Heinrich Heine Universität Düsseldorf

# Lexical storage and morphological segmentability effects on the production of English derivatives

Simon David Stein
Ingo Plag

DFG Deutsche Forschungsgemeinschaft
FOR2373

## Frequency and duration

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### Lexical frequency

How often does a linguistic unit occur in a language?

### Acoustic duration

How long do we pronounce linguistic units?

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How long do we pronounce linguistic units?

higher → shorter

## Storage in the mental lexicon

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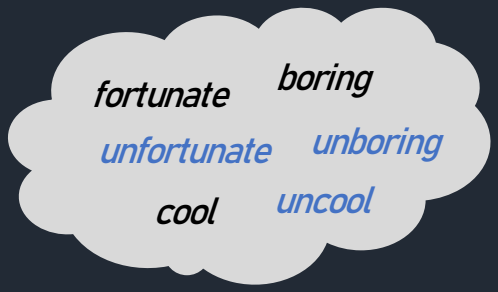
### Whole-word storage




complex words are stored unanalyzed



Caselli et al. 2016, examples from Hay 2007: 40–41

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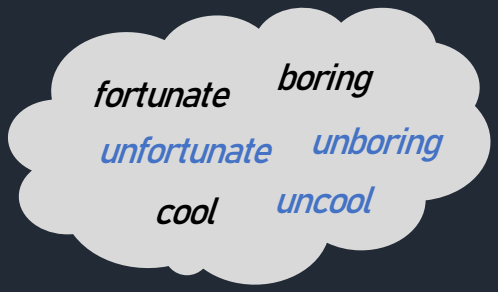


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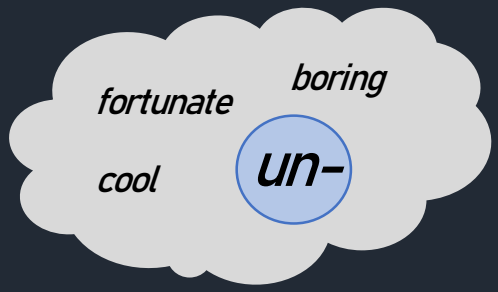


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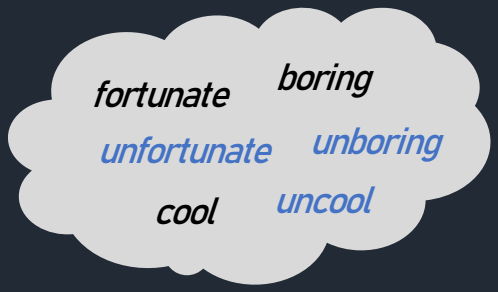


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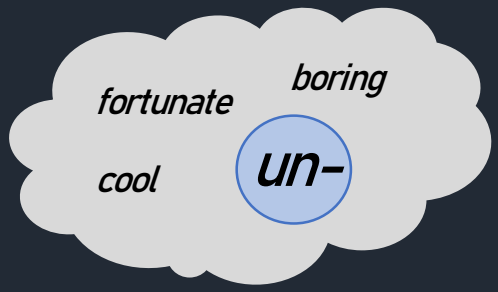


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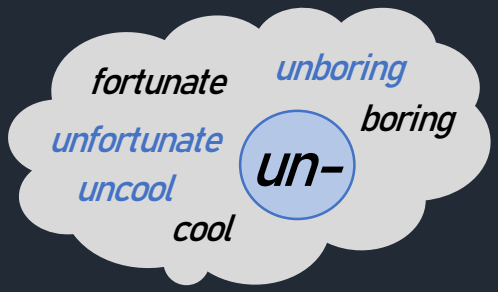


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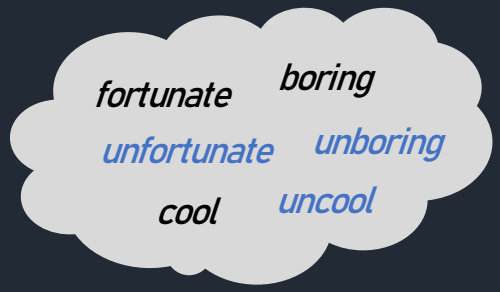


