Age-related changes in different forms of skill learning: Is there a critical period?

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Is there a dedicated time for learning new skills?

- Learning fundamentally associated with childhood and young adulthood
- General assumption: learning is most effective at these ages
- Also general view: skills like playing a musical instrument, mastering sports or learning a language are best acquired if learning starts early in childhood with a lot of practice
- Critical periods for skill learning? (Lenneberg 1967, Johnson and Newport 1989 for language, eg. ??Shahin et al., 2004 for music ??Ebert et al. 1995)

Critical periods in skill learning

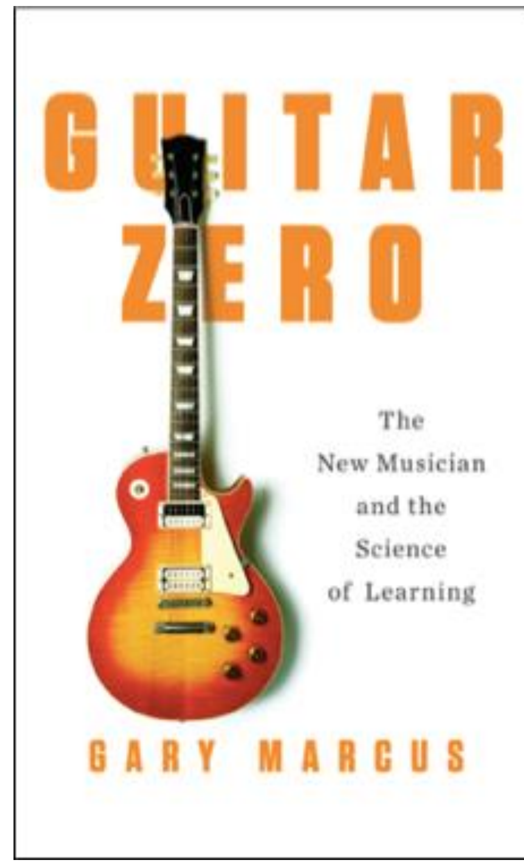
- Age windows in experience, when stimuli or practice relevant to skill in question is more effective than at other ages.
  - readiness for environmental stimulation to be effective
  - specific time limit
  - Effects of stimulation or lack of stimulation during this period is permanent or long lasting
  - Critical periods exist for all of human behavior (cognitive, social, emotional, and motoric)
- Age of acquisition effect?
- Proficiency (amount of practice) effect? Also varies with age.
  - 5-10 years of experience and intense practice to reach excellence even for the talented
- Existence still controversial

Late bloomers and late starters

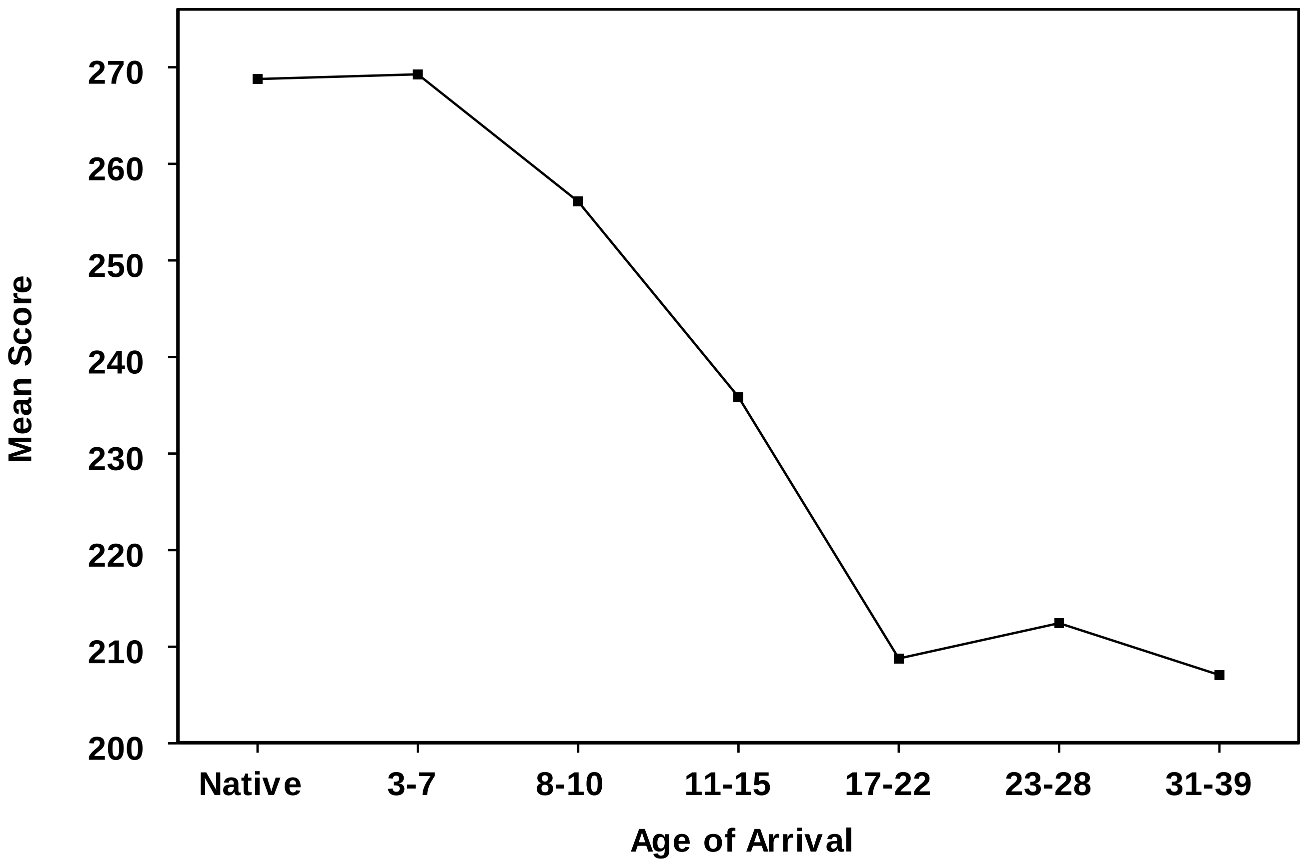
- Writing
  - Joseph Conrad did not start to learn English until 21, started writing in English at 31, first published at 37
  - Raymond Chandler first short story at 45, *The Big Sleep* at 51.
  - Anthony Burgess, William S. Burroughs both published first at 39.
- Music
  - Xenakis only started studying composition at 30
  - Leonard Cohen learned to play the guitar in his teens, first album at 32.
- Painting
  - Csontváry started painting at 27

Critical periods

- It is definitely possible to learn language, music, driving a car, engage in sport or dancing in adulthood
  - generally not with an aspiration to excel at something
- Increased interest in lifelong learning and adult plasticity
- NYU psychologist Gary Marcus: sabbatical devoted his sabbatical to learning to play the guitar to demonstrate adult plasticity of the brain
- Skill learning does take place at all ages
- But is it equally effective at all ages?



