EVIDENCE FOR A LEARNING BIAS AGAINST "SALTATORY" PHONOLOGICAL ALTERNATIONS IN ARTIFICIAL LANGUAGE LEARNING

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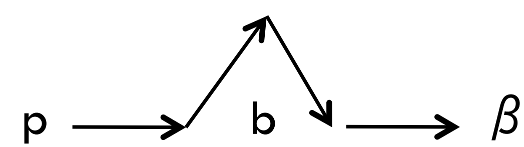
Saltatory phonological alternations

- Saltatory alternation = alternation in which an intervening sound is "jumped over"
- Example from Campidanian Sardinian[1]:
  - p → β / V___ , but b remains unchanged

/pani/ → [sːu βãi] 'the bread'

/binu/ → [sːu bĩu] 'the wine'



  - This is a productive process that occurs at the other places of articulation as well.

1. Bolognesi, 1998

More saltatory alternations

- Some other examples:
  - Colloquial Northern German[1]
    - g → x / ___# , k remains unchanged
  - Polish[2]
    - g → ʒ / ____ V_{+front} , ʤ remains unchanged
  - Suma (a tonal example)[3]
    - L → H / H___# in associative construction, final M remains unchanged
  - Note that these other cases are more limited in nature.

1. Ito & Mester, 2003 2. Lubowicz, 2002 3. Bradshaw, 1998

Research question

- Thus, saltatory alternations are possible, but cross-linguistically rare (at least relative to non-saltatory ones).

- Question: Do learners have a bias against learning saltatory alternations?
  - I will present 4 artificial language experiments with interesting results indicating that they do.

Overview (Experiments 1-4)

- Artificial language learning (n = 20 for all experiments)
- Basic design strategy: Withhold certain information during exposure (ambiguous input), then test on the withheld cases to see which assumptions participants make[1]
- Same basic method for Exp 1-4, but types of items in training varies
- 3 phases:
  - Exposure
  - Verification of learning
  - Generalization

1. E.g., see Wilson, 2006; Finley, 2008; and others

Experiment 1- Method

- Artificial language learning (Auditory)
- Exposure phase: Train on p → v, t → ð / V__V

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"lanap"

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“lanavi”

Experiment 1

- Exposure phase: Train on p → v, t → ð / V__V
  - All singular words are CVCVC, sound inventory drawn from a subset of English phonemes
  - 36 changing items ending in /p/ or /t/
    - lanap ~ lanavi (18 of this type)
    - bunat ~ bunaði (18 of this type)
  - 36 non-changing Filler items
    - Ending in /m, n, l, r, s, ʃ/
    - Example: kasam ~ kasami
  - Crucially, no words ending in intervening /b, d, f, θ /

Experiment 1

- Verification phase: Did they learn the pattern?
- Task: Hear a previously heard singular form and choose the correct plural form
  - 2-alternative forced choice test → Choose between two options: changing and non-changing.
  - 32 words from Exposure phase (8 p, 8 t, 16 fillers)
  - Must get at least 80% to move on – so that I know they have learned the pattern

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“lanapi”...“lanavi”

???????????????

Experiment 1

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Note: Changing option for fillers:
/m, r, ʃ/ → v (kasami … kasavi)
/n, l, s/ → ð

"lanapi"…"lanavi"

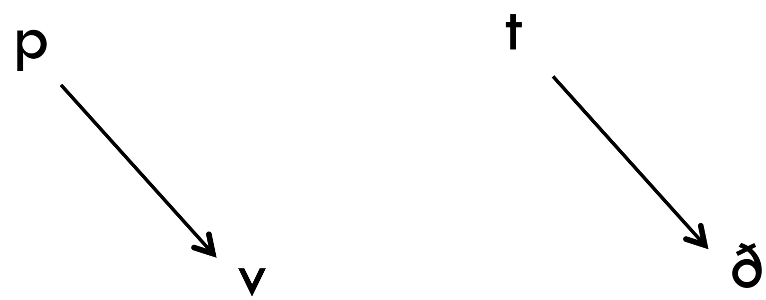
???????????????

Experiment 1 - Method

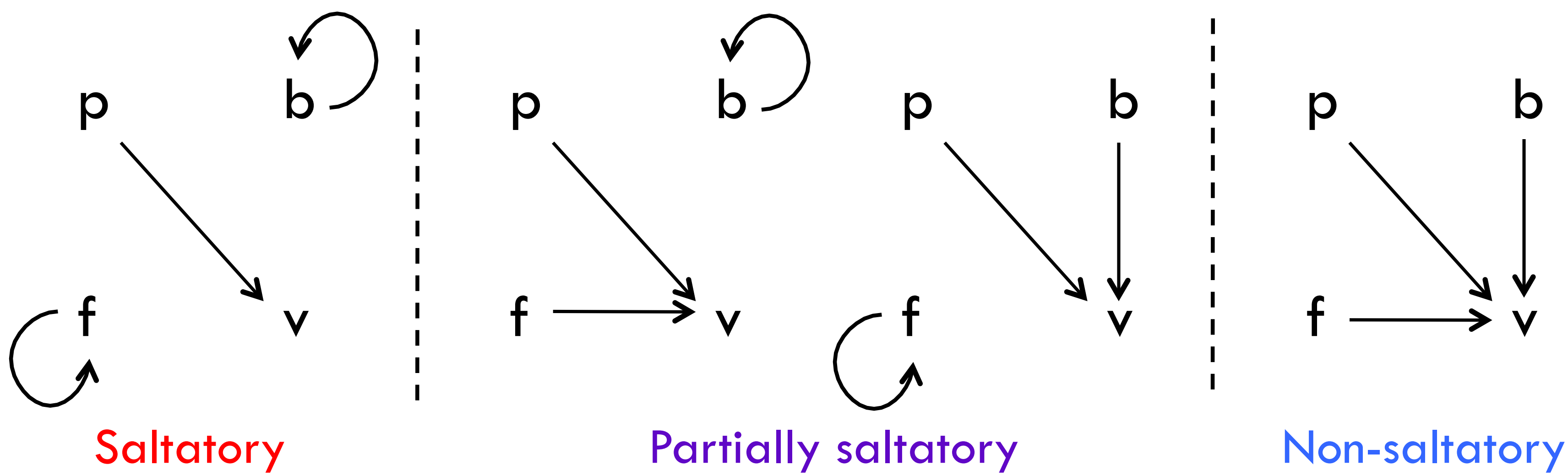
- Generalization phase: Same task as verification phase, but with novel words.
  - 24 words ending in /p, t/
  - 24 fillers
  - But crucially also 24 words ending in the untrained, intervening sounds /b, d, f, θ /

Experiment 1

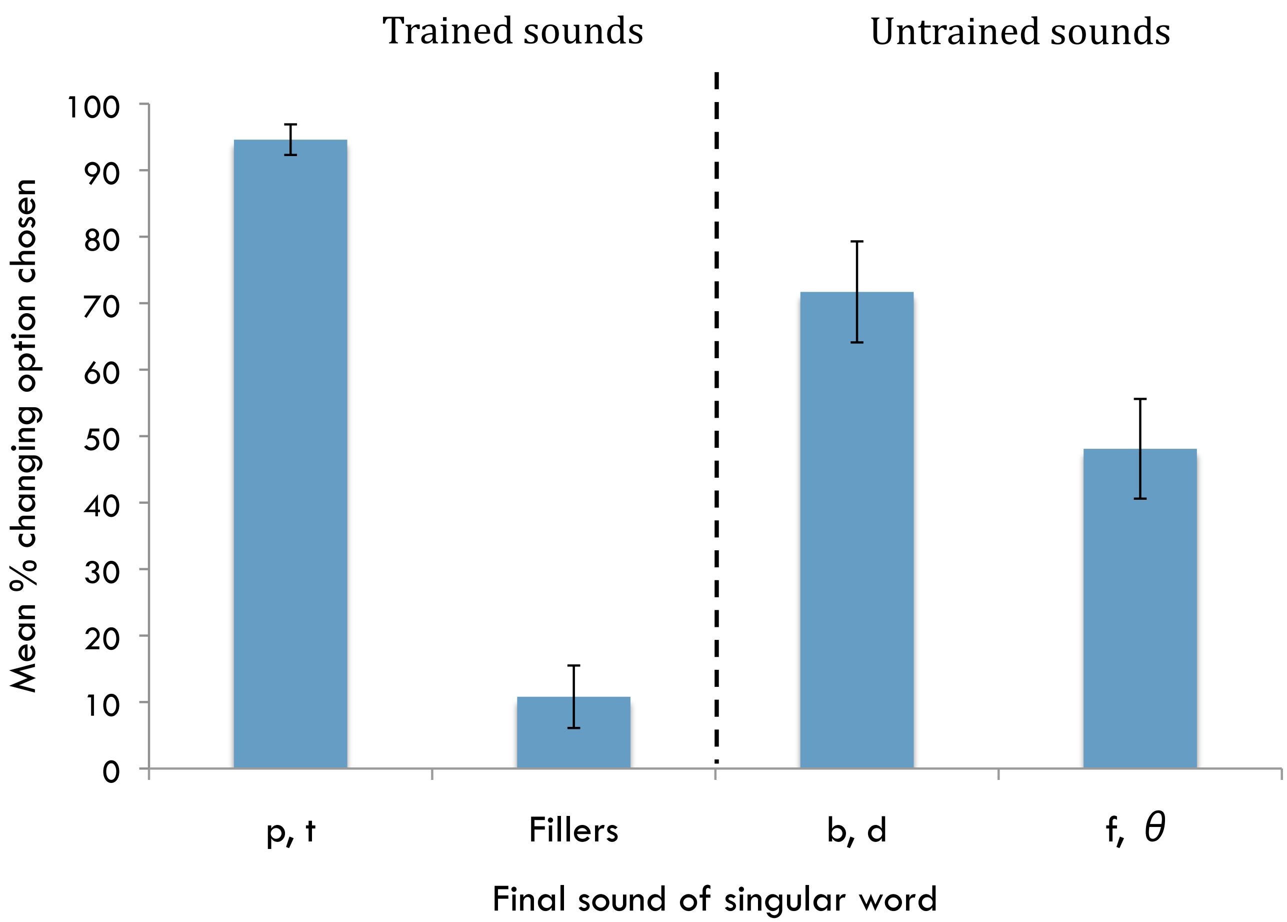
Input:



Possible interpretations of input: (Coronals analogous)



Experiment 1 – Results (all words are novel)