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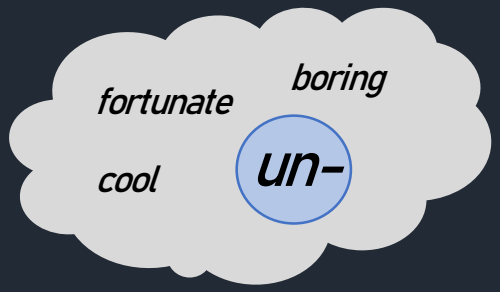


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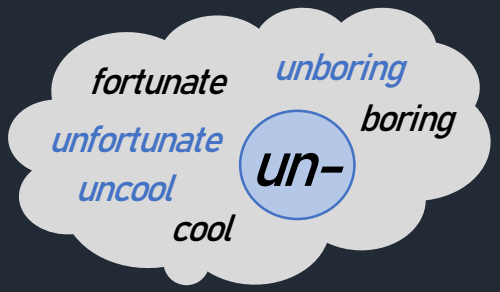


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## Segmentability

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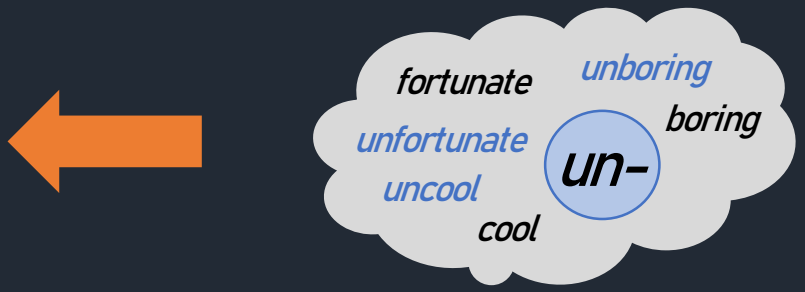


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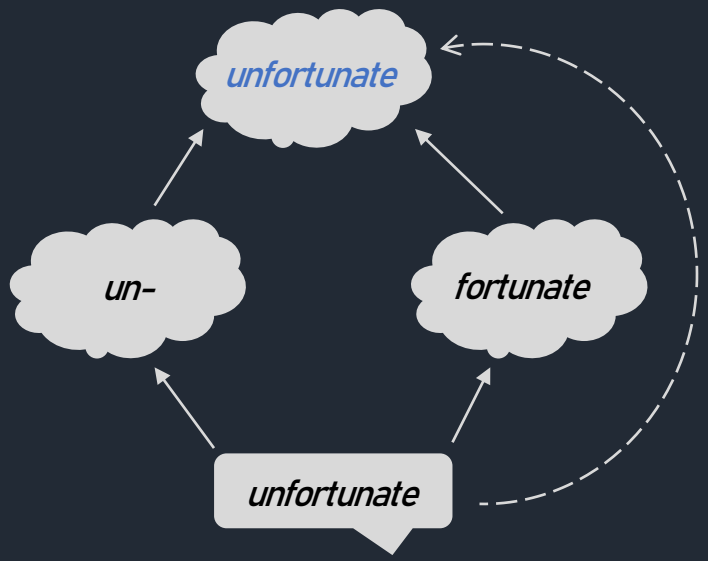


adapted from
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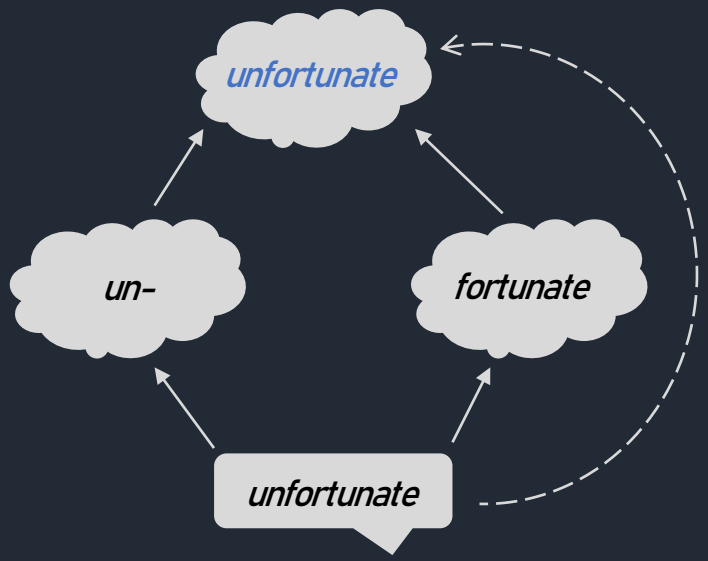