Critical period effect in second language acquisition: Johnson and Newport, 1989



Qualitatively different language learning beyond CP (Ullman et al. 2012)

- critical period / sensitive period for language learning. (Lenneberg's CPH, 1967)
- Weber-Fox and Neville (1999) neural subsystems involved in language processing differ as a function of age of acquisition.
- from birth through puberty?

children	procedural LTM	declarative LTM
L1	grammar	words
L2	grammar	words

adults	procedural LTM	declarative LTM
L1	grammar	words
L2	---	grammar & words

No critical period

- There is no critical period for second language learning, although there are important age effects.
- Critical period effects are in fact age-related effects due to entrenchment and competition, and social commitment (e.g. Hernandez, A., Li, P., & MacWhinney, B., 2005)
- What is important is not the timing of learning, but the quality and quantity of exposure.
- Existence of CP implies steep decline in ability. Meta-analysis of L2A end-state studies (Birdsong and Molis 2001): ongoing simple straight-line declines in attainment.
- Language is not a unitary ability.

Evidence of native-likeness in late learners

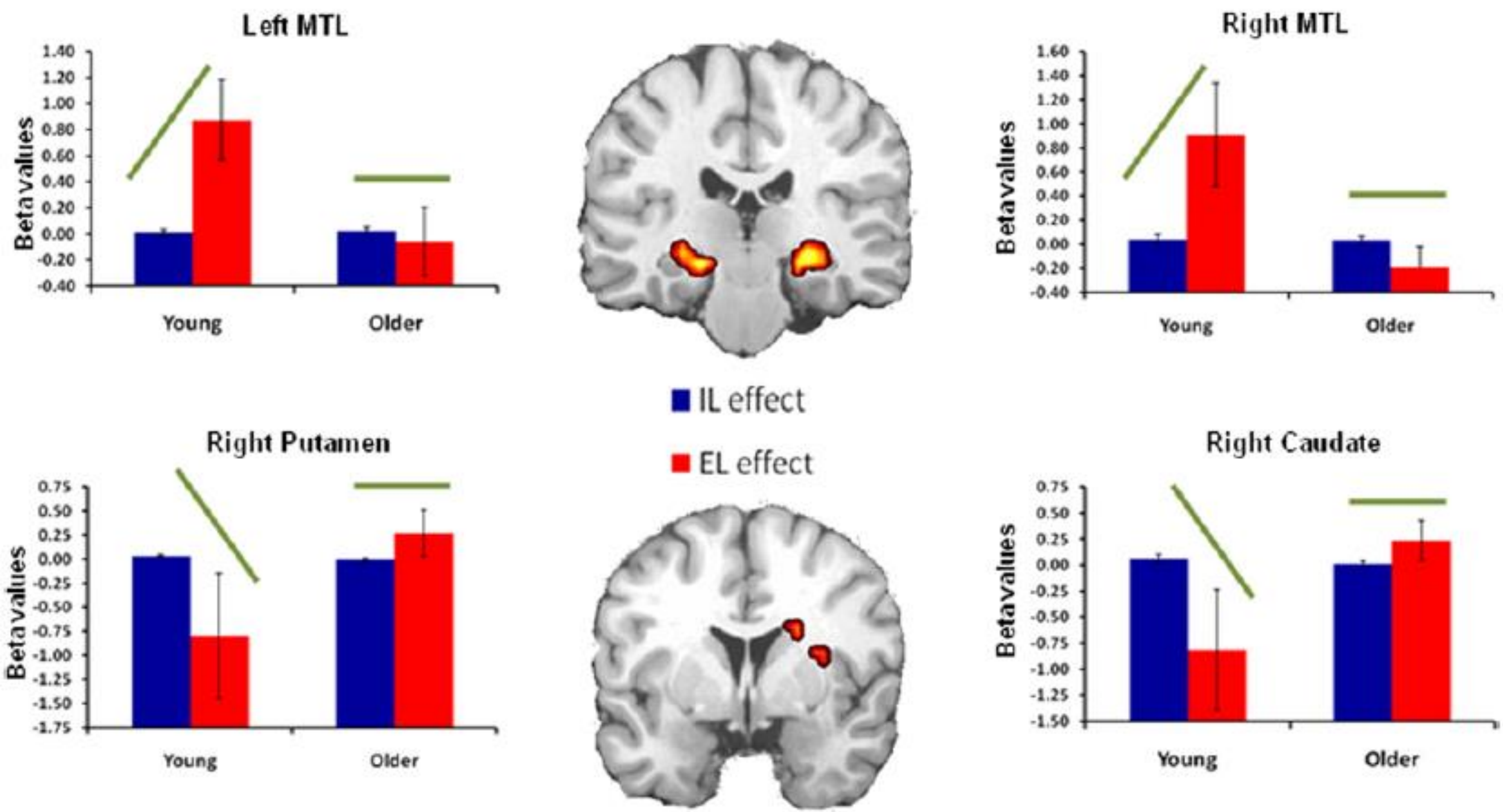
- Friederici Lab (e.g. Rossi et al. 2006, Friederici et al., 2002)
  - Native speakers of German Natives show
    - for semantic violations: N400
    - for syntactic violations: ELAN & P600
  - Native speakers of Russian, after 5 years in Germany
    - for semantic violations: N400
    - for syntactic violations: no ELAN, but P600
  - Brocanto and mini-Nihongo Learners: ELAN and P600
  - fMRI Conclusion: L1 and L2 use same areas, but L2 relies more on Broca's
- Ullman Lab (e.g. Morgan-short et al. 2012)
  - Adult SLA may rely on the same brain mechanisms as first language acquisition
    - Dependent on method of learning (immersion instead of classes), proficiency

Why is skill learning interesting for psycholinguistics?

- Grammar is a skill
- Language-specific innate mechanism, UG
  - Existence of critical period: argument for innateness
  - Beyond CP, no full access to UG
  - Lenneberg 1967, originally formulated for 1st LA, later SLA
- General learning mechanisms: sequence learning (specific and abstract), categorization--SL

Development of skill learning: invariance?

