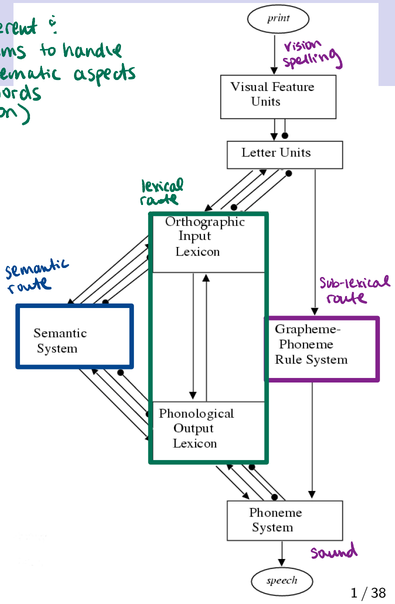
Dual-route model of word reading

(Coltheart et al. 1993, 2001, *Psych. Rev.*)

Qualitatively different & separate mechanisms to handle systematic vs. unsystematic aspects of knowledge w/ words (pseudo vs. exception)



- **Sublexical Route** encodes systematic spelling-sound knowledge by grapheme-phoneme correspondence (GPC) rules
  - Necessary for pronouncing novel "pseudowords" (e.g., MAVE) use rules to figure out spellings → pronunciations sounding out words
- **Lexical Route** encodes whole-word spelling-sound correspondences
  - Necessary for overriding GPC rules to pronounce "exception" words (e.g., HAVE) rules give wrong answer
- **Semantic Route** plays limited role

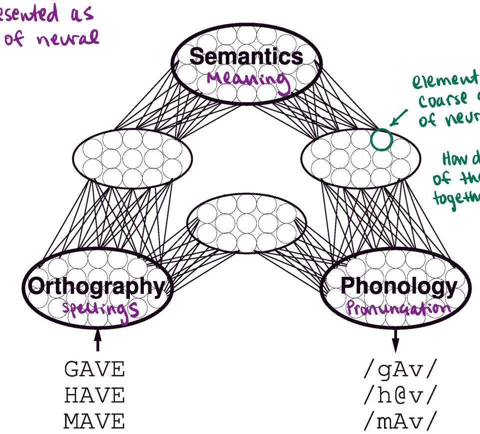
  Basis on which we understand words

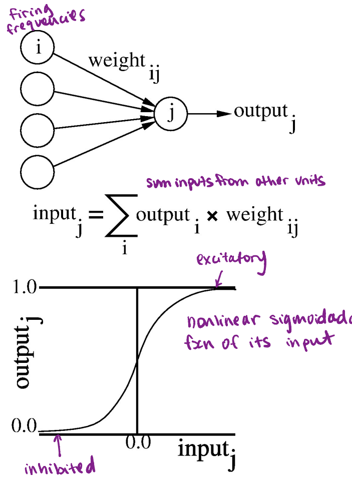
A neural-network framework for word reading

Qualitatively similar & adaptable mechanisms to handle systematic vs. unsystematic aspects of knowledge w/ words (pseudo vs. exception)

Triangle model (Seidenberg & McClelland, 1989, *Psych. Rev.*; Plaut et al., 1996, *Psych. Rev.*; Harm & Seidenberg, 2004, *Psych. Rev.*)

· now represented as patterns of neural activity





$$\text{input}_j = \sum_i \text{output}_i \times \text{weight}_{ij}$$

Computational principles in word reading

Distributed representations

Orthography, phonology, and semantics are represented by distributed patterns of activity such that similar words are represented by similar patterns.

Distributed knowledge

Knowledge of the relationships among orthography, phonology, and semantics is encoded across connection weights that are learned gradually through repeated experience with words in a way that is sensitive to the *statistical structure* of each mapping.

Interactivity

Mapping among orthography, phonology, and semantics is accomplished through the simultaneous interaction of many units, such that familiar overall patterns (including appropriate responses) become stable. Stable attractor patterns

Seidenberg and McClelland (1989, *Psych. Rev.*)

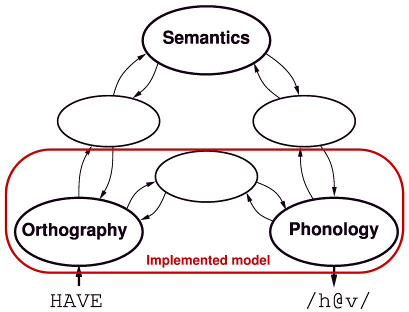
supporting the triangle model

Method

(artificial NN trained on word pronunciation)

- Feedforward network trained with back-propagation to pronounce 2897 monosyllabic words
- Representations of orthography and phonology based on context-sensitive triples of letters or phonemic features

  distributed patterns so similar spellings had similar patterns

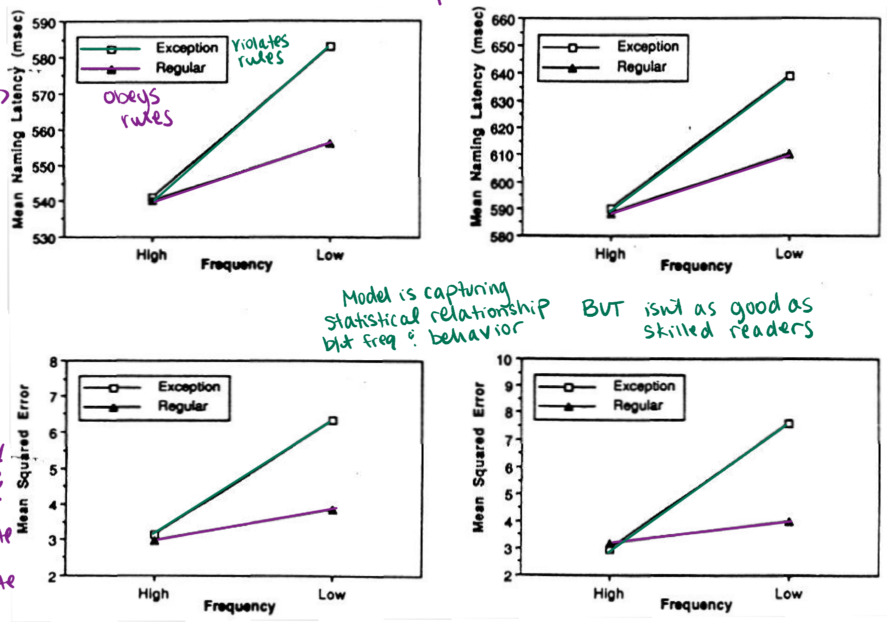


Results

sensitive to frequencies/commonality of words

- After 250 training epochs, network correctly pronounces 97.3% of words, including most exception words.
- Error pattern accounts for many empirical effects of frequency and consistency on naming latencies.
- Did **not** read pronounceable nonwords as accurately as skilled readers