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| Word | Frequency | Segmentability | Prediction |
|---|---|---|---|
| fortunate | 6000 | low | shorter duration |
| unfortunate | 6915 | | |
| boring | 7483 | high | longer duration |
| unboring | 4 | | |



Caselli et al. 2016, examples from Hay 2007: 40–41, frequencies from COCA, Davies 2008

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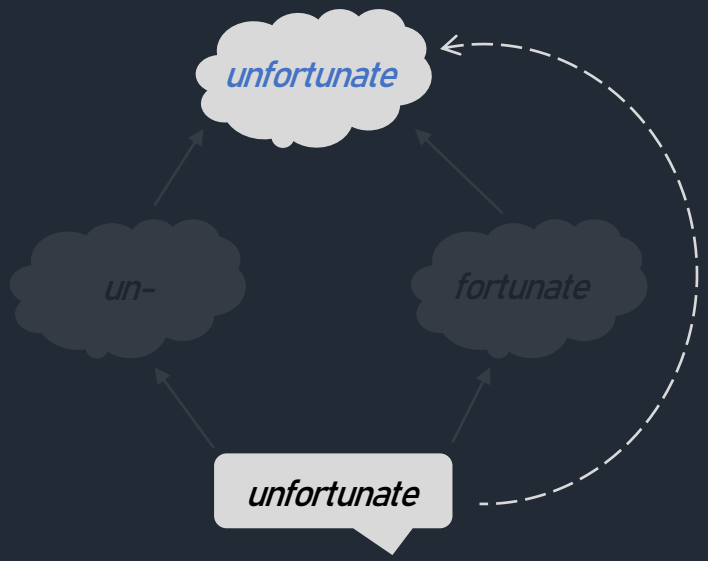


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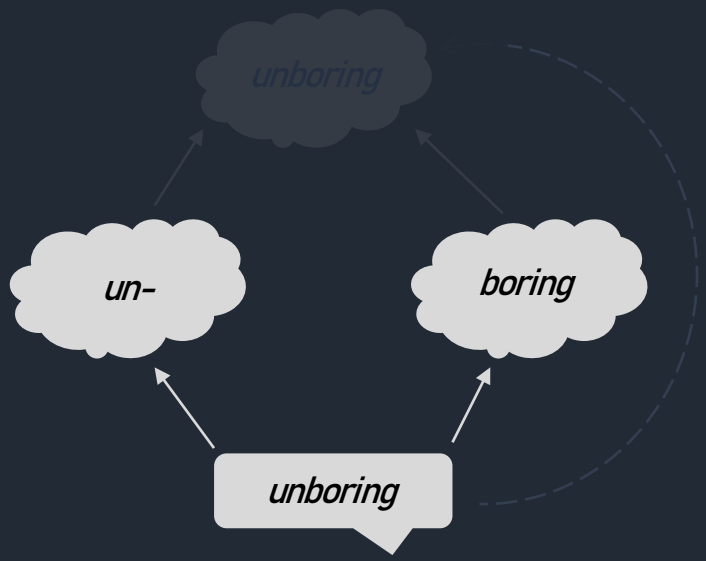


