DEVELOPMENTAL DYSLEXIA

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Specific Learning Disabilities (SLD)

Children with normal IQ can fail to reach acceptable standards in key curricular areas such as reading and math

Development Dyslexia (DD)

Developmental disorder in learning to read, not due to impairments in general intelligence, sensory problems, emotional disturbances, or inadequate schooling.

Estimated prevalence 4-8%
Strong heritability (54-75%)

Reading is not only important for "reading"

Reading has cognitive consequences that extend beyond the task of extracting meaning from text – it produces an exponential growth of vocabulary and background knowledge

Standardized measures of first grade reading ability (decoding, word recognition, comprehension) can predict the volume of reading 10 years later!
(Cunningham & Stanovich, 1998

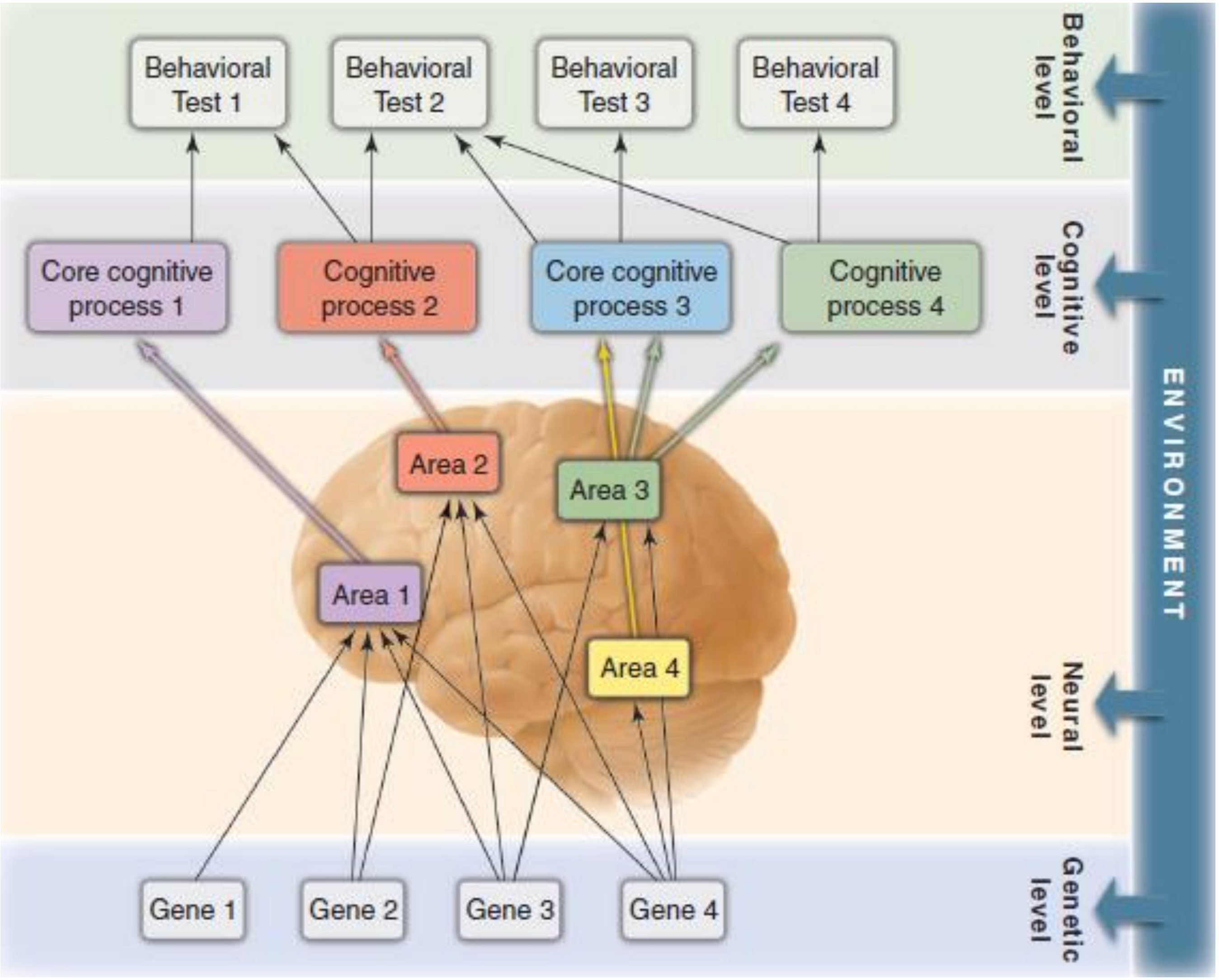
What is the consequence of poor reading?

Poor readers, children who experience greater difficulty in learning to read, begin to be exposed to much less text than their more skilled peers

A dyslexic child may read in one year the same number of words of a good reader in two days!

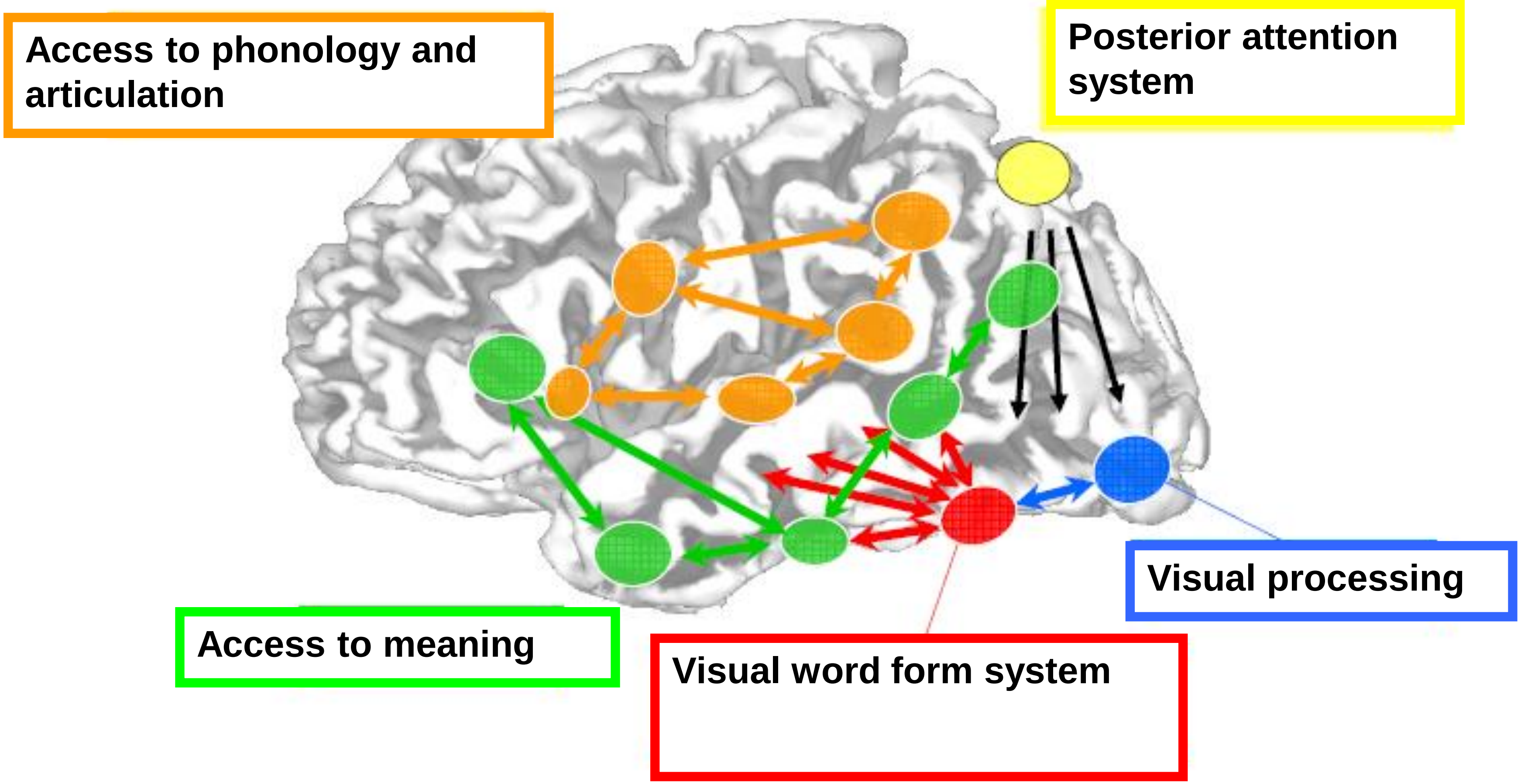
A *rich-get-richer and poor-get-poorer* phenomenon: Out-of-school reading volume is particularly important and it is a powerful predictor of vocabulary and knowledge differences among children

Understanding Specific Learning Disabilities



A causal modeling framework for understanding the relationships among levels of explanations: genetic, neural, cognitive, and behavioral (Morton & Frith, 1995; figure from Butterworth & Kovac, 2013)

The functional anatomy of reading



Impaired decoding in dyslexia

- Decoding is usually measured through non-word reading
- Most studies on English dyslexics report a non-word reading deficit in comparison to both chronological age (CA) and reading level (RL) controls.
- In consistent orthographies, the deficits are more often reported only in the comparison with age matched controls (CA). When considering reading fuency (speed), differences are also found with respect to RL controls (Ziegler et al., 2003, *JECP*; also see Paulesu et al., 2001, *Science,* on adult dyslexics)
- In general, the difficulty of dyslexics seems to be related to inefficient processing of small grain-size units (Ziegler & Goswami, 2005, *Psych. Bull.*)

The subtyping problem

• The existence of subtypes of dyslexia is controversial (vedi Stanovich et al., 1997, *J. Ed. Psy;* Ramus, 2004, *TINS;* Ziegler & Goswami, 2006, *Psych. Bull.*)

• The evidence about two subtypes derives on the regression method: measures of performance in using lexical and phonological procedures in normal children allow the definition of confidence intervals for the typical performance, agains which the dyslexic population is evaluated.

• The initial studies (Castles & Colthear, 1993, *Cognition)* used a comparison only with children matched for chronological age. Later studies (Manis et al., 1996, *Cognition;* Stanovich et al., 1997, *J. Ed. Psy.*) found that surface dyslexia virtually disappeared when matching for reading age. This was confirmed in studies on Spanish (Gonzales, 2000) and French (Sprenger-Charolles et al., 2000)

• Manis et al. conclude that surface dyslexia is a <u>delay of typical development</u>, whereas phonological dyslexia represents a <u>deviant developmental pattern</u>.

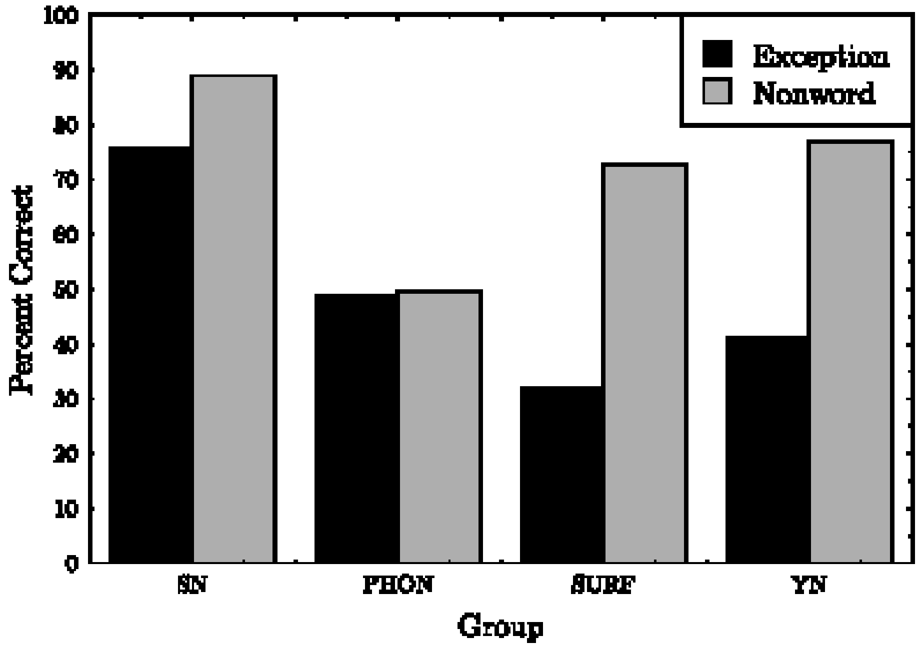


Figure 18. Data from Manis et al. (1996), both dyslexic groups exhibited impairment on both exceptions and nonwords, but phonological dyslexics showed a greater impairment on nonword performance, and the surface dyslexics showed a greater impairment on exception word performance. PHON = phonological dyslexics; SURF = surface dyslexics, SN = same-aged normals, YN = younger normals.