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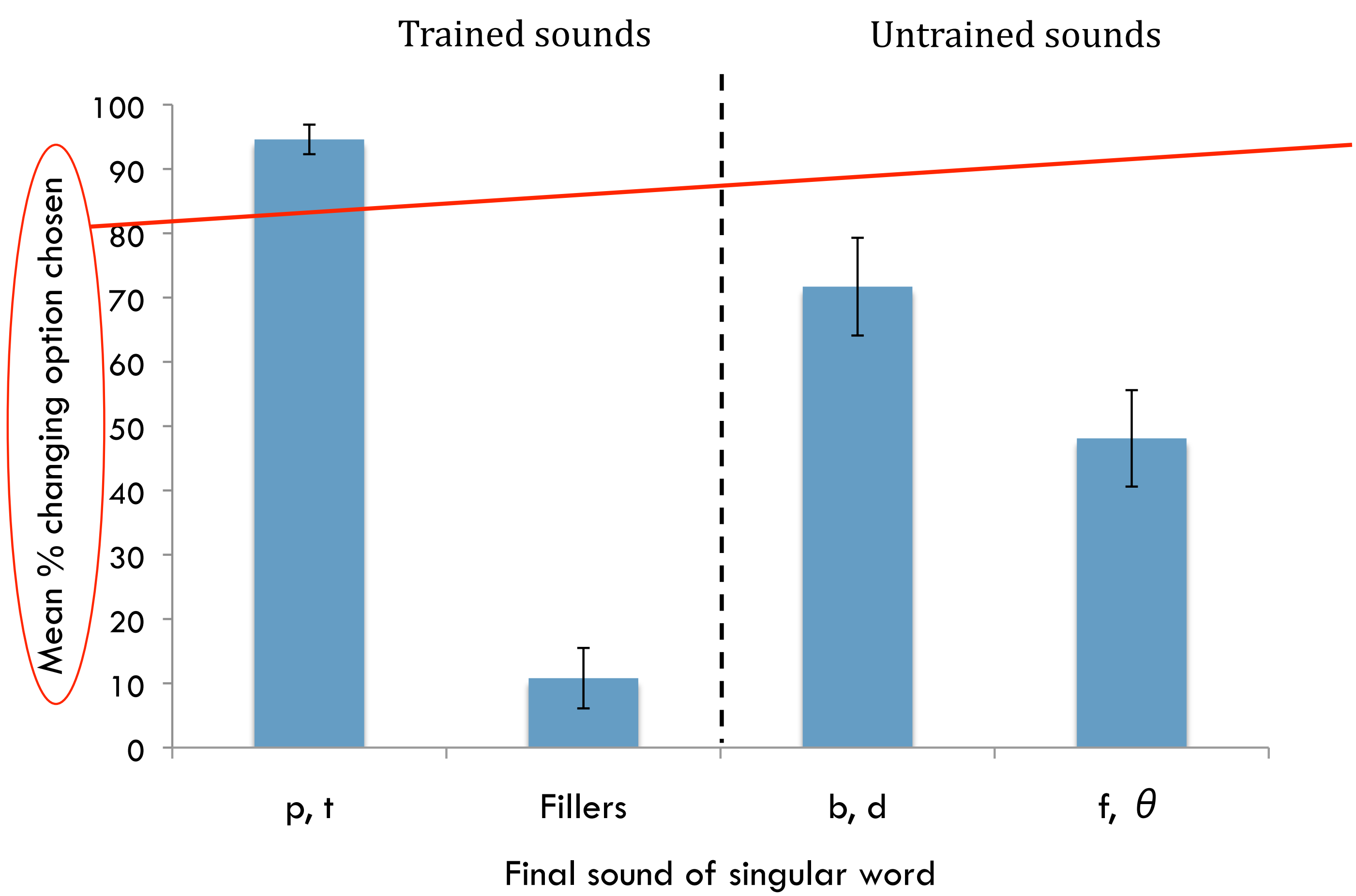
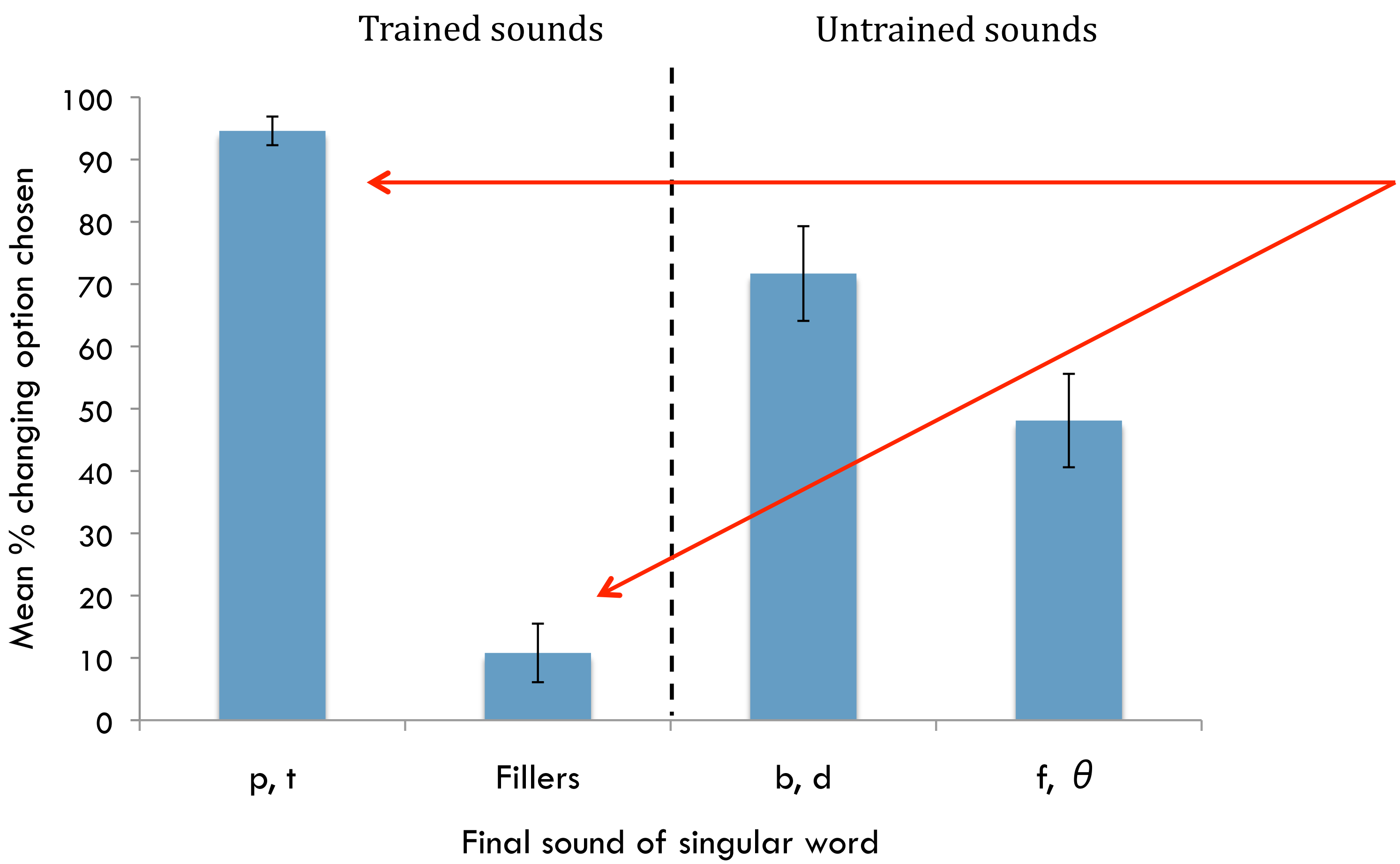


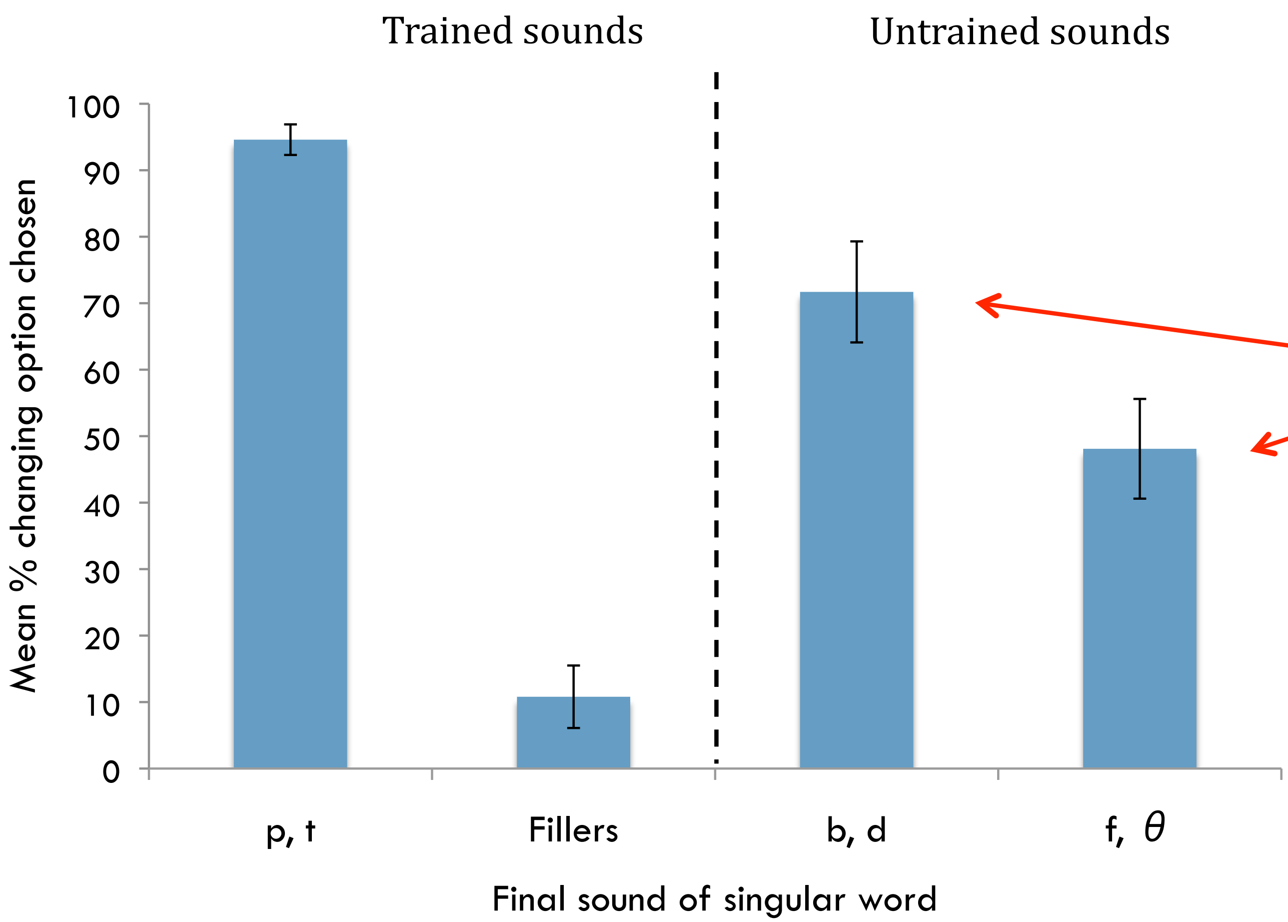
E.g., for a word like *lanap*, how frequently did participants choose *lanavi* rather than *lanapi*?

Experiment 1 – Results (all words are novel)



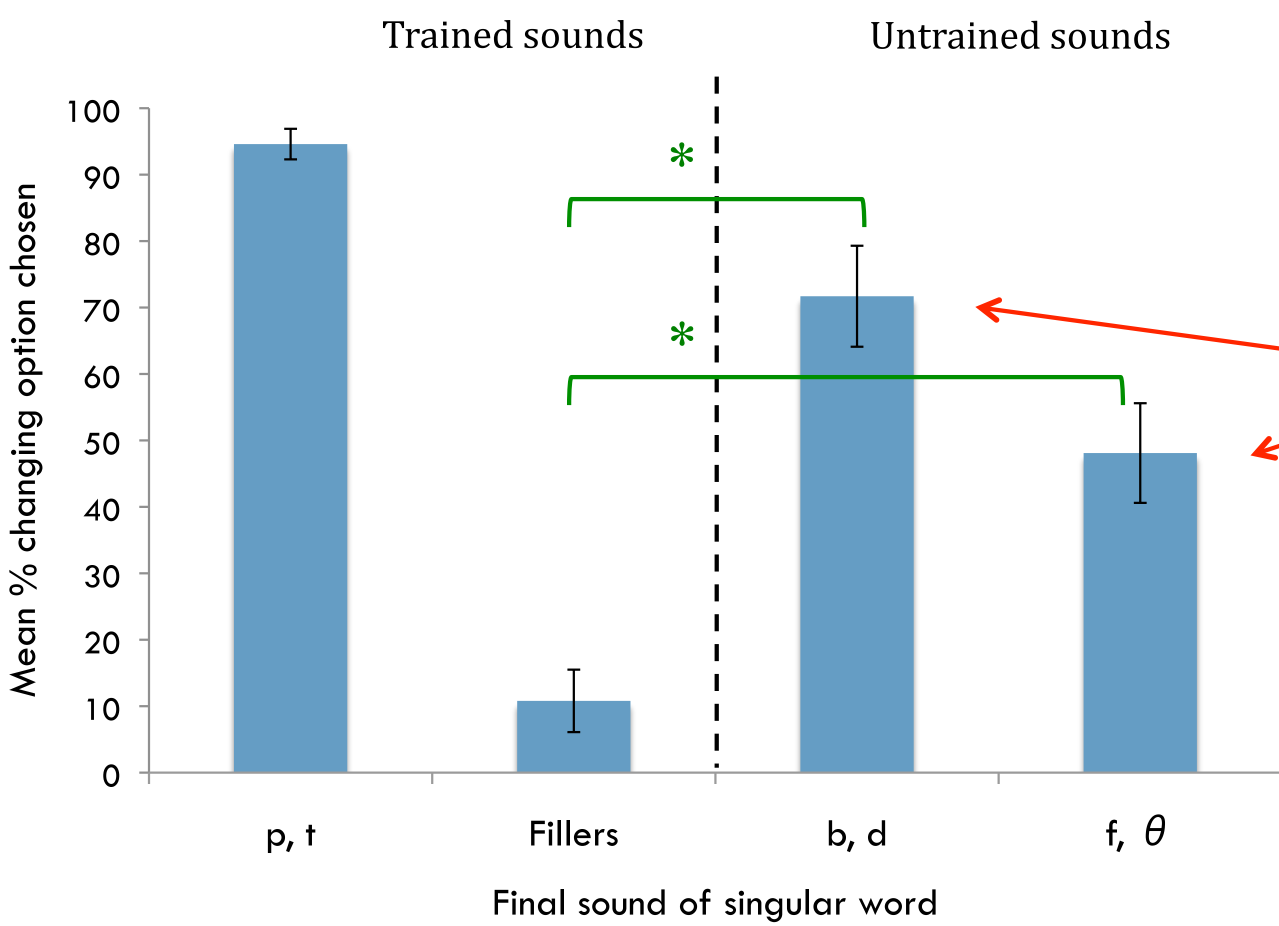
Participants learned pattern and extended it to new forms of the same type.