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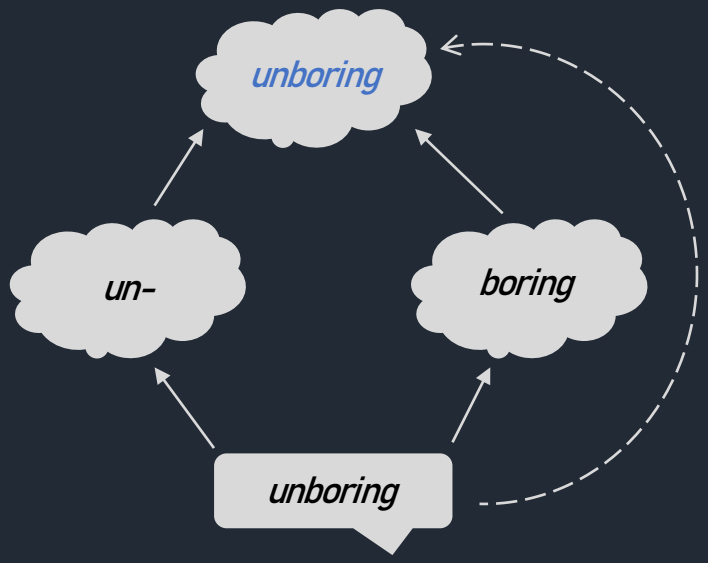


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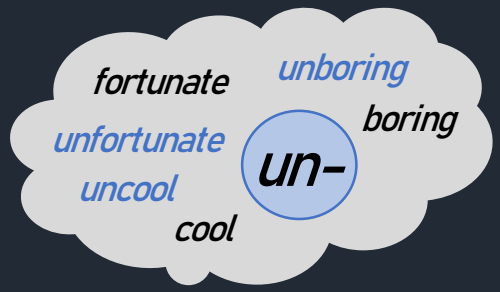


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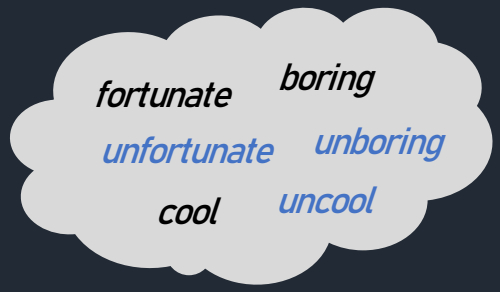


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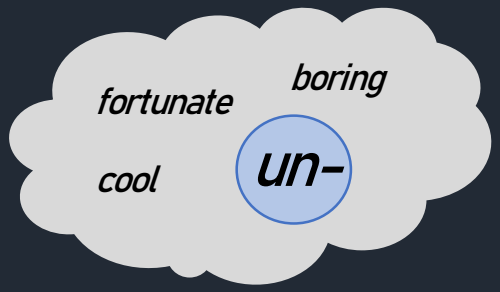


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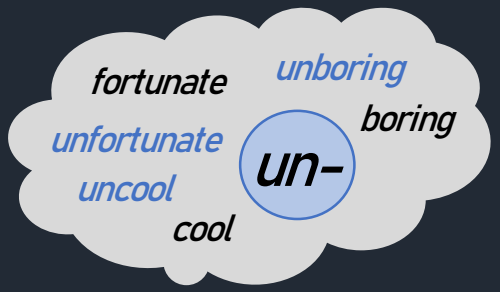


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- inflectional suffixes *-ing*, *-ed*, and *-s*
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- segmentability effects for *un-* and *-ly*



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- segmentability effects for *un-* and *dis-*
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Contradictory evidence:
Why do the frequency measures sometimes show and sometimes not show effects?



Caselli et al. 2016, Hay 2003, 2007, Plag and Ben Hedia 2018

## Present study

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### Hypothesis 1

Higher word frequency → shorter duration

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Higher relative frequency → longer duration

≈ more segmentability

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Higher word frequency → shorter duration of word, base, and affix

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# Data and measurement

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### Data collection

- AudioBNC
- Forced Alignment
- Praat textgrids
- manual cleaning of results



Coleman et al. 2012, Boersma and Weenik 2014

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### Affixes N

| | | | |
|---|---|---|---|
| *-ness* | 363 | *pre-* | 123 |
| *-less* | 216 | *dis-* | 689 |
| *-wise* | 289 | *un-* | 960 |
| *-ize* | 476 | *in-* | 342 |
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- multiple linear regression in R using lm-function
- variable transformations
- trimming of datasets
- backwards exclusion of non-significant variables



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- speech rate
- number of syllables
- biphone probability sum
- bigram frequency



Coleman et al. 2012, Boersma and Weenik 2014, R Core Team 2017, Davies 2008, Vitevitch and Luce 2004

