rain vs. rian—Cornelissen et al., 1997).

Visual Processing

- Children with binocular instability make more visual errors when letter size is decreased (Cornelissen et al., 1991)
- and when the letters are crowded closer together (Atkinson, 1991).
- They tend to misspell irregular words by attempting to sound them out, making ‘phonological regularization’ errors (Cornelissen et al., 1994, 1994b).

Visual Processing

- Importantly, because their instability is binocular, their visual confusion may be exacerbated by the two eyes presenting different competing versions of where individual letters are situated.
- Hence, reading using only one eye with the other blanked will often improve their reading (Fowler and Stein, 1979; Stein and Fowler, 1981, 1985; Cornelissen et al., 1992; Stein, Richardson and Fowler, 2000).

AUDITORY/PHONOLOGICAL PROBLEMS

- Although it remains possible that some sorts of visual processing problems correlate with dyslexia,
- the scientific consensus for the last several decades has been that dyslexia is a language-based disorder whose primary underlying deficit involves problems in phonological processing
- that lead to later problems processing written language (Vellutino et al. 2004; Patterson 2015).

AUDITORY/PHONOLOGICAL PROBLEMS

- The other main skill required for reading is to be able quickly to produce the sounds (phonemes) that each letter or group of letters stands for.
- It is generally agreed that many dyslexics fail to develop adequate phonological skills (Liberman et al., 1974; Lundberg, Olofsson and Wall, 1980; Snowling, 1981; Bradley and Bryant, 1983; Snowling, 1987).

AUDITORY/PHONOLOGICAL PROBLEMS

- SENSITIVITY TO CHANGES IN SOUND FREQUENCY AND AMPLITUDE
- Letter sounds consist of relatively slow (2–50 times per second) changes in frequency
- and changes in speech amplitude.
- Hence, distinguishing them depends on being able to identify these transients in the speech signal (Tallal, 1980; Moore, 1989)

AUDITORY/PHONOLOGICAL PROBLEMS

- It was found that dyslexics as a group are considerably worse at detecting these transients than good readers,
- i.e. they require significantly larger changes in frequency or amplitude to distinguish them (McAnally and Stein, 1996; Stein and McAnally, 1996; Witton et al., 1997, 1998; Menell, McAnally and Stein, 1999; Talcott et al., 1999, 2000)

AUDITORY/PHONOLOGICAL PROBLEMS

- With regards to auditory processing, one theory is that developmental dyslexia is linked to problems in phonological awareness:
- that is, in the ability to explicitly segment a speech stream into units such as syllables, rimes and phonemes.
- The term “explicit” is important because natural speech perception segments the acoustic input into different units automatically and effortlessly, but tasks that require an awareness of these units may depend on other mechanisms *(Ramus & Szenkovits, 2008).*

AUDITORY/PHONOLOGICAL PROBLEMS

- These tasks include counting syllables, detecting phonemes.
- Developmental dyslexics tend to be impaired in these tasks across all languages in which they have been tested *(Ziegler & Goswami, 2005).*
- In terms of brain mechanisms, they may depend on the auditory dorsal stream for speech segmentation,
- in contrast to the auditory ventral stream for speech comprehension *(Hickok & Poeppel, 2004).*

Developmental dyslexia

- This auditory dorsal stream includes the left temporoparietal area (planum temporale) which is anatomically more symmetrical in developmental dyslexics *(Galaburda et al., 1985).*
- The normal pattern is for it to be larger in the left hemisphere of non-dyslexics.

Developmental dyslexia

- More recent research shows that the degree of asymmetry is correlated with phonological awareness abilities *(Eckert et al., 2001),*
- and these phonological awareness abilities in children predict the degree of activation of the VWFA to nonwords *(Shaywitz et al., 2002).*

AUDITORY/PHONOLOGICAL PROBLEMS

- Phoneme awareness develops over several years and is strongly correlated with literacy skill.
- However, research on early language development eventually demonstrated that phonemic representations are not innate and instead develop in response to linguistic input (Patterson 2015).

AUDITORY/PHONOLOGICAL PROBLEMS

- for all children, phonological representations start out as fairly holistic. Babies likely represent most words as single entities.
- With language development, phonological representations begin to emphasize syllables,
- then subsyllabic distinctions, and ultimately individual phonemes (e.g., Metsala & Walley 1998).

SENSORY BASIS OF READING PROBLEMS

- It thus appears that we can explain a large amount of the differences in reading ability in terms of basic sensory sensitivity to visual and auditory transients (Stein 2001).
- In one group of 10 year olds, visual motion and auditory sensitivity accounted for nearly two thirds of their differences in reading and spelling ability (Talcott et al., 2000).

Orthographic Learning

- In recent years there has been increasing interest in an orthographic learning account of reading problems, which emphasizes not phonological representations themselves but rather the ability to establish mappings between phonemes and graphemes, or letters and sounds (e.g., Aravena et al. 2013).
- a single core phonological deficit is insufficient to explain reading difficulties

Orthographic Learning

- results of family-risk designs and longitudinal studies of children with early speech/language disorders indicate that
- many children develop normal-range literacy skills despite preschool phonological deficits similar in magnitude to those of children who ultimately develop dyslexia (Bishop et al. 2009, Peterson et al. 2009, Snowling et al. 2003).