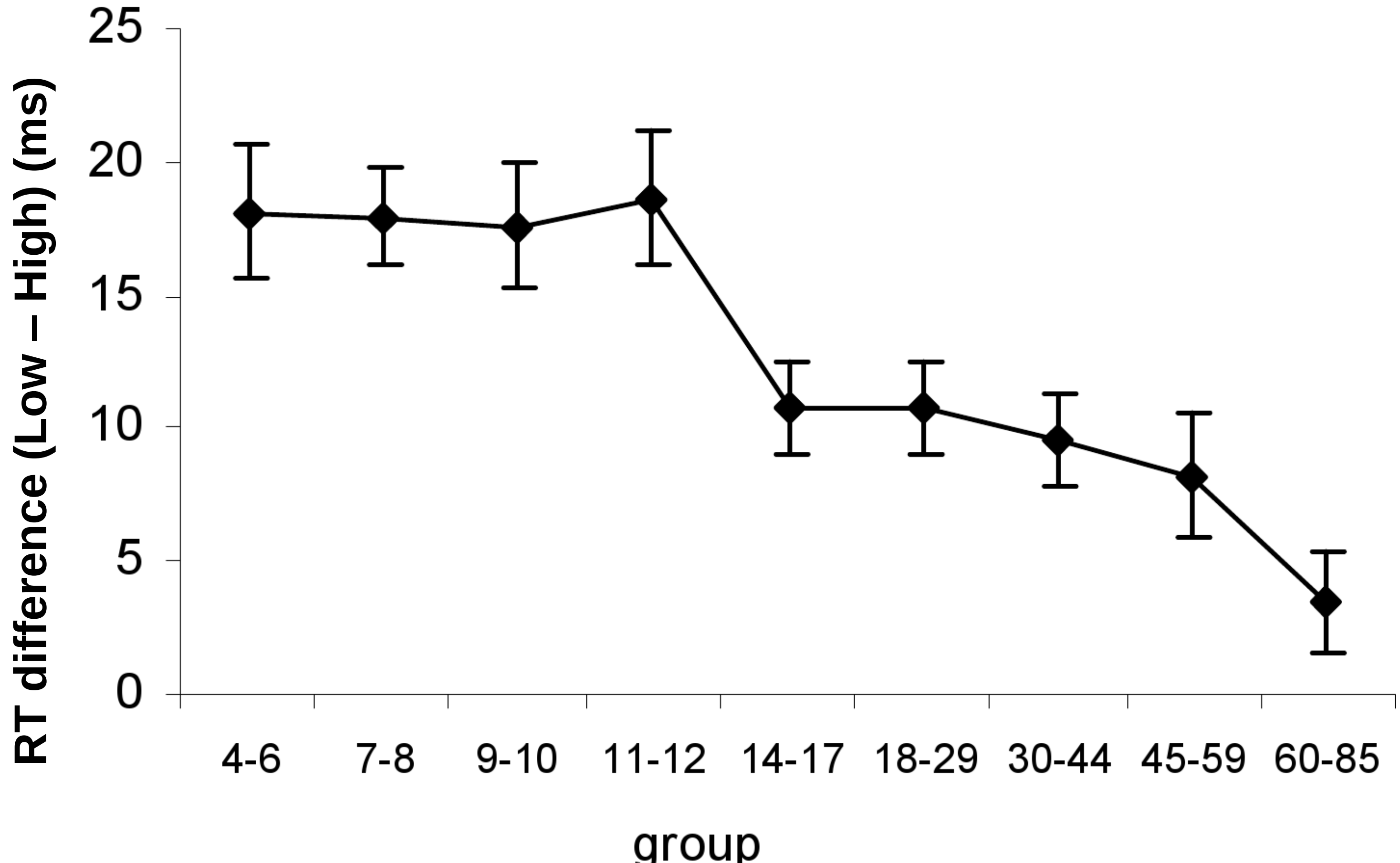
- No changes in the rate of learning between children and adults (Meulemans, Van der Linden, & Perruchet, 1998)
- skill learning abilities exist in infants already (Saffran, Aslin, Newport, 1996)
- skill learning robust, and operates even in neurological impairments like amnesia (Cohen and Squire, 1992)
- skill learning is associated with evolutionarily older brain regions (basal gangia and cerebellum) that mature early (Reber, 1992, 1993).


Left MTL
Betavalues
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
Young
Older
Right MTL
Betavalues
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
Young
Older
IL effect
EL effect
Right Putamen
Betavalues
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
Young
Older
Right Caudate
Betavalues
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
Young
Older

Development of skill learning: age-related improvement and decline?

- Larger SL learning effect in adults than children (e. g. Fletcher, Maybery, & Bennett, 2000; Maybery, Taylor, & O'Brien-Malone, 1995; Thomas et al., 2004).
- 2) fronto-striatal regions play an important role in SL; these go through considerable development well into adolescence
- Decline in aging for tasks requiring integration (probabilistic sequence learning but not for spatial cuing, Howard and Howard, 1997, 2007)—working memory effect?

Development of SL: age-related decline? Critical period?



N=421; ASRT task

Janacsek, Fiser, & Nemeth (in press). *Developmental Science* Skill learning across human lifespan

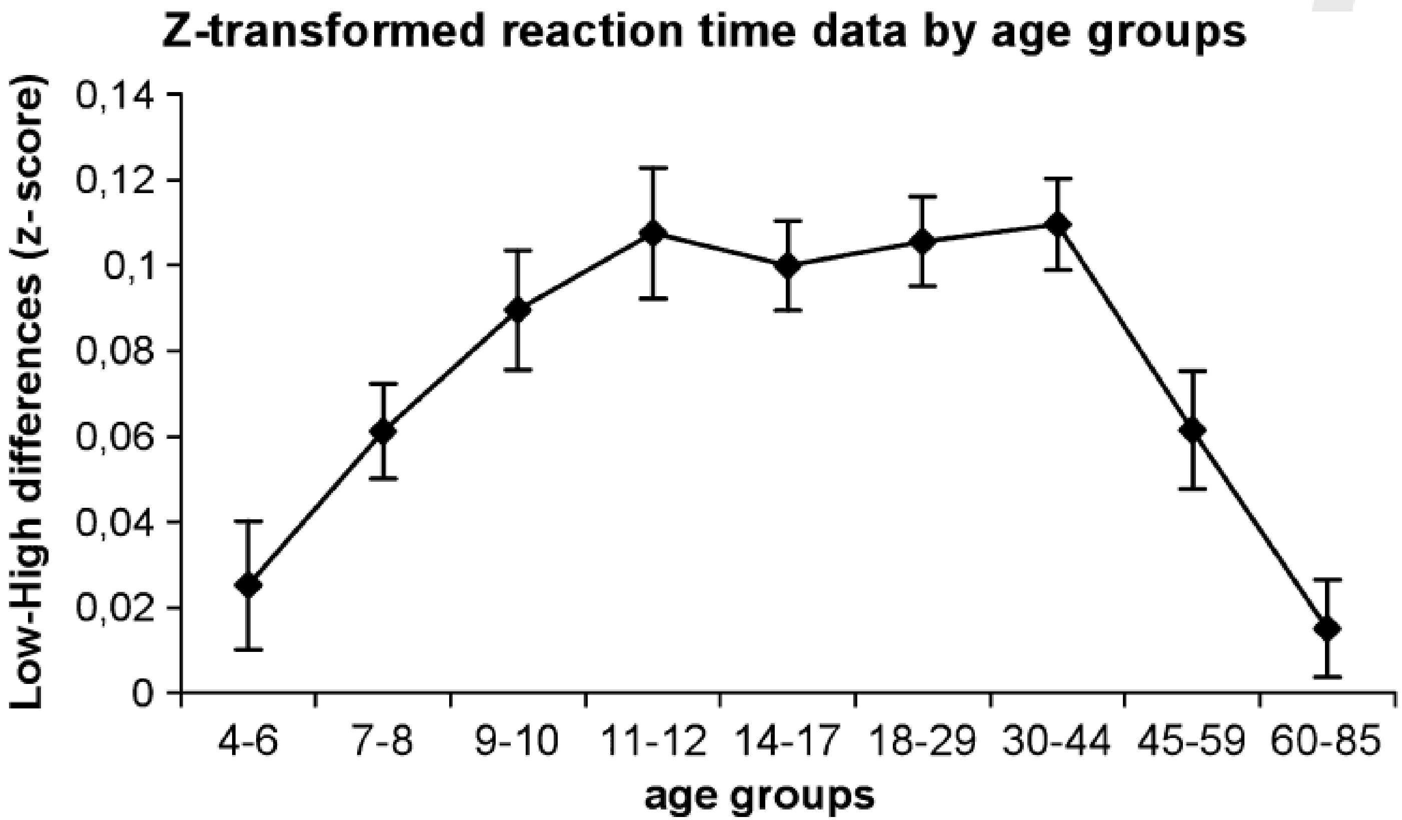
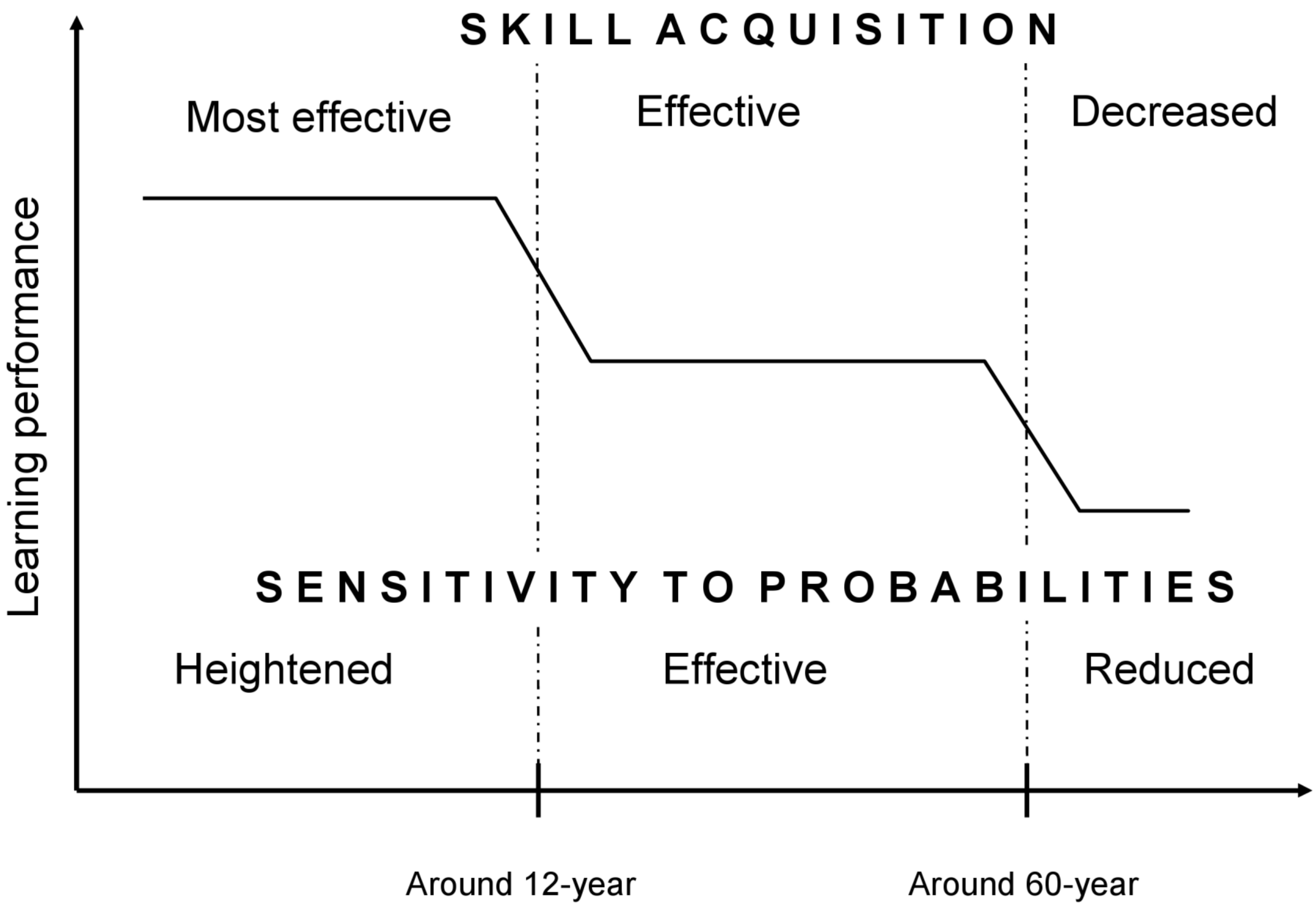