The "dyslexia mess"

Developmental dyslexia has been attributed to a variety of specific deficits:

- linguistic/cognitive level (e.g., phonological deficit)
- sensory level (e.g., magnocellular visual deficit; temporal processing deficit)
- neuroanatomical level (e.g., cerebellar deficit)
- genetic level (e.g., deletion of gene DCDC2)

- A satisfactory theory of dyslexia should address phenomena that are clinically relevant (i.e., the reading difficulties) rather than characterize dyslexia through a myriad of associated deficits
- Proliferation of theories that associate the vagueness of verbal statements to the lack of clear hypotheses about the consequences of the "preferred deficit" on the functional and neural architecture of reading
- Which way out? Use computational models to investigate causal relations between specific deficits and reading skills

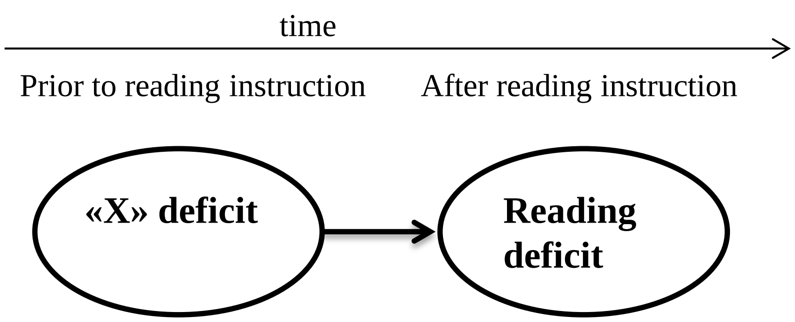
The core deficit issue

- Phonological deficit (Bradley & Bryant, 1983, *Nature*)

- Impaired auditory processing:
  - temporal processing deficit (Tallal et al., 1996; Temple et al., 2000, PNAS)
  - speech perception deficit (Goswami et al., 2004, *PNAS*)
- Visual deficit, magnocellular system (Eden et al., 1996, *Nature*)

- Noise exclusion (Sperling et al., 2005, *Nature Neurosc.*)

- Spatial attention deficit (Facoetti et al., 2006, *Cognitive Neuropsychology;* Facoetti et al., 2010, *JoCN*)

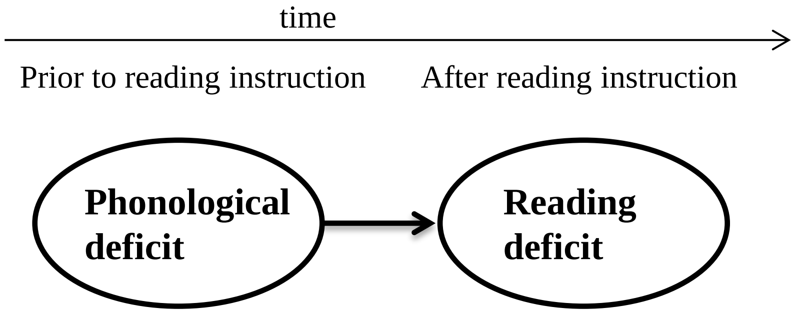


Predictions of a causal model

- Deficit «X» exists before learning to read
- Severity of deficit «X» predicts variations in severity of reading deficit

Phonological deficit in dyslexia

- A deficit in representing and using phonological information is considered as a critical factors for the onset of developmental dyslexia (e.g. Snowling, 2000; Ziegler & Goswami, 2005, *Psych. Bull.*)
- Dyslexic children in different countries show similar phonological deficits. The sequential development of phonological awareness is atypical:
    - preschoolers at risk for dyslexia have difficulties in the manipulation of syllables and rhymes (e.g. Schneider et al., 2000, *J.Ed.Psych.*)
    - deficit at the phoneme level is present in English dyslexic children even when matched to control children for their reading ability
    - in consistent orthographies, the deficit is less pervasive and usually it is only found in the younger children. Longitudinal study on Dutch dyslexics: preschool → rhyme deficit; first grade → phoneme deficit; sixth grade → no deficit (De Jong & van der Keij, 2003, *J.Ed.Psy*.)



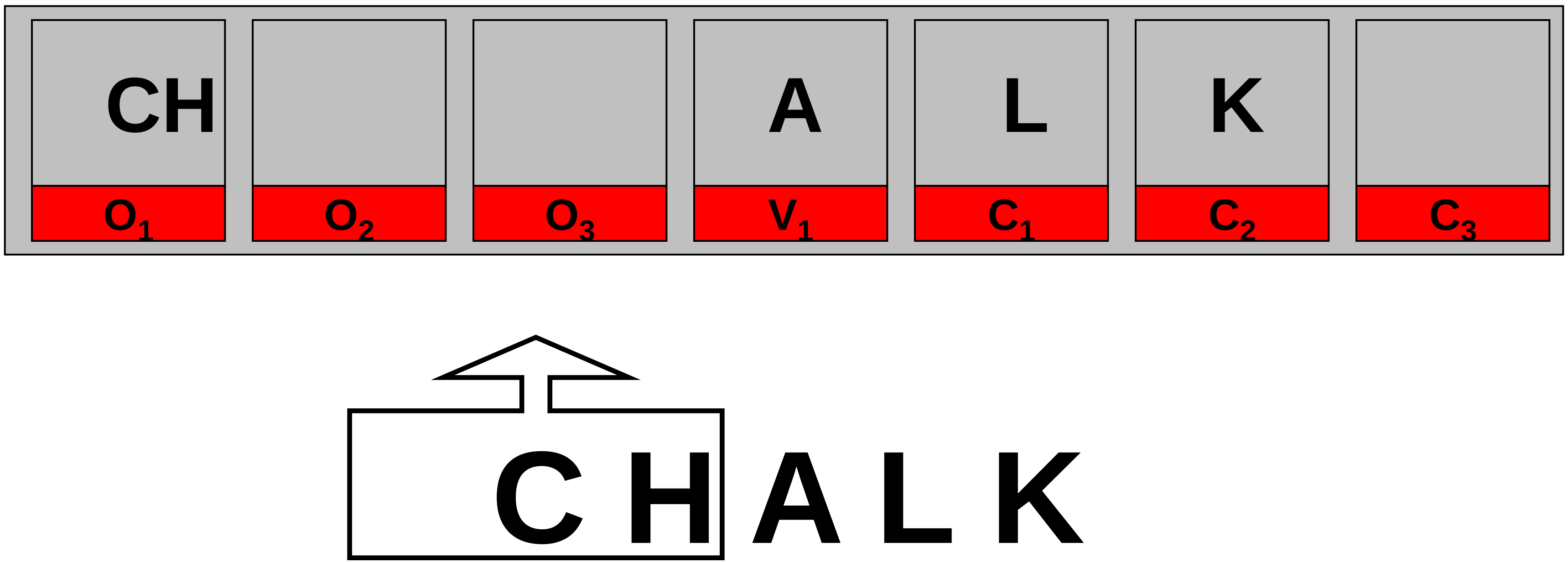
Visuo-spatial attention and reading

- In CDP+, spatial attention is crucial for grapheme segmentation in the phonological decoding process (sublexical route)

- Manipulations of visual attention make skilled adult readers more inefficient in reading nonwords as compared to words

- Patients with hemispatial neglect (i.e., a deficit of spatial attention following parietal lesions) make more errors on nonwords compared to words. They also show preserved lexical-semantic processing in reading, suggesting an interaction between the visual spatial attentional system and the different reading routes

Grapheme Parsing



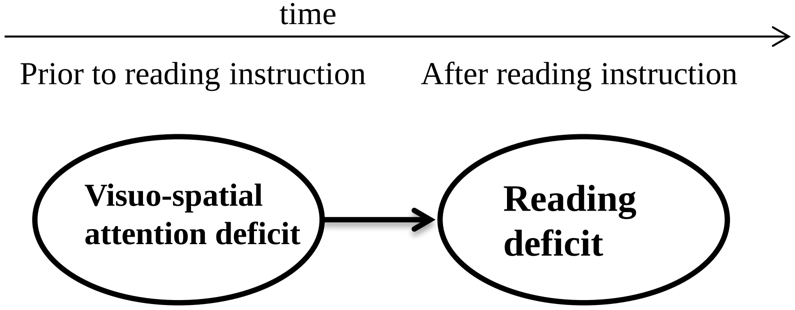
Attentional window moves from left to right over letter level
(letters detectors encode letter identity and absolute spatial position)

Window size: 3 letters = biggest grapheme

Spatial attention and developmental dyslexia

Impaired visual spatial attention has been repeatedly described in DD (e.g., Facoetti et al., 2000, *Cortex*; Facoetti & Molteni, 2001, *Neuropsychologia*; Buchholz & McKone, 2004, *Dyslexia*; Cestnick & Coltheart, 1999, *Cognition*; Roach & Hogben, 2007, *Brain*)

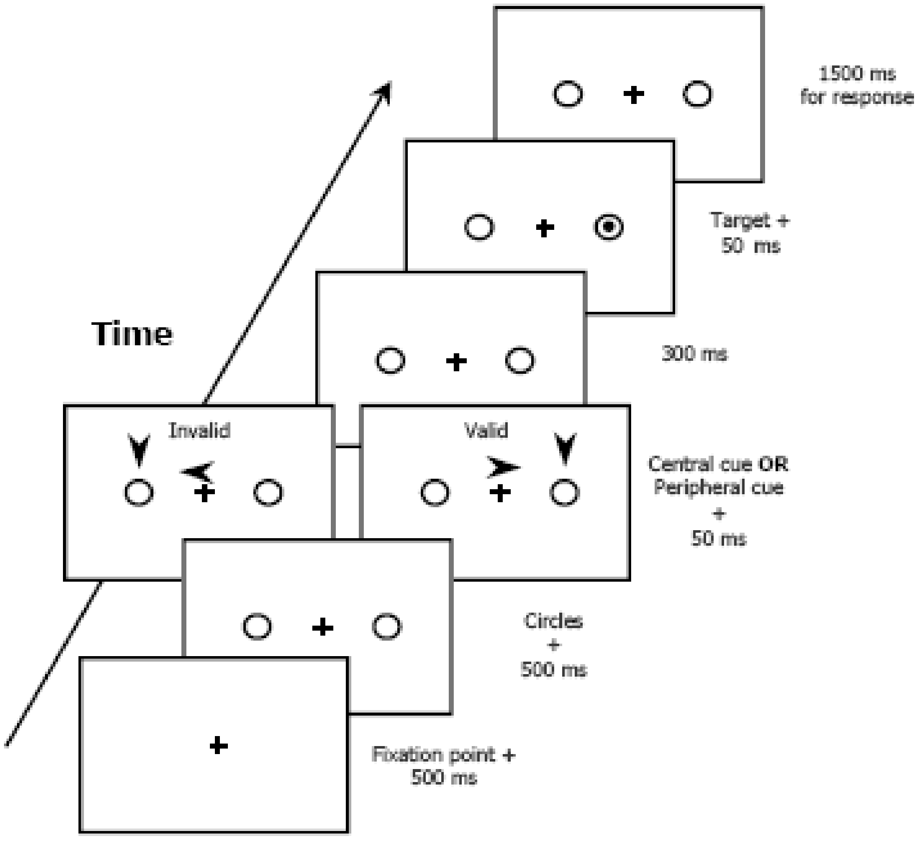
If visuo-spatial attention is crucial for sublexical reading (grapheme segmentation etc.) as predicted by CDP+, its impairment in dyslexia should have a specific impact on phonological decoding (measured by the ability to read nonwords)