As you learn words you get feedback from environment to improve network subjects are slow w/ low frequency exception words



Latency

violates rules

obeys rules

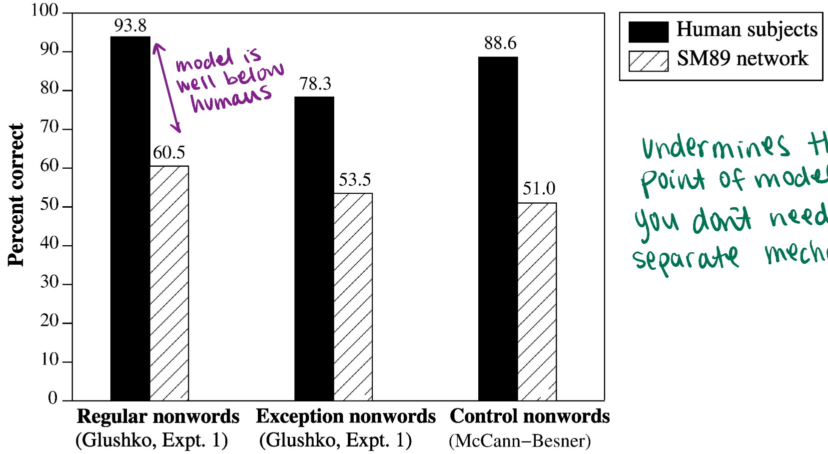
Model is capturing statistical relationship b/t freq & behavior

BUT isn't as good as skilled readers

MSE

really accurate = fast
less accurate = slow

Nonword reading (Seidenberg & McClelland, 1989)



model is well below humans

Undermines theoretical point of model that you don't need two separate mechanisms

nonword HEAN
regular word (DEAN)

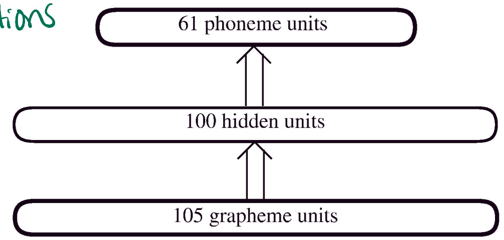
nonword HEAF
exception word (DEAF)

FRANE
(BRANE) pseudo homophones

Plaut, McClelland, Seidenberg and Patterson (1996, *Psych. Rev.*)

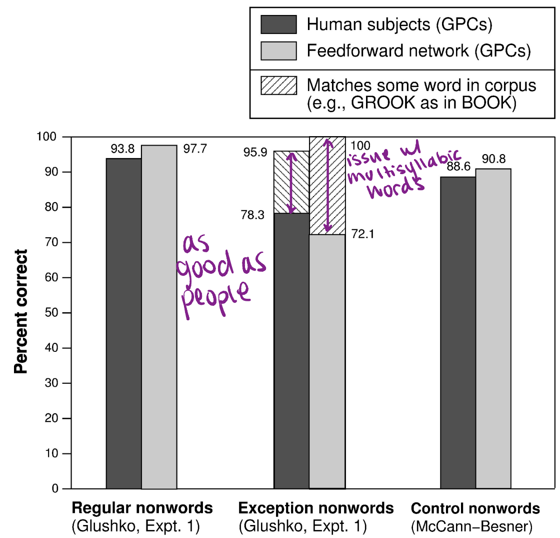
- Used grapheme- and phoneme-based representations that condense spelling-sound regularities
- Trained with back-propagation on 2998 monosyllabic words (SM89 corpus plus additional 101 words) using log-frequencies to scale weight changes
- After 300 training epochs, network pronounces *entire* training corpus correctly (100% correct)

Changed representations that model used for orthography / phonology
↓
does better job



Nonword reading (Plaut et al., 1996)

capturing right similarities
↓
model can learn words & is really well-trained



as good as people

issue w/ multisyllabic words

Impaired reading in surface dyslexia

damage to left temporal lobe
could read prior to damage

- Brain damage to left temporal lobe (stroke, head injury, or degenerative disease) in premorbidly literate adult
- Severe impairment to **semantics**, or to semantics-phonology mapping
- Nonword reading is generally intact
- Word reading *accuracy* influenced by frequency and regularity:

make lots of mistakes on irregular or exception words

Patient	Correct Performance (%) HF Reg	LF Reg	HF Exc	LF Exc	%Reg's	NW
MP	95	98	93	**73**	90	95.5
KT	100	89	47	**26**	85	100

- Exception words produce *regularization errors*

they regularize nonwords
lost lexical knowledge

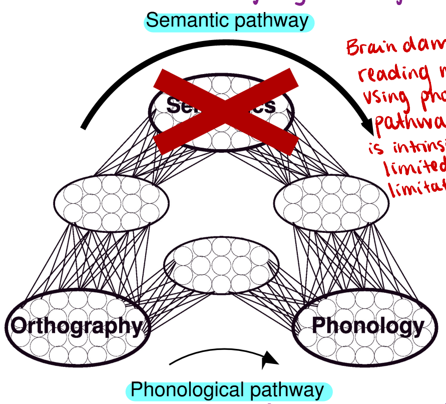
DEAF ⇒ "deef"	FLOOD ⇒ "flude"	SAID ⇒ "sayed"
GONE ⇒ "goan"	BROAD ⇒ "brode"	STEAK ⇒ "steek"
SHOE ⇒ "show"	SEW ⇒ "sue"	ONE ⇒ "own"

Also termed *Legitimate Alternative Reading of Components* (LARC) errors; can also occur on regular words (FOOD ⇒ "fud"; cf. FLOOD)

Division of labor between pathways

- Phonological and semantic pathways combine to support oral reading
- As semantic pathway develops, demands on phonological pathway diminish
- Impairment of semantic pathway by brain damage reveals latent limitations of **intact** phonological pathway

·doesn't know anything about regularity



Brain damage: reading mostly using phonological pathway ∴ it is intrinsically limited (reveals limitations)

·struggles w/ low freq exception words

As system is learning (semantic pathway gains competence), it relieves some of the pressure on the phonological pathway (especially exception words)

