Is Memetics a Science? Lessons from Language Evolution

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Thanks to My Collaborators

- Nick Chater
- Florencia Reali
- Luca Onnis
- Bruce Tomblin
- Patricia Reeder
- Chris Conway

Memes as Replicators (Dawkins, 1976)

- A meme is "a unit of cultural transmission, or a unit of *imitation*"
- Memes are subject to natural selection
- Memetic survival qualities
  - longevity
  - fecundity
  - copying-fidelity

Memes and the Ideosphere

- Most meme belong to the ideosphere:
  - wearing baseball caps backwards
  - catchy tunes
  - scientific ideas
- Memes tend to derive from incremental processes of intelligent design, explicit evaluations, and decisions to adopt
- Memes are products of "*sighted watchmakers*"

Can memetics help us understand the specific nature of particular cultural products?

Memes and Language

- Blackmore (1999) suggests that language evolved through imitation-based competition between words and expressions as a vehicle for meme transmission
- van Driem (2005) argues that memes should be construed as meanings mediated by linguistic forms, whose competition drives language evolution

→ Brain adaptations for language memes

Memes vs. Language

Memes	Language
no biological constraints on evolution	evolution constrained by biology
no intrinsic link between brains and memes	close fit between brains and language
acquired through conscious effort and/or instruction	effortless acquisition with milestones
no universality	species universal

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You are in: **Science/Nature**

Wednesday, 14 August, 2002, 18:09 GMT 19:09 UK

First language gene discovered

A few changes in a gene explains why chimps can't talk

By Helen Briggs
BBC News Online science reporter

Scientists think they have found the first of many genes that gave humans speech.

Without it, language and human culture may never have developed.

See also:

03 Oct 01 | Science/Nature
Scientists unlock mysteries of speech

28 Mar 00 | Science/Nature
'Single mutation led to language'

24 May 02 | Science/Nature
Smart chimps get their reward

Internet links:

Nature
Wellcome Trust Centre for Human Genetics
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Date for first Australians
Fifth closest star

Cultural Transmission of Language

- *"… much of the replicative information needed to perpetuate language is stored in culture, not in the genes."* Donald (1998: p. 50)
- *"… the actual grammatical structures of modern languages were humanly created through processes of grammaticalization during particular cultural histories, and through processes of cultural learning, …"* Tomasello (2000: p. 163)
- *"… language evolved* culturally *as a more or less cumulative set of 'inventions' that exploited the pre-adaptation of a brain that was 'language ready' but did not genetically encode general properties of, for example, grammar."* Arbib (2003; p. 182)

Language Evolution through Cultural Transmission

- Emerging perspective on language evolution:

  E.g.: Arbib (2003), Christiansen (1994), Davidson (2003), Deacon (1997), Donald (1998), Givon (1998), Kirby & Hurford (2002), Tomasello (2003)

  - Grammatical structure emerged through cultural transmission of language across many generations of learners

  - Grammatical structure is not a product of biological evolution

Problems with Cultural Transmission

- Cultural transmission alone cannot explain:
  - the complex and intricate structure of language
  - the existence of language universals
  - the close match between language and underlying mechanisms
  - the species-specificity and species-universality of human language
- Innate constraints on cultural transmission are needed

"It's not a question of Nature vs. Nurture; the question is about the Nature of Nature."

Liz Bates

Outline

- Language as shaped by the brain
- Neural bases for processing sequential information and language
- Sequential learning and language acquisition
- Genetic bases for sequential learning and language
- Conclusions

Language as Shaped by the Brain

Language Learning and Evolution

- Why is language learnt so readily, and why is language structured the way it is?
- ~~Why is the brain so well-suited for learning language?~~
- Why is language so well-suited to being learned by the brain?
- Cultural transmission has shaped language to be as learnable/usable as possible by human brain mechanisms

E.g., Christiansen (1994), Deacon (1997), Kirby (2000)

Language as an Organism

- Highly complex systems of interconnected constraints
- Evolved in a symbiotic relationship with the human brain
- Adaptive complexity arises from random linguistic variation winnowed by selectional pressures deriving from the brain
- Product of *"blind watchmakers"*

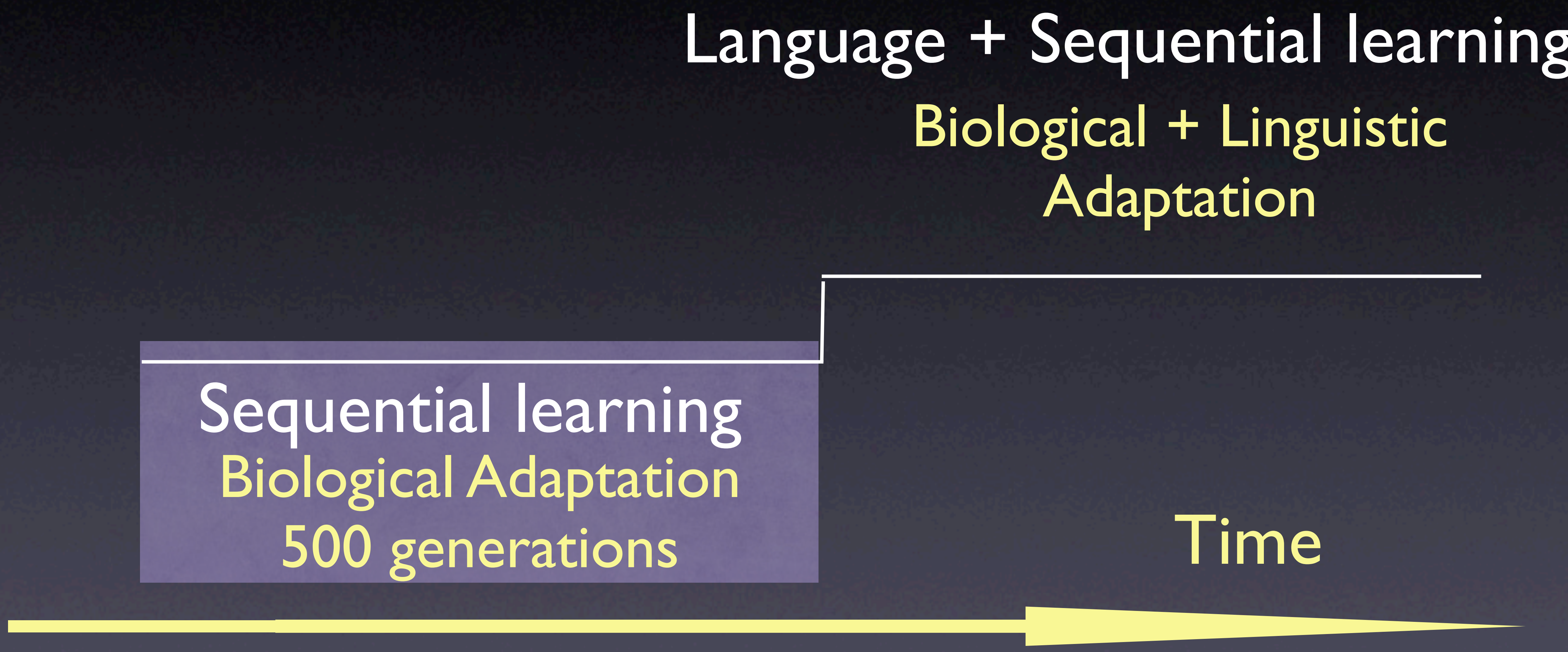
Multiple Constraints

- Constraints from thought
- Pragmatic constraints
- Perceptuo-motor factors
- Cognitive constraints on learning and processing

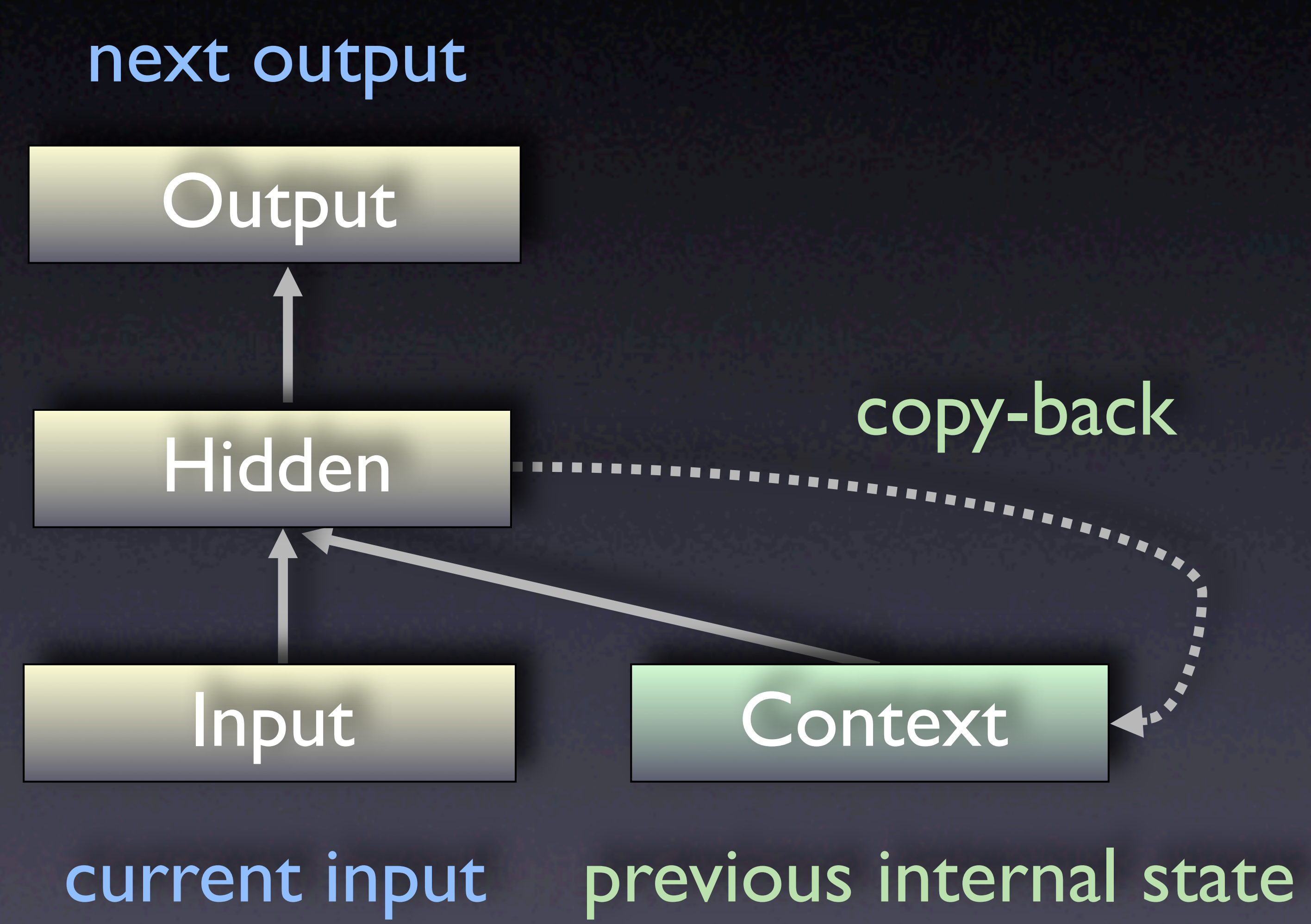
How to Explain Word Order?