Visuo-spatial attention and phonological decoding in developmental dyslexia

Visuo-spatial attention task:

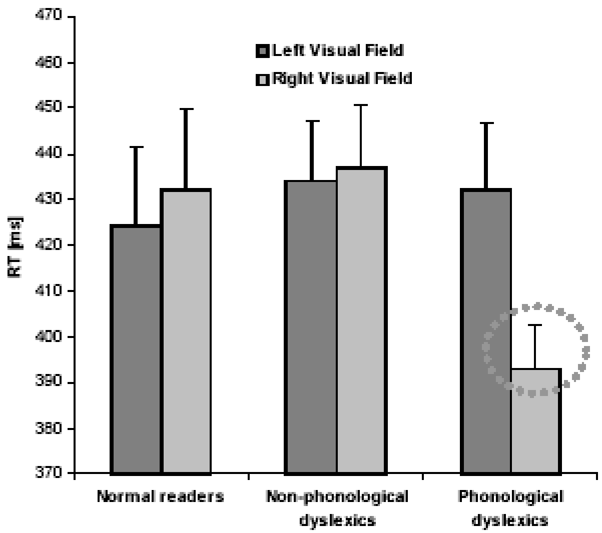
- Cued detection (Posner task)
- Simple RTs (button-press)
- No linguistic content



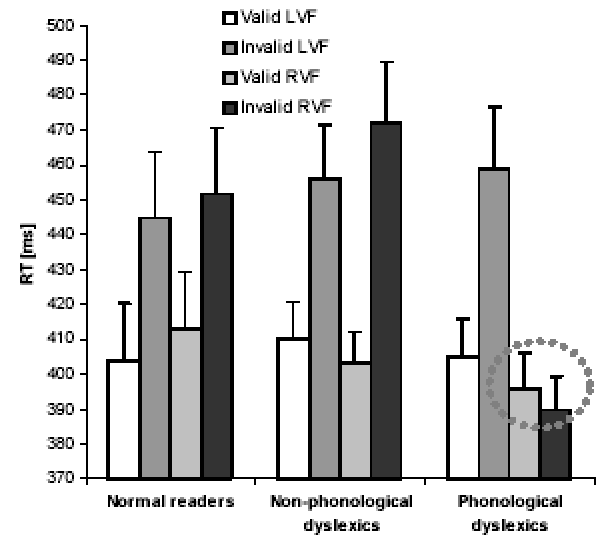
Facoetti et al., 2006, *Cog. Neuropsych.*

	Phonological dyslexics (N=10)		Non-phonological dyslexics (N=10)		Comparison	
	M	SD	M	SD	t(18)	p
Age	11.4	2.32	11.3	2.41	0.94	0.93
Global IQ	104.2	9.58	100.4	11.26	0.81	0.43
Nonword reading accuracy	-3.64	1.22	-0.61	0.85	6.44	<0.001
Word reading accuracy	-5.75	2.29	-4.01	2.52	1.62	0.12

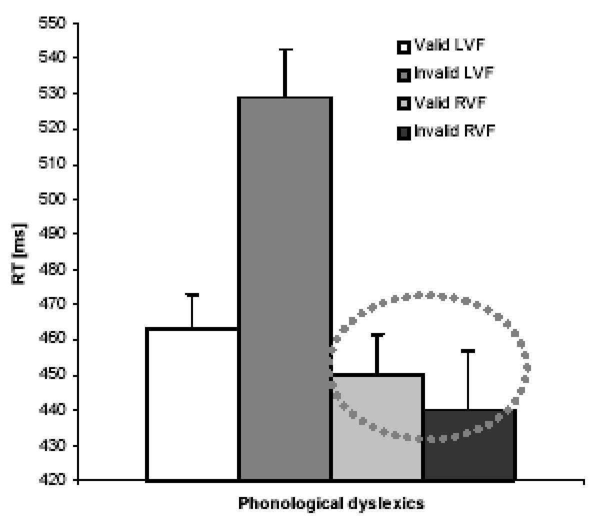
Table 1. Age, global IQ, nonword and word reading accuracy (z-scores) in DD children in Experiment 1.



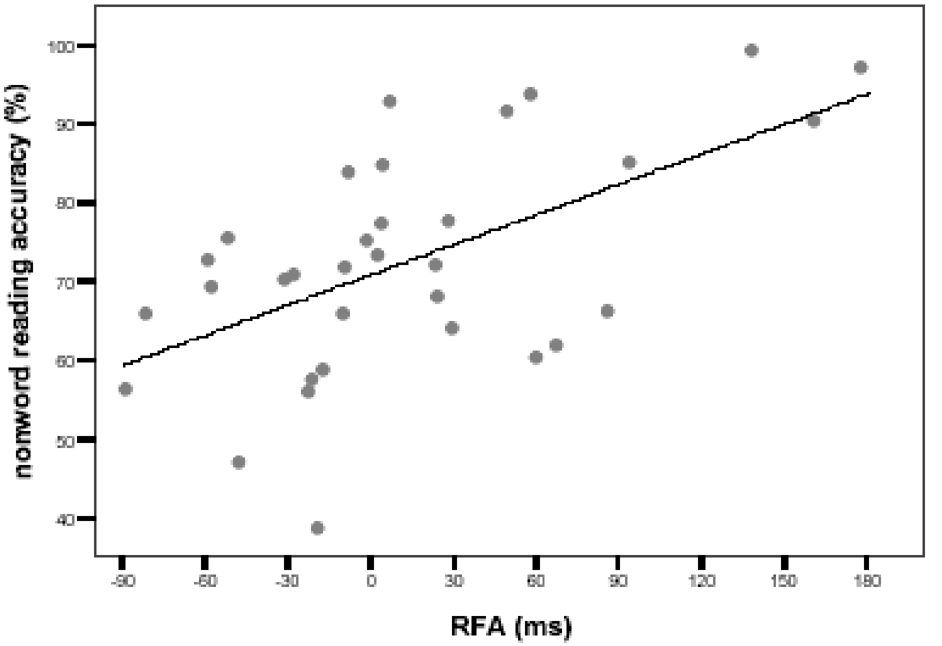
Mean reaction times (RTs) and standard errors as a function of group (phonological dyslexics, non-phonological dyslexics and normally reading children) and target location (left visual field and right visual field) (Experiment 1).



Mean reaction times (RTs) and standard errors as a function of group (phonological dyslexics, non-phonological dyslexics and normally reading children), cue condition (valid and invalid) and target location (LVF=left visual field and RVF=right visual field) (Experiment 1).



Mean reaction times (RTs) and standard errors as a function of cue condition (valid and invalid) and target location (LVF=left visual field and RVF=right visual field) in phonological dyslexic children (Experiment 2).



Scatter plot of the relationship between right focused attention (RFA, i.e., the RT difference between invalid and valid cue condition to targets in the right visual field) and nonword reading accuracy (percent correct responses) across our entire sample of developmental dyslexic children (N=33). The regression line results from the equation 70.8+0.13 x RFA, which accounts for 33% of the variance.

• Attention orienting deficit predicts nonword reading accuracy

• Graphemic parsing requires focused attention and precise orienting of attention along the letter string. Inefficient control will impact the operations of the phonological decoding mechanism.

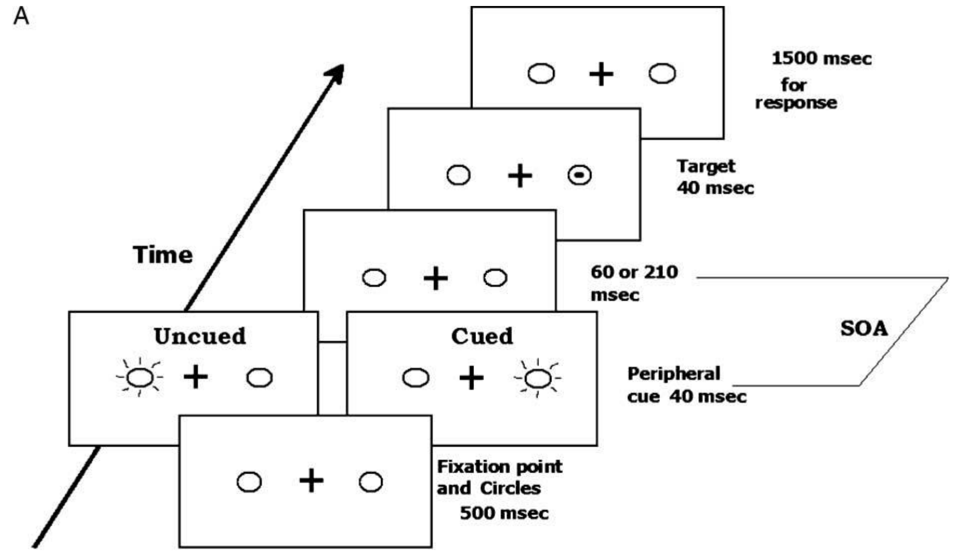
Components of spatial attention in DD

- Multi-sensory rather than uni-sensory (visual) deficit
- Core deficit: automatic (i.e., exogenous) orienting (linked to right temporo-parietal cortex)
- Abnormal time-course rather than lack of orienting
- Inefficient orienting in DD but not in normal children matched for reading level (RL controls).

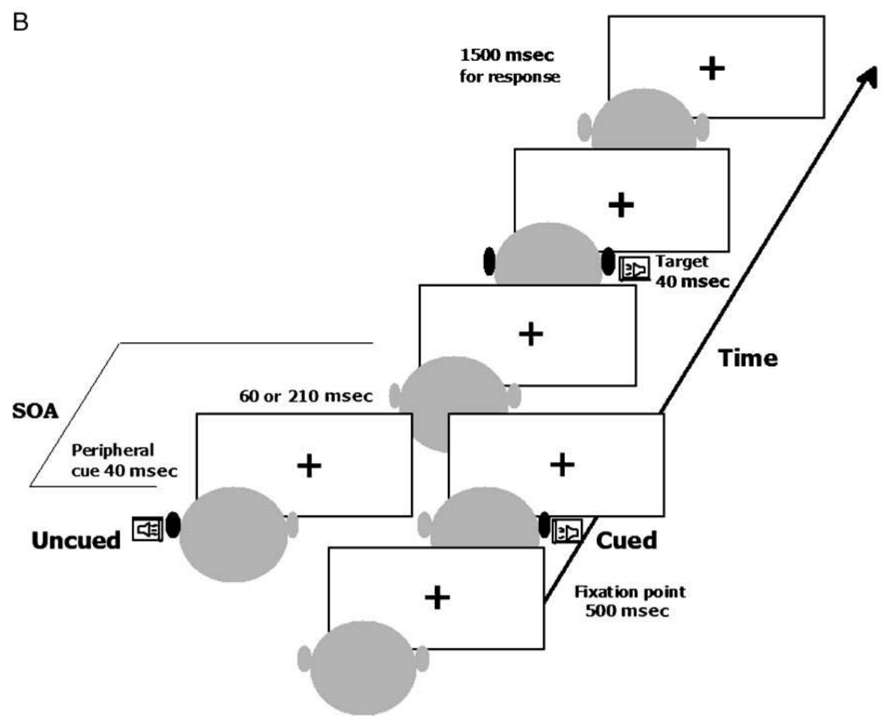
Prediction: a sluggish time-course of automatic spatial attention is a specific marker of impaired nonword reading in DD.