Orthographic Learning

- Conversely, children with multiple cognitive deficits are at much higher risk for dyslexia.
- many cognitive-linguistic constructs predict later dyslexia.
- The constructs that are most consistently implicated include phonological awareness, rapid serial naming,
- verbal short-term memory, vocabulary and other aspects of broader oral language skill, and graphomotor processing speed (McGrath et al. 2011, Pennington et al. 2012, Scarborough 1998, Wolf & Bowers 1999).

Orthographic Learning

- by age 4 or 5 years, phonological awareness is the dominant predictor;
- and tasks emphasizing speed (i.e., rapid serial naming and processing speed) become increasingly important as literacy development progresses,
- probably because they are more linked to reading fluency than to single- word reading accuracy (Pennington & Lefly 2001, Puolakanaho et al. 2008, Scarborough 1990, Snowling et al. 2003, Torppa et al. 2010).

Orthographic Learning

- recently there has been renewed interest in the possible role of visual attentional deficits in reading difficulties (Facoetti et al. 2010).
- Visual attention is measured through paradigms that require participants to recognize pictures surrounded by some other visual pictures
- some of these skills probably contribute to performance on nonlinguistic processing speed tasks known to be correlated with reading.

Orthographic Learning

- One study demonstrated that performance on visual attention tasks in preschool significantly predicted reading ability two years later, after accounting for the influence of reading-related phonological processing skills (Franceschini et al. 2012).
- a deficit in visual attention might represent an additional cognitive difficulty that interacts with language problems to cause reading failure

The Multiple Deficit Model

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The Multiple Deficit Model

- The single deficit model (Morton & Frith, 1995; Pennington & Ozonoff, 1996) held that each neurodevelopmental disorder, such as dyslexia, autism, or ADHD, was due to a single underlying cognitive deficit, such as a phonological deficit in dyslexia, a theory of mind deficit in autism, or an inhibition deficit in ADHD.
- The single cognitive deficit model failed for both theoretical and empirical reasons.

The Multiple Deficit Model

- Regarding theory, the single deficit model failed because it took a static neuropsychological approach to understanding neurodevelopmental disorders (Oliver, Johnson, Karmiloff-Smith, & Pennington, 2000; McGrath 2019).
- According to this approach, there were innate, localized cognitive modules in the human brain,
- and each neurodevelopmental disorder was due to a deficit of its particular cognitive module.

The Multiple Deficit Model

- Considerable research has contradicted this modular approach to understanding human typical and atypical cognitive development (as reviewed in Johnson & De Haan, 2011).
- Unlike cognitive modules, specialized processing areas of the human brain are not strictly localized, or innate.
- Instead, these specializations emerge developmentally and interactively, and their brain substrates change as they develop.

The Multiple Deficit Model

- Empirically, the single deficit model failed because it was common to find children with neurodevelopmental disorders that lacked the key underlying cognitive deficit,
- as well as children without the disorder that nonetheless had the key underlying deficit (McGrath 2019).

The Multiple Deficit Model

- But, most importantly, it failed empirically
- because it could not account for the pervasive phenomenon of comorbidity among developmental disorders, (McGrath 2019).

The Multiple Deficit Model

- The Multiple Deficit Model (MDM) of neurodevelopmental disorders (Pennington, 2006) was proposed because the single deficit model had failed.
- there are multiple possible risk factors for each neurodevelopmental disorder and that some of these risk factors are shared by comorbid disorders.

The Multiple Deficit Model

- The MDM also accounts for inter-individual variability in profiles by proposing that each risk factor is probabilistically (rather than deterministically) related to neurodevelopmental disorders.
- The MDM is a multi-level framework for understanding neurodevelopmental disorders,
- spanning etiology (genes, environments, and gene-environment interplay),
- brain mechanisms,
- neuropsychology,
- and behavioral symptoms.

The Multiple Deficit Model

- The MDM framework has been useful for directing research toward shared risk factors between disorders that may contribute to comorbidity.
- For example, it was found that processing speed weaknesses partially explain the comorbidity between dyslexia, dyscalculia, and ADHD (McGrath et al., 2011; Peterson et al., 2017)
- and that oral language weaknesses further contribute to the comorbidity of dyslexia and dyscalculia (Peterson et al., 2017).

The Multiple Deficit Model

- One lesson from dyslexia research is that some children (roughly 25%) can be adequately explained by single deficits even though multiple deficits contribute at the population level (Pennington et al., 2012).
- The second lesson is that all of the cognitive deficits identified so far are probabilistic predictors and cannot be considered "core."

The Multiple Deficit Model

- This is true even for the phonological awareness and reading abilities (Hulme & Snowling, 2013).
- approximately 50% of children with dyslexia do not have a phonological awareness deficit (Pennington et al., 2012).

The Multiple Deficit Model

- Research in the MDM framework could eventually lead to the development of new treatment approaches that are particularly suited to children with comorbid conditions, (Larson, Russ, Kahn, & Halfon, 2011; Willcutt et al., 2013).

The Multiple Deficit Model

- For example, the finding that oral language weaknesses partially explain the overlap between dyslexia and dyscalculia (Peterson et al., 2017) suggests that interventions addressing academic vocabulary,
- listening comprehension,
- or other language skills might be especially valuable for students who struggle across the curriculum

Thank You for Your Attention