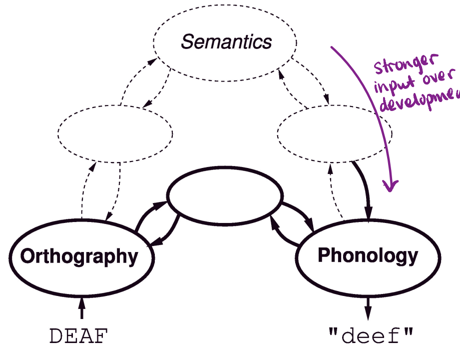
⇒ **Reading (low-frequency) exception words should rely on semantic support**

Simulation of surface dyslexia

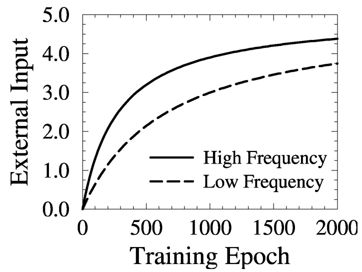
approximate contribution of semantic pathway to phonology

train pathway w/ extra help

- Feedforward network with weight decay
- Contribution of semantics approximated by external correct input to phoneme units that increases gradually and is frequency-sensitive

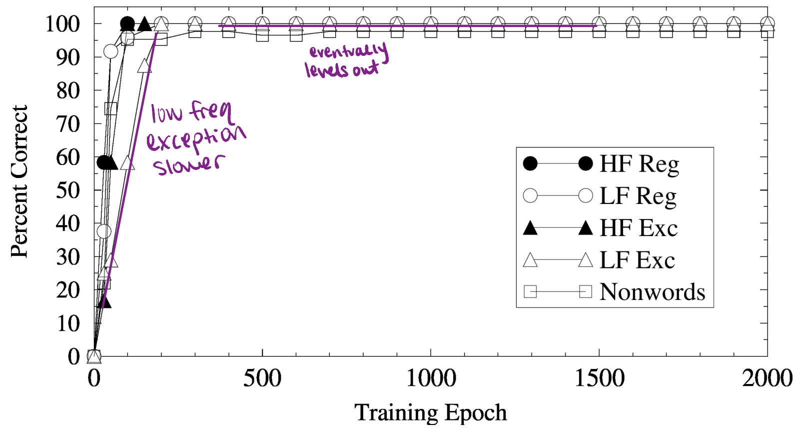


stronger input over development



Overt reading performance

Healthy



eventually levels out

low freq exception slower

Surface dyslexia → focal dimensia (Tix disease)

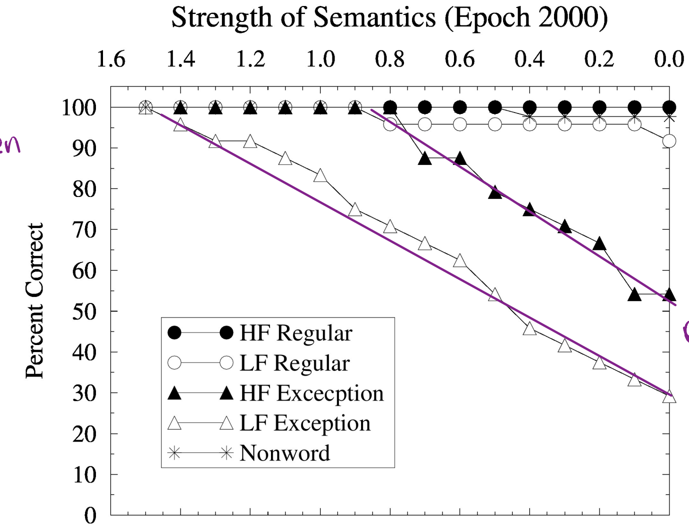
Prediction:
- If you have semantic damage, you will be surface dyslexic

Is that always true?

Effect of progressive semantic deterioration

Apply a degenerative disease

gradually weaken support from semantics & add some noise

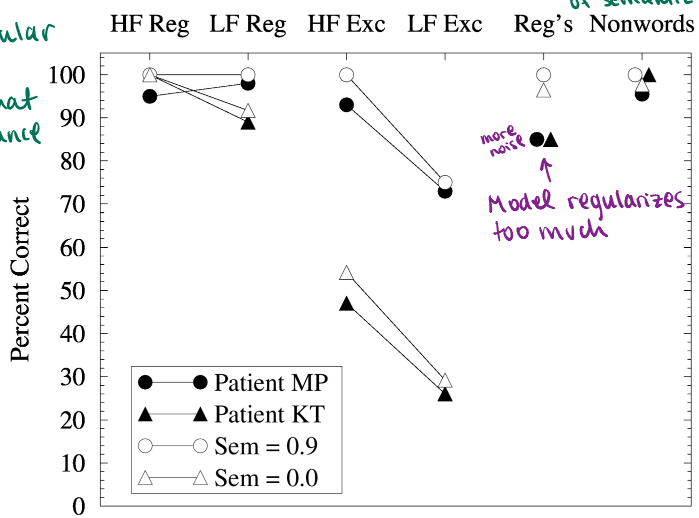


exception words

Surface dyslexia: Individual patients (MP and KT)

Surface dyslexia represents intact performance of phonological pathway, but some degree of semantic damage

Can find particular degrees of deterioration that match performance of two patients



more noise

Model regularizes too much

Accounts for control data too

Semantic impairment without surface dyslexia?

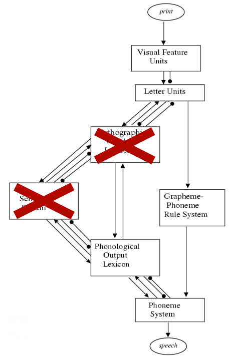
Counterexamples

WLP (Schwartz et al., 1979); probable semantic dementia
- PPVT 37%; HF exception reading 98% Bad vocab, good reading
- Eventually exhibited surface dyslexia (PPVT 10%; HFE reading 75%) Eventually bad reading

DRN (Cipolotti & Warrington, 1995); scientist with semantic dementia
- LF exceptions: 95% reading, 29% generating definitions
good low frequency exceptions, bad semantic

DC (Lambon Ralph et al., 1995); left school at 14, Alzheimer's dementia
- LF exceptions: 95% reading, 31% generating definitions
good low frequency exceptions, bad semantic

EM (Blazely, Coltheart, & Casey, 2005); secretary with semantic dementia
- 98% reading; 34% picture naming