Figure 2 *Sequence learning measured the z-transformed RT data in all groups.*

Janacsek, Fiser, & Nemeth (in press). *Developmental Science*

Janacsek et al. conclusions



Janacsek, Fiser, & Nemeth (in press). *Developmental Science*

Age-related changes in three paradigms of SL

Different paradigms of SL

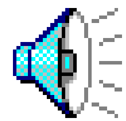
- Artificial grammar learning
- Serial Reaction Time Task
- Probabilistic Category Learning

- Systematic studies across lifespan are missing (except Janacsek et al.)

- Same SL mechanism behind all→similar developmental pathways, correlations between performance
- Different mechanisms→different developmental pathways, no correlation
  - Involvement of different anatomical structures, dissociations in clinical groups

Artificial grammar learning

- Saffran (2002)
  - S → AP + BP + (CP)
  - AP → A + (D)
  - BP → CP + F
  - CP → C + (G)
- 2x58 sentence, ~8 minutes
- Example sentences:
  - ket szir dol mug
  - nub diz szir dol tof



Category				
A	gok	teb	ket	nub
C	rék	szir	rad	gyil
D	zót	diz		
F	tof	mug	gán	nef
G	dol	vóp		

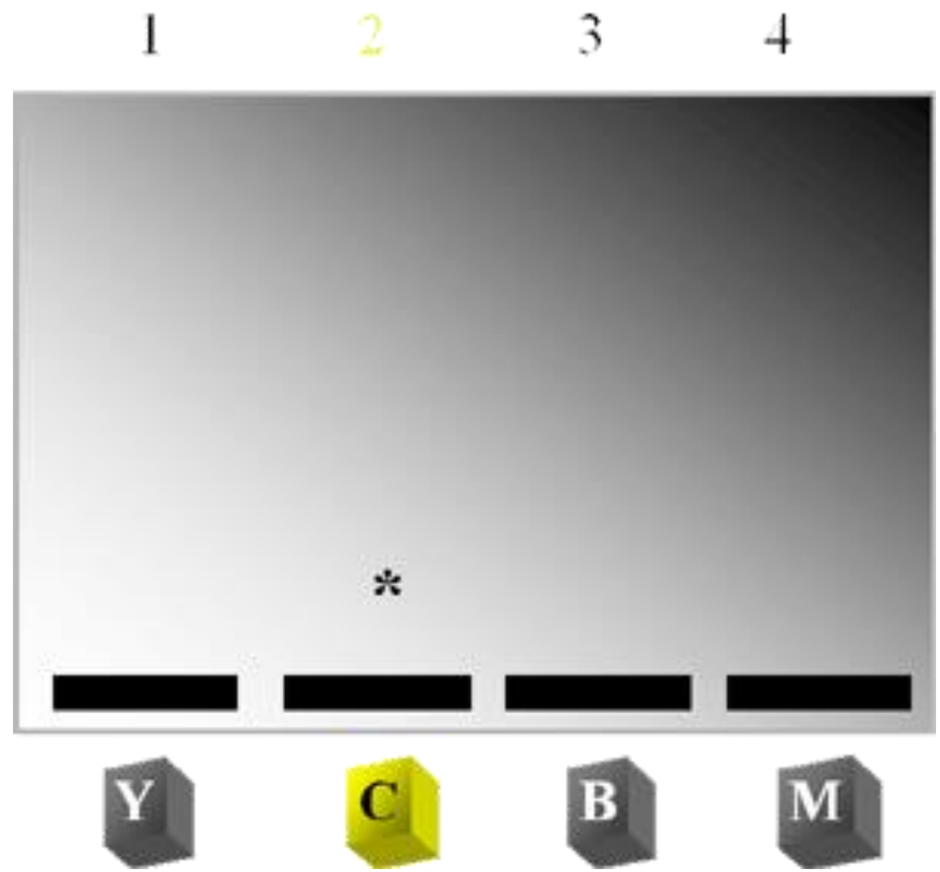
Implicit sequence learning: the serial reaction time task (SRT)