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- separate models for durations and frequencies: 81 models



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## Frequency and segmentability effects

| duration | word | affix | base |
|---|---|---|---|
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| word frequency | | | |
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p < .001 expected direction

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|---|---|---|---|---|---|---|
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| word frequency | | | | | | | | | |
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| relative frequency | | | | | | | | | |
| affix | dis- | | | | | | | | |
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| affix | dis- | | | un- | | | | | |
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| | | |
|---|---|---|
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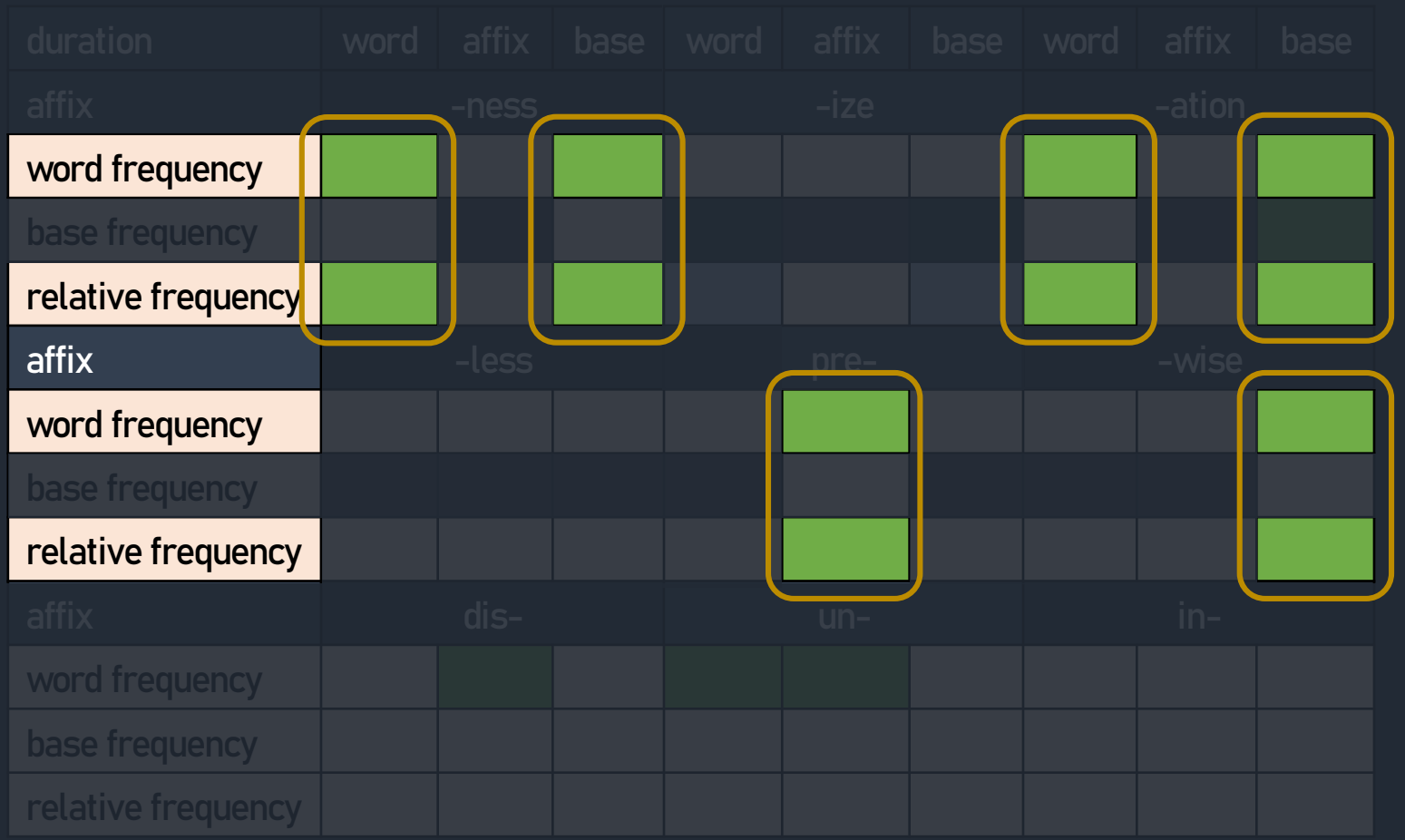


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| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

## Prefixes vs. suffixes

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ... the type of affix?