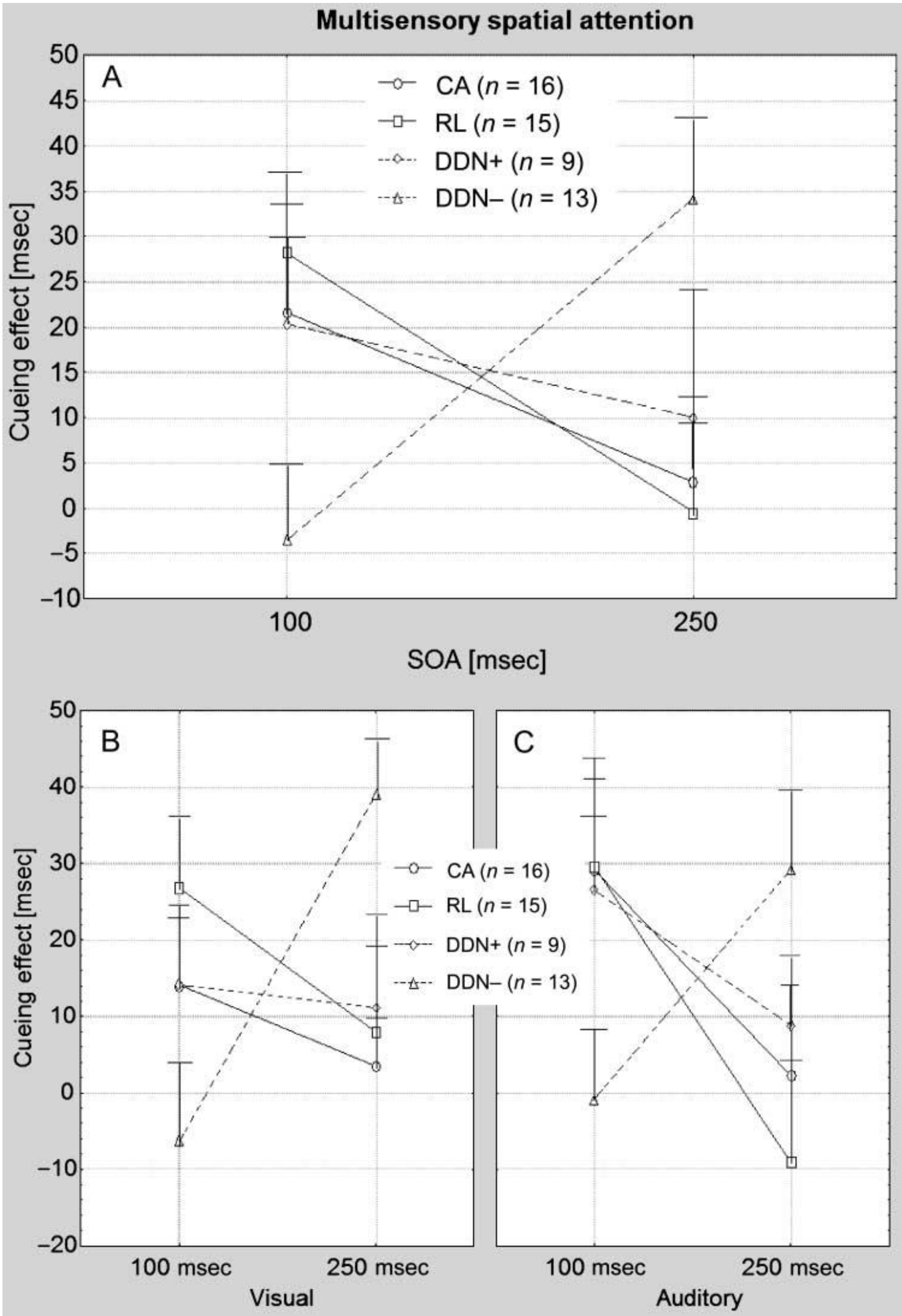
Facoetti, .., Zorzi, 2010, *Journal of Cognitive Neuroscience*

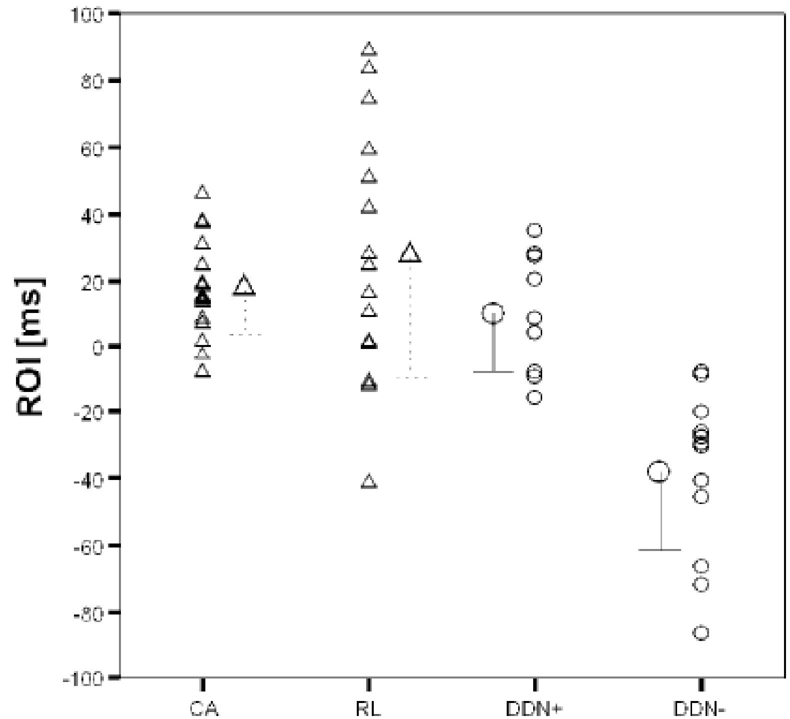
Visual task

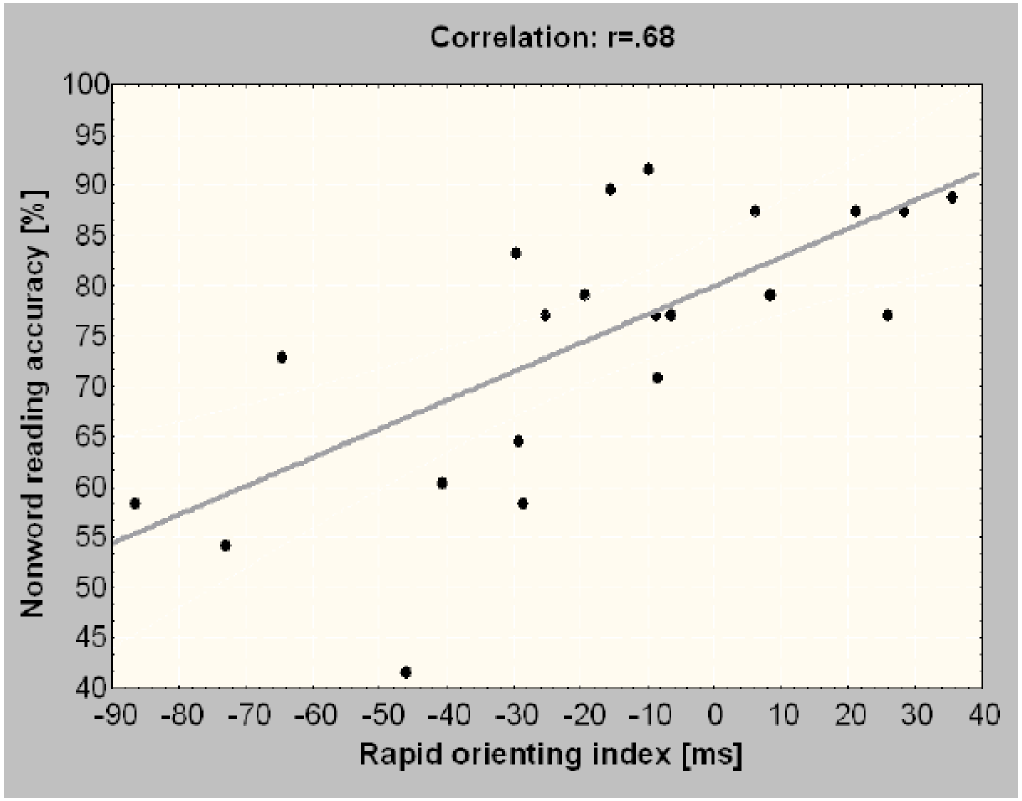


Auditory task




Multisensory spatial attention
A
CA (n = 16)
RL (n = 15)
DDN+ (n = 9)
DDN– (n = 13)
Cueing effect [msec]
SOA [msec]
100
250
B
C
Cueing effect [msec]
100 msec
250 msec
Visual
100 msec
250 msec
Auditory


ROI [ms]
CA
RL
DDN+
DDN-



N=22 dyslexics

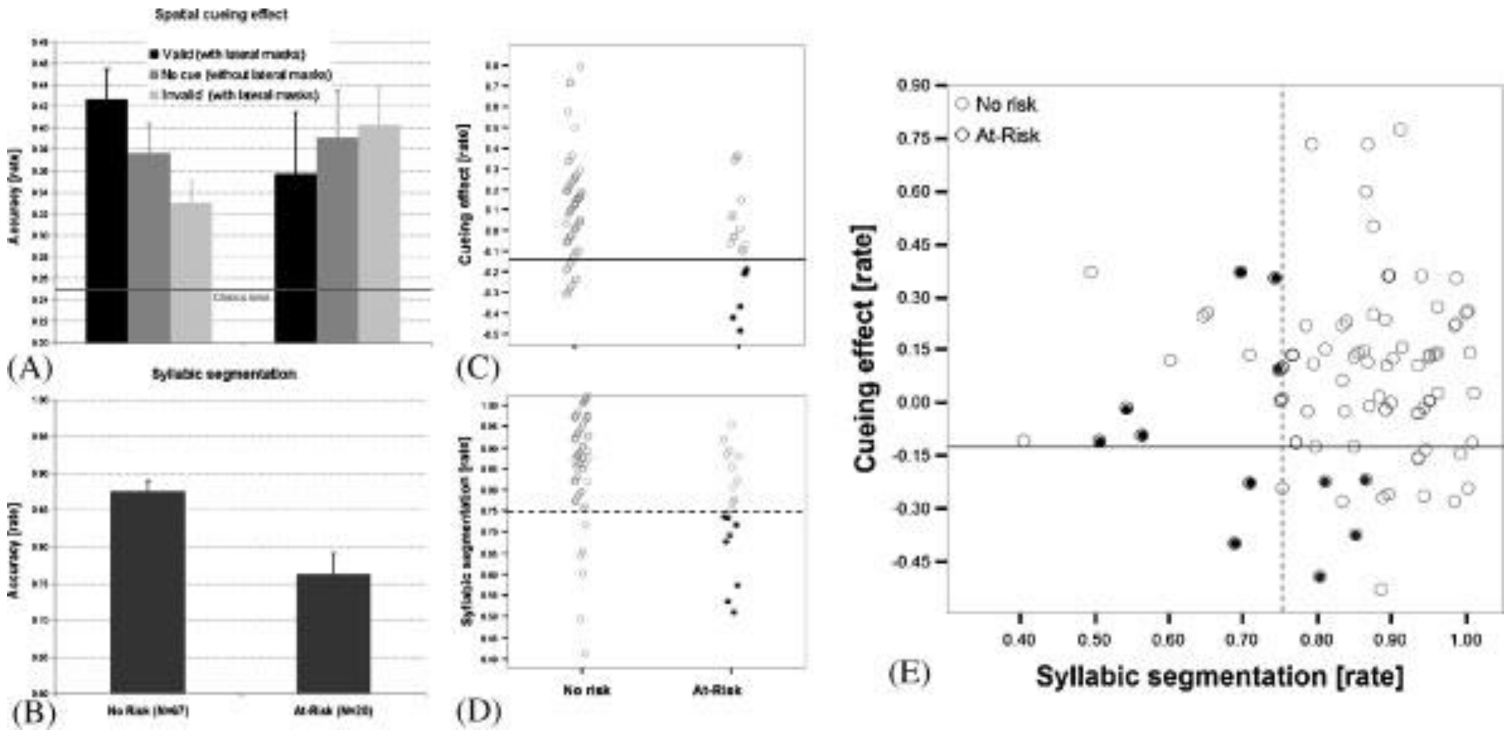
ROI accounts for 31.5% of unique variance (partialling out age, IQ, phonological skills)

