# Re-defining the limits of implicit learning with Tang poetry

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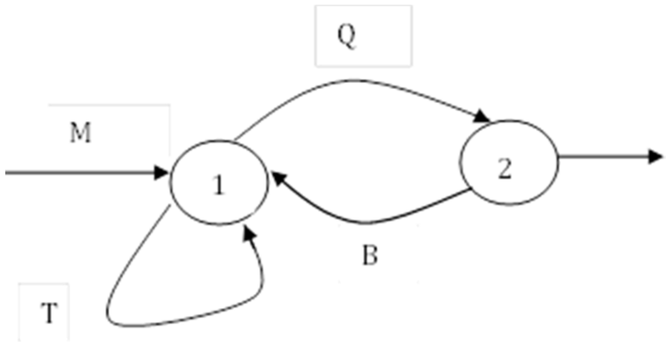



1. [0] -> M[1]
2. [1] -> T[1]
3. [1] -> Q[2]
4. [2] -> B[1]
5. [2] -> ε

[0], [1], [2] are non-terminals

Example string:
M[1]
-> MT[1]
-> MTT[1]
-> MTTQ[2]
-> MTTQ

**Finite state grammar**

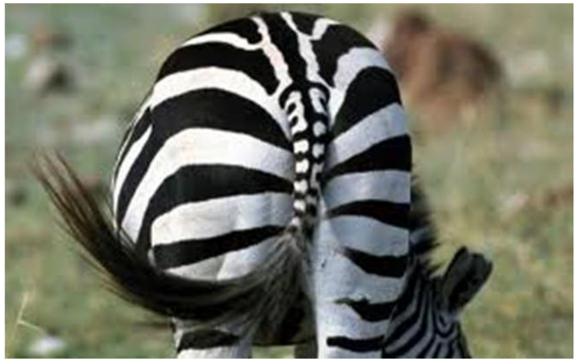
MTTQ

People learn:

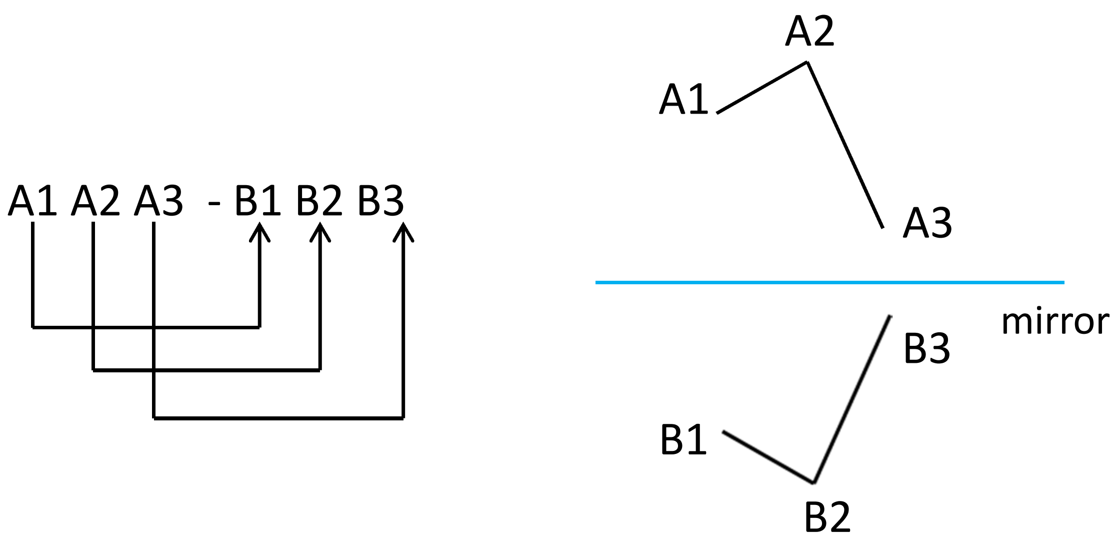
Chunks: MT, TT, TQ, MTT, TTQ

Whole items: MTTQ

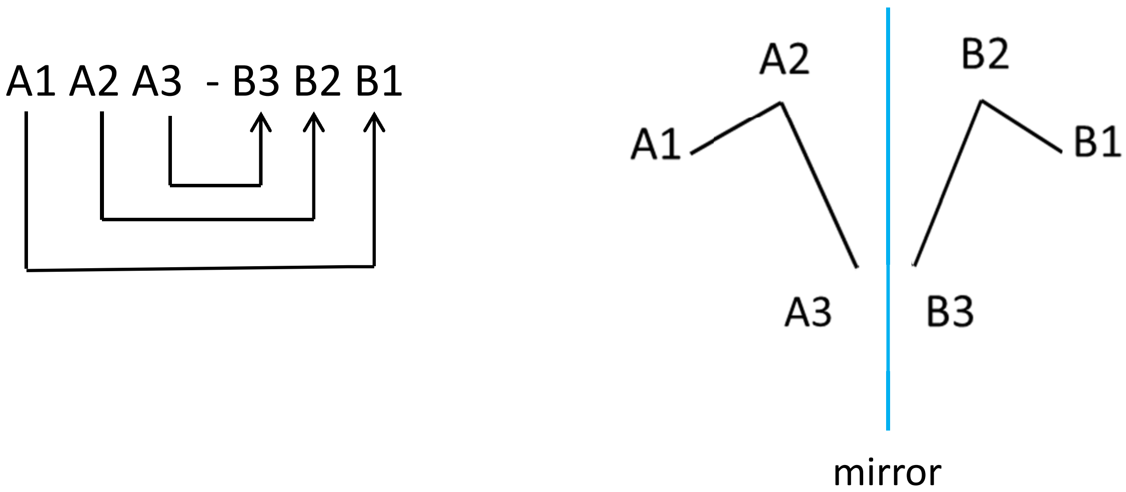
Repetition structure: 1223 (so they can classify KXXV as grammatical)

Rapid detection of a face or behind with mirror symmetry might be useful?

