Spelling as statistical learning: evidence from artificial lexicon experiments with typically developing children

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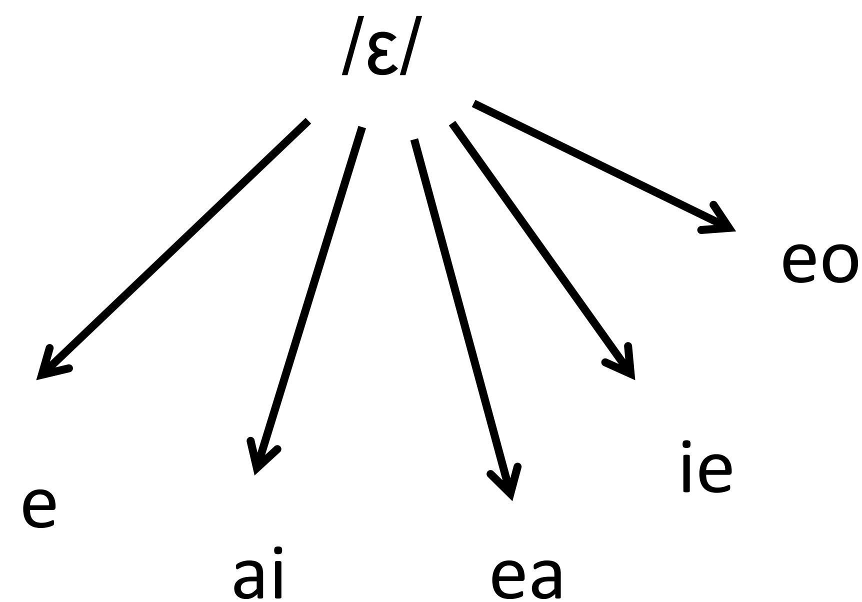
Learning to spell in inconsistent orthographies



good spelling involves more than pure memorization

Learning to spell in inconsistent orthographies

- Spelling of inconsistent sound-letter correspondences is actually not that ‘chaotic’ if probabilistic orthographic patterns or ‘rules’ are taken into consideration
- For example:
  - 1) medial /ɛ/ is commonly spelled with an e (e.g., beg) but less frequently before /d/ (e.g., h**ea**d)
  - 2) most common spelling of medial /i/ is ea (e.g., beam), but not before /p/ (e.g., d**ee**p)
  - 3) /ɝ/ is commonly spelled with ur (e.g., curd) but not after /w/ (e.g., w**o**rk, w**o**rth)

Learning to spell in inconsistent orthographies

- Naturalistic (e.g., Treiman, 1993) and some experimental work suggests that children's early spelling attempts respect some properties of their orthography
  - pess vs. ppes
  - Children comply to such patterns in pseudoword spelling/2afc tasks (Cassar & Treiman (1997; Pacton et al., 2001)
- Limitations
  - Little control over distributional properties of the input and children's explicit knowledge
  - No insight into the underlying computational mechanisms
    - Incidental (statistical) learning mechanisms?

Statistical learning

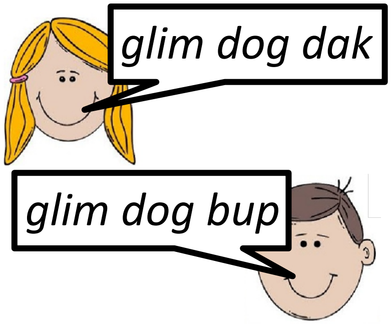
- General purpose learning device: Basis of humans' **ability to extract statistical patterns** of varying complexity **from the input**
  - e.g., pair frequencies, conditional probabilities btw adjacent elements
- Key role in language acquisition & development
  - e.g., phonotactics: Infants are sensitive to restrictions on which and where phonemes (or sequences of phonemes) can occur (Jusczyk et al., 1993)
    - English words do not begin with /ŋ/ (but Vietnamese words do)

Statistical learning

- Spoken language research suggests that restrictions on where sounds can occur and which sounds combinations are legal are learnt naturally from early in life
- What about literacy?
  - Literacy acquisition is more protracted
  - Stage models of literacy development (e.g., Frith, 1985; Gentry, 1982)
    - Sensitivity to written language patterns develops at the latest stage of literacy development
  - Testable hypothesis: do statistical learning mechanisms operate in written language from early on?

Artificial lexicon experiments

- Popular methods in language acquisition research
- Exposure to miniature linguistic systems
  - e.g., small lexicons
- Provides complete control over input to learning
  - …..golatudaropigolatutibudopab ikudaropipabikutibudodaropitib udogolatupabikugolatu …..



Saffran et al. (1996)

Samara et al. (2017)

Today: 3 studies

- Study 1
  - Validates these artificial methods in the written language domain
- Study 2
  - Addresses further questions regarding orthographic sensitivity in childhood
- Study 3
  - Explores constraints in children's statistical learning abilities

Study 1: Incidental learning of novel positional and context-based patterns

Samara & Caravolas (2014). JECP

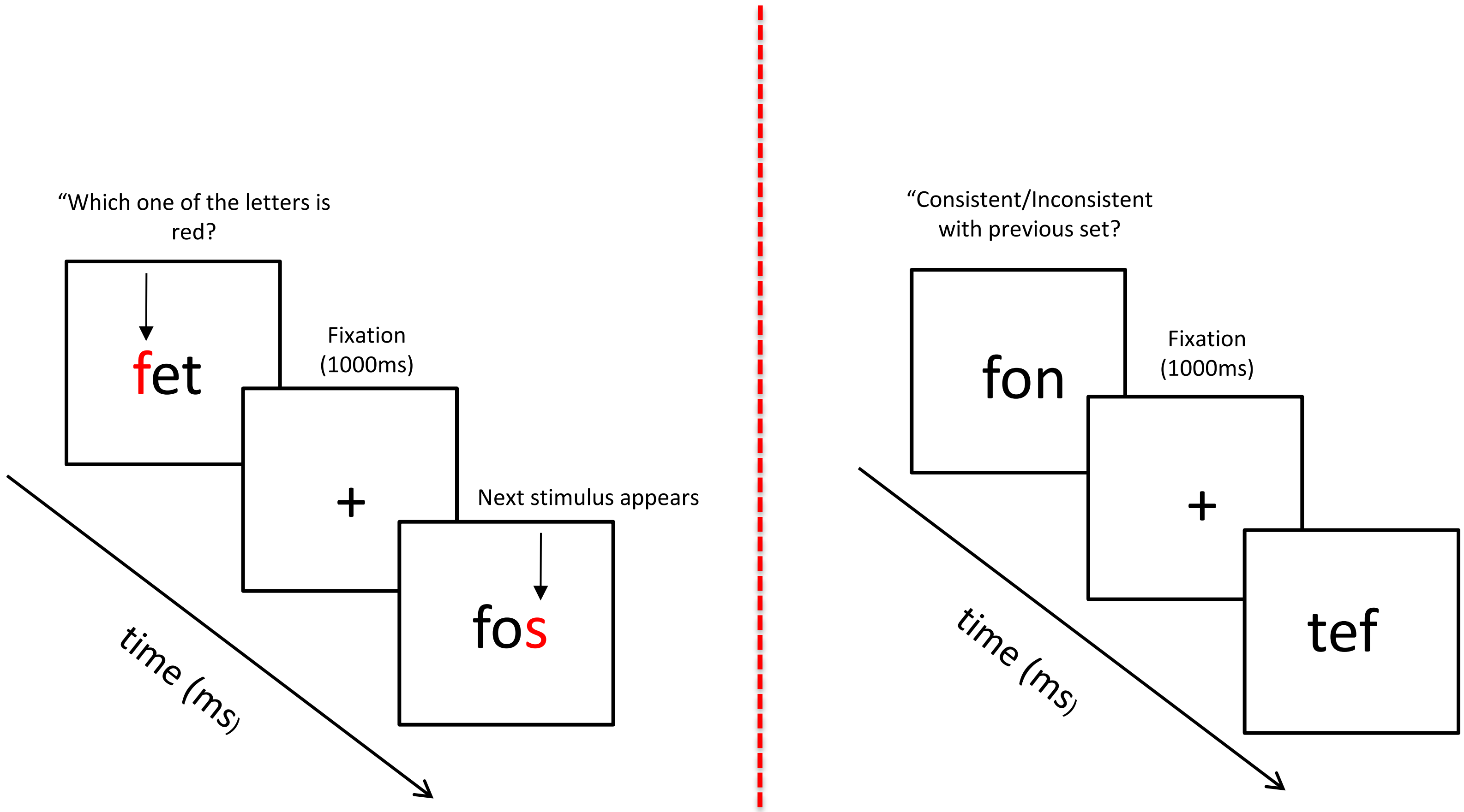
Design

- 7-year-olds (Year 2) vs. adults
- Two type
  - Position not begin with ll
  - Context z are illegal spelling l combina)
- Can these ntal brief exposure to visual stimuli that embed them?

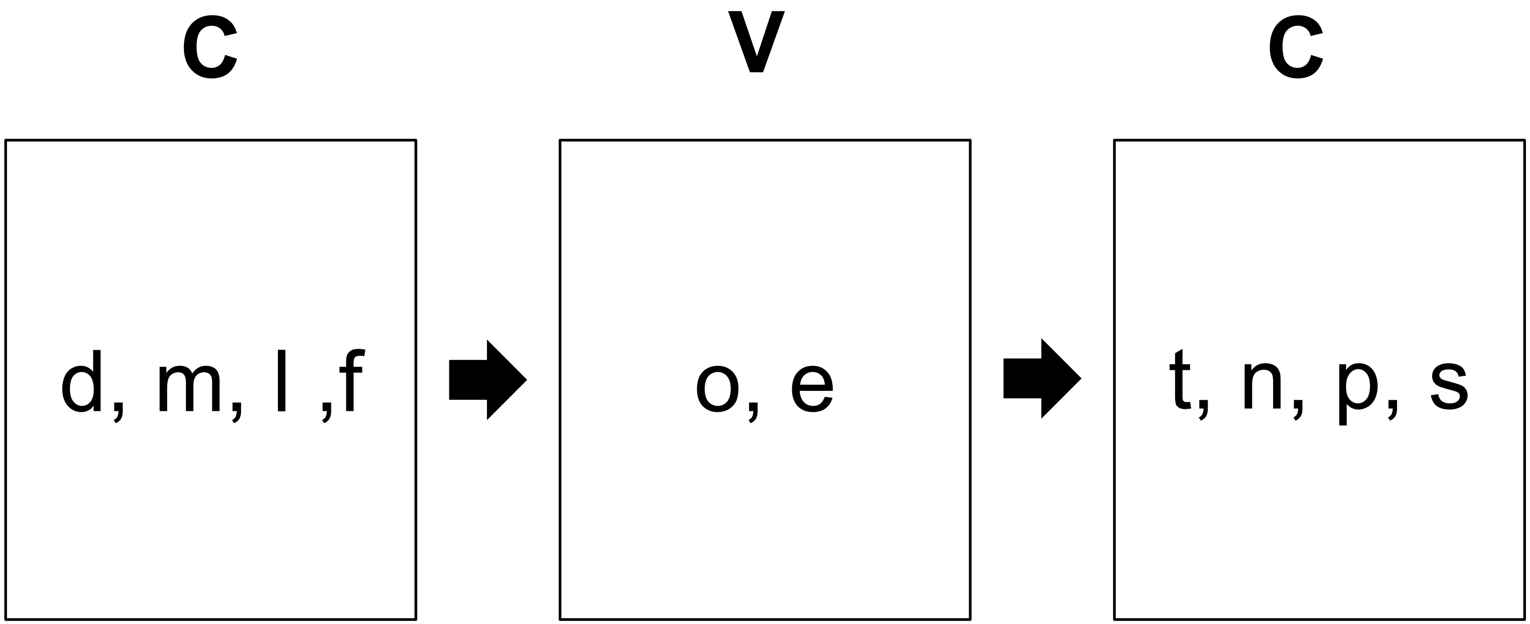
The Incidental Graphotactic Learning task

Exposure phase

Test phase



Stimuli: positional patterns



d, m, l, f only occur in C_1 position (t, n, p, s cannot)

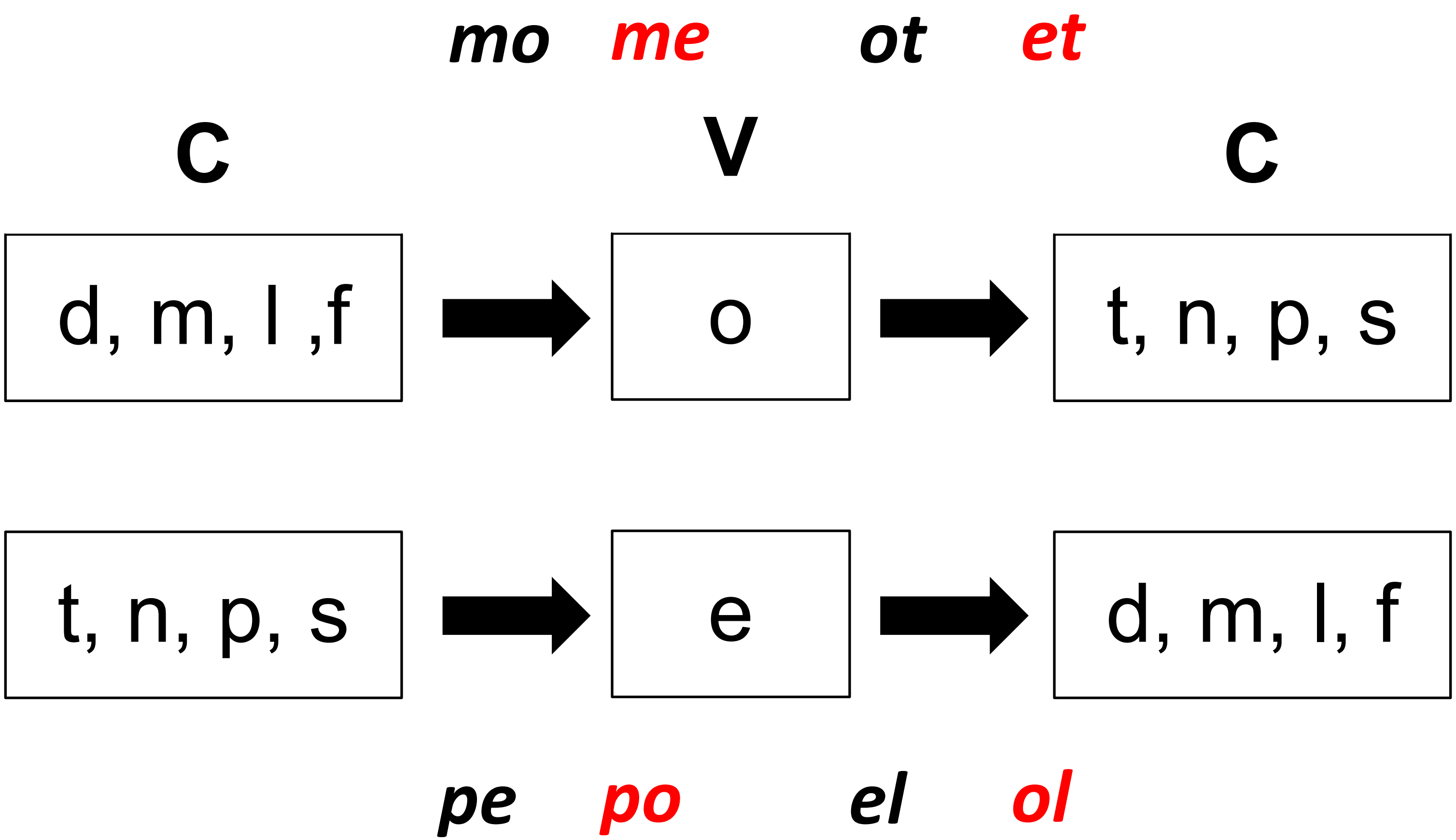
t, n, p, s only occur in C_2 position (d, m, l, f cannot)

Stimuli: positional patterns

d o t	l o t
d e n	l e n
d o p	l o p
d e s	l e s
m e t	f e t
m o n	f o n
m e p	f e p
m o s	f o s

LU	**IL**
d e t	t o d

Stimuli: context-based patterns

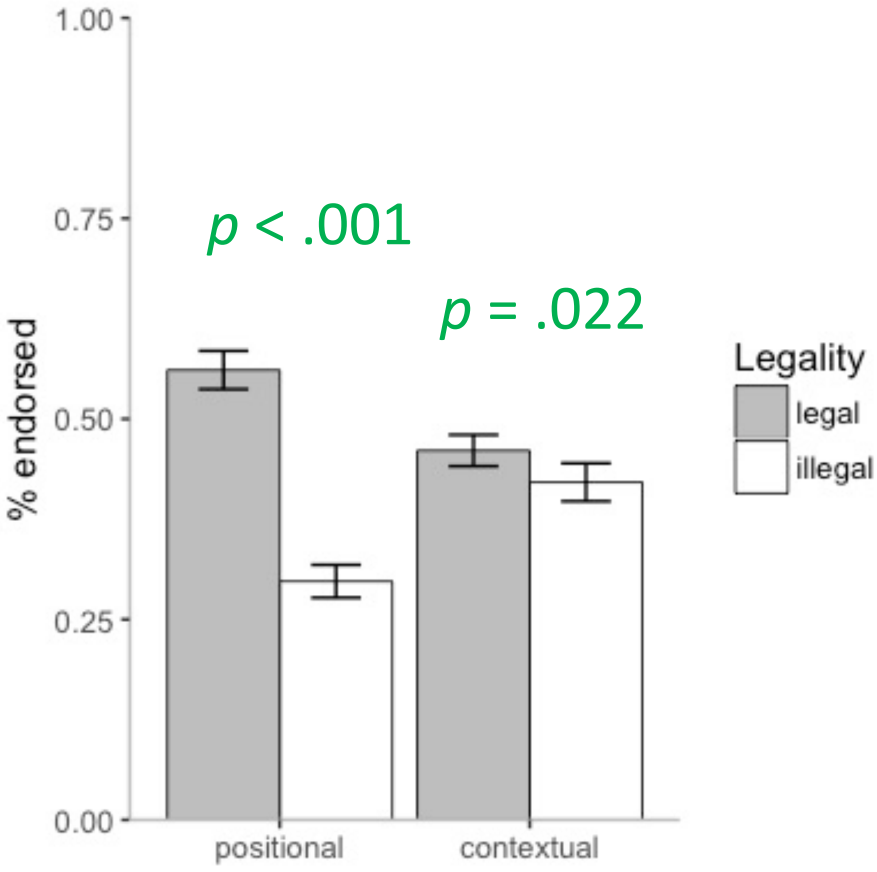


Stimuli: context-based patterns

d o t	t e m
d o p	t e f
m o n	n e d
m o s	n e l
l o t	p e m
l o p	p e f
f o n	s e d
f o s	s e l

LU	**IL**
d o n	d e t
n e f	l e n

Results: Legality judgments

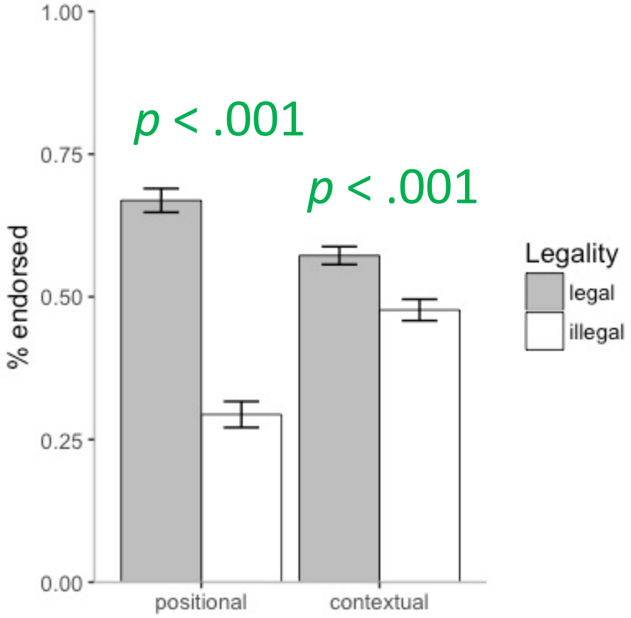


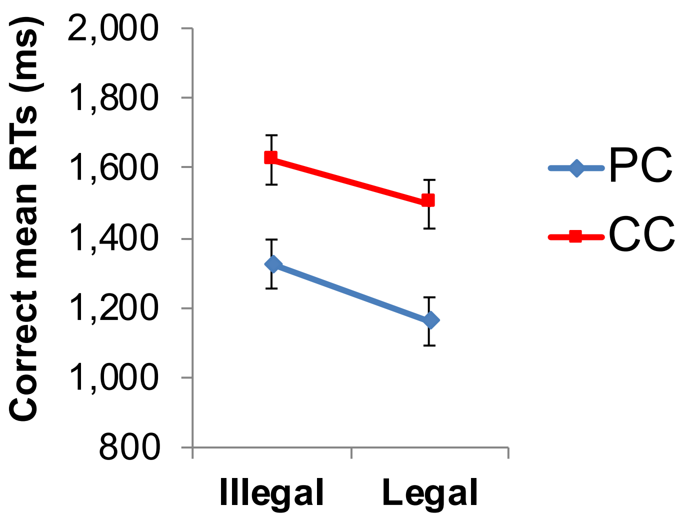
n = 137

mean = 7;5 [years;months]

- Significant learning in both condition
- Learning moderated by pattern complexity (although detection of single letters, e.g., det might have accentuated the difference)

Same pattern of results in adults





Note: Positional patterns learned more reliably than contextual patterns (and adults are, overall, better learners than children)

In sum…

- Study 1 provides evidence that novel positional and context-based patterns can be learn under brief incidental experimental conditions
- Suggests that statistical learning processes operate among 7-year-olds and underlie this ability

Limitations

- Redundancy of cues: Above chance learning under highly favourable conditions…
  - PC learning: constraints on the position of single letters, as well as body (CV) and rime-level unit constraints
  - CC learning: Constraints are exemplified both in word beginnings and ends
- Are both word contexts necessary for learning to occur?
- If not, are they equally beneficial to learners?

Study 2: Incidental learning of context-based patterns within word-initial (CV) vs. rime-level (VC) units: Evidence from English and Turkish

Samara, Singh, & Wonnacott (in preparation)

Study 2: Rationale

- More naturalistic design: Can patterns *in each position* can be learned independently ?
- Word-initial (CV) vs. rime-level (VC) comparison
  - Are rimes special?
  - Linguistic and psycholinguistic work suggests that syllables consist of two “blocks”: i) the onset, that contains the initial consonant(s), and ii) the rime, that contains the vowel and word-final consonant(s)
  - Many studies in reading and oral language have shown these units have behavioural relevance for developing and skilled literacy performance
  - If rimes are special, learning patterns from such units should be stronger than learning from CV units

Patterns in word-initial (CV) vs. rime (VC) units

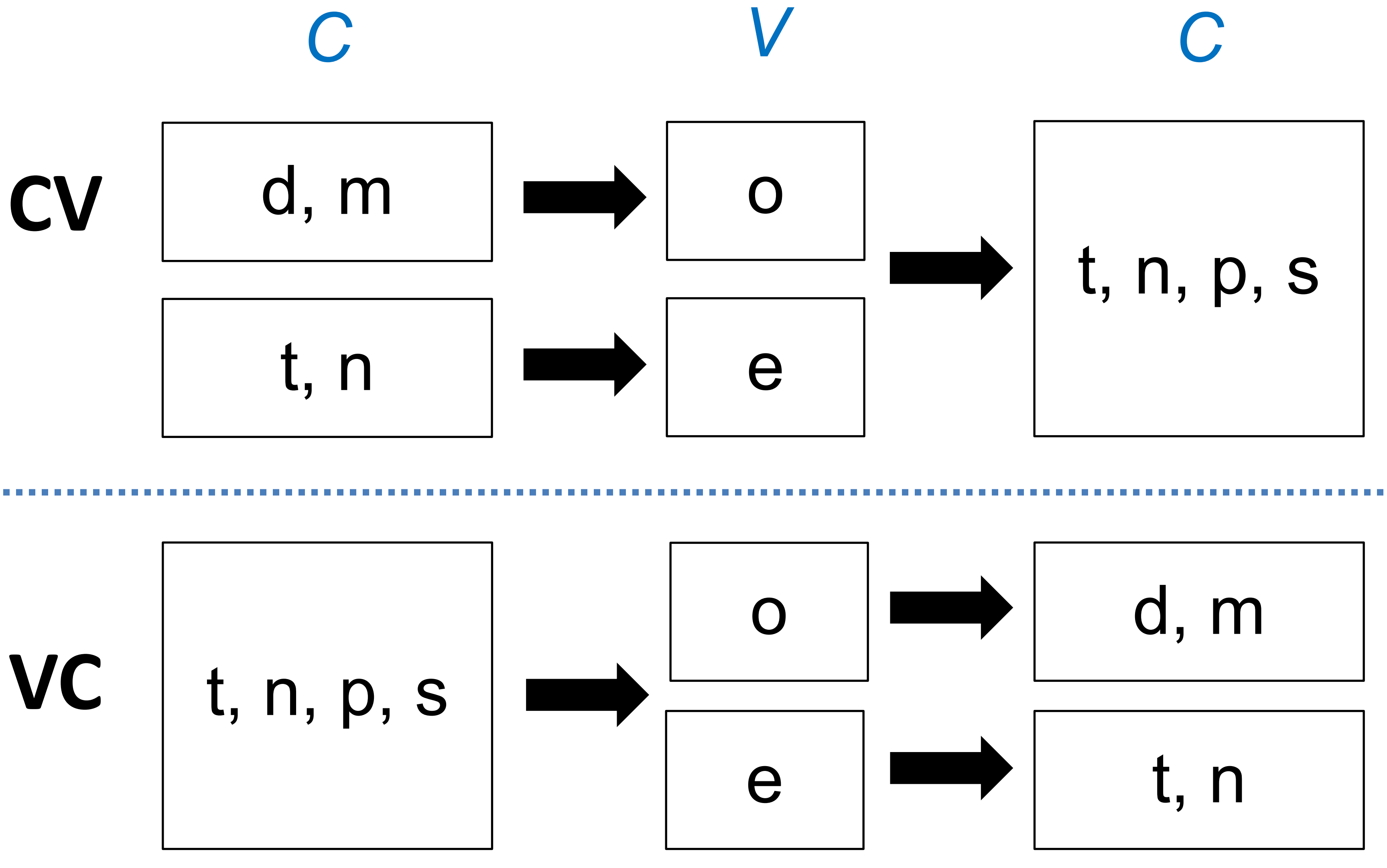
- E.g. 1: medial /ɛ/ is commonly spelled with an e (e.g., beg) but less frequently before /d/ (e.g., head)
- E.g. 2: most common spelling of medial /i/ is ea (e.g., beam), but not before /p/ (e.g., d**ee**p)
- E.g. 3: /ɝ/ is commonly spelled with ur (e.g., curd) but not after /w/ (e.g., w**o**rk, w**o**rth)

VC (rime) patterns are far more common in English than CV (word-initial) patterns

Methods & Procedure

- 78 English-speaking children
  - CV condition: n = 45 (mean age = 7.14 years)
  - VC condition: n = 33 (mean age = 7.37 years)
- 37 Turkish-speaking children
  - CV condition: n = 19 (mean age = 6.71 years)
  - VC condition: n = 18 (mean age = 6.75 years)
- Variant of the IGL task introduced in study 1
  - Learning spread across 2 days; tested on day 2
  - Exposure cover task: respond to the stimulus color

Stimuli



Data analyses

- Bayes Factor (BF) analyses
  - Indicates the relative strength of evidence for two theories/models (e.g., H1 vs. H0)
  - **Allows for three type of conclusions:**
    - Strong evidence for the alternative [BF > 3]
    - Strong evidence for the null [BF < 1/3]
    - Data insensitivity (i.e., the data does not favour either theory) [1/3 < BF < 3]

Data analyses

- **Model1:** Model predicting above chance learning performance vs. model predicting chance performance in in CV condition
- **Model2:** Model predicting above chance learning performance vs. model predicting chance performance in VC condition
- **Model3:** Model predicting a performance advantage in the word-final (VC) relative to the word-initial (CV) condition vs. model predicting CV = VC performance

BF analyses

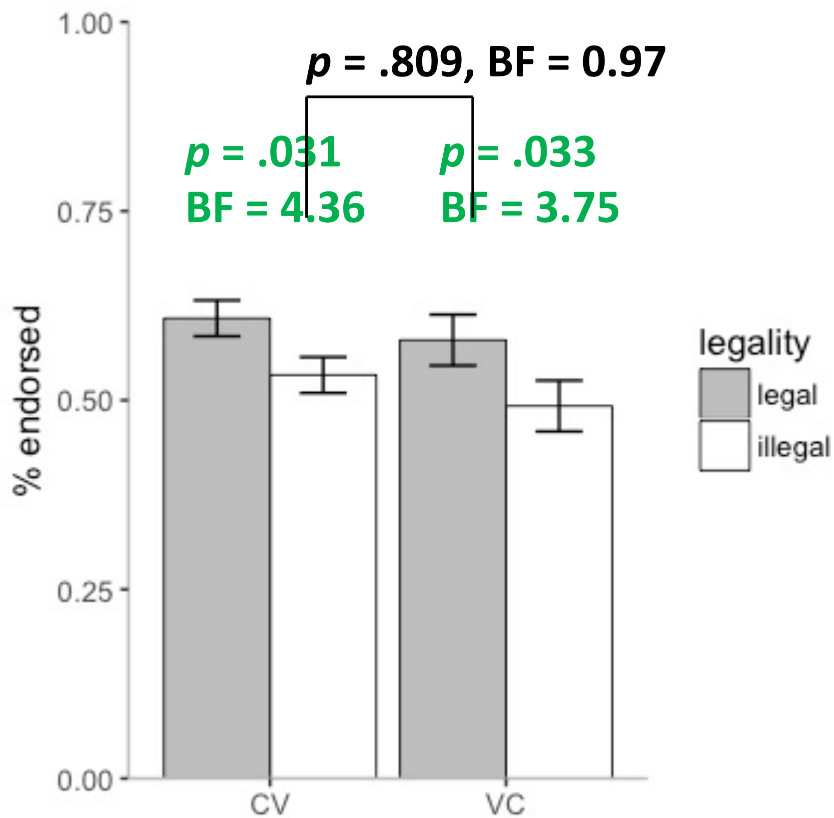
- The BF is based on the principle that evidence supports the theory that most strongly predicts it
- We know what the null predicts but we also need to know what H1 predicts…

BF analyses (cont.)

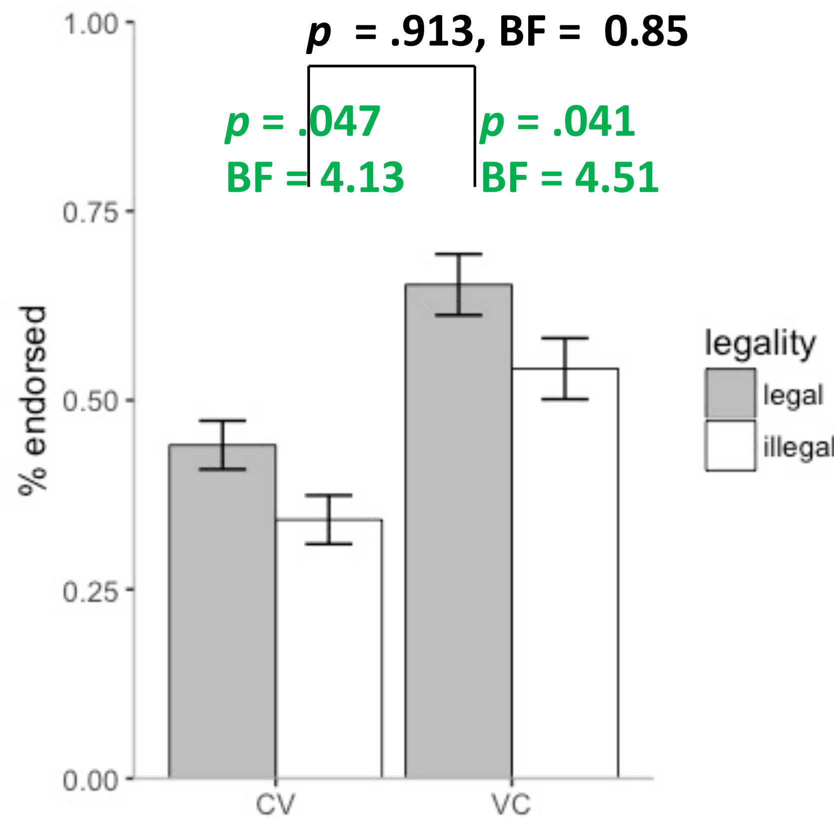
- **Model1:**
  - **H1:** Predicted ES = learning equivalent to that reported for contextual learning in study 1
- **Model2:**
  - **H1:** Predicted ES = learning equivalent to that reported for contextual learning in study 1
- **Model3:**
  - **H1:** Rough **maximum predicted ES =** learning equivalent to that reported for contextual learning in study 1 in the word-final (VC) condition ***MINUS*** chance performance in the word-initial (CV) learning

Results

English-speaking



Turkish-speaking



In sum…

- Substantial learning of novel context-based patterns both within CV (body) and VC (rime-level) units
- Findings replicate in two linguistic contexts (and hold when we collapse across the 2 datasets)

In sum…

- No evidence of the predicted word-final advantage
  - Power analyses show that, based on our current level of variance, approximately 700 (!) participants are needed to provide evidence of no difference in performance between conditions (i.e., if the true mean difference between conditions was actually zero)

Study 3: Incidental learning of written patterns with no phonological counterpart

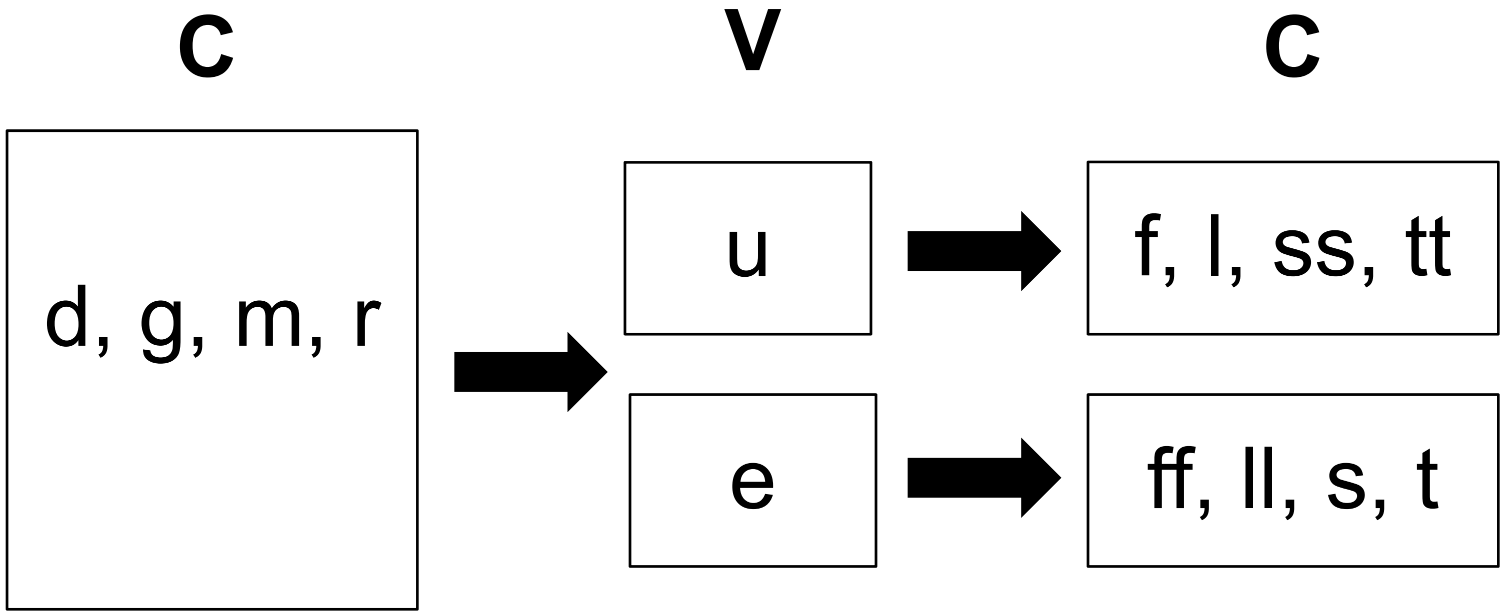
Samara, Singh, & Wonnacott (in preparation)

Incidental learning of written patterns with no phonological counterpart

- Purely orthographic ‘rules’ that place **constraints** on **where and when** certain **letters** (or letter combinations) can **occur**
- Some of them may be easy to verbalize and may be explicitly taught
  - e.g., gz and dz are illegal spellings of frequent word-final sound combinations in English; *bagz, *padz
- But others are not….

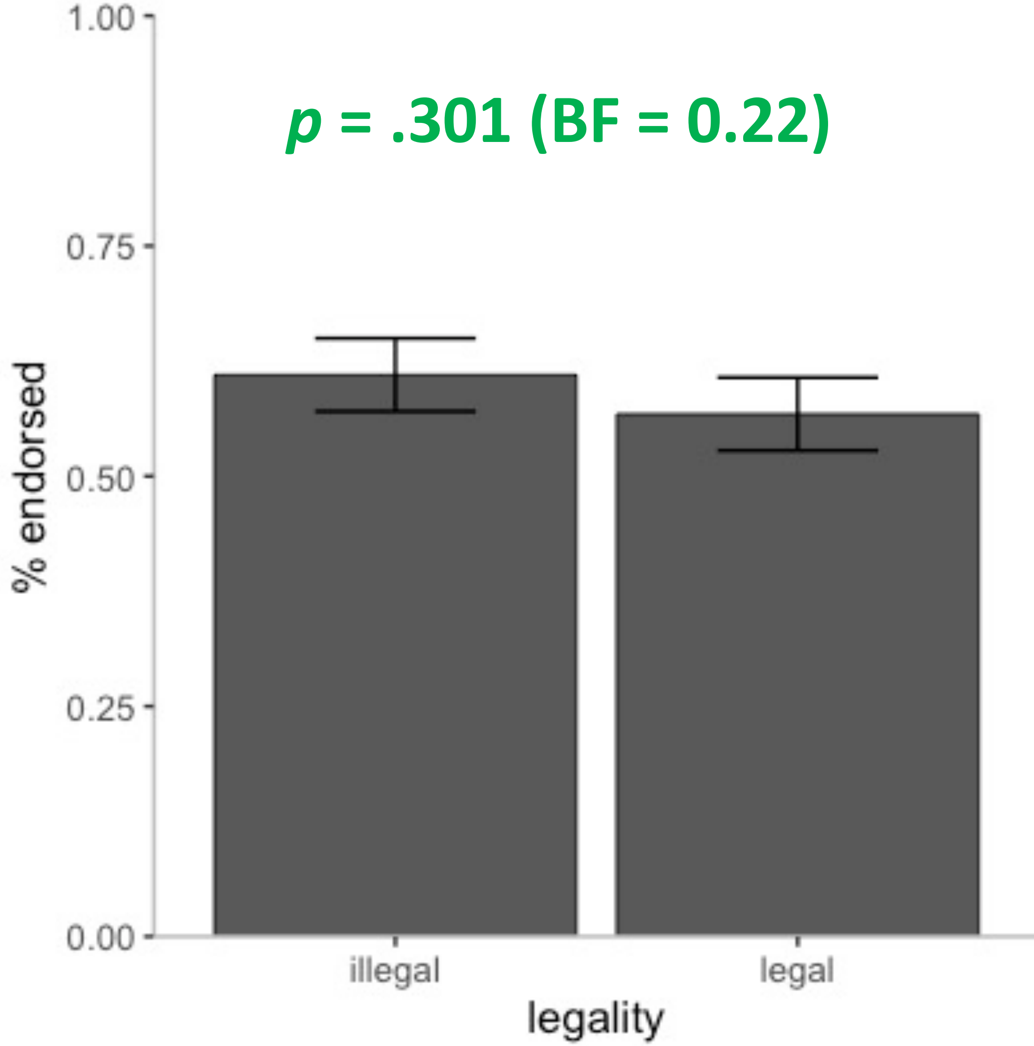
Incidental learning of graphotactics with no phonological counterpart

e.g., list1



note: incidental exposure in the context of one-back task

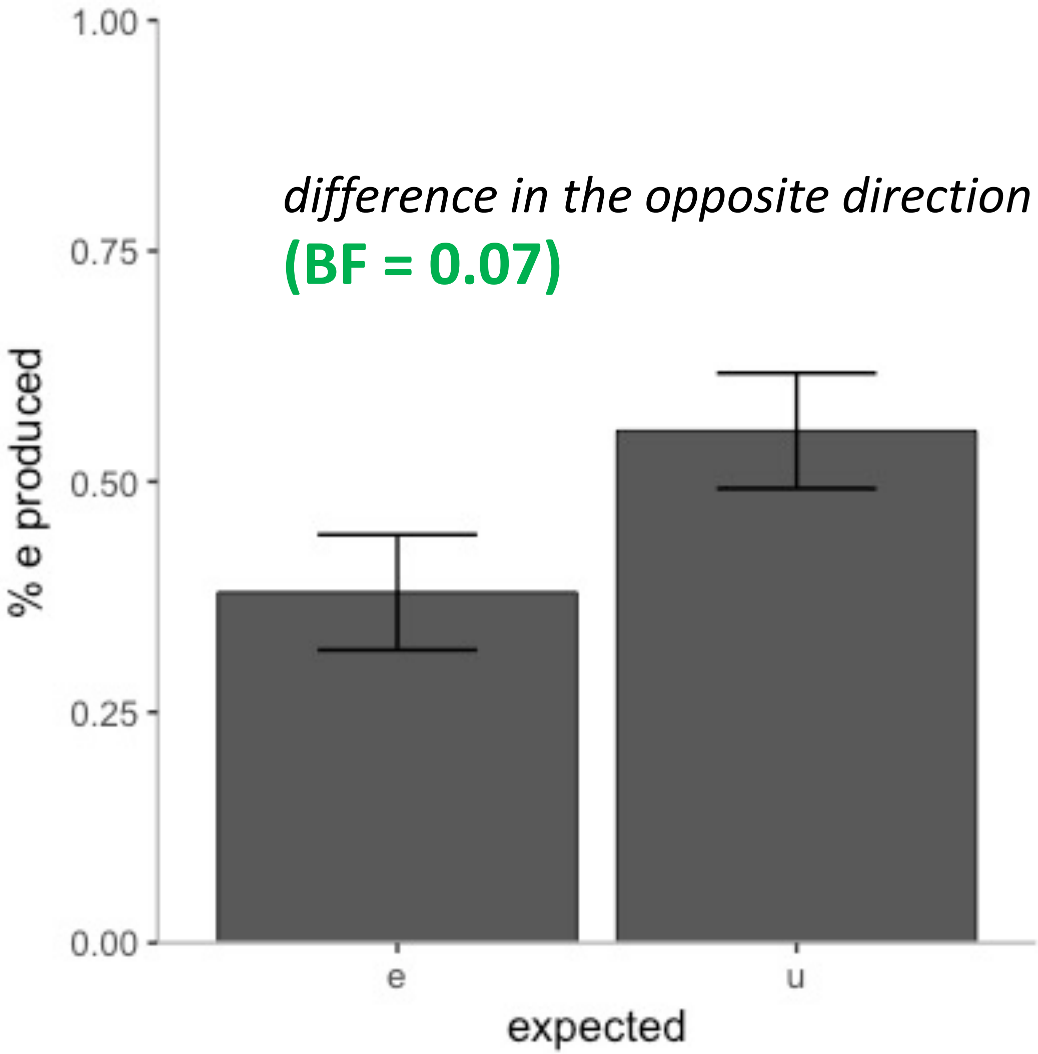
Results: Legality judgments (exp3a)



n = 25
mean = 7.25 years

Predicted ES = learning equivalent to that reported for learning CVs and VCs in study 2

Results: Fill-in-the blanks (exp3a)



difference in the opposite direction

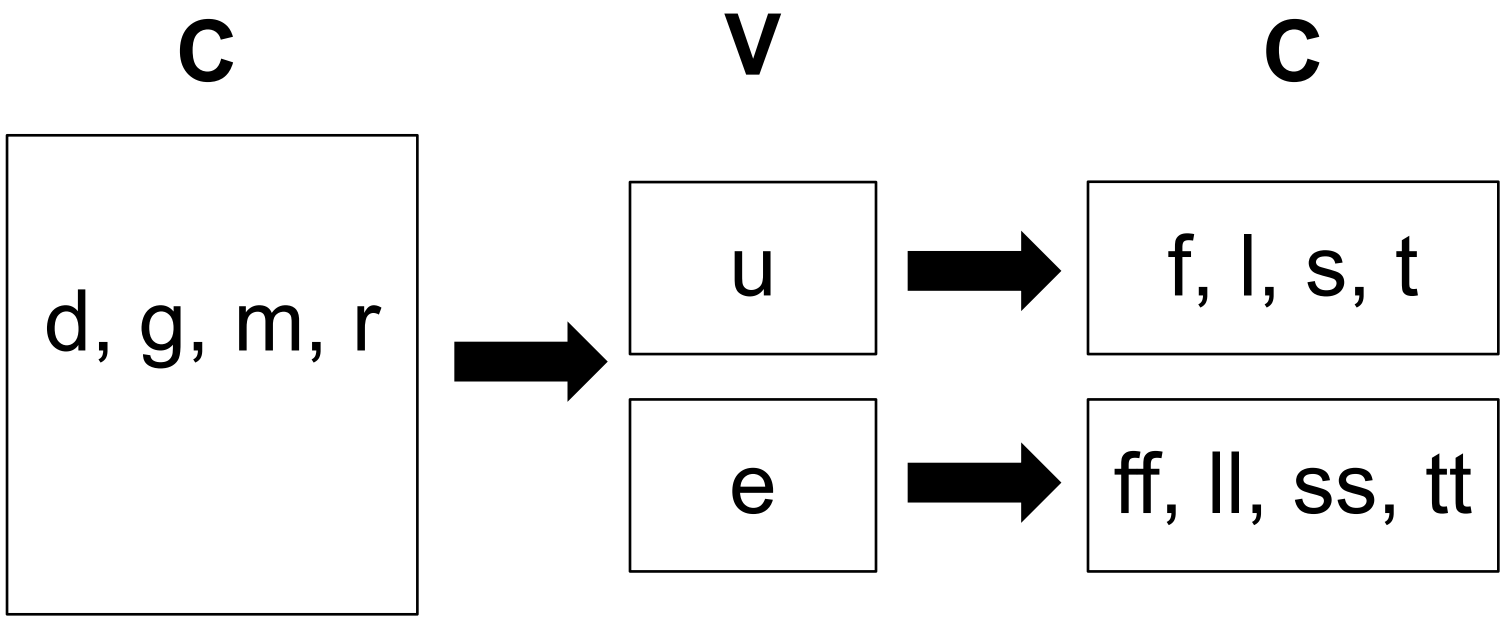
(BF = 0.07)

n = 25
mean = 7.25 years

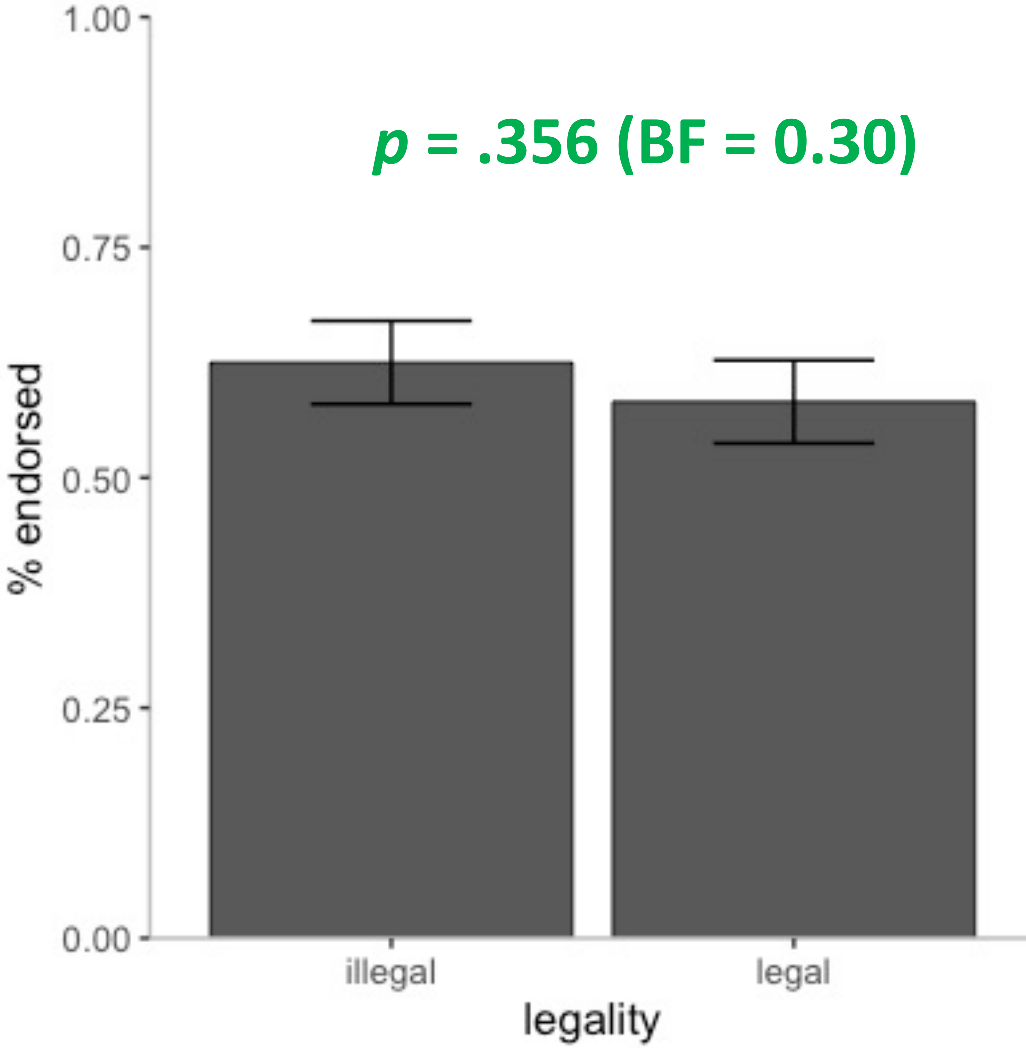
Predicted ES = learning equivalent to that reported in a pilot study assessing contextual constraints learning in children: similar to study 1

Incidental learning of written patterns with no phonological counterpart (v.2)

e.g., list1



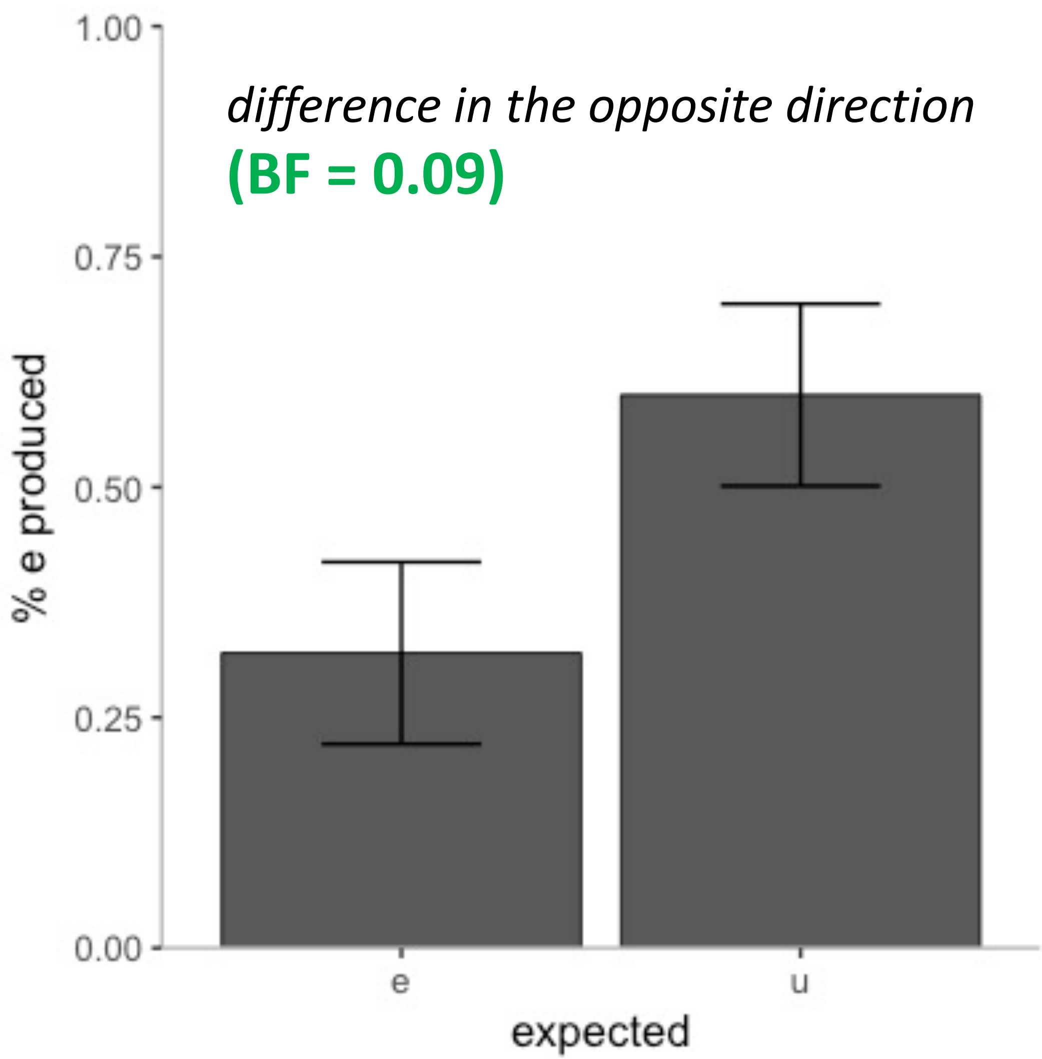
Results: Legality judgments (exp3b)



n = 25
mean = 7.24 years

Predicted ES = learning equivalent to that reported for learning CVs and VCs in study 2

Results: Fill-in-the blanks (exp3b)



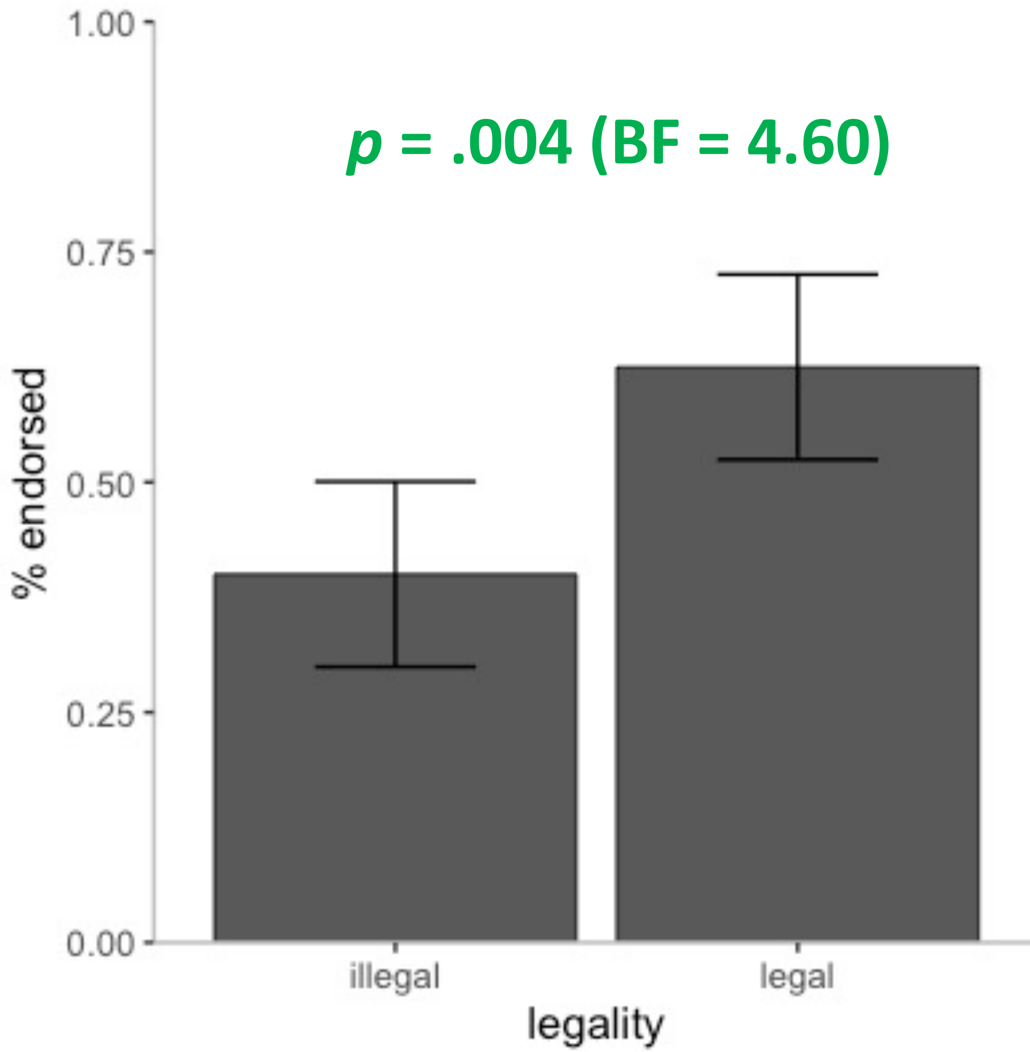
n = 25
mean = 7.24 years

Predicted ES = learning equivalent to that reported in a pilot study assessing context-based learning in children: similar to study 1

Explicit learning of written patterns with no phonological counterpart

- Identical design to exp.3b
- Similar methods to exp.3b (1-back task)
- Explicitly taught the patterns: “In Freddie’s language, double letters come after “u” and single letters come after “e”.
  - 2 examples from exposure phase are provided
- BFs calculated as in experiments 3a & 3b

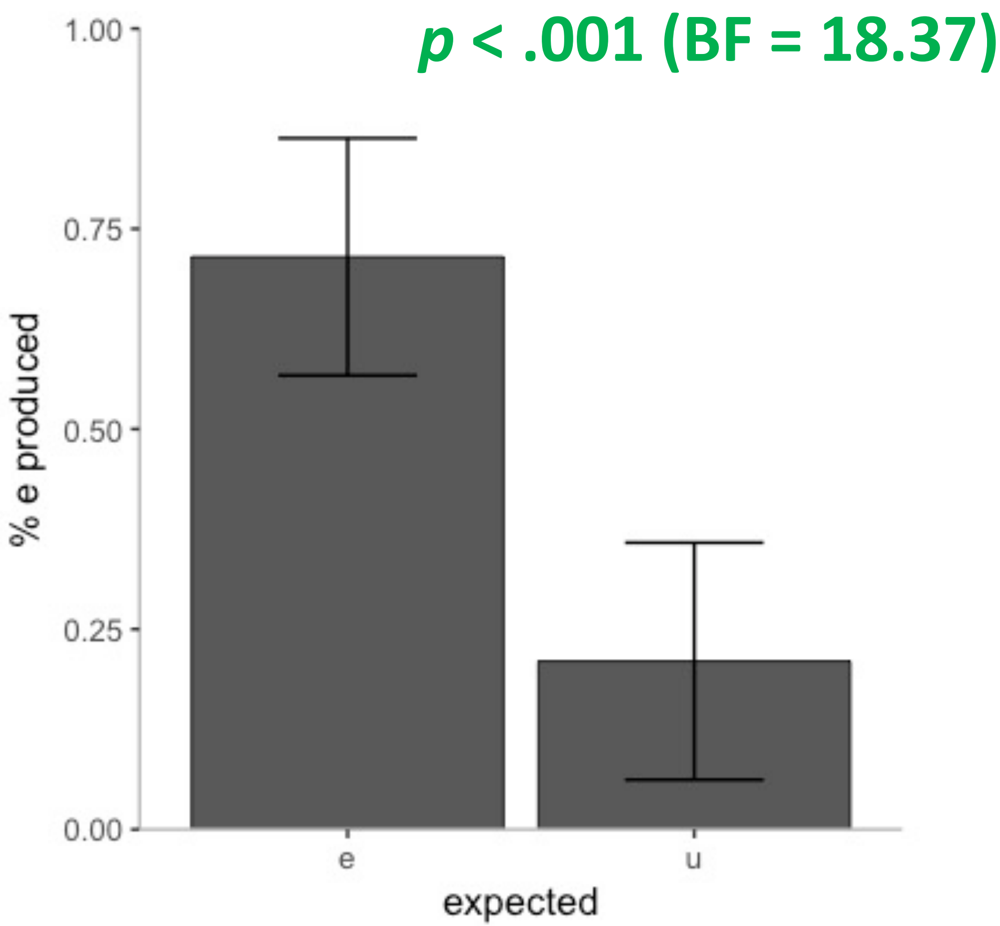
Results: Legality judgments (exp3c)



n = 25
mean = 7.19 years

Predicted ES = learning equivalent to that reported for learning CVs and VCs in study 2

Results: Fill-in-the blanks (exp3c)



n = 25
mean = 7.19 years

Predicted ES = learning equivalent to that reported in a pilot study assessing context-based learning in children: similar to study 1

In sum…

- Substantial evidence that novel context-based patterns with rime-level (VC) are not learnt by 7-year-olds when presented under incidental exposure conditions
- Patterns of the ‘easier’ type are, however, are readily learnt under explicit training conditions

Bringing it all together

- Study 1
  - Validates methods in written language domain
  - Demonstrates that, from 7 years of age, children are sensitive to novel positional and context-based patterns
- Study 2
  - Employs similar methods to address further questions regarding orthographic sensitivity in childhood
  - Establishes that redundant cues are not necessary for learning to occur
- Study 3
  - Establishes some constraints on the statistical learning abilities of children: that is, some patterns that are easily learnt explicitly, are hard to acquire incidentally (at least, under brief experimental conditions)

Bringing it all together

- Implications for theories of literacy development
  - Elucidate the learning mechanisms that allows ortho-phonographic learning to emerge in the absence of explicit instruction
  - Argues against “late” stage-based models of literacy development (Frith, 1985; Gentry, 1982) by showing that (at least some) orthographic learning occurs early
  - Corroborates a statistical learning account of learning to spell (Pollo et al., 2008; Treiman, 2017; Treiman & Boland, 2017)

Directions for future research

- **Exploring the role of statistics**
  - Are children sensitive to conditional forward and backward probability (e.g., the probability that q is followed by u and that u is preceded by q), which may be more relevant for learning to spell than joint probability (e.g., frequency of qu)?
  - Are children sensitive to manipulations of (more naturalistic) probabilistic orthographic patterns? (head vs. bed)
    - Are these exceptions learnt best in a staged manner (i.e., whereby patterns are learnt and consolidated first before exceptions are introduced)?
- **Homophone learning**
  - Are these patterns simply too hard to learn incidentally?
  - Can learning occur for the easier positional patterns that children are thought to have picked up from as early as kindergarten (e.g., pess vs. ppes)

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  - Ayse Aktas

Thank you for listening!

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Adults-study 1

Measure	Range	Mean (*SD*)	1	2	3	4	5	6
PC learning (*n* = 55)								
1. IGL	-0.16 – 2.75	1.15 (0.70)	—	-.14	.07	.12	.04	-.12
2. WRAT Reading[a]	49.00 – 66.00	60.47 (3.94)		—	.59**	.46**	.01	.33*
3. WRAT Spelling	38.00 – 57.00	47.00 (3.21)			—	.56**	.06	.46**
4. Exception Words[b]	69.00 – 79.00	74.89 (2.42)				—	.32*	.46**
5. TOWRE-SWE[c]	1.49 – 2.68	2.13 (0.22)					—	.50**
6. TOWRE-PDE[c]	0.73 – 1.75	1.28 (0.20)						—
CC learning (*n* = 56)								
1. IGL	-0.36 – 1.16	0.27 (0.36)	—	-.05	-.16	.13	.18	.01
2. WRAT Reading	51.00 – 67.00	60.23 (3.54)		—	.63**	.72**	.35	.64**
3. WRAT Spelling	37.00 – 55.00	46.57 (3.88)			—	.62**	.13	.48*
4. Exception Words[b,d]	71.00 – 79.00	75.74 (1.91)				—	.38	.65**
5. TOWRE-SWE[c,d]	1.58 – 2.55	2.12 (0.21)					—	.52*
6. TOWRE-PDE[c,d]	0.76 – 1.77	1.26 (0.20)						—

Kids-study 1

Measure	Range	Mean (*SD*)	1	2	3	4
		PC learning (*n* = 60)				
1. IGL	-0.81 – 2.68	0.83 (0.73)	—	.19	.10	.13
2. Reading[a]	6.00 – 119.00	73.55 (22.93)		—	.85**	.77**
3. NW Reading[a]	9.00 – 70.00	35.45 (14.68)			—	.71**
4. PWM[b]	6.00 – 61.00	29.13 (10.25)				—
		CC learning (*n* = 62)				
1. IGL	-0.81 – 1.47	0.15 (0.46)	—	-.11	-.09	-.09
2. Reading[a]	6.00 – 123.00	78.06 (20.77)		—	.83**	.72**
3. NW Reading[a]	2.00 – 72.00	39.94 (18.23)			—	.67**
4. PWM[b]	5.00 – 52.00	30.19 (9.98)				—

Dyslexic adults

Variable	Skilled readers (n = 30)	Dyslexic readers (n = 19)
WRIT Vocabulary	-.15	.32
WRIT Matrices	-.16	.34
WRAT Reading	-.26	.22
WRAT Spelling	-.04	.26
WAIS Digit Span	.15	-.16[b]
WAIS Symbol Search	.04	.44
RAN digits mean time[a]	-.07	.04
RAN objects mean time[a]	.11	.01
NWPD latencies	.15[b]	.01[a]

Note. WRIT = Wide Range Intelligence Test; WRAT = Wide Range Achievement Test; WAIS = Wechsler Adult Intelligence Scale; RAN= Rapid Automatized Naming; NWPD = NonWord Phoneme Deletion.
[a]In seconds. [b]Log transformed.