12 long sequence x 5

12 blocks

1-11 repeating sequence,

12 random

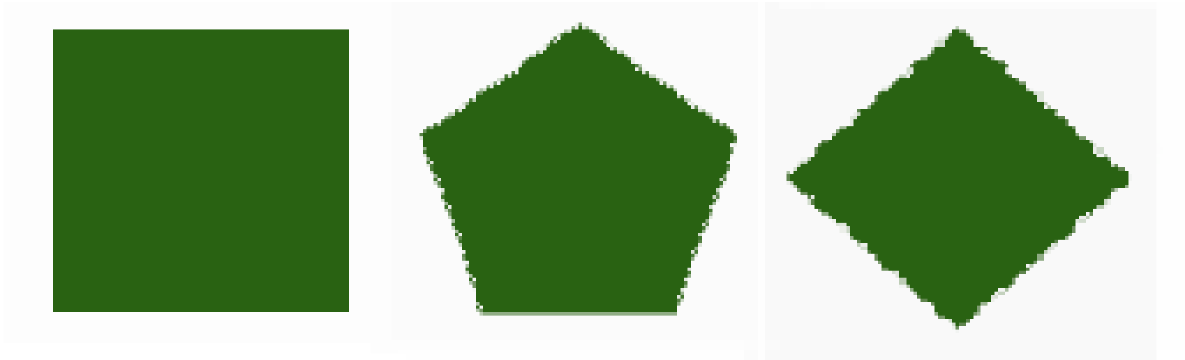


Sequence:

ycymcbmybcmb
121423413243

Probabilistic Category Learning: The Weather Prediction Task

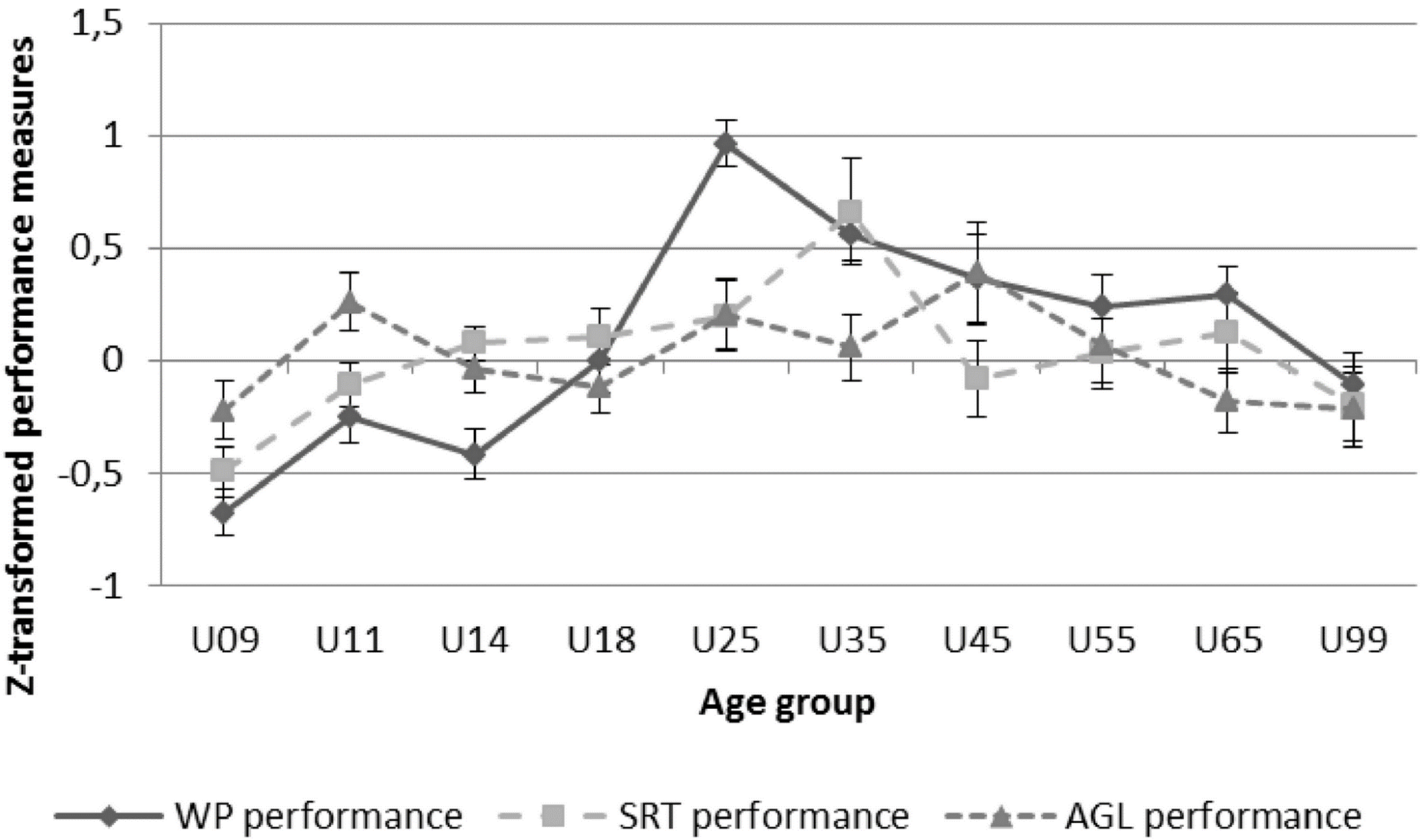
- dichotomic forced choice task
- Immediate feedback after decision
- Four cues, predictive values: 85,7%, 70%, 30%, 14,3%



Participants

Age group (years)	7–9	9–11	11–14	14–18	18–25	25–35	35–45	45–55	55–65	65+	Total
Mean age	7,9	9,8	11,9	15,5	20,6	29,4	40,8	49,8	60,0	72,1	31,8
N	64	63	63	57	37	37	28	45	43	43	480
female	32	29	26	31	23	20	19	25	29	29	263
male	32	34	37	26	14	17	9	20	14	14	217

Age-related changes in SL



Age-related changes in SL: summary

- AGL
  - Small age effect
  - Weaker learning in the 7-9 group. No learning in 65+. Same level of learning in all other groups
- PCL
  - Strong age effect
  - Learning is most effective between 18 and 65. Smaller learning in 7-9 than in older groups.
- SRT
  - Raw RTs: Strong age effect on motor learning, no on sequence learning.
    - No SL in 7-9.
  - Z-scores: Strong age effect on both motor and sequence learning
    - Learning is most effective between 11 and 35.
    - Smaller learning in 7-9 and in 65+

Age-related changes in SL: conclusions

- Smaller learning in 7-9 year olds and 65+ on all tasks→SL gets better with age, than starts to decline above 65
  - Complexity effect?
  - Methodological problems with children?
    - Testing not age-appropriate (especially AGL)
    - Training is too short
- Some forms of SL get better with age, and (at least the ones tested by the tasks) are just as effective in adulthood as in childhood
- Problems: are AGL, PCL, SRT good SL paradigms?
    - ←→age related changes do not follow developmental pattern of explicit learning
    - Performance is above chance in all age groups, even in the youngest

Age-related changes in SL: conclusions

- SL: inverted U-curve as for other types of learning→Age-related improvement then decline in aging
- Timing is different for all tasks. Differences in task difficulty?
- Also compatible with invariance models modulated by WM effect. Further analyses are needed to clarify WM contribution to these tasks.
- SL mechanism behind AGL, PCL and SRT might be at least partially different
- No critical period for SL itself.
  - CP for perception of speech sounds? Motor development?
  - Late starters/bloomers
    - More difficult to find in sports or among musicians (not composers)
    - Dependent on development of the body (e.g. fingers are fully grown in the 20s) and perceptual abilities instead of changes in SL?

Different forms of skill learning in Specific Language Impairment

Specific Language Impairment (SLI)

- Significant deficits in language ability in the absence of neurological, social or other cognitive impairments
- Language problems are explained by
  - Specific impairments of grammatical representations?
  - More general problem in processing?
  - *More general problem with skill learning*?

SLI as a learning problem

- „dysphasics do not have the normal language acquisition mechanism described by Pinker (1984) that would allow, or, perhaps, even compel them to construct inflectional paradigms on the basis of regularities hypothesized on the basis of observed linguistic evidence" (p.47).—SLI as a deficit of implicit grammatical rule acquisition (Gopnik and Crago, 1991)
- a 'problem of slow intake of relevant data due to the reduced speed of processing', a general processing limitation (Leonard, 1998)
- slower learning in SLI due to the deficit in working memory→ a difficulty in reaching the 'critical mass' of lexical representations required for grammatical generalizations (Bates and Goodman, 1997)

Impaired skill learning in SLI?

- Language acquisition is skill learning
- The Procedural learning deficit (PDH, Ullman and Pierpont, 2005)
  - abnormal development of the networks constituting the procedural system associated with skill learning
  - SLI is not specific, and does not only affect language
  - greatest neurobiological differences are found in the basal ganglia (especially in the nucleus caudatus) and in the Broca region of the frontal lobe (Gauger et al., 1997; Vargha-Khadem et al., 1998; Belton et al., 2002).
  - Declarative memory is relatively intact

Impaired skill learning in SLI?

- statistical learning abilities: domain general learning skills that help both word segmentation and grammar learning (e.g. Gómez & Gerken, 1999, 2000; Saffran, Aslin & Newport, 1996; Saffran, 2002),
- extracting statistical regularities and abstracting away from them is the core problem (domain-general; Evans et al., 2009; Hsu & Bishop, 2010)
- overlap of skill learning of sequential information and linguistic processes→LI involves deficits in *sequential* learning (e.g. Christiansen et al., 2010; Christiansen, Conway, & Onnis, 2012).

Skill learning in SLI: previous results

- Slower learning on the SRT in adolescents with SLI (Tomblin et al., 2007)
  - RTs slower for SLI w primarily grammatical deficits only
- Learning on the SRT is as good in SLI as in TD (Gabriel et al., 2011)
- impaired implicit motor sequence learning (SRT) in 51 children with language impairment relative AC TD children (Lum et al. 2011)
  - Declarative memory intact
  - Declarative memory measures were associated with lexical abilities in SLI and TD
  - grammar associated with procedural performance in TD
  - Grammar correlated with declarative memory in SLI
- No problem with initial learning, but impaired consolidation (Hedenius et al. 2011)

skill learning in SLI: previous results

- statistical learning on word and tone segmentation tasks: deficits in domain-general skill learning abilities in children with SLI (Evans et al. 2009)
  - Deficits of skill learning outside the procedural domain
- Learning of nonadjacent dependencies is problematic (Plante et al. 2002, Grunow et al. 2006)
  - AXB, e.g. *pel* *wadim* *jic*; *pel* *kicey* *jic*

Questions

- General deficit of implicit/procedural learning in SLI?
- Different vulnerability of different tasks in SLI?
  - Problems on sequential tasks only
  - Problems with learning verbal info only

Method

- Testing 3 different forms of skill learning
  - 1) the Serial Reaction Time Task (SRT) testing the learning of motor sequences
  - 2) Artificial Grammar Learning (AGL) testing the extraction of regularities from auditory sequences
  - 3) Probabilistic Category Learning in the Weather prediction task (PCL-WP), a non-sequential categorization task

Participants: SLI

- Exclusive criteria+at least 1.5 SD below age norms on at least 2 out of 4 language tests
- Language tests:
  - Receptive vocabulary (PPVT; Dunn and Dunn, 1981)
  - Nonword repetition (Racsmány et al. 2005)
  - Grammatical comprehension (TROG; Bishop, 1983)
  - Sentence repetition (MAMUT; Kas and Lukács, in prep.

Participants

- Children with SLI
  - N = 29
  - Mean age = 9.1 years [7.08 – 11.5]
- Controll children
  - N = 87
  - Mean age = 9.14 [7.10 – 11.8]

	under08	under09	under10	under11	under12
SLI	5	9	8	4	3
Control	15	27	24	12	9

Implicit motor sequence learning: the serial reaction time task (SRT)

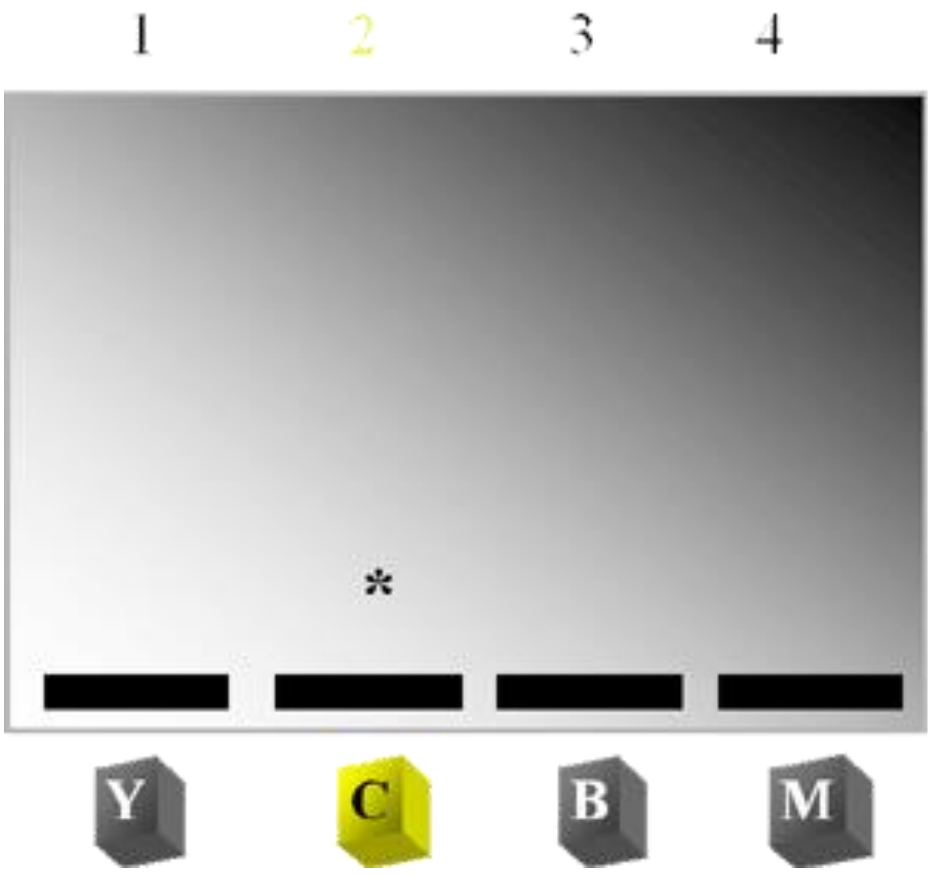
12 long sequence x 5

12 blocks

1-11 repeating sequence,

12 random

x12



Implicit verbal sequence learning: Artificial grammar learning

- Saffran (2002)
  - S → AP + BP + (CP)
  - AP → A + (D)
  - BP → CP + F
  - CP → C + (G)
- 2x58 sentence, ~8 minutes
- Random vs. ordered presentation
- Example sentences:
  - rud neb vot
  - bif gal szig vot
  - bif gal neb rász kav

Category				
A	bif	hep	mib	rud
C	kav	lam	neb	szig
D	lor	gal		
F	dup	dók	rász	vot
G	tez	péf		

Implicit nonsequential learning: probabilistic Category Learning on the Weather Prediction Task

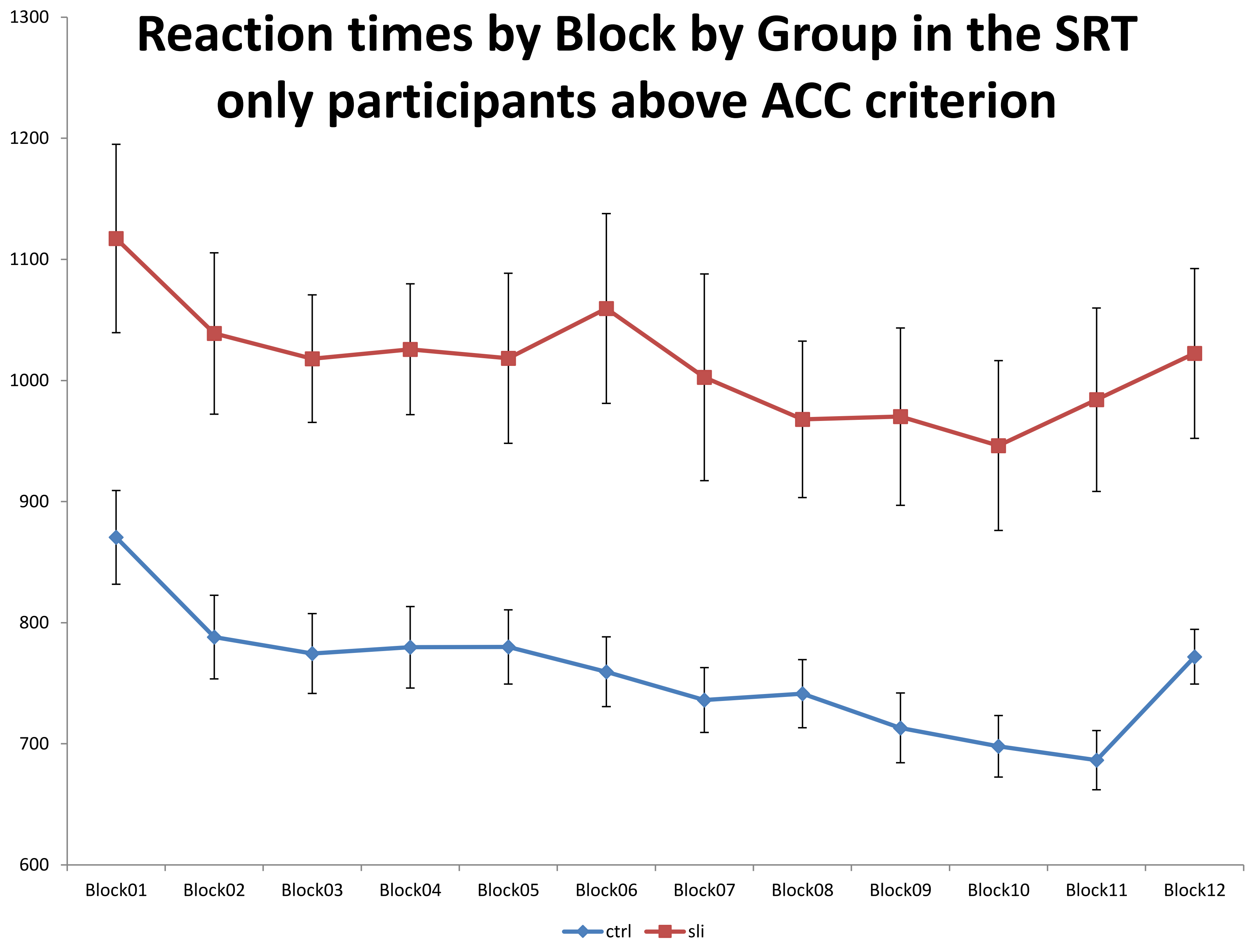
- Predict wether it would be rain or sunshine based on a combination of geometric shapes
  - dichotomic forced choice task
  - Immediate feedback after decision
  - Four cues, predictive values: 85,7%, 70%, 30%, 14,3%

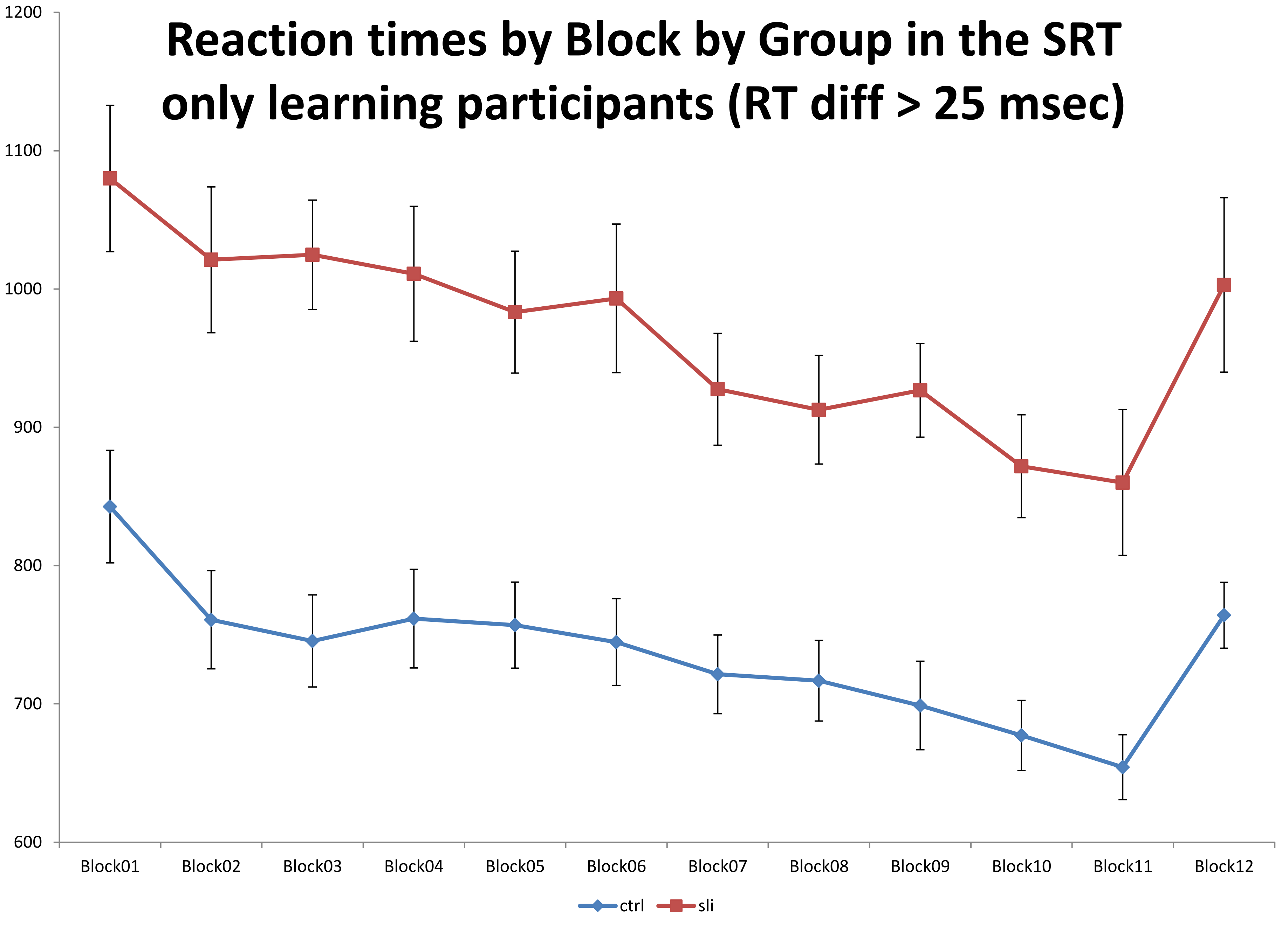
The percentage of learners in each category by group in the three tasks

Task	Group	Learners	Non-learners	Other
SRT task***	SLI	32.14%	25.00%	42.86%
	CTRL	77.01%	9.20%	13.79%
AGL task*	SLI	25.00%	53.57%	21.43%
	CTRL	56.32%	31.03%	12.64%
WP task	SLI	48.28%	41.38%	10.34%
	CTRL	57.47%	27.59%	14.94%

Learners: AGL, WP >55%, SRT: 12-11 >25msec

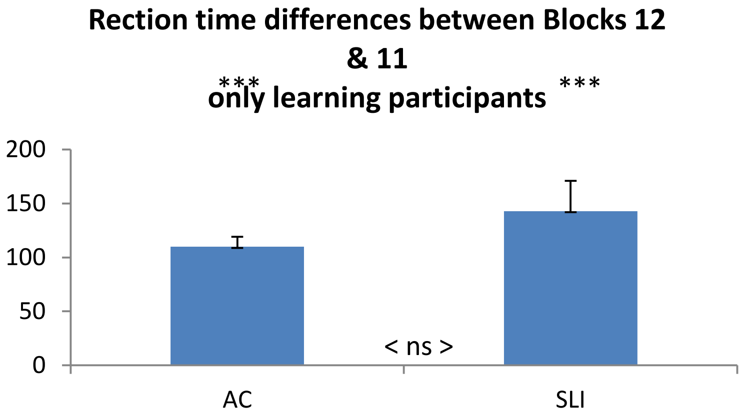
Non-learners: AGL, WP bw 45% and 55%, SRT: 12-11 <25msec

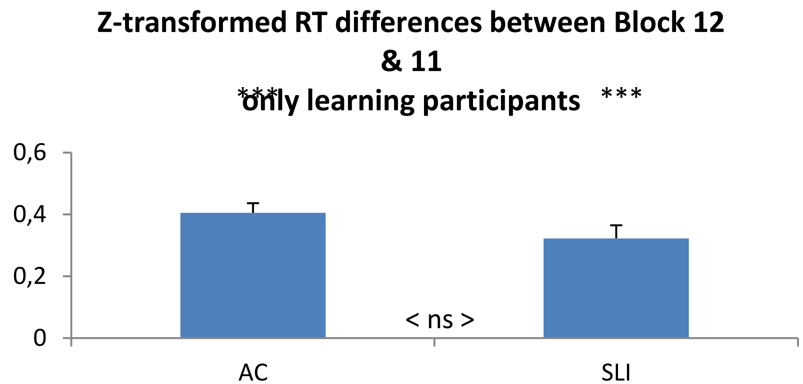

Reaction times by Block by Group in the SRT
only participants above ACC criterion
1300
1200
1100
1000
900
800
700
600
Block01
Block02
Block03
Block04
Block05
Block06
Block07
Block08
Block09
Block10
Block11
Block12
ctrl
sli

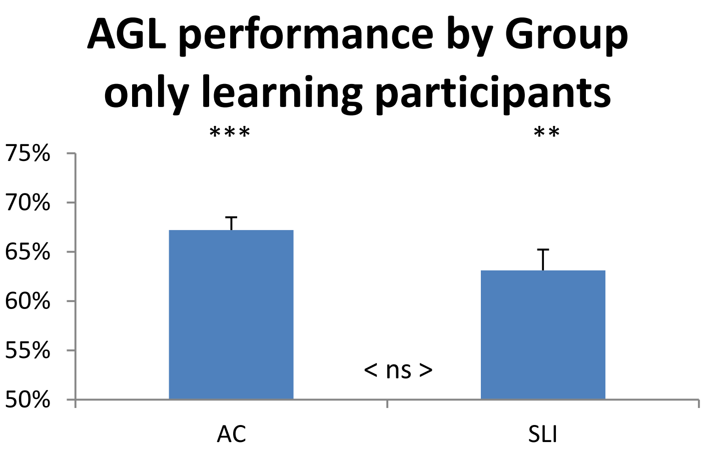


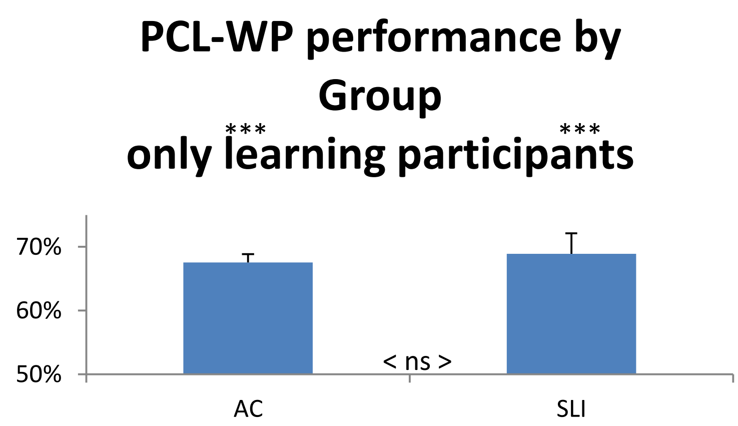
Reaction times by Block by Group in the SRT only learning participants (RT diff > 25 msec)
1200
1100
1000
900
800
700
600
Block01
Block02
Block03
Block04
Block05
Block06
Block07
Block08
Block09
Block10
Block11
Block12
ctrl
sli

Raw RT and Z-transformed RT differences between Blocks 12 & 11









Results

- For the two implicit sequence learning tasks, a significantly smaller proportion of children showed any evidence of learning in the SLI than in the TD group
- The difference was more evident for the AGL task
- The proportion of learners on the PCL task was the same in the SLI and TD groups.
- The amount of learning for learners was overall comparable in the two groups (with great individual variation).

Conclusions

- Domain-general processes of skill learning are vulnerable in SLI
- The deficit primarily affects tasks with sequentially organized stimuli
  - Is it *restricted* to the sequential domain?
- The sequence learning deficit is only present in a subgroup of children with SLI
  - Heterogeneity of SLI (and TD children too)
- Further research is needed to clarify the relationship of deficits in skill learning and language

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