The Cognitive Neuroscience of Reading and Dyslexia

Dr. Anna Woollams
Neuroscience & Aphasia Research Unit
School of Psychological Sciences
University of Manchester

Outline

• Components of reading:
  – Cognitive
  – Neural

• Acquired dyslexia:
  – Peripheral
  – Central

• Learning to read:
  – Phonological awareness
  – Developmental dyslexia

Why study reading?

• Fluent effortless reading of text is a common and critical skill in modern literate societies

• Most common form of reading is silent reading for meaning, a complex task that seems easy:
Measuring reading

- Measure people’s eye movements whilst reading connected text (EMR)
  - Fixation and saccades
- More recently, neuroimaging (fMRI) whilst reading single words or text
  - Activation location and level
- But the simplest and most widely used measure is reading single words aloud
  - Accuracy and reaction time (RT)

Cognitive components

Spelling: MAKE
Sound: /m1k/

Orthography
Phonology
Semantics

Whole-word
Sub-word

Adapted from Seidenberg & McClelland (1989)

Neural components

Spelling: MAKE
Sound: /m1k/

Visual processing
Semantic retrieval system
Speech output system

Adapted from Price (2004)

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What is acquired dyslexia?

- Any reading disorder that arises as a result of brain injury in previously literate adults
- Encompasses a variety of different reading problems
- Shallice and Warrington (1980)
  - Peripheral dyslexias are disorders of letter and word identification
    - Attentional, neglect, hemianopic, pure
  - Central dyslexias are disorders of phonological or semantic processing
    - Surface, phonological, deep

Attentional dyslexia

- First noted by Shallice and Warrington (1977) in two patients, FM and PT, with deep left parietal lesions who could read aloud single words, but couldn’t name the constituent letters, despite accurate naming of these letters when presented alone
- Performance is worse for pairs of words and in text, with letters migrating between words:
  - WIN FED as FIN FED
  - POT BIG HU T as BUT BIG HUT

Attentional dyslexia (2)

- FM and PT therefore have a problem with encoding cross-word letter position
- A similar disorder involving single word reading, termed “letter position dyslexia”, has also been reported in Hebrew speaking Patient BS (Friedmann & Gvion 2001):
  - BREAD as BEARD, SLAT as SALT
- BS therefore has a problem with encoding letter position within single words
Neglect dyslexia

- A reading disorder resulting from inattention to the left side of stimuli arising from right parietal lesions.
- Patient VB (Ellis et al. 1987) showed impaired reading of the left hand side of lines of text and with single words:
  - ELATE as PLATE; JAUNT as HAUNT

Neglect dyslexia (2)

- The performance of VB indicates a problem determining leftmost letter identity of a word.
- There are, however (at least) two types of visual neglect (Lee et al. 2009):
  - Perceptual-attentional (body-centered)
  - Representational-imagery (object-centered)
- Right of centre presentation will improve reading for body-centered but not object-centered cases.

Hemianopic alexia

- Lesions are focused in left medial occipital lobe (primary visual cortex) (Leff et al. 2006)
- Produces a right homonymous hemianopia, which compromises perception of input:

Reproduced from Pflugshaupt et al. (2009)
Hemianopic alexia (2)

- Defined by a marked disruption of text relative to single word reading (Leff et al. 2000)
- Single word reading is also slowed (Leff et al. 2001) due to a problem determining rightmost letter identity, particularly in longer words

Pure alexia

- Cannot efficiently encode the identity of all of the letters in a word
- Performance is characterised by:
  - A strong effect of word length (BED > BREAD)
  - Markedly slowed reading (seconds per word)
  - Letter by letter (LBL) reading (B-R-E-A-D)
  - Letter misidentifications (BREAD as BROAD)
  - Lexicality effects (BREAD > PREAD)
  - Imageability effects (BREAD > BRIEF)

Pure alexia (2)

- Suggests that reading problems result from a more general visual processing deficit
- Berman et al. (1998): picture naming of five pure alexic patients was strongly influenced by visual complexity

Adapted from Schuett et al., (2008)
Adapted from Behrmann et al., (1998)
Pure alexia (3)

- Leff et al. (2006): focus of lesions of six pure alexics in the left mid-fusiform gyrus (left ventral occipito-temporal cortex)
- Crosshairs show area activated in visual word recognition tasks in normal readers, known as the “visual word form area” or VWFA

Adapted from Leff et al., (2006)

Surface dyslexia

- A deficit in reading aloud exception words of varying severity, more pronounced for infrequent words
- Much better at naming regular words (HINT) and nonwords (FINT) than irregular words (PINT), which are regularised

Surface dyslexia (2)

- Woollams et al. (2007): exception word reading of 51 semantic dementia patients predicted by performance in semantic tasks of picture naming and spoken word-picture matching
- Indicates importance of semantics for supporting exception word reading

Adapted from Woollams et al., (2007)
Surface dyslexia (3)

- Extent of anterior temporal lobe atrophy in semantic dementia correlates with performance on:
  - Semantic tasks (spoken word to picture matching) (Mummery et al. 2000)
  - Reading aloud accuracy for exception words (Brambati et al. 2009)

Phonological dyslexia

- Much better at naming regular (MINT) and exception (PINT) words than nonwords (FINT), which are lexicalised
- Strong lexicality effects are accompanied by an impact of imageability upon word reading accuracy (Crisp & Lambon Ralph 2006)
- Phonological test (phoneme blending) performance impaired in six cases, particularly when the response required is a nonword (Patterson & Marcel 1992)

Phonological dyslexia (2)

- Deficits in nonword reading result from a phonological deficit:
- Crisp & Lambon Ralph (2006) found phoneme blending/segmentation predicts nonword reading accuracy
- Rapcsak et al. (2009): phonological scores predicted word and particularly nonword reading performance

Reproduced from Rapcsak et al., (2009)
Phonological dyslexia (3)

Rapcsa et al. (2009): phonological processing is supported by a network of perisylvian regions, damage to only part of which is sufficient to cause reading deficits.

Deep dyslexia

• Shares some symptoms with phonological dyslexia, although more pronounced:
  – Profoundly impaired nonword reading
  – Marked imageability effects in word reading
• Error responses include types that are also seen in some cases of phonological dyslexia:
  – “Visual” errors: SIGNAL as SINGLE, DECREE as DEGREE
• The defining feature of deep dyslexia is the presence of semantic errors in reading aloud:
  – BLOOD as HEART, COST as MONEY, ERROR as WRONG

Deep dyslexia (2)

• Alternative hypotheses have been put forward as to the functional cause of the disorder:
  – A severe phonological deficit, leaving semantic activation unconstrained (Jefferies et al. 2007)
  – An additional semantic deficit, as semantic errors related to performance on meaning level tests (Crisp & Lambon Ralph 2006)
• Deep dyslexia occurs in the context of large left-hemisphere lesions, with variation in location and/or extent (Price et al. 1998):
  – CJ: left temporo-parietal lesion
  – JG: left temporo-parietal and left inferior/middle frontal lesion
Deep dyslexia (3)

- Some researchers have suggested that deep dyslexia results from abnormal RH reading (Weeke et al. 1997)
- Although increased activation in the RH can been seen in deep dyslexia, it is debatable if this is “abnormal”

Reproduced from Price et al., (1998)

Learning to read

Adapted from Seidenberg & McClelland (1989)

Phonological awareness

- Bradley and Bryant (1983) explored the relationship between ability to process speech sounds and learning to read
- Measured sound processing skills of 403 pre-literate 4/5 year old children using “odd-one-out” method:
  - hill, pin, pig; cot, pot, hat; doll, hop, top
- Found a significant correlation with word reading ability in the remaining 368 children when tested again at 8/9 years old
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Phonological awareness (2)

• Bradley and Bryant (1983) also used an experimental approach and gave training to some children with poor phonological awareness
  – Phonemic: (hen, hat); (hen, pet); (hen, man)
  – Conceptual: (hen, bat); (hen, pig); (hen, duck)

• Those that received phonemic training achieved significantly higher reading scores when tested at 8/9 years old than those who received conceptual training

Self-teaching

• Well developed phonological representations facilitate learning letter-sound mappings

• Share (1995) proposed that the phonological decoding (sub-word translation) allows formation of links between meaning and orthography (whole-word mappings)

• This process works for regular words (e.g. pink).

What is developmental dyslexia?

• Failures to achieve literacy arise for many reasons, such as intellectual impairment or lack of schooling

• Developmental dyslexia: any failure to acquire age-appropriate reading skills despite adequate intelligence and education

• Usually operationalised in terms of deficits in reading comprehension and/or oral reading of single words, with variation across studies
Developmental dyslexic subtypes

- Most developmental dyslexics show deficits in both word and nonword reading accuracy
- Castles and Coltheart (1993) identified surface and phonological developmental dyslexic subtypes with worse than expected reading of exception words or nonwords, respectively

Developmental surface dyslexia

- Better at naming regular words and nonwords than exception words, which are regularised
- Patient MI (Castles & Coltheart 1996)
  - 9 years at test
  - Above average verbal IQ (130)
  - Word reading: PINT 27% < MINT 87%
  - Nonword reading: FINT 87%
  - Definition of spoken words normal

Semantic deficits?

- Nation and Snowling (1998) compared two groups of children that varied in the text comprehension abilities, but were matched according to their nonword reading abilities
- The poor readers performed worse than the good readers on the semantic tasks of synonym judgment and semantic fluency
- These semantic weaknesses also undermined reading aloud performance specifically for low-frequency exception words
Developmental phonological dyslexia

- Better at naming regular and irregular words than nonwords, which are lexicalised

- Patient HM (Temple & Marshall 1983)
  - 17 years at test
  - Reading age 10 years, 7 months
  - Average verbal IQ (105)
  - Word reading: PINT/MINT 100%
  - Word reading showed an effect of imageability
  - Nonword reading: FINT 64%

Phonological deficits?

- Manis et al. (1996) showed impaired performance amongst phonological dyslexics in phoneme position analysis
- Duncan & Johnston (1999) found poor readers were impaired only phonological tasks involving phoneme manipulation:

Imaging evidence

A recent meta-analysis imaging studies has found evidence of underactivation in developmental dyslexics relative to controls in areas associated with both semantic and phonological processing
Conclusions

- Both neuroimaging and patient data confirm the predictions of a cognitive “triangle” model
- Case series have revealed underlying deficits in primary processing systems
- More work is needed on interventions for both acquired and developmental dyslexias
- Future neuroimaging of developmental dyslexics should consider subtypes

References