Not due simply to severity of semantic impairment
- Other equally anomic semantic dementia patients exhibit surface dyslexia

GC (Patterson et al., 1994)	45% picture naming	38% LF Exc reading
PC (Blazely et al., 2005)	29% picture naming	49% LF Exc reading

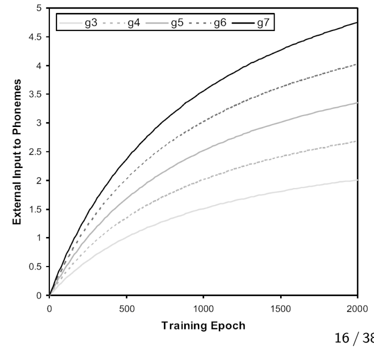
Distribution of surface dyslexia among semantic dementia patients

(Woollams, Lambon Ralph, Plaut, & Patterson, 2007, *Psych. Rev.*)

Patients
- 51 semantic dementia patients; 100 total testing sessions
- **Word reading** on Patterson and Hodges (1992) "surface" list
- **Composite semantic score** derived from performance on picture naming and spoken word-picture matching

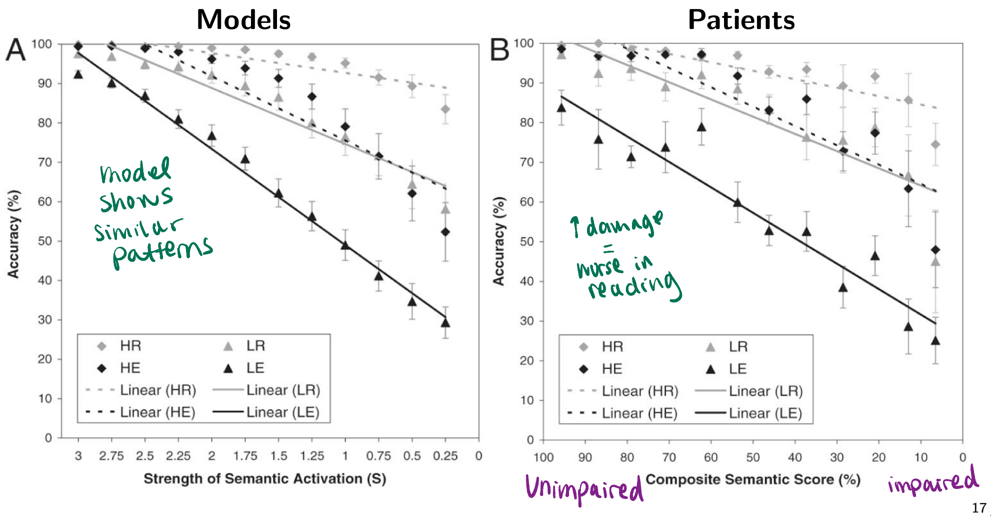
Models
- Trained replications of Plaut et al. (1996) simulation varying only *semantic strength* ($g = 3$ to 7; original simulation used $g = 5$)
- Semantic "lesions" make semantic support for phonology *weaker* and *more noisy*

varied strength of semantic support

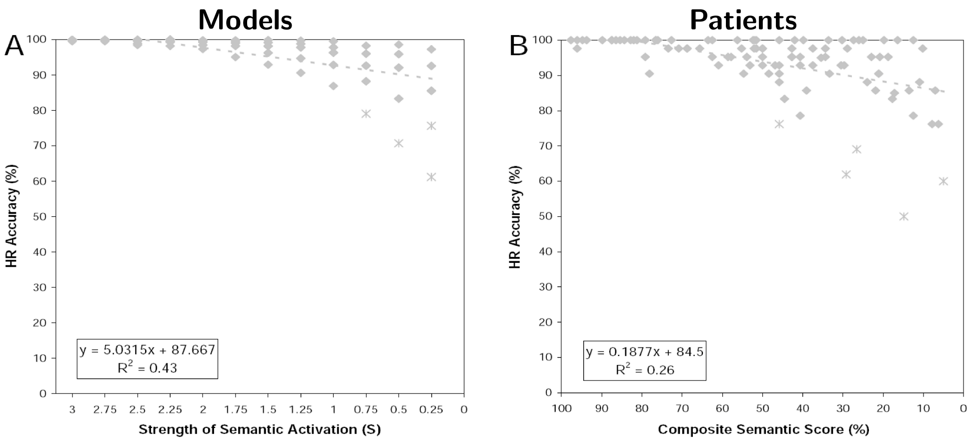


Hyperlexia → pronounces words well w/ no understanding

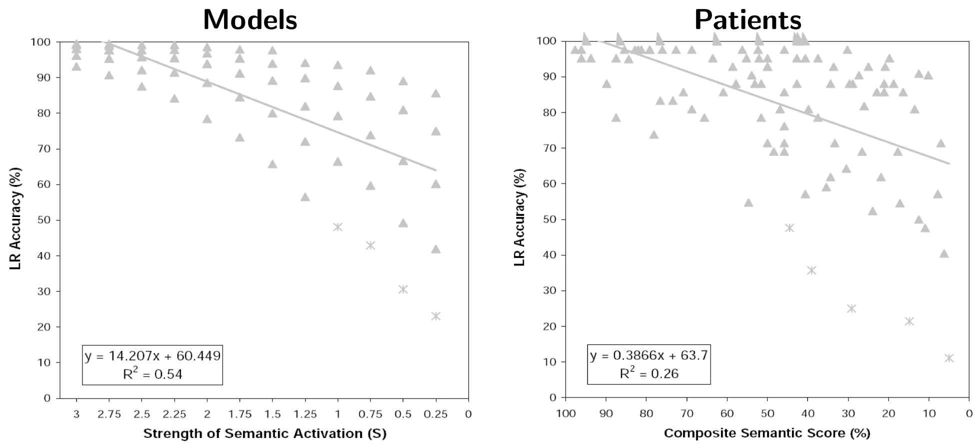
Reading accuracy as a function of semantic impairment