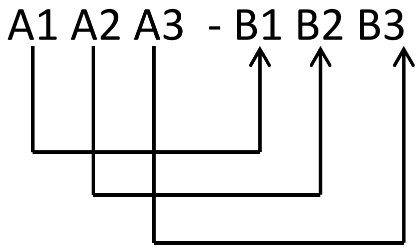


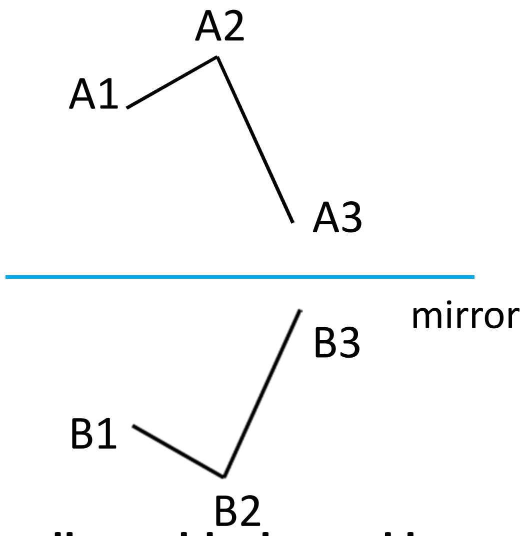

Cross serial dependency/ inversion




Centre embedding/ retrograde

**Tenzin, Trinley, Tumpo wore**

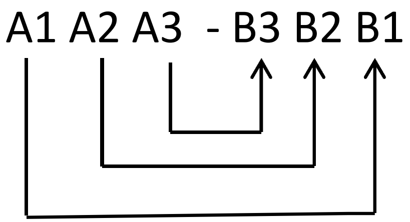


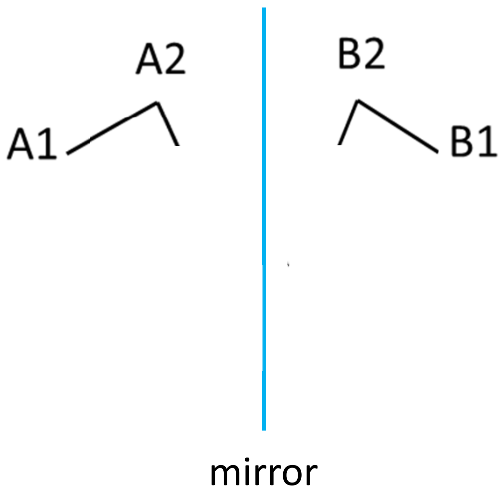




Cross serial dependency/ inversion

**yellow, black, red hats, respectively**

**The bamboo the panda ate was fresh**




Centre embedding/
retrograde

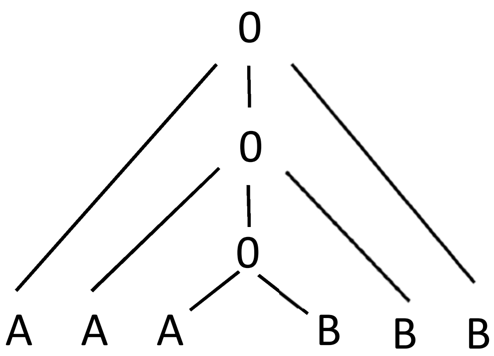
Retrograde symmetry:

A1A2A3-B3B2B1

1. [0] -> Ai[0]Bi
2. [0] -> ε

(where [0] is a non-terminal)

Context free grammar




Inverse symmetry:

A1A2A3-B1B2B3

1. [0]-> Ai [0] [i]
2. [0]-> ε
3. Ai [j] -> Ai Bj
4. Bj [i] -> [i] Bj

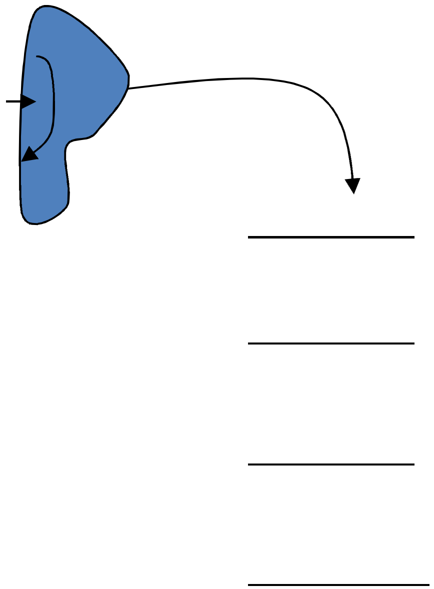
(where [0], [i] are non-terminals)

Context-sensitive grammar

0001-> 1110 inverse

Stack:

Input:
0001



0001-> 1110 inverse

Stack:

1

0

0

0

Symmetry seems to be processed automatically
and to be relevant for homo sapiens: mate selection, aesthetics, language

It is not an arbitrary rule but one with ecological significance

Yet it requires a learning device more complex than finite state

Friedierci: Maybe different neural regions (Broca vs Operculum) process finite vs supra-finite state structures