## Prefixes vs. suffixes

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

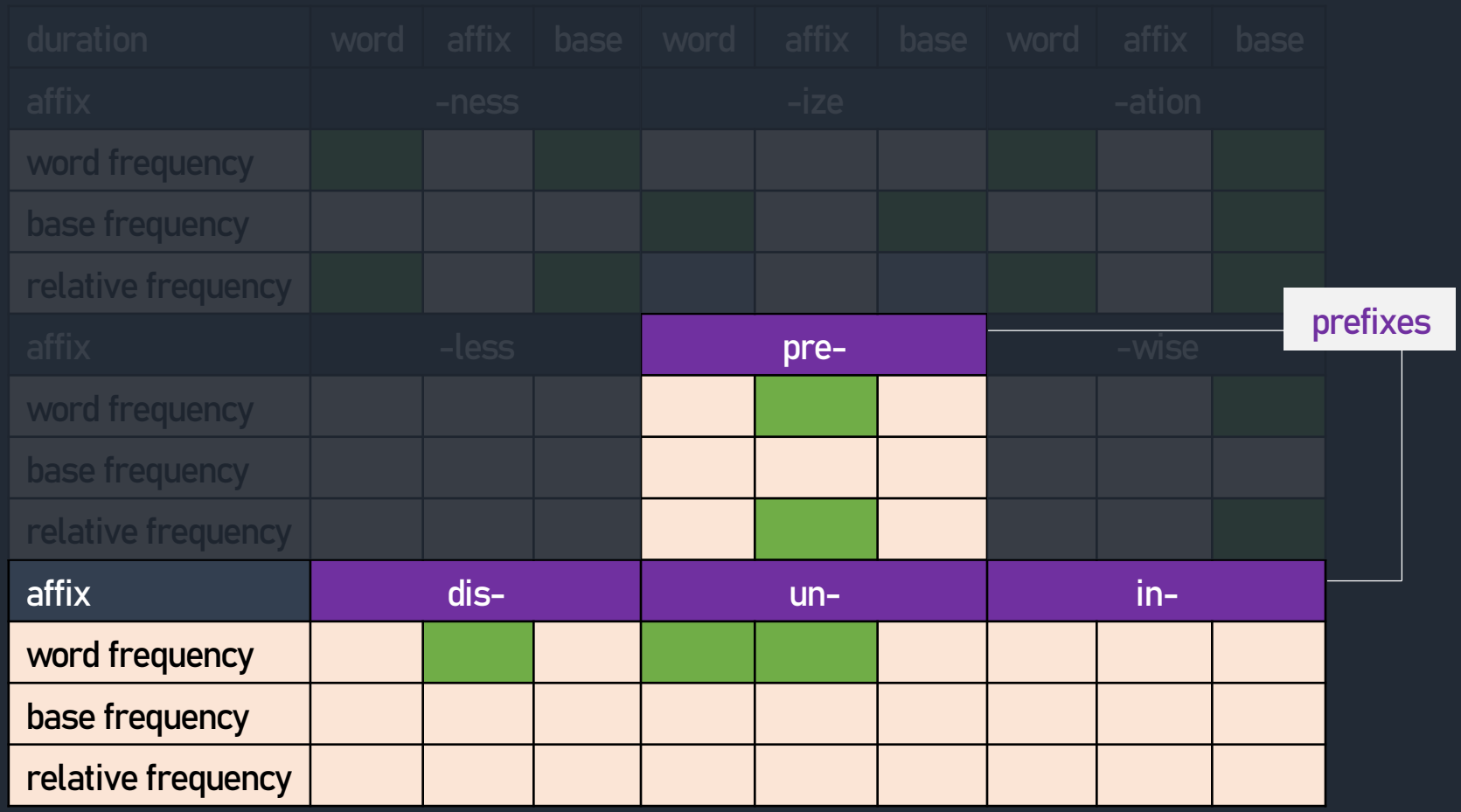
suffixes

p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ... the type of affix? ✗

## Prefixes vs. suffixes




p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ... the