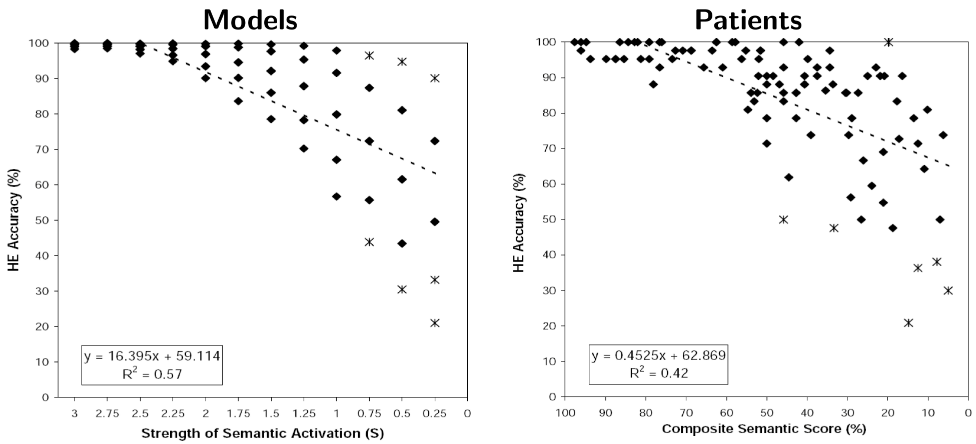
High-frequency regular words



Low-frequency regular words

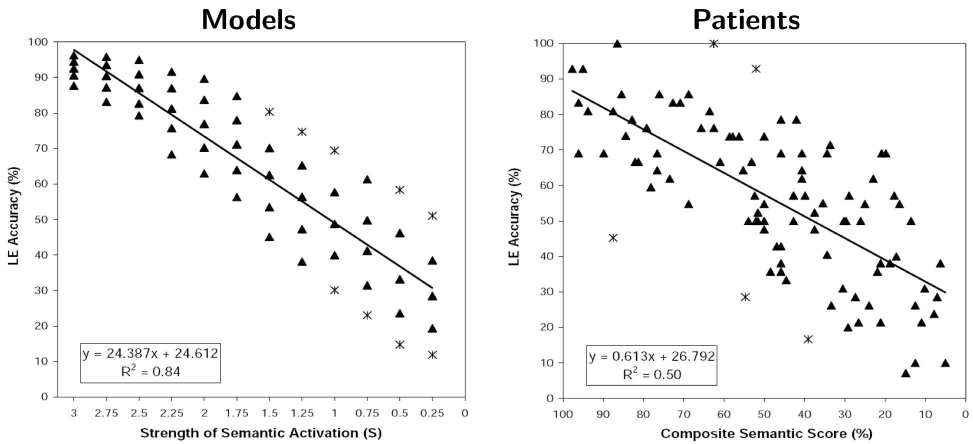


High-frequency exception words

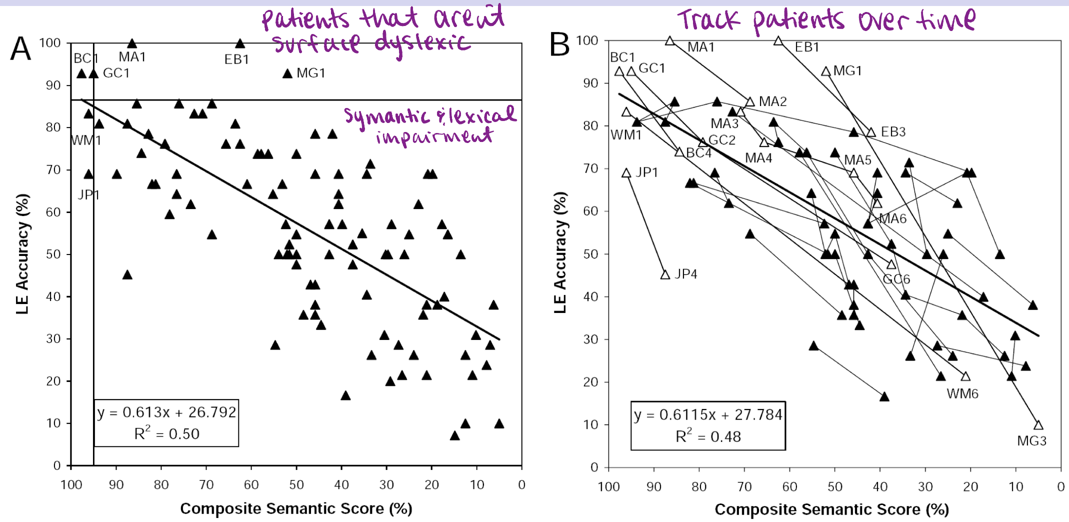


Low-frequency exception words

general strong relationship b/t the degree of semantic impairment & degree of exception word impairment

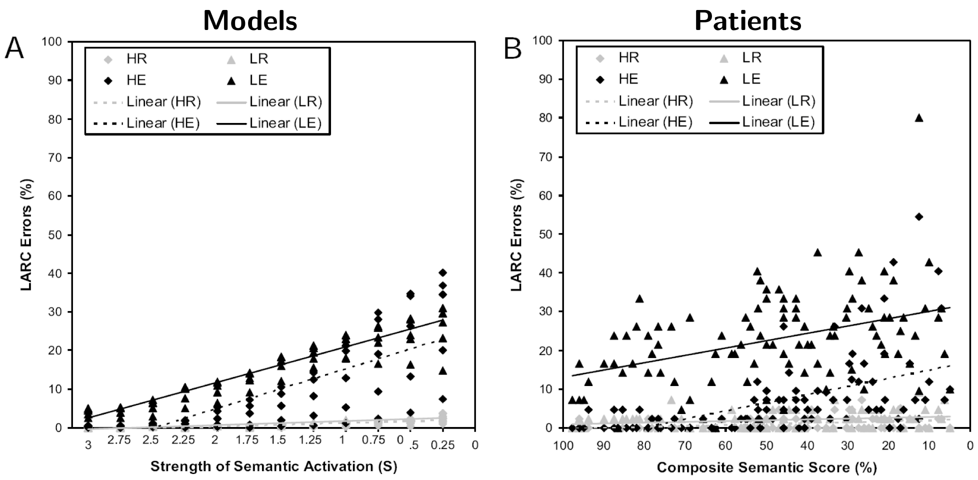


Outliers (PatientsPatients; longitudinal observations connected by lines)



Legitimate Alternative Reading of Component (LARC) errors

(e.g., FOOD ⇒ "fud"; DEAF ⇒ "deef"; includes "regularization" errors)