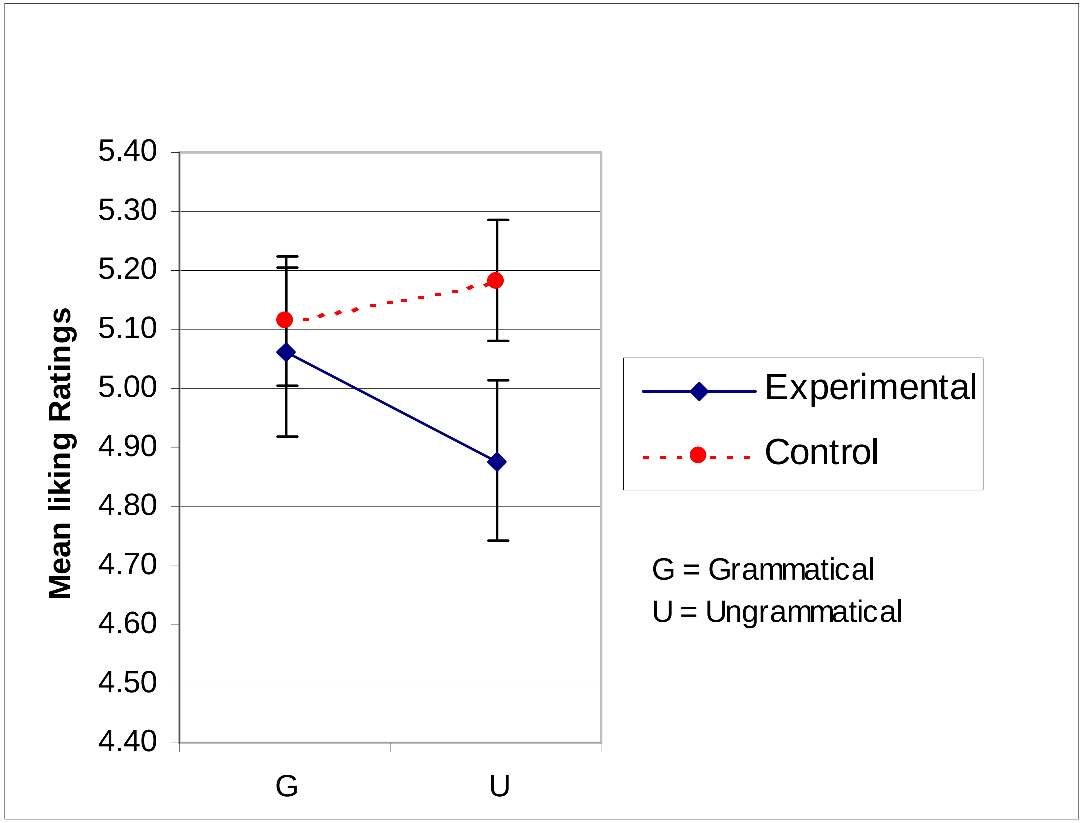
Kuhn and Dienes 2005

# Grammatical Tune showing inversion

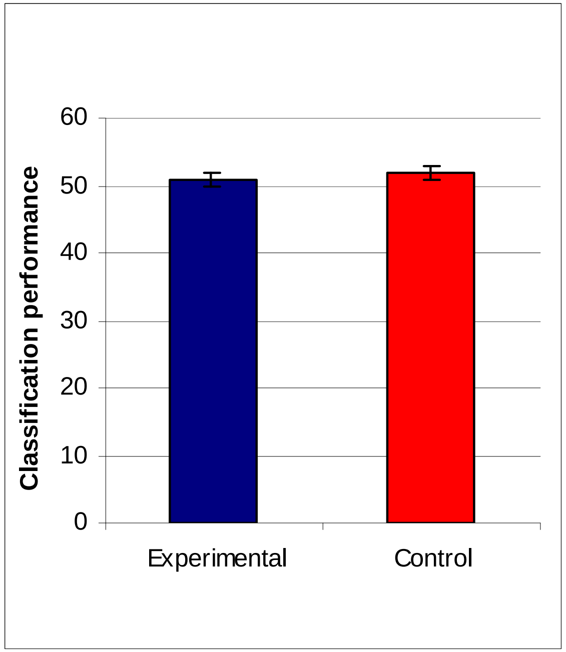
Contour -3 +6 +1 +3 -6 -1

Kuhn & Dienes 2005

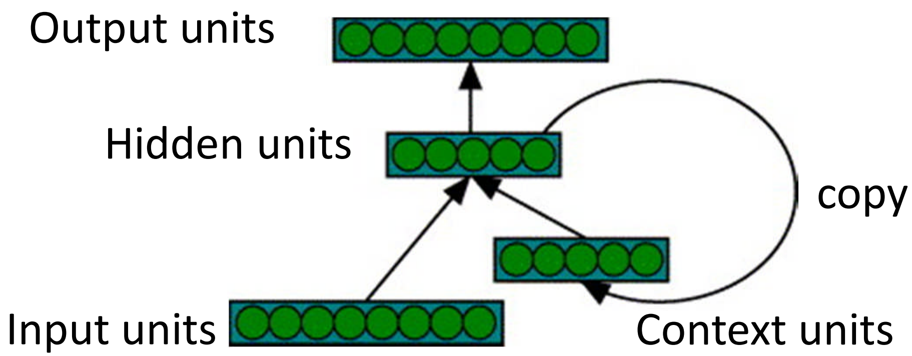
# Liking ratings




# Classification performance



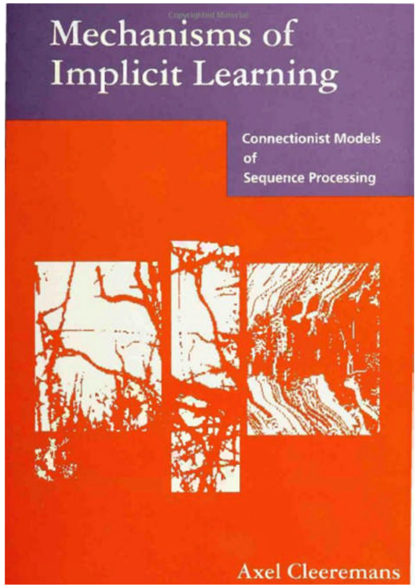
Kuhn and Dienes 2008

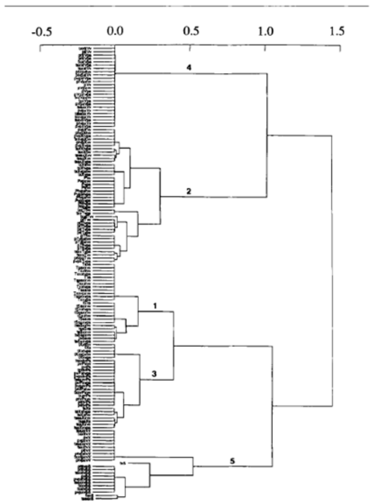



SRN learns fixed length long distance associations.

Have either subjects or SRN learnt a symmetry?

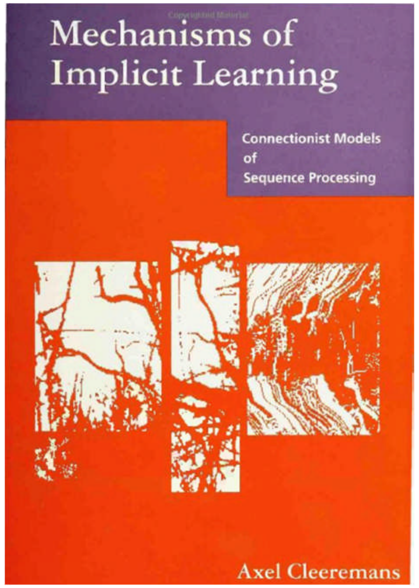
Need to show generalisation to new lengths.

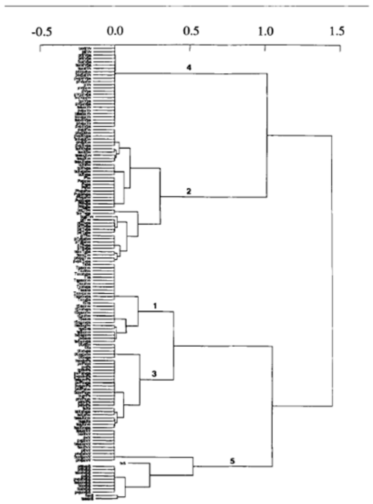



SRN as a “graded finite state” processor

SRN has a memory buffer – can it be a graded context-free or context sensitive processor?




SRN as a “graded finite state” processor

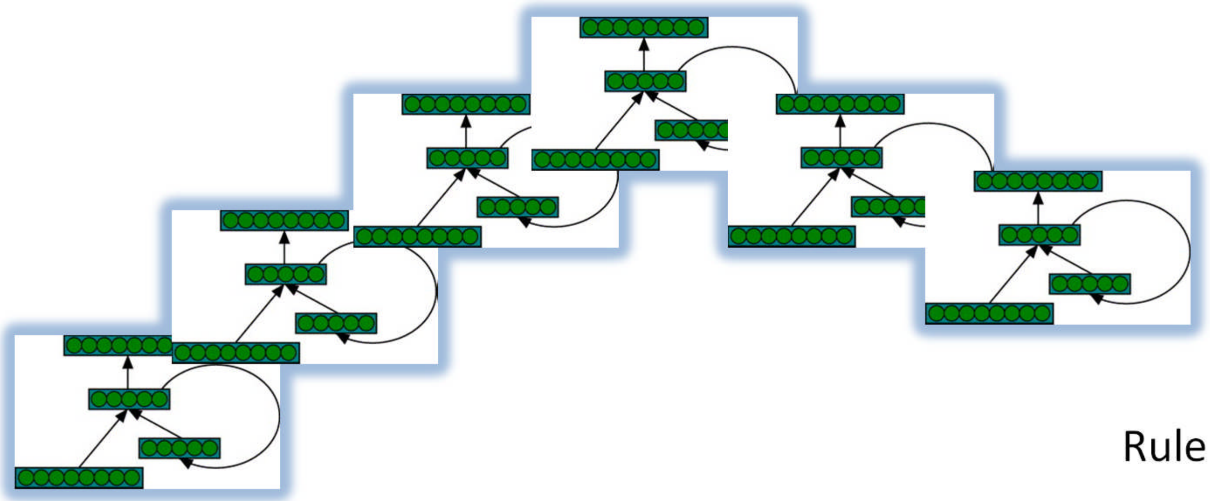
SRN has a memory buffer – can it be a graded context-free or context sensitive processor?

Rodrigues Wiley & Elman 1999: SRN exposed to a^n b^n (ab, aabb, aaabbb, …) can develop a counter and thereby generalize to untrained lengths

Rule learning

Statistical learning
Simple associative learning

SRN as a bridge

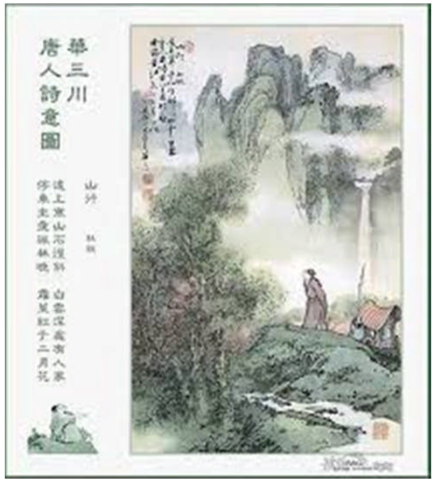


Statistical learning
Simple associative learning

Rule learning

The SRN CAN learn interesting rules in a graded way – but not guaranteed.
What it can learn is an empirical non-obvious question.

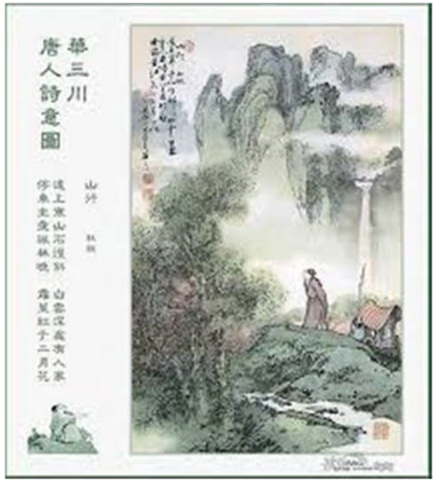
Tang poetry

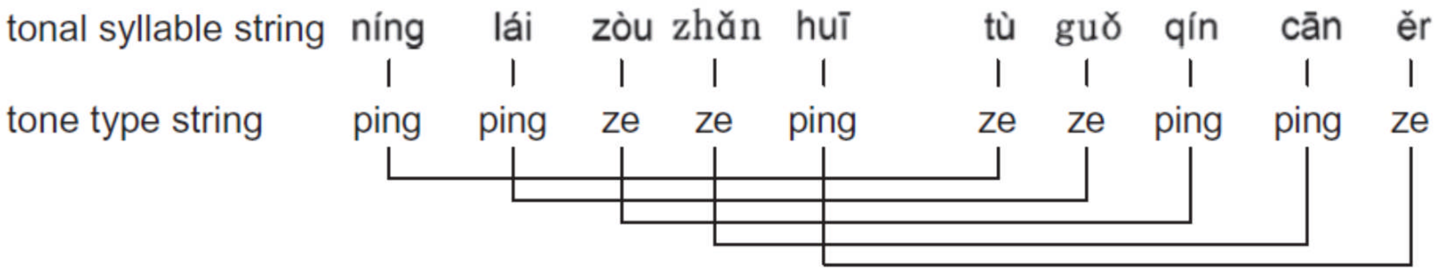


Tang poetry:

Divides Chinese tones (1-4) into two categories:
ping (1,2) and ze (3,4)

And specifies an inversion relation in successive lines:



Jiang et al 2012

<u>Materials:</u>
Inverses and non-inverses balanced in terms of:

Global chunk strength, anchor chunk strength, mean feature frequency, repetition structure

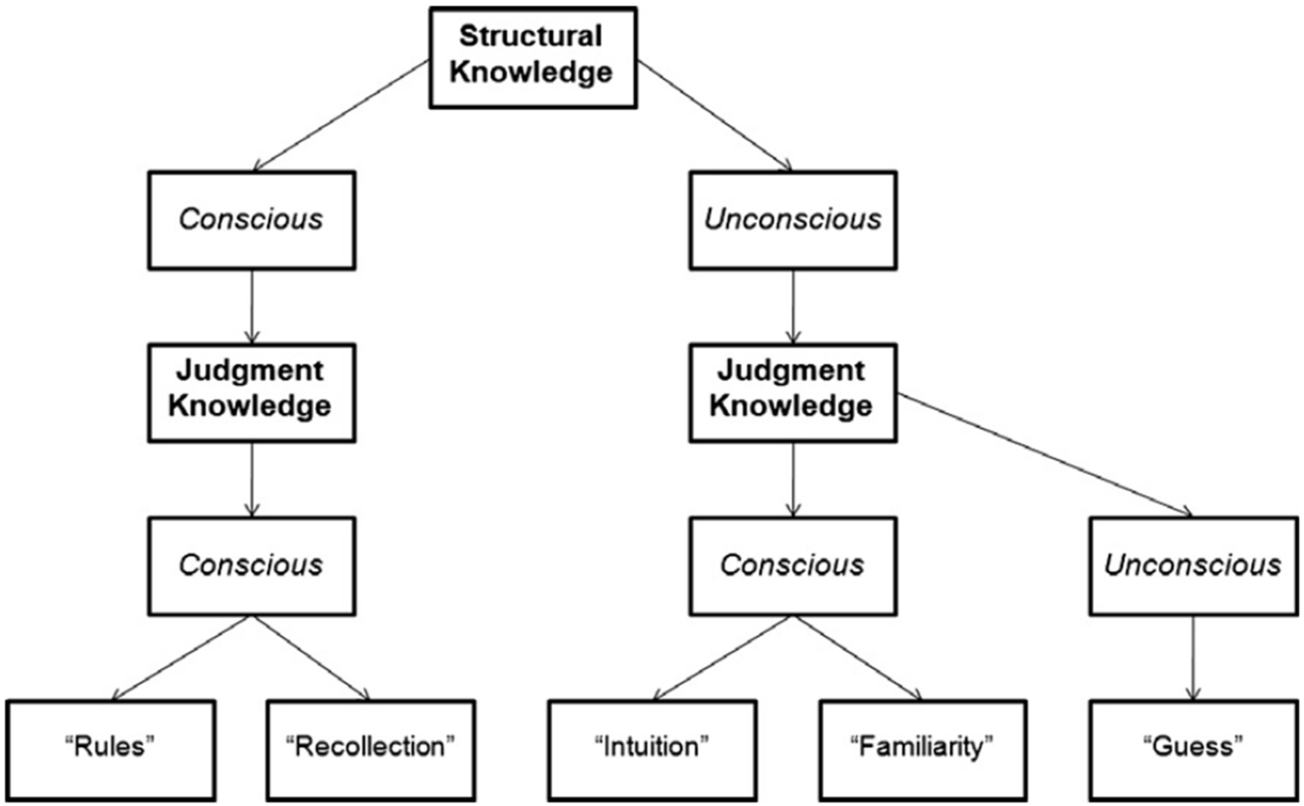
all at the level of:

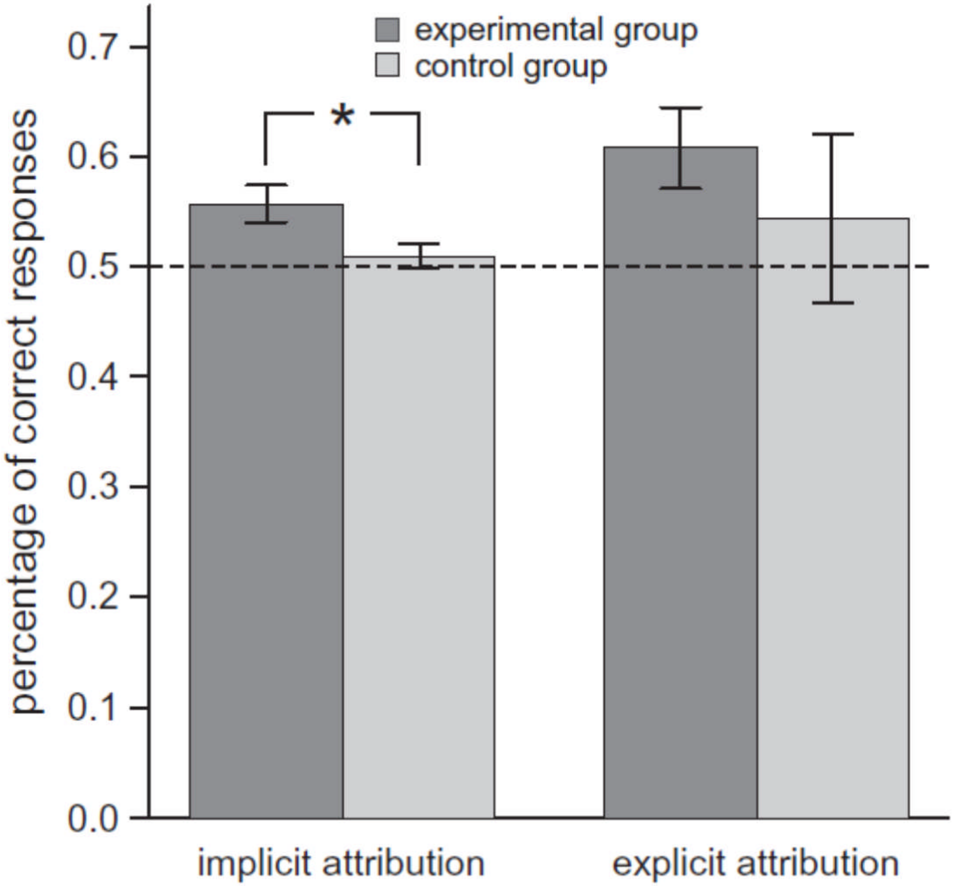
Syllables, tones, tone types

<u>Training:</u>
S repeated back 48 strings, 3 times

<u>Test:</u>
1. Each of 32 test strings judged as rule governed or not
2. Structural attribution judgment: Random, Intuition, Recollection, Rules

Judgment knowledge: Knowledge that a string is rule governed
Structural knowledge: Knowledge that enabled that judgment