Experiment 1 – Results (all words are novel)



Participants generalized to intervening sounds at a high rate, even with no evidence for such a change!

Experiment 1 – Results (all words are novel)



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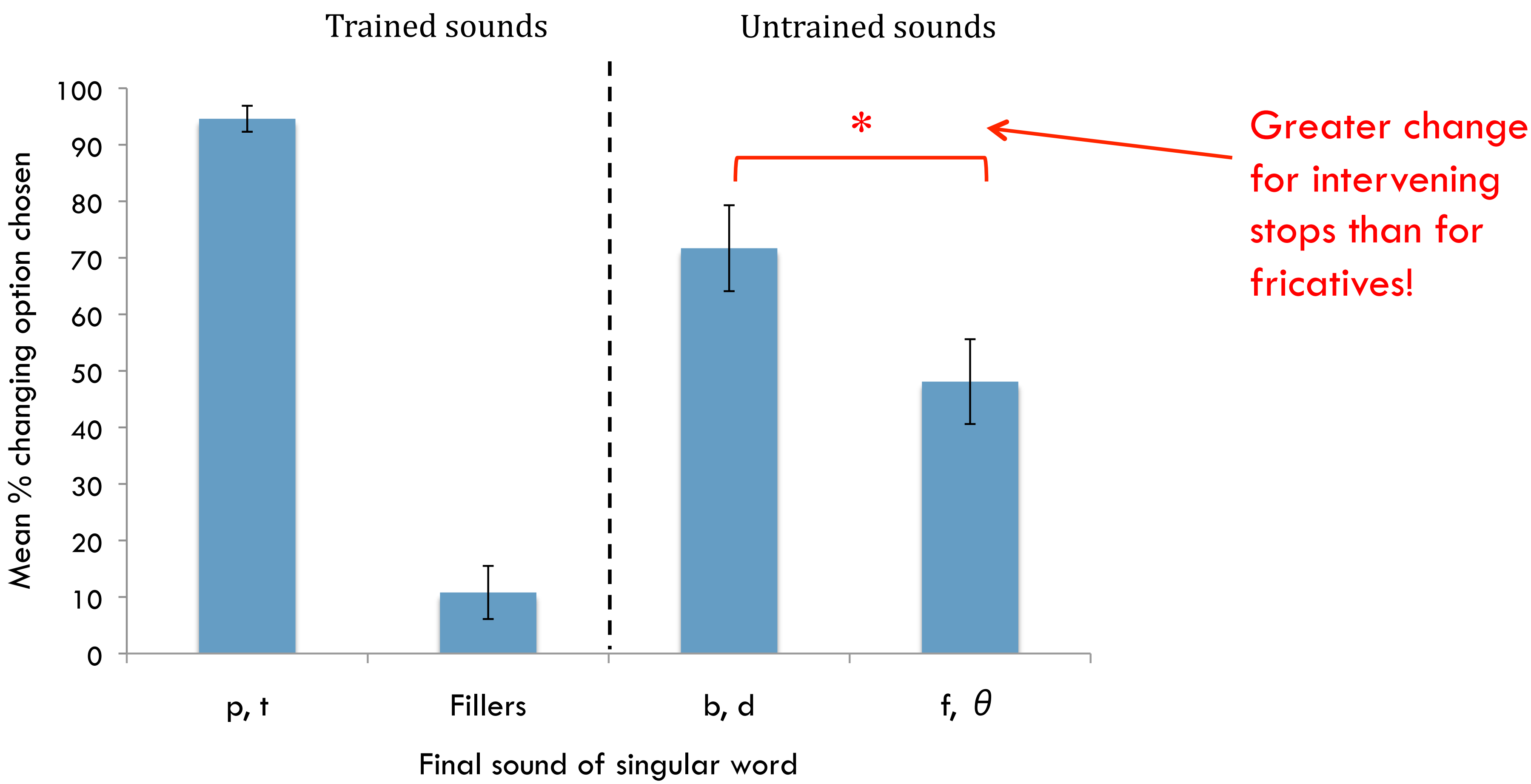

Observations so far

- Given ambiguous input, learners generalize to make learned alternations non-saltatory.
- There is a preference towards changing voiced stops more than voiceless fricatives.
  - Binary abstract features cannot account for this difference
  - Perhaps perceptual similarity is important

	Sounds	Confusability/ Similarity
Labials	b ~ v	.153
	f ~ v	.039
Coronals	d ~ ð	.103
	θ ~ ð	.029

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→ = avg. of (rate that b is mistaken for v and rate that v is mistaken for b) (from confusion matrix data[1])

1. Wang & Bilger, 1973

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Indeed, voiced stops [b, d] are more confusable with voiced fricative targets [v, ð] than voiceless fricatives [f, θ].

Two alternate explanations

- They just learned a more general rule: all stops become voiced fricatives between vowels

- Product-oriented responses:[1] large number of [-vi] and [-ði] plural endings resulted in a bias towards choosing those endings for new cases
  - ½ of the plurals ended in [-vi] or [-ði]
  - 1/12 ended in each of [-mi], [-ni], [-li], [-ri], [-si], [-ʃi]

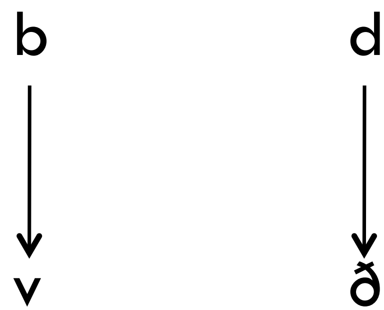
2. Bybee & Slobin, 1982

Experiment 2 - Control

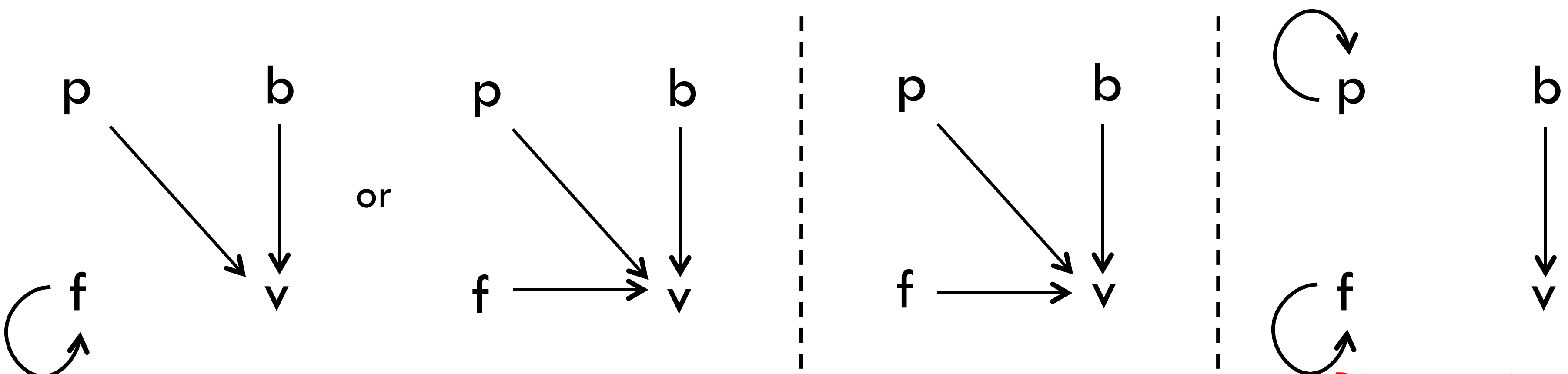
- Train on b → v and d → ð, withhold p, t, f, θ .
- Designed to address alternate explanations:
  - If learning a more general rule or responding based on product-oriented schema, then effect should remain.
  - If it is really something about the intervening sound, then the effect should be greatly reduced.

Experiment 2 - Control

Input:



Expected behavior: (Coronals analogous)



More general rule (Similar to Exp 1)

Product-oriented responses (Similar to Exp 1)

Bias against saltations (Different from Exp 1)

Experiment 2 - Control

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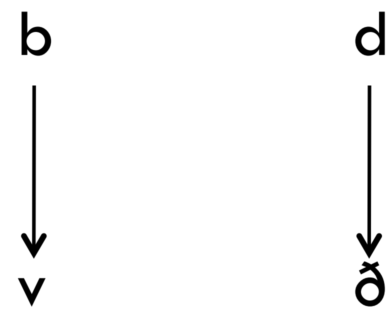
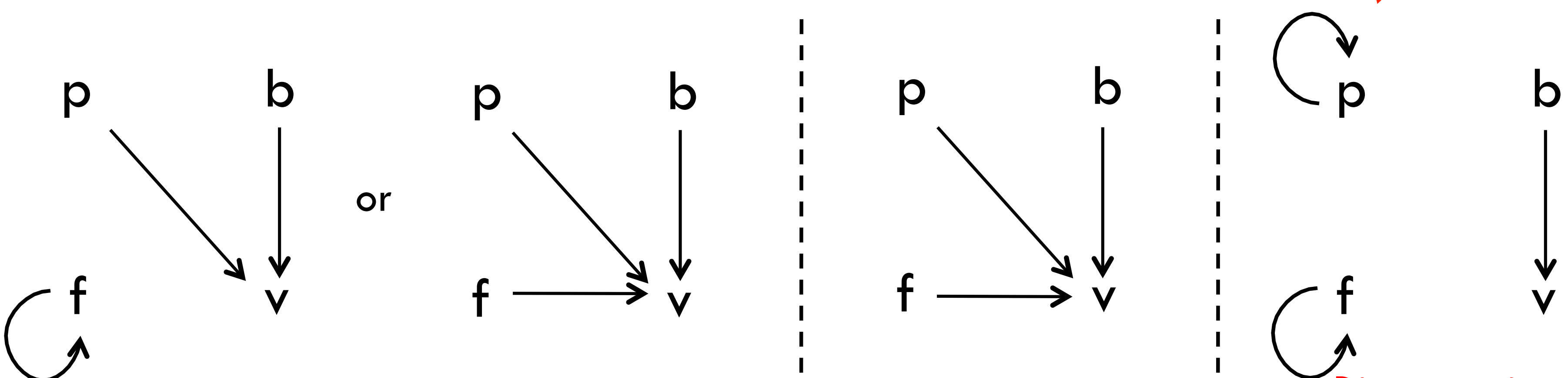


Expected behavior:

Little generalization to other sounds

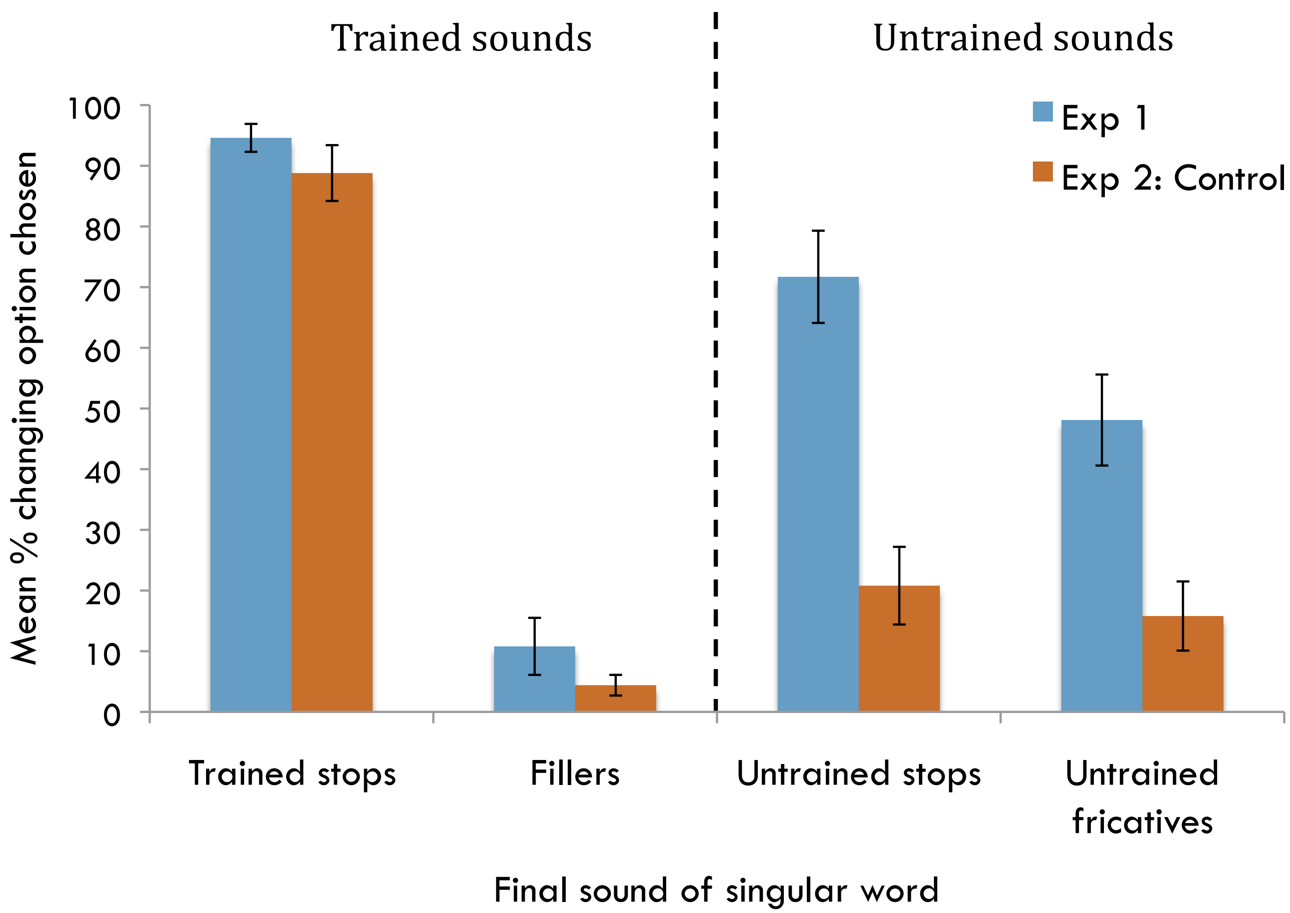


More general rule (Similar to Exp 1)

Product-oriented responses (Similar to Exp 1)

Bias against saltations (Different from Exp 1)

Experiment 2 – Results



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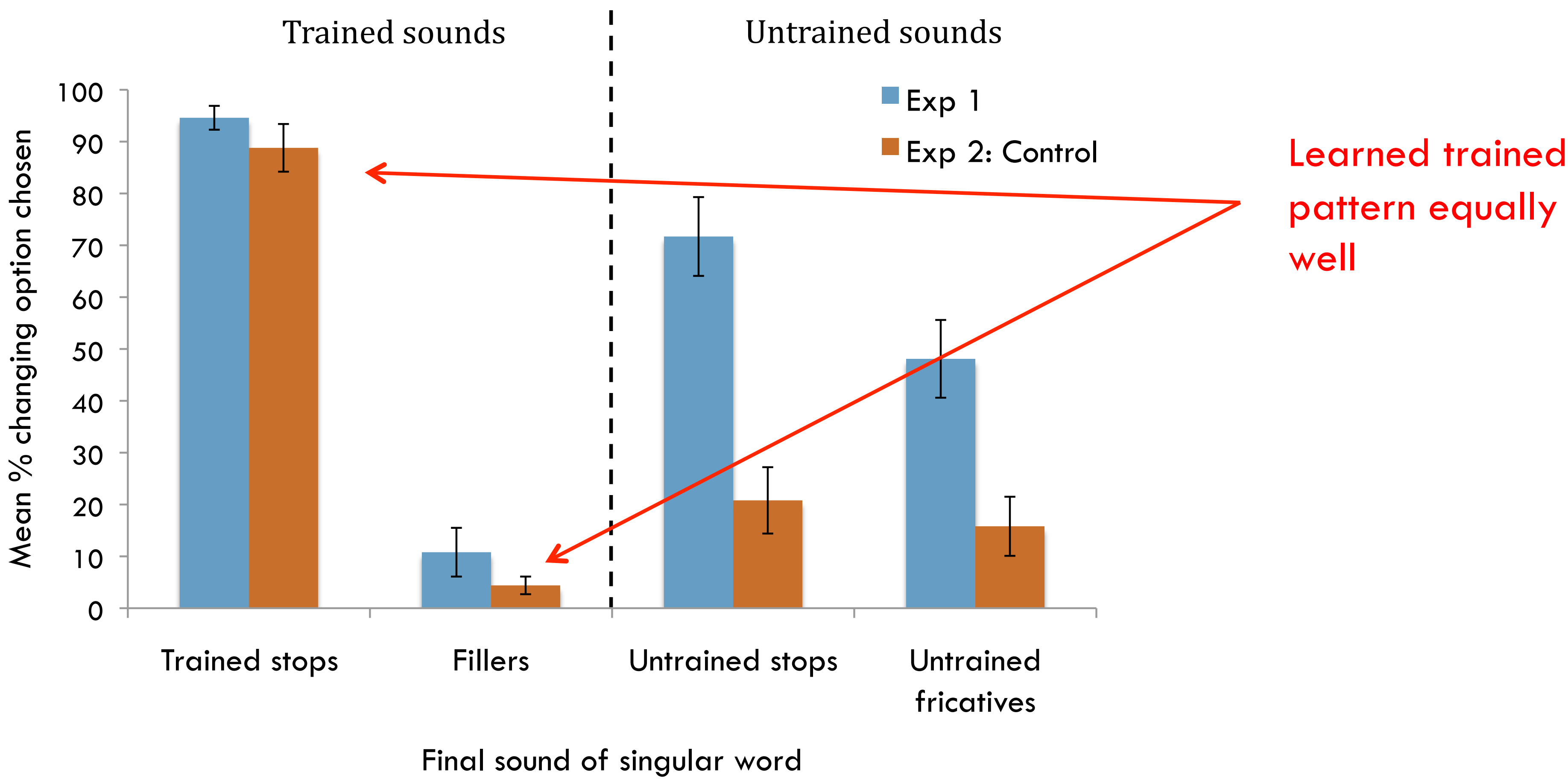

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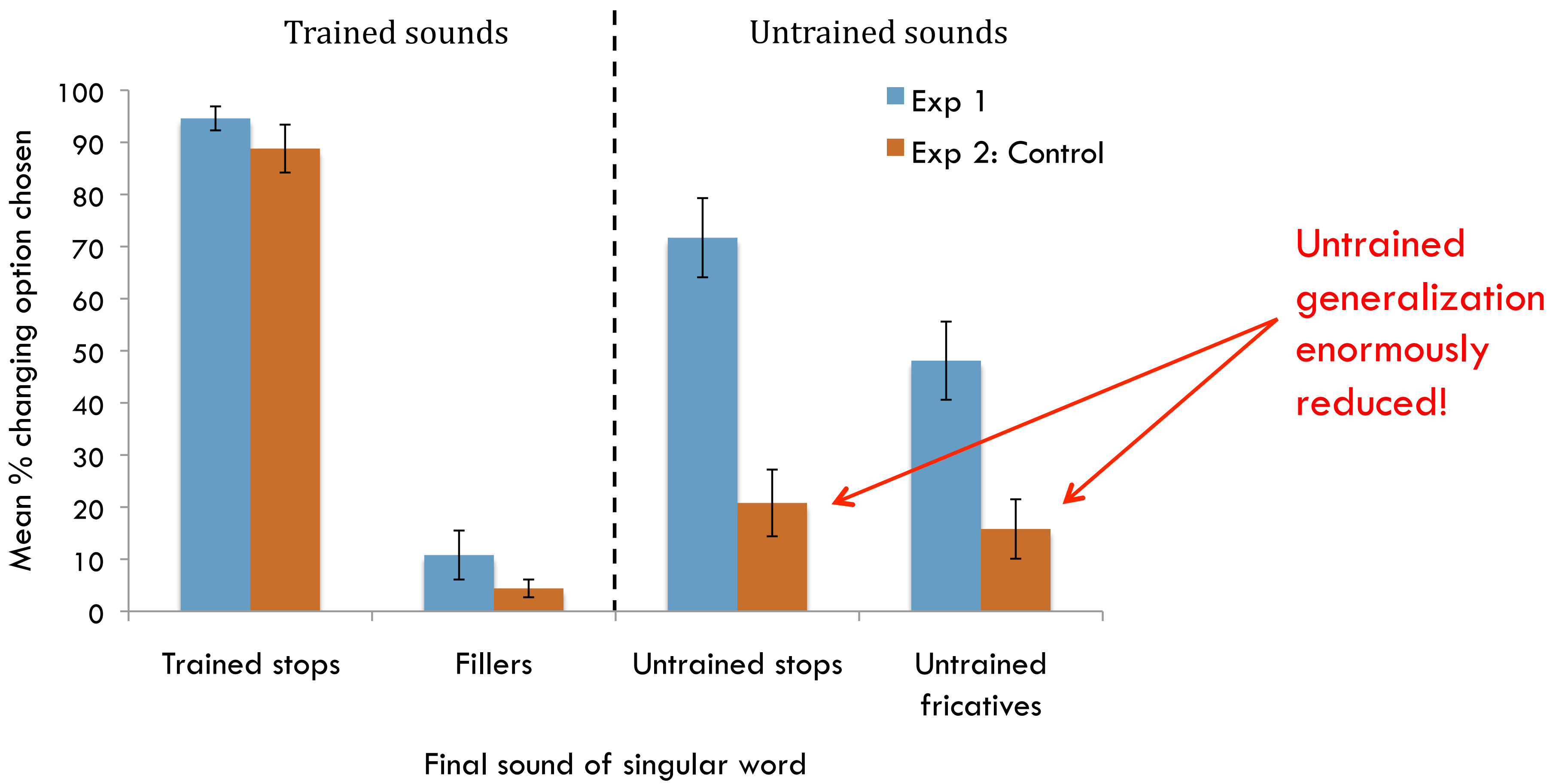

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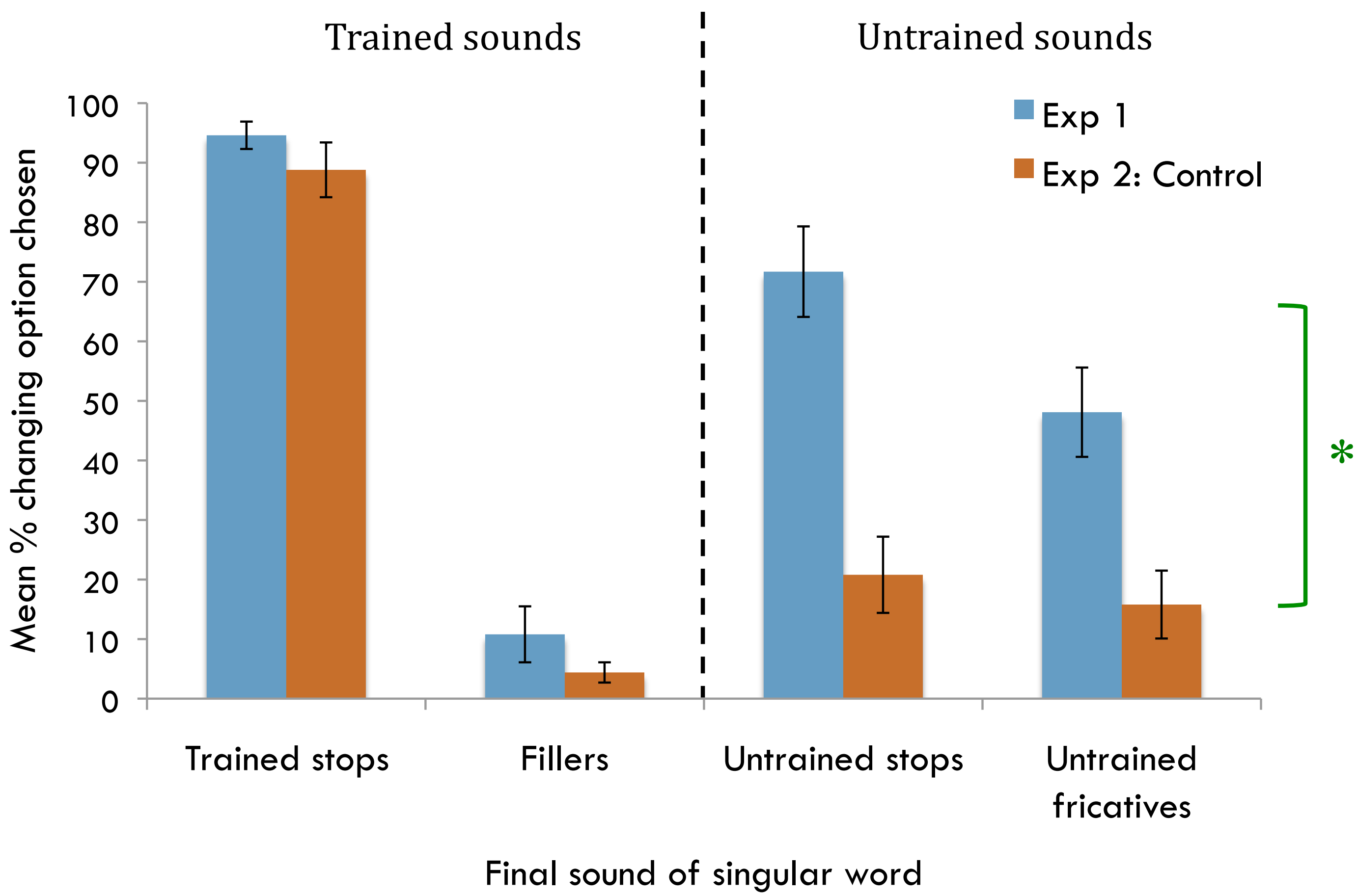
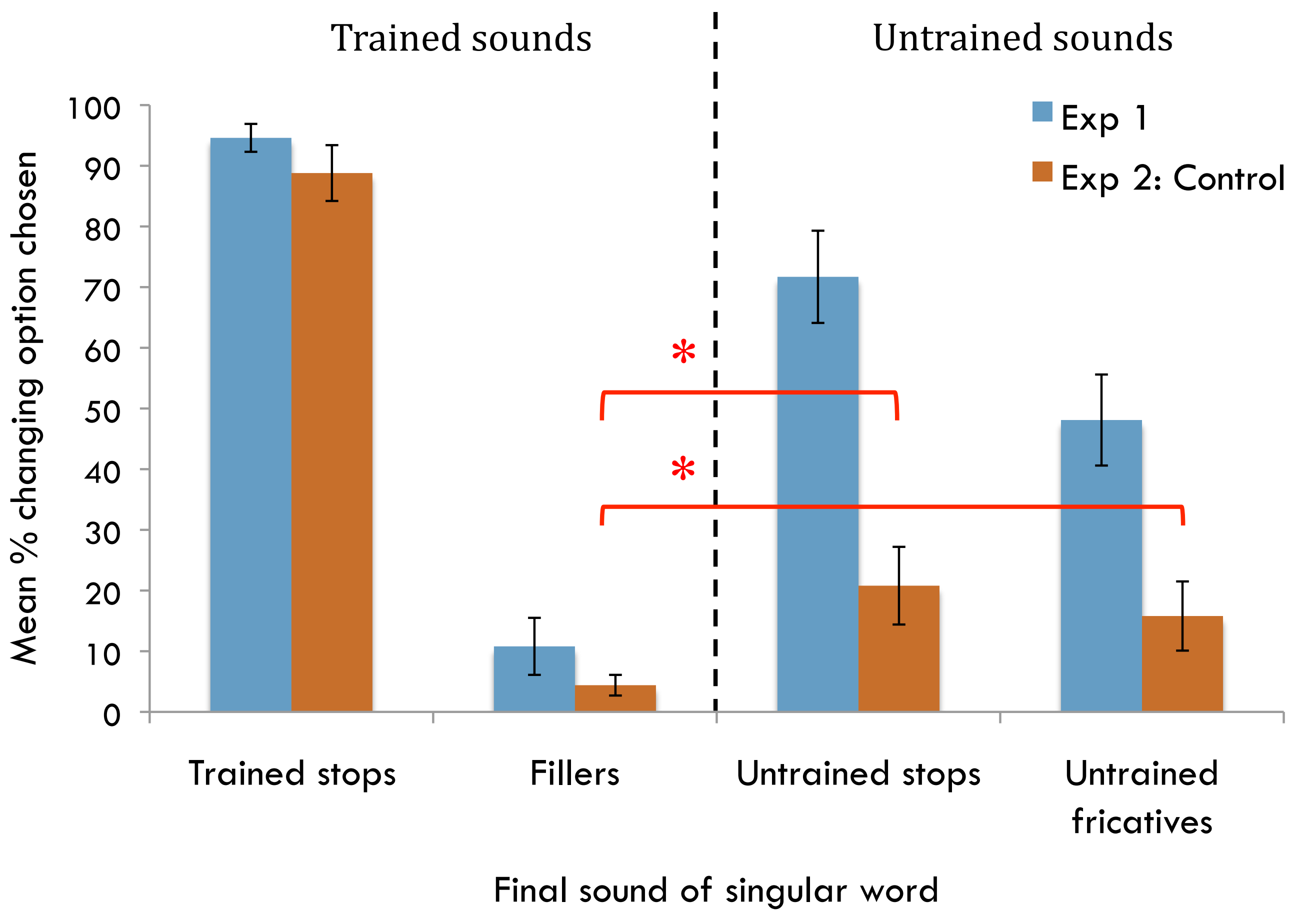


2 x 2 ANOVA: Sig. main effect of Exp for untrained sounds (Type x Exp)

Experiment 2 – Results



Still sig. different than trained fillers → can think of this as the basic effect of being trained vs. untrained

Observations so far

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  - This effect cannot be explained by participants learning a general rule or by product-oriented responses.
- There is a preference towards changing voiced stops more than voiceless fricatives.
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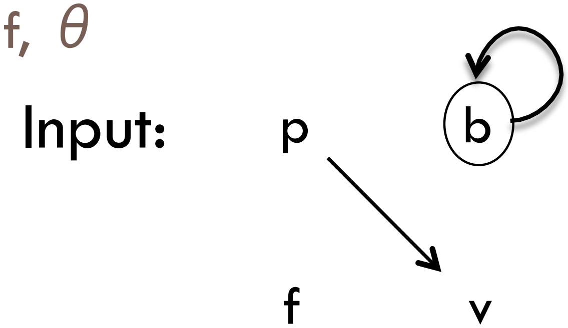
Experiment 3 – Blocked stops

- Train participants on p → v and t → ð, but also that b and d do not change
- In training:
  - 18 p → v
  - 18 t → ð
  - 18 non-changing b, d (9 of each)
  - 18 non-changing fillers
  - Nothing about f, θ



(Coronals analogous)

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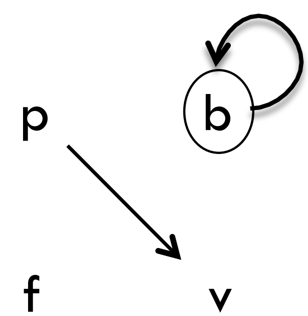
Equal # of non-changing fillers and non-changing b, d

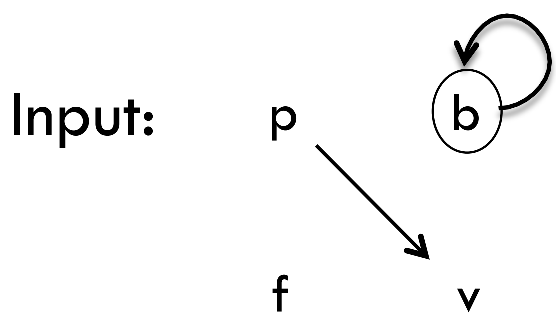
Input:



(Coronals analogous)

Experiment 3 – Blocked stops

- Prediction: If there is bias against saltatory alternations
  - % changing option for fricatives /f, θ/ should remain high



(Coronals analogous)

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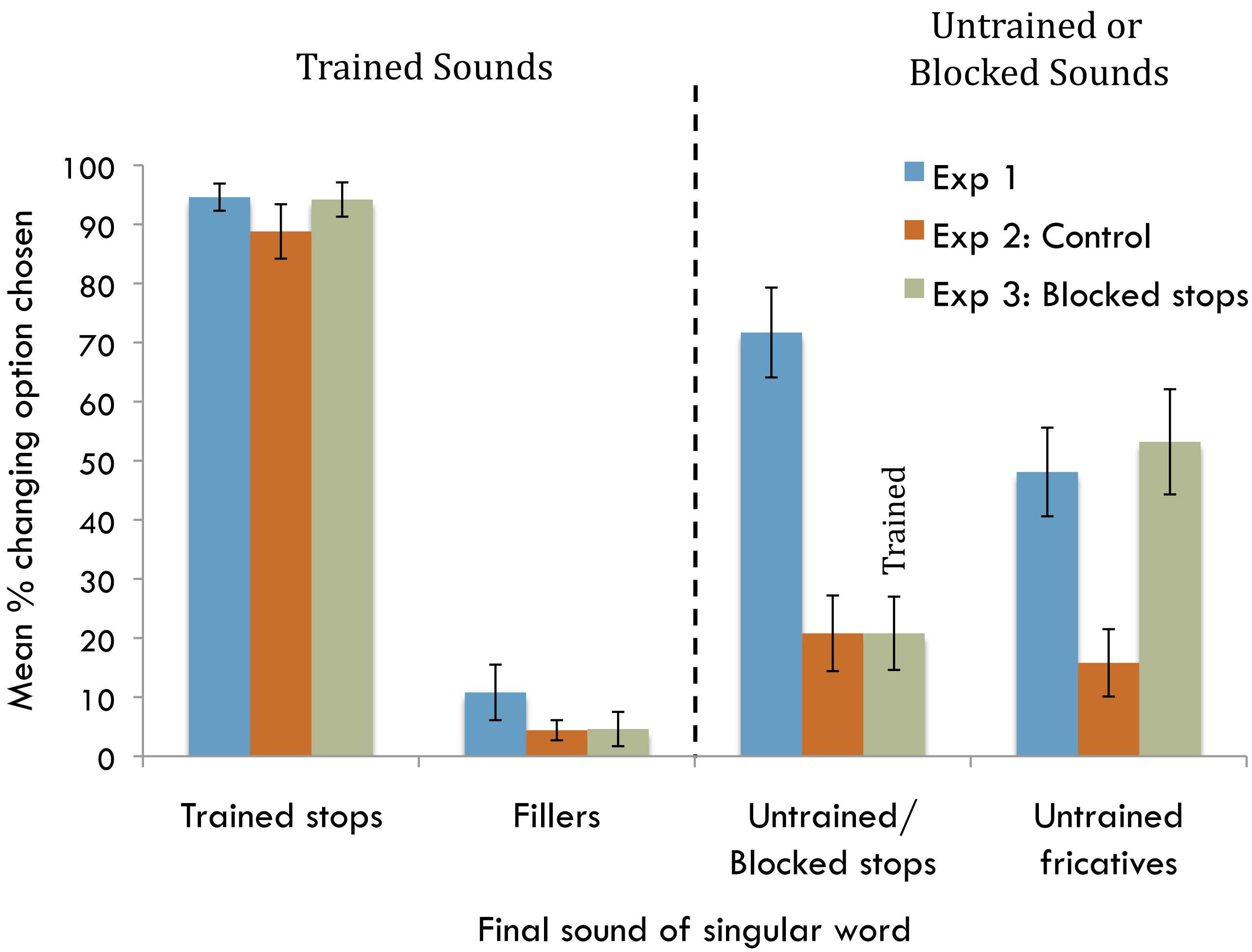