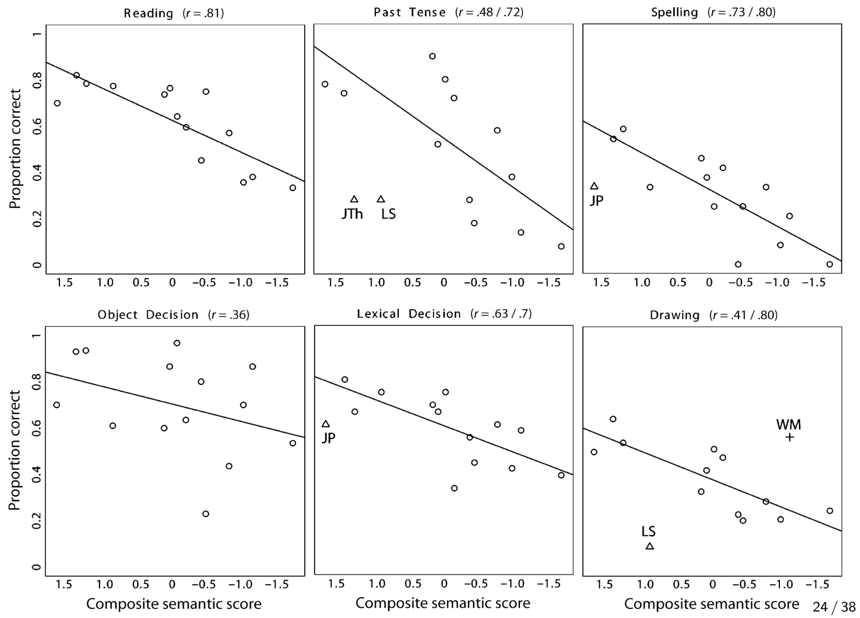


Concomitant deficits

(Patterson et al., 2006, *JCN*)

SD patients are impaired on "exceptions" in wide range of tasks

As you get worse at symantics you also get worse at idiosyncracies (exception words)

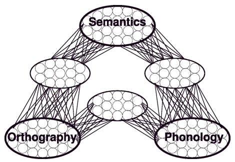


Conclusions (Woollams et al., 2007)

- The distributed connectionist "triangle" model of word reading predicts that semantic impairment should generally give rise to surface dyslexia.
- Variants intended to approximate pre- and post-morbid individual differences capture the distribution in the severity of occurrence of surface dyslexia among semantic dementia patients.
- Semantically impaired patients with intact reading are not qualitatively different but can be understood as falling in the tail of the same distribution.
- The field of cognitive neuropsychology would be best served by examining the full distribution of behavioral patterns caused by brain damage rather than by focusing on dissociations among single-case studies.

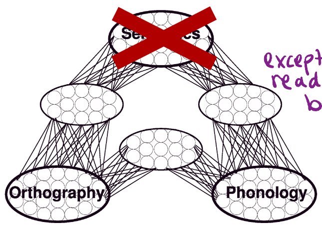
Triangle model of word reading

- Separate semantic and phonological pathways
- Entire system participates in processing all types of items



Surface dyslexia

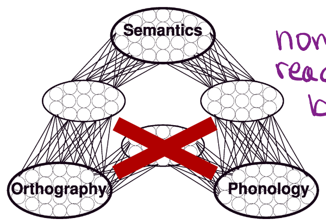
- Normal pseudoword reading
- Regularize exception words



exception word reading is bad

Phonological/deep dyslexia

- Relatively intact word reading
- Very poor pseudoword reading

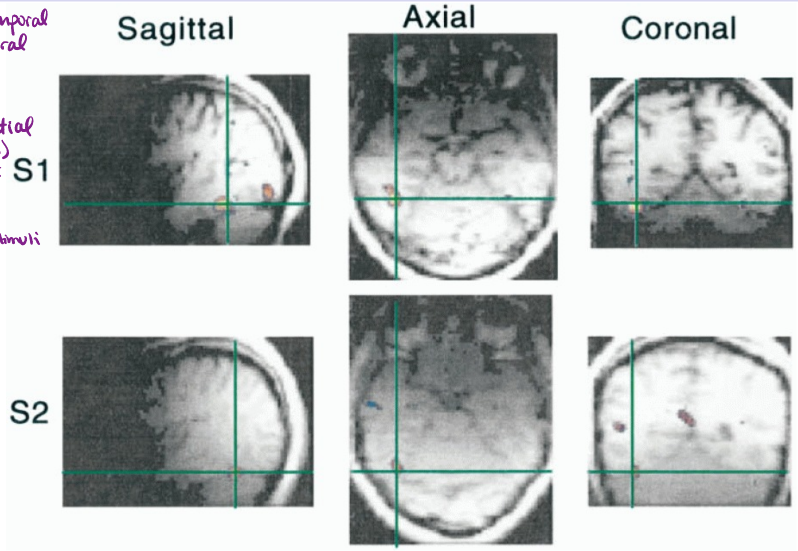


nonword reading is bad

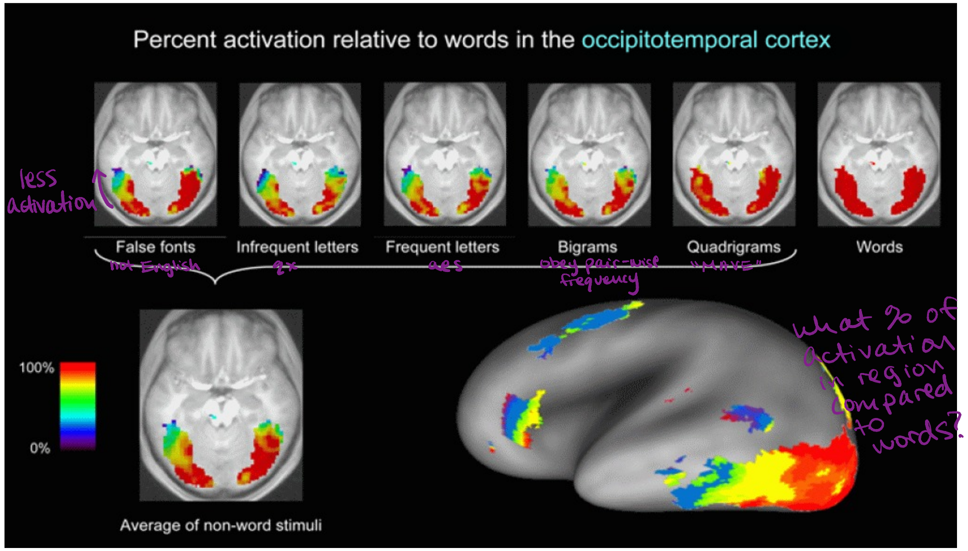
Visual word-form area (VWFA) (Kanwisher et al., 1997, *JNS*)

left ventro-temporal occipital-temporal region

· Shows differential (selective responses) to orthographic stimuli (words) relative to nonorthographic stimuli