25% random 45% intuition
Unconscious structural knowledge

20% memory 10% rules
Conscious structural knowledge

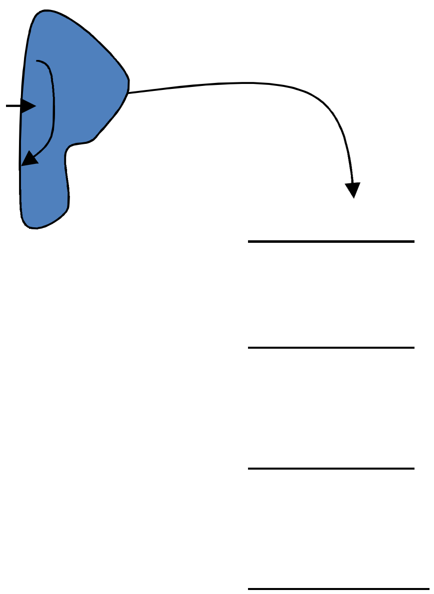
People acquired unconscious structural knowledge of a tonal inversion

0001-> 1110 inverse

0001-> 1000 retrograde

Stack:

Input:
0001



0001-> 1110 inverse

0001-> 1000 retrograde

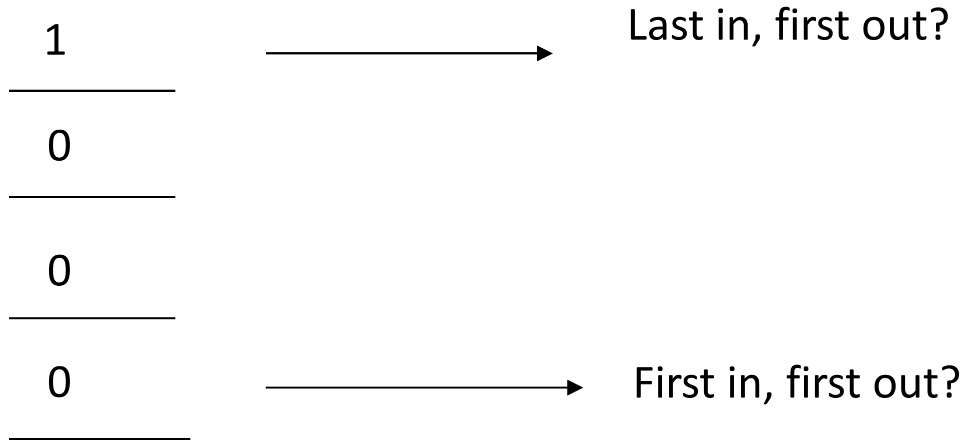
Stack:

| |
|---|
| 1 |
| 0 |
| 0 |
| 0 |

0001-> 1110 inverse

0001-> 1000 retrograde

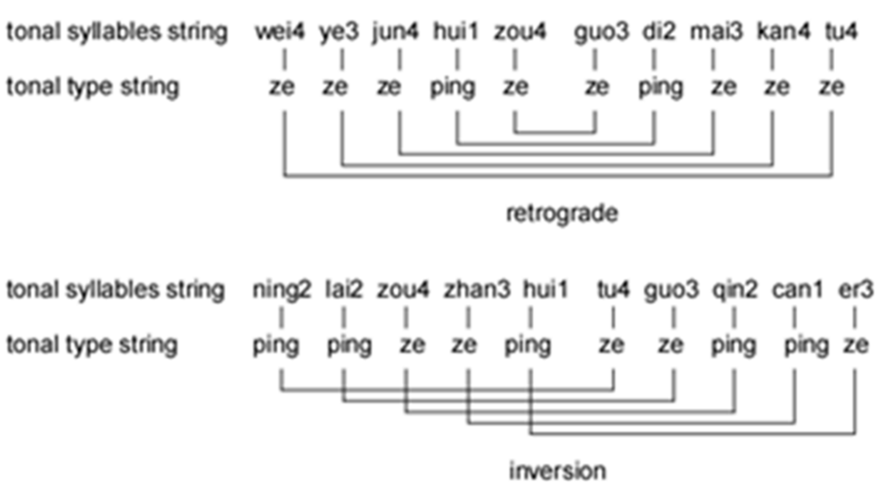
Stack:



Can people learn retrograde symmetry?

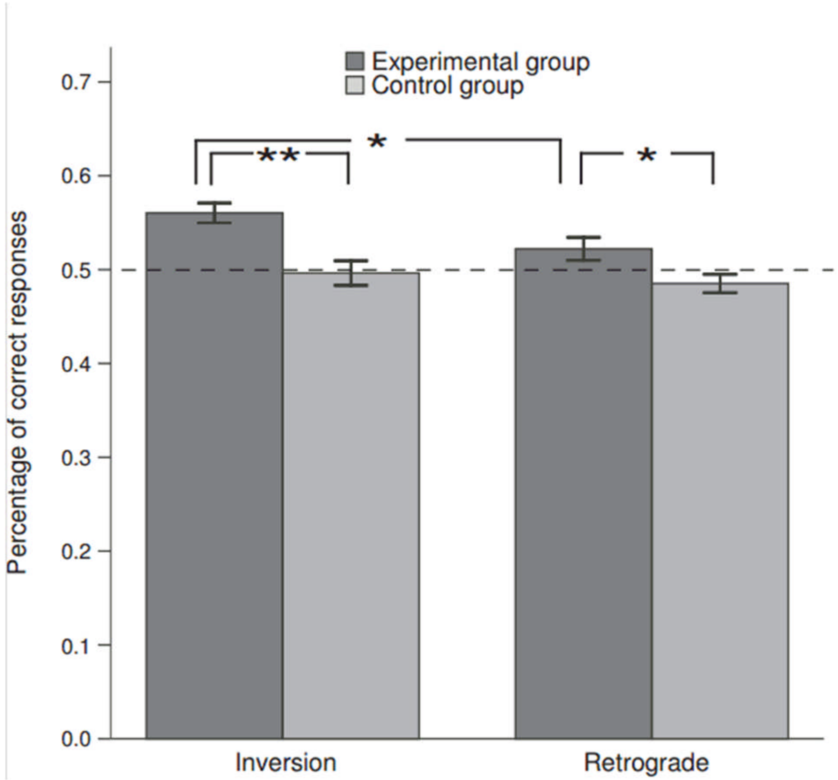
Which is easier – inverse or retrograde?

Li et al, 2013



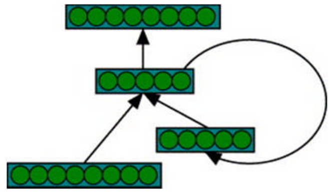

<u>Training:</u>
Repeat 48 strings, 3 times. Either retrogrades or inverses.

<u>Test:</u>
1. Classify 48 new strings, half with violations in $2^{nd}$ and $4^{th}$ position (and corresponding $7^{th}$ and $9^{th}$ locations in last half of string)
2. Structural knowledge attributions