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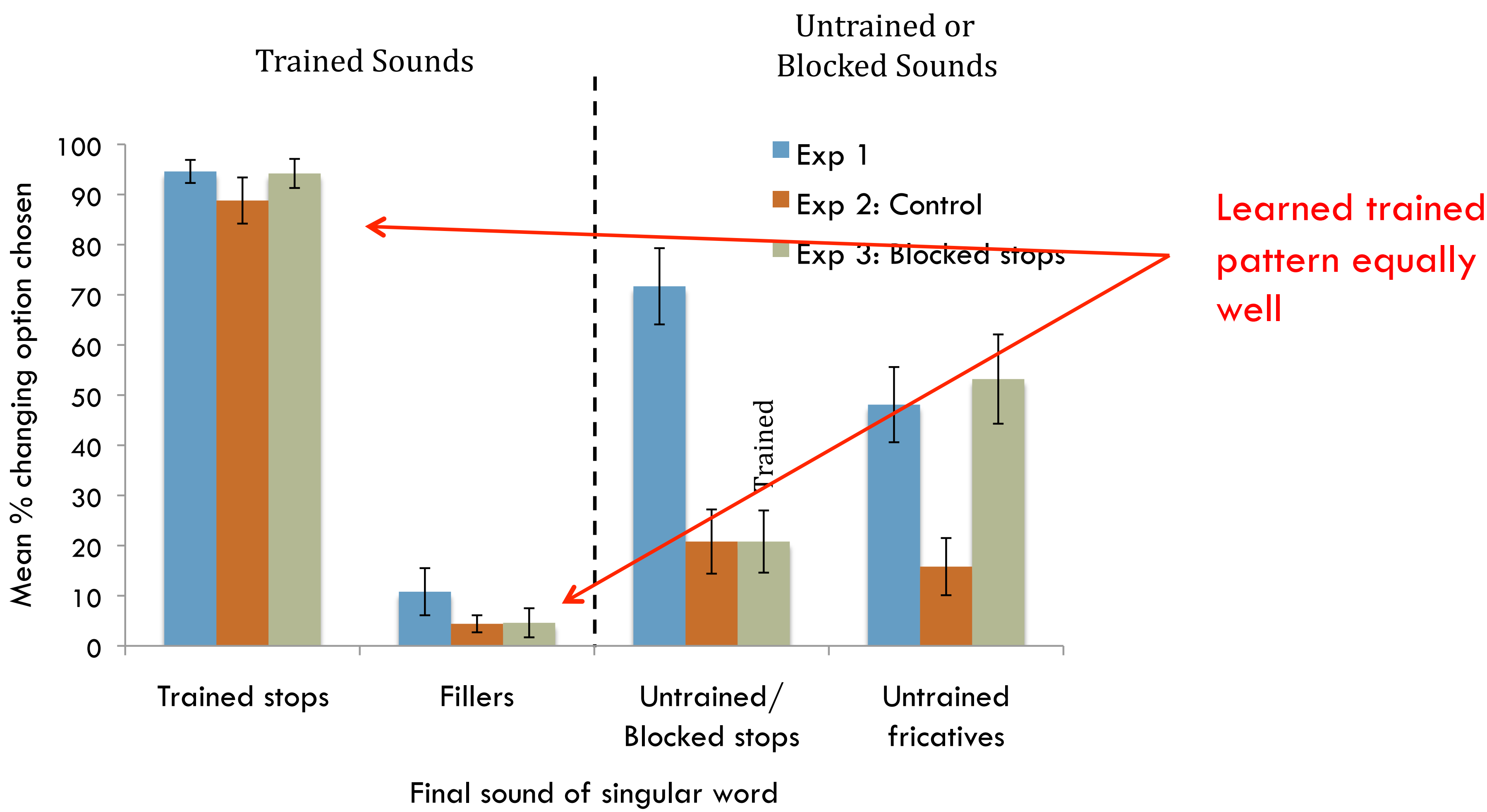

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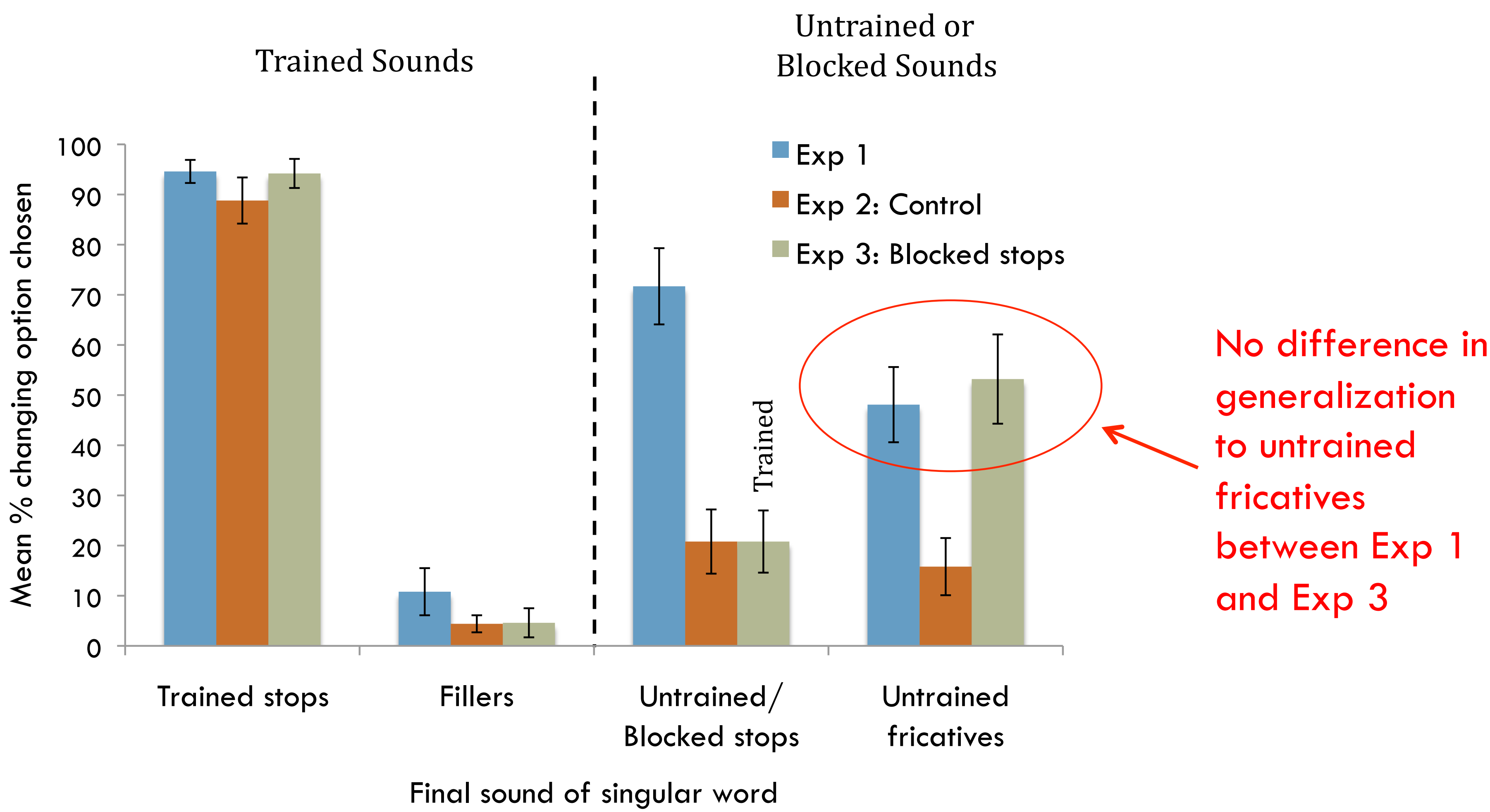

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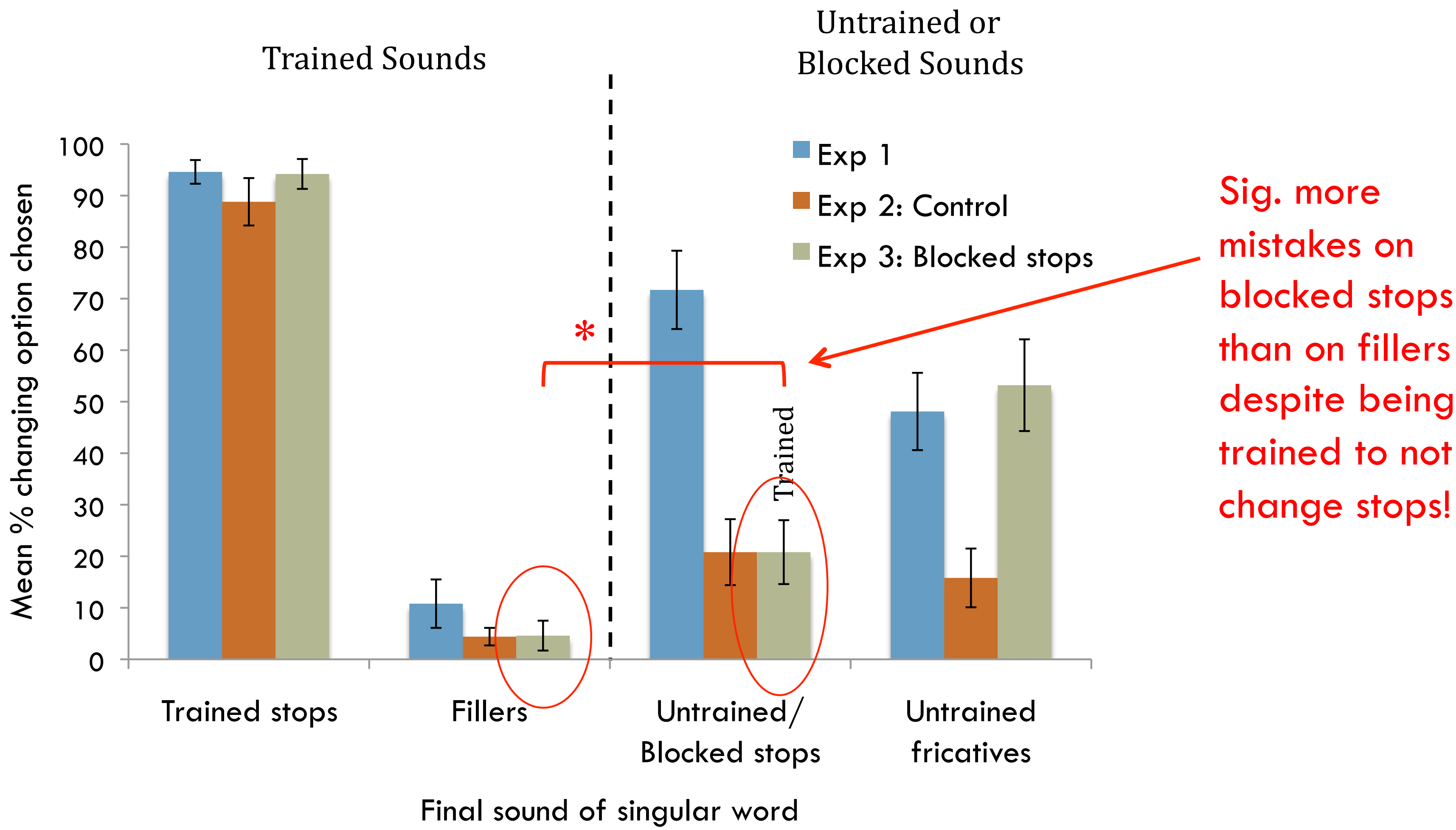