Hierarchical response to orthographic structure (Vinckier et al., 2007, *Neuron*)



less activation

not English

qx

aes

obey pair-wise frequency

"MAVE"

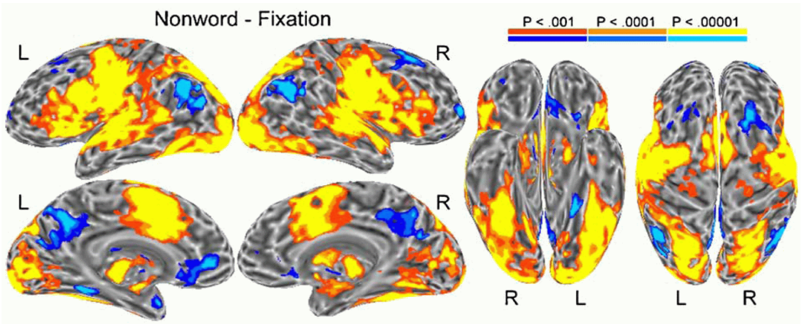
what % of activation in region compared to words?

fxn of how word-like stimuli are

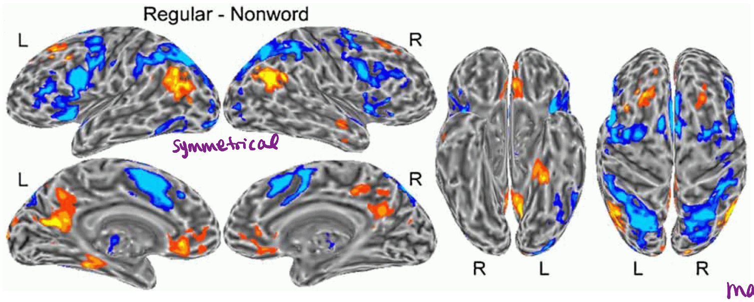
Effects of frequency and regularity

(Binder, Medler, Desai, Conant, & Liebenthal, 2005, *NeuroImage*)

- BOLD response to regular words, irregular words, nonwords
- Lexical: Contrast regular words and nonwords orthographically & phonologically matched
- Sublexical: Contrast irregular words and nonwords spelling consistent vs. not

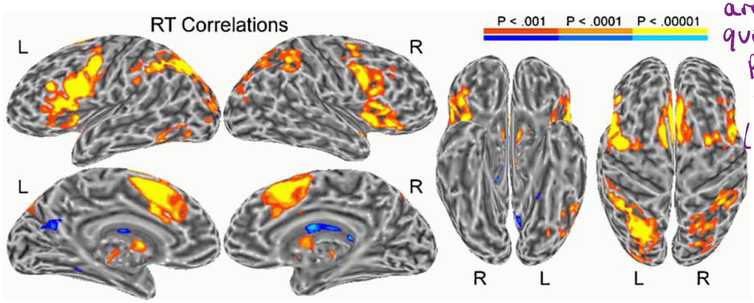


negative diffs
positive diffs



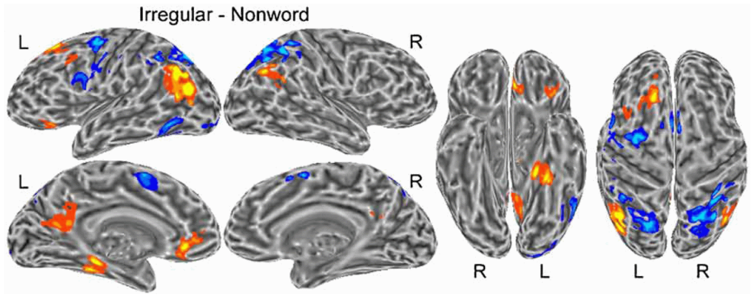
symmetrical

correlate the BOLD signal w/ latency



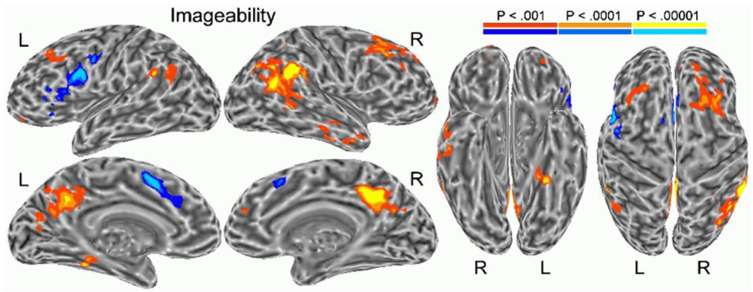
maybe certain areas are just quicker at processing anything (not lexical)

Similar areas



Relative contribution of semantics

ex: truth vs. table



Conclusions (Binder et al., 2005)

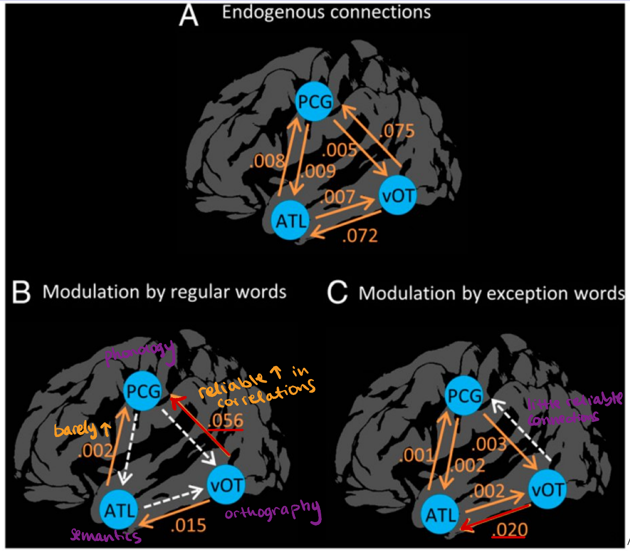
- Several regions showed responses that increased with naming difficulty (nonword > irregular word > regular word) and were correlated with RT.
- No regions were consistent with a nonlexical, rule-based mechanism (i.e., nonword > regular word > irregular word).
- Several regions were activated more by words than nonwords, but equally so for irregular and regular words, and they showed effects of word imageability (semantics).
- Results are broadly consistent with triangle model (and some versions of a traditional dual-route model).

