Listening difficulties can be caused by deficits in auditory processing, speech processing, cognition and language

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Thanks to my collaborators .....

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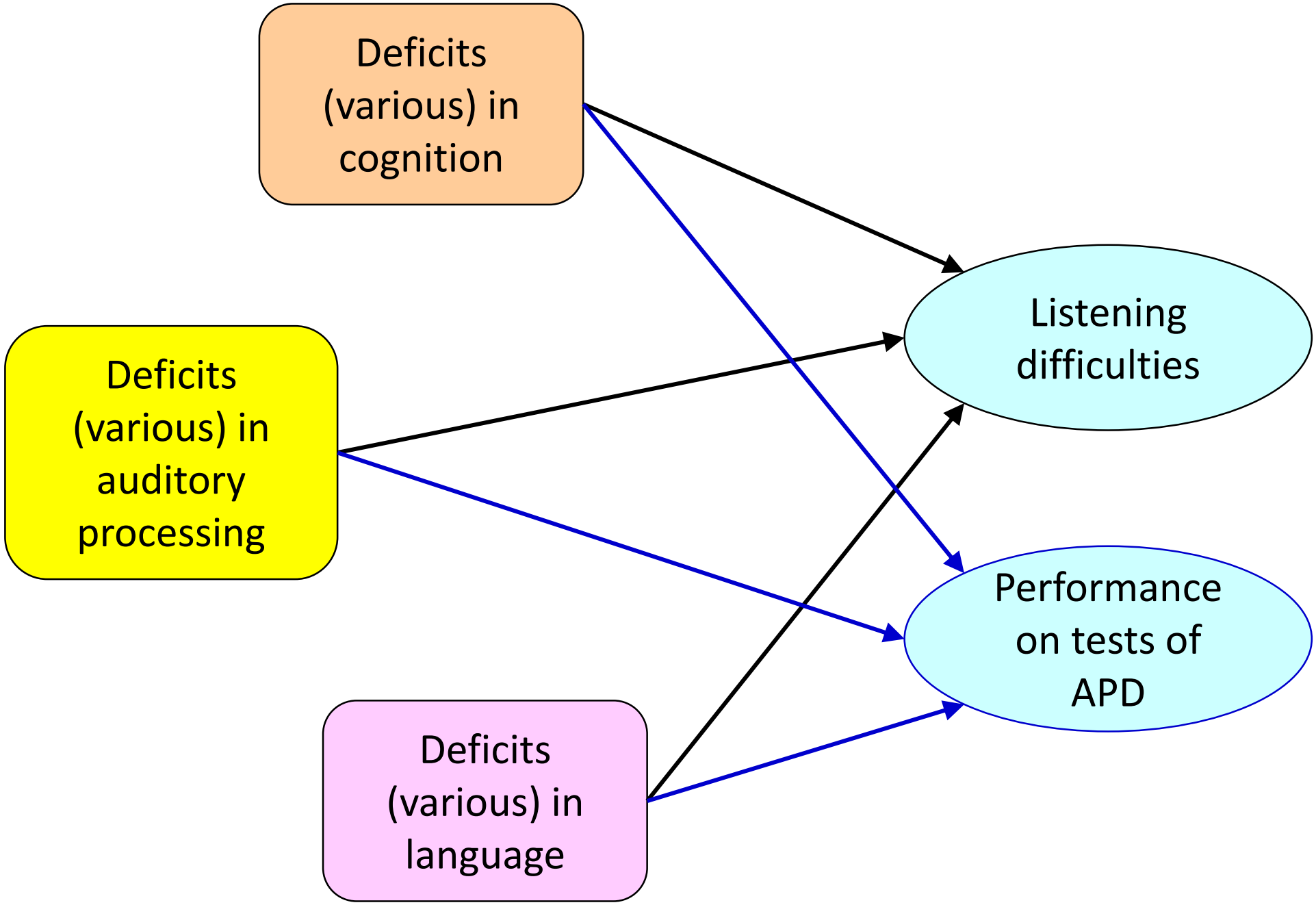
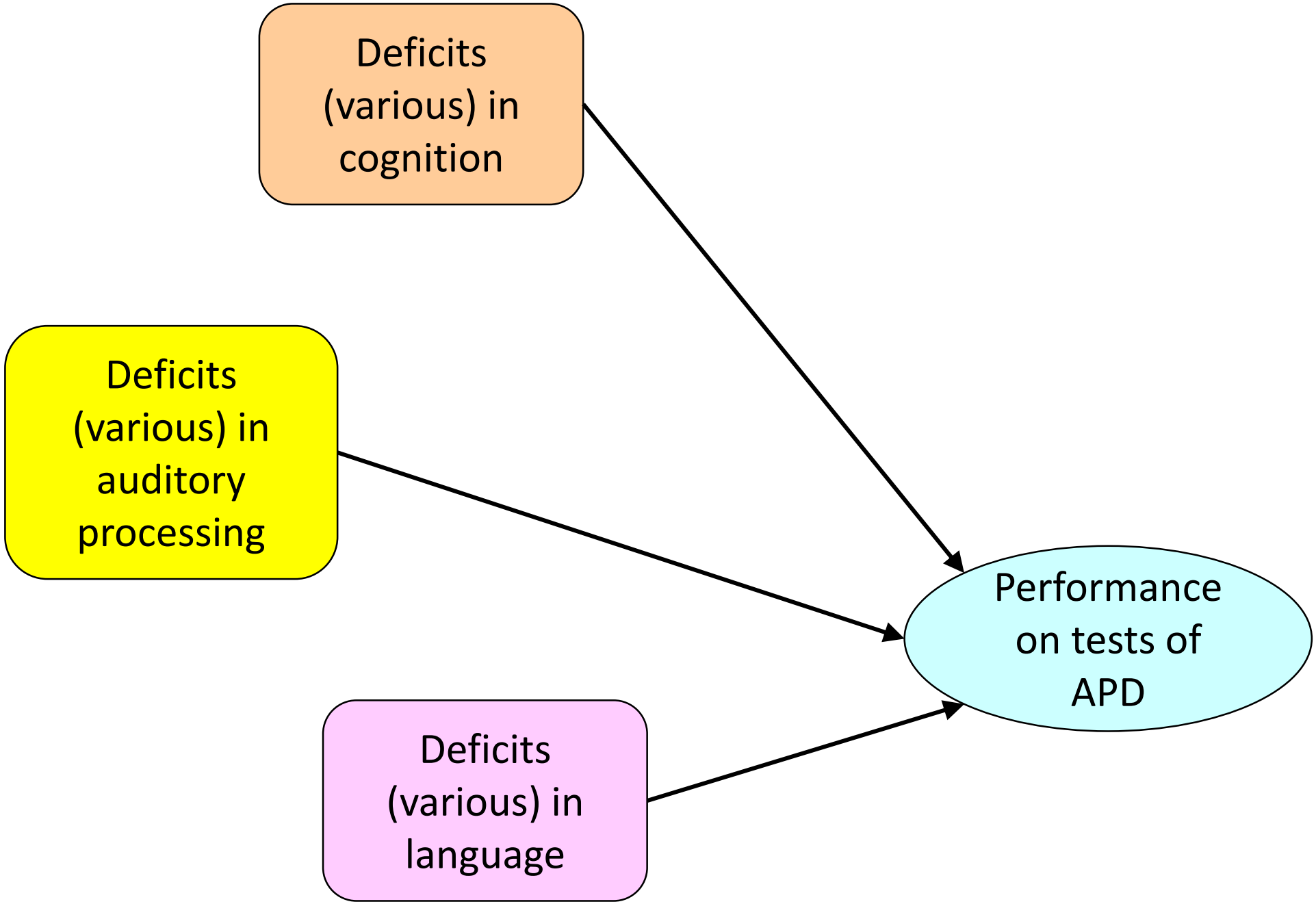
What you might remember

- Listening difficulties have multiple causes, which need to be allowed for, and quantified.
- Diagnosing the type(s) and extent of auditory processing disorder present requires quantitative control of the effects of:
    - Memory,
    - Attention,
    - Intelligence, and
    - Language,

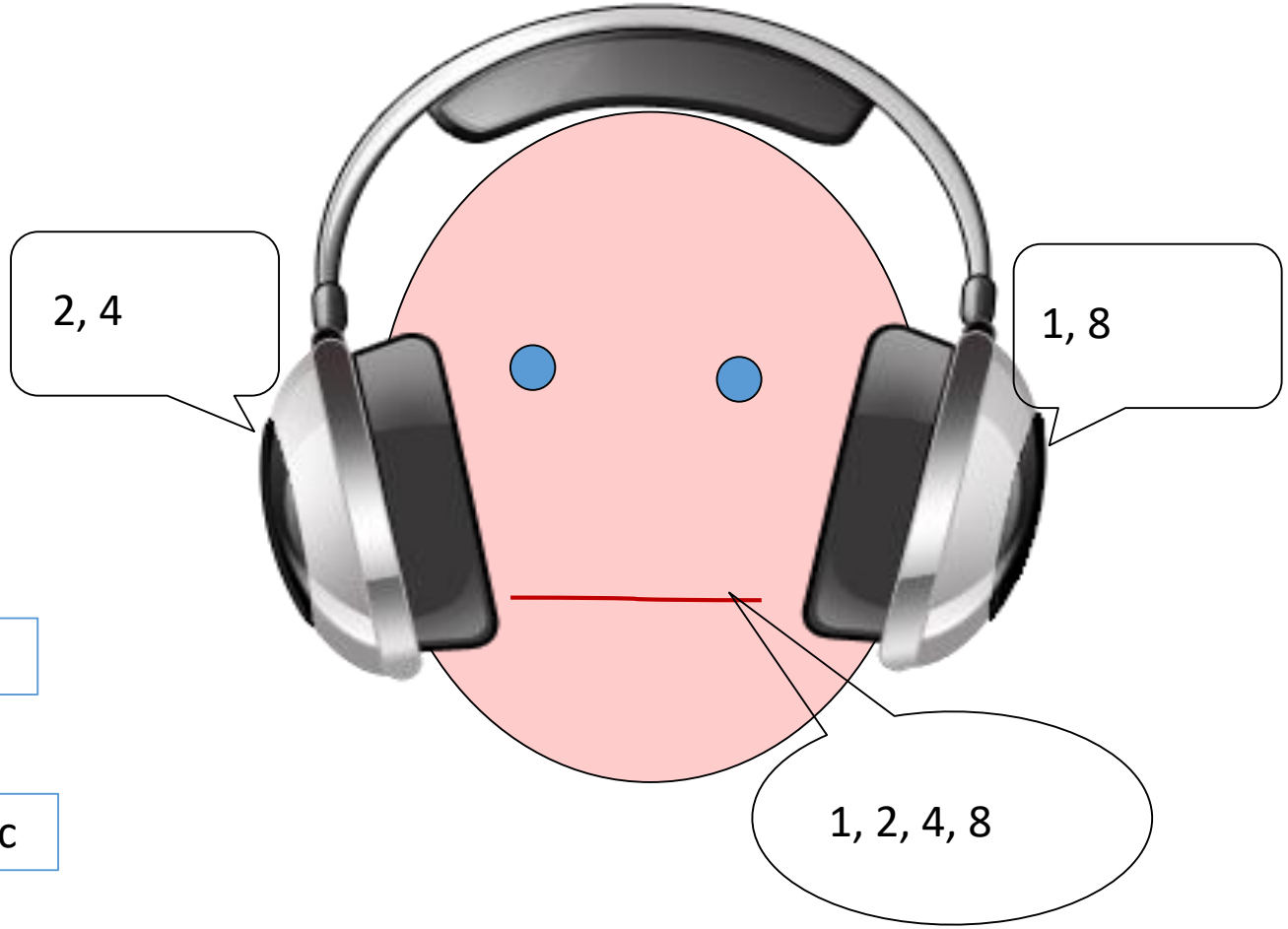

Deficits (various) in cognition
Deficits (various) in auditory processing
Deficits (various) in language
Listening difficulties
Performance on tests of APD


Deficits (various) in cognition
Deficits (various) in auditory processing
Deficits (various) in language
Performance on tests of APD

Example of a test that tests multiple abilities

- Dichotic digits test – Musiek (1983) - 333 citations
- Easy to administer and score
- Often failed by children seeking APD assessment

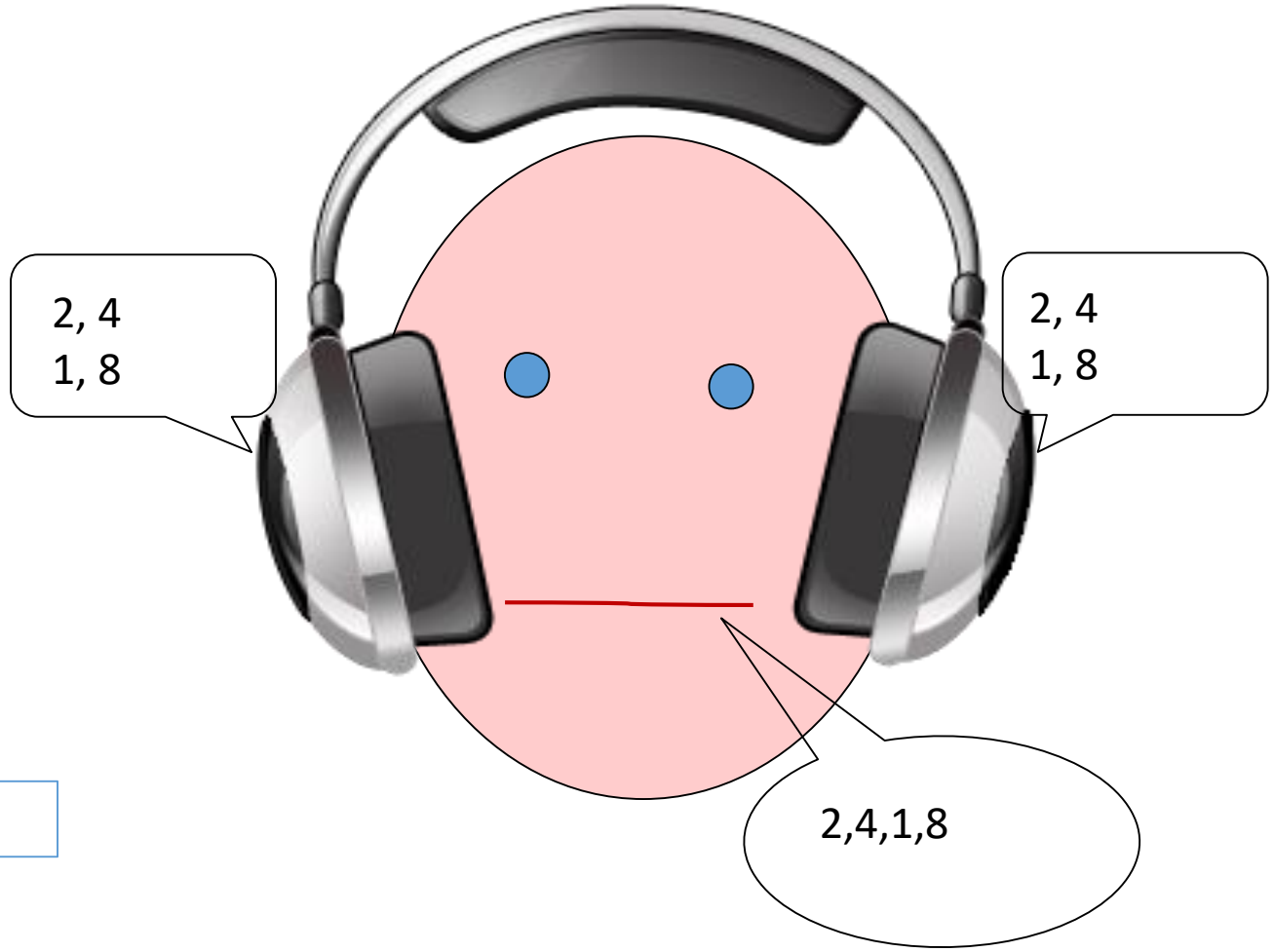
Dichotic Free Recall Paradigm



DDT file

DDdT - dichotic

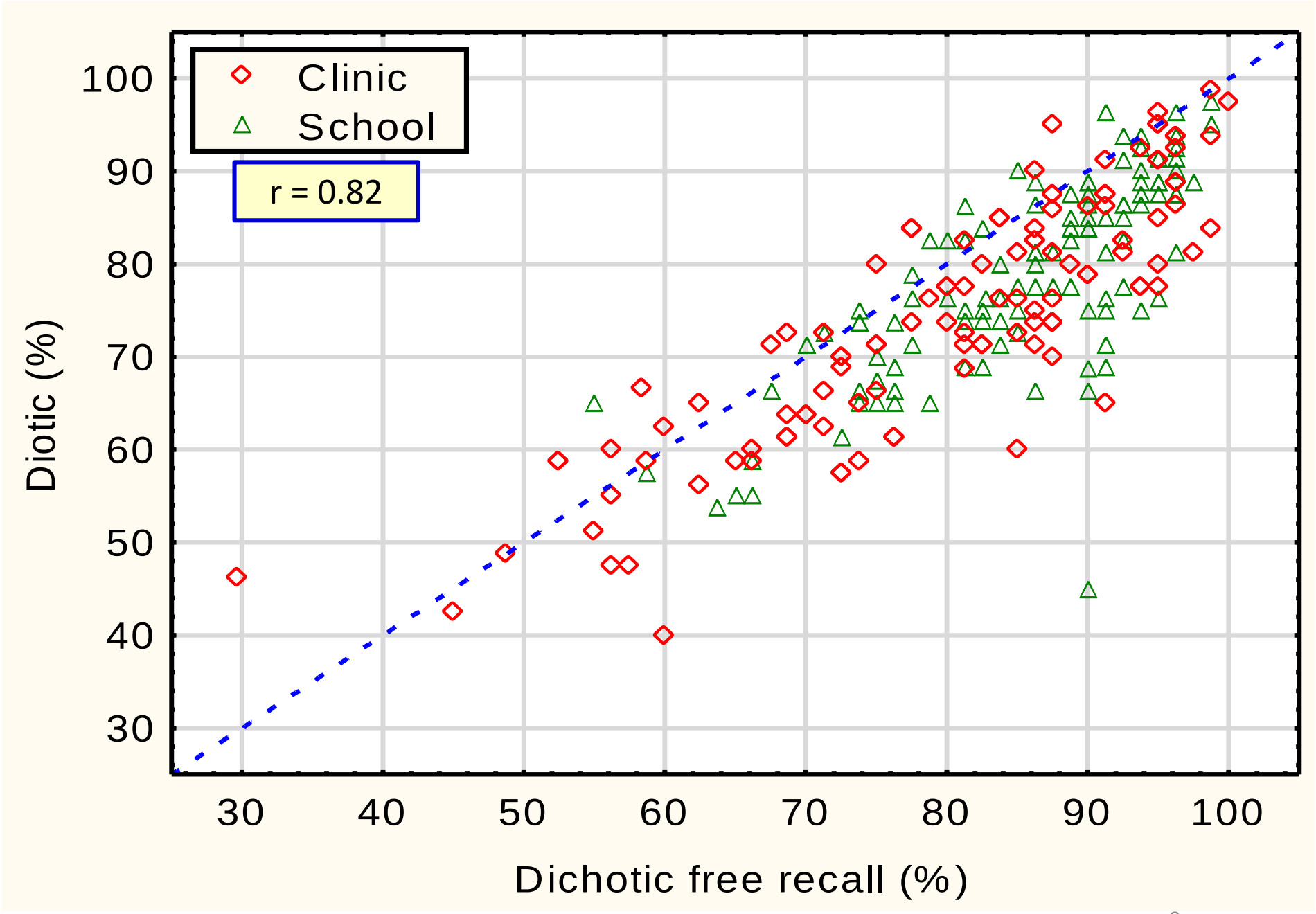
Diotic Paradigm



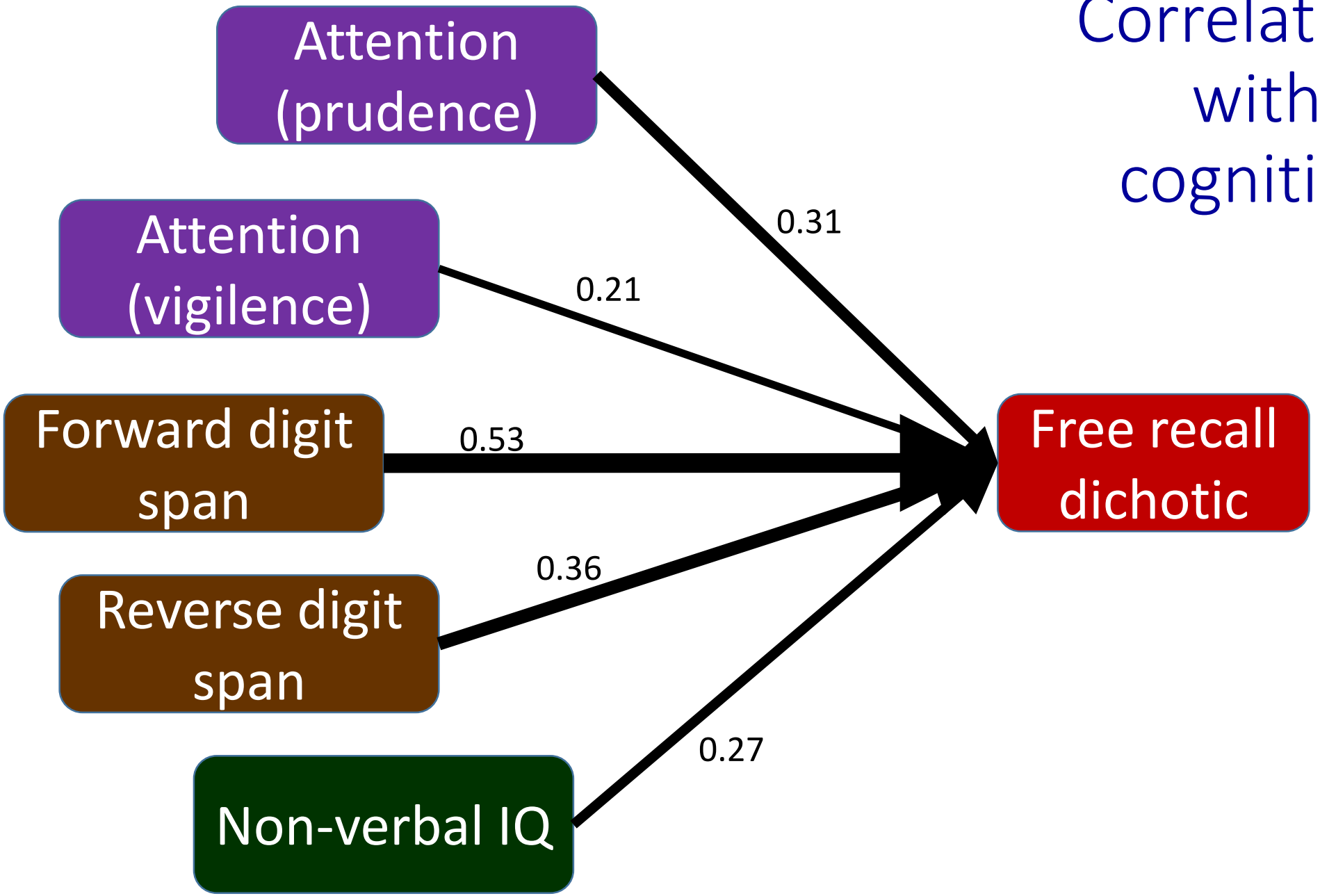
Dichotic
Digits
difference
Test

DDdT - diotic

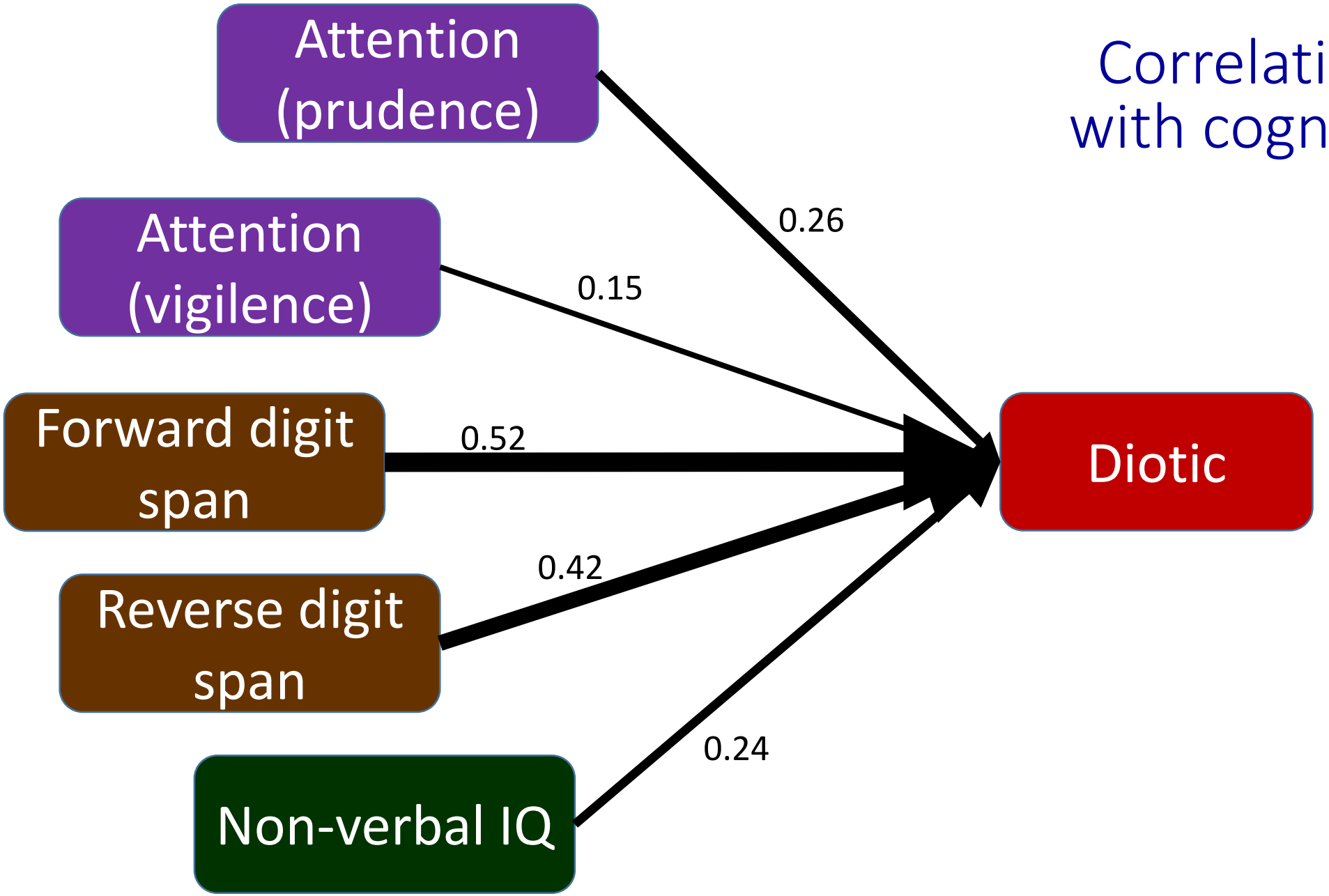
Dichotic versus diotic (%)



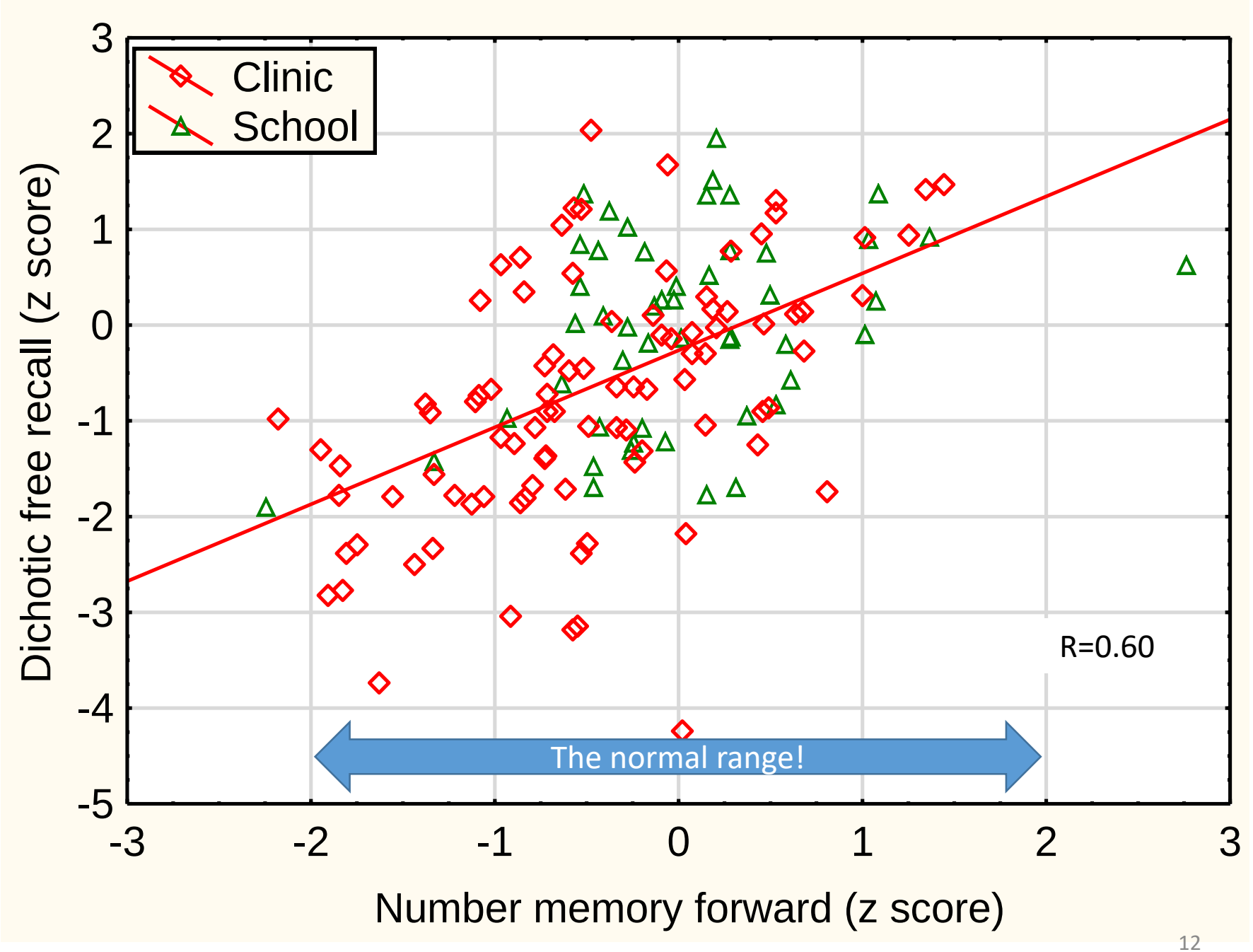
Correlations with cognition



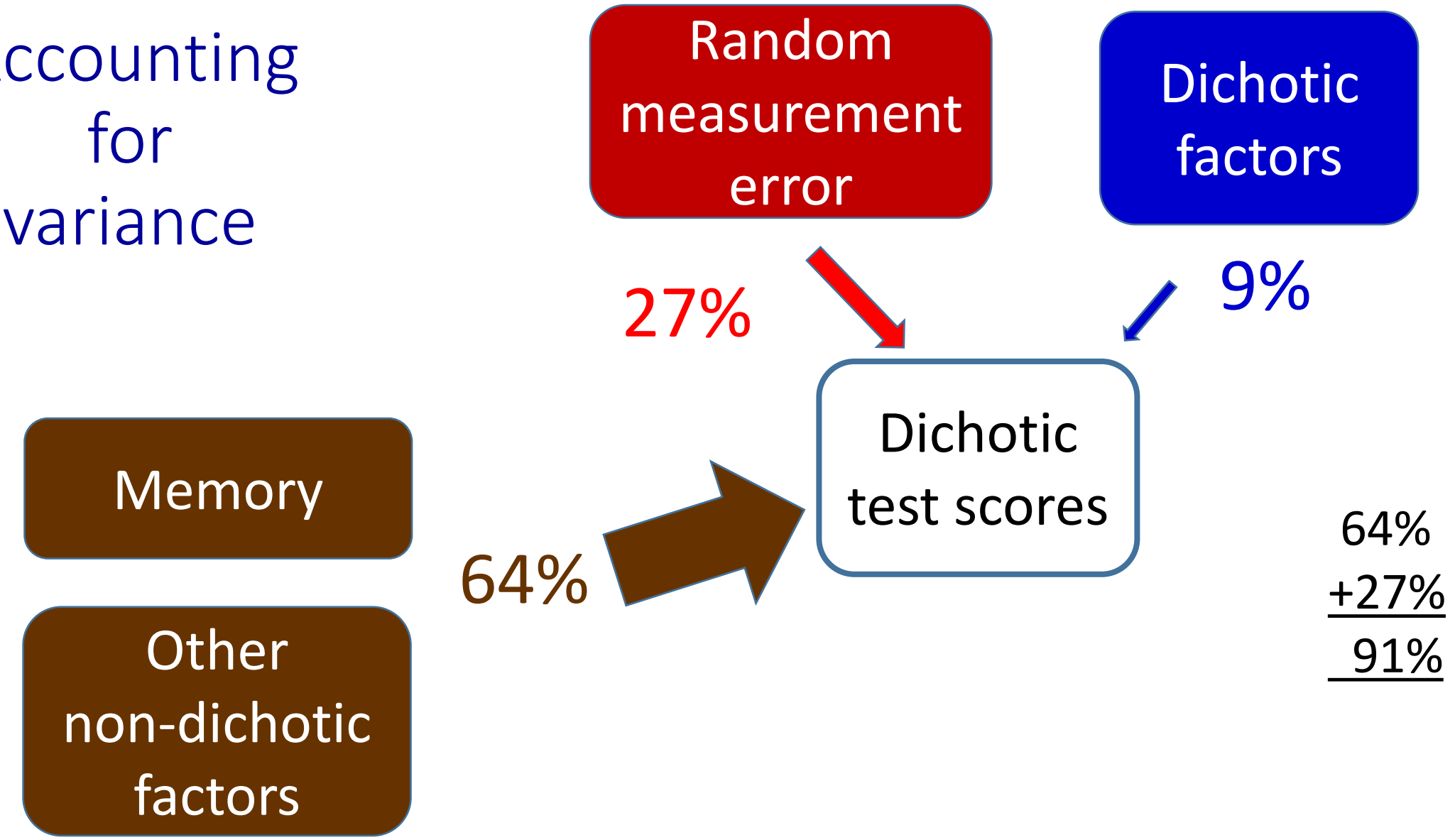
Correlations with cognition



Dichotic scores and memory



Accounting for variance



64%
+27%
91%

.. and then there's attention!

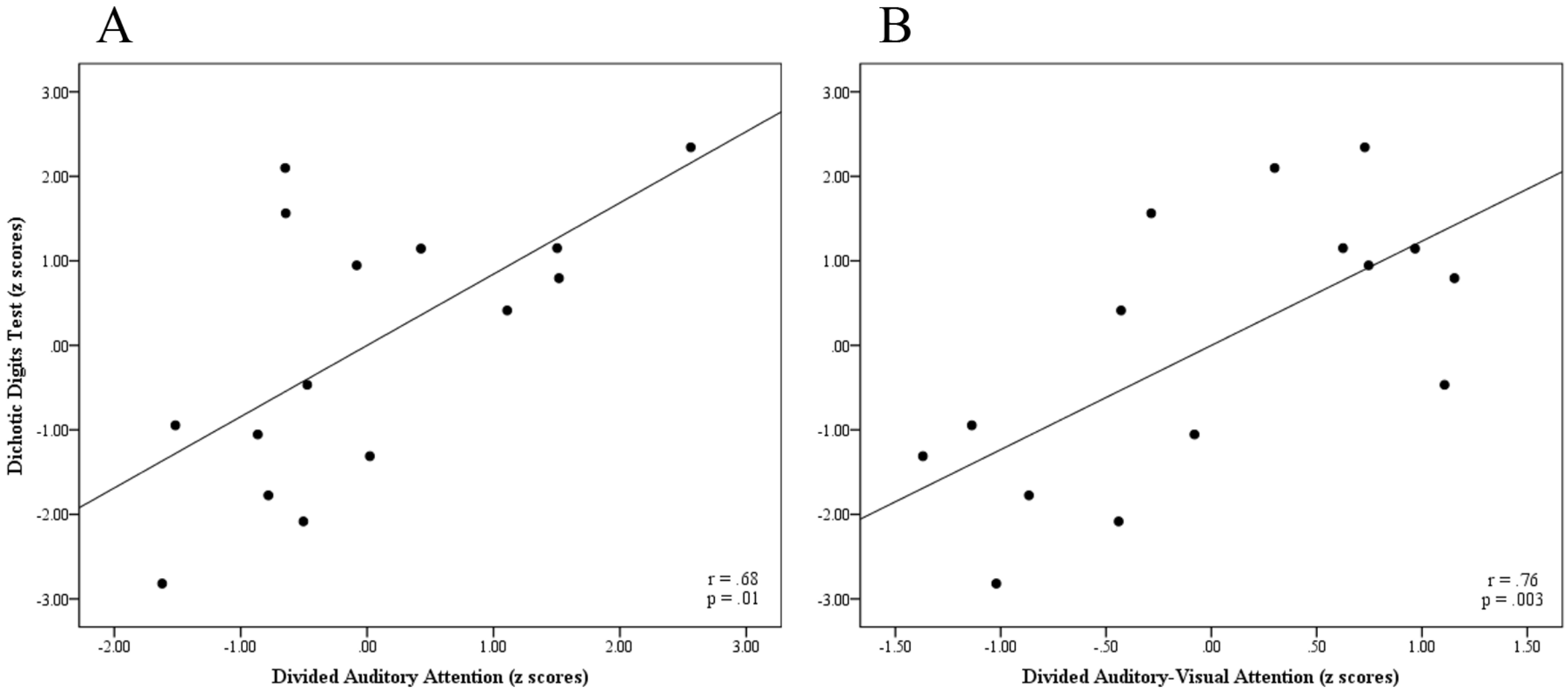
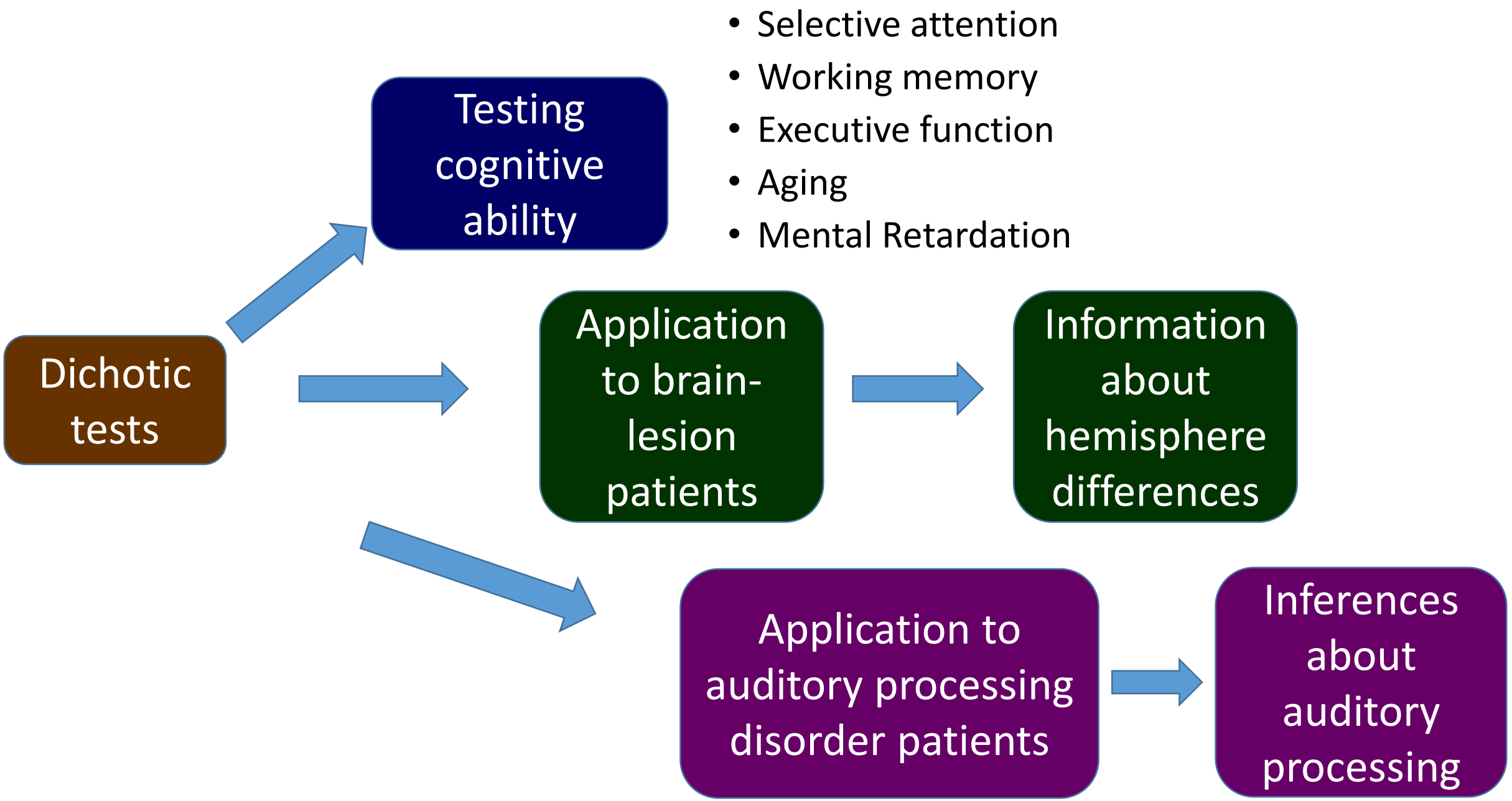
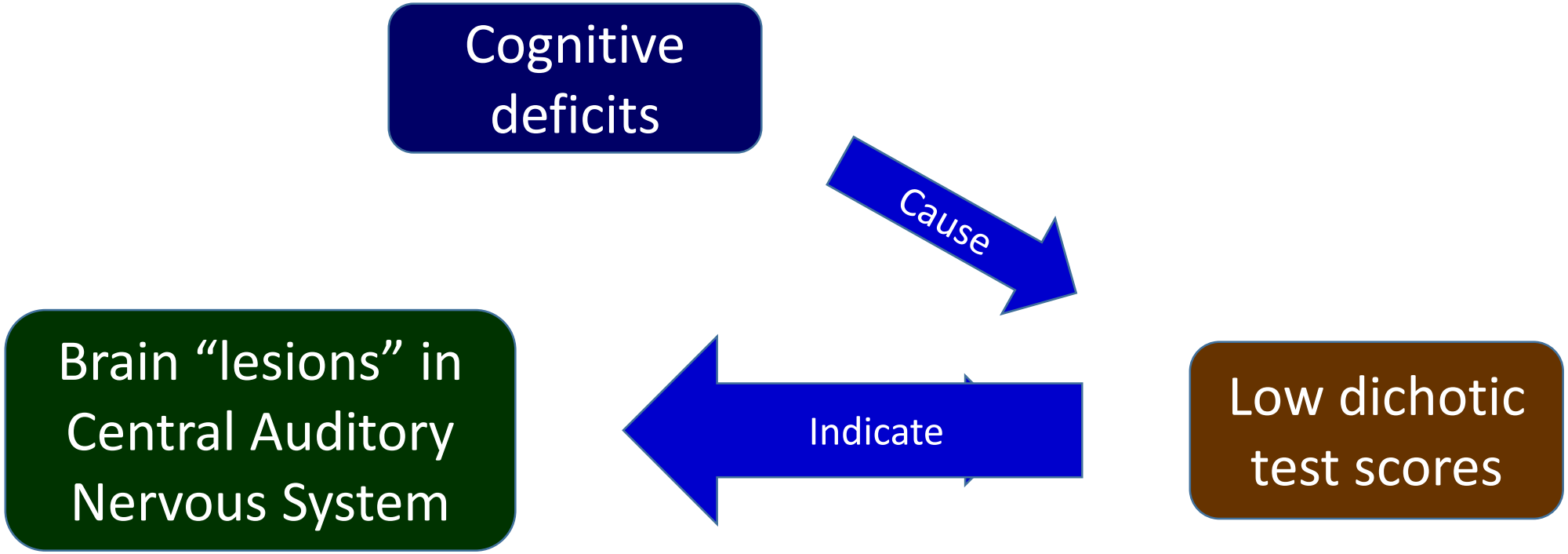


Fig 1 from Stavrinos (2018)


Dichotic tests
Testing cognitive ability
Selective attention
Working memory
Executive function
Aging
Mental Retardation
Application to brain-lesion patients
Information about hemisphere differences
Application to auditory processing disorder patients
Inferences about auditory processing


Cognitive deficits
Cause
Brain “lesions” in Central Auditory Nervous System
Indicate
Low dichotic test scores

What ***not*** to do in "sensitising" a test

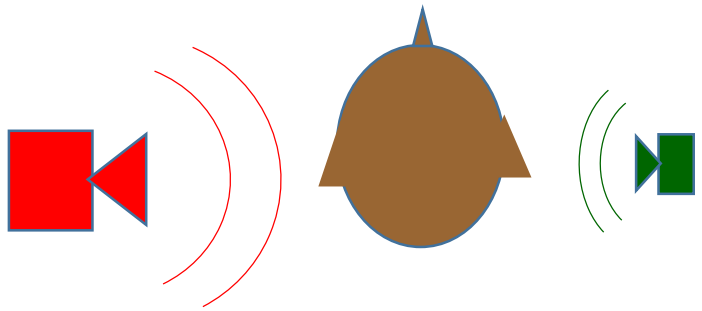
Problem: A test gives ceiling performance for too many people

Usual solution: Make the test harder by demanding additional skills:

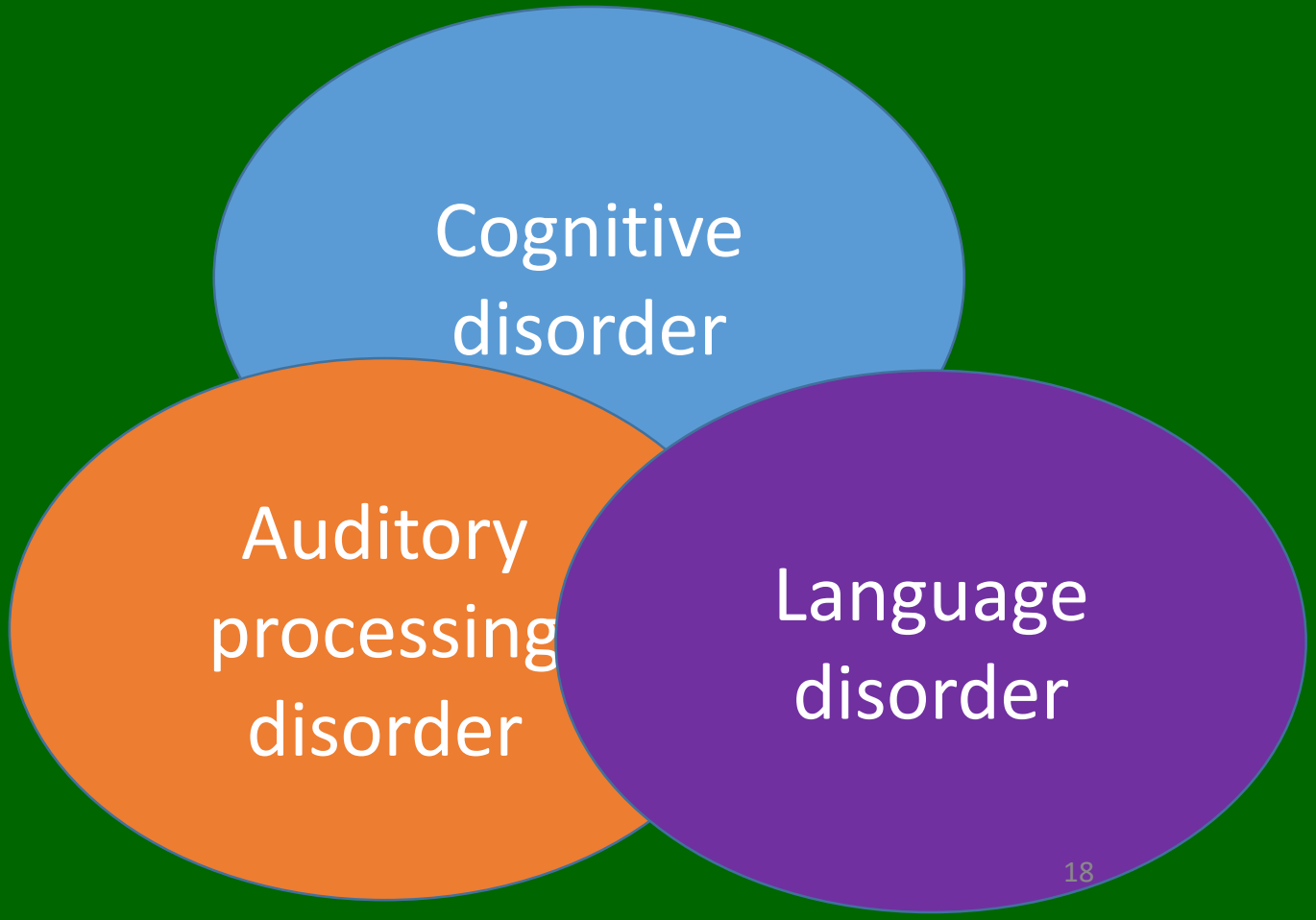
- dichotic digits – make it two pairs, or three pairs → memory ↑
- speech tests – low-pass filter it → vocabulary ↑, phonetic awareness ↑

Result: Scores decrease below ceiling, but cause become uncertain

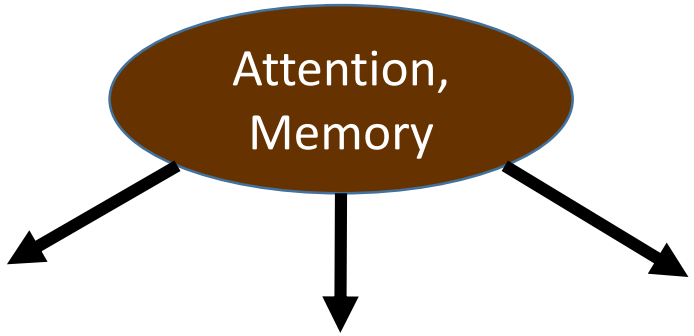
An alternative: Adaptively change inter-aural level

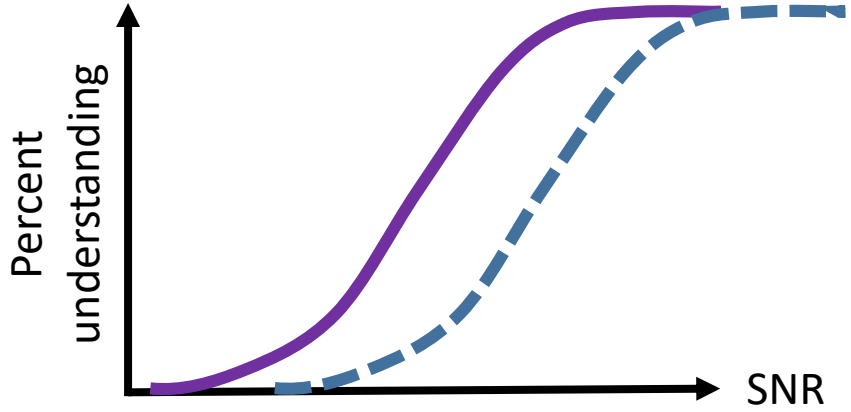


Disentangling the disorders



Speech understanding – what could go wrong?





Auditory (speech) input

Auditory processing

- Auditory filtering
- Envelope analysis
- Temporal fine structure
- Spatial analysis

Complex signals analysed

Speech processing

- Phonemic awareness
- Comparison to stored templates (phonemes, syllables or words)
- Categorical perception

Phonemes, syllables or words identified

Language processing

- Morphology knowledge
- Syntactic knowledge
- Semantic knowledge
- Prosody knowledge
- (World knowledge)

Under-standing

Degrade the input

Noise

Spatial cues

Rate

Reverb

Phonemic and lexical neighbourhood density

These enable auditory closure

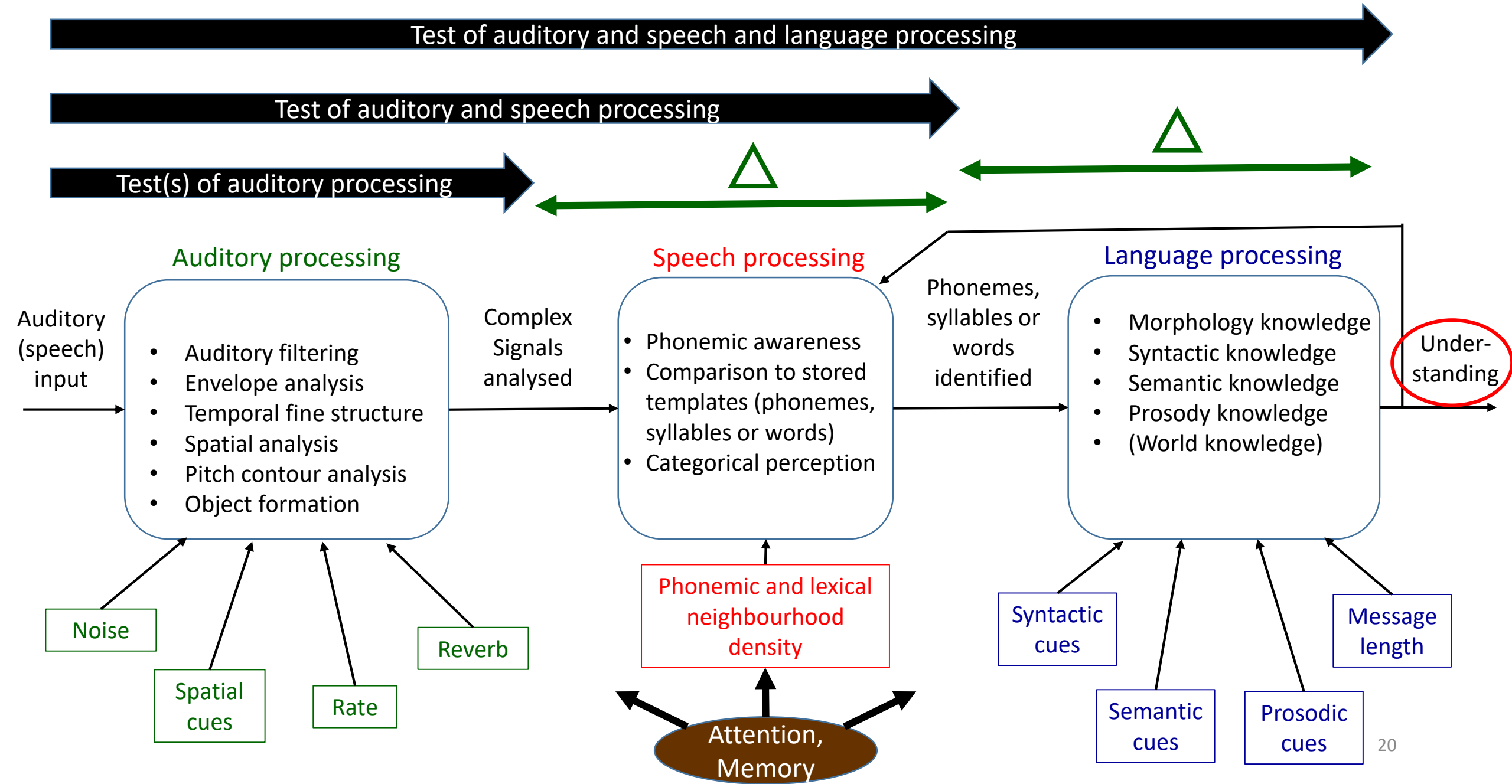
Syntactic cues

Semantic cues

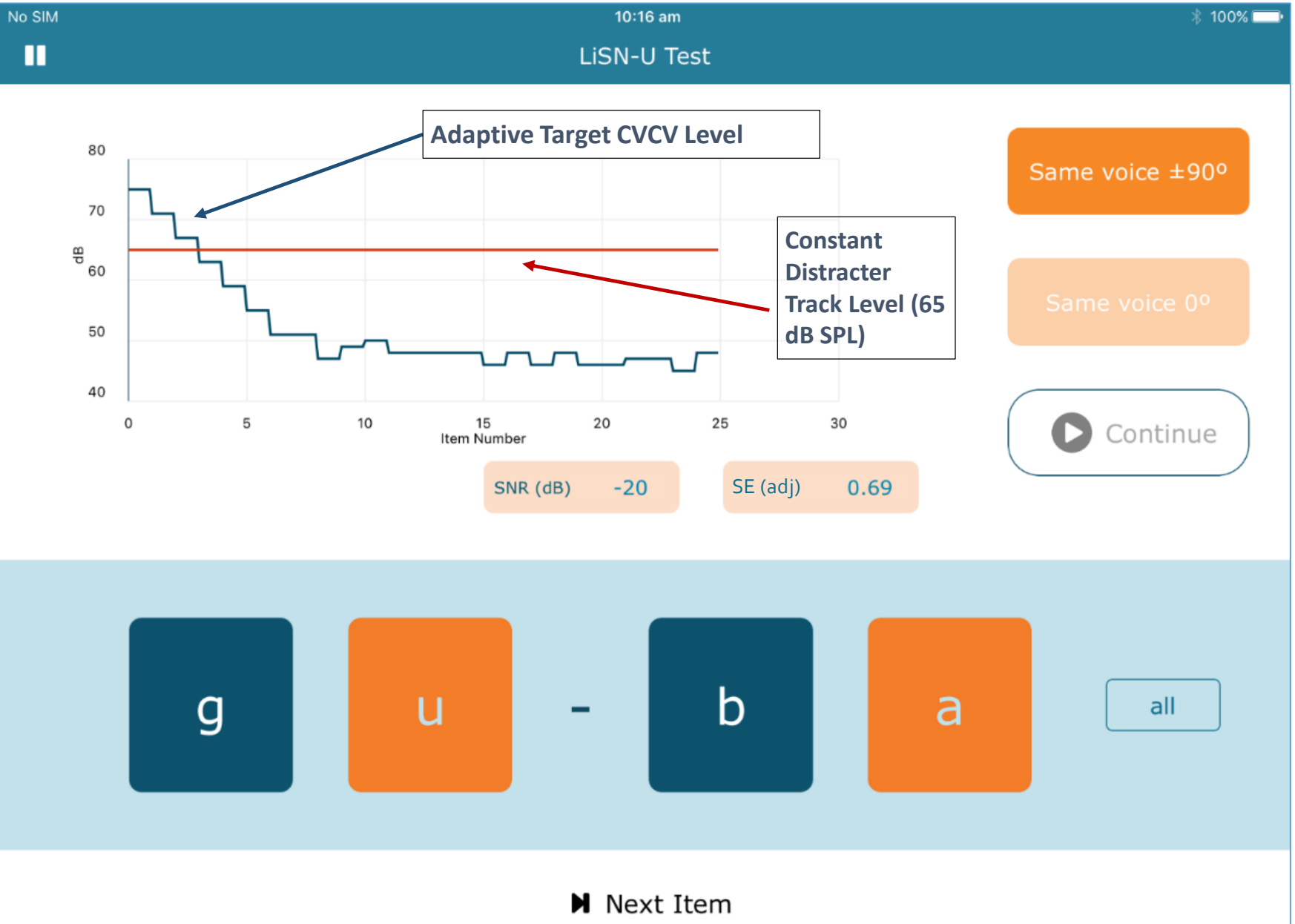
Prosodic cues

Message length

Speech recognition – where is the problem?



Listening in Spatialized Noise – Universal (LiSN-U) Test



Adaptive Procedure:

0 correct = +3 dB

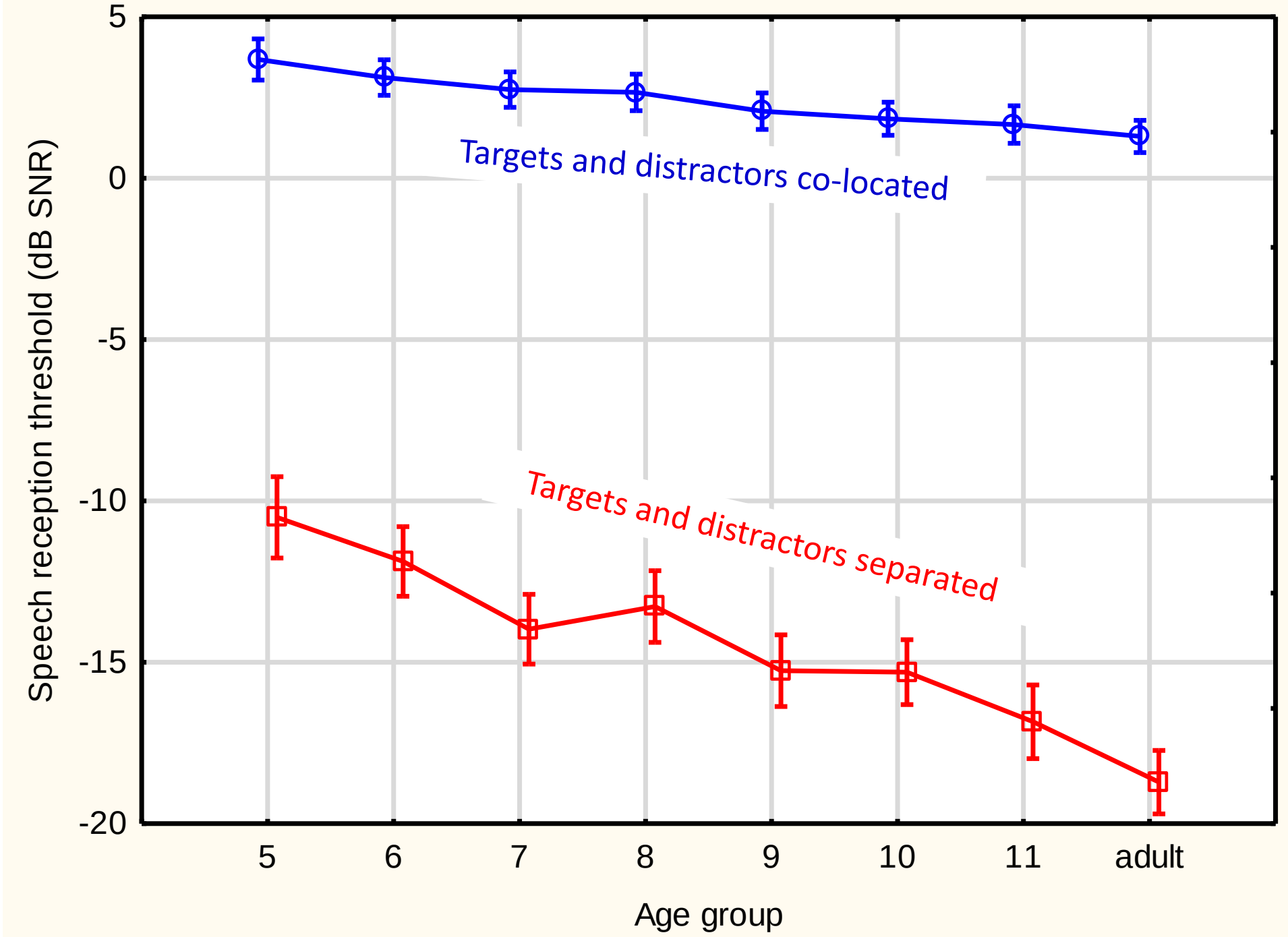
1 correct = +2 dB

2 correct = +1 dB

3 correct = no change

4 correct = -2 dB

LiSN-U performance versus age



So,
top-level testing
to find the strength of deficit in each area,
but ….

How do we find the specific deficit(s)?

How do we find the specific deficit(s) causing listening difficulties?

1. **Differential testing**
   - DDdT (Dichotic digits difference test, Cameron et al, 2016)
   - SPIN (Speech in noise test; Kalikow, Stevens & Elliott, 1977)
   - LiSN-S (Listening in spatialized noise sentences test, Cameron & Dillon, 2007)
2. **Allow for other abilities** that affect test scores (just like we allow for age)
3. **Use tests that rely only minimally on other abilities**

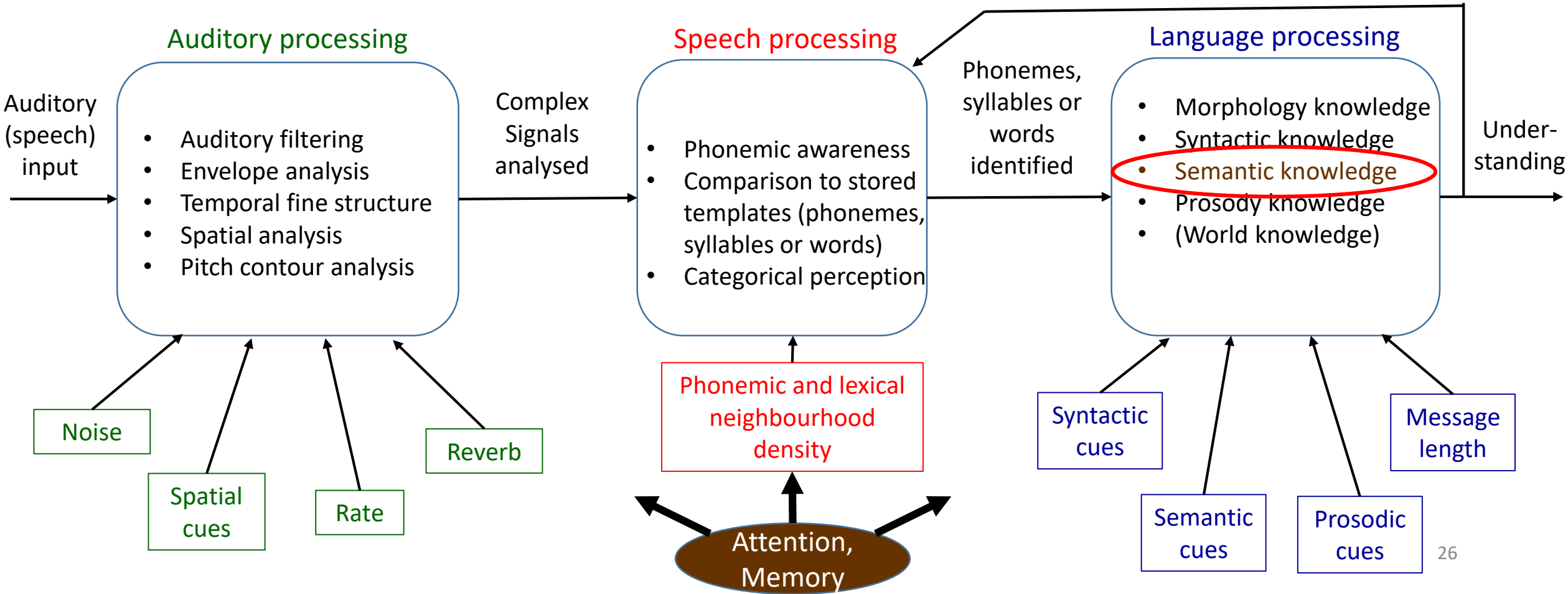
Differential testing (e.g. SPIN – Kalikow, Stevens & Elliot, 1977)

Sheldon, Pichora-Fuller & Schneider (2008)

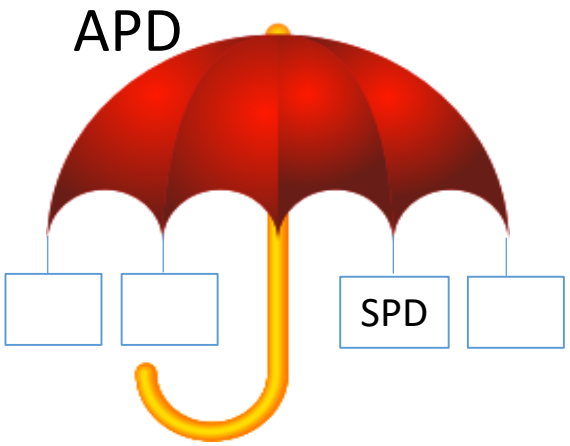
Test of auditory and speech and language processing (with semantic cues) → SRT_1

Test of auditory and speech and language processing (with no semantic cues) → SRT_2

$\Delta SRT = SRT_2 - SRT_1$



Diagnosing spatial processing disorder with the Listening in Spatialized Noise - Sentences (LiSN-S) test

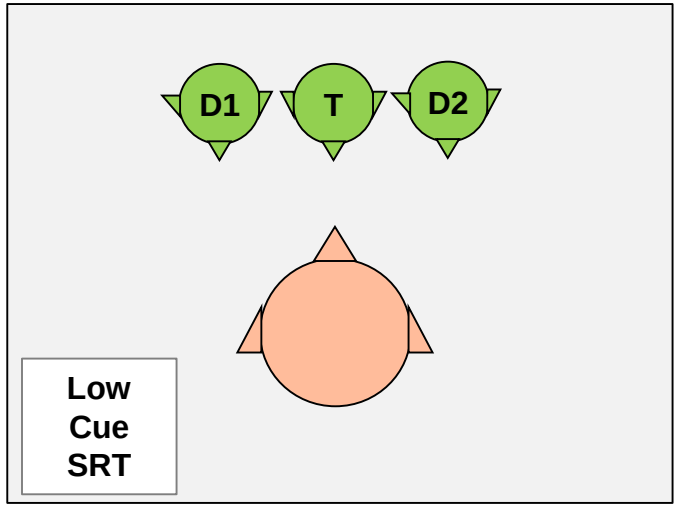


Disclosure

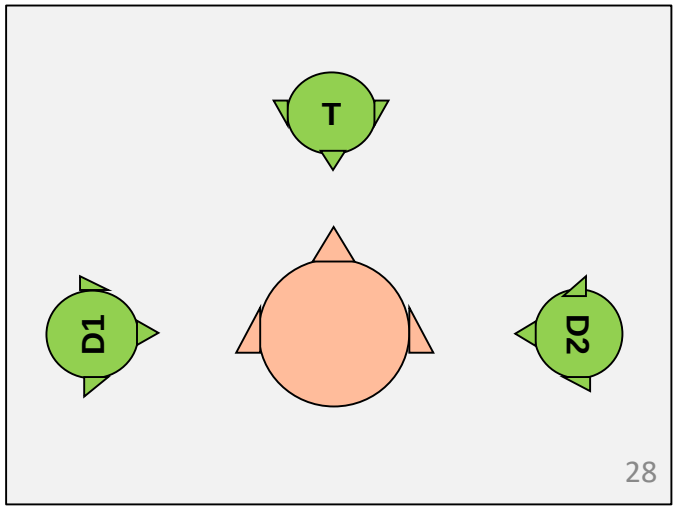
Licensed to Phonak

Listening in Spatialized Noise – Sentences test: To diagnose Spatial Processing Disorder

Same Direction



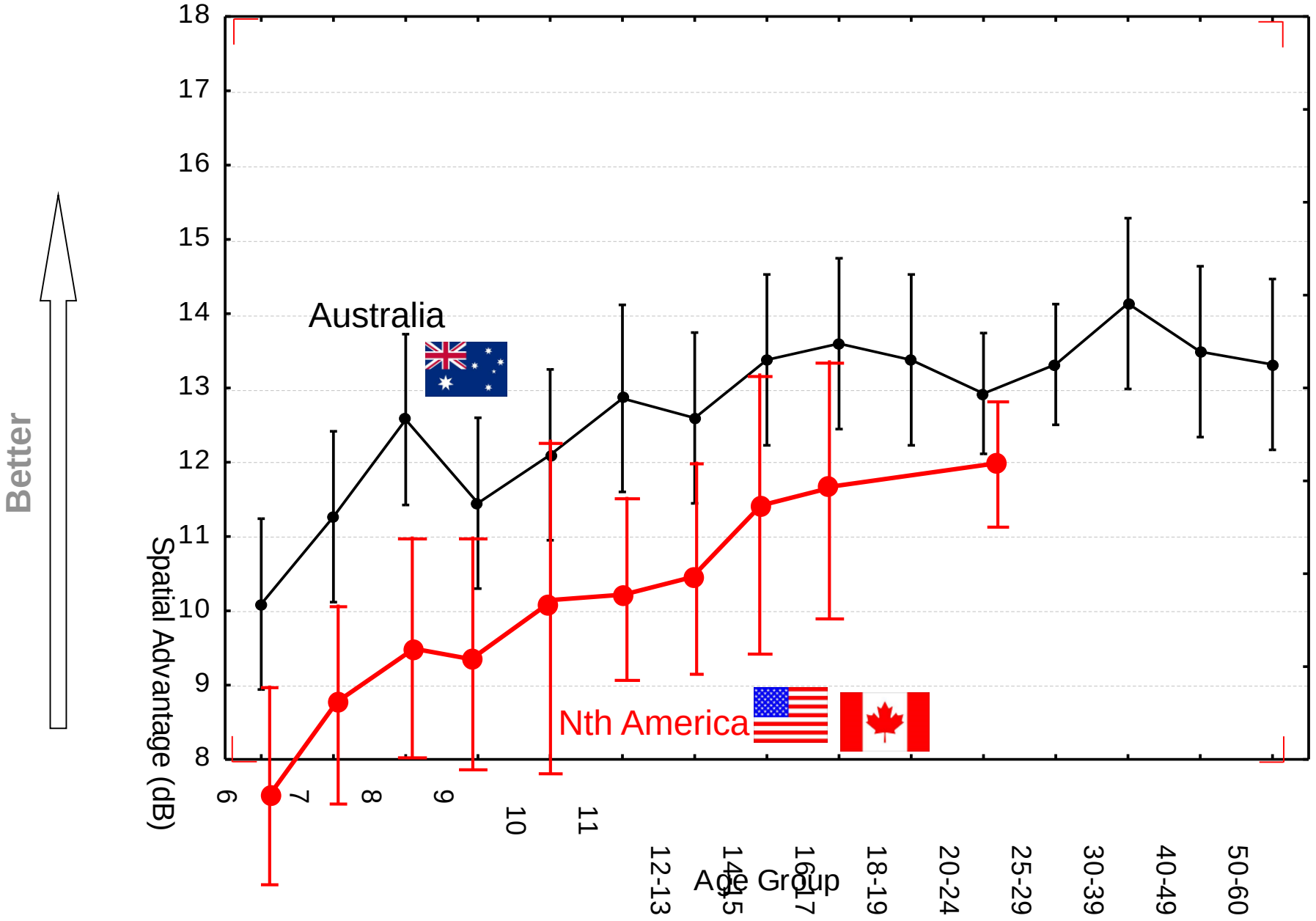
Different Directions



Spatial Advantage

LiSN-S test

Spatial Advantage (≡ Spatial Release from Masking)



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3. Use tests that rely only minimally on other abilities

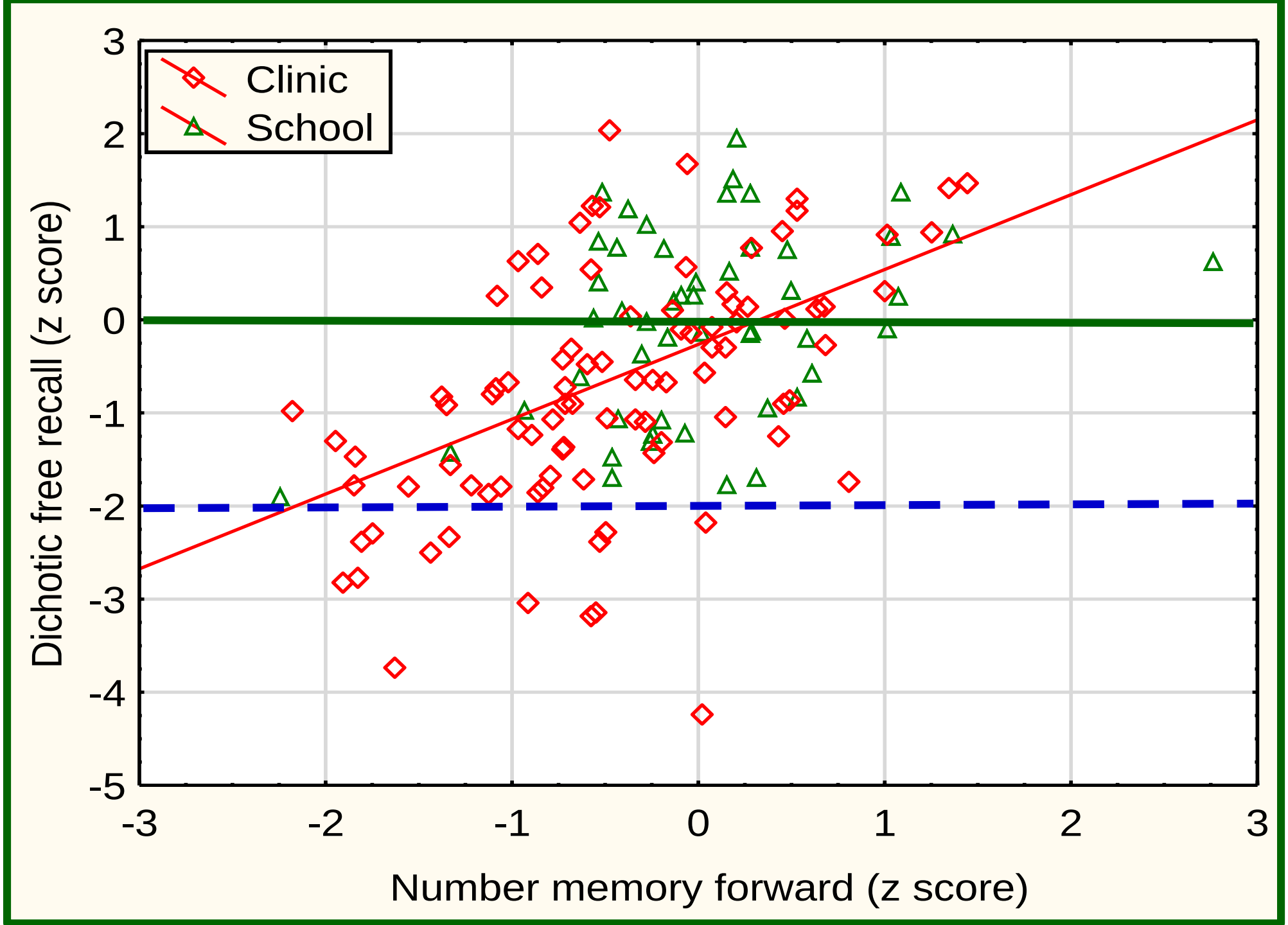
Allowing for related abilities

APD test z-score = AP ability + c.(memory) + d.(attention)

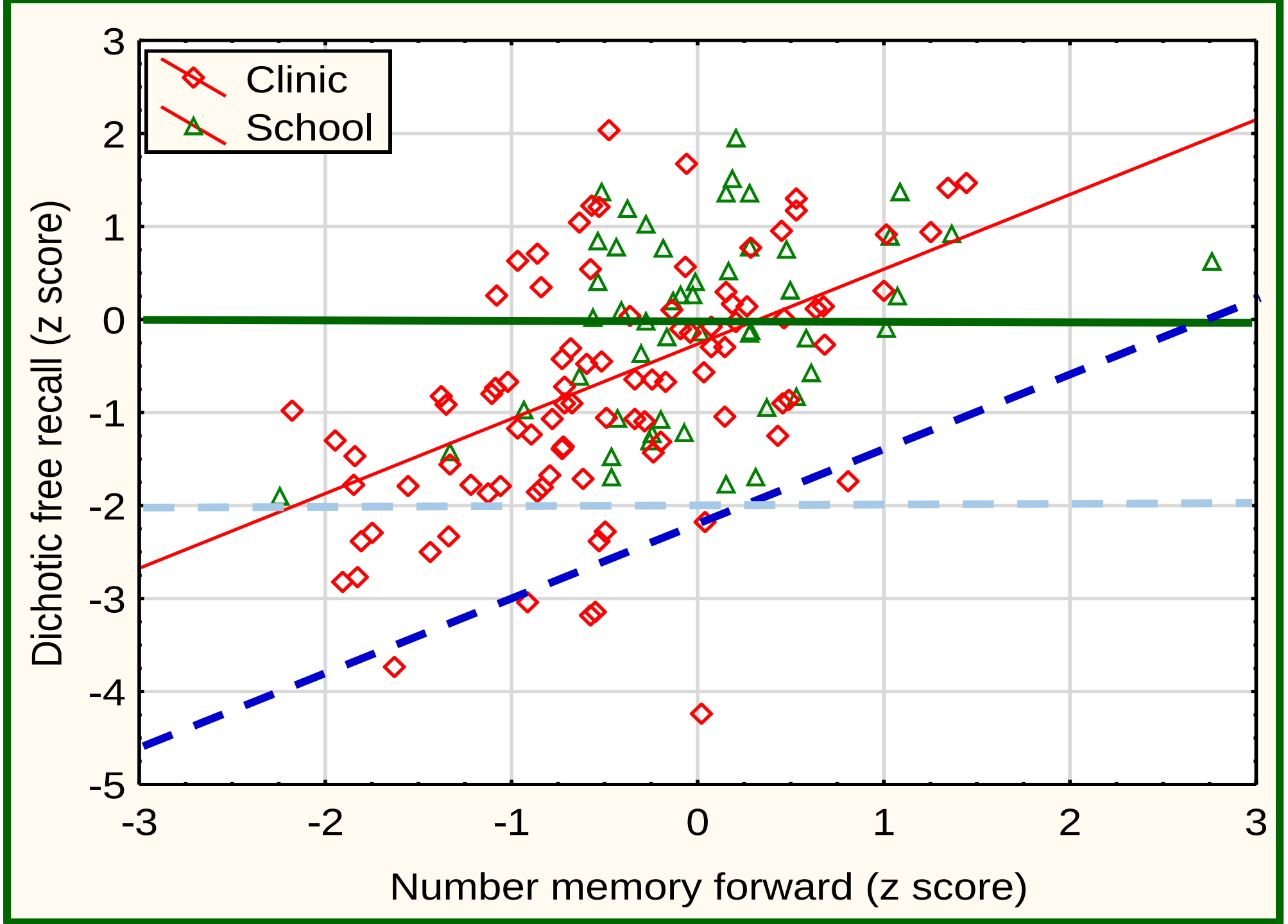
Therefore:

$\widehat{\text{AP ability}}$ = APD test z-score – c.(memory) – d.(attention)

Dichotic scores and memory



Dichotic scores and memory



But how do we allow for attention?

Sustained attention?

Divided attention?

Executive attention?

Switching attention?

.... and is it:

Auditory attention

Visual attention

How motivating is the attention task?

The attention that matters in diagnosing APD is …..

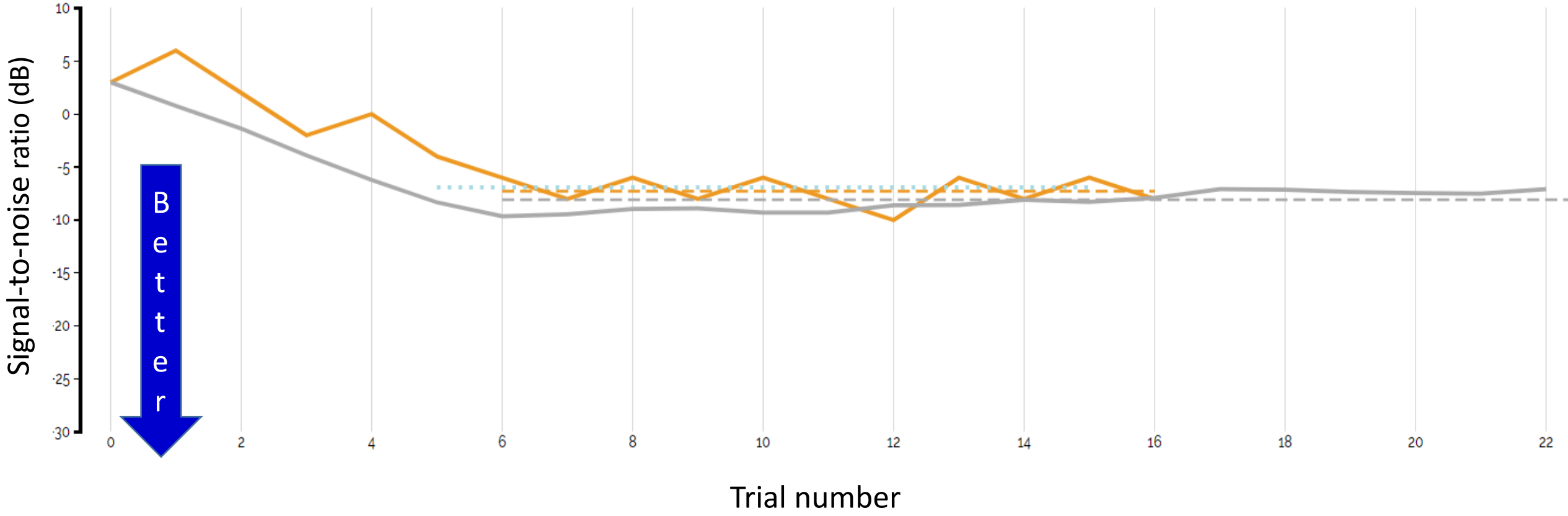
Allowing for attention

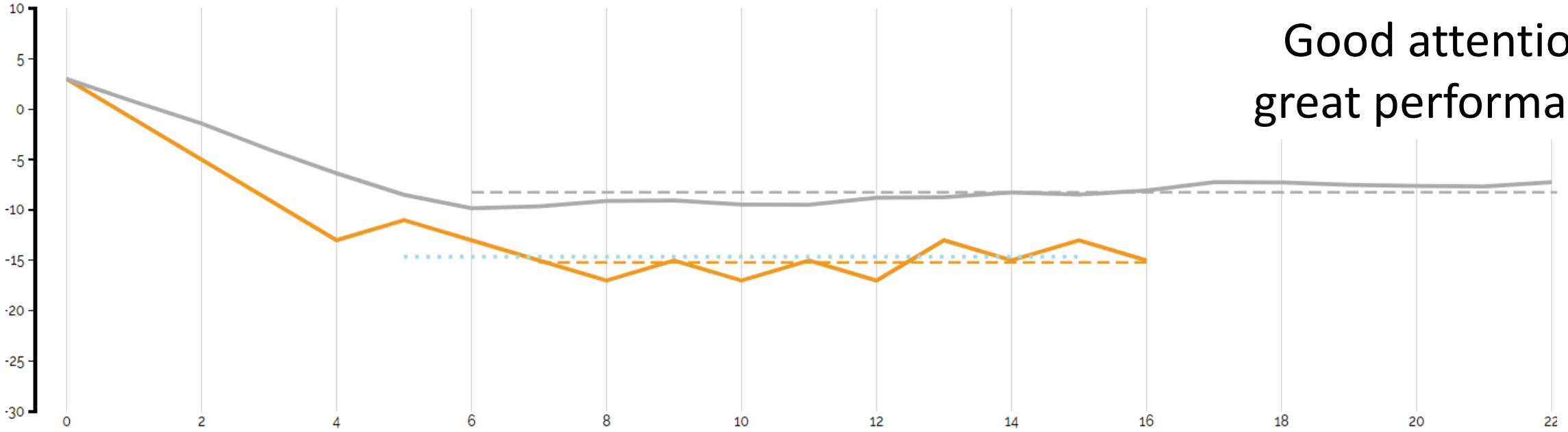
Sound Scouts™
Hear for your future.

Sound Scouts game/tests

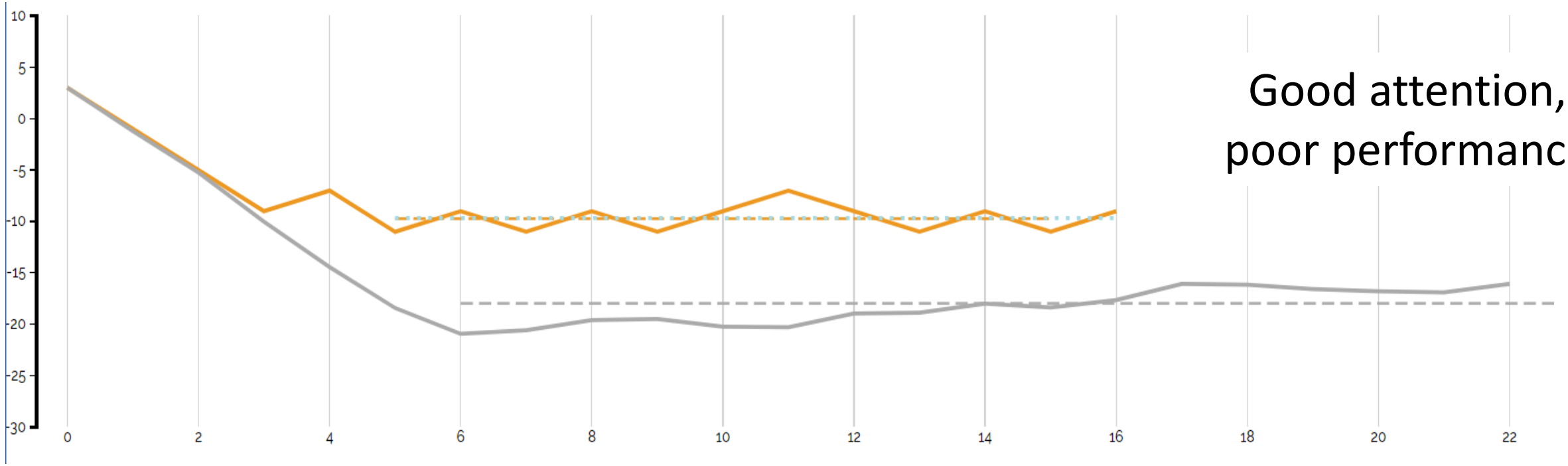
- Speech in quiet
- Speech in noise
- Tone in noise

Adaptive track with good attention and average speech in noise ability



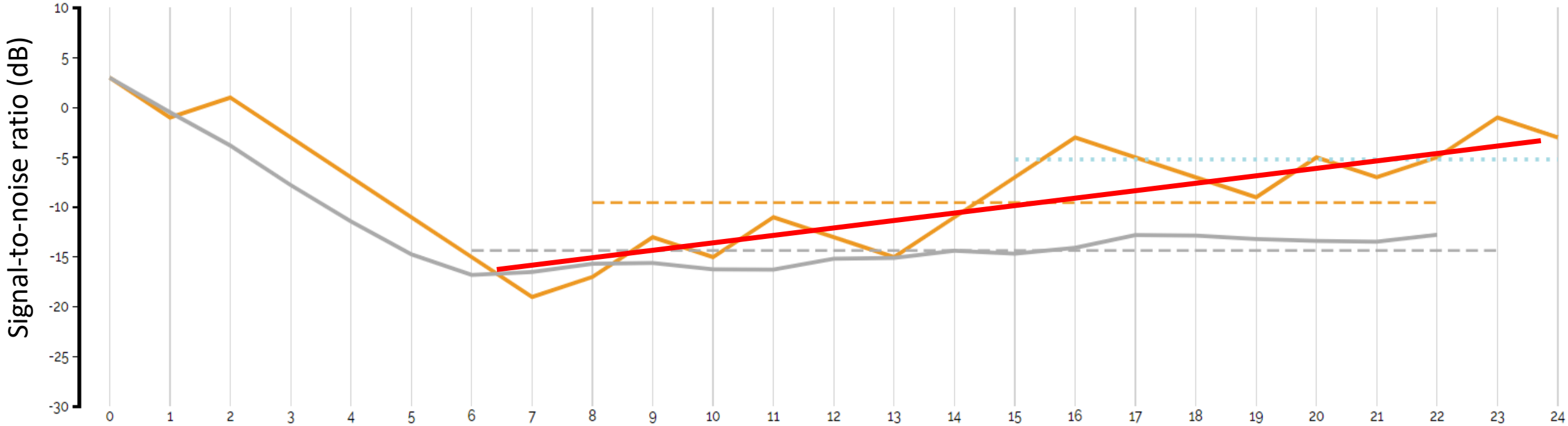


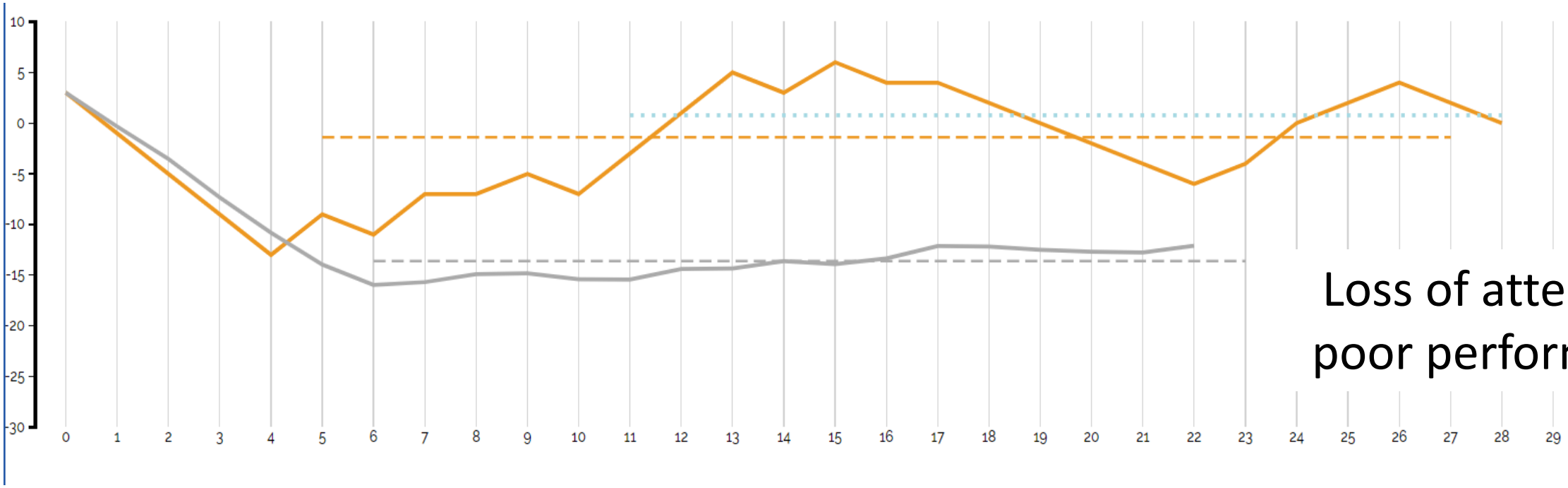
Good attention,
great performance



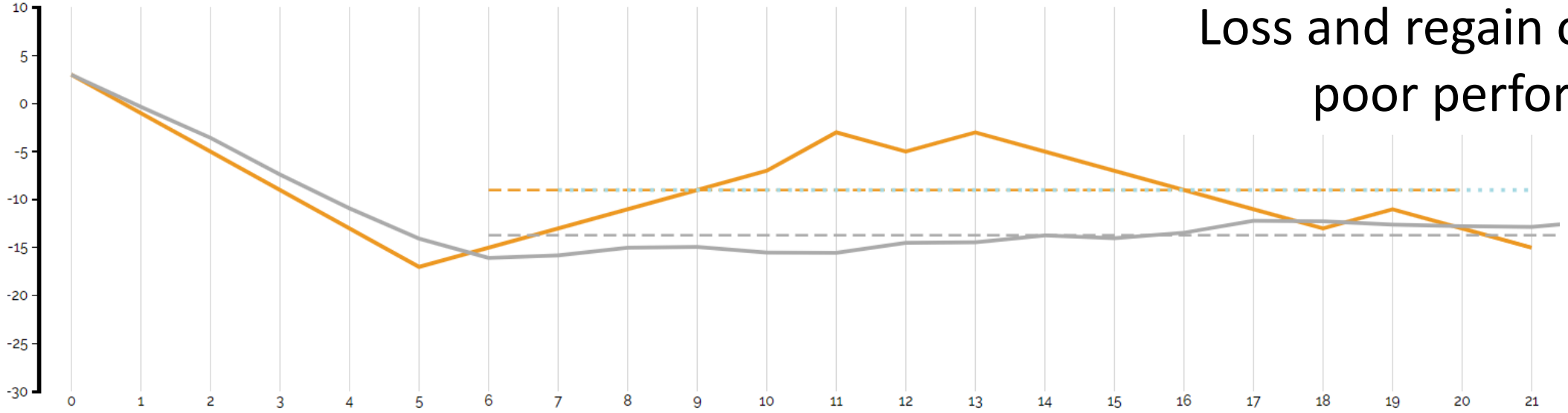
Good attention,
poor performance

Adaptive track with poor attention

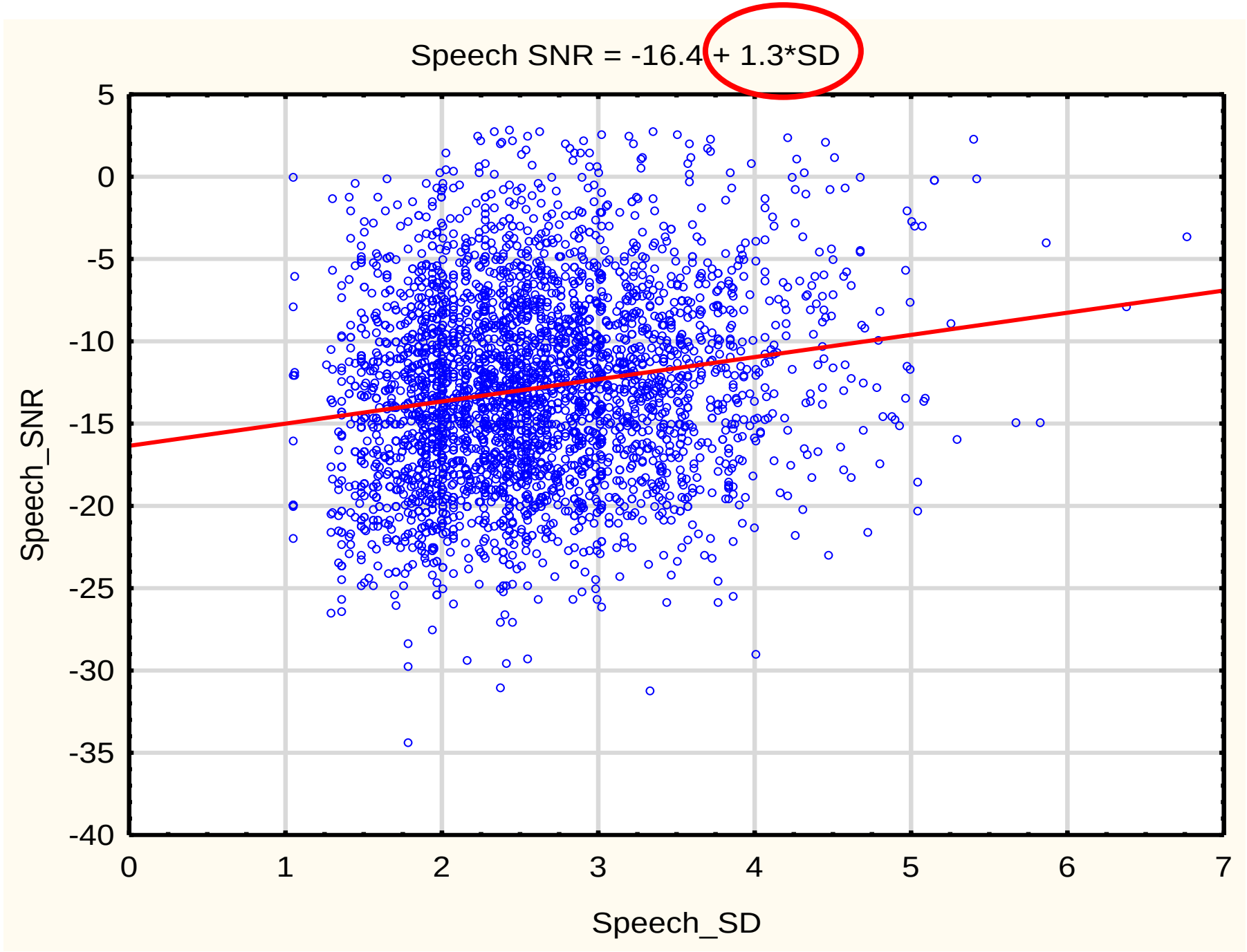




Loss of attention, poor performance



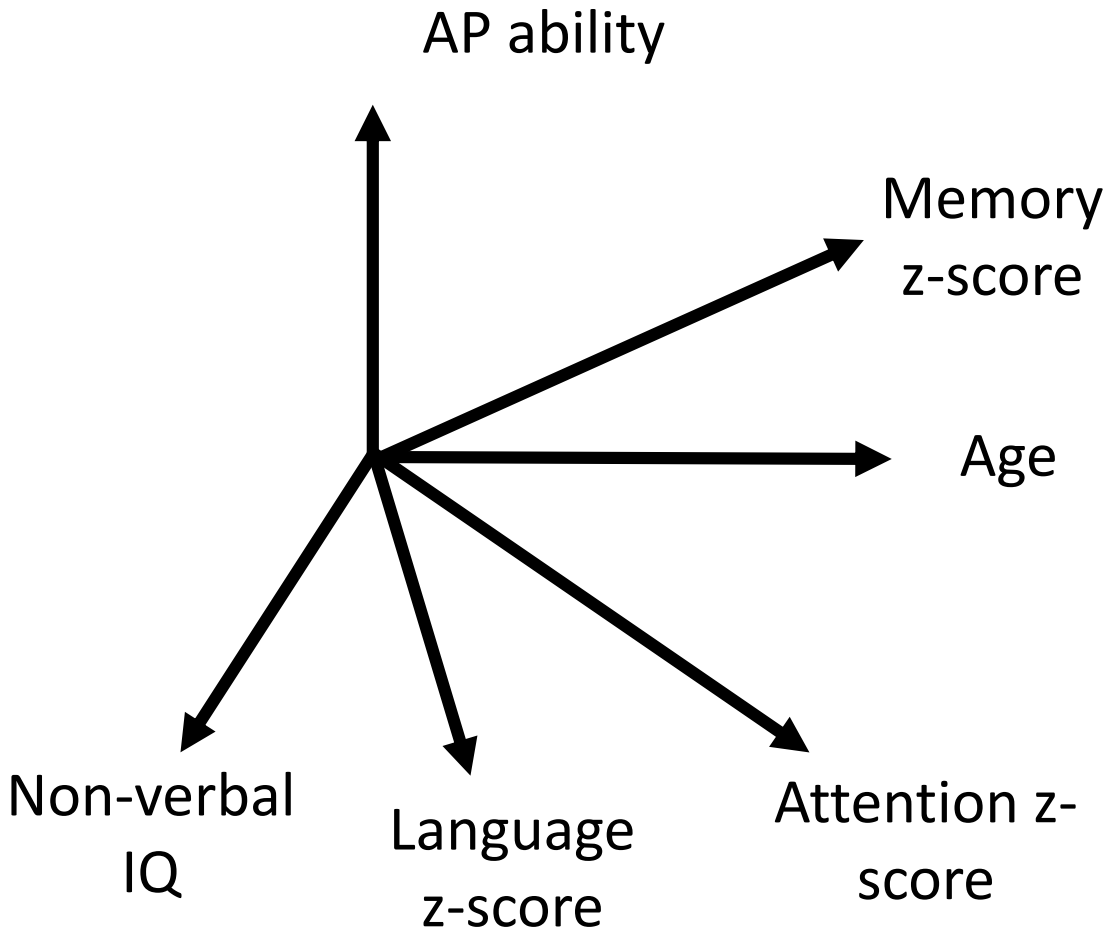
Loss and regain of attention, poor performance


Speech SNR = -16.4 + 1.3*SD
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Speech_SNR
0
1
2
3
4
5
6
7
Speech_SD

Allowing for related abilities

1.3*SD

$\widehat{\text{AP ability}}$ = APD test z-score – c.(memory) – d.(attention)



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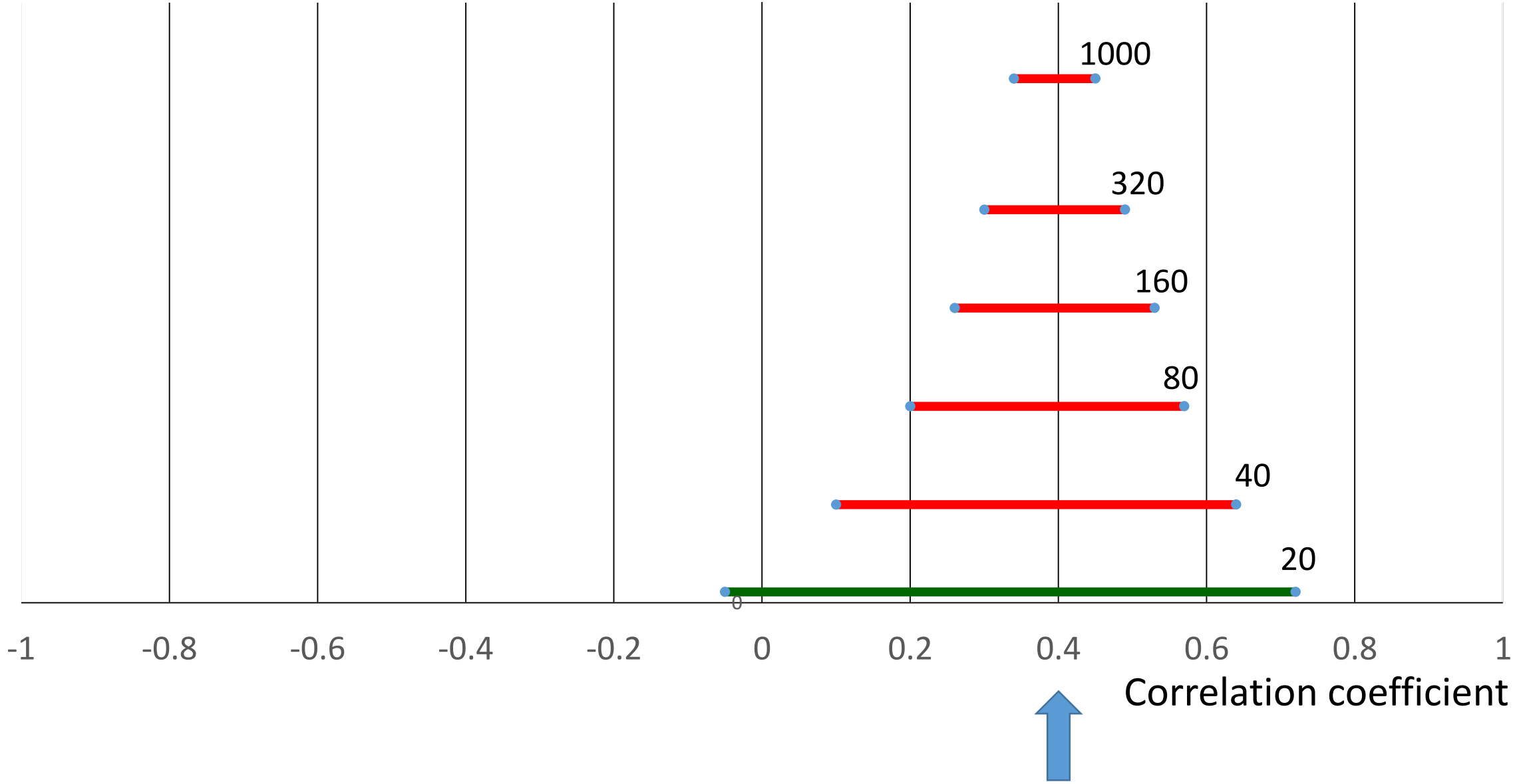
But which cognitive or language abilities affect which auditory processing tests?

Correlations !



Cognitive
(NVIQ, memory, attention)

APD
(dichotic, non-speech)

APD
(speech tests)

Outcomes
(reading, questionnaires, language)

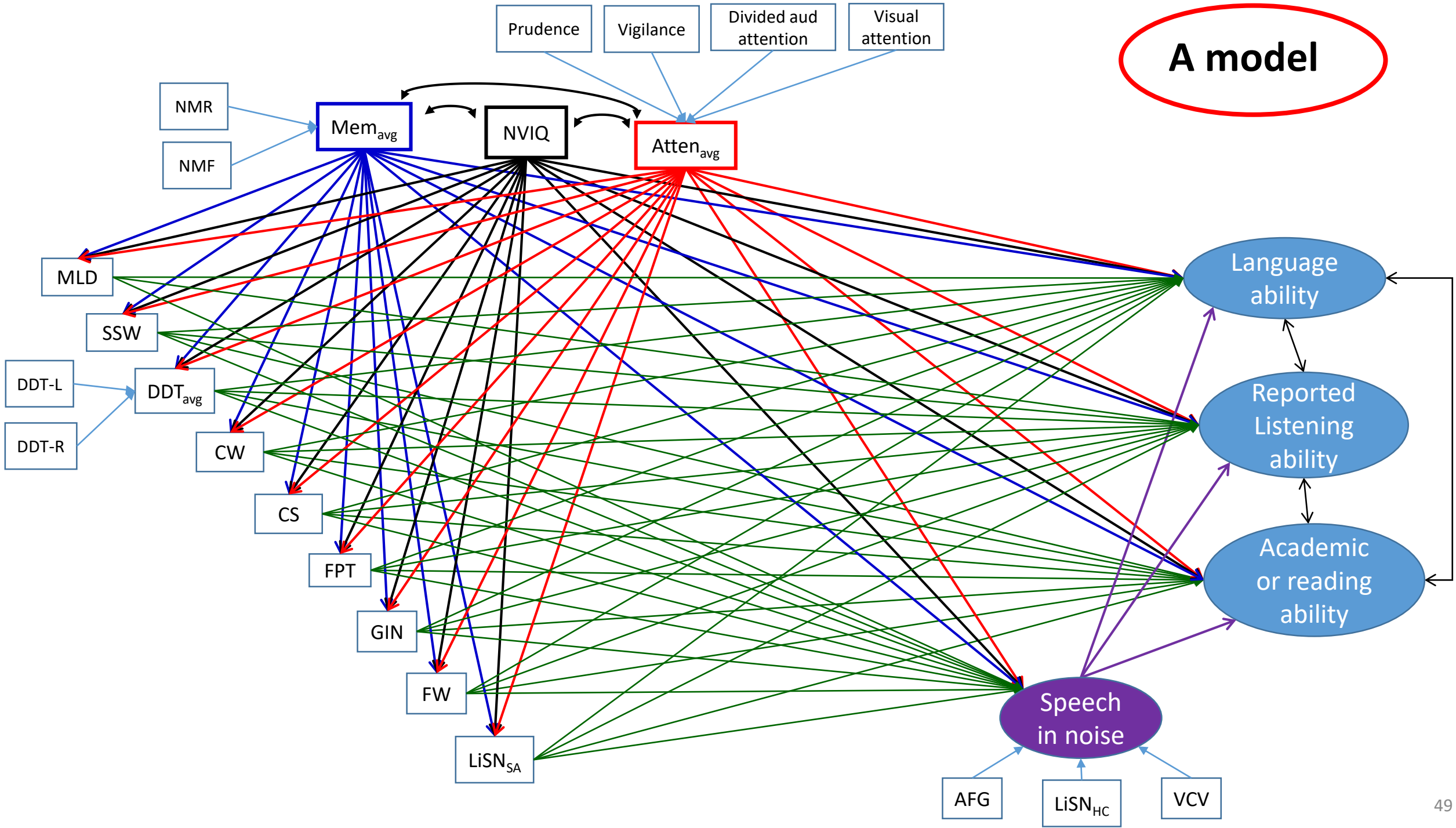
	NVIQ	NMF	NMR	NMF+NMR	Prudence	Vigilance	Div Aud Tten	Vis Sus Atten	DDT-L	DDT-R	DDT-Avg	FPT	SSW	MLD	RGDT or GIN	Filtered words (Scan)	Competing words (Scan)	Competing sentences (Scan)	AFG (Scan)	VCV	LiSN-S HC	LiSN-S Spat Adv	WARP or TOWRE	Combined reported listening	CHAPS	SIFTER	Life	Fishers	CCC-2 SLI	CCC-2 PLI	CCC-2 GCC	Receptive language (CELF-4)	Expressive language (CELF-4)	Overall academic ability
NVIQ	1.00	0.27	0.32	0.19	0.28	0.25		0.27	0.31	0.16	0.36	0.38		0.09	0.12	-0.04	-0.03	-0.02	0.09	-0.08	0.22	0.08	0.34	0.40			0.21	0.24						0.60
NMF	0.27	1.00	0.45	0.86	0.18	0.15		0.07	0.32	0.27	0.37	0.31		0.16	0.12	0.04		0.09			0.15	-0.01	0.44	0.24	0.08	0.06	0.03	0.29						0.44
NMR	0.32	0.45	1.00	0.83	0.22	0.26		0.26	0.26	0.22	0.31	0.35		-0.05	0.04	0.11		0.21			0.16	0.02	0.53	0.36	0.26	0.27	0.07	0.36						0.59
NMF+NMR	0.19	0.86	0.83	1.00		0.29		0.19	0.32	0.27	0.40	0.35		0.06	0.08	0.20	0.34	0.33	0.15	0.22	0.18	0.01	0.47	0.35	0.24		0.17	0.43						0.59
Prudence	0.28	0.18	0.22		1.00	0.54			0.37	0.22	0.36		0.18			0.42	0.55		0.49							0.12	-0.08						
Vigilance	0.25	0.15	0.26	0.29	0.54	1.00	0.76	0.62	0.25	0.22	0.26	0.33	0.21	0.02	0.17	-0.10	0.01		-0.17		0.12	0.07	0.39	0.31			0.19	0.22	0.53	0.16		0.15	0.03	0.31
Div Aud Tten						0.76	1.00				0.68										0.08	-0.03							0.66	0.24				
Vis Sus Atten	0.27	0.07	0.26	0.19		0.62		1.00	0.24	0.20	0.22	0.19		0.07	-0.01						0.00	0.01	0.30	0.20			0.18	0.16						0.28
DDT-L	0.31	0.32	0.26	0.32	0.37	0.25		0.24	1.00	0.47	0.85	0.37		-0.02	0.13	0.20		0.36			0.17	0.21	0.29	0.21	0.18	0.24	0.11	0.31				0.06	0.18	0.48
DDT-R	0.16	0.27	0.22	0.27	0.22	0.22		0.20	0.47	1.00	0.76	0.29		-0.04	0.11	0.20		0.32			0.17	0.18	0.20	0.34	0.09	0.15	0.08	0.31				0.16	0.33	0.36
DDT-Avg	0.36	0.37	0.31	0.40	0.36	0.26	0.68	0.22	0.85	0.76	1.00	0.36		-0.11	0.09						0.18	0.18	0.41	0.32			0.11	0.38				0.00	0.19	0.52
FPT	0.38	0.31	0.35	0.35		0.33		0.19	0.37	0.29	0.36	1.00		-0.02	0.25	0.21		0.26			0.12	0.12	0.36	0.20	0.11	0.14	0.01	0.21				0.34	0.30	0.39
SSW					0.18	0.21							1.00			0.64	0.57		0.26														
MLD	0.09	0.16	-0.05	0.06		0.02		0.07	-0.02	-0.04	-0.11	-0.02		1.00	0.01						-0.08	0.02	-0.03	-0.14			-0.07	-0.05				0.21	0.07	0.08
RGDT or GIN	0.12	0.12	0.04	0.08		0.17		-0.01	0.13	0.11	0.09	0.25		0.01	1.00						0.13	0.18	0.30	0.10			-0.07	0.12				0.03	0.05	0.07
Filtered words (Scan)	-0.04	0.04	0.11	0.20	0.42	-0.10			0.20	0.20		0.21	0.64			1.00	0.35	0.33	0.38	0.20			0.08		0.20	0.19					0.11			
Competing words (Scan)	-0.03			0.34	0.55	0.01							0.57			0.35	1.00	0.48	0.32	0.21			0.21		0.15						0.10		
Competing sentences (Scan)	-0.02	0.09	0.21	0.33					0.36	0.32		0.26				0.33	0.48	1.00	0.26	0.25			0.17		0.19	0.14					0.07	0.25	0.25	
AFG (Scan)	0.09			0.15	0.49	-0.17							0.26			0.38	0.32	0.26	1.00	0.14			0.00								0.13			
VCV	-0.08			0.22												0.20	0.21	0.25	0.14	1.00					0.28									
LiSN-S HC	0.22	0.15	0.16	0.18		0.12	0.08	0.00	0.17	0.17	0.18	0.12		-0.08	0.13						1.00	0.35	0.34	0.20			0.27	0.08	0.24	-0.15				0.15
LiSN-S Spat Adv	0.08	-0.01	0.02	0.01		0.07	-0.03	0.01	0.21	0.18	0.18	0.12		0.02	0.18						0.35	1.00	0.12	0.07			0.03	0.08	0.09	-0.01				0.03
WARP or TOWRE	0.34	0.44	0.53	0.47		0.39		0.30	0.29	0.20	0.41	0.36		-0.03	0.30	0.08	0.21	0.17	0.00		0.34	0.12	1.00	0.54	0.13		0.30	0.38						0.67
Combined reported listening	0.40	0.24	0.36	0.35		0.31		0.20	0.21	0.34	0.32	0.20		-0.14	0.10						0.20	0.07	0.54	1.00			0.62	0.80						0.62
CHAPS		0.08	0.26	0.24					0.18	0.09		0.11				0.20	0.15	0.19		0.28			0.13		1.00	0.66								
SIFTER		0.06	0.27						0.24	0.15		0.14				0.19		0.14							0.66	1.00								
Life	0.21	0.03	0.07	0.17	0.12	0.19		0.18	0.11	0.08	0.11	0.01		-0.07	-0.07						0.27	0.03	0.30	0.62			1.00	0.14						0.29
Fishers	0.24	0.29	0.36	0.43	-0.08	0.22		0.16	0.31	0.31	0.38	0.21		-0.05	0.12						0.08	0.08	0.38	0.80			0.14	1.00						0.56
CCC-2 SLI						0.53	0.66														0.24	0.09							1.00	0.59				
CCC-2 PLI						0.15	0.24														-0.15	-0.01							0.59	1.00				
CCC-2 GCC																0.11	0.10	0.07	0.13												1.00			
Receptive language (CELF-4)						0.15			0.06	0.16	0.00	0.34		0.21	0.03			0.25														1.00		
Expressive language (CELF-4)						0.03			0.18	0.33	0.19	0.30		0.07	0.05			0.25															1.00	
Overall academic ability	0.60	0.44	0.59	0.59		0.31		0.28	0.48	0.36	0.52	0.39		0.08	0.07						0.15	0.03	0.67	0.62			0.29	0.56						1.00

Ahmed (2017)
Ahmed & Ahmed (2016)
Brenneman et al (2017)
Cameron et al (in prep)
Cameron et al (2015)

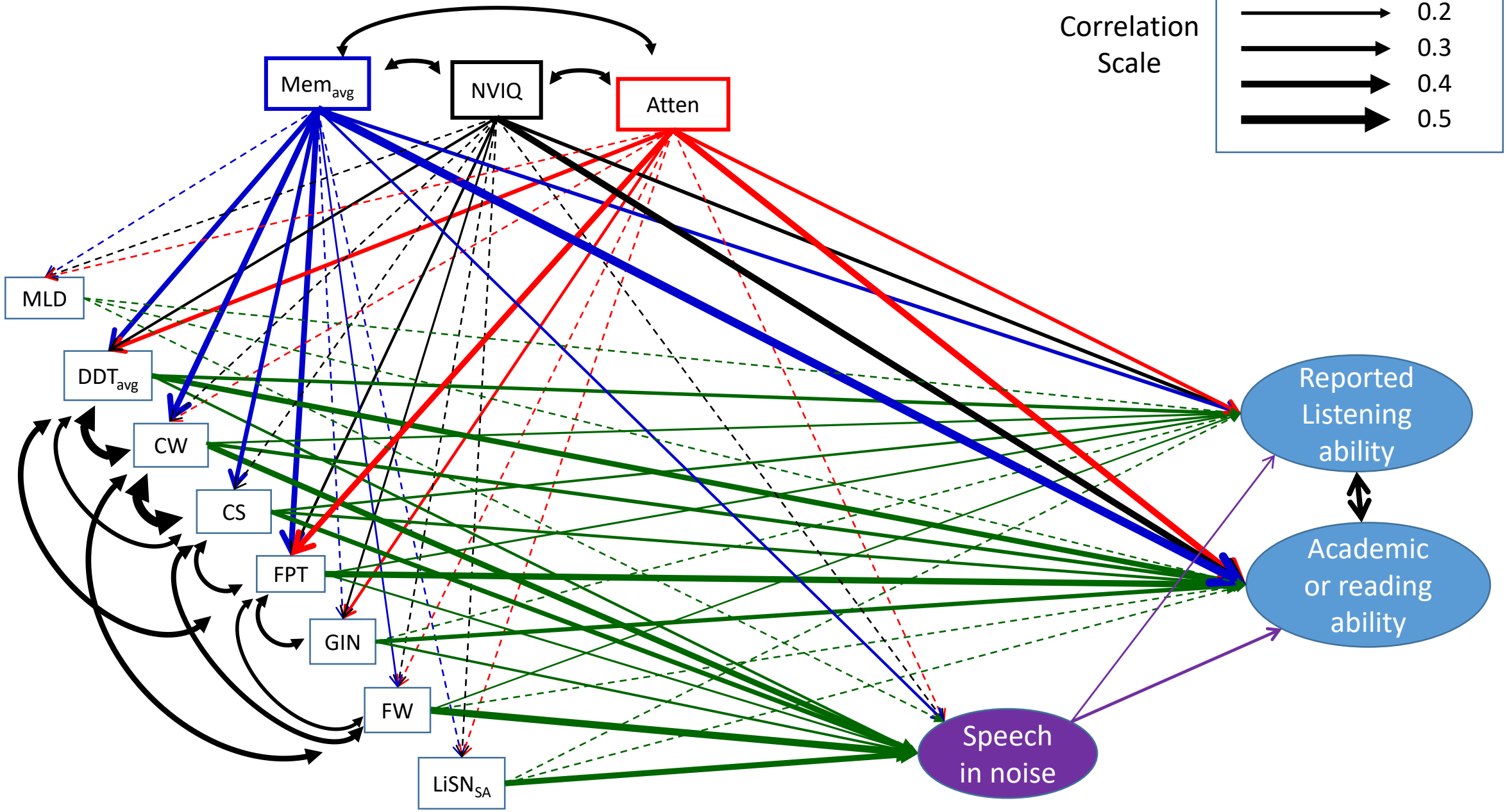
Cameron et al (2016)
Gyldenkaerne et al (2014)
Harris et al (1983)
Maerlander (2010)
Maerlander et al (2004)

Riccio et al (2005)
Dillon & Sirimanna (2014)
Sharma et al (2009)
Stavrinos et al (2018)
Tomlin et al (2015)

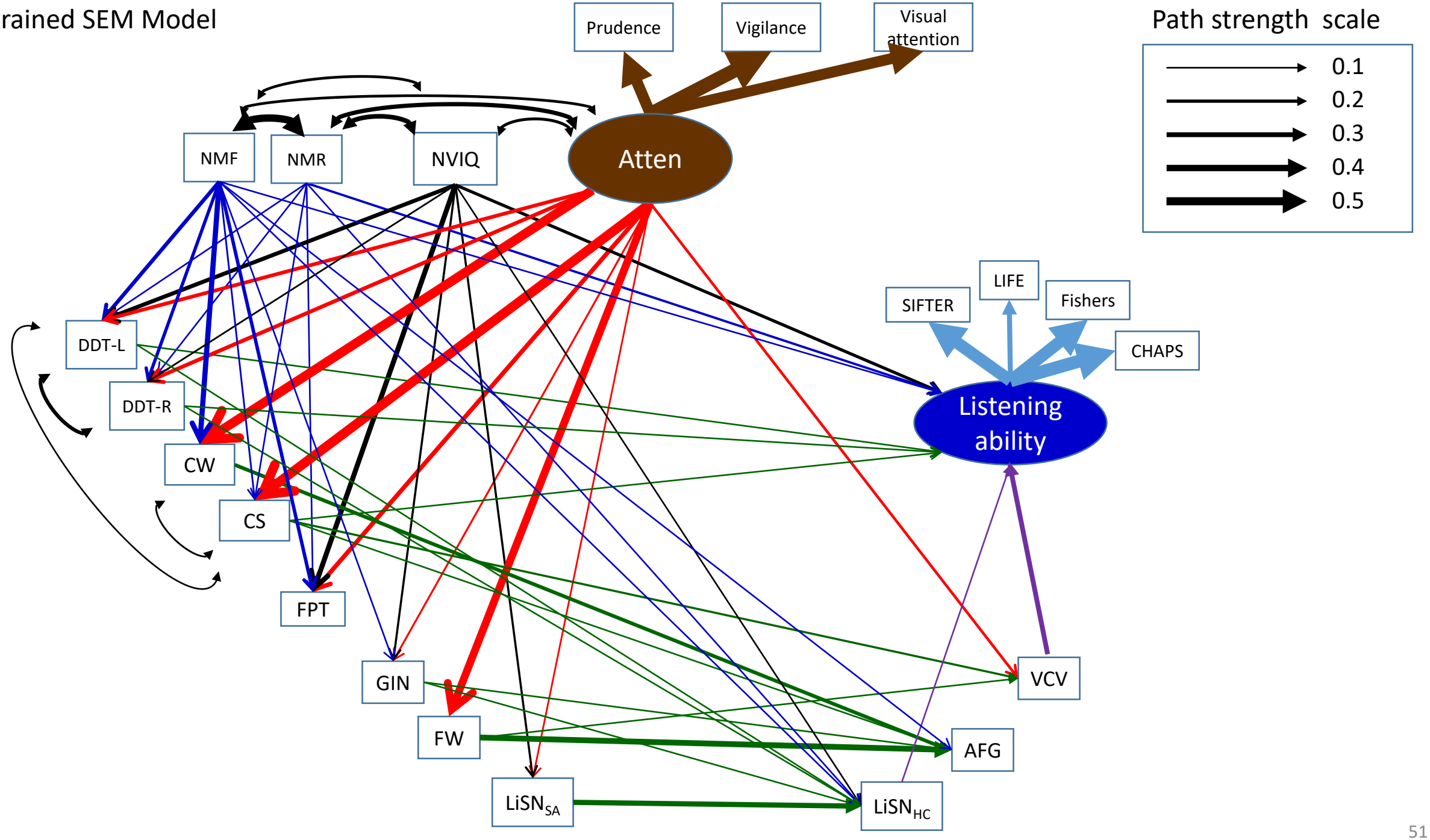
Weihing et al (2015)
Wilson et al (2011)


A model
Prudence
Vigilance
Divided aud attention
Visual attention
NMR
NMF
Mem avg
NVIQ
Atten avg
MLD
SSW
DDT-L
DDT-R
DDT avg
CW
CS
FPT
GIN
FW
LiSN SA
Language ability
Reported Listening ability
Academic or reading ability
Speech in noise
AFG
LiSN HC
VCV

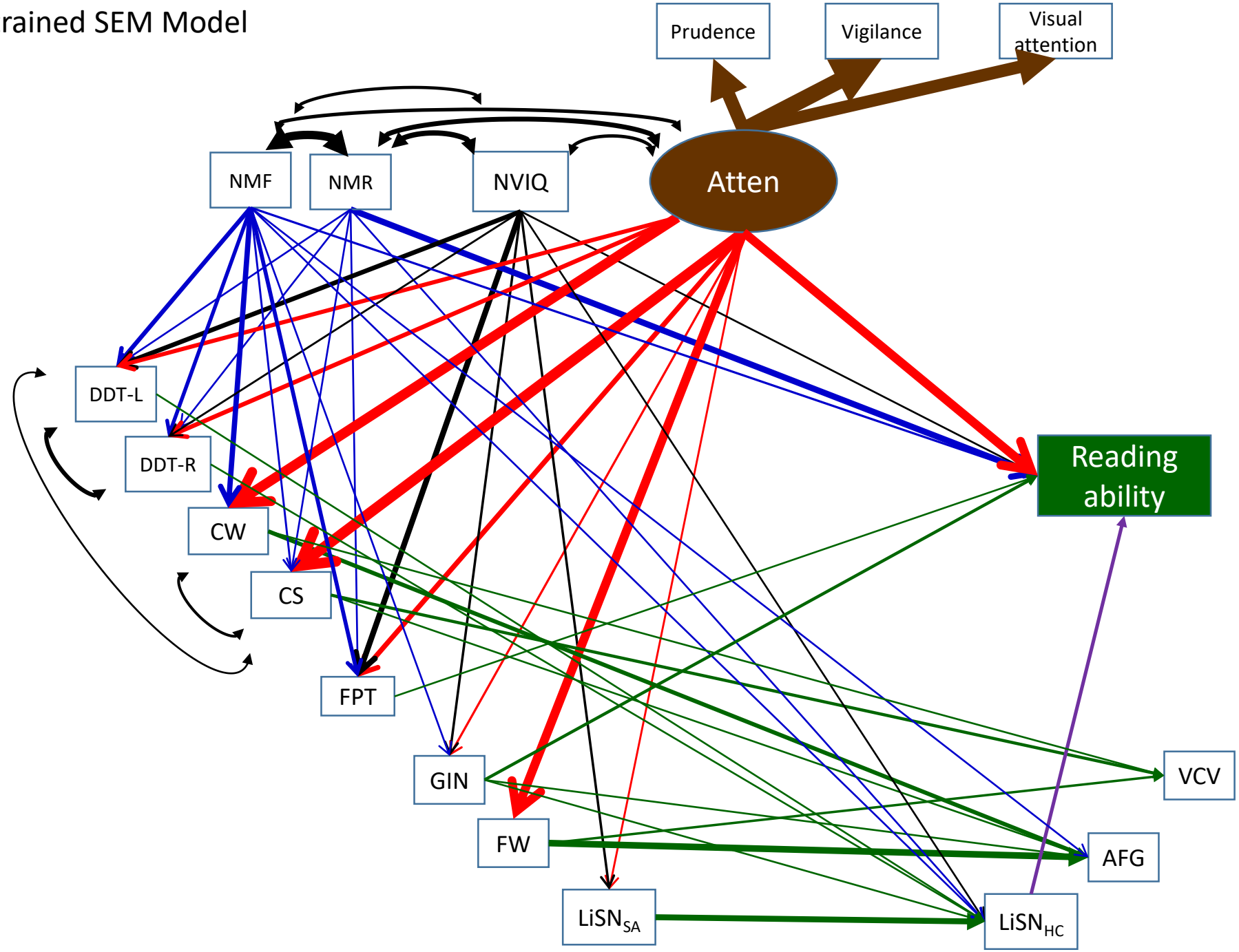
Observed correlations



Constrained SEM Model



Constrained SEM Model



Are listening difficulties *mostly*: Language, Auditory processing, or Cognition ?

University of Melbourne

Spatial processing disorder: 3 / 105

3%

Tomlin et al (2015)

P=0.000 000 000 000 1

Australian Hearing

Spatial processing disorder 130 / 666

20%

Cameron et al (2015)

Next steps

- Top level tests
  - Language specific
  - Language independent
- High-level auditory processing tests
- More specific auditory processing tests
  - Tests administered depend on high level results
  - Tests scores
    - Independent of memory, attention, and language, by design; or
    - Corrected for memory, attention, and language

THE HEARING CRC

MACQUARIE University
SYDNEY·AUSTRALIA

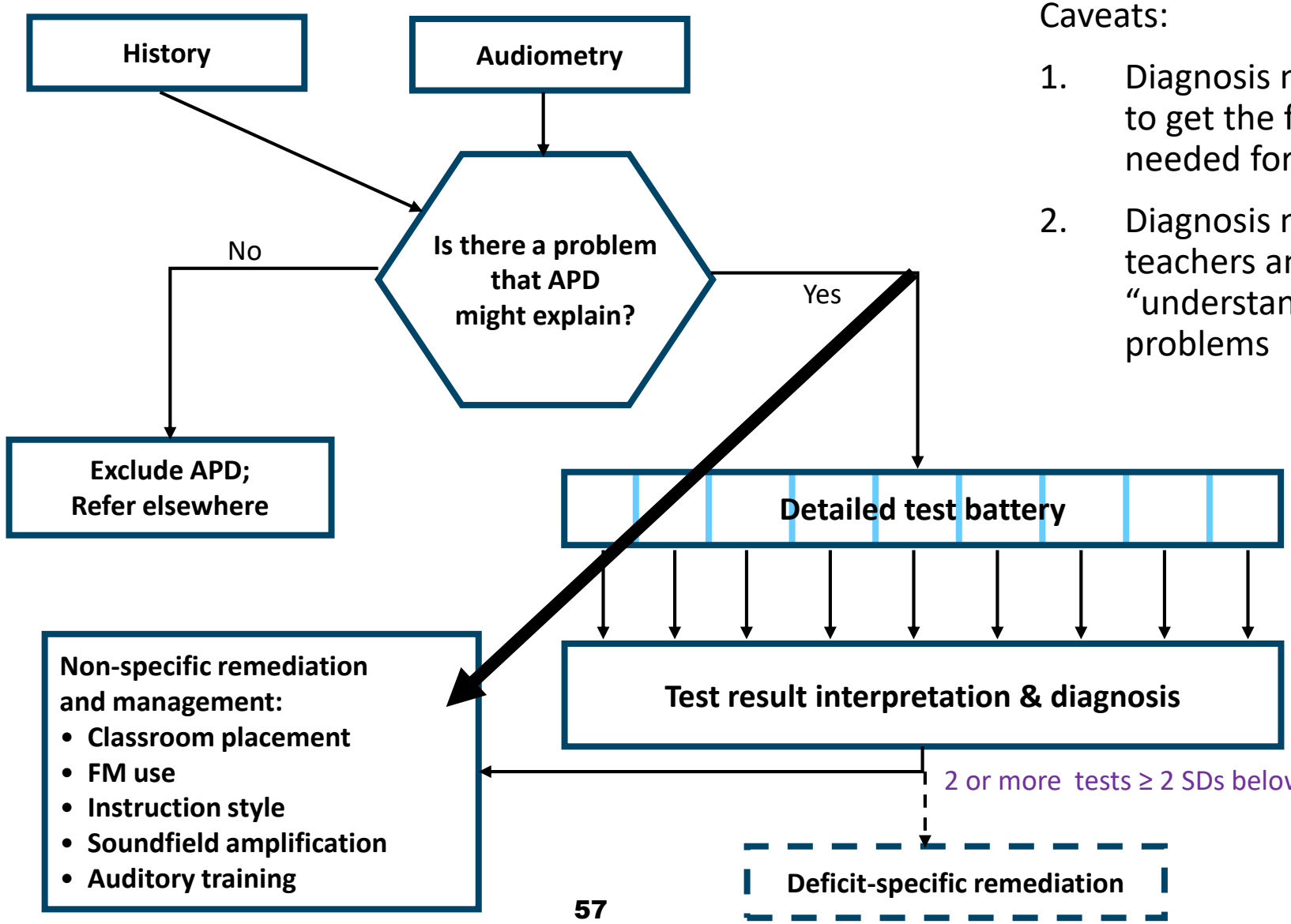
MANCHESTER 1824
The University of Manchester

NAL
National Acoustic Laboratories

Thanks for listening

Questions?

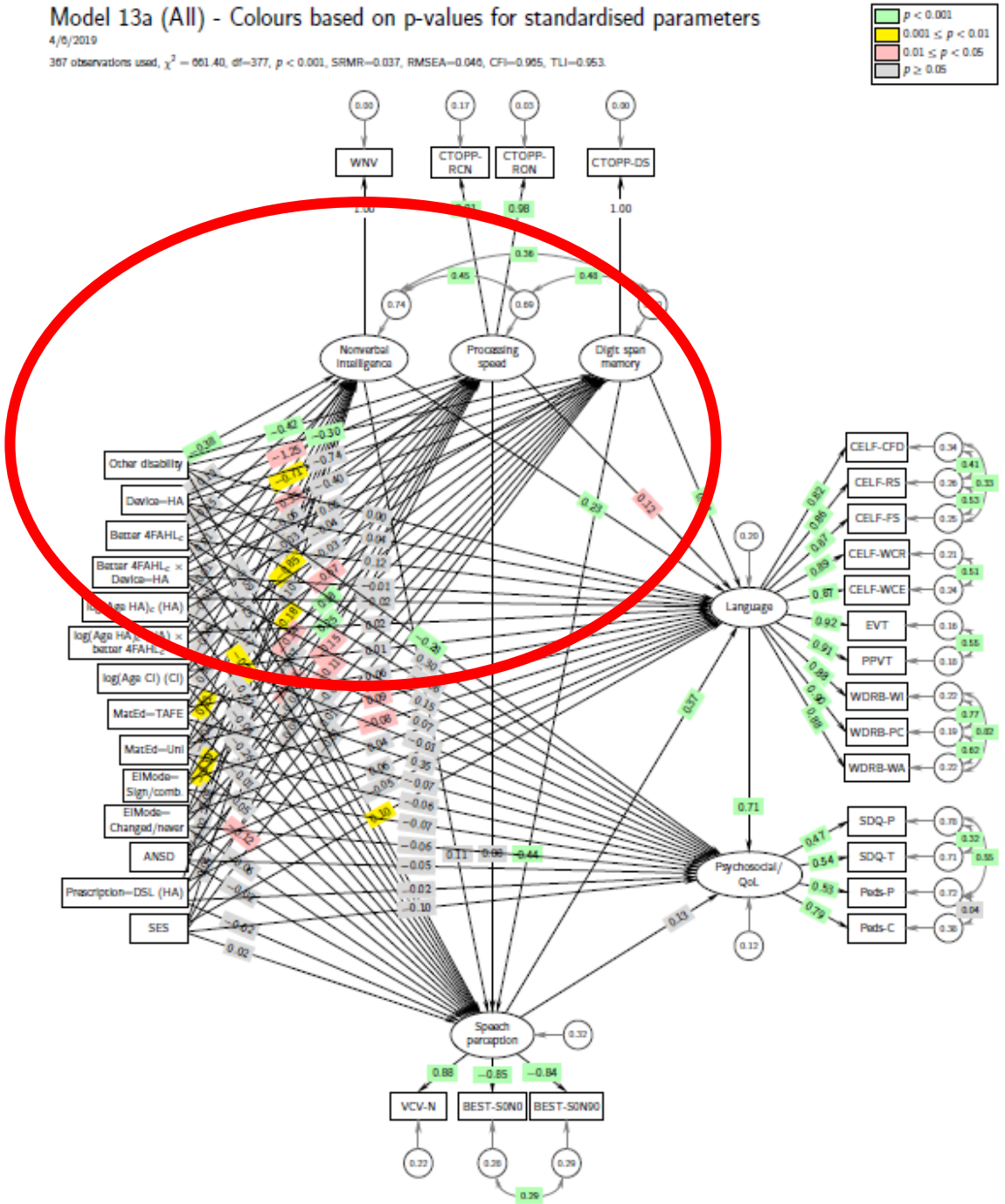
Traditional approach to APD testing



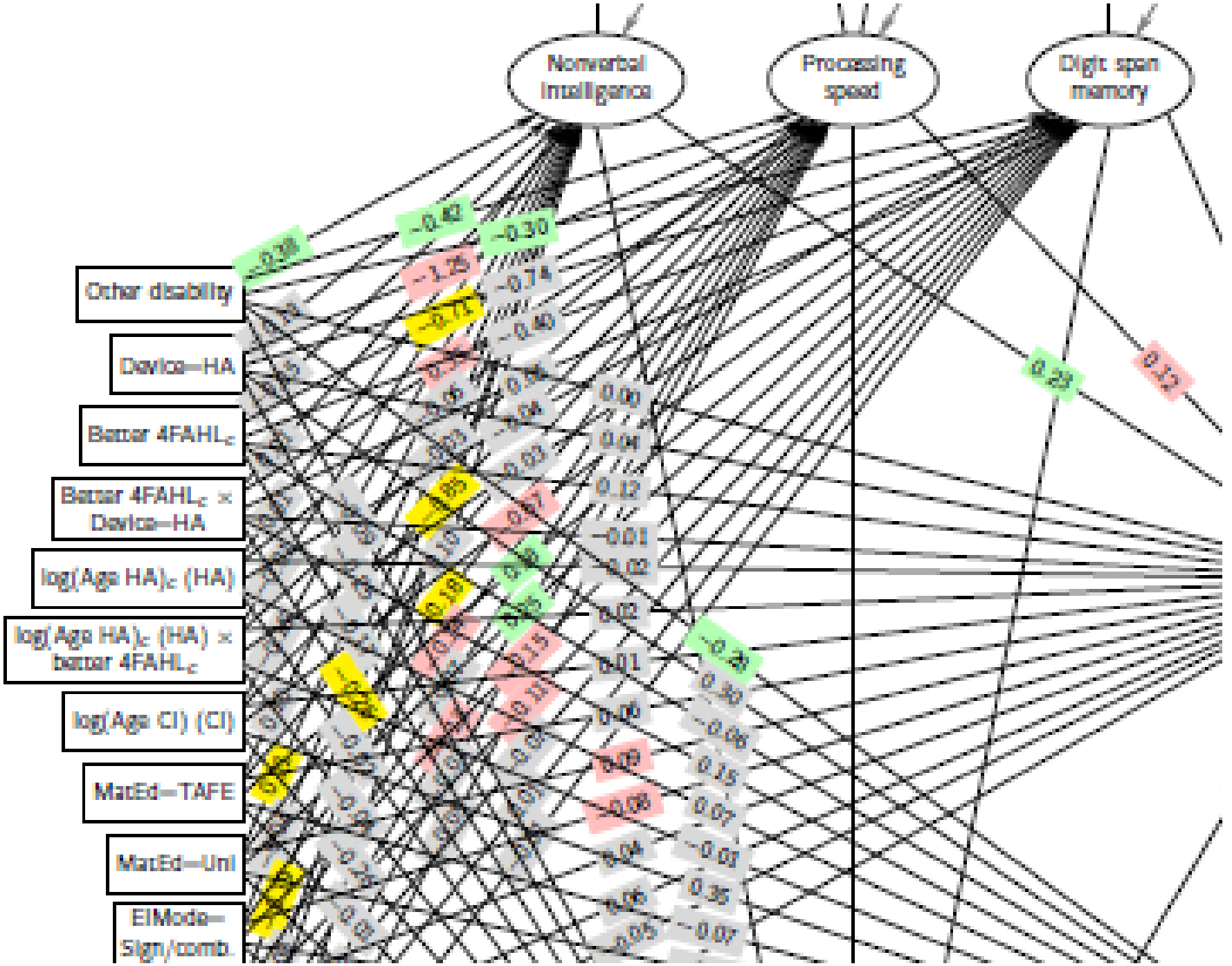
Caveats:

1. Diagnosis may be needed to get the funding needed for management
2. Diagnosis may help teachers and/or parents "understand" reason for problems

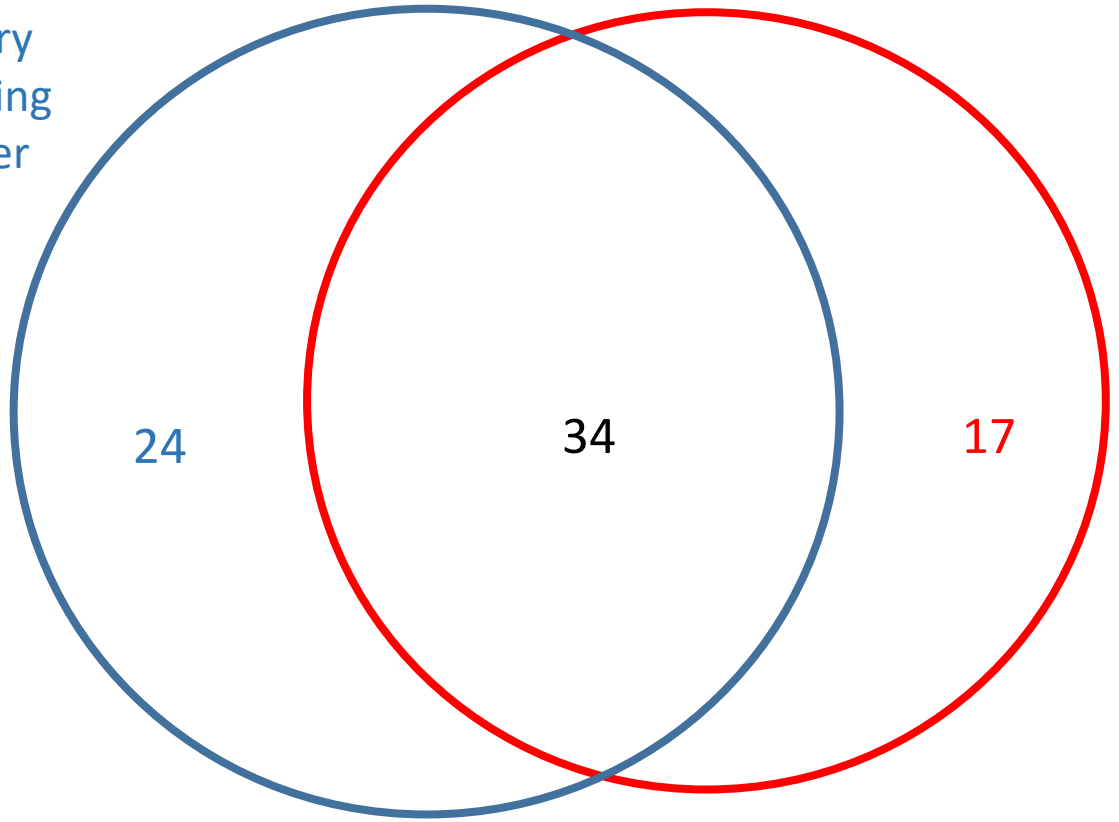
Early management, cognitive abilities, speech perception, language, and psychosocial.



Impact of early …



Relation between APD and Attention Disorder



101 children with listening difficulties

Gyldenkaerne, Dillon, Sharma and Purdy (2014); JAAA.

Instead of “What disorder(s) does this person have” ….

How strongly do deficits in each of: cognition, auditory processing, and language impede speech understanding

With a common unit of measure!

Bornstein & Musiek (1992)

Vanniasegaram, Cohen & Rosen (2004)

Dawes, Bishop, Sirimanna, Bamiou (2008)

Sharma, Purdy & Kelly (2009)

Rosen, Cohen, Vanniasegaram (2010)

Umat, Mukari, Ezan & Din (2011)

Ahmed, Ahmed, Bath, Ferguson, Plack & Moore (2014)

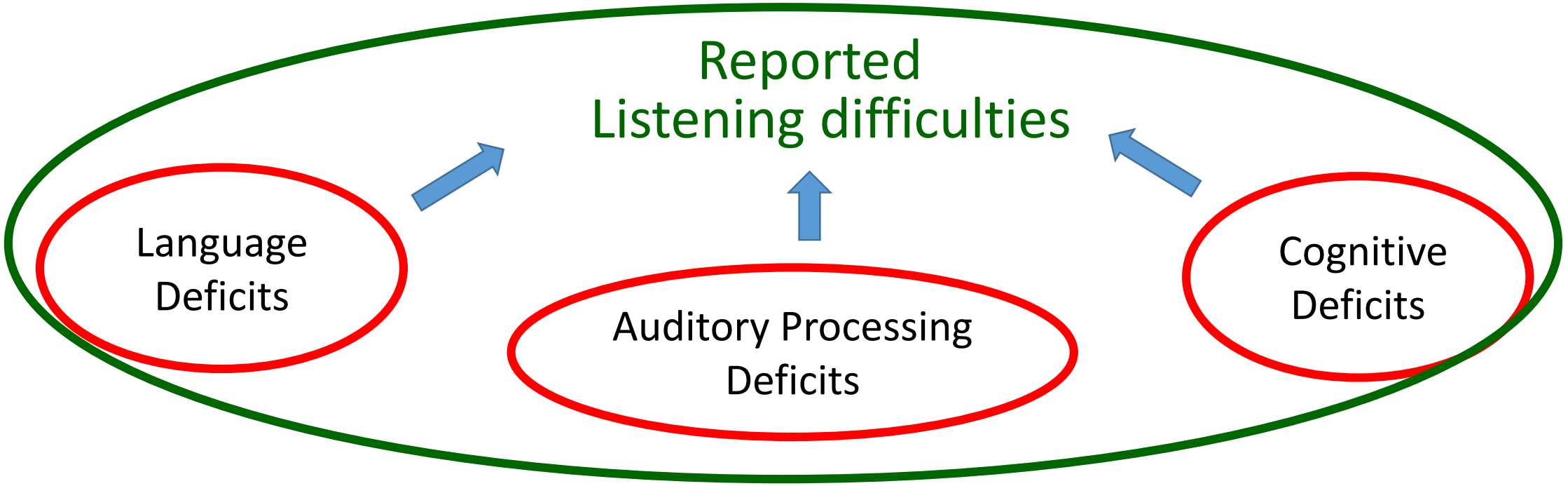
Gyldenkaerne, Dillon, Sharma, Purdy (2014)

Boothalingam, Allan, Allen & Purcell (2015)

Saxena, Allan & Allen (2015)

Ahmed & Ahmed (2016)

Neijenhuis, de Wit, Luinge (2017)



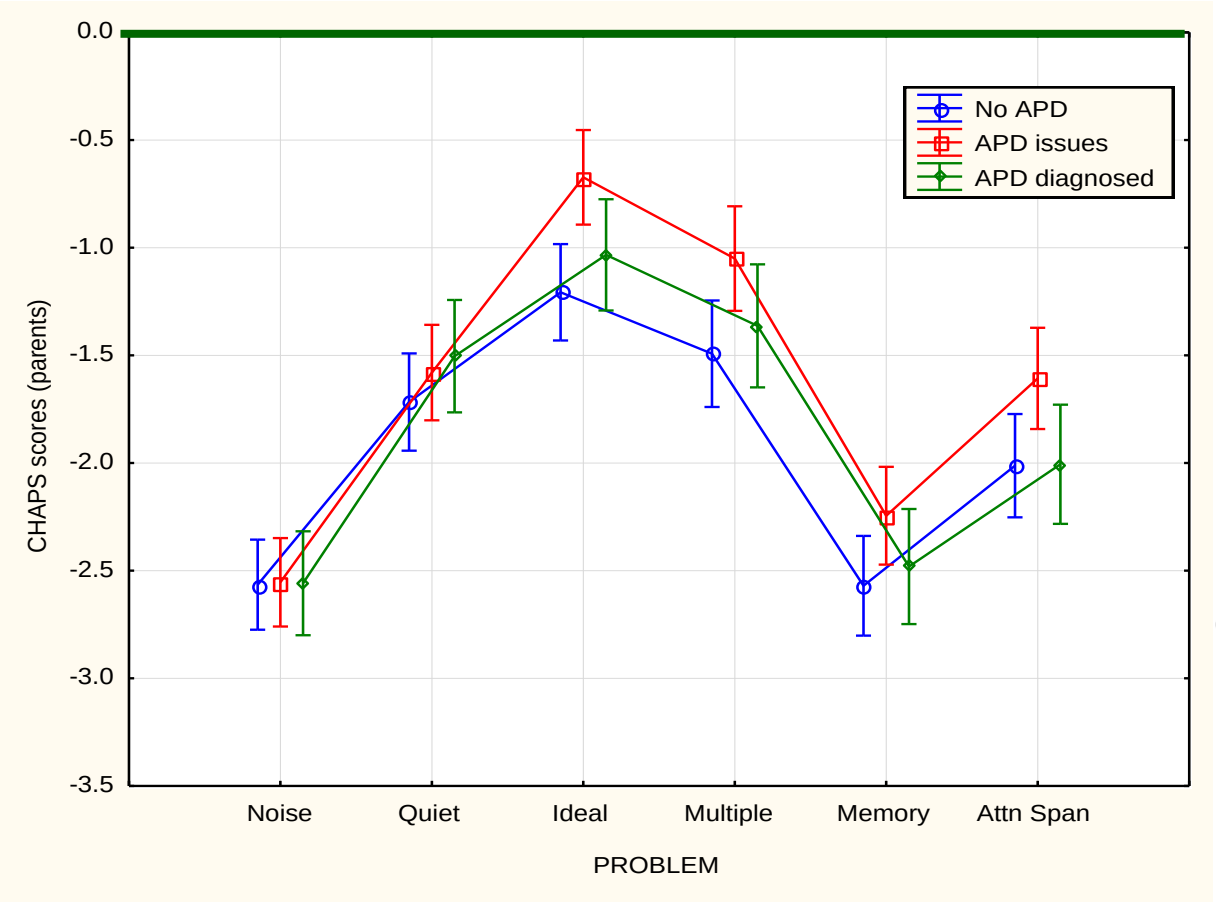
Dawes, Bishop, Sirimanna, Bamiou (2008):

"Children diagnosed with APD reported similar symptoms and similarly had high rates of co-morbid learning problems *[as those not diagnosed with APD]*".

CHAPS questionnaire results – Great Ormond Street APD Clinic, London

CHildren's
Auditory
Performance
Scale

Parents



Same difficulty

Slightly more difficulty

More difficulty

Considerably more difficulty

Teachers