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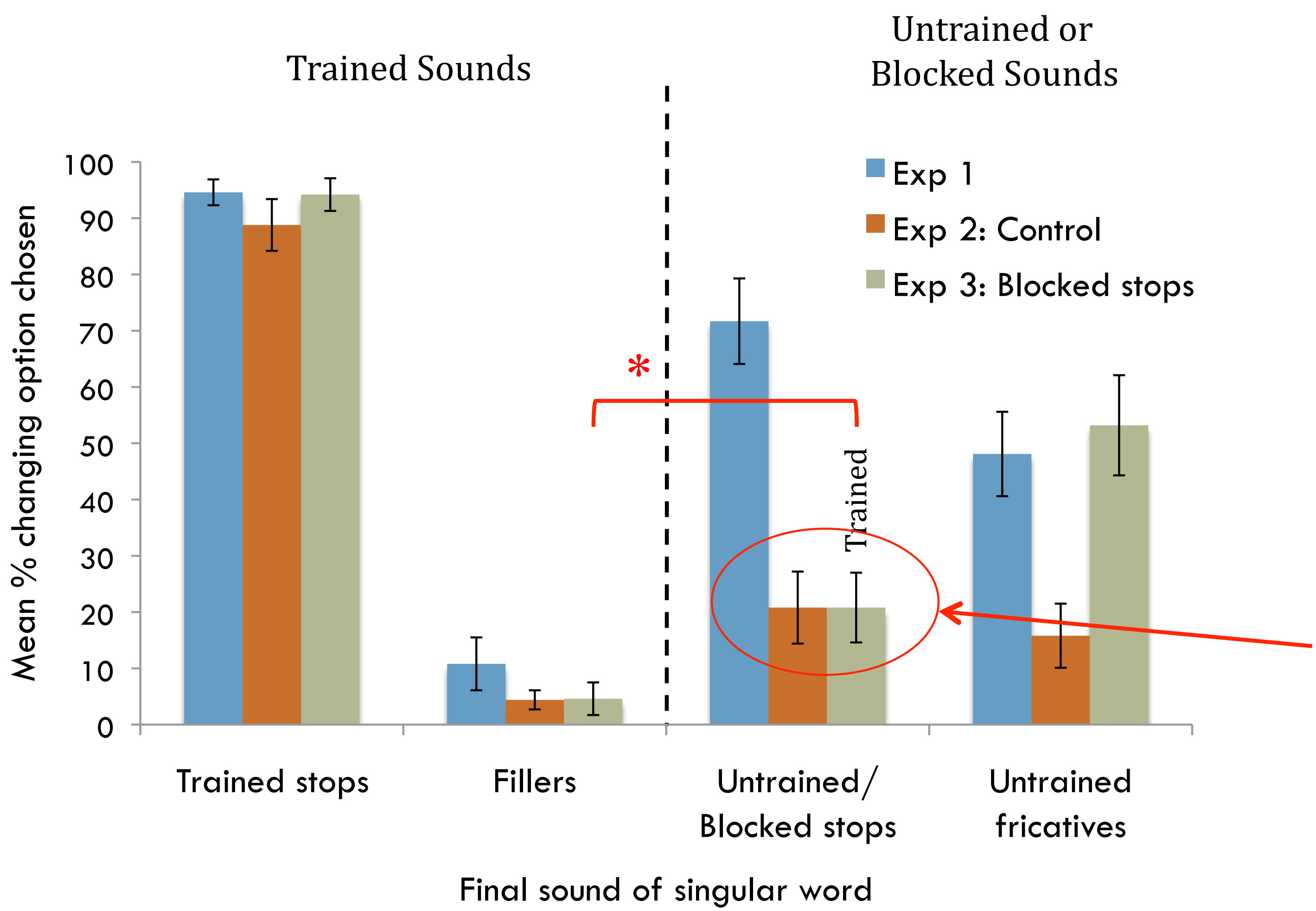
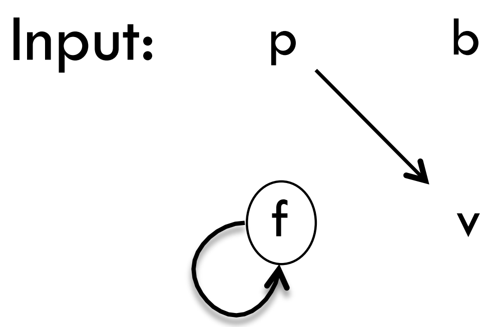


Equal to Exp 2 even though Exp 3 is <u>trained</u> and Exp 2 is <u>untrained</u>!

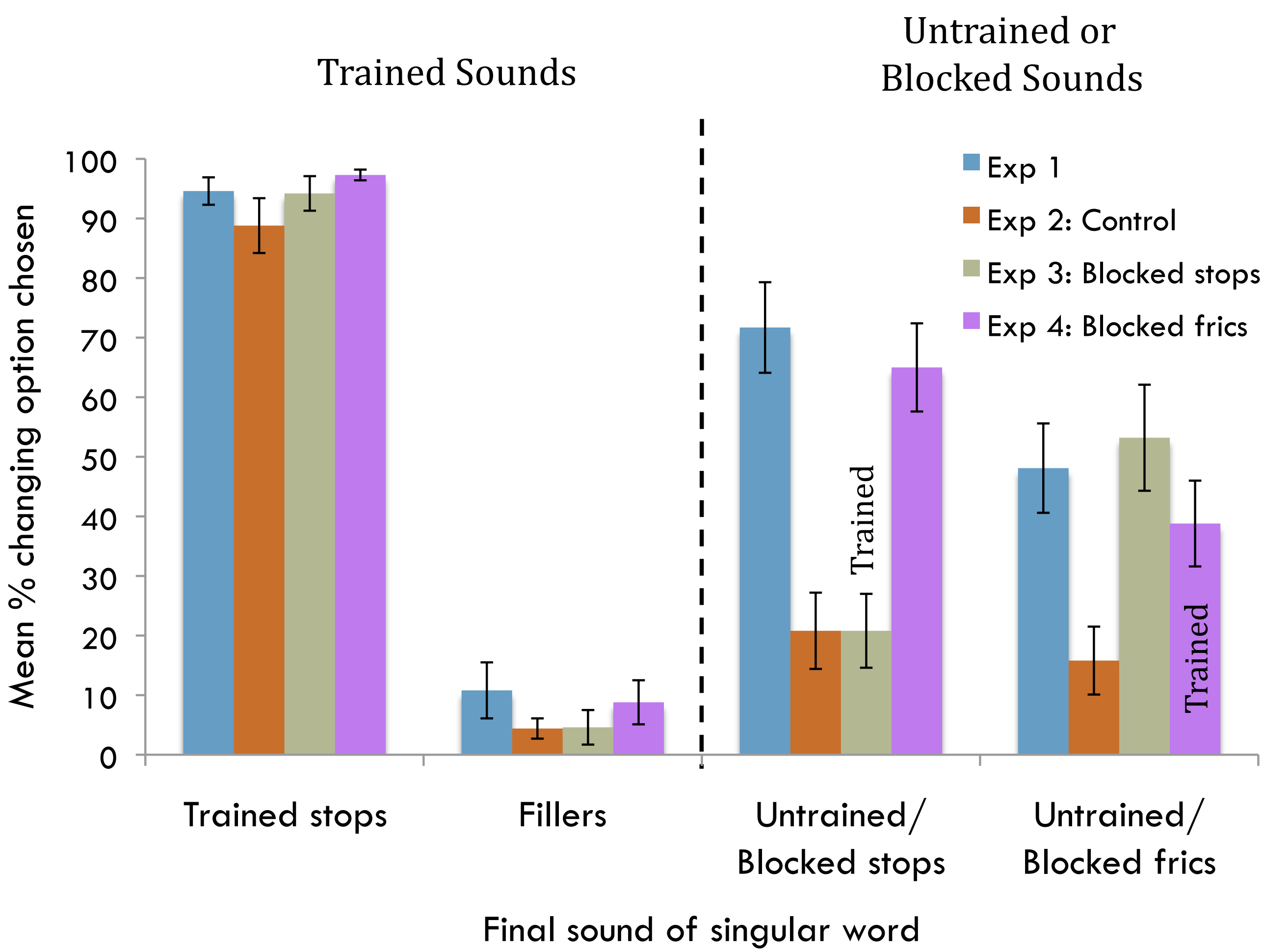
Experiment 4 – Blocked Fricatives

- Same as Exp 3, but the fricatives are blocked instead of the stops
- Will we see the same pattern?



(Coronals analogous)

Experiment 4 – Results



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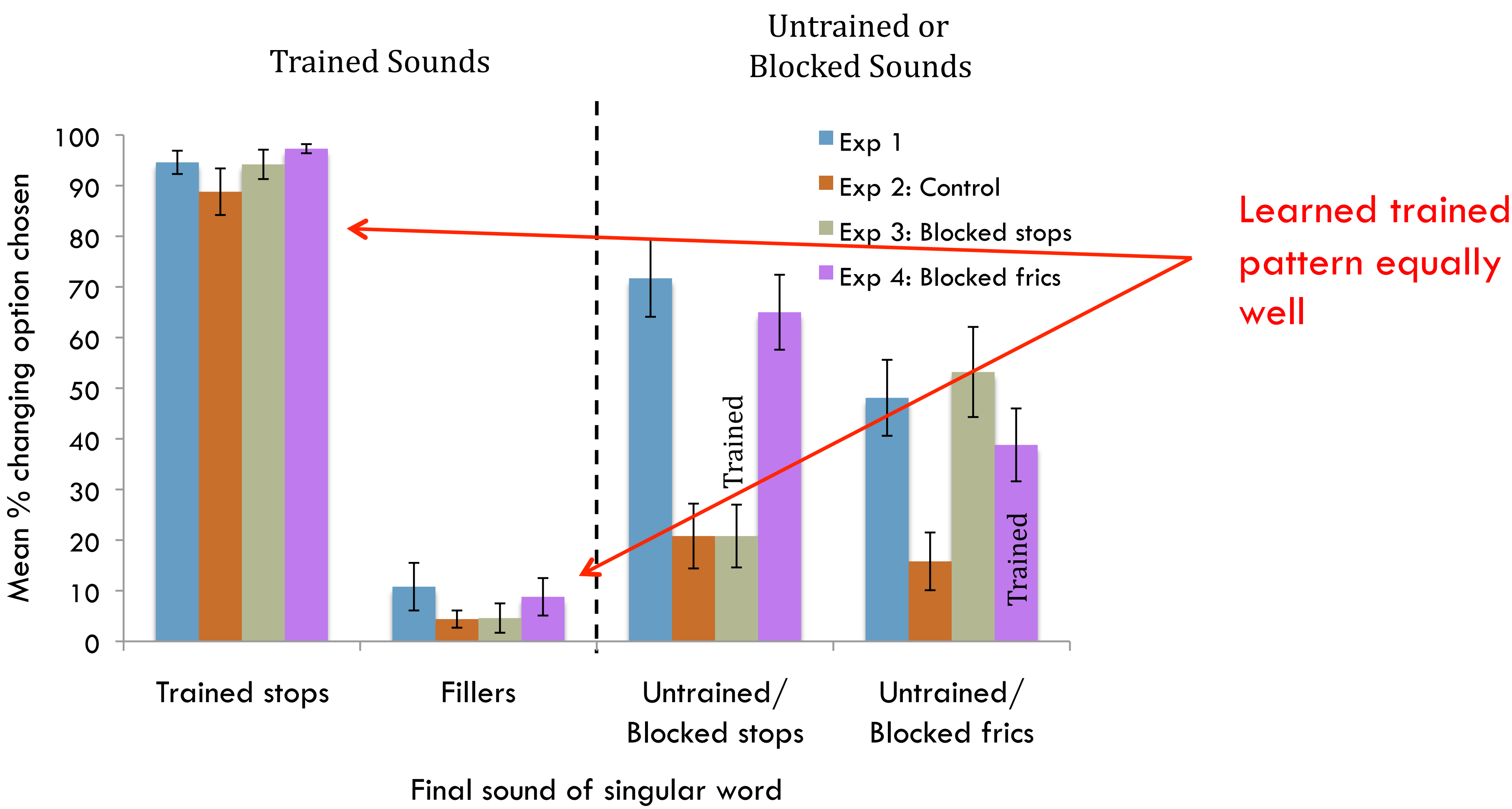