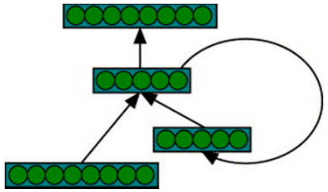

Guess 23%
Intuition 77%

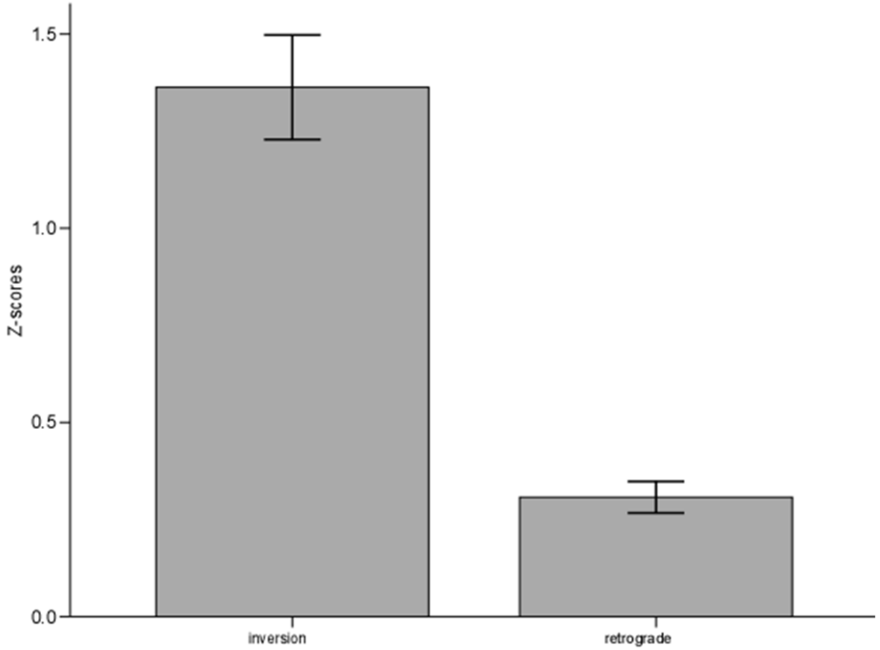
Guess 34%
Intuition 66%



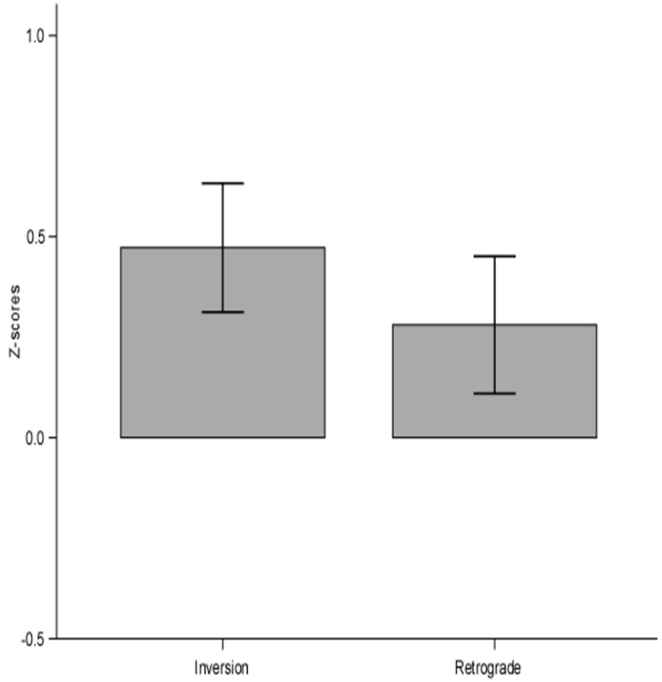
Range of parameter values used in the simulations.

| Network parameter | Value |
|---|---|
| Learning rate | 0.1, 0.3, 0.5, 0.7, 0.9 |
| Momentum | 0.1, 0.3, 0.5, 0.7, 0.9 |
| Number of hidden units | 5, 10, 15, 30, 60, 120 |
| Epochs | 100 |



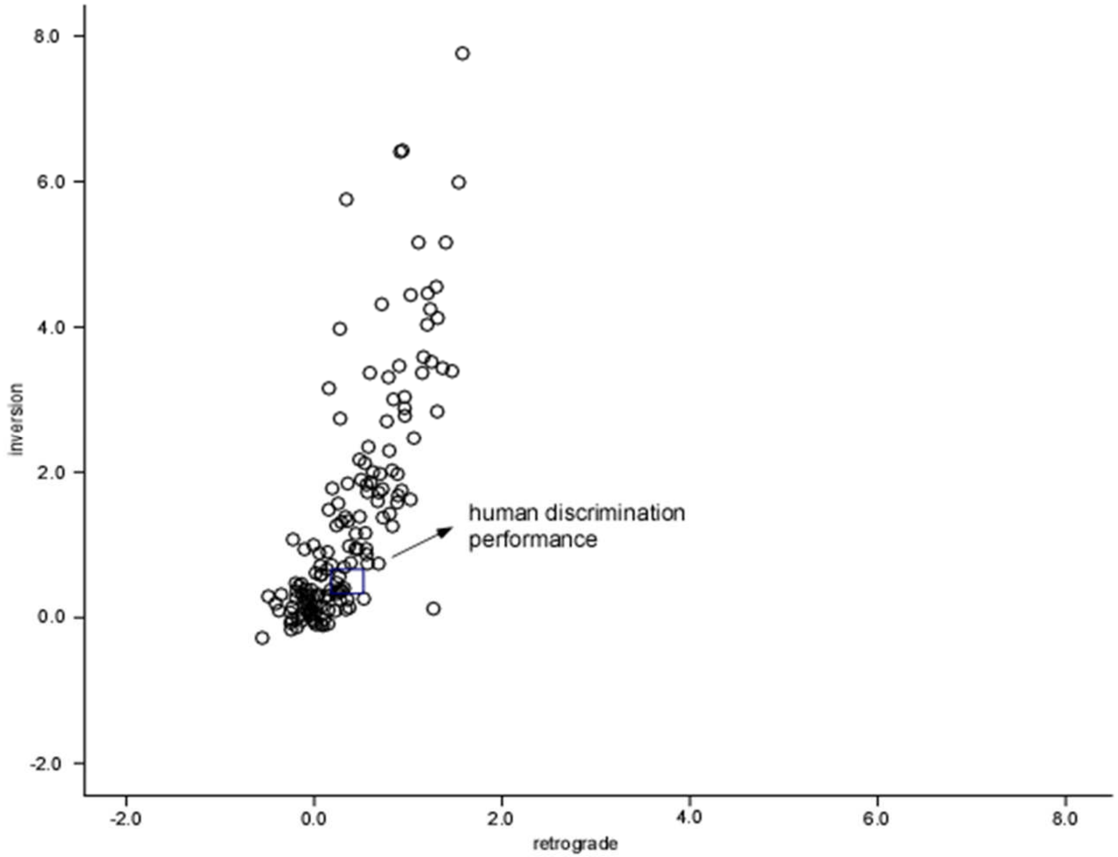


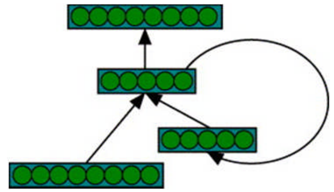

people

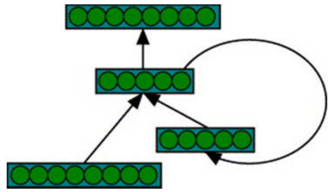



Like people SRN characteristically finds inverse easier than retrograde and can learn both

=> SRN and people have a buffer more like a first in-first out for implicit learning


8.0
6.0
4.0
2.0
0.0
-2.0
inversion
-2.0
0.0
2.0
4.0
6.0
8.0
retrograde
human discrimination
performance