- Classical view:
  - X-bar Theory (Chomsky, 1986)
  - Biological adaptation – part of UG (Pinker, 1994)
- Alternative perspective:
  - Word order regularities emerged through cultural transmission of language across many generations of learners/users
  - Word order is not a product of biological evolution

Simulation Overview



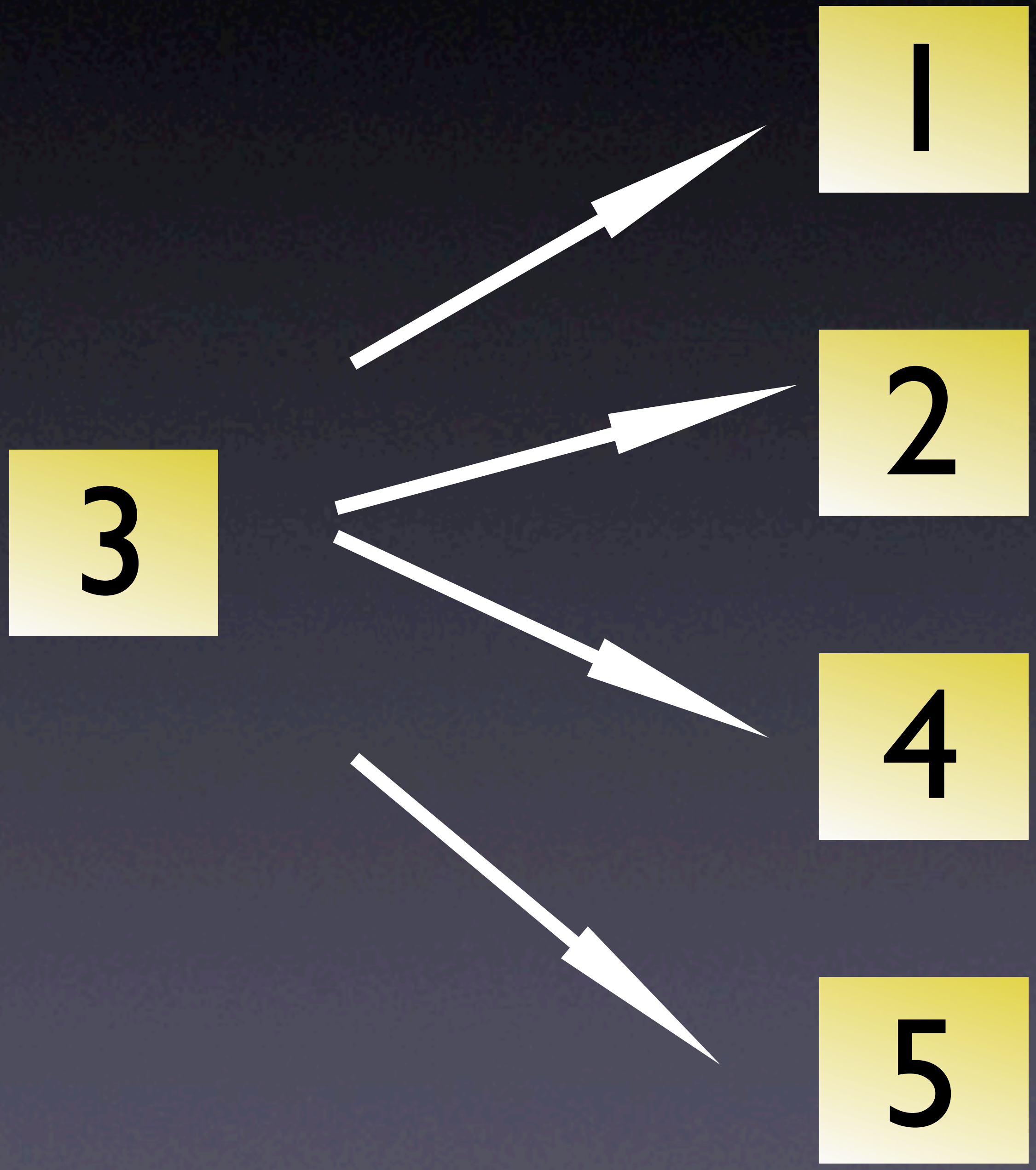
The Learners: SRNs



Simple Recurrent Network (Elman, 1990)

The Sequential Learning Task

- Networks were trained on a serial reaction time learning task (Lee, 1997)
  - Input: Sequences of digits from 1-5
  - Task: Predict the next digit
  - Constraint: Digits are presented in random order with no repetition
    - 3 2 4 1 5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1
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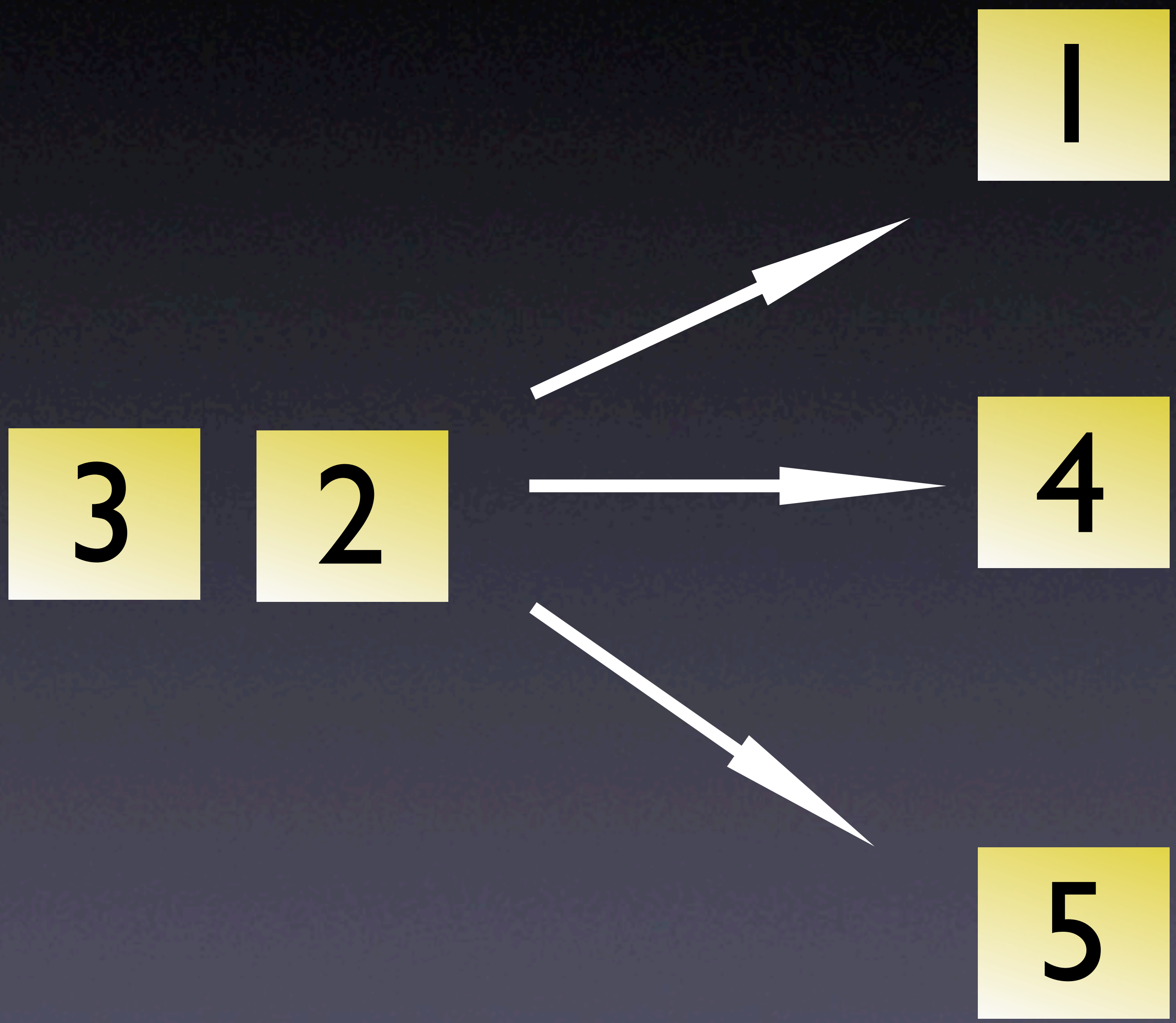

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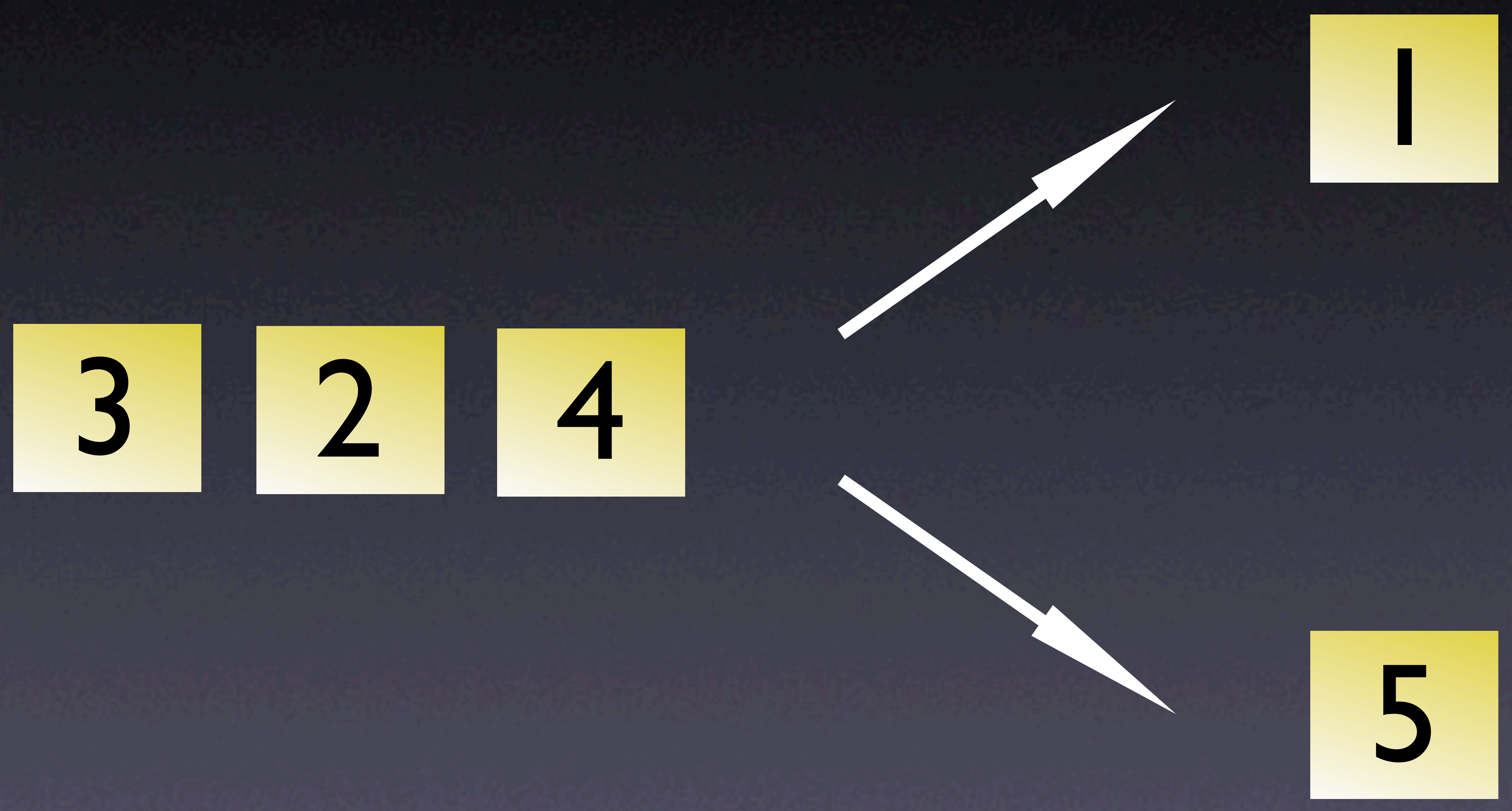
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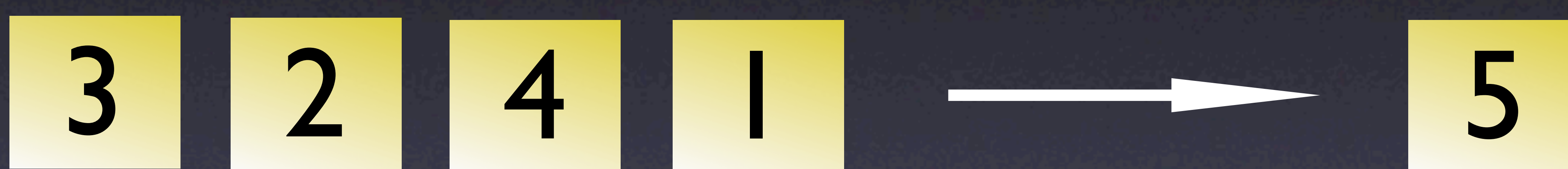

3
2
4
1
5

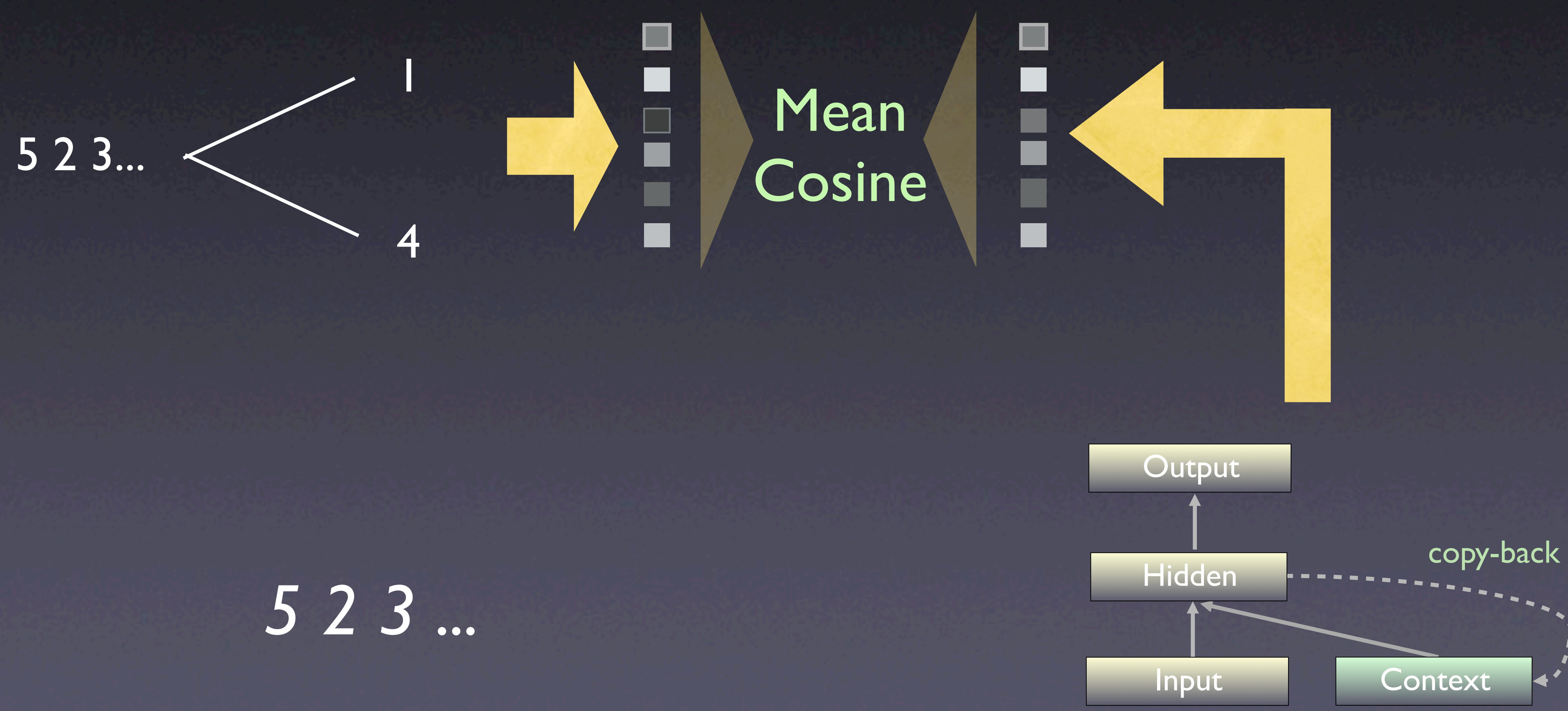
Training Details

- SRNs: 21 input units, 6 output units and 10 hidden and context units
- Localist representation of digits:
  - Input: Four units encoded each digits
  - Output: Each unit encoded one digit and one unit marked the End of String (EOS)
- Training set: 500 random 5-digit sequences
- Test set: 200 random 5-digit sequences

Scoring SL Performance

Full-conditional probability vector for possible next number

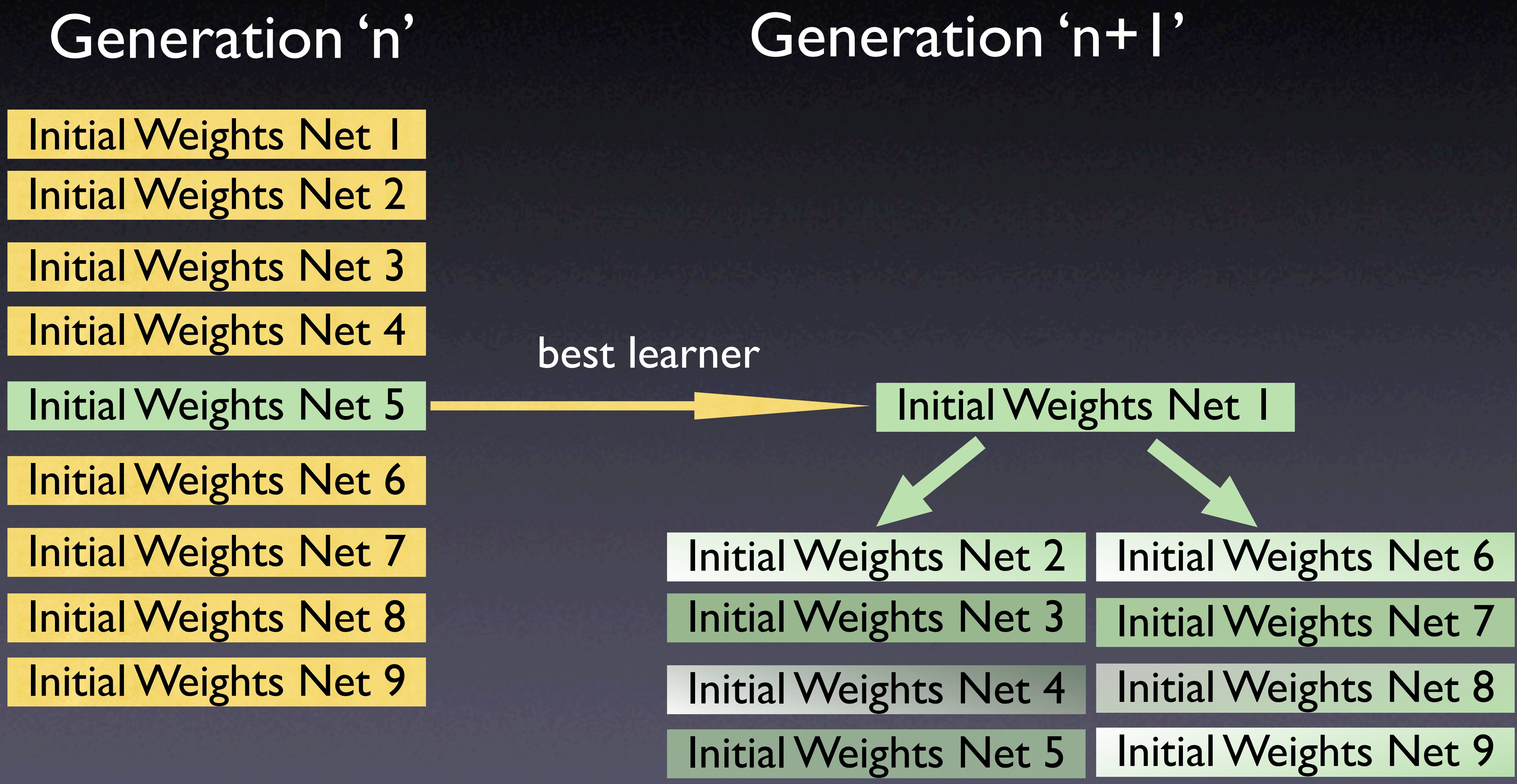
Probability vector for possible next number



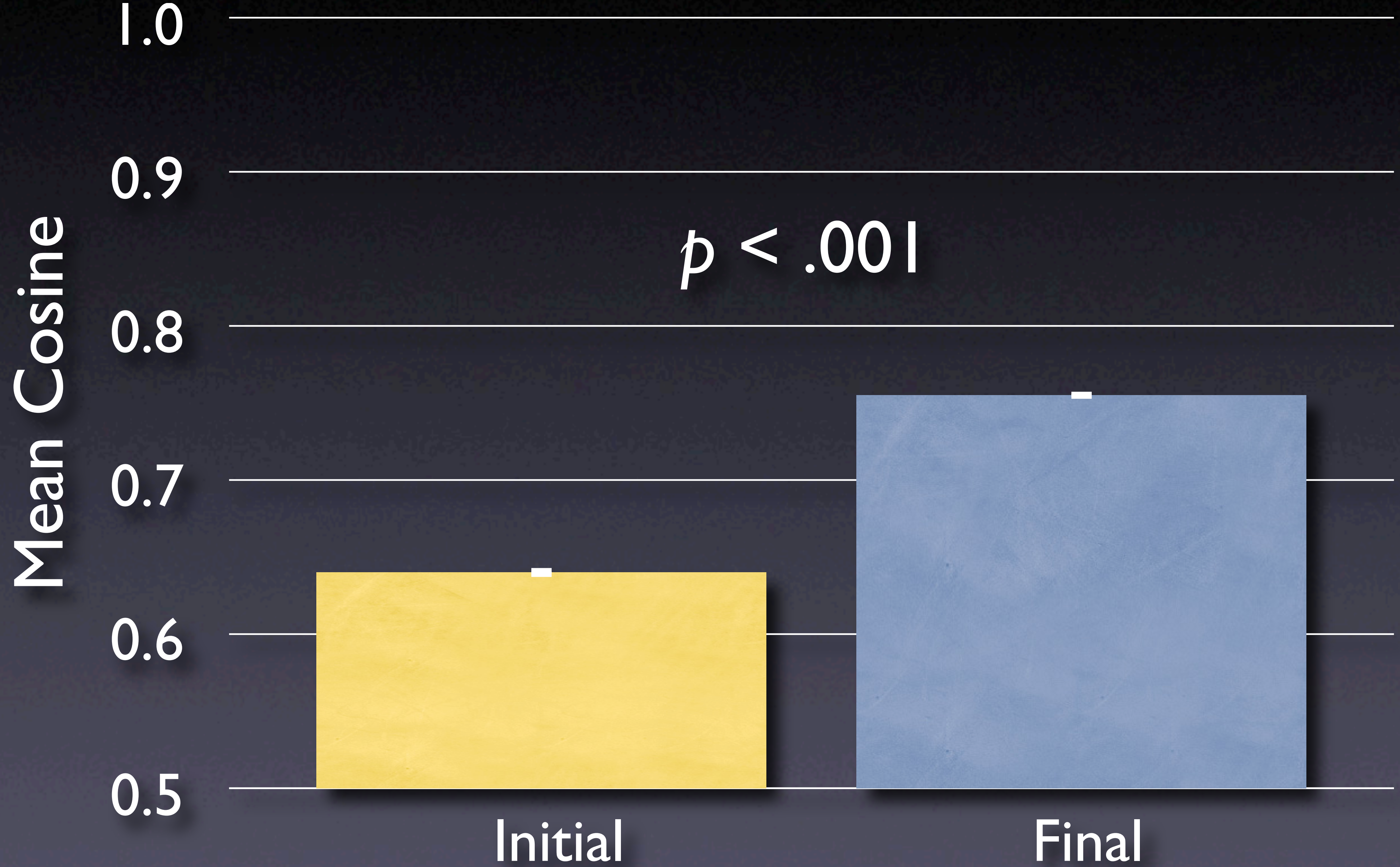
Biological Evolution of SRNs

- SRN "genome": Initial weights prior to learning
- The initial weights for the best learner were selected for each generation
- The winner weights were mutated to produce 8 "offspring"
    - By adding a random normally distributed vector (sd = 0.05) (Batali, 1994)

Biological Evolution in SRNs



Results: 500 Generations



Source: Reali & Christiansen, *Interaction Studies*, in press

Simulation Overview

Language + Sequential learning

Biological + Linguistic Adaptation

Sequential learning

Biological Adaptation

500 generations

Time

Linguistic and Biological Evolution

- Languages: 5 different languages compete each generation
- Linguistic Adaptation: Best learnt language survives and produces 4 "offspring"
- Biological Adaptation: Networks are selected based on their linguistic performance
- SL Constraint: Only networks performing minimally at average level on the sequential learning task were selected

Grammar Skeleton

S	→	{NP VP}	(1)
NP	→	{N (PP)}	(2)
PP	→	{adp NP}	(3)
VP	→	{V (NP) (PP)}	(4)
NP	→	{N PossP}	(5)
PossP	→	{Poss NP}	(6)

Grammar Example

S	→	VP NP	(Head Final)
NP	→	N (PP)	(Head First)
PP	→	adp NP | NP adp	(Flexible)
VP	→	V (NP) (PP)	(Head First)
NP	→	PossP N	(Head Final)
PossP	→	Poss NP | NP Poss	(Flexible)

Networks

- Input Layer (21 units):
  - Localist encoding of the vocabulary
    - 8 nouns, 8 verbs, 3 adp, 1 poss and EOS
- Output layer (6 units):
  - Localist encoding of the grammatical roles
    - Object, Subject, Adp, Verb, Poss and EOS

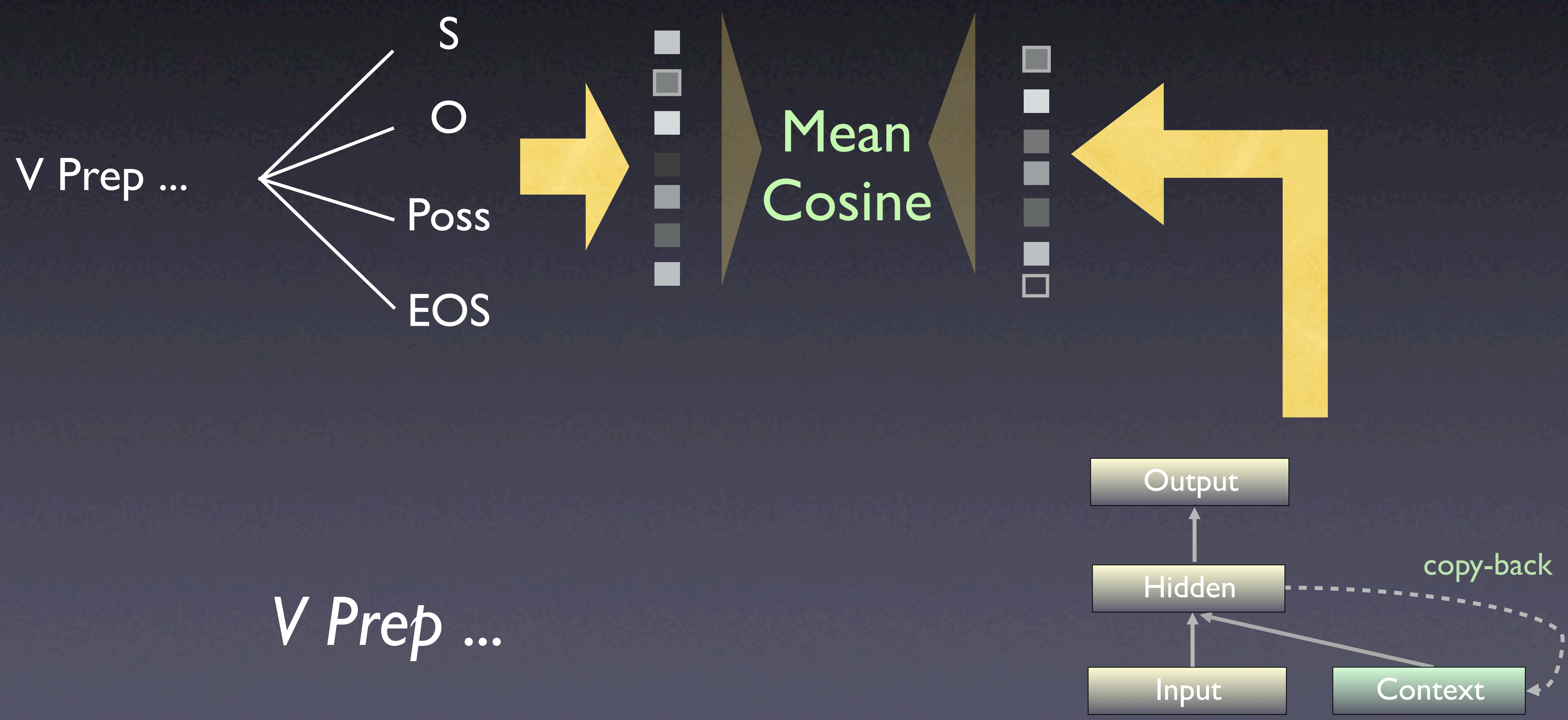
Linguistic Task

- Task: Predict next grammatical role in a sentence
- Training corpus: Learning from 1,000 sentences from each grammar
- Test corpus: Processing of 100 sentences from each grammar

Scoring Language Performance

Full-conditional probability vector for possible next grammatical roles

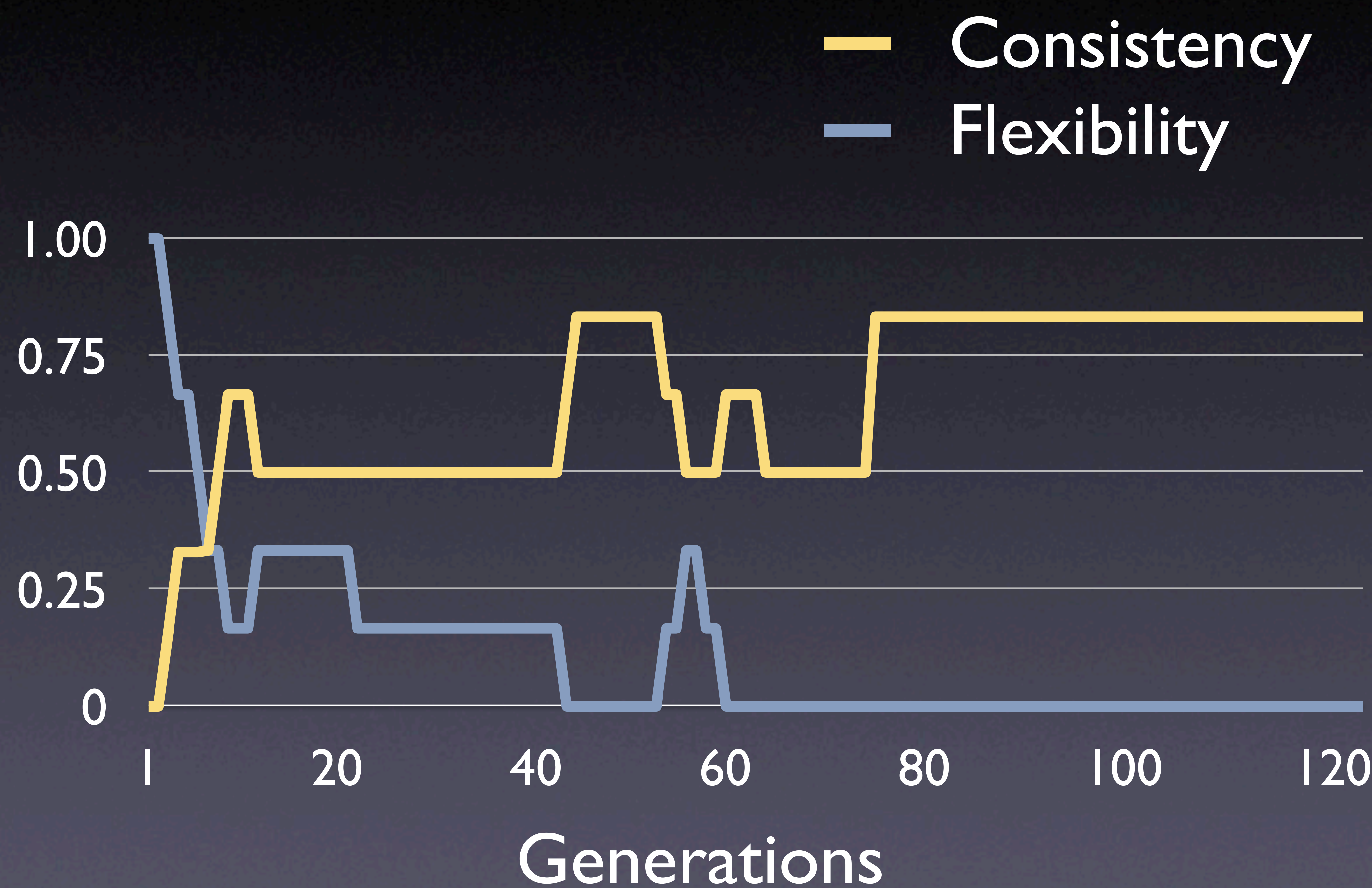
Probability vector for possible next grammatical roles



Linguistic Evolution

- Initial state: All flexible head ordering
- Language variation: Random mutations in the head order of any re-write rule
- Mutation rate: A re-write rule mutates with a probability of 1/12
- When the same language is selected for 50 consecutive generations the simulation stops and that language is considered the "winner language"

Winner Language Over Time

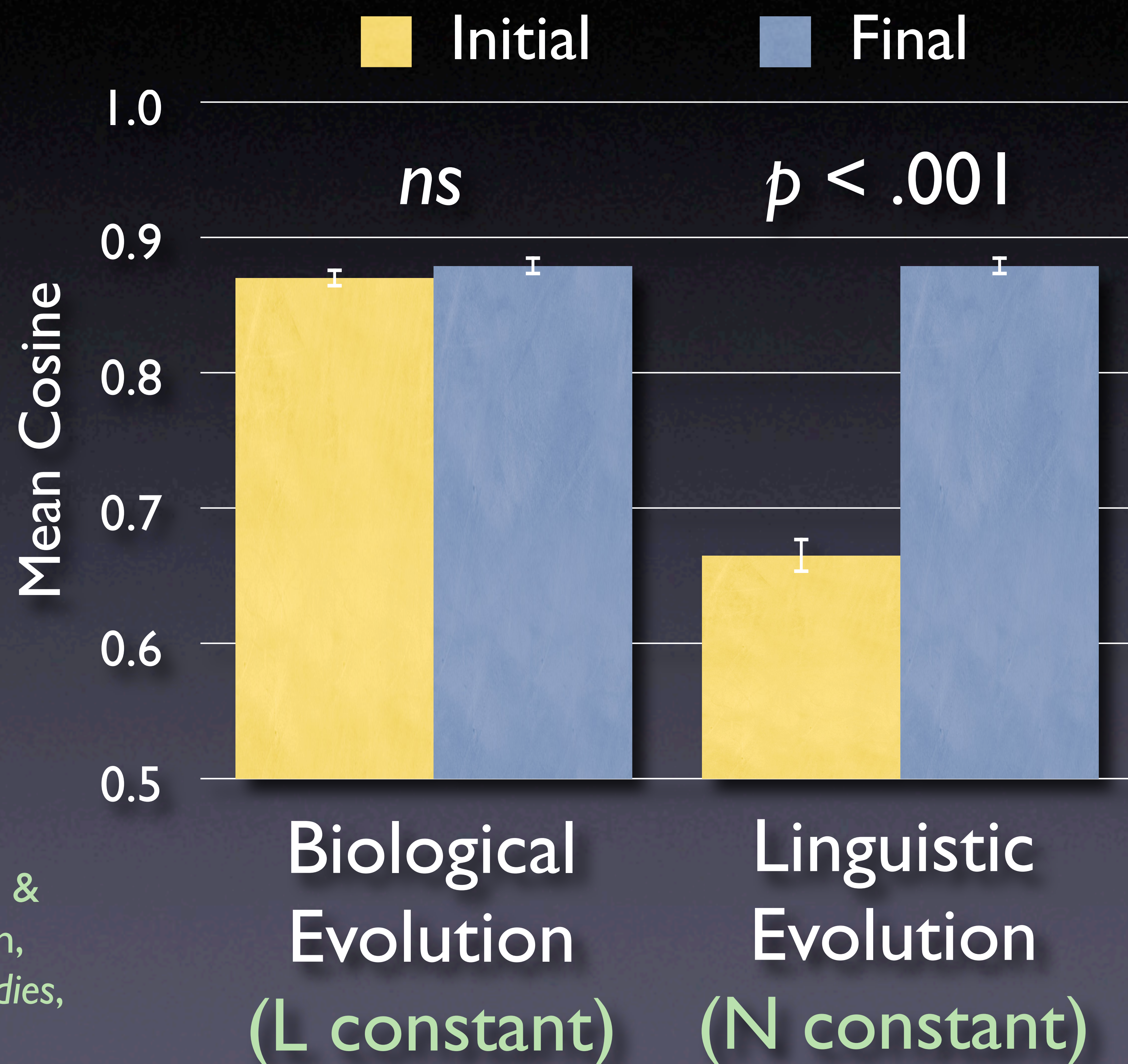


Source: Reali & Christiansen, *Interaction Studies*, in press

Evolving Head-Order Consistency

- Flexibility: No flexible re-write rules
- Consistency: All winner languages had 5 re-write rules with the same head order (out of 6)
- Head Order: All winner languages were SOV

Biological vs. Linguistic Adaptation



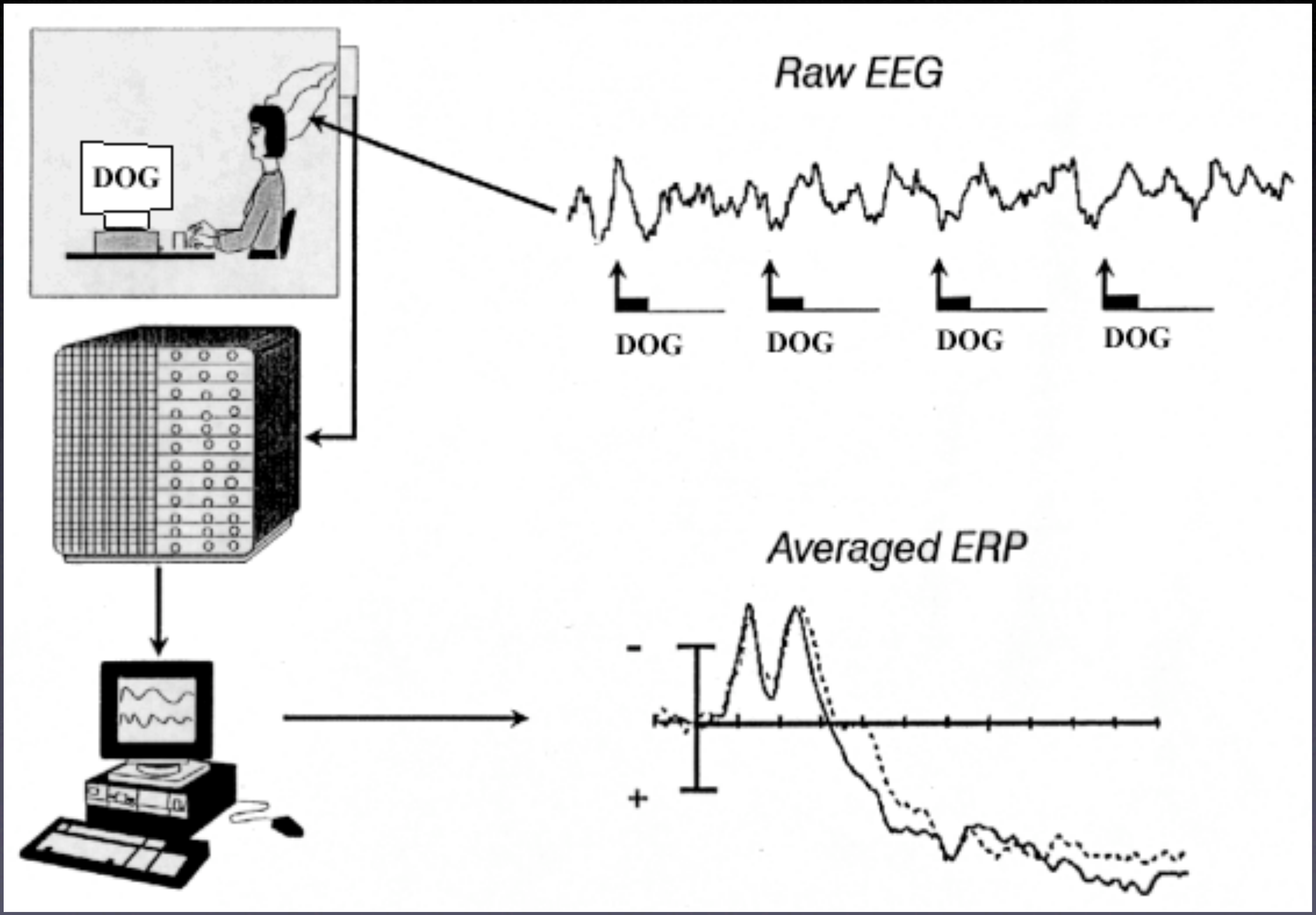
Source: Reali & Christiansen, *Interaction Studies*, in press

Interim Summary (I)

- If language and learners evolve simultaneously, linguistic adaptation constrained by sequential learning overpowers biological adaptation
- Sequential learning constraints become embedded in the structure of language
- Linguistic forms that fit these biases are more readily learned, and hence propagated more effectively from speaker to speaker

Neural Bases for Processing Sequential Information and Language

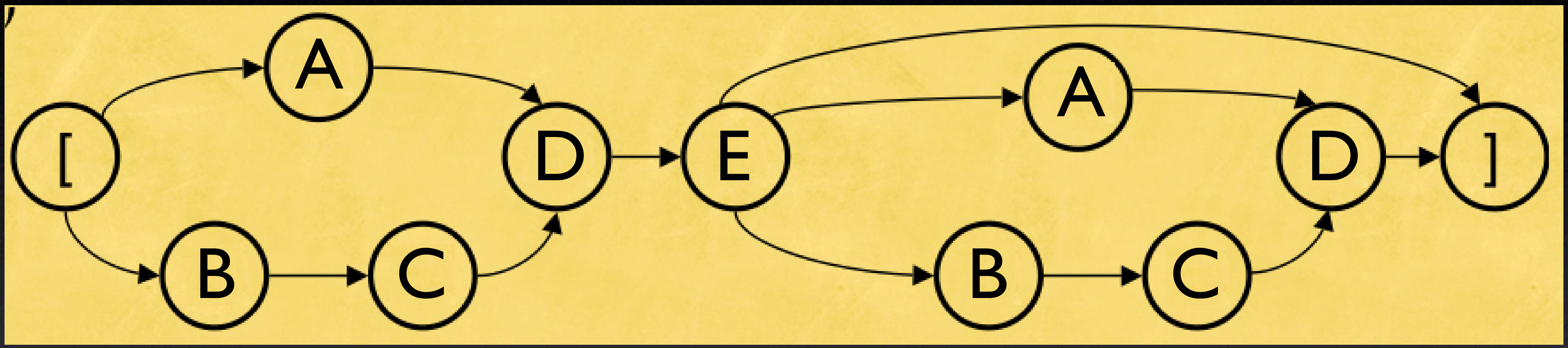
Event-Related Potentials (ERP)



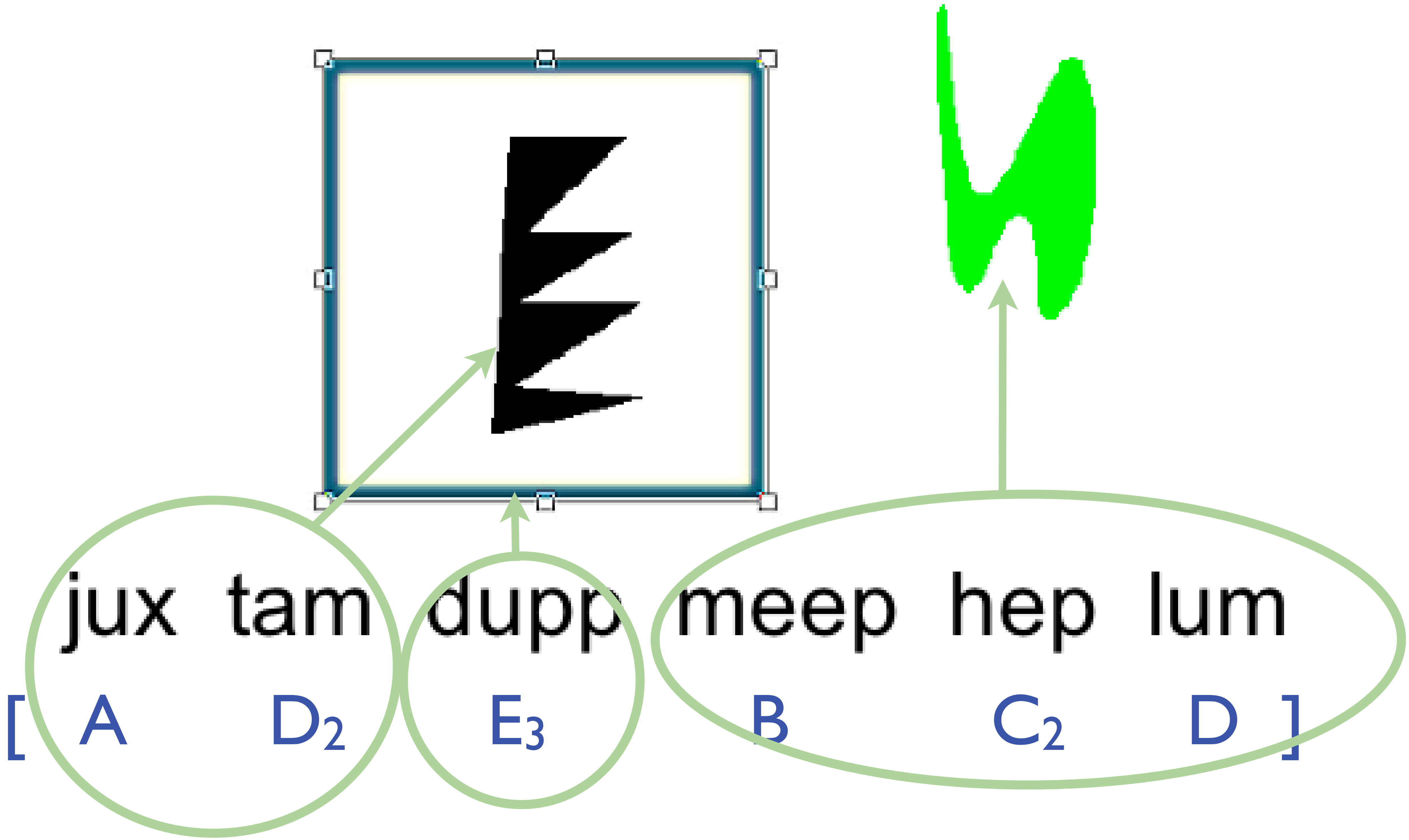
ERP Experiment

- Same set of participants (N=18) engaged in 2 tasks involving on-line processing of
  - sequential information
  - language

Sequential Learning Stimuli



- 5 categories of stimuli and 10 tokens:
  - A (1), B (1), C (2), D (3), E (3)
- Tokens:
  - *jux, dupp, hep, meep, nib, tam, sig, lum, cav,* and *biff*


jux tam dupp meep hep lum
[A D2 E3 B C2 D]

Sequential Learning Procedure

- Learning Phase
  - Unsupervised learning
  - Sequences shown along with visual referents
    - Four-stage, increasing complexity
- Test Phase: 60 new sequences
  - 30 legal and 30 illegal
    - B C_1 D_3 E_1 A D_2
    - B C_1 D_3 D_1 A D_2

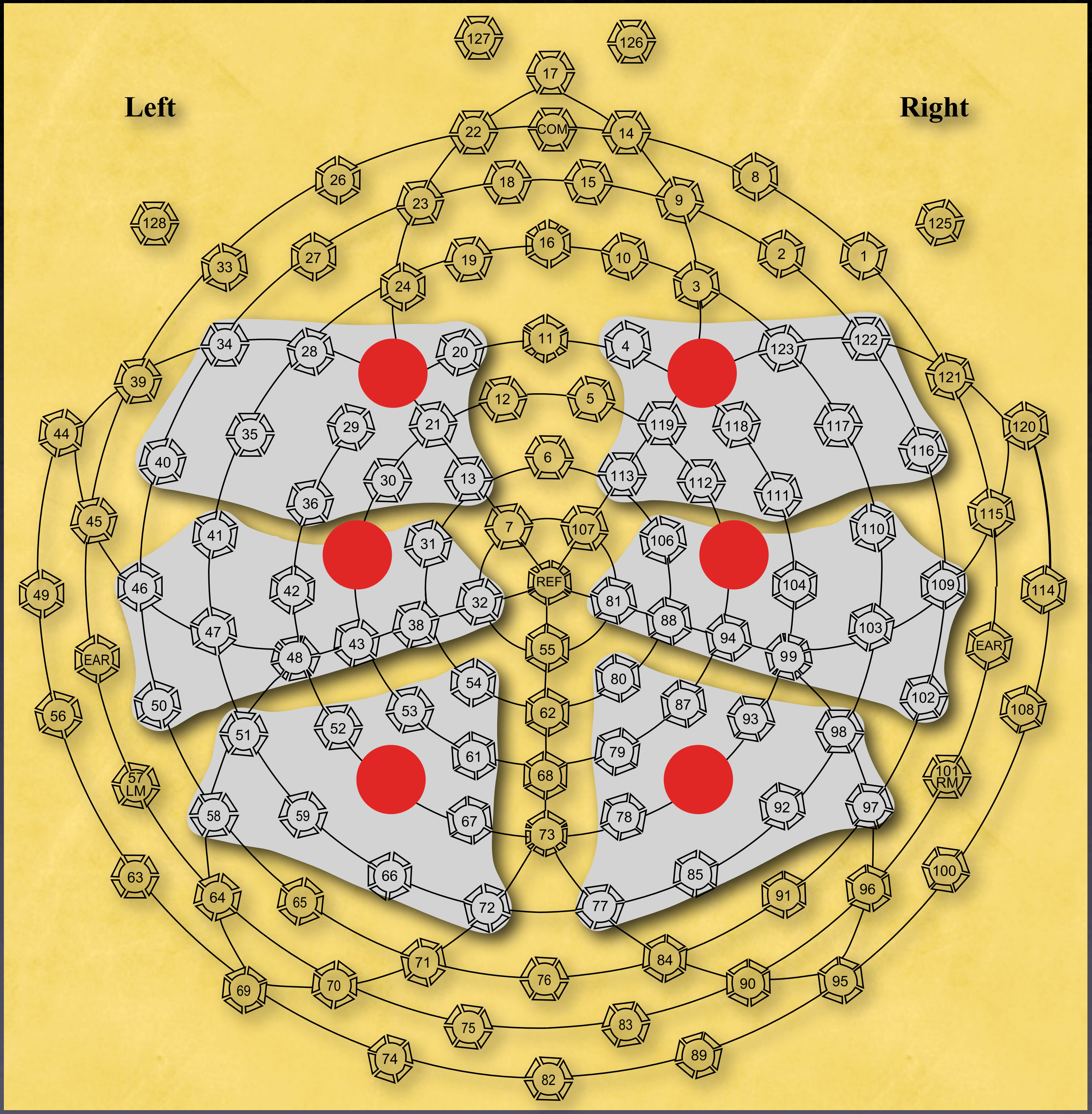
Natural Language Task

- Processing natural language sentences, some with subject-noun/verb agreement violations
  - *Most cats like to play outside.*
  - *Most cats likes to play outside.*
- 60 sentences + fillers
  - 30 grammatical and 30 ungrammatical
  - Sentence presented one word at a time

Behavioral Results

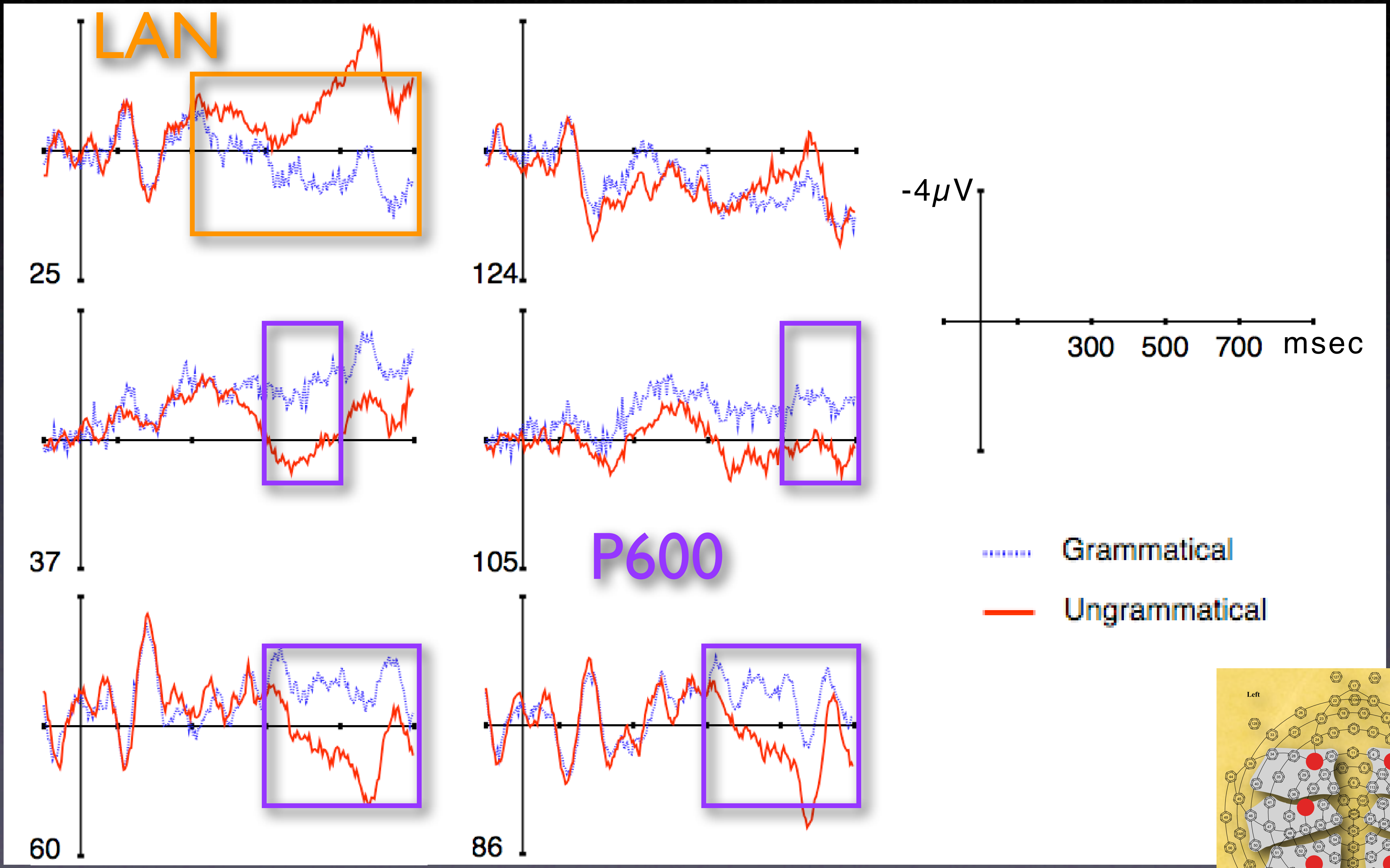
- Behavioral dependent variable:
  - classification accuracy
- Sequential learning: 93.9% correct
- Natural language: 92.9% correct

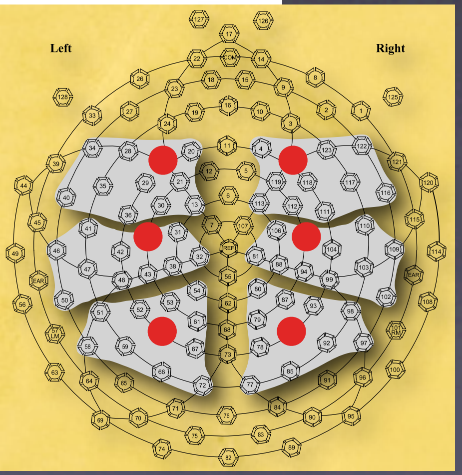
ERP Regions of Interest



Source: Barber & Carreiras, *Jrnl Cog Neuro*, 2005

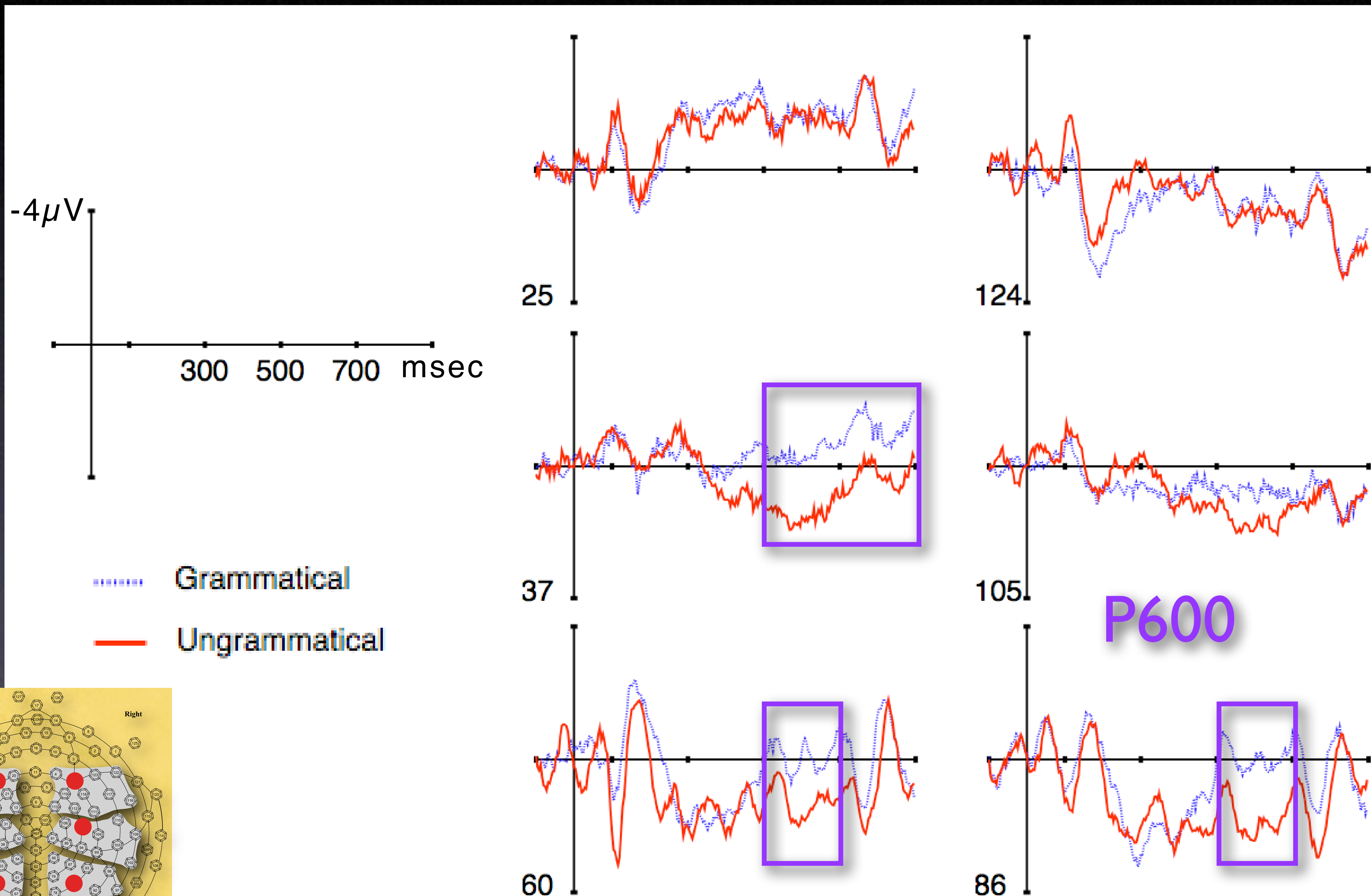
Natural Language ERPs

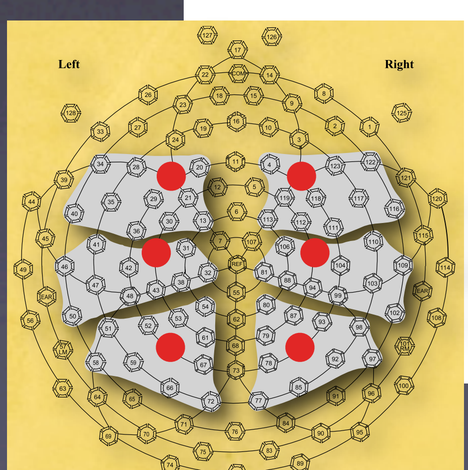




Source: Christiansen, Conway & Onnis, *Proc. Cogn. Sci. Soc.*, 2007

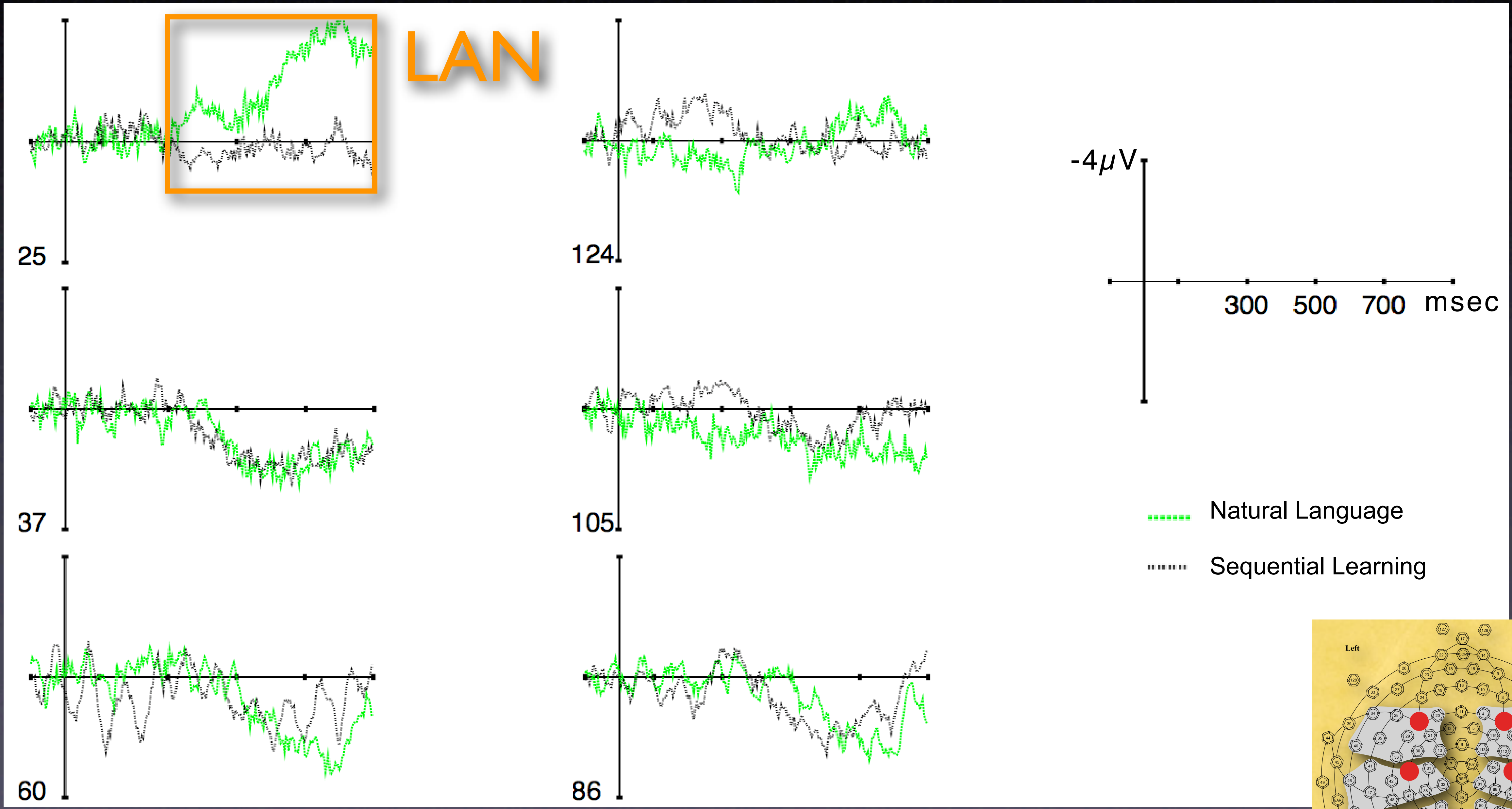
Sequential Learning ERPs

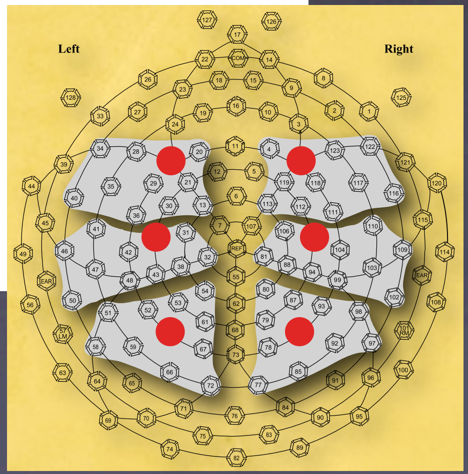




Source: Christiansen, Conway & Onnis, *Proc. Cogn. Sci. Soc.*, 2007

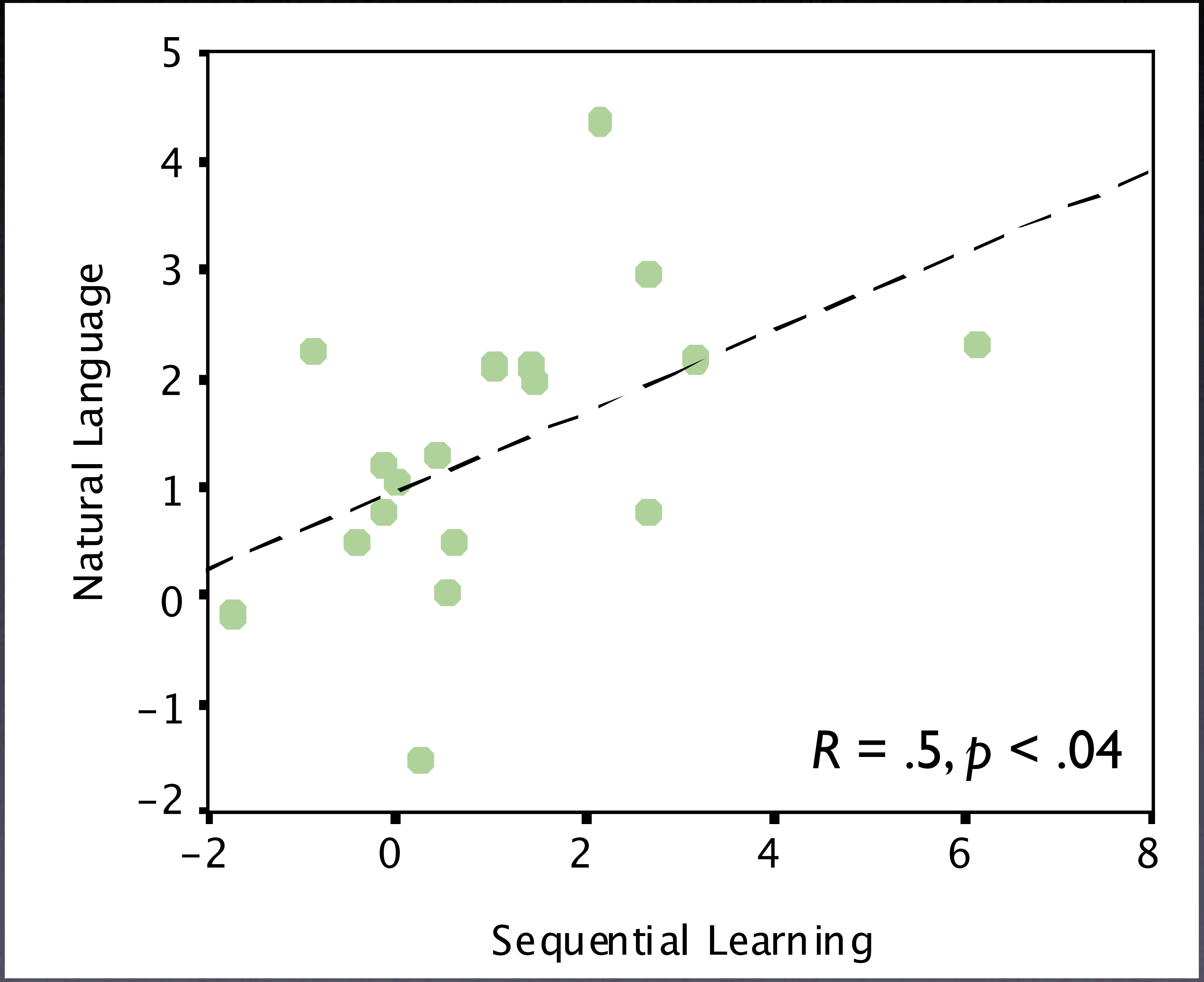
Difference Waves





Source: Christiansen, Conway & Onnis, *Proc. Cogn. Sci. Soc.*, 2007

Using Sequential Learning P600 to Predict Natural Language P600



Source: Christiansen, Conway & Onnis, *Proc. Cogn. Sci. Soc.*, 2007

Interim Summary (II)

- Similar P600 effect for incongruencies in sequential learning and language
- The P600 component is an indication of violation of expectations
- Same neural mechanisms used for processing sequential learning and language

Sequential Learning and Language Acquisition

Innate Cognitive Constraints on Sequential Learning

- Language universals reflect cognitive constraints on sequential learning and processing, rather than innate linguistic knowledge
- Prediction: Evidence of the innate cognitive constraints underlying linguistic universals should still be present in human performance on sequential learning

Sequential Learning Experiment

Consistent Grammar			Inconsistent Grammar		
S	→	NP VP	S	→	NP VP
NP	→	(PP) N	NP	→	(PP) N
PP	→	NP post	PP	→	pre NP
VP	→	(PP) (NP) V	VP	→	(PP) (NP) V
NP	→	(PossP) N	NP	→	N (PossP)
PossP	→	NP Poss	PossP	→	Poss NP

Vocabulary: *jux, dupp, hep, meep, nib, vot, rud. lum, cav, biff*

Experimental Design

- Conditions
  - Training on Consistent vs. Inconsistent grammar
- Training Phase
  - 3 blocks of 30 grammatical items
- Test Phase
  - 30 novel grammatical items
  - 30 ungrammatical items

Experimental Procedure

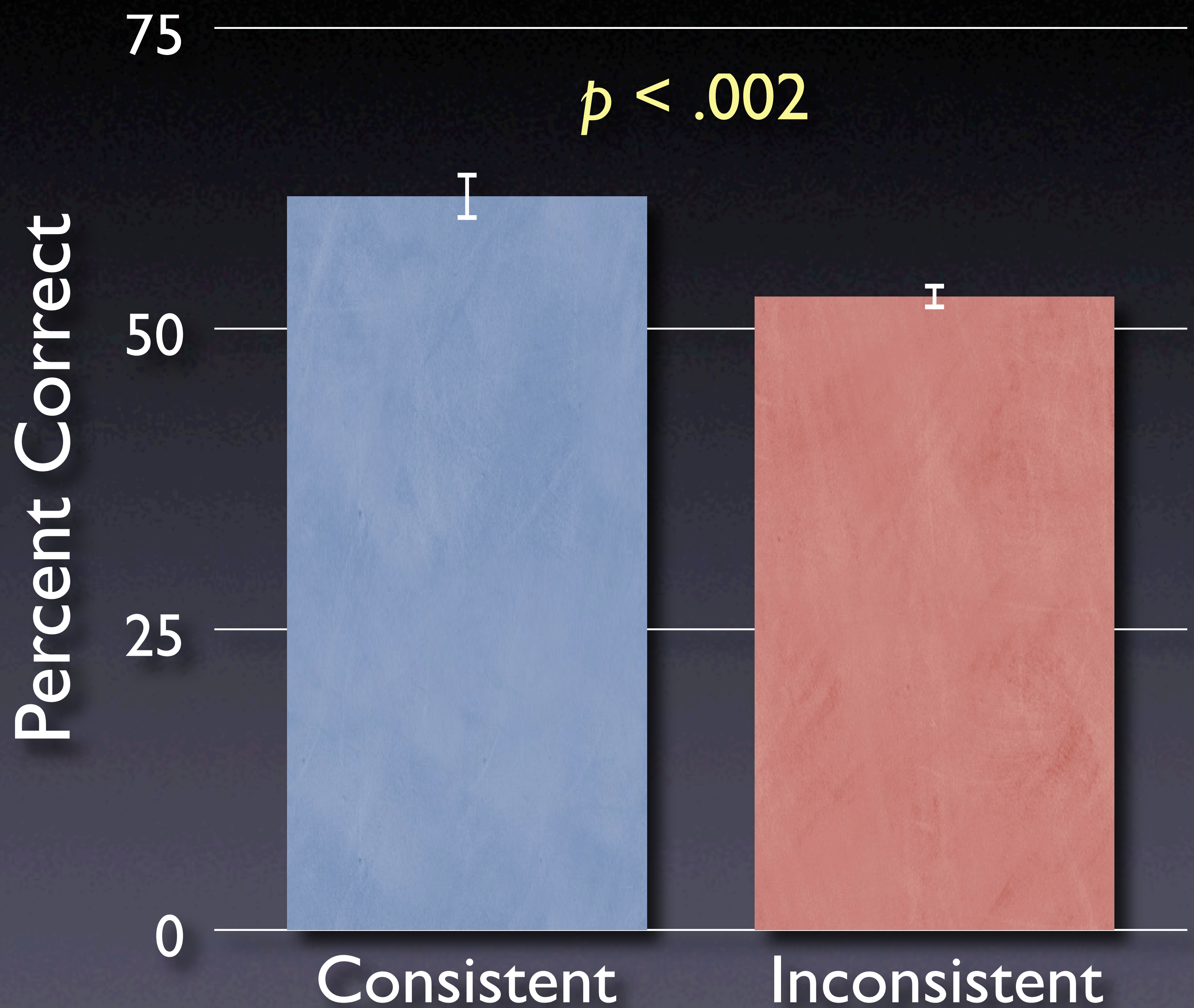
Training

Consistent	Inconsistent
jux vot hep vot meep nib	*jux meep hep vot vot nib*

Testing

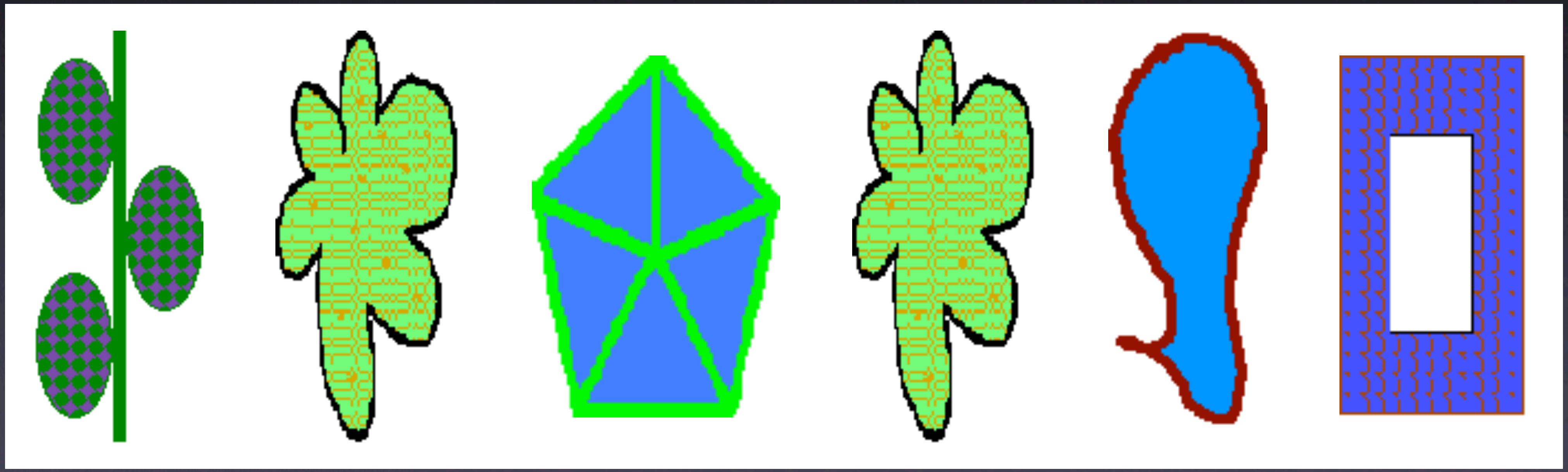
Grammatical	Ungrammatical
cav hep vot lum meep nib	*cav hep vot rud meep nib*

Classification Performance

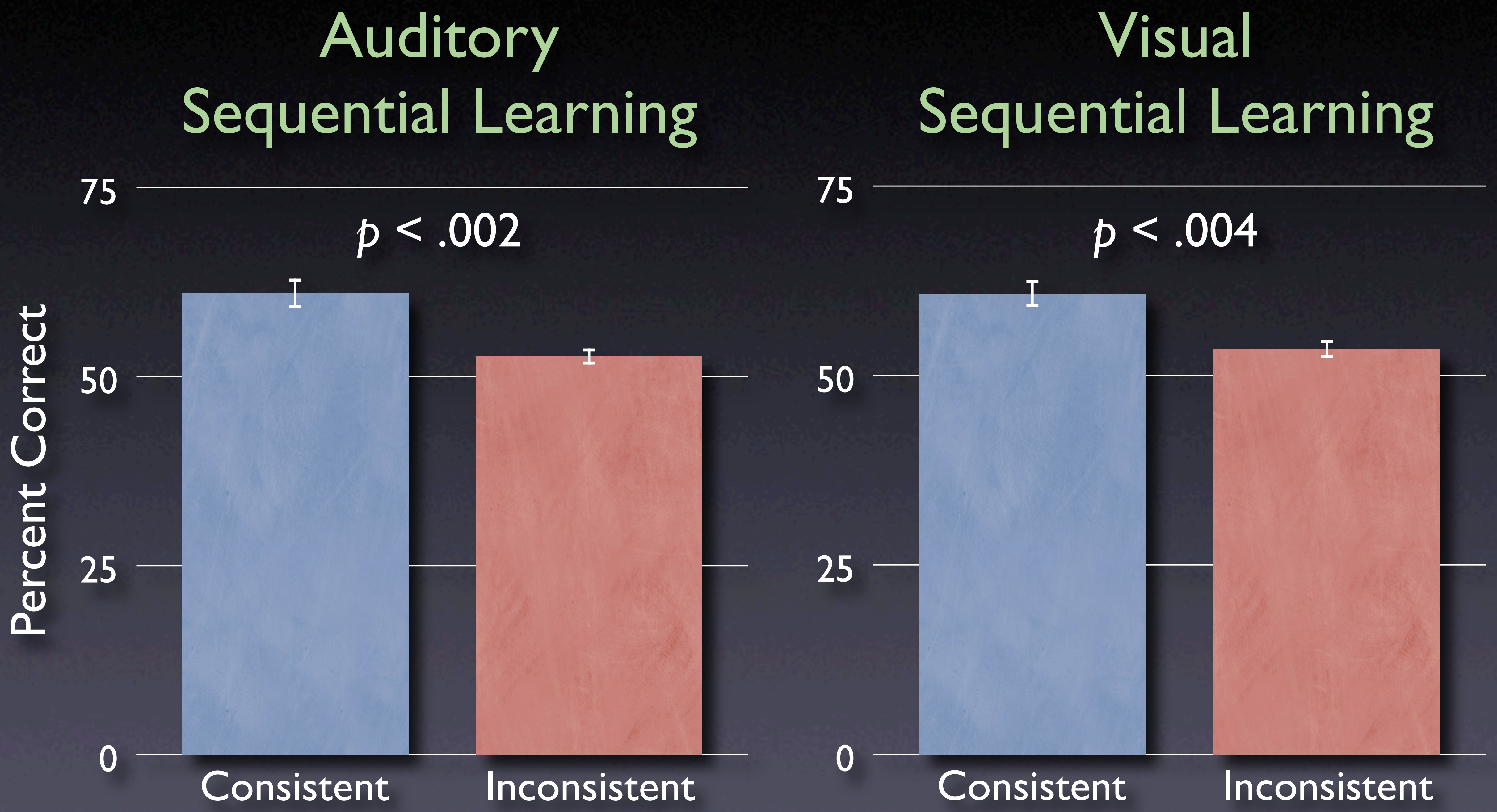


Source: Christiansen & Reeder (in prep)

Visual Sequence Learning



Classification Performance



Source: Christiansen & Reeder (in prep)

Interim Summary (III)

- Constraints on sequential learning give rise to specific patterns of acquisition
- Word order universals may be seen as "fossilized" sequential learning constraints

Genetic Bases for Sequential Learning and Language

FOXP2 (I)

- *FOXP2* = Forkhead bOX P2 (Lai et al, 2001)
  - codes for transcription factors – i.e., affects the expression other genes
- *FOXP2* mutation leads to brain abnormalities
  - caudate nucleus (Vargha-Khadem et al., 1998)
- *FOXP2* is also expressed in the embryonic development of the lungs, heart and gut

Molecular Evolution of *FOXP2*

- *FOXP2* is very well preserved in evolution
  - Only one amino acid change in the 75 million years since mice and chimps diverged
  - But 2 changes in the 6 million years since humans and chimps diverged
  - Became fixed in humans about 200,000 years ago
- Neanderthals have the human version of *FOXP2*

FOXP2 (II)

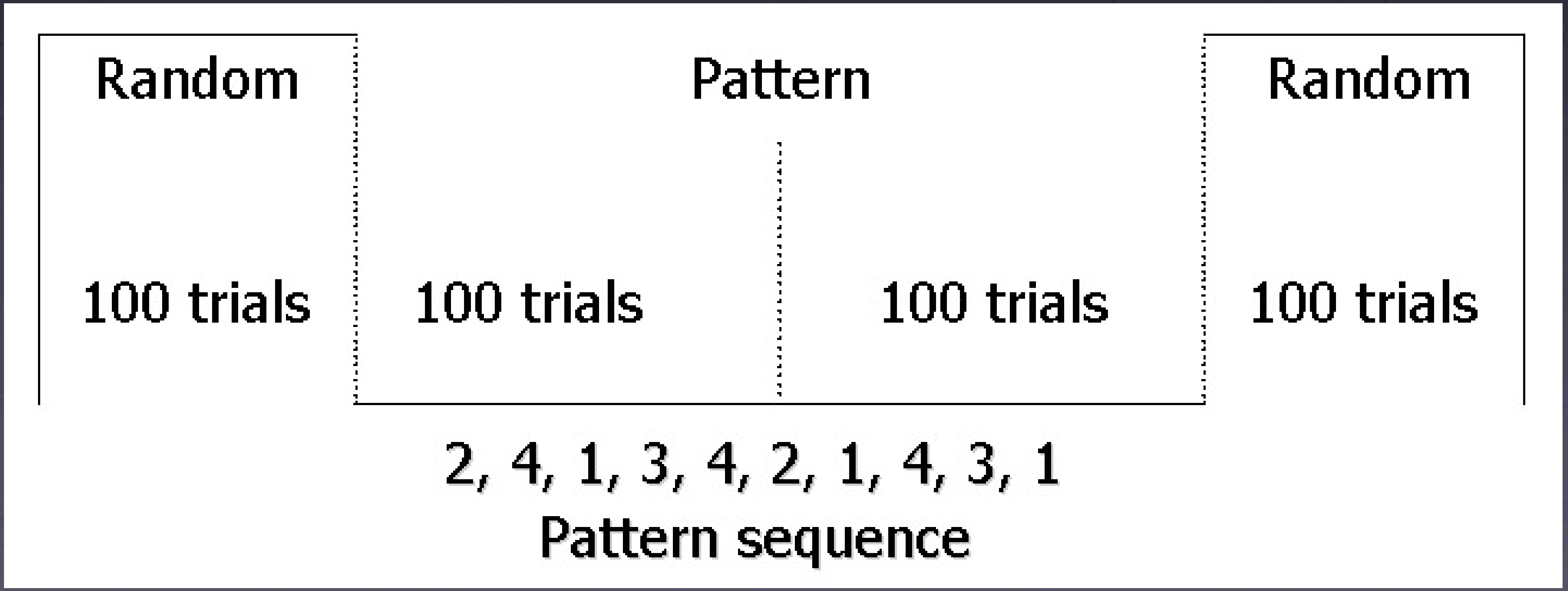
- *FOXP2* important for the development of cortico-striatal system (Watkins et al., 2002)
- Cortico-striatal system implicated in sequential learning (Packard & Knowlton, 2002)
- *FOXP2* involved in sequential learning?

Molecular Genetic Study of Sequential Learning

- Participants 159 8th-graders
  - 100 typical language learners
  - 59 children with language impairment (LI)
- Both groups have equivalent non-verbal IQ
- Blood or saliva samples obtained for recovery of DNA

Sequential Learning Task

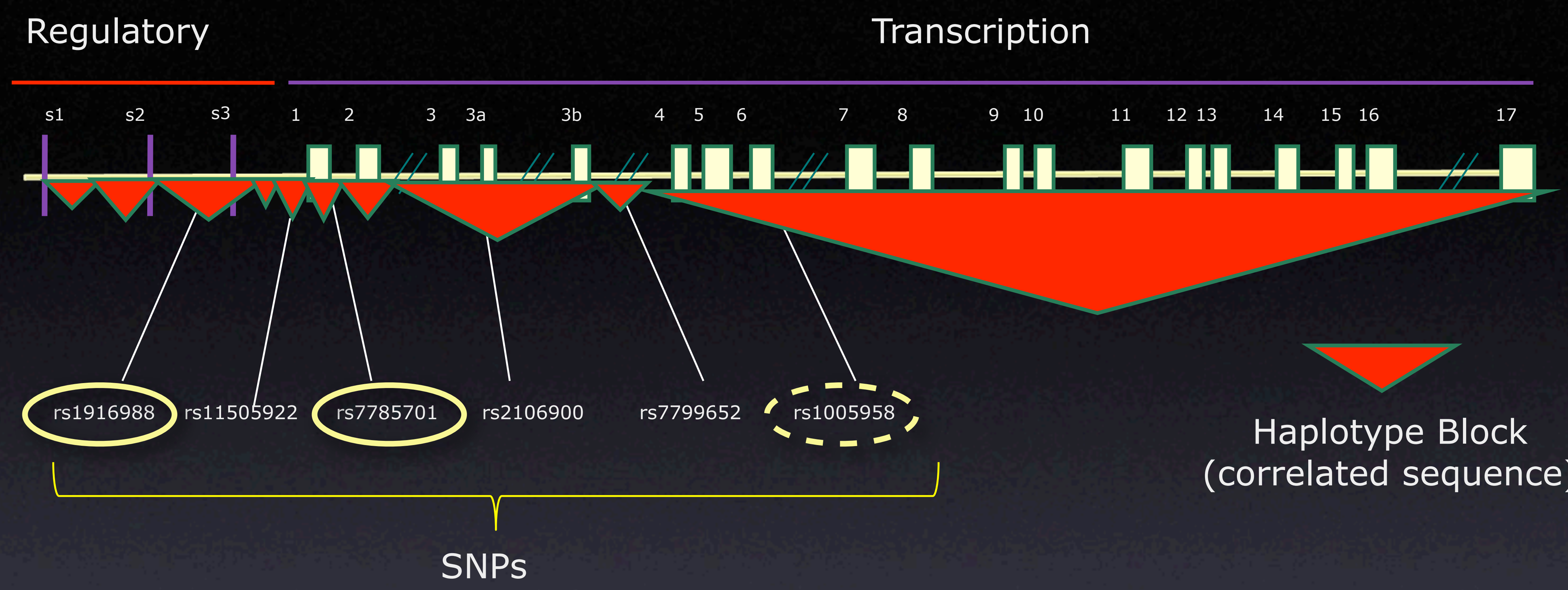
- Serial-Reaction Time (SRT) task:
  - A target appears in one of 4 horizontal frames and the subject indicate where using 4 corresponding buttons



Genetics Terminology

- DNA base difference between individuals: Single Nucleotide Polymorphism (SNP)
- Sets of nearby SNPs inherited in blocks
- Pattern of SNPs in a block: Haplotype
- HapMap maps haplotypes using tag-SNPs

Procedure



- 6 SNPs extracted to cover principal haplotype blocks within *FOXP2*
- SRT data analyzed using growth curve analyses
- Test for differences in learning rates as a function of a participant's genotype at each SNP locus

Interim Summary (IV)

- *FOXP2* genotypic variance is associated with individual differences in SRT learning and language status
- Same genetic basis for individual differences in both sequential learning and language

Conclusions

Conclusions (I): Language Evolution

- Language has evolved through cultural transmission shaped by the brain
  - Same neural and genetic bases for sequential learning and language
  - Constraint on sequential learning can explain aspects of linguistic structure
- Future work should uncover the nature of the constraints shaping the cultural evolution of language

Conclusions (II):
Lessons from Language Evolution

- Treat memes as organisms, adapted to a specific environmental niche
- Produce testable memetic hypotheses by incorporating empirical constraints arising from specific environments
- Some parts of memetics may never be amenable to scientific enquiry

Conclusions (III): Experimental Memetics

- Linguistic adaptation as a possible model for memetics?
- Focus on processes of cultural transmission:
  - simulation studies
  - behavioral experiments
  - social network web experiments

Thanks