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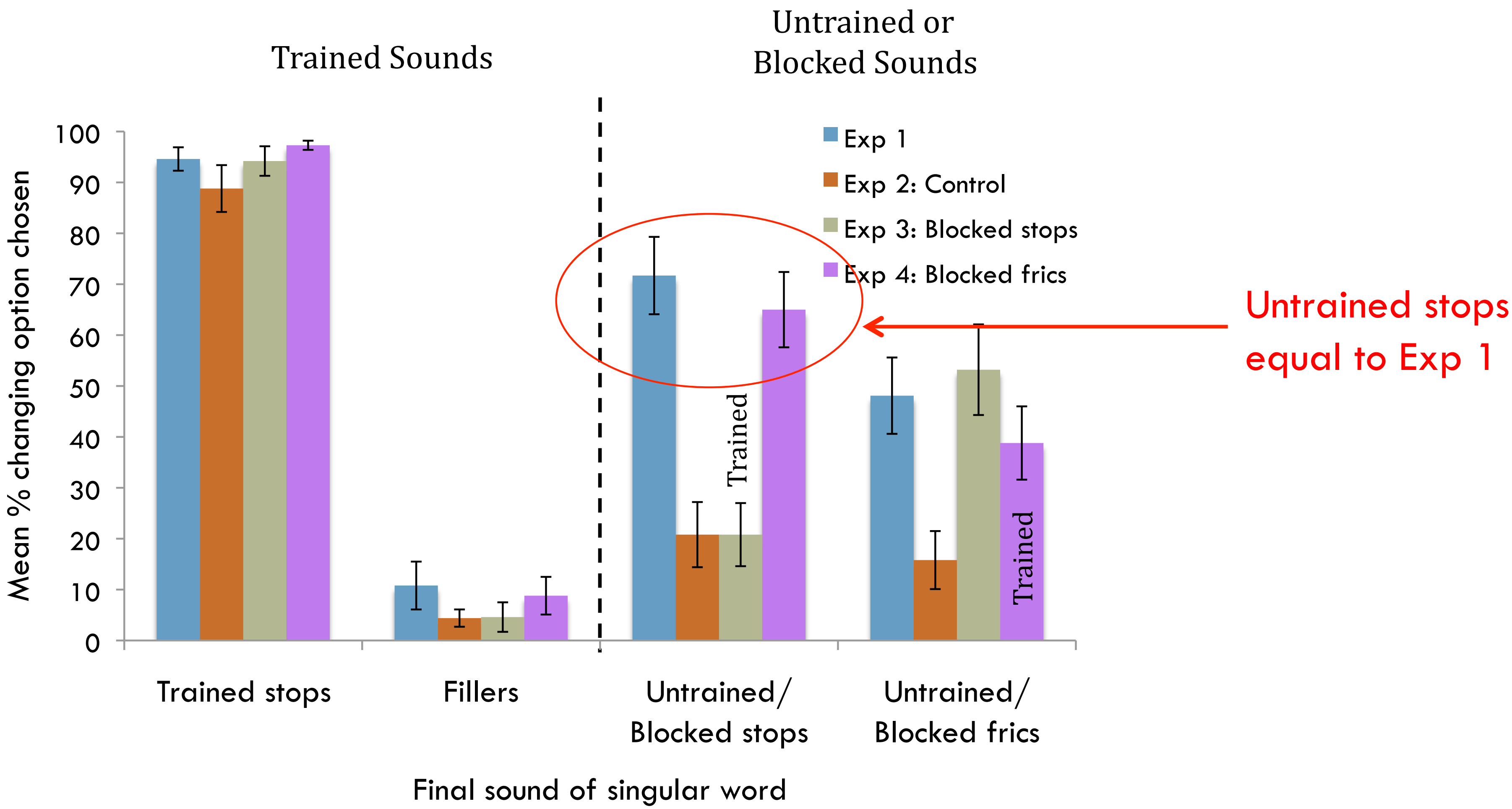
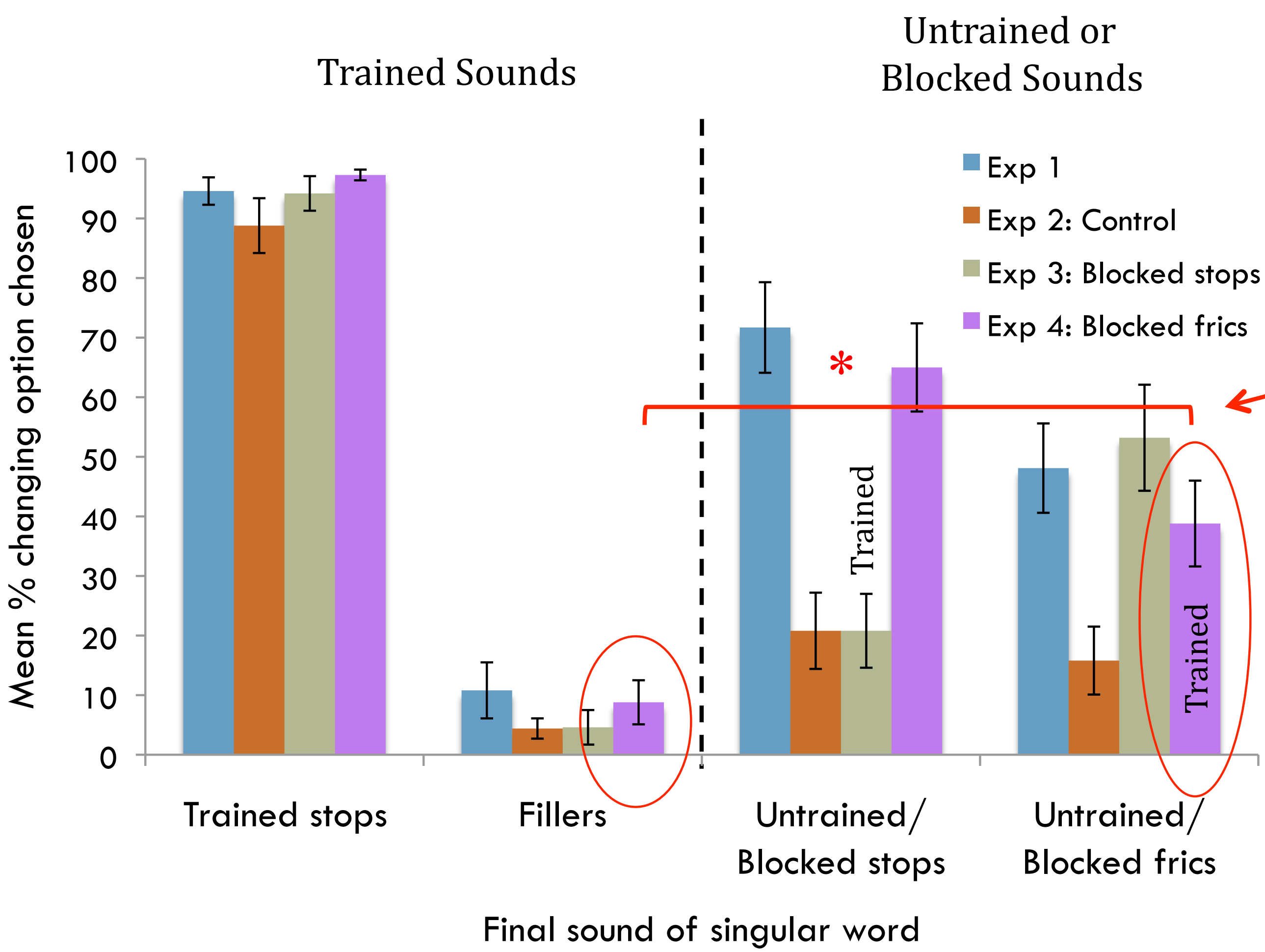
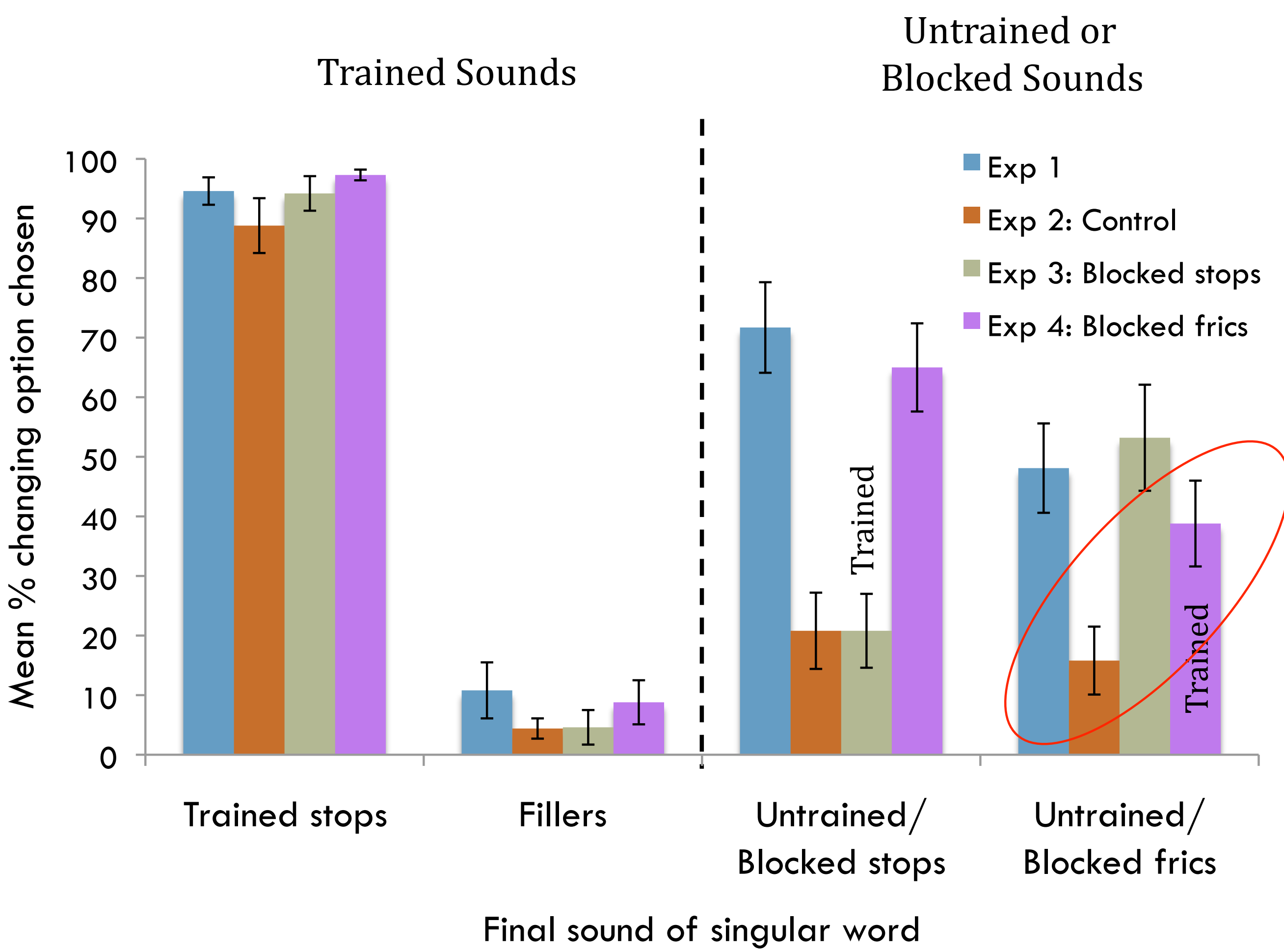


Experiment 4 – Results



Sig. more errors on blocked frics than on fillers despite being trained to not change frics!

Experiment 4 – Results



Greater than Exp 2 even though Exp 4 is trained and Exp 2 is untrained!

Observations so far

- Given ambiguous input, learners generalize to make learned alternations non-saltatory.
  - This effect cannot be explained by participants learning a general rule or by product-oriented responses.
- There is a preference towards changing voiced stops more than voiceless fricatives.
  - Binary abstract features cannot account for this difference
  - Perhaps perceptual similarity is important
- Even when learners are trained that intervening sounds should not change, they have a *tendency* to change them to make the alternation non-saltatory.

Theoretical Implications

What do we know?

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What do we know?

- Natural languages exist with saltatory alternations.
  - So phonological theory must be able to generate grammars that allow saltatory alternations.
  - Even this is not totally straightforward (e.g., classical OT[1] cannot handle them).

1. Prince & Smolensky, 1993/2004

Theoretical Implications

What do we know?

- Natural languages exist with saltatory alternations.
  - So phonological theory must be able to generate grammars that allow saltatory alternations.
  - Even this is not totally straightforward (e.g., standard OT[1] cannot handle them).
- Saltatory alternations are relatively rare and I have shown that learners are biased against learning a system containing them.
  - So our theories of phonological learning should account for why these alternations are dispreferred in learning

1. Prince & Smolensky, 1993/2004

Nature of the bias

- Substantive bias[1]
  - Steriade's P-map[2] principle seems to be a good basis for such a bias in this case (at least for a starting point)
    - P(erceptual)-map → Humans are aware of perceptual relationships between sounds (in a given context) and alternations should minimize perceptual changes
    - Accounts for a preference for short distance changes over long distance changes
    - Also accounts nicely for the preference in Exp 1 to change b → v more than f → v (b is more perceptually similar to v).

1. E.g., Wilson, 2006; Finley & Badecker, 2008; etc. 2. Steriade 2001/2008

Nature of the bias

- Preliminary computational modeling looks promising for the P-map:
  - Maximum Entropy grammar learning[1] with weighted constraints banning relevant alternating pairs (e.g., *p~v)
  - Input/test items based on experiments
  - With a prior (= bias) based on the P-map, the model does pretty well; the unbiased model fails
- Is P-map sufficient?
  - Further experiments/modeling will help determine whether something else has a role (e.g., general dispreference for saltation that is more than just perceptual distance)

1. Goldwater & Johnson, 2003

Future directions

- More computational modeling
  - Will help explore what types of biases work and make predictions for additional experiments
- Open response/production experiments
- Infant study
  - Do infants display a bias against saltation when learning phonological alternations?
  - Will help determine if this bias is operational in child language acquisition

Conclusions

- Learners are biased against learning saltatory alternations
  - When trained on alternations that are (potentially) saltatory, they make assumptions/errors that make them not saltatory
- Perceptual similarity appears to play a role in this bias
- A substantive bias based on the P-map seems like a promising starting point for modeling the effect

Thank you!

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