fMRI evidence for semantic involvement in reading aloud
(Hoffman, Lambon Ralph, & Woollams, 2015, *PNAS*)

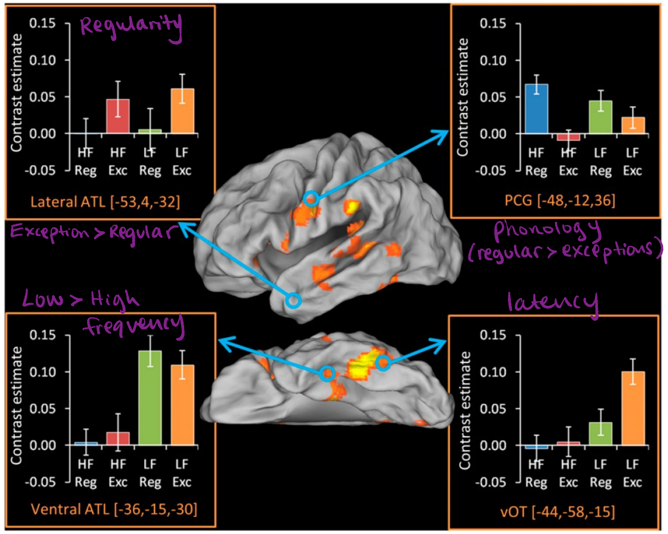
- Little direct evidence for activation in anterior temporal lobes (ATL) during reading aloud
  - Likely because of poor BOLD signal in ATL due to susceptibility artifact (air cavities)
- Used distortion-correct functional imaging of reading aloud, crossing frequency and consistency
- Measured brain activation in specific ROIs
  - ventral occipito-temporal (vOT) [Orthography] → visual word-form area
  - precentral gyrus (PCG) [Phonology] → premotor pronunciation
  - ventral anterior temporal (vATL) [Semantics]
  - lateral anterior temporal (lATL) [Semantics ⇒ Phonology]
- Correlated activation with behavioral measure of "semantic reliance" (regularity effect among low-imageable words)

Modulation of functional connectivity

Functional interactions between regions and their modulation by regular and exception words
- positive values are increases
- orange are reliable



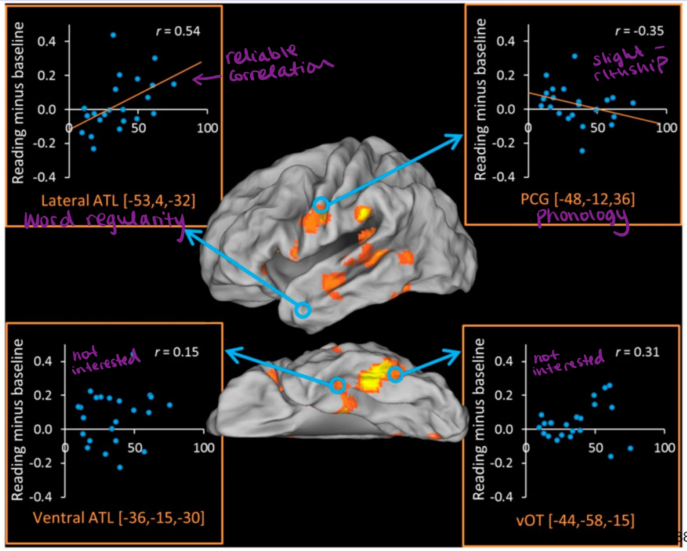
BOLD responses to specific word types



- vOT: difficult/RT
- PCG: regularity
- vATL: (inverse) frequency
- lATL: (inverse) regularity

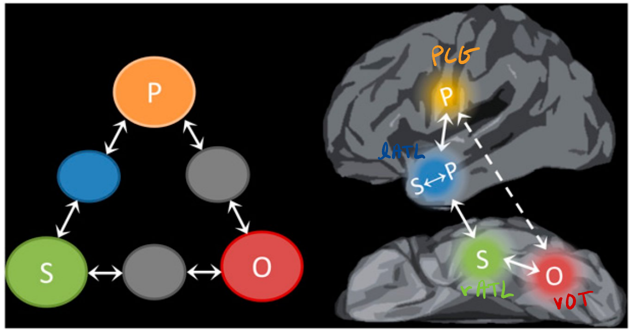
Correlations with semantic reliance

Correlations between reading activation and semantic reliance in each ROI



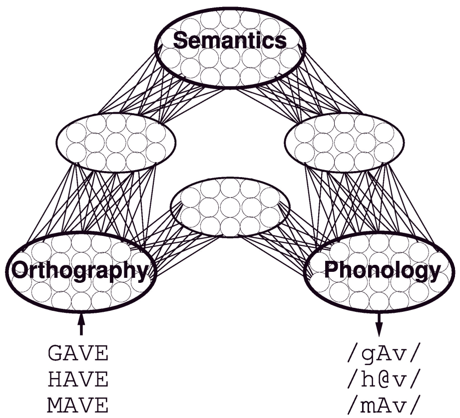
Conclusions (Hoffman et al., 2016)

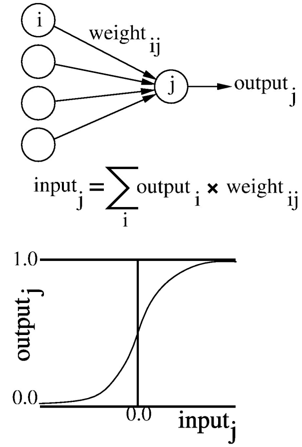
- Increased functional connectivity during reading implicates semantic recruitment
- Lateral ATL activation increased in reading exception words and correlated with degree of semantic reliance in reading aloud (S ⇒ P)
- Anatomic bases of O ⇒ S and O ⇒ P mappings yet to be determined (but see Graves et al., 2014, *Brain & Lang.*)
  - O ⇒ P: posterior superior and middle temporal gyri
  - O ⇒ S: angular gyrus / inferior temporal sulcus?



A neural-network framework for word reading

Triangle model (Seidenberg & McClelland, 1989, *Psych. Rev.*; Plaut et al., 1996, *Psych. Rev.*; Harm & Seidenberg, 2004, *Psych. Rev.*)





Common mechanism that adapts to statistics of the problem at hand (spelling → sound > → semantics)

↑ difficulty → relies ↑ on other areas