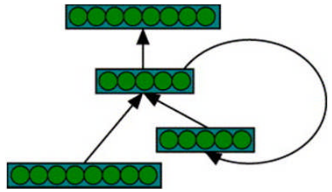


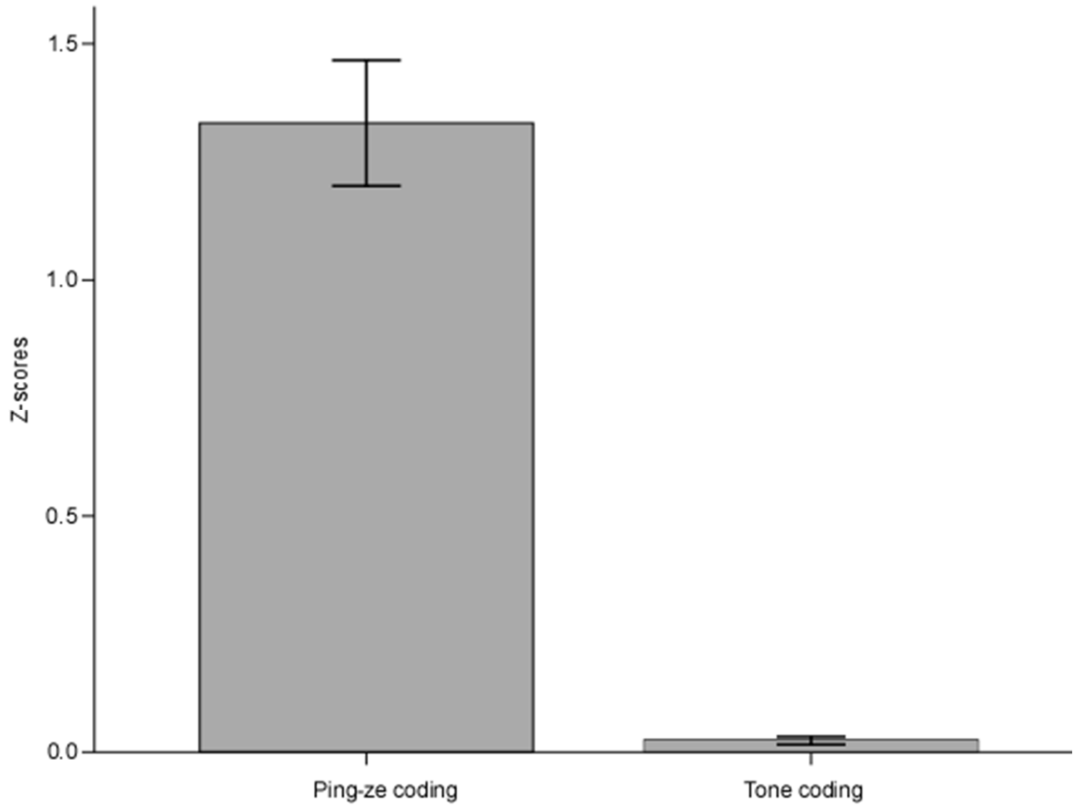
| Rule | Grammaticality | Six | | Seven | | Eight | | Nine | | Ten | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | SE | M | SE | M | SE | M | SE | M | SE |
| Retrograde | G | 0.61 | 0.02 | 0.95 | 0.01 | 0.33 | 0.01 | 0.80 | 0.02 | 0.58 | 0.03 |
| | UG | 0.61 | 0.02 | 0.56 | 0.02 | 0.33 | 0.02 | 0.70 | 0.02 | 0.60 | 0.02 |
| Inversion | G | 0.95 | 0.01 | 0.95 | 0.01 | 0.88 | 0.02 | 0.92 | 0.01 | 0.96 | 0.01 |
| | UG | 0.95 | 0.01 | 0.41 | 0.02 | 0.88 | 0.02 | 0.43 | 0.03 | 0.95 | 0.01 |

*Note*. G = grammatical, UG = ungrammatical.

Subjects already know ping-ze categories

Is such prior knowledge essential for learning the inversion?





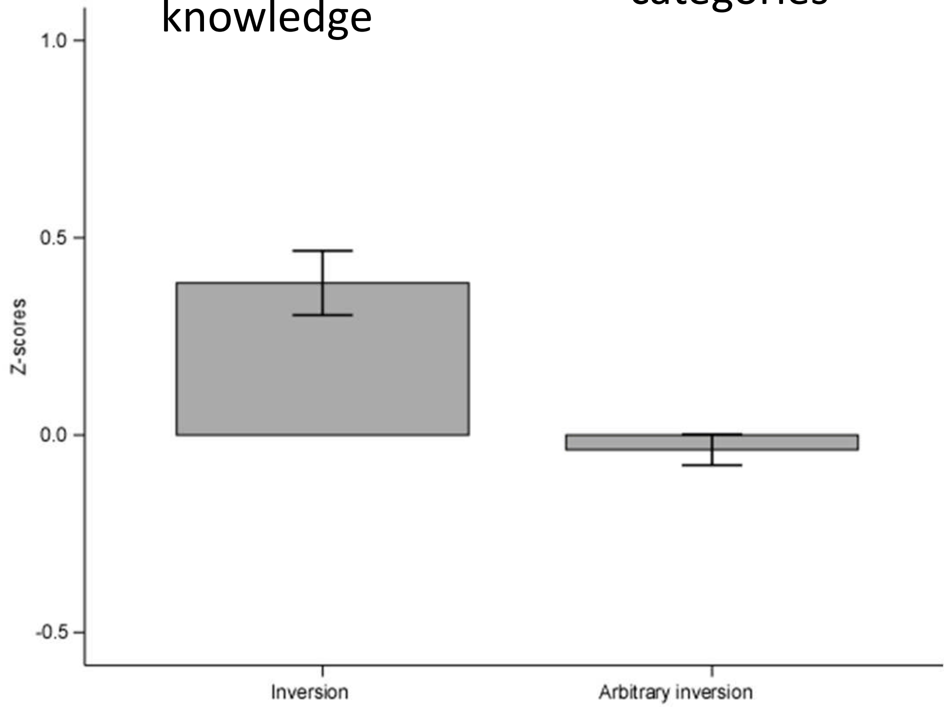

SRN requires pre-existing ping-ze categories.
Prediction: People will not learn with arbitrary classification of tones

Category 1 (“ping”) = 1,3
Caregory 2 (“Ze”) = 2,4

(Arbitrary from point of view of Chinese – not pre-trained)

Ping-ze categories given by prior knowledge

Arbitrary categories




Guess 47% Intuition 48% Memory 3%
Rule 2

SRN correctly predicts that people need pre-existing ping-ze categories

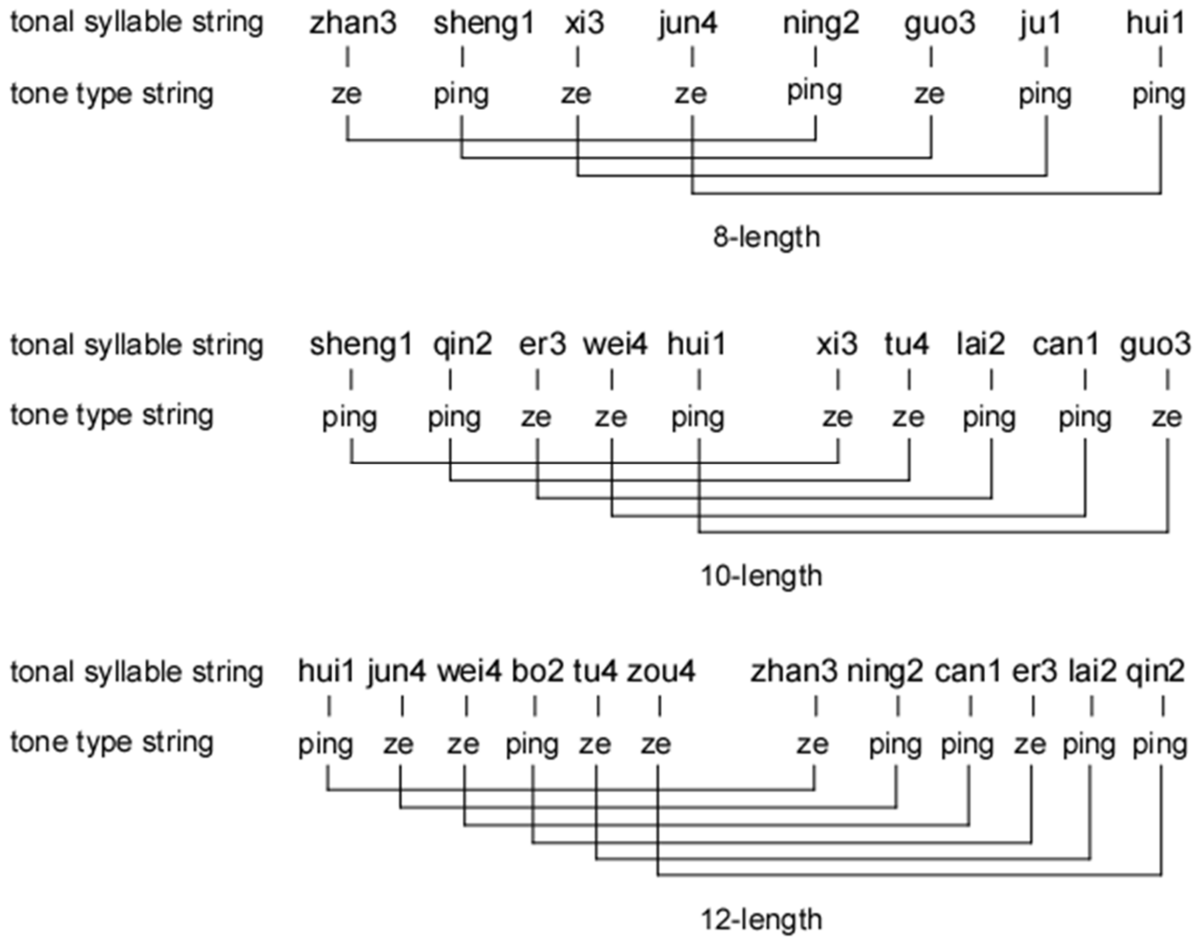
What has been learnt?

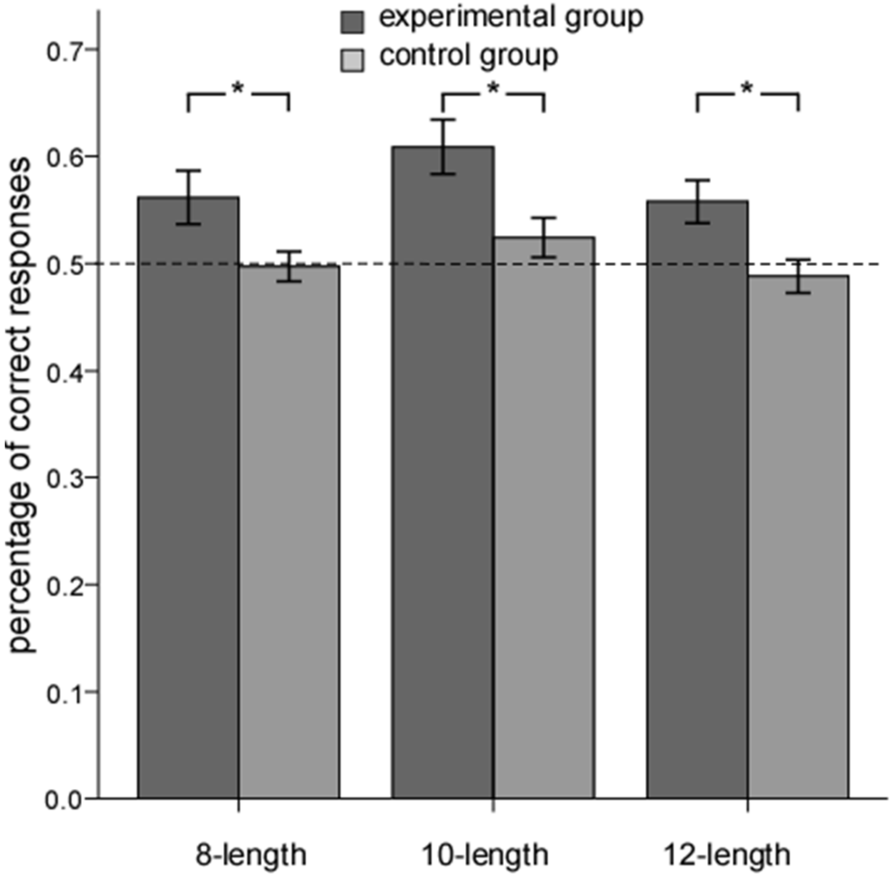
Two theories:

1. The symmetry per se, i.e. length can be treated as a variable by the system

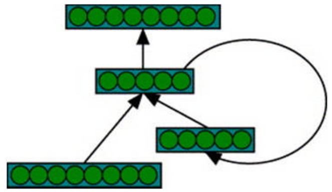
2. Prediction over a fixed distance (Kuhn & Dienes 2008)

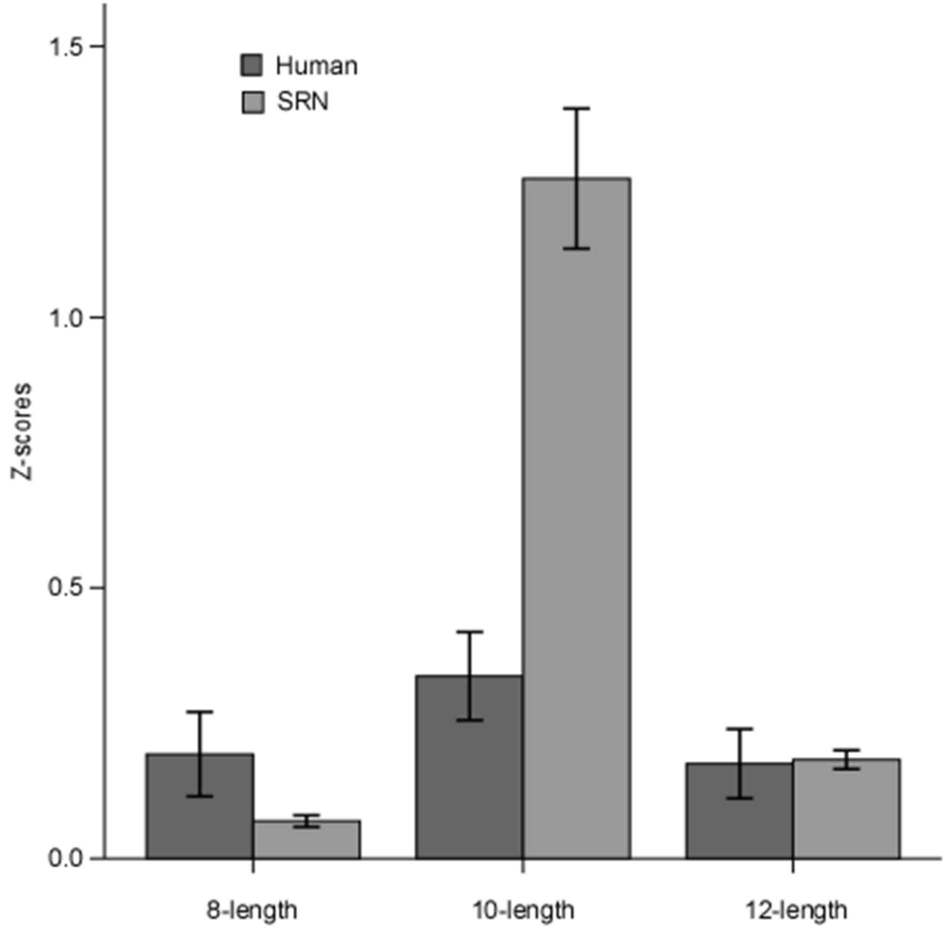
Test:
Can people/models generalize to inversions of different length?


tonal syllable string
zhan3 sheng1 xi3 jun4 ning2 guo3 ju1 hui1
tone type string
ze ping ze ze ping ze ping ping
8-length
tonal syllable string
sheng1 qin2 er3 wei4 hui1 xi3 tu4 lai2 can1 guo3
tone type string
ping ping ze ze ping ze ze ping ping ze
10-length
tonal syllable string
hui1 jun4 wei4 bo2 tu4 zou4 zhan3 ning2 can1 er3 lai2 qin2
tone type string
ping ze ze ping ze ze ze ping ping ze ping ping
12-length




Attributions:
99% implicit





Human
SRN
Z-scores
1.5
1.0
0.5
0.0
8-length
10-length
12-length

But surely people (and SRN?) can learn symmetry …

In these models SRN has no means for learning length as a variable.

If put in a “middle marker” its performance deteriorates.

Need to train SRN (with middle marker) and people on poems of different lengths

So they learn length is something to be generalized over

Then test on yet different lengths

We have ongoing evidence that people may be learning genuine symmetry:

People do not use fluency for classifying standard artificial grammars (Scott & Dienes, 2010); but symmetry processing should reduce processing time (R. Reber et al 2004). So does implicit knowledge of Tang inverses rely on fluency or not?

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Symmetry (unlike chunking) produces large fluency effects and people use fluency to classify (Fuqiang Qiao PhD thesis, submitted)

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Brain regions involved in learning symmetry versus chunking – fMRI indicates possibly different? (cf Friederici on regular versus supra-regular grammars)

Soon we will bridge the gap from association to symmetry …