Implicit learning of abstract structures: How can it be computationally modelled?

Zoltan Dienes, University of Sussex, UK

Active playful experience with mathematical structures can lead to a type of understanding …

“The fact that many less children were able to give explicit evaluations of the tasks than did adults, coupled with the fact that their mean performances were entirely comparable … shows that verbalizations were not necessary … the final test of whether a child understands a structure is his ability to handle that structure …”

Dienes and Jeeves 1965 p 96

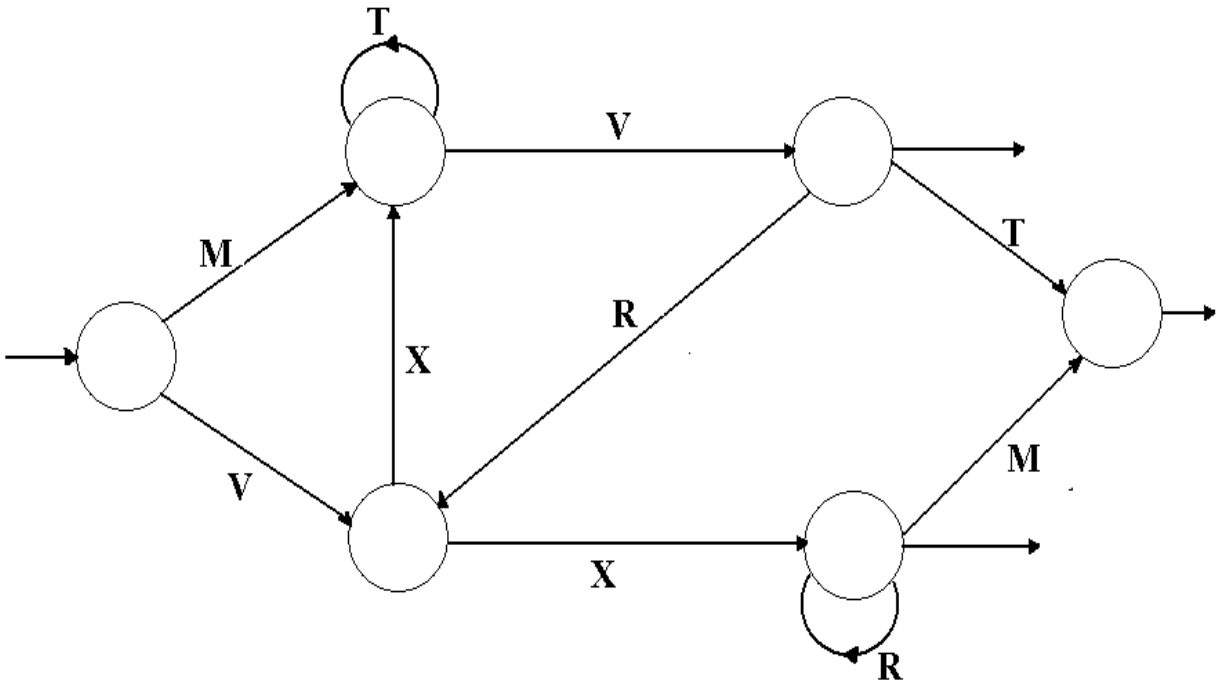
An intuitive understanding can (and maybe should) arise before an explicit one.

Implicit learning

People learn to make decisions on a task more accurately or more quickly without being able to justify their decisions adequately.

OR:
The learning process by which people come to acquire implicit (unconscious) knowledge.

Consider:
Acquisition of natural language, social skills, musical appreciation, many practical skills



Art Reber

1967 “implicit learning”

An example of a “finite state grammar” used for generating stimuli in artificial grammar learning experiments

People learn to classify test items though find it hard to describe relevant rules

MTTTTV

MVRX

VXRR

VXTVRX

MTTVT

VXM

MTVRX

MTV

MVRXVT

MVRXRR

1. VXTTTV

2. MVRTR

3. MVRXRM

4. MTVT

5. MTRVRX

6. VXRM

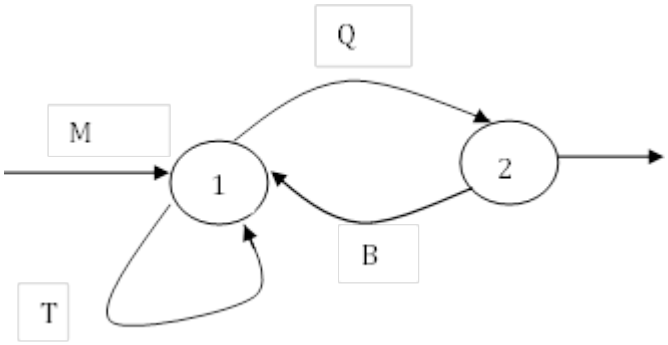
7. VRVXV

8. MXRRM

1. Y
2. N
3. Y
4. Y
5. N
6. Y
7. N
8. N

Donald Broadbent

Investigated implicit knowledge in the 1970s – 90s



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

MTTV

People learn:

Chunks: MT, TT, TV, MTT, TTV

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

Training phase -> knowledge of structure of training items (structural knowledge)

Test phase -> knowledge that an item does or does not have that structure (judgment knowledge)

Presumably, conscious structural knowledge leads to conscious judgment knowledge

But if structural knowledge is unconscious, judgment knowledge could be conscious or unconscious.

Consider natural language: If shown a sentence one can know it is grammatical and consciously know that it is grammatical, but not know at all why it is grammatical

If both structural knowledge and judgment knowledge unconscious => phenomenology is of guessing

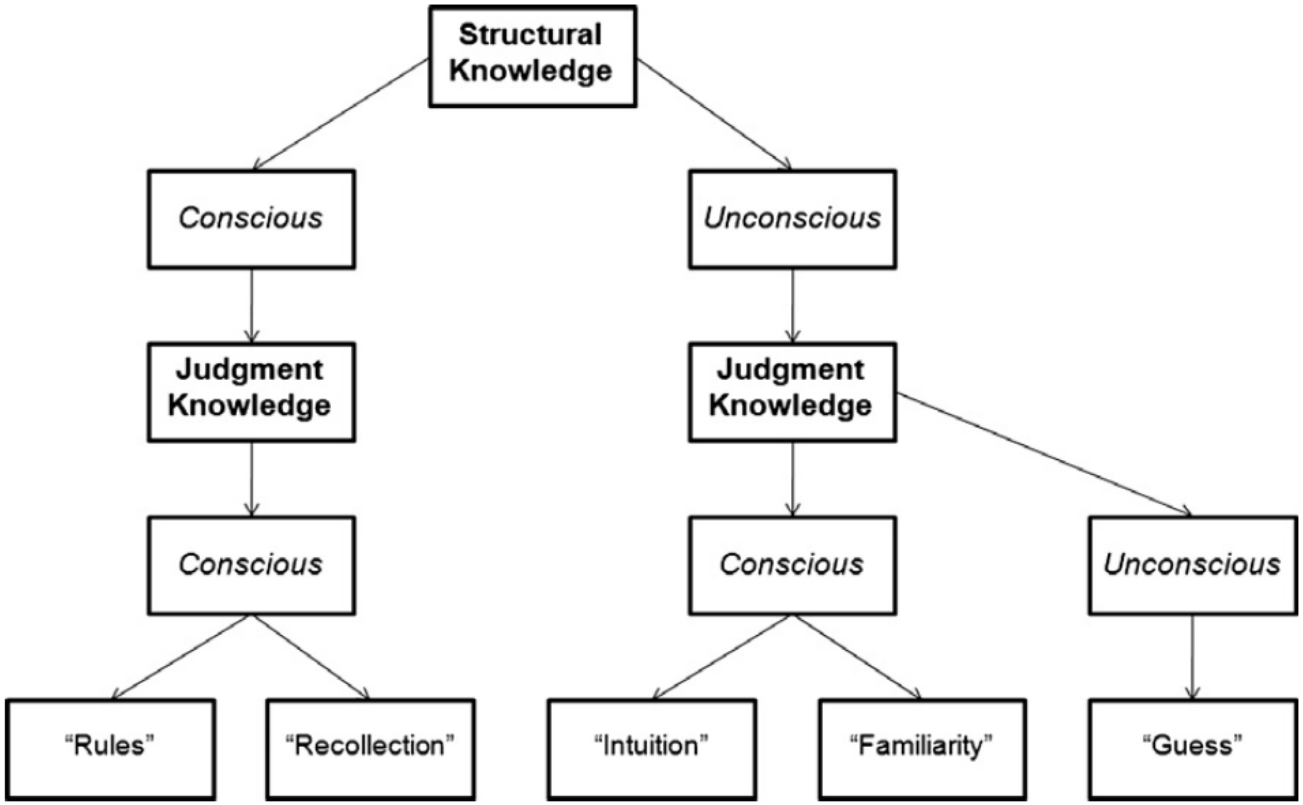
If structural knowledge unconscious but judgment knowledge conscious => phenomenology is of intuition (cf natural language)

In both cases, we have unconscious structural knowledge.

In second case, people know that they know.

Dienes & Scott 2005; Scott & Dienes, 2008

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



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Adv Cogn Psychol. 2012; 8(2): 121–131.
Published online 2012 May 21. doi: 10.2478/v10053-008-0109-x
PMCID: PMC3367869
PMID: 22679467

Social intuition as a form of implicit learning: Sequences of body movements are learned less explicitly than letter sequences

Elisabeth Norman[1,2] and Mark C. Price[1]

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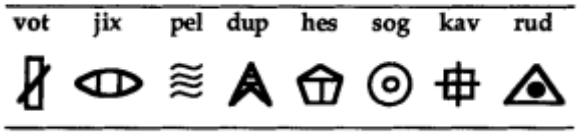
Unconscious structural knowledge: 55% (2%)
Conscious structural knowledge: 47% (4%)

People trained in one domain can apply unconscious knowledge to a new one

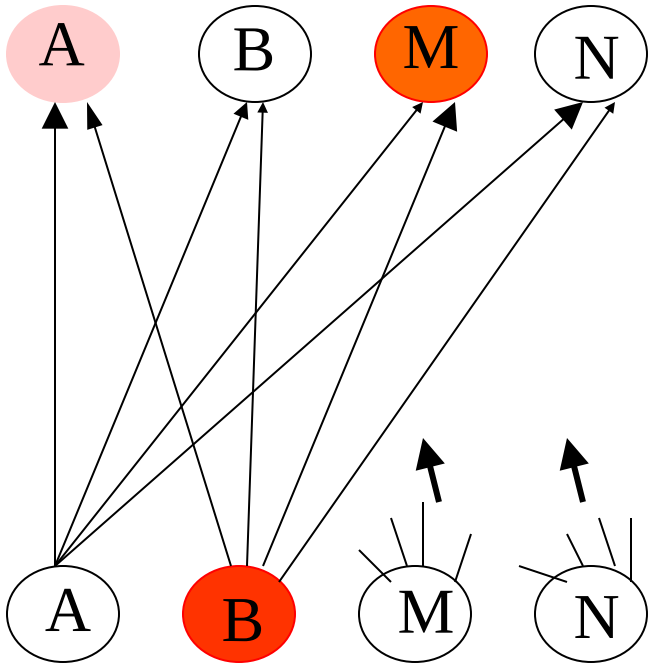
Altmann Dienes & Goode 1995:



There is a mechanism that can determine structure through perceptual variability

Neural network models:

Output units: prediction of which letter will be next

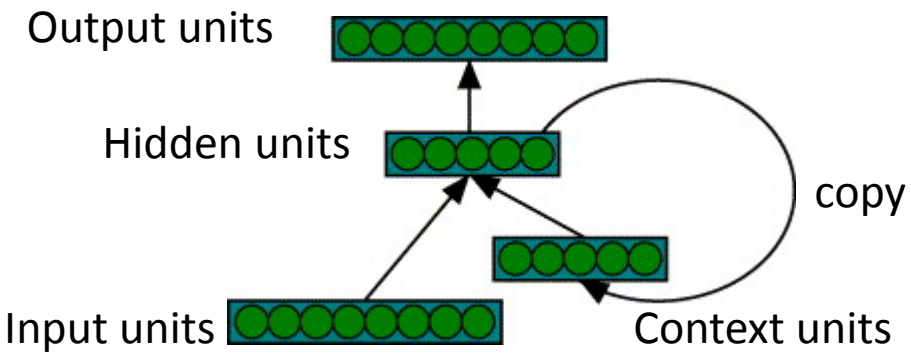


Pattern of weights codes knowledge of sequential regularities

Activation flows along the weights according to their value (synaptic strength); the value is changed with learning so that the output better matches reality

Input units: pattern of activation codes e.g. which letter is currently focused on

The Simple Recurrent Network (SRN) of Elman 1991



SRN come to have a memory and can learn indefinitely into the past

COGNITIVE SCIENCE Vol 23 (1) 1999, pp. 53–82 ISSN 0364-0213

Mapping across Domains Without Feedback: A Neural Network Model of Transfer of Implicit Knowledge

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GERRY T. M. ALTMANN
University of York, UK
SHI-JI GAO
Research Institute of Economic System and Management, China

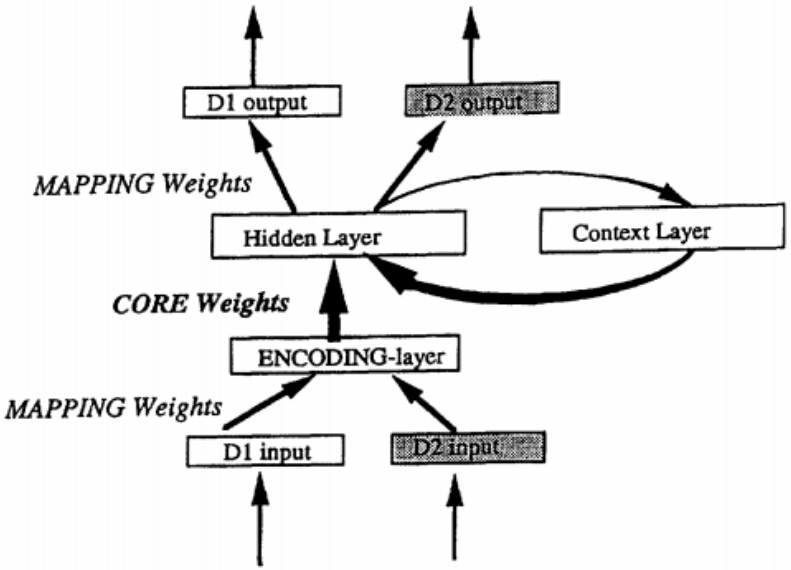


Figure 3. Modification of the SRN to enable transfer between different domains (D1 and D2).

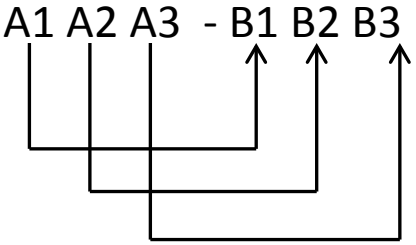
MTTV

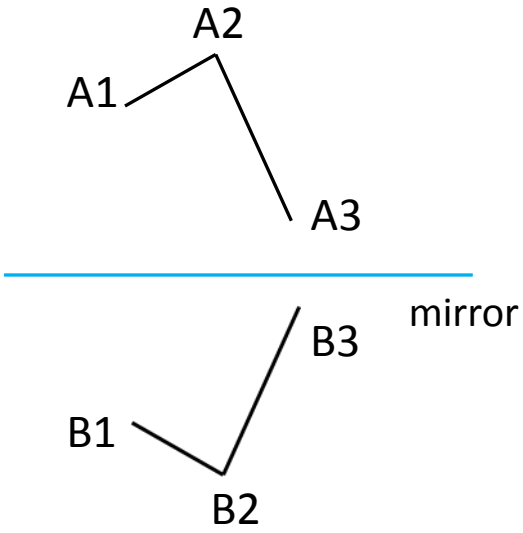
People learn:

Chunks: MT, TT, TV, MTT, TTV

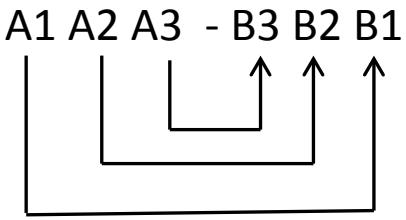
Repetition structure: 1223 (so they can classify KXXV as grammatical)

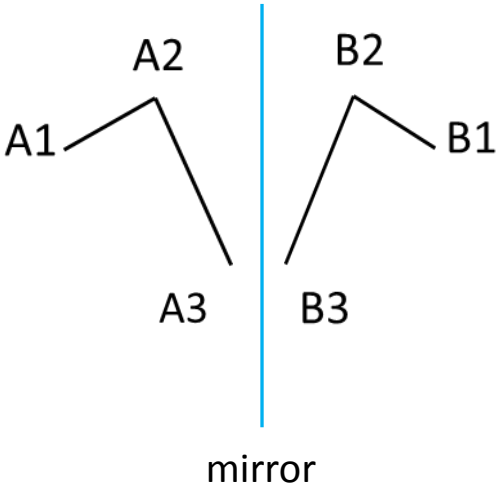
Rapid detection of a face or behind with mirror symmetry might be useful?





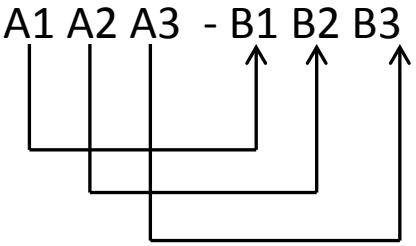
Cross serial dependency/ inversion

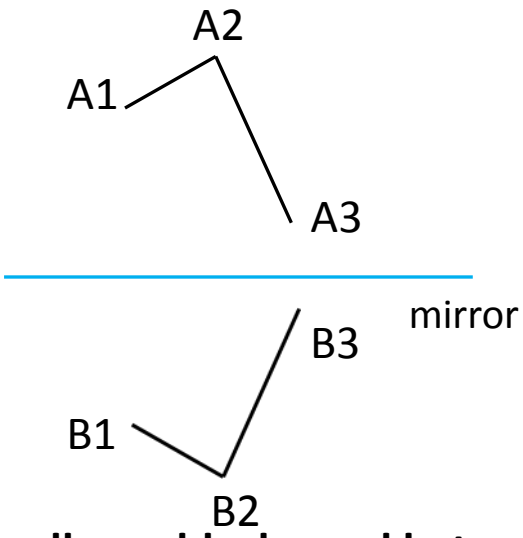




Centre embedding/ retrograde

Tenzin, Trinley, Tumpo wore

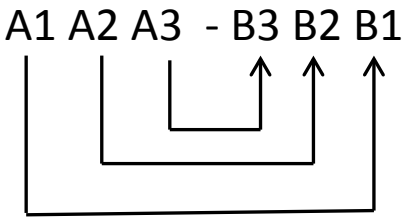


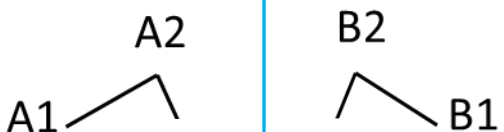


Cross serial dependency/ inversion

yellow, black, red hats, respectively

The bamboo the panda ate was fresh





Centre embedding/
retrograde

mirror

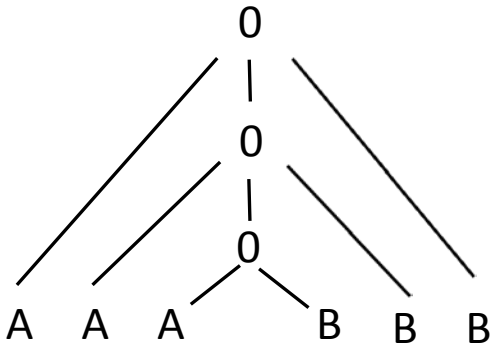
Retrograde symmetry:

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

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

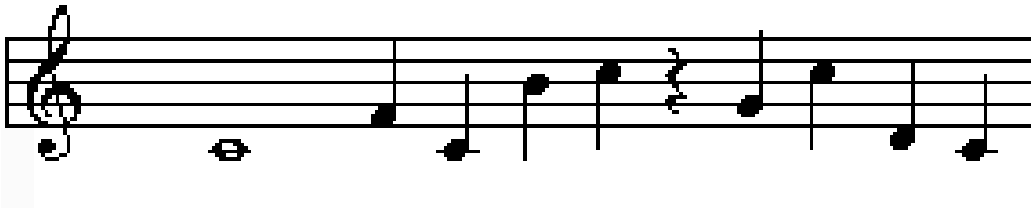
It is not an arbitrary rule but one with ecological significance

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

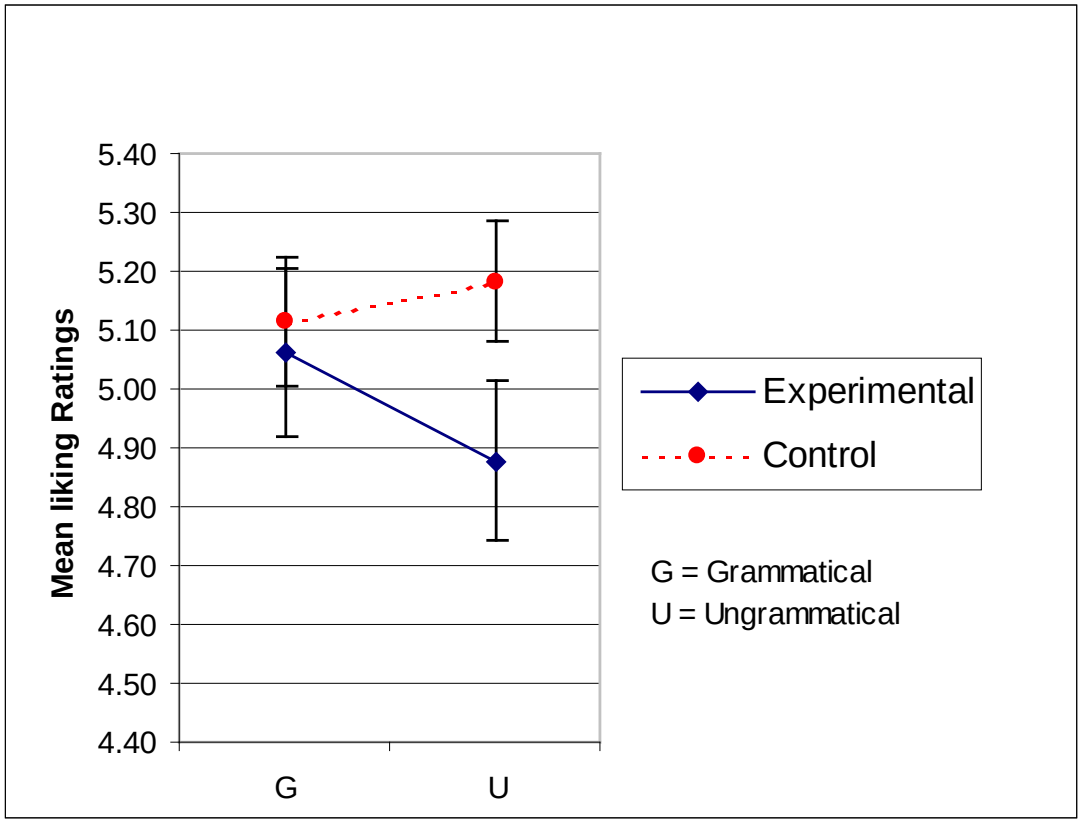
Grammatical Tune showing inversion



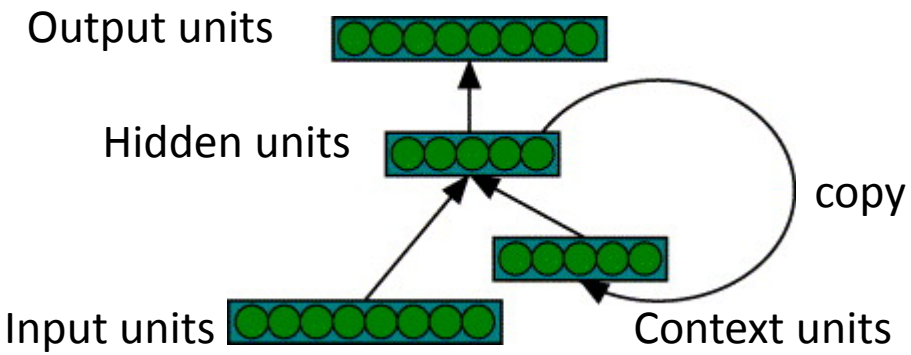
Contour -3 +6 +1 +3 -6 -1

Kuhn & Dienes 2005

Liking ratings



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.

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Cognitive Science 28 (2004) 531–558

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Can musical transformations be implicitly learned?

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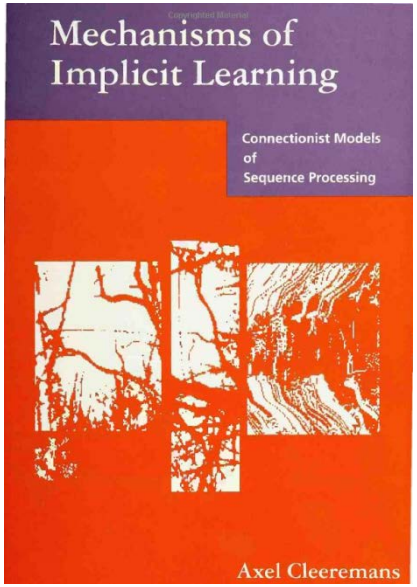
Received 11 April 2003; received in revised form 4 March 2004; accepted 8 March 2004

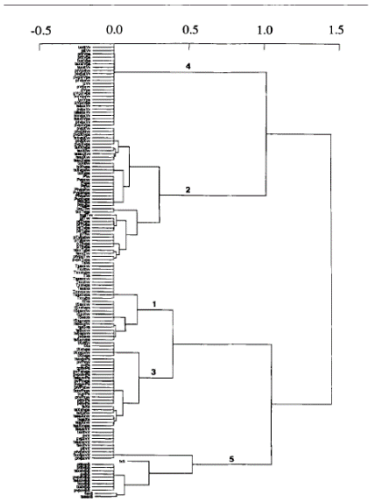
Available online 18 May 2004

Abstract

The dominant theory of what people can learn implicitly is that they learn chunks of adjacent elements in sequences. A type of musical grammar that goes beyond specifying allowable chunks is provided by serialist or 12-tone music. The rules constitute operations over variables and could not be appreciated as such by a system that can only chunk elements together. A series of studies investigated the extent to which people could implicitly (or explicitly) learn the structures of serialist music. We found that people who had no background in atonal music did not learn the structures, but highly selected participants with an interest in atonal music could implicitly learn to detect melodies instantiating the structures. The results have implications for both theorists of implicit learning and composers who may wish to know which structures they put into a piece of music can be appreciated.

Keywords: Implicit learning; Music; Serialism; Chunks; Unconscious knowledge





SRN as a “graded finite state” processor

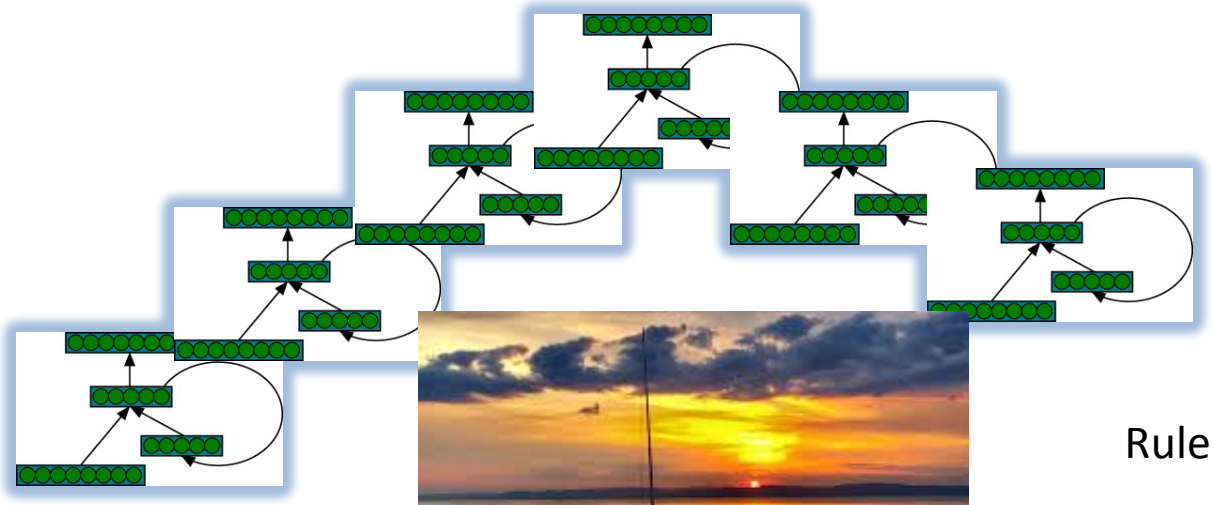
SRN has a memory buffer – can it be a graded context-free or context sensitive processor?

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



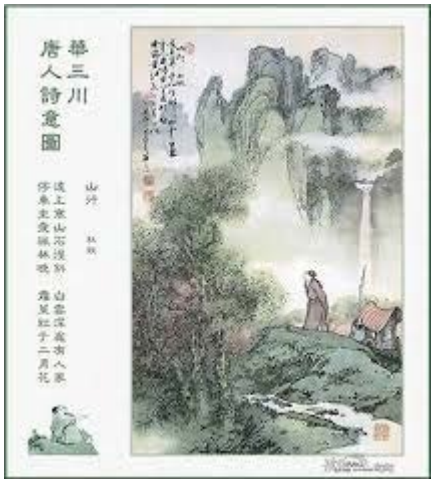
Statistical learning
Simple associative learning

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.

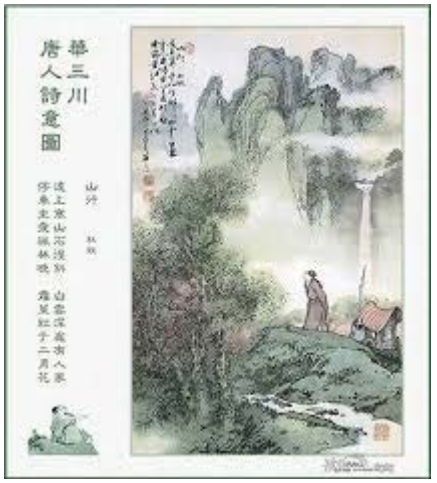
Tang poetry



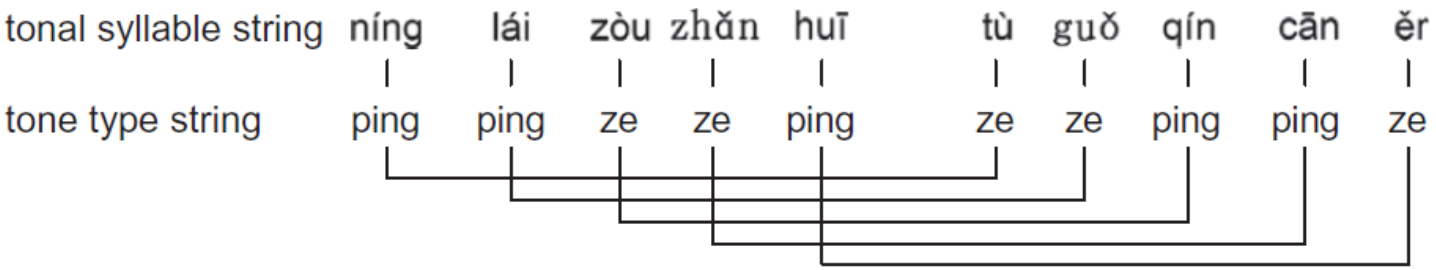
Xiuyan Guo, Shan Jiang, Feifei Li,
East China Normal University, China

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

Materials:

Inverses and non-inverses balanced in terms of:

chunk strength, mean feature frequency, repetition structure

all at the level of:

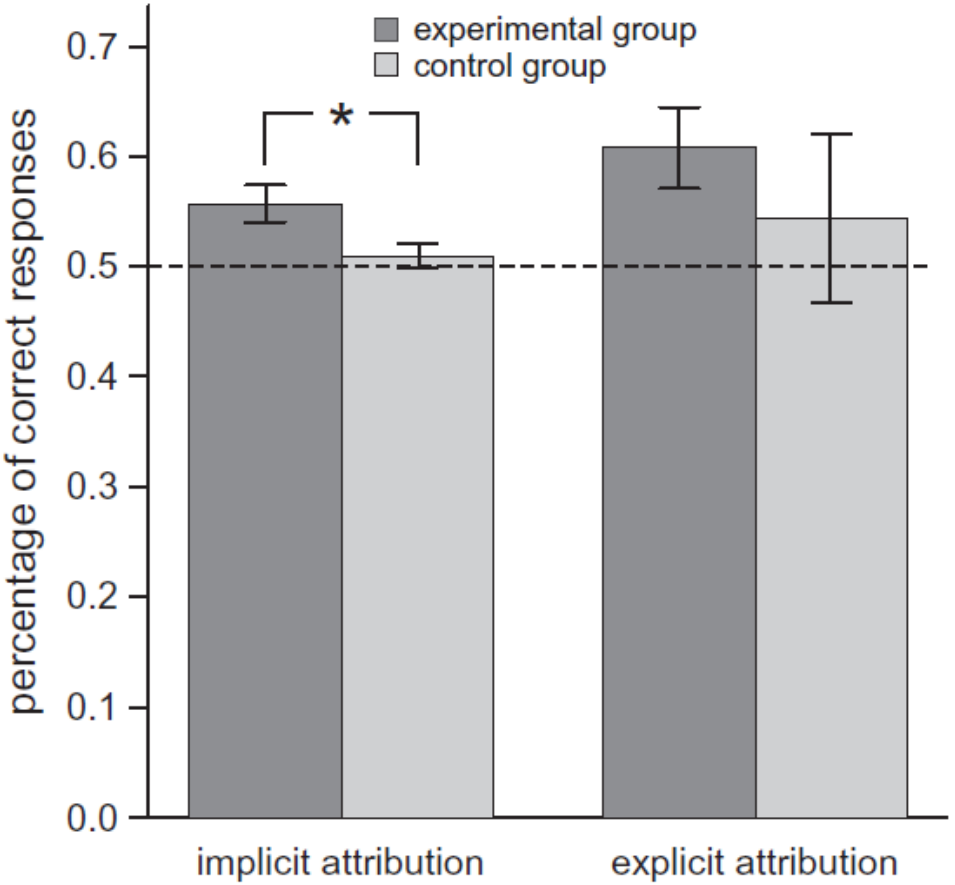
Syllables, tones, tone types

Training:

S repeated back 48 strings, 3 times

Test:

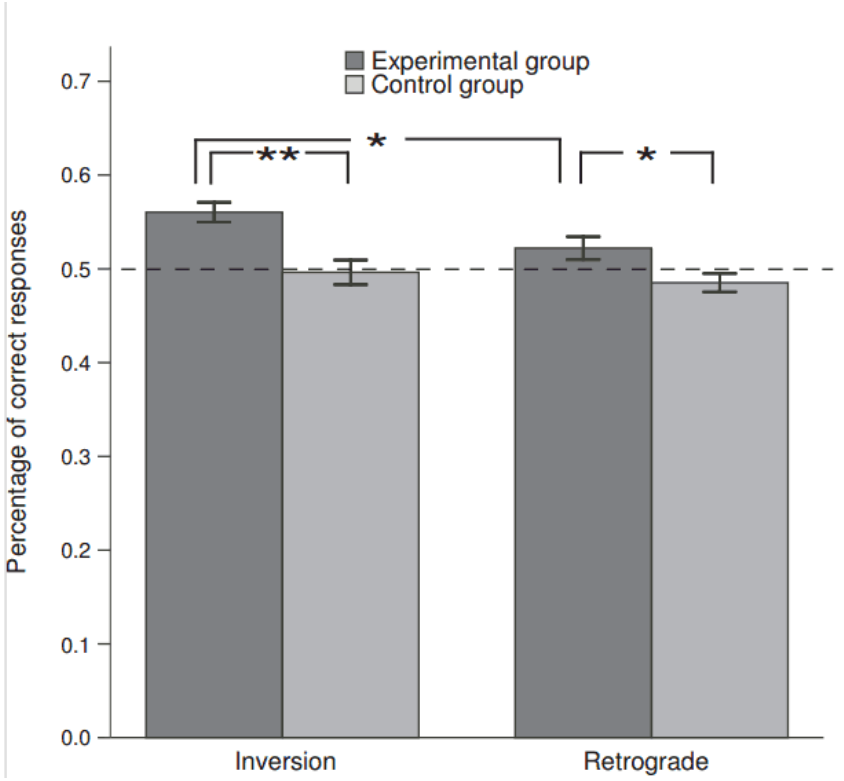
1. Each of 32 test strings judged as rule governed or not
2. Structural attribution judgment: Random, Intuition, Recollection, Rules



25% random 45% intuition
Unconscious structural knowledge

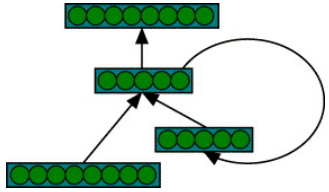
20% memory 10% rules
Conscious structural knowledge

People acquired unconscious structural knowledge of a tonal inversion

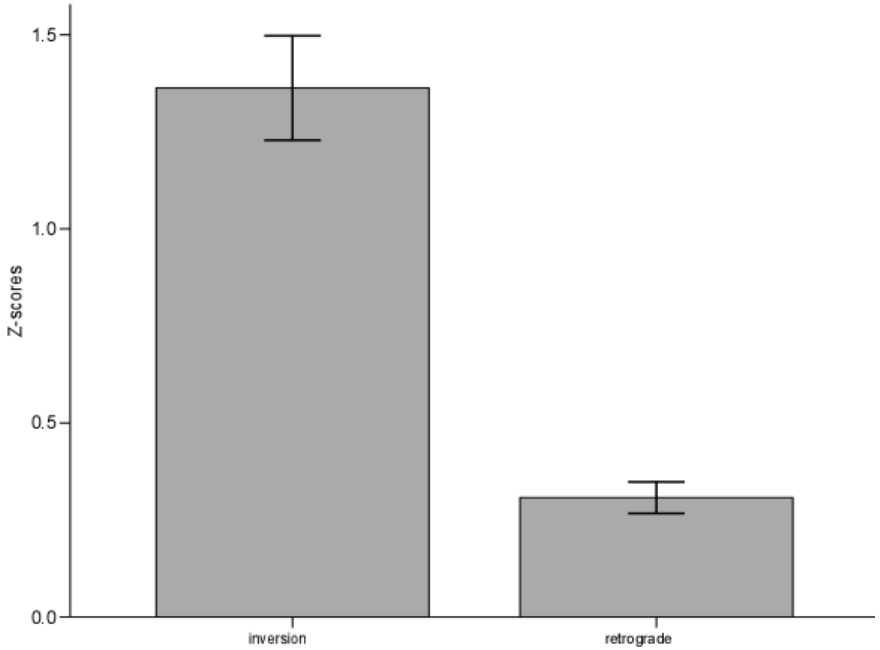


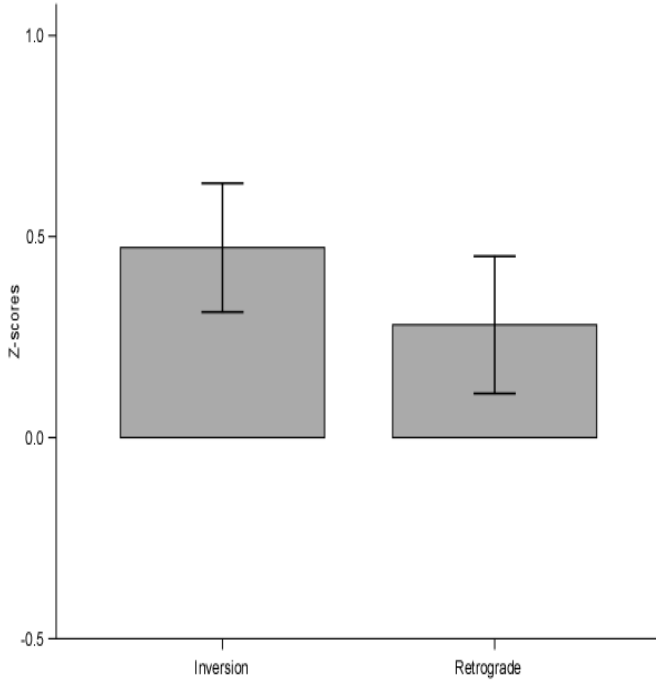
Guess 23%
Intuition 77%

Guess 34%
Intuition 66%



people





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

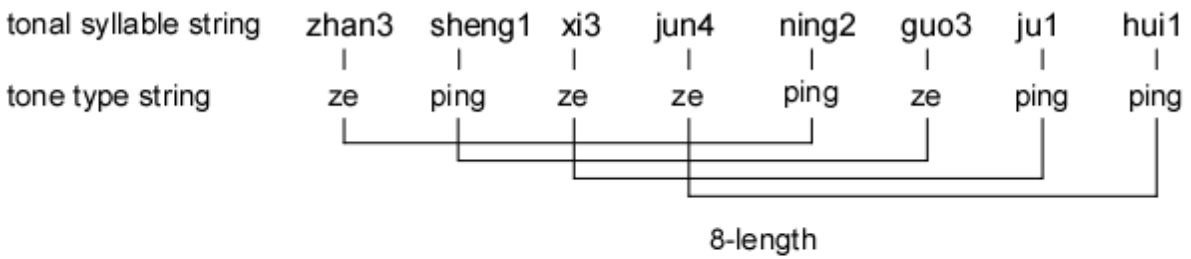
What has been learnt?

Two theories:

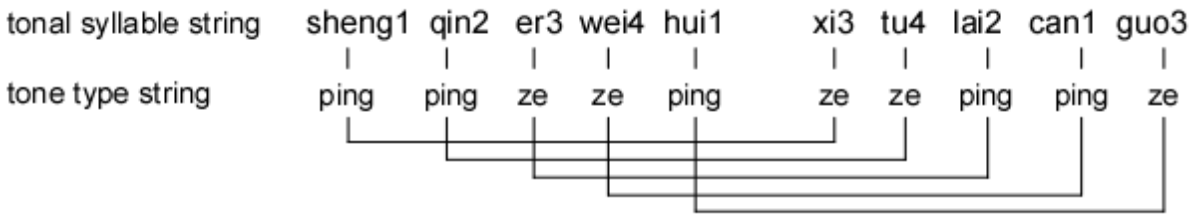
1. The symmetry per se, i.e. length can be treated as a variable by the system

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

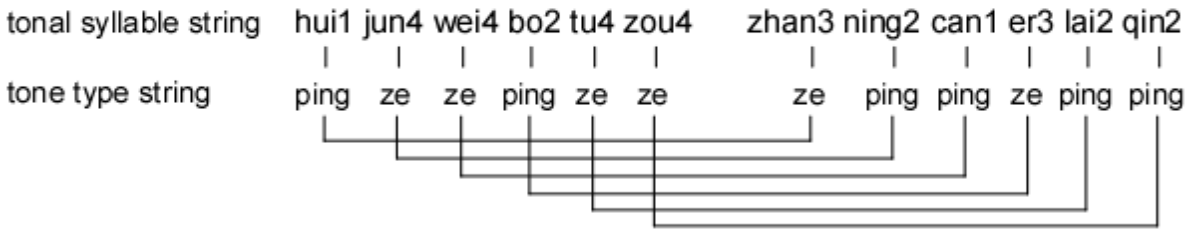
Test:
Can people/models generalize to inversions of different length?



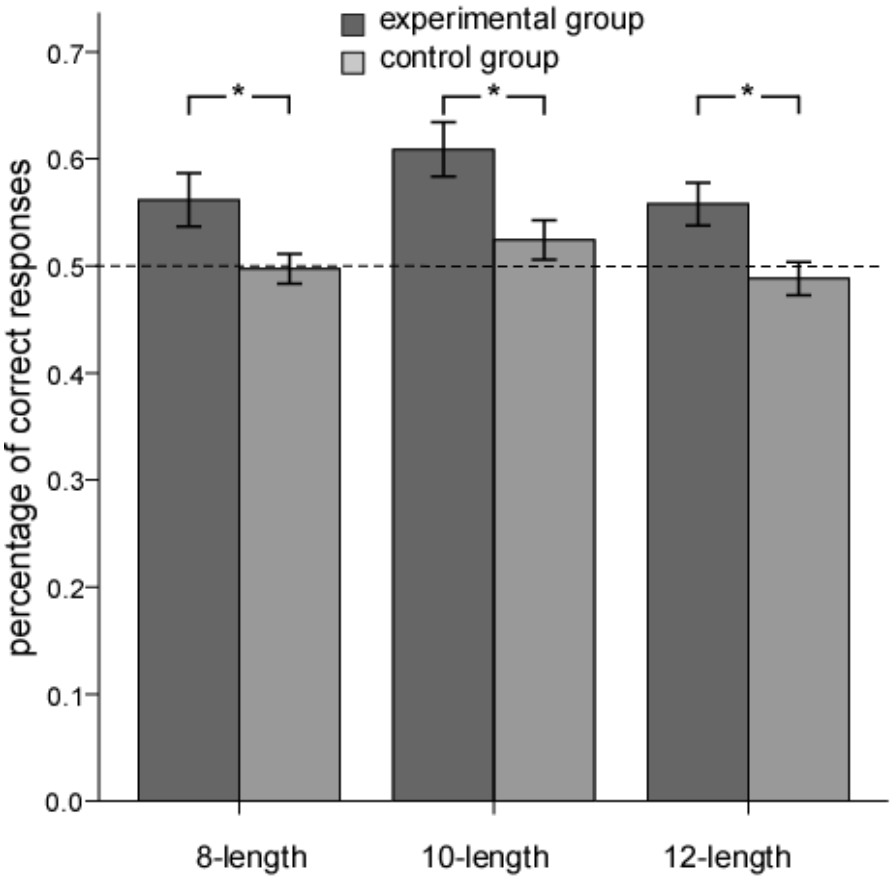
8-length



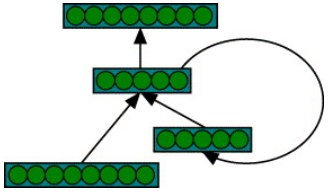
10-length

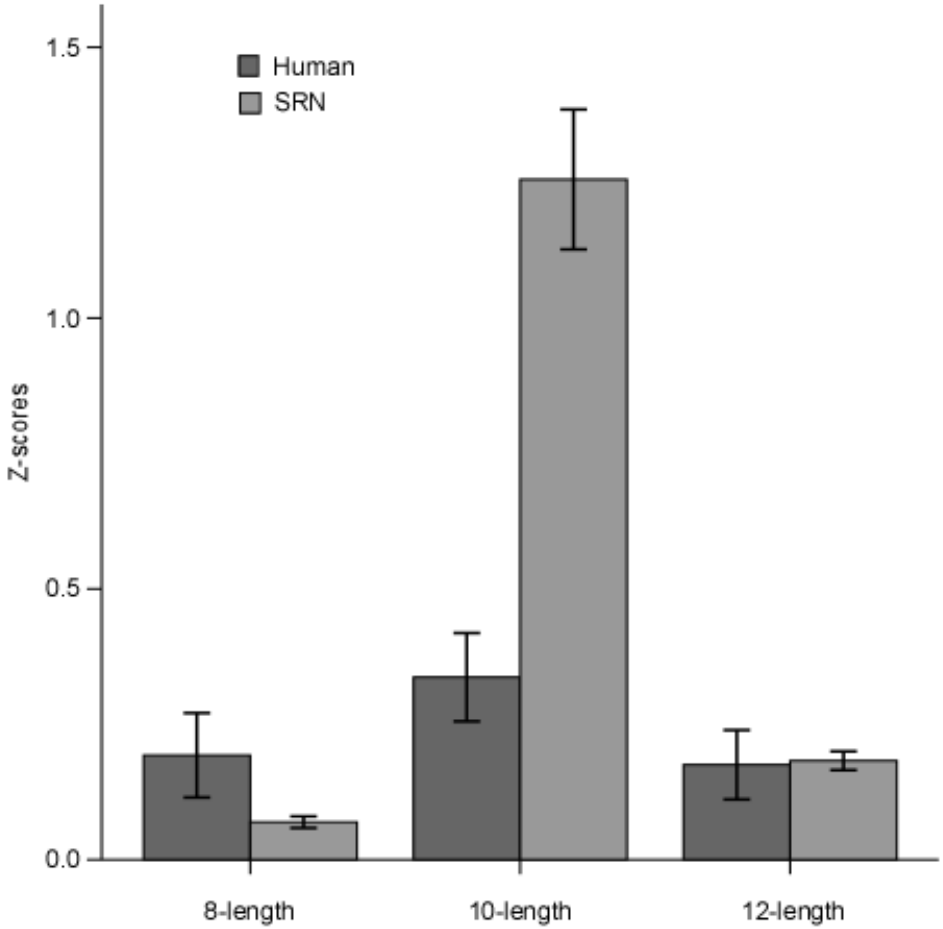


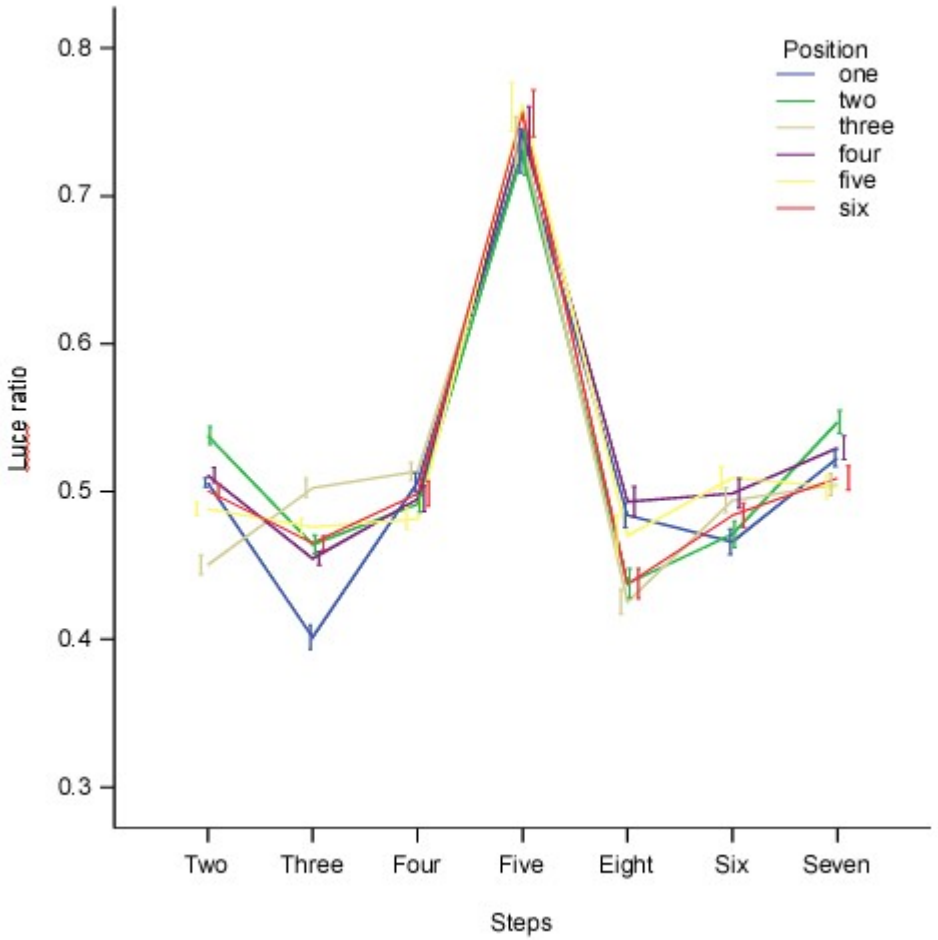
12-length



Attributions:
99% implicit




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


Position
one
two
three
four
five
six
0.8
0.7
0.6
0.5
0.4
0.3
Luce ratio
Two
Three
Four
Five
Eight
Six
Seven
Steps

Conjecture:

The SRN only learns to generalize to different lengths because of exposure to different lengths in the test phase

The SRN, as much as children, obeys the pedagogical principle of mathematical variability

The interplay between implicit and explicit learning may be pedagogically important

Pure implicit learning can (and can be modelled to)

learn complex structures,
detect structure through different perceptual embodiments
generalize through exposure to the full range of the functional form

It may thus form part of the process my grandfather was investigating