type of affix? ✗

## Affix length

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

p < .001 expected direction

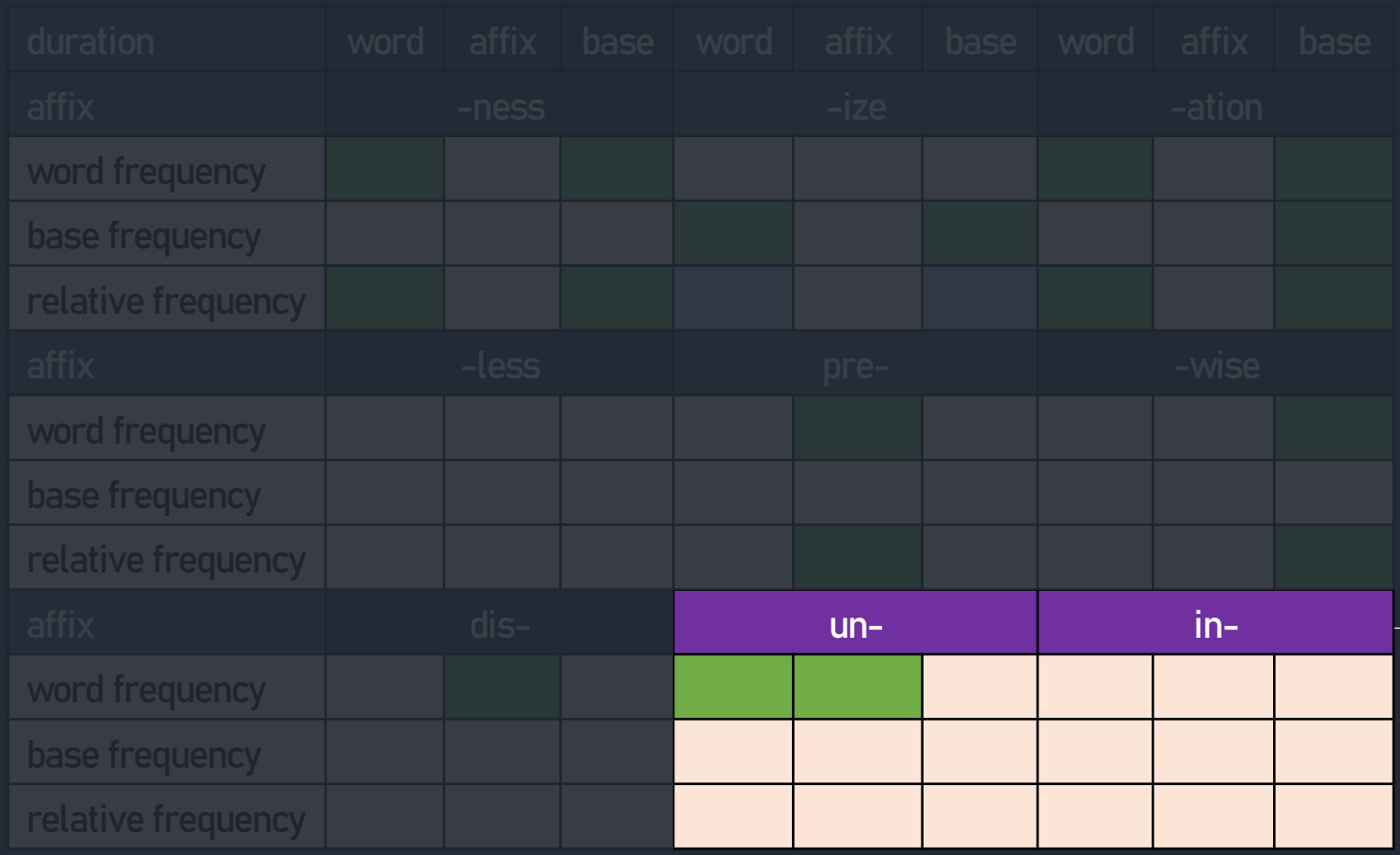
p < .001 unexpected direction

Are the differences related to ...

the type of affