Memory for Phonological Structure

Colin Wilson
Johns Hopkins University

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Outline

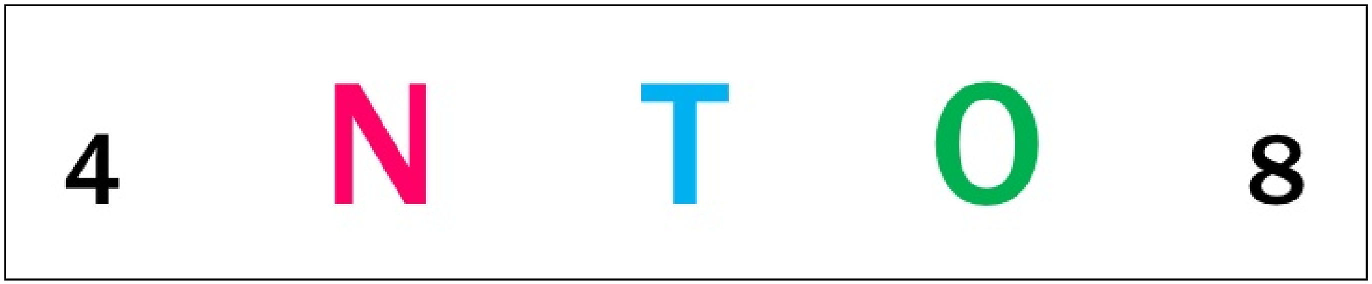
- Fallibility of perception and memory
- Memory for phonological structure
  - Segment combinations in words
    syllables, tiers, edges, interiors
  - Feature combinations in segments
- Representational similarity model
- Memory errors and artificial grammar learning

DIGIT	LETTER	LETTER	LETTER	DIGIT

4 N T O 8

Memory for combinations (Treisman & Schmidt 1982)

Letters (T S N OX) combined with colors (Pink, Yellow, Green, Blue Brown) flanked by digits and displayed briefly (100–200 ms)



Participants reported black digits and letters, colors, positions. “They were told not to guess, but to report only what they were fairly confident they had seen.”

Illusory conjunctions (33% of responses, 24% corrected for chance)
Ex. Blue N or Red T in left position

> **“The main result was that conjunction errors in reporting the colored letters significantly exceeded errors which combined one feature with one not present in the display.”**

Similar findings in probe verification tasks and for many other stimulus types …

Illusory conjunctions

- Letters, colors, shapes, sizes, solidity (outline vs. filled), …
  Treisman & Schmidt 1982, Chastain 1982, Prinzmetal et al. 1984, Ivry & Prinzmetal 1991
- Components of faces (e.g., hair, mouth, eyes, nose)
  Reinitz & Lammers 1992, Jones et al. 2006, McKone & Peh 2006
- Pitch and duration of tones
  Thompson et al. 2001
- Chinese character radicals
  Fang & Wu 1989, Flores d'Arcais et al. 1994, Lai & Huang 1988
- Constituents of written compound nouns
  Reinitz & Demb 1994, Jones & Atchley 2006, Leding et al. 2007, Leding 2015
  `witch hunt` … `spacecraft` … `witchcraft` ?
  `crossroad` … `rainbow` … `crossbow` ?
- Verb-particle combinations (Brehm & Goldrick, submitted)
  `He will cut the meat` … `He will lock up the bicycle`
  … `He will cut up the meat` ?

Illusory conjunctions

- Colors and letters in individual words (orthographic syllable structure studies)

  Prinzmetal et al. 1986, 1991, Rapp 1992, Doignon et al. 2005, Maïonchi-Pino et al. 2008

  anvil vs. anvil

- Letters in multi-word displays

  Allport 1977, Mozer 1982, McClelland & Mozer 1986, Treisman & Souther 1986, Van der Velde et al. 1989, Davis & Bowers 2004, Fischer-Baum et al. 2011, Shetreet & Friedmann 2011

  LINE + LACE ~ 350 ms display → LANE
  COPE + CAGE ~ 96 ms display → CAPE
  FAST + FICROT / FOPICT 200 ms display → FACT

- Syllables, segments, features of spoken words

  Speech errors / spoken recall: Conrad 1964, Morton 1964, Wickelgren 1965, 1966, Fromkin 1973, Baars & Motley 1974 *et seq*., Ellis 1980, **Treiman & Danis 1988**, **Treiman et al. 1994**, Hartley & Houghton 1996, Goldrick 2004, Page et al. 2007, Walker 2007, Lee & Goldrick 2008, …

  Dichotic presentation, probe verification: Morais et al. 1987, 1991, Kolinsky 1992, **Kolinsky et al. 1995**, Mattys & Samuel 1997, Mattys & Melhorn 2005, Zeng & Mattys 2011

Recombination errors in spoken recall **(Treiman & Danis 1988)**

English participants listened to lists of six CVC nonwords and repeated each list

gɛɹ   vaŋ   kus   dæl   jɔb   ʃim

Recombination errors

Ex. jɔb + $\underline{\text{ʃim}}$ → j$\underline{\text{im}}$ / $\underline{\text{ʃ}}$ɔb   cf. jɔ$\underline{\text{m}}$ / $\underline{\text{ʃ}}$ib

> "The most common ... error type was one in which the initial C originated from one to-be-remembered stimulus and the final VC originated from another. ... **These results are consistent with the view that the spoken CVCs are coded, at some level, in terms of onset and rime units. These units can become 'unglued' and recombine to form a CVC that was not in the original list.**"

- Rime cohesiveness: VL > VN > VO
- Complex margins: CCV + $\underline{\text{CCV}}$ → CC$\underline{\text{V}}$ VCC + $\underline{\text{VCC}}$ → VC$\underline{\text{C}}$
- Korean syllables (Lee & Goldrick 2008): cvc + $\underline{\text{cvc}}$ → cv$\underline{\text{c}}$
- **English bisyllables** (Treiman et al. 1994): CVOVC + $\underline{\text{CVOVC}}$ → CV$\underline{\text{OVC}}$

Research question

Illusory conjunctions / recombination errors are frequent in perception, memory, recall: they reveal partially independent 'components' of mental representations

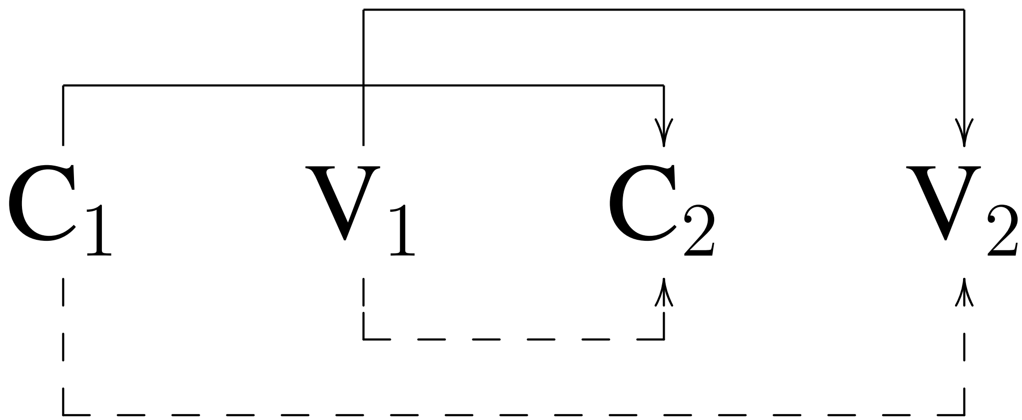
Can recombination errors provide a source of external evidence for the structure of phonological representations?

Syllable structure	Treiman & Danis 1988, Treiman et al. 1994, Hartley & Houghton 1996, Lee & Goldrick 2008, …
C-tier / V-tier	?
Word edge / interior	?
Phonological features	Baars & Motley 1974, Kolinsky et al. 1995, Goldrick 2004, Walker 2007, Zeng & Mattys 2011, …

moraic structure (Kubozono 1989, Nakayama & Saito 2014), prosodic boundaries (Choe & Redford 2012)

Experiment 1: C/V-tiers vs. Edge/interior

Are the C-tier and V-tier separable components of English speakers' mental representation of spoken words (cf. edge and interior relations)?



Materials

- Synthesized CVCV trochees with C ∈ [p b t d k g], V ∈ [i eɪ æ ɔ oʊ u]
- Items arranged into triplets containing no repeated segments
- Triplets divided into two trial type sets (counterbalanced)
- Phonotactics controlled within set (positional unigram, bigram, tiers, etc.)

Experiment 1: C/V-tiers vs. Edge/interior

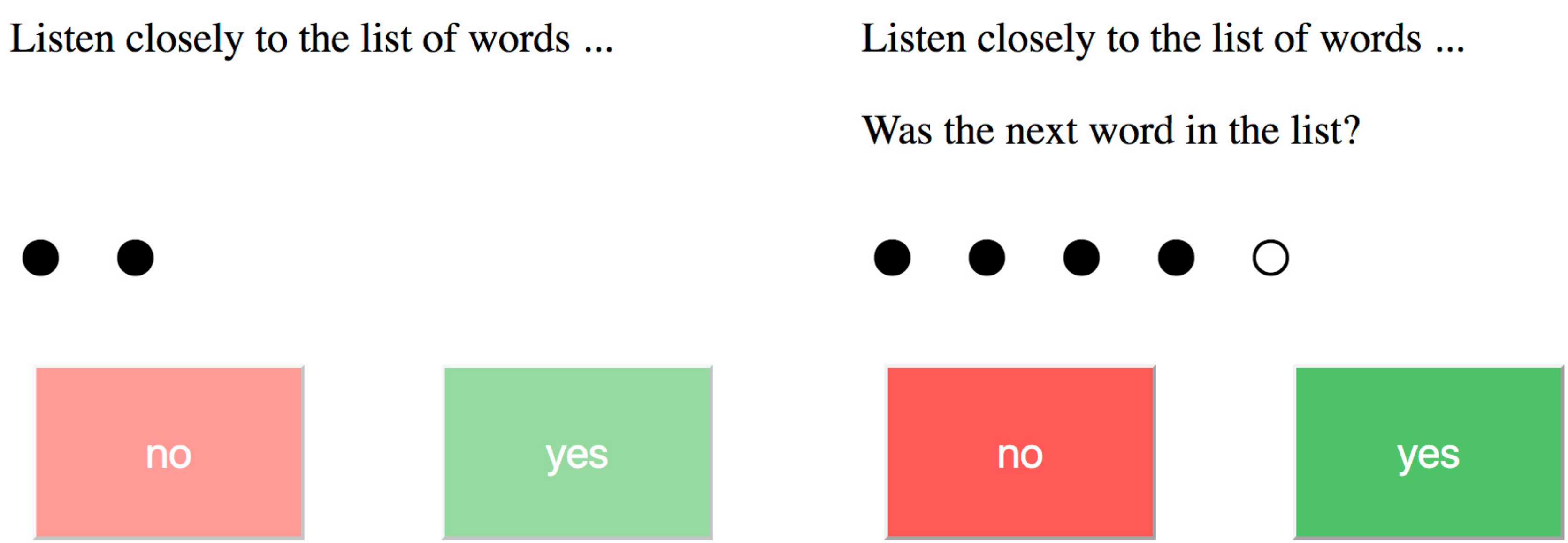
Procedure

In each trial participants listened to a list of four CVCV memory items, and then made a binary judgement to a CVCV probe (“was the next word in the list?”)

	item1		*item2*		*recomb*		*item3*		*probe*
Tier	CVCV	500ms	$\underline{CVCV}$	500ms	$\underline{C}V\underline{C}V$	500ms	(distractor)	1250ms	$C\underline{V}C\underline{V}$ $\underline{CVCV}$
Edge	CVCV	500ms	$\underline{CVCV}$	500ms	$\underline{C}VC\underline{V}$	500ms	(distractor)	1250ms	$C\underline{VC}V$ $\underline{CVCV}$

- Triplet structure: no shared segments in *item1*, *item2*, *item3* (= distractor)
- Order of trials, and order of *item1* and *item2* in a trial, freely randomized
- Within participant 1/2 of trials of each type had conjunction probes, 1/2 of trials had identity probes (counterbalanced)

Experiment 1: C/V-tiers vs. Edge/interior



Ex. tɔpo … bedæ … tepæ … giku …… bɔdo (= tier recombination)

Experiment script

Custom HTML5 + JavaScript via External HIT

Audio preloading and presentation adapted from Slote & Strand (2015)

Experiment 1: C/V-tiers vs. Edge/interior

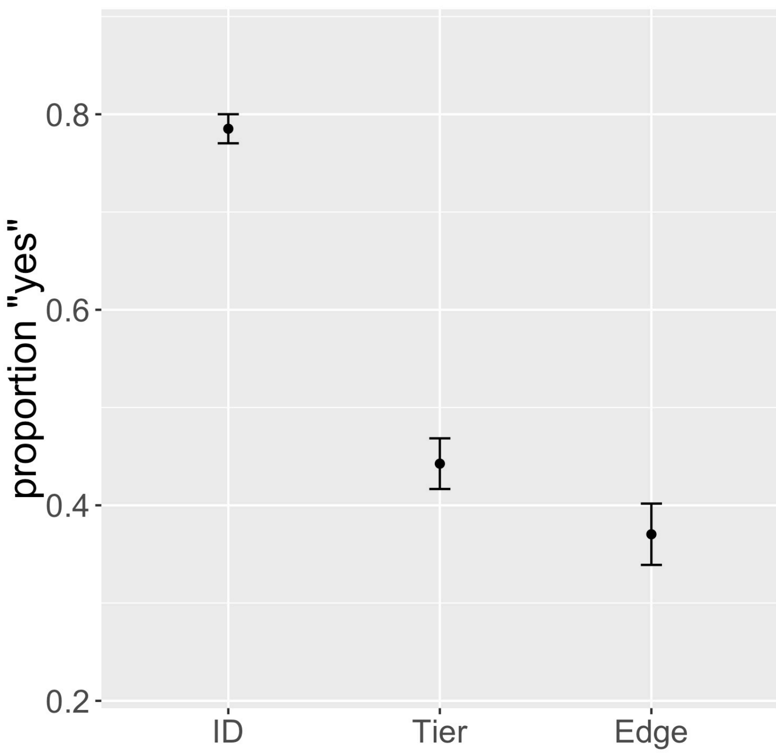
Participants

36 participants (9 for each of 4 conditions) recruited through MTurk

- 16 female / 20 male
- 20 - 61y (median 30.5)
- geographically diverse (slightly more from PA)
- 27 listened through headphones, 9 through speakers
- each participant completed 60 trials in $<$ 30 min

Experiment 1: C/V-tiers vs. Edge/interior

Results



	proportion "yes"
ID	.79 (.01)
Tier	.44 (.03)
Edge	.37 (.03)

Mixed-effects logistic regression

Intercept	$\beta = 0.19$
ID vs. Tier, Edge	$\beta = 2.33$ *
Tier vs. Edge	$\beta = 0.31$ *

Experiment 1: C/V-tiers vs. Edge/interior

Tier-based illusory conjunctions

Participants judged $C\underline{V}C\underline{V}$ probes as “heard” more often than $C\underline{VC}V$ probes, consistent with separable C/V-tiers in the representation of spoken memory items

- Not reducible to skeletal overlap
  (Sevald et al. 1995, Floccia et al. 2003; orthography: Berent et al. 2001, Berent & Marom 2005)
  All memory items and probes followed the same CVCV template

- Not reducible to syllable overlap (Treiman & Danis 1988, Kolinsky et al. 1995)
  Neither $C\underline{V}C\underline{V}$ nor $C\underline{VC}V$ probes shared a syllable with any memory item

- Note reducible to word-initial consonant exchange (Davis 1989; Fowler et al. 1993)
  Both $C\underline{V}C\underline{V}$ and $C\underline{VC}V$ probes shared C_1 with one item, ‘body’ with none

- Not reducible to overlap of individual segments (Kolinsky et al. 1995)
  Every segment of $C\underline{V}C\underline{V}$ and $C\underline{VC}V$ probes occurred once in memory list

But Tier vs. Edge effect is modest ($\Delta < .10$, odds ratio 1.16) so replicate and refine …

Experiment 1b: C/V-tiers vs. Edge/interior

Tier recombination probes and Edge recombination probes in Experiment 1 were different items

- Result could be spurious if specific items are inherently preferable
- Cross-item comparison has lower power than within-item comparison

Previous sample size small for online experiment, increase somewhat (N = 45)

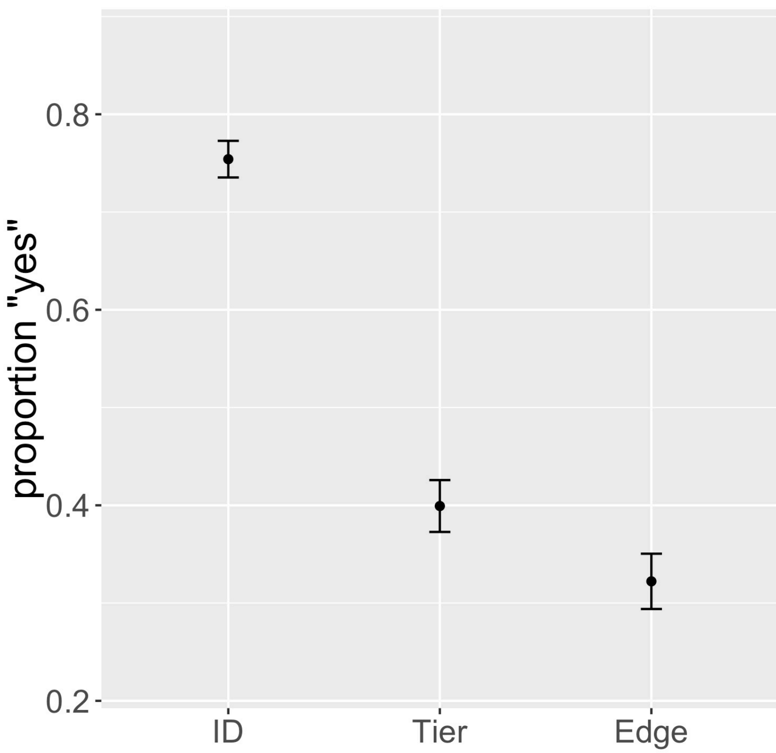
Materials and procedure

Identical to Experiment 1 except that same CVCV probes appeared in all conditions (counterbalanced)

		item1		*item2*		*recomb1*		*recomb2*		*probe*
1/4	**Tier**	CVCV	500ms	CVCV	500ms	CVCV	500ms	(distractor)	1250ms	CVCV
1/4	**Edge**	CVCV	500ms	CVCV	500ms	CVCV	500ms	(distractor)	1250ms	CVCV
1/2	**ID**	CVCV	500ms	CVCV	500ms	(any)	500ms	(distractor)	1250ms	CVCV

Experiment 1b: C/V-tiers vs. Edge/interior

Results



	proportion “yes”
ID	.75 (.02)
Tier	.40 (.03)
Edge	.32 (.03)

Mixed-effects logistic regression

Intercept	$\beta = -0.01$
ID vs. Tier, Edge	$\beta = 2.36$ *
Tier vs. Edge	$\beta = 0.39$ *

Overall “yes” response rate somewhat lower than in Experiment 1, but Tier vs. Edge effect replicated

Experiment 1c: C/V-tiers vs. Edge/interior

Materials and procedure

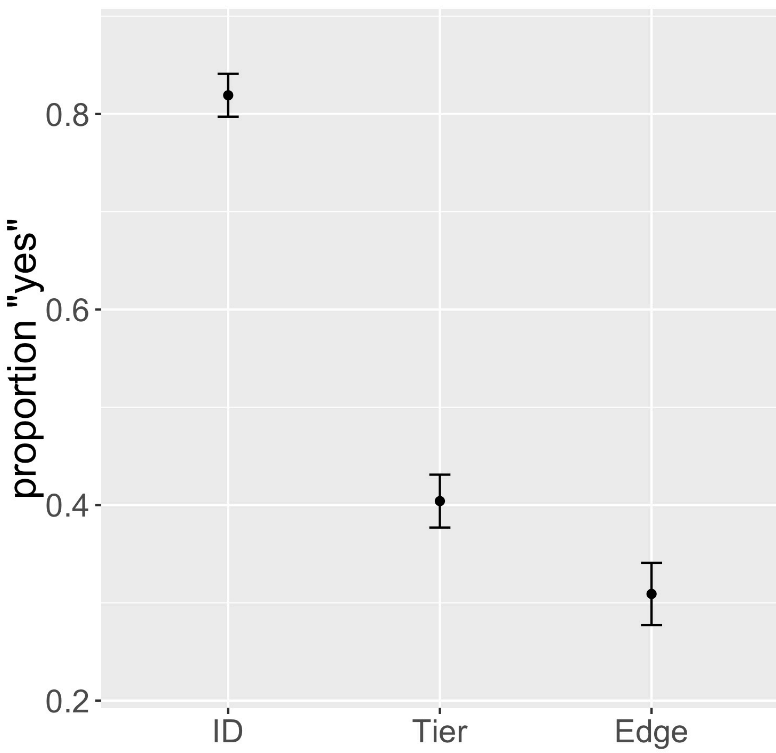
Identical to Experiment 1b with minor change that order first three list members (*item1*, *recomb1*, *recomb2*) was freely randomized

		item1		*recomb1*		*recomb2*		*item3*		*probe*
1/4	**Tier**	CVCV	500ms	$\underline{\text{C}}\text{V}\underline{\text{C}}\text{V}$	500ms	$\text{C}\underline{\text{V}}\text{C}\underline{\text{V}}$	500ms	(distractor)	1250ms	$\underline{\text{CVCV}}$
1/4	**Edge**	CVCV	500ms	$\underline{\text{C}}\text{VC}\underline{\text{V}}$	500ms	$\text{C}\underline{\text{VC}}\text{V}$	500ms	(distractor)	1250ms	$\underline{\text{CVCV}}$
1/2	**ID**	CVCV	500ms	$\underline{\text{CVCV}}$	500ms	(any)	500ms	(distractor)	1250ms	$\underline{\text{CVCV}}$

As in Experiment 1b, *recomb2* memory item in each ID trial was chosen from $\underline{\text{C}}\text{V}\underline{\text{C}}\text{V}$, $\text{C}\underline{\text{V}}\text{C}\underline{\text{V}}$, $\underline{\text{C}}\text{VC}\underline{\text{V}}$, or $\text{C}\underline{\text{VC}}\text{V}$ (counterbalanced)

Experiment 1c: C/V-tiers vs. Edge/interior

Results



	proportion “yes”
ID	.82 (.02)
Tier	.40 (.03)
Edge	.31 (.03)

Mixed-effects logistic regression

Intercept	$\beta = 0.10$
ID vs. Tier, Edge	$\beta = 3.02$ *
Tier vs. Edge	$\beta = 0.50$ *

Somewhat more polarized response pattern than in first two experiments, but Tier vs. Edge effect replicated

alternative analysis: mean d-prime (ID vs. CC) = 1.16 vs. mean d-prime (ID vs. VC) = 1.52

Experiment 2: C/V-tiers vs. CV syllables

How does the bond between C/V-tier elements compare with the cohesiveness of members of CV syllables? (cf. VC rimes in Treiman & Danis 1988)

Materials and procedure

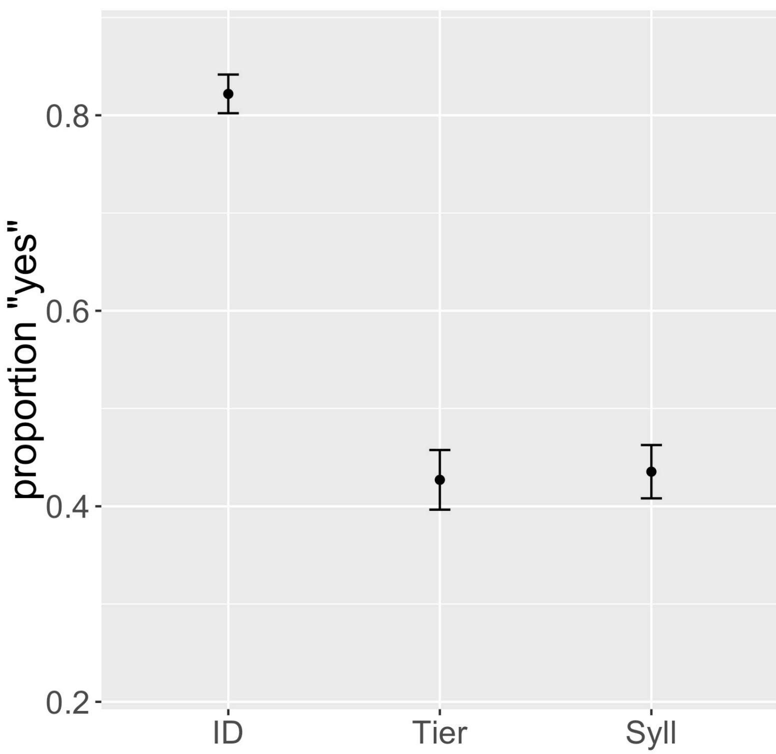
Identical to previous experiment but comparing tier vs. syllable recombinations

		item1		*recomb1*		*recomb2*		*item3*		*probe*
1/4	**Tier**	CVCV	500ms	$\underline{C}V\underline{C}V$	500ms	$C\underline{V}C\underline{V}$	500ms	(distractor)	1250ms	$\underline{CVCV}$
1/4	**Syll**	CVCV	500ms	$\underline{CV}CV$	500ms	$CV\underline{CV}$	500ms	(distractor)	1250ms	$\underline{CVCV}$
1/2	**ID**	CVCV	500ms	$\underline{CVCV}$	500ms	(any)	500ms	(distractor)	1250ms	$\underline{CVCV}$

where *recomb2* memory item in each ID trial was chosen from $\underline{C}V\underline{C}V$, $C\underline{V}C\underline{V}$, $\underline{CV}CV$, or $CV\underline{CV}$ (counterbalanced)

Experiment 2: C/V-tiers vs. CV syllables

Results



	proportion "yes"
ID	.82 (.02)
Tier	.43 (.03)
Edge	.44 (.03)

Mixed-effects logistic regression

Intercept	$\beta = 0.33$ *
ID vs. Tier, Syll	$\beta = 2.53$ *
Tier vs. Syll	$\beta = -0.04$
	$(p > .7)$

Experiment 3: CV syllables vs. Edge/interior

Bonding strength of C/V-tier elements is greater than that of edge/interior elements, and similar to CV cohesiveness $\Rightarrow$ CV Syll $>$ Edge/Interior

Materials and procedure

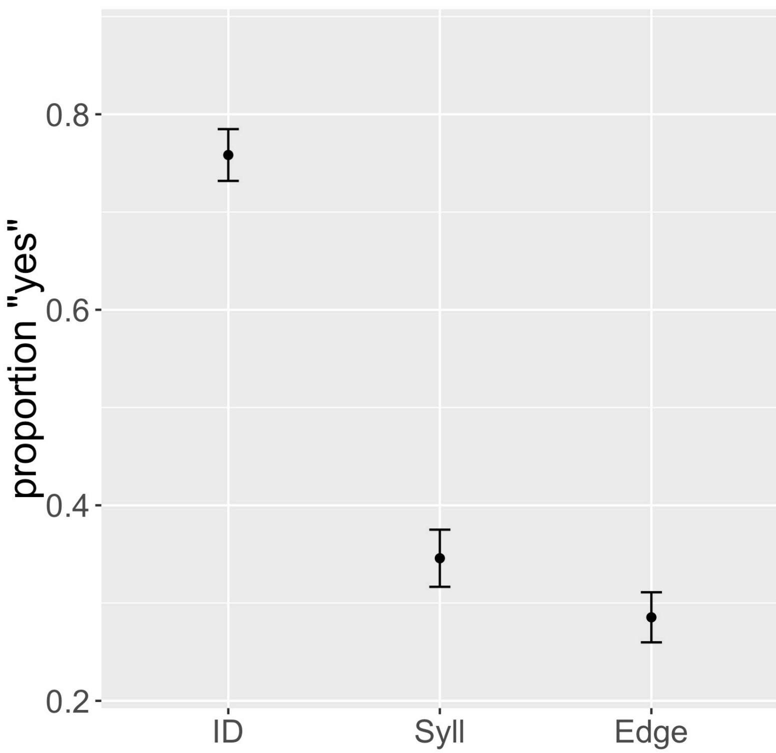
Identical to preceding but comparing syllable vs. edge/interior recombinations

		item1		*recomb1*		*recomb2*		*item3*		*probe*
1/4	**Syll**	CVCV	500ms	$\underline{\text{CV}}\text{CV}$	500ms	$\text{CV}\underline{\text{CV}}$	500ms	(distractor)	1250ms	$\underline{\text{CVCV}}$
1/4	**Edge**	CVCV	500ms	$\underline{\text{C}}\text{VC}\underline{\text{V}}$	500ms	$\text{C}\underline{\text{VC}}\text{V}$	500ms	(distractor)	1250ms	$\underline{\text{CVCV}}$
1/2	**ID**	CVCV	500ms	$\underline{\text{CVCV}}$	500ms	(any)	500ms	(distractor)	1250ms	$\underline{\text{CVCV}}$

where *recomb2* memory item in each ID trial was chosen from $\underline{\text{CV}}\text{CV}$, $\text{CV}\underline{\text{CV}}$, $\underline{\text{C}}\text{VC}\underline{\text{V}}$, $\text{C}\underline{\text{VC}}\text{V}$ (counterbalanced)

Experiment 3: CV syllables vs. Edge/interior

Results



	proportion “yes”
ID	.76 (.03)
Tier	.35 (.03)
Edge	.29 (.03)

Mixed-effects logistic regression

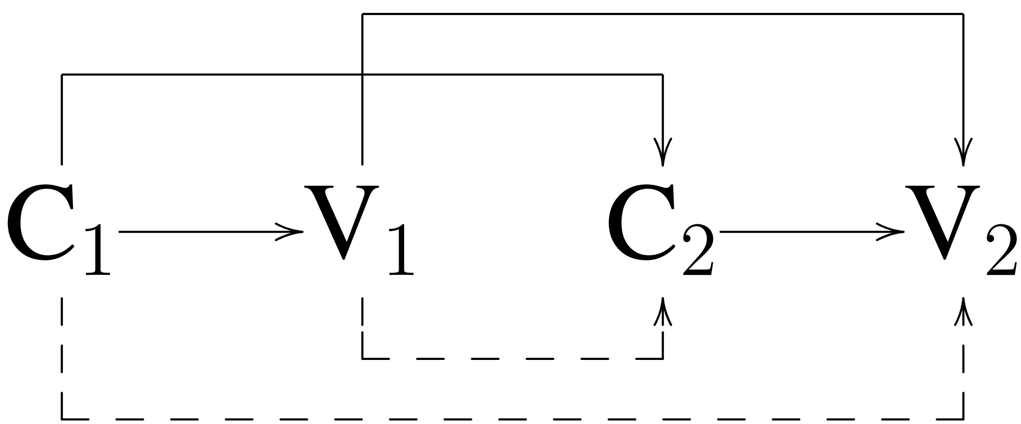
Intercept	$\beta = -0.15$
ID vs. Syll, Edge	$\beta = 2.76$ *
Syll vs. Edge	$\beta = 0.30$ *

Interim summary

Illusory conjunction errors in memory for English spoken disyllables support a dependency between elements on C/V-tiers

similar in strength to tautosyllabic CV bond (alt. ‘released’ - ‘release enabler’)

stronger than edge/interior dependencies



Interim summary

Compatible with multiple formalizations of tier-based dependencies

- Nonlinear representations (McCarthy 1979/1982 and subsequent work; see Spencer 1988 for application to English strong verb alternations such as *sing* ∼ *sang*)

$$
\begin{array}{cccccccccccccc}
\text{p} & & \text{g} & & & \text{k} & & \text{t} & & & \text{p} & & \text{g} & \\
| & & | & & & | & & | & & & | & & | & \\
C_1 & V_1 & C_2 & V_2 & \ldots & C_1 & V_1 & C_2 & V_2 & \rightsquigarrow & C_1 & V_1 & C_2 & V_2 \\
 & | & & | & & & | & & | & & & | & & | \\
 & \text{oʊ} & & \text{æ} & & & \text{i} & & \text{u} & & & \text{i} & & \text{u}
\end{array}
$$

- CC- and VV- correspondence relations
(Walker 2000, Rose & Walker 2004, Hansson 2001/2010, Gallagher & Coon 2009, Sasa 2009, Rhodes 2010, Bennett 2013, Shih & Inkelas 2014, …)

- Tier-based adjacency or precedence relations (see also Raimy 1999 on precedence reln)
(Hayes & Wilson 2008, Smolensky 2009, Heinz 2010, Heinz et al. 2011, McMullin & Hansson 2014, …)

	Segmental tier	C-tier	V-tier	· · ·
[poʊgæ]	{(p,oʊ), (oʊ,g), (g,æ)}	{(p,g)}	{(oʊ,æ)}	

Directions

- Empirical exploration of tier-based illusory conjunctions

- Do all consonant sequences form equivalent C-tier dependencies?
- Do tier dependencies encode adjacency independently of precedence?
- Can we isolate contributions of C-tier and V-tier dependencies? [see model]
- Is there any evidence for edge or interior relations? [see model]

- Parallelisms between phonological and orthographic wordform representations

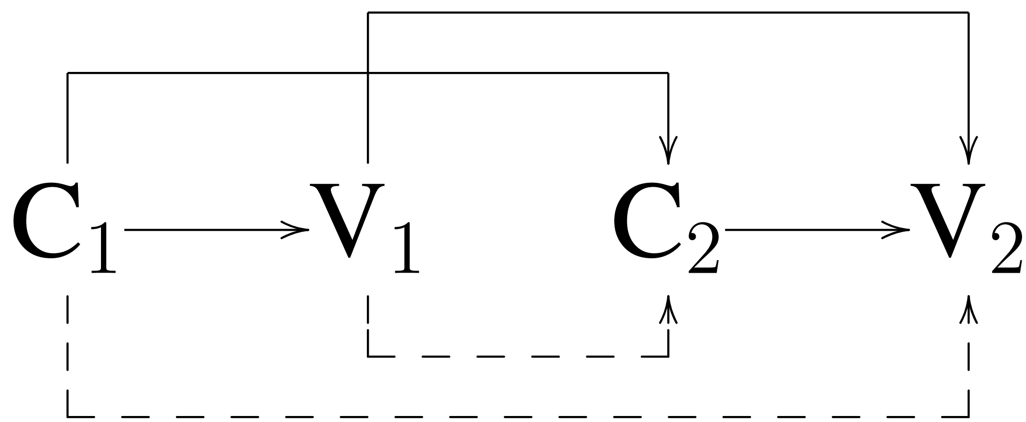
Caramazza & Micelli 1990, Badecker 1996, Van Ooijen 1996, Tainturier & Caramazza 1996, Caramazza et al. 2000, Cutler et al. 2000, Berent et al. 2001, Buchwald & Rapp 2003, 2006, Berent & Marom 2005, Lupker et al. 2008, New et al. 2008, Perea & Acha 2009, Fischer-Baum & Rapp 2015, Duñabeitia & Carreiras 2011, Moates & Marks 2012, Chetail et al. 2014, Comesaña et al. 2016, Massol et al. 2016, Schubert & Nickels 2016

- Representational similarity model of memory errors

- Relating memory errors and artificial grammar learning

Representational similarity model

- Phonological representations contain multiple overlapping components (hierarchical nodes, tiers, correspondence chains, dependencies, …)



- Illusory conjunctions could potentially result from literal 'ungluing' (Treiman & Danis 1988) and recombination of pieces of structure as in nonlinear morph/phon

- Develop a similarity model encompassing many (weighted) components without literal fragmentation + recombination mechanism

  Focus on phonological *structure* not recombinatory *process*

Representational similarity model

- Why do participants judge $\underline{\mathrm{CVCV}}$ probe as "old" more often when memory items include $\underline{\mathrm{C}}\mathrm{V}\underline{\mathrm{C}}\mathrm{V}$ and $\mathrm{C}\underline{\mathrm{V}}\mathrm{C}\underline{\mathrm{V}}$ (cf. $\underline{\mathrm{C}}\mathrm{VC}\underline{\mathrm{V}}$, $\mathrm{C}\underline{\mathrm{VC}}\mathrm{V}$)?

  Greater probe-item similarity from shared C/V-tiers (cf. edge/interior)

$$sim(\underline{\mathrm{CVCV}}, \underline{\mathrm{C}}\mathrm{V}\underline{\mathrm{C}}\mathrm{V}) + sim(\underline{\mathrm{CVCV}}, \mathrm{C}\underline{\mathrm{V}}\mathrm{C}\underline{\mathrm{V}})$$
$$>$$
$$sim(\underline{\mathrm{CVCV}}, \underline{\mathrm{C}}\mathrm{VC}\underline{\mathrm{V}}) + sim(\underline{\mathrm{CVCV}}, \mathrm{C}\underline{\mathrm{VC}}\mathrm{V})$$

- How is the similarity measure $sim(x, y)$ defined?

  Embed phonological forms in a high-dimensional vector space: $x \mapsto \mathbf{x}$

  Vector dimensions indicate feature and segment (co)occurrence

  Dimensions are weighted, similarity is weighted dot product:

$$sim(x, y) = \langle \mathbf{x}, \mathbf{y} \rangle_{\mathbf{w}} = \sum_i w_i x_i y_i$$

Representational similarity model

Binary dimensions of similarity (illustrated for [poʊgæ])

Seg	C_1 = [p]		V_1 = [oʊ]		C_2 = [g]		V_2 = [æ]
[labial]	1	[high]	0	[labial]	0	[high]	0
[coronal]	0	[mid]	1	[coronal]	0	[mid]	0
[dorsal]	0	[low]	0	[dorsal]	1	[low]	1
[−voice]	1	[−back]	0	[−voice]	0	[−back]	1
[+voice]	0	[+back]	1	[+voice]	1	[+back]	0

⊕ segment-specific dimensions at each position

Syll$_1$ (initial, primary)	[p]-[oʊ]	**Syll**$_2$ (final, nonprimary)	[g]-[æ]
			⋮
[labial] - [high]	0		
[labial] - [mid]	1	[dorsal] - [high]	0
[labial] - [low]	0	[dorsal] - [mid]	0
		[dorsal] - [low]	1
	⋮		⋮
[labial] - [+back]	1	[dorsal] - [−back]	1
[−voice] - [mid]	1	[+voice] - [low]	1
[−voice] - [+back]	1	[+voice] - [−back]	1

⊕ segment-pair dimensions for each syllable

Representational similarity model

Binary dimensions of similarity (illustrated for [poʊgæ])

C-tier	[p]-[g]	**V-tier**	[oʊ]-[æ]
			⋮
[labial] - [labial]	0	[mid] - [high]	0
[labial] - [coronal]	0	[mid] - [mid]	0
[labial] - [dorsal]	1	[mid] - [low]	1
	⋮		⋮
[labial] - [+voice]	1	[mid] - [−back]	1
[−voice] - [dorsal]	1	[+back] - [low]	1
[−voice] - [+voice]	1	[+back] - [−back]	1

$\oplus$ segment-pair dimensions for each tier

Edge	[p]-[æ]	**Interior**	[oʊ]-[g]
	⋮	[mid] - [dorsal]	1
[labial] - [low]	1	[mid] - [+voice]	1
[labial] - [−back]	1	[+back] - [dorsal]	1
[−voice] - [low]	1	[+back] - [+voice]	1
[−voice] - [−back]	1		⋮

$\oplus$ segment-pair dimensions for each relation

Representational similarity model

Similarity computation

- $sim(x, y) = \langle \mathbf{x}, \mathbf{y} \rangle_{\mathbf{w}} = \sum_i w_i x_i y_i$
- All dimensions are binary $0/1$, therefore simply count number of shared 1s for each dependency and multiply by corresponding weight

Ex. sim([poʊgæ], [pigɔ]) $=$

	$w_{\textbf{Seg}} \cdot (3+0+3+1)$	C_1 + V_1 + C_2 + V_2 feature/segment overlap
$+$	$w_{\textbf{Syll1}} \cdot 0$	no feature or segment combos shared
$+$	$w_{\textbf{Syll2}} \cdot 2$	[dorsal] - [low], [+voice] - [low]
$+$	$w_{\textbf{C-tier}} \cdot 5$	[labial] - [dorsal], [labial] - [+voice], …, p - g
$+$	$w_{\textbf{V-tier}} \cdot 0$	no feature or segment combos shared
$+$	$w_{\textbf{Edge}} \cdot 2$	[labial] - [low], [$-$voice] - [low]
$+$	$w_{\textbf{Inter}} \cdot 0$	no feature or segment combos shared

Representational similarity model

- Calculate total similarity between probe and four memory items with attention weights, for example:

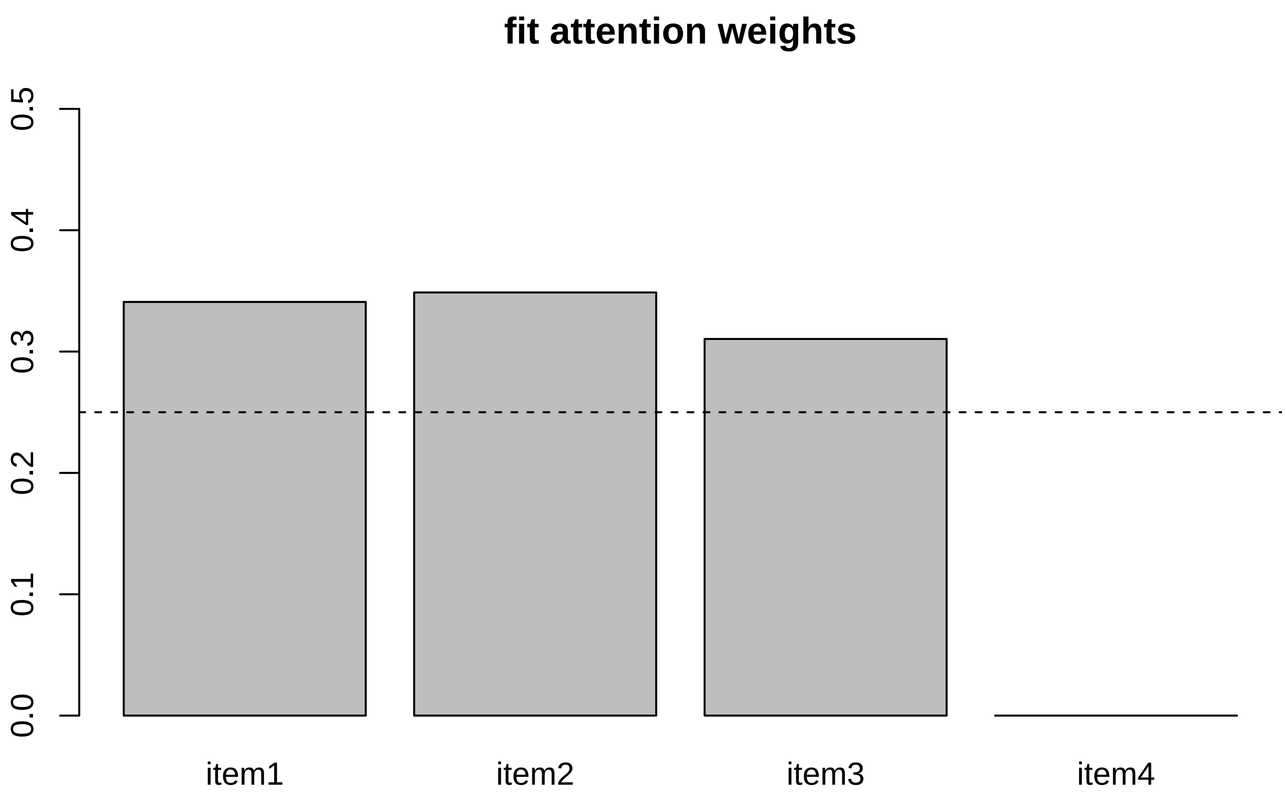
$$\begin{aligned}\phi(\underline{\text{CVCV}}) &= \alpha_1 \cdot sim(\underline{\text{CVCV}}, \text{C}\underline{\text{V}}\text{C}\underline{\text{V}}) \;+\\ &= \alpha_2 \cdot sim(\underline{\text{CVCV}}, \text{CVCV}) \;+\\ &= \alpha_3 \cdot sim(\underline{\text{CVCV}}, \underline{\text{C}}\text{V}\underline{\text{C}}\text{V}) \;+\\ &= \alpha_4 \cdot sim(\underline{\text{CVCV}}, \text{distractor})\end{aligned}$$

- $p(\text{“yes”}) \;=\; \sigma[\phi(\text{probe})] = \dfrac{1}{1 + \exp(-[\phi(\text{probe}) + bias_j])}$

  where $bias_j$ is “yes” response bias term for jth participant ($\sim$ random effect)

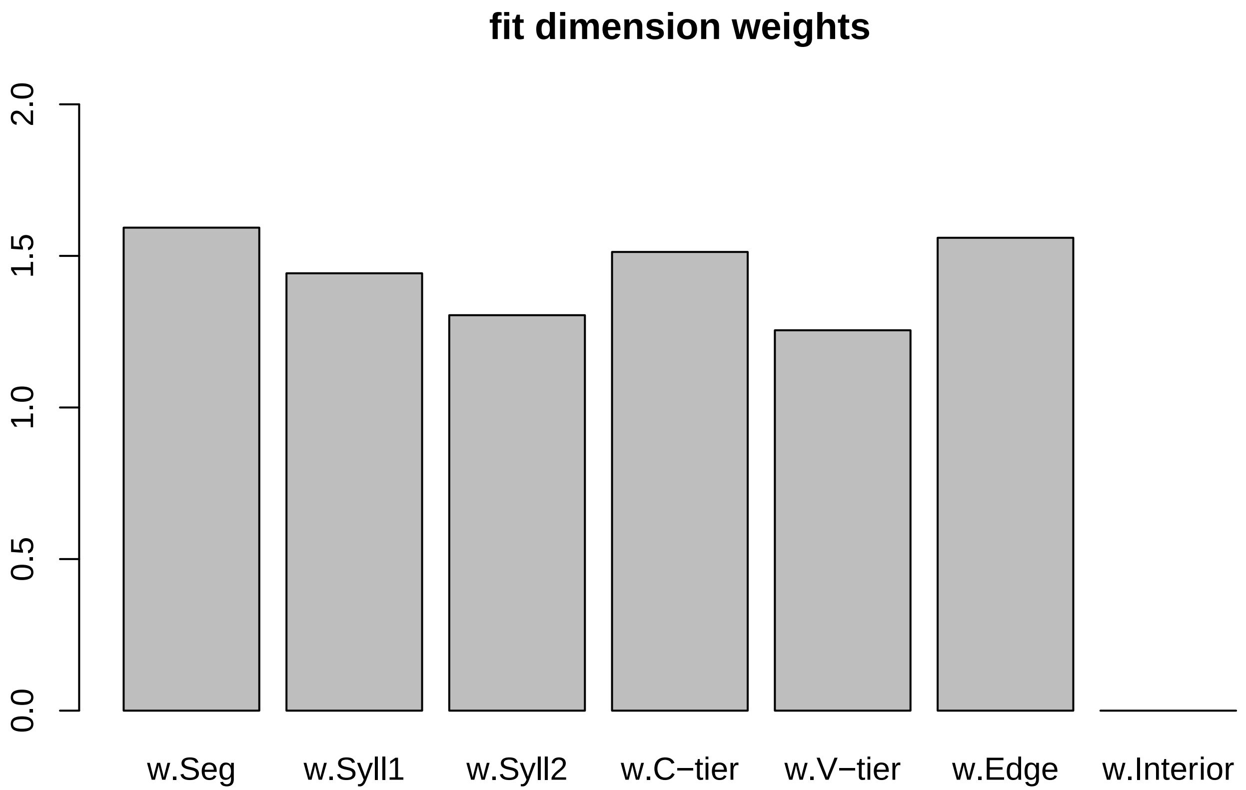
- Fit parameters to all non-identity trials from Experiments 1-3
  dimension weights $\mathbf{w} = w_{\textbf{Seg}}, w_{\textbf{Syll}_1}, w_{\textbf{Syll}_2}, w_{\textbf{C-tier}}, w_{\textbf{V-tier}}, w_{\textbf{Edge}}, w_{\textbf{Inter}}$
  attention weights for memory items $\alpha_1, \alpha_2, \alpha_3, \alpha_4$

Representational similarity model



It seems that participants completely ignored the distractor memory items

Representational similarity model

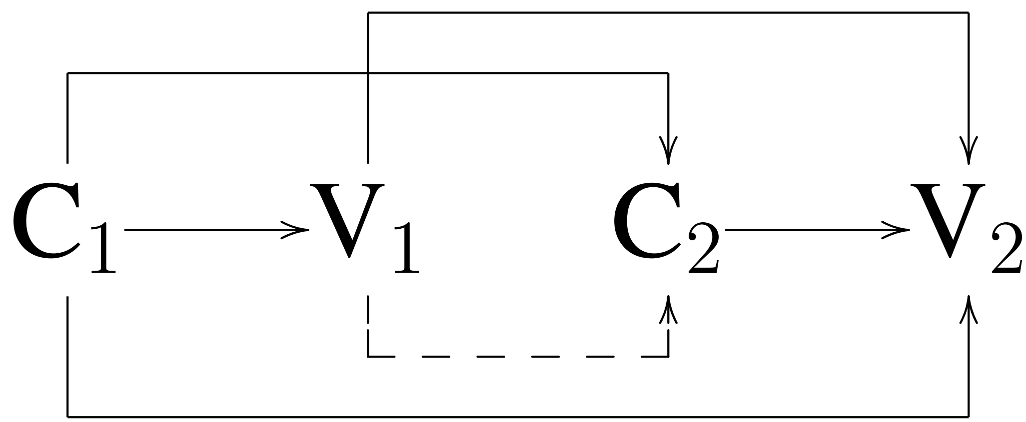


- Model assigned similar weights to segmental and all other dimensions of similarity *except* shared interior relation (heterosyllabic $V_1 \rightarrow C_2$)

- Distinction between edge and interior dependencies was not manipulated in experimental design: a purely model-based result

Memory errors and artificial grammar experiments

- Phonological representations contain multiple overlapping components



- Previous external evidence for C/V-tier dependencies from AG experiments
  - Moreton (2011): direct inspiration for Experiments 1-3
  - Newport & Aslin (2004): statistical learning of two C_1-C_2-C_3 or V_1-V_2-V_3 subsequences (see also Bonatti et al. 2005, Toro et al. 2008, Koo & Callahan 2011, Koo & Oh 2013, Gonzalez-Gomez & Nazzi 2012, 2016, …)

- Model-based prediction: learnability of edge dependencies ($C_1 \rightarrow V_2$)
  any experimental precedent? cf. edge-in autosegmental association (Yip 1988, Buckley 1990, Lombardi & McCarthy 1991, Hyman & Udo 2002, Bobaljik 2006) — but only applies on C/V/tone tier?

Memory errors and artificial grammar experiments

What is the relationship between patterns of memory error and learning / generalization in artificial grammar experiments?

- Memory errors are present even for small numbers of items, and are highly systematic (recombination of components, featural similarity, …)
- Do (should) artificial grammar experiments in phonology routinely test for memory of familiarization items?
- How can analyses of artificial grammar results compare accounts based on memory failures vs. rule / constraint learning?
- Scales of time and pattern
  - Memory effects arise in *single trials* ($\sim$ 10-15 seconds) and in the absence of any *experiment-wide pattern*
  - AG experiments typically have many exposures to a single pattern over the course of 5-30 min prior to testing

Experiment 4: features of onset consonants

Cristia et al. (2013) tested familiarity of Exposure and New (Near, Within, Far) word-initial onsets in CVNV(C) items after ∼ 30 min of training

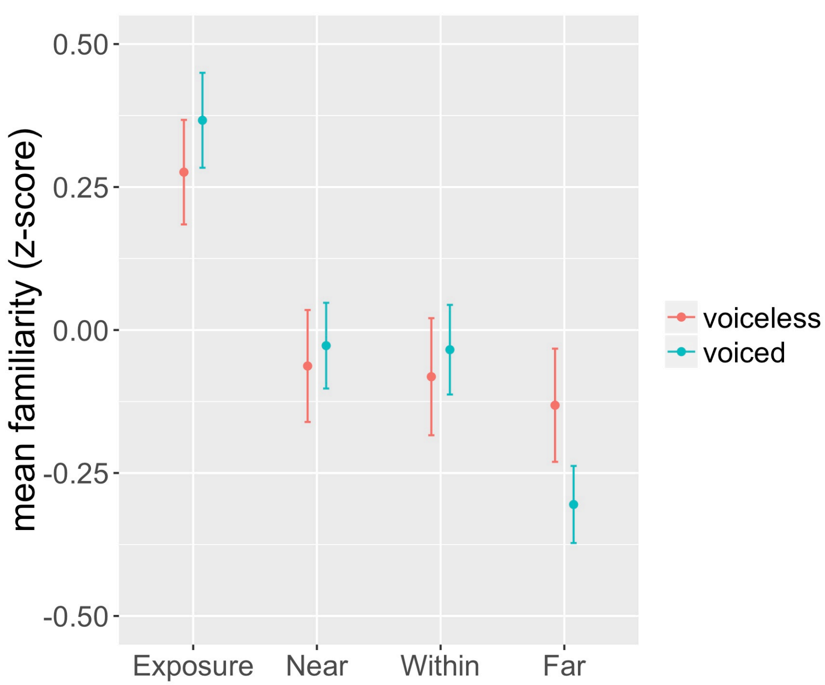
24 conditions: ex. Exposure = [g d v z ʒ], Near = [k], Within = [b], Far = [p]

(see also Linzen & Gallagher 2016 for much briefer exposure to a single pattern)

Experiment 4: memory procedure as in Exp 1-3 (pseudorandom, counterbalanced)

All 24 conditions tested *across trials* for each participant

Cristia et al. (2013) familiarity task



Working memory task

Summary

- Errors in perception and memory are ineluctable and systematic

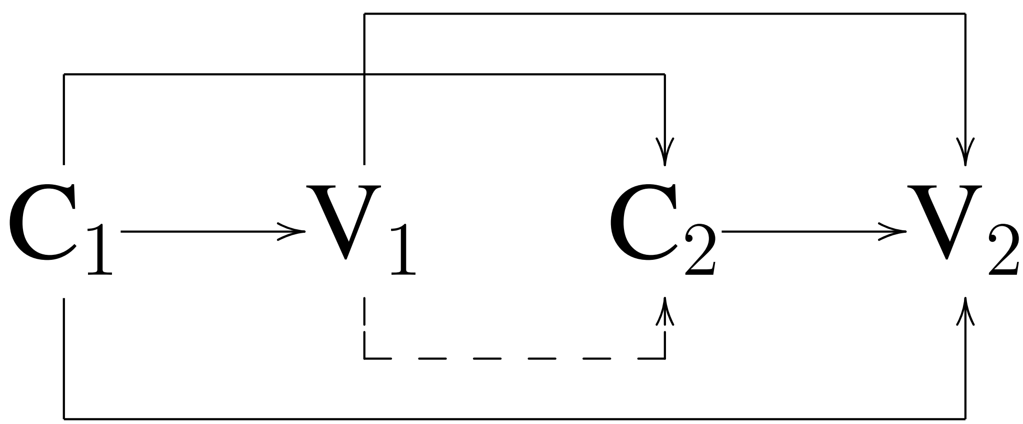
- Illusory conjunctions / recombination errors provide a source of external evidence for the structure of phonological representations
  (see also Pycha 2016, 2017 and previous work on phonological 'false memories')
    - Early studies on syllabic structure
    - New evidence for C/V-tiers
    - Edge dependencies?
    - …

- Memory errors after brief experience may show patterns of generalization like those observed with much greater exposure to an experiment-wide pattern

  Immediate creation, blending, reconstruction of phonological structures

Thank you!

And thanks to Claire Moore-Cantwell, Sara Finley, Jonathan Flombaum, Paul Smolensky, Eleanor Chodroff, Mackenzie Young for useful discussion



keywords: illusory conjunctions, conjunction errors, feature (mis)binding, false memories, word illusions, migration paradigm