Table 3. Multiple Regression Analyses

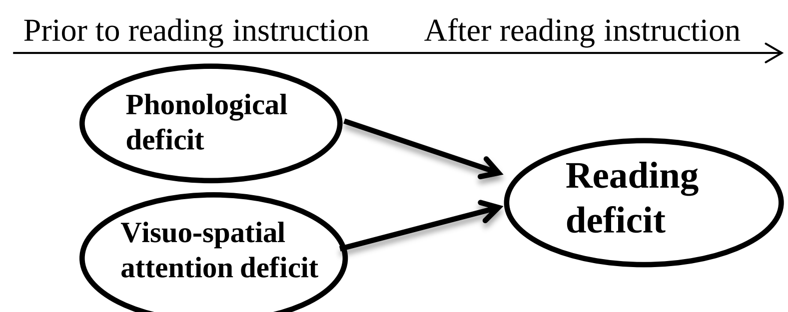
	Nonword		*Word*	
	R^2 *Change*	*p*	R^2 *Change*	*p*
Step 1: Age	.001	*ns*	.040	*ns*
Step 2: IQ	.004	*ns*	.012	*ns*
Step 3: Phonological skills	.27	< .05	.278	< .05
Step 4: ROI	.315	< .005	.123	.07

Percentage of unique variance in nonword and word reading accuracy of all dyslexic children (n = 22) accounted for by the different predictors (age, IQ, phonological skills, and ROI) in the four-step fixed-entry multiple regression analysis.

Both spatial attention and phonological processing are impaired in preschoolers at-risk for dyslexia

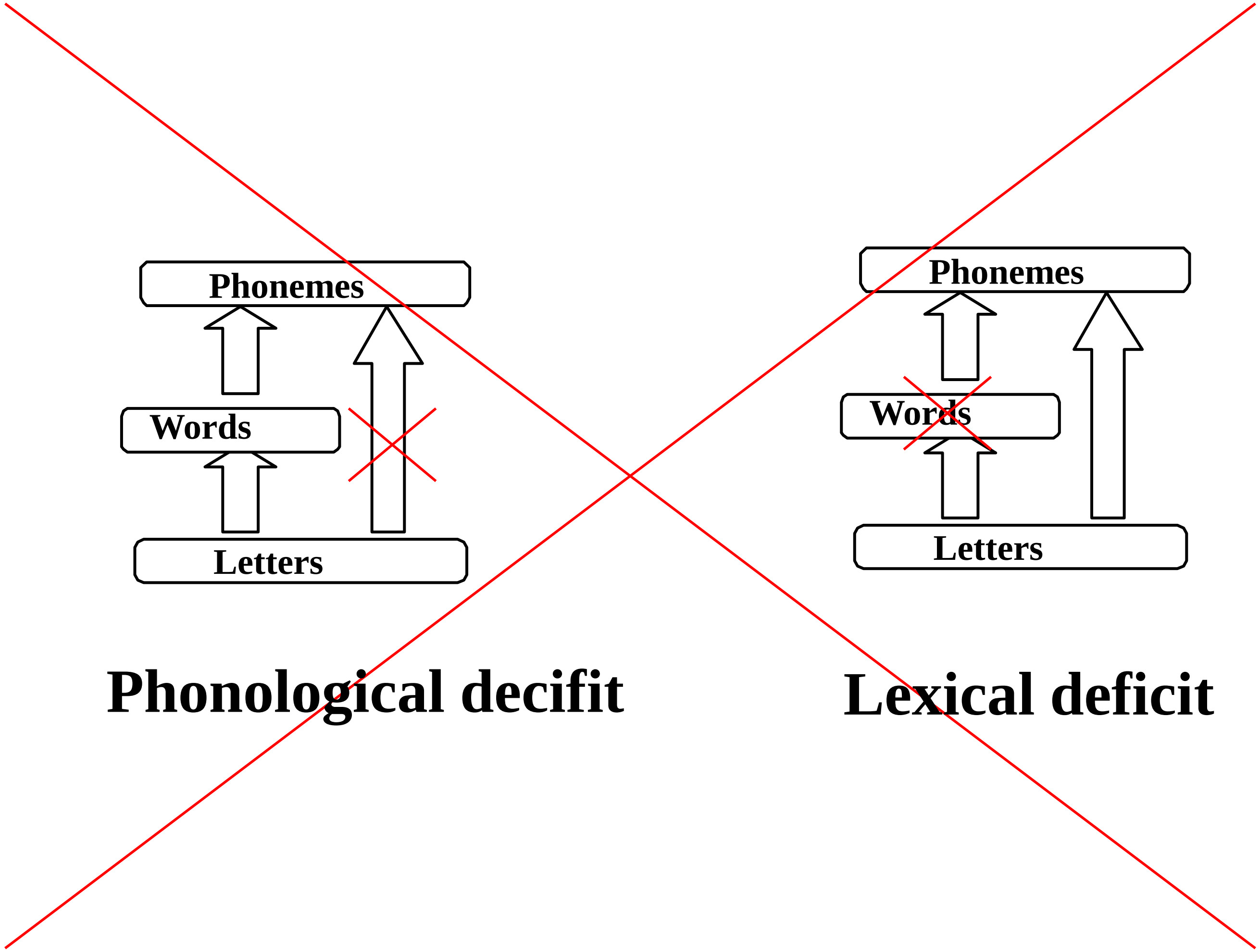


A: Performance in peripheral target identification as a function of Group (No Risk: n=67 and At-Risk: n=20) and Cue condition (valid, invalid and no cue). B: Syllabic segmentation performance. C: Individual data in visual spatial attention task (30% below 1 SD) D: Individual data in syllabic segmentation task (40% below 1 SD). E. Individual data in both tasks.



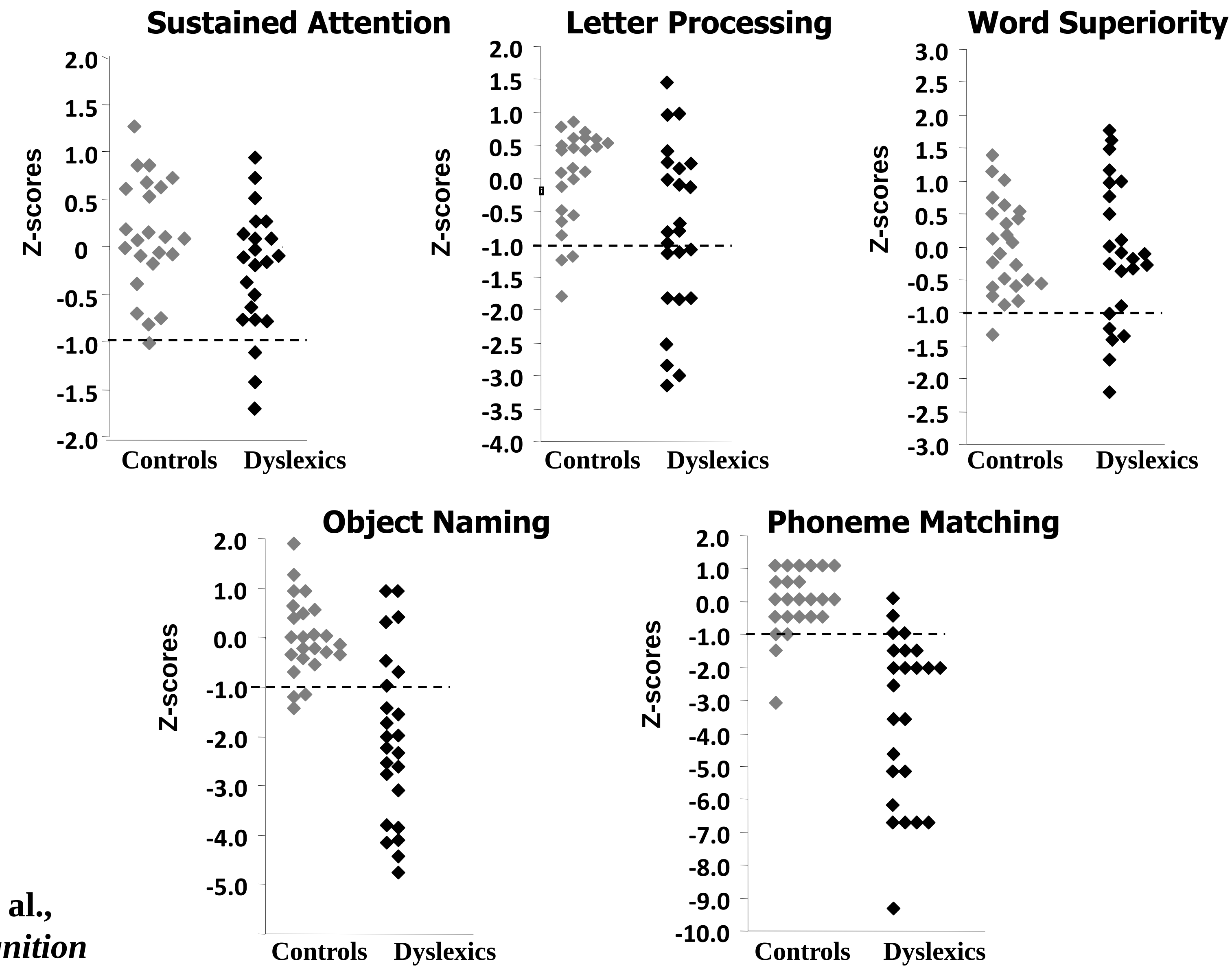
Facoetti, .., Zorzi, 2010, *Dyslexia*

«Where» is the deficit ?



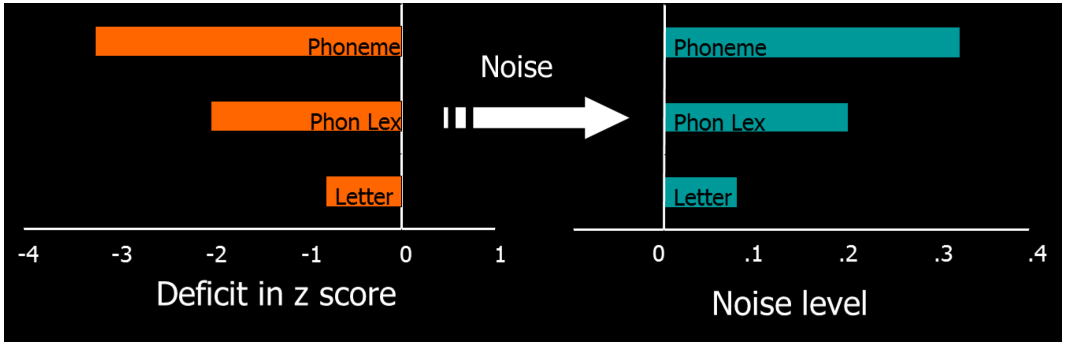
"Adult neuropsychological models don't work for neurodevelopmental syndromes"
A. Karmiloff-Smith (and many others..)

Individual differences: Assessing components of the reading network



Ziegler et al., 2008, *Cognition*

From component tasks to individual simulations

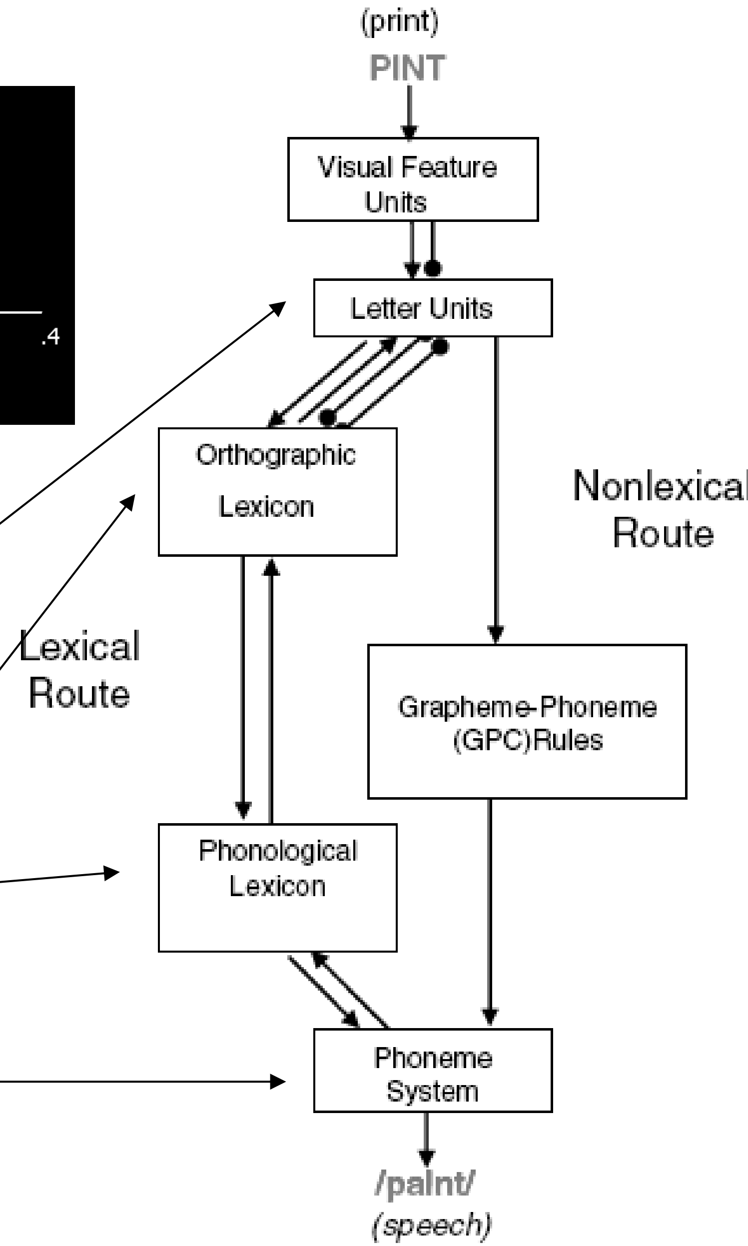


Letter search (consonant strings)

Letter search (word superiority)

Picture naming (RAN)

Phoneme matching



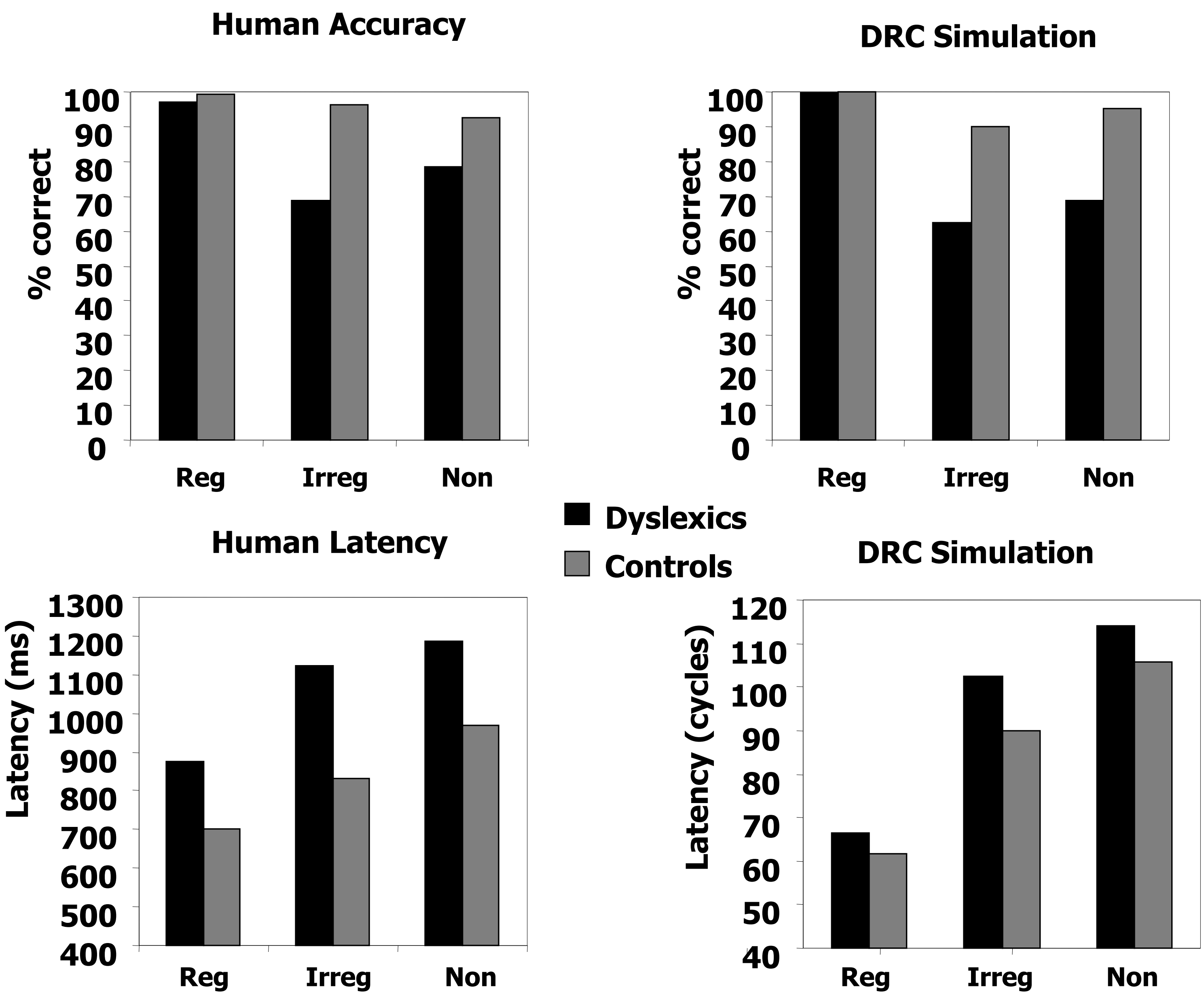
Ziegler et al., 2008, *Cognition*

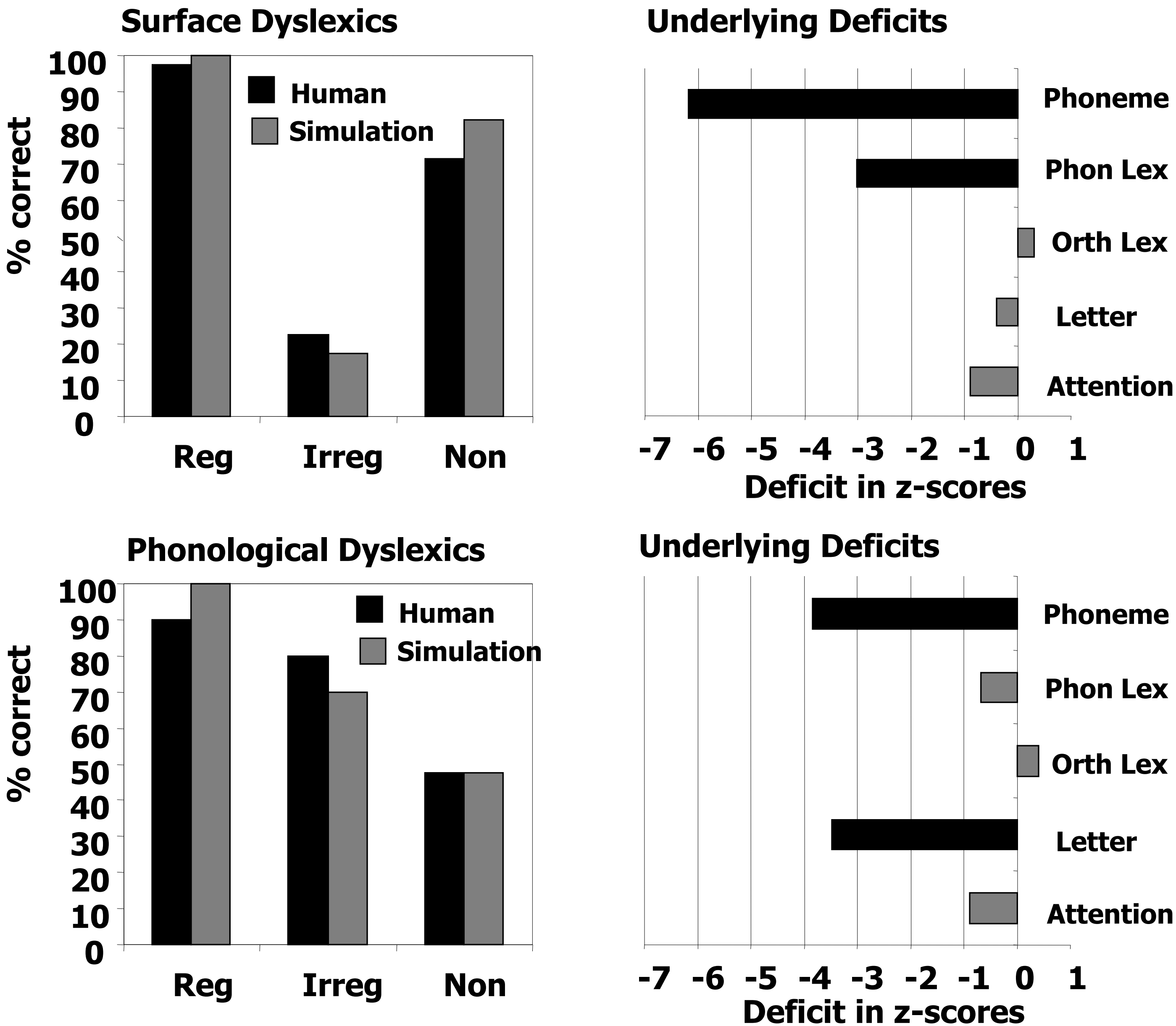
Appendix A

	Type	Reading accuracy (% correct)						Reading latency						z-score deficits			Noise parameter ($x \times 10^{-3}$)		
		Dyslexics			Model			Dyslexics (ms)			Model (cycles)			Dyslexics			Model		
		REG	IR	NON	REG	IR	NON	REG	IR	NON	REG	IR	NON	Letter	P−Lex	Phon	Letter	P−Lex	Phon
1	Surface♠	100	20	90	100	10	95	1355	1360	1384	72	115	118	0.00	−2.32	−5.91	0	9	3
2	Surface♠	100	20	55	100	20	48	1233	985	1459	70	96	120	−2.83	−4.14	−3.85	57	17	2
3	Ssurface♠	90	20	70	100	30	100	864	880	1174	69	106	113	0.44	−1.40	−4.39	0	6	2
4	Surface♠	100	30	70	100	10	86	1020	995	1255	80	134	125	−0.81	−3.07	−8.77	16	12	5
5	Phono♣	80	80	40	100	80	52	735	823	1191	64	97	112	−1.81	−0.66	−0.97	36	3	1
6	Phono♣	100	80	55	100	60	43	849	1473	1048	68	102	120	−3.12	−2.74	−3.85	62	11	2
7	Mixed♠	100	60	75	100	70	71	796	1857	1252	71	108	115	−0.78	−3.79	−4.96	16	15	3
8	Mixed	100	70	75	100	70	62	805	1331	1086	65	105	121	−1.81	−3.82	−4.01	36	15	2
9	Mixed♠	90	70	95	100	80	86	732	844	994	65	100	110	−0.07	−2.53	−1.35	1	10	1
10	Mixed	100	60	75	100	60	43	803	1225	1023	64	101	112	−1.12	−2.22	−3.06	22	9	2
11	Mixed	90	70	75	100	40	62	822	1446	970	69	97	120	−0.66	−4.42	−6.30	13	18	3
12	Mixed♣	100	80	75	100	50	62	1105	1529	1439	68	110	116	−1.06	−1.96	−4.77	21	8	3
13	Mixed	90	10	35	100	60	43	1441	–	1699	66	106	114	−1.80	−4.73	−5.00	36	19	3
14	Mild	100	80	90	100	80	86	875	943	1475	61	94	107	−0.11	−1.53	−0.22	2	6	0
15	Mild♠	100	90	80	100	80	95	894	964	934	65	103	109	0.24	−0.95	−1.55	0	4	1
16	Mild	100	90	90	100	90	95	537	612	698	65	102	109	0.99	0.98	−1.93	0	0	1
17	Mild	100	90	90	100	90	95	764	1034	848	62	90	106	1.48	0.33	−0.78	0	0	0
18	Mild	100	90	95	100	70	76	669	1002	968	64	105	114	−1.10	−1.98	−1.93	22	8	1
19	Mild	100	100	90	100	80	100	715	1216	1339	65	104	111	0.17	0.44	−1.73	0	0	1
20	Mild	100	100	90	100	90	95	550	662	661	65	103	109	0.27	−0.46	−1.55	0	2	1
21	Mild	100	100	90	100	90	81	826	1102	1529	61	89	106	0.97	−1.70	−0.40	0	7	0
22	Comp	90	80	90	100	40	29	812	961	1101	67	109	130	−2.51	0.98	−6.10	50	0	3
23	Comp	100	90	95	90	70	14	1175	1805	2111	63	90	92	−0.98	−4.09	−2.50	20	16	1
24	Comp♠	100	70	100	100	80	33	636	793	827	69	97	131	−2.99	−2.60	−1.93	60	10	1

Notes. ♠, surface dyslexic according to regression method; ♣, phonological dyslexic according to regression method; comp, compensated dyslexic; REG, regular; IR, irregular; NON, nonword; Phon, phoneme; P-Lex, phonological lexicon.

Performance in ancillary tasks (Z-scores) are used to ***add noise*** in specific model components **proportionally to the size of the individual deficit**. The model is then tested in the reading task (regular and irregular words, nonwords)


Human Accuracy
DRC Simulation
% correct
100
90
80
70
60
50
40
30
20
10
0
Reg
Irreg
Non
Dyslexics
Controls
Human Latency
DRC Simulation
Latency (ms)
1300
1200
1100
1000
900
800
700
600
500
400
Latency (cycles)
120
110
100
90
80
70
60
50
40


Surface Dyslexics
% correct
100
90
80
70
60
50
40
30
20
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0
Human
Simulation
Reg
Irreg
Non
Underlying Deficits
Phoneme
Phon Lex
Orth Lex
Letter
Attention
-7 -6 -5 -4 -3 -2 -1 0 1
Deficit in z-scores
Phonological Dyslexics
% correct
100
90
80
70
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Human
Simulation
Reg
Irreg
Non
Underlying Deficits
Phoneme
Phon Lex
Orth Lex
Letter
Attention
-7 -6 -5 -4 -3 -2 -1 0 1
Deficit in z-scores

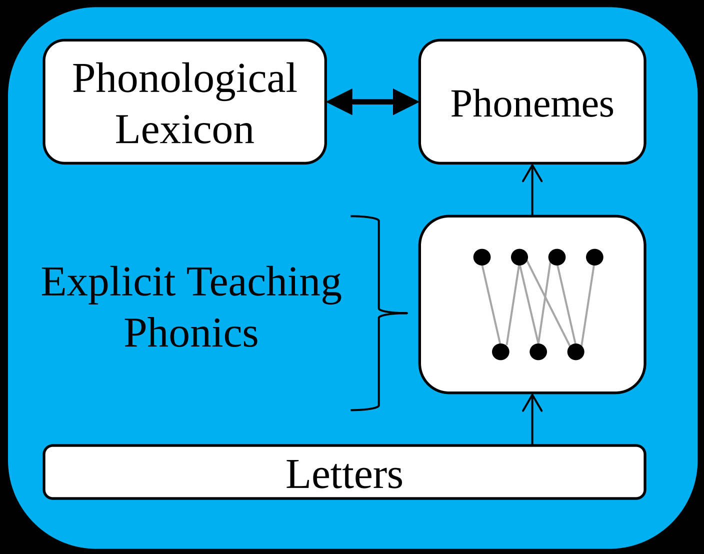
Interim Summary

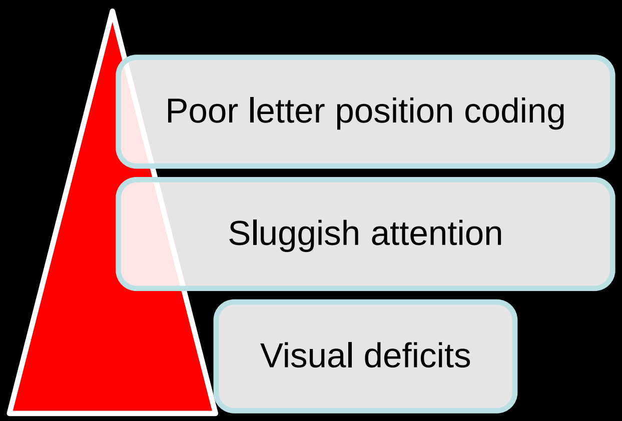
• The heterogeneity of developmental dyslexia can be addressed by simulating individual differences in reading different kinds of words on the basis of underlying deficits in core components of the reading system.

• Almost all dyslexics (regardless of subtypes) had deficits in more than one component task

• The simulations not only accounted fairly well for individual reading patterns but also captured the different dyslexia profiles discussed in the literature (i.e., surface, phonological, mixed, etc.)

Visual deficit

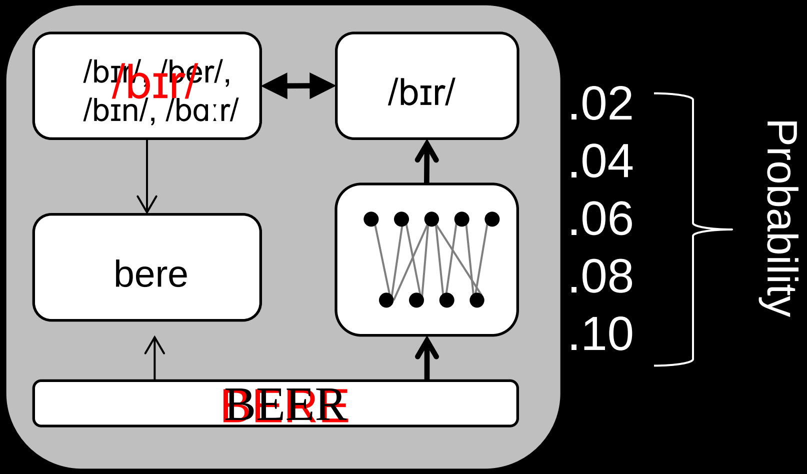




Ziegler et al., 2014
PTRS

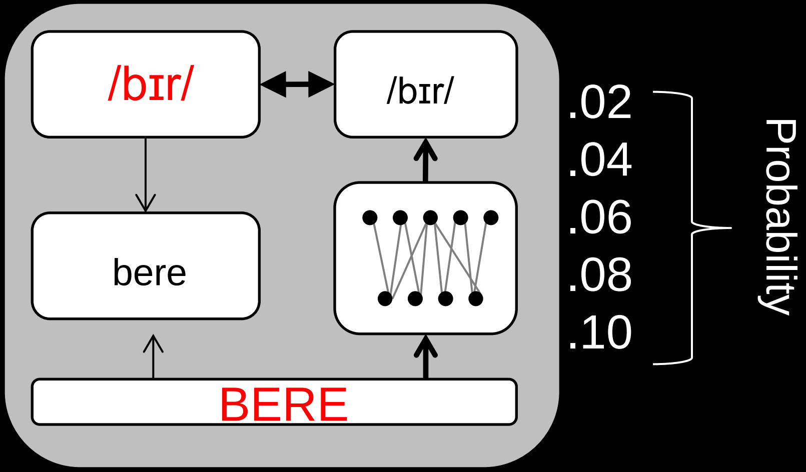
Visual deficit

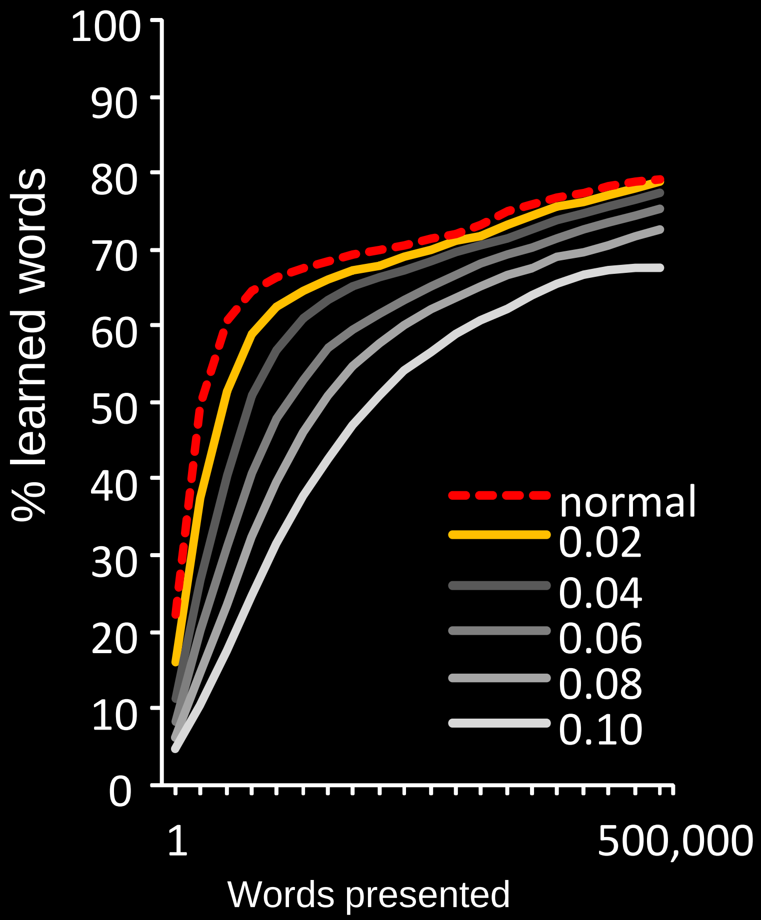
Each letter in the word can be swapped with a neighboring letter with a given probability



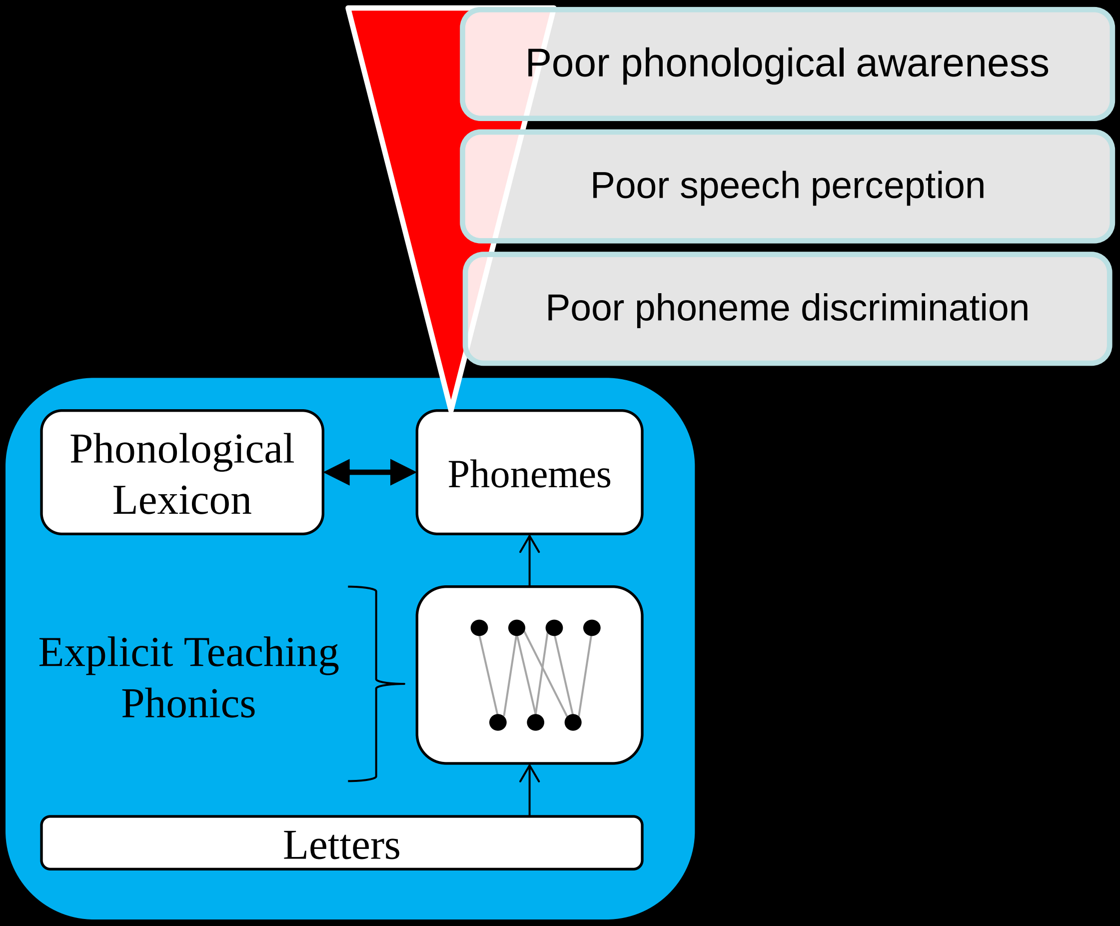
Visual deficit

Each letter in a word can be swapped with a neighboring letter with a given probability



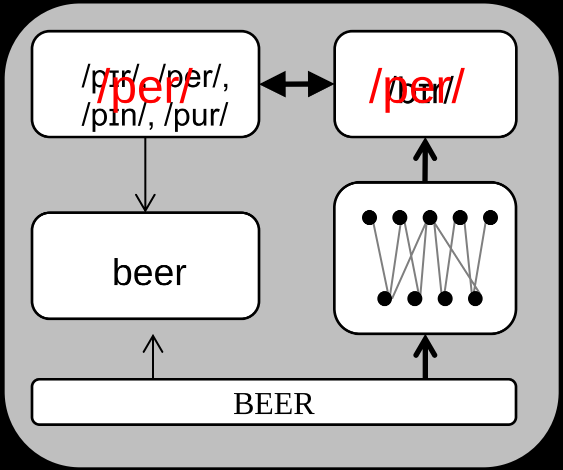


Phonological deficit



Phonological deficit

Phonological deficit: swapping of a phonome during decoding with a phonetically similar one (eg, /b/ -> /p/)

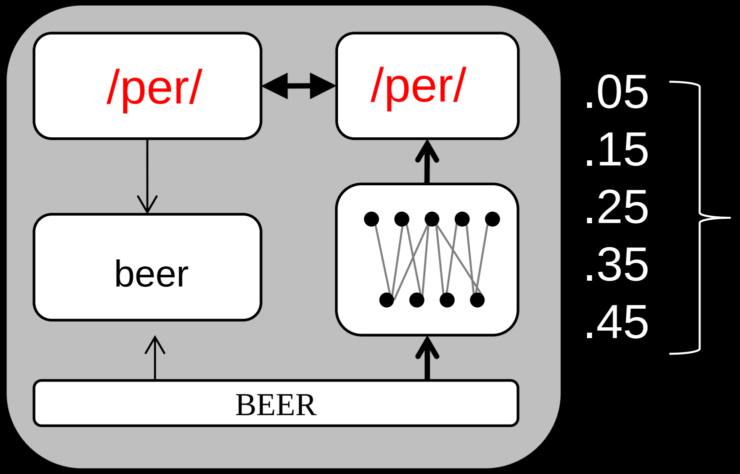


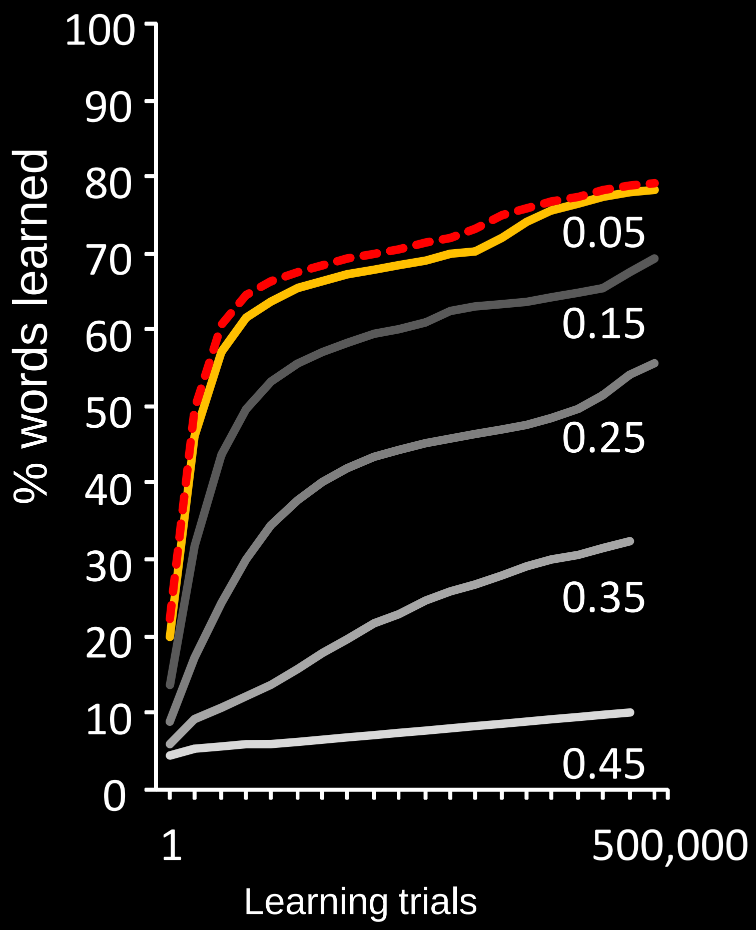
.05
.15
.25
.35
.45

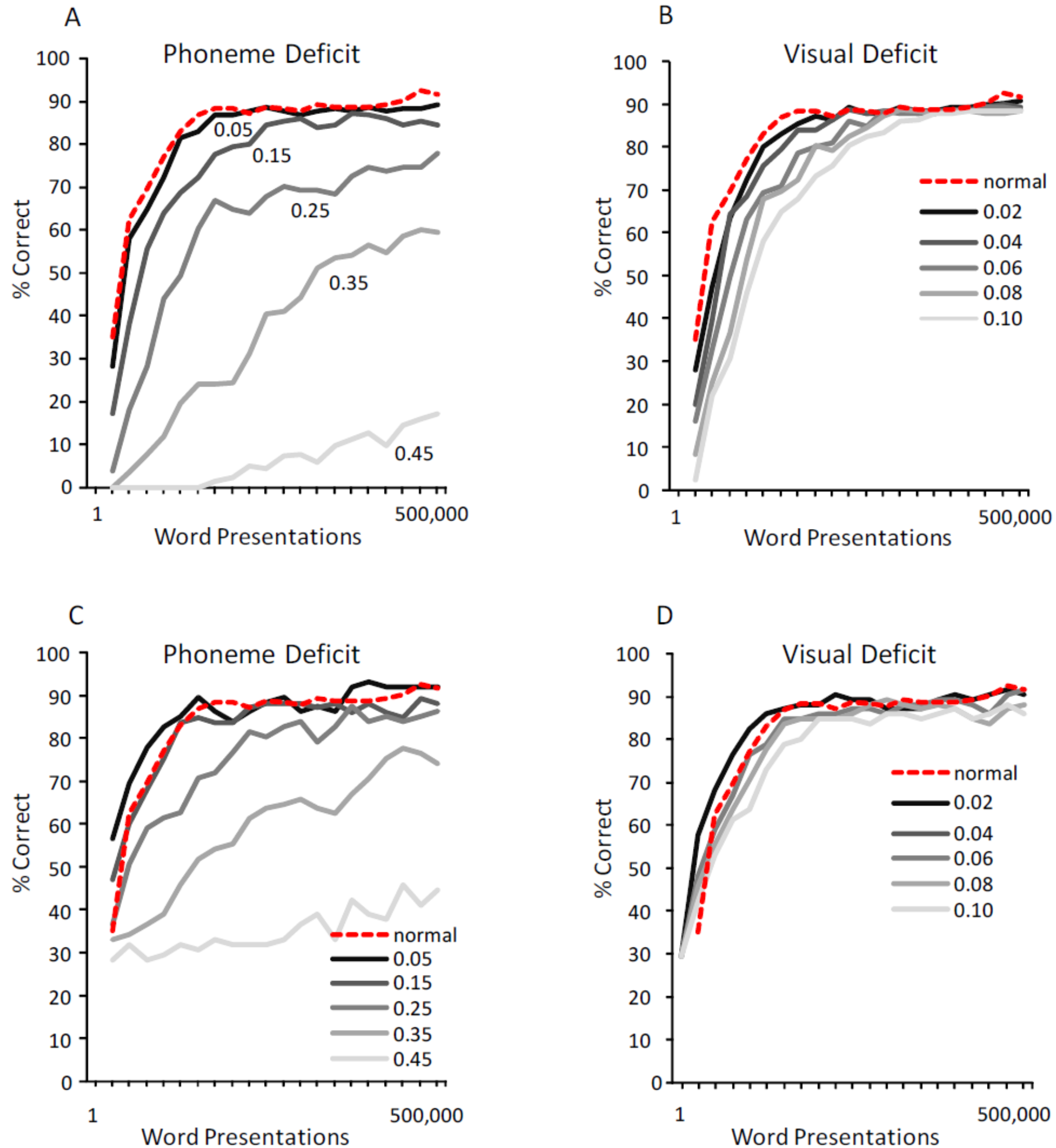
Probability of this happening

Phonological deficit

Phonological deficit: swapping of a phoneme during decoding with a phonetically similar one (eg, /b/ -> /p/)







Effects of phoneme and visual deficits on nonword reading. A and B: simulations with the relatively hard nonwords. C and D: simulations for the relatively easy nonwords. The dotted line represents the unimpaired network. All simulations were run with a word recognition threshold of .15.

Summary

- Dyslexia is a multi-componential syndrome – this is the main source of heterogeneity / individual differences in dyslexic profiles

- “Core deficits” are those that can be identified prior to learning to read and can be causally linked to reading performance
    - currently: phonological deficit and visuo-spatial attention deficit

- Connectionist learning models can be used to investigate the acquisition of cognitive skills in normally developing children as well as atypical patterns displayed by learning disabled children (including individual differences)

- Prospects:
    - individual diagnosis based on core deficits of components of the reading system
    - develop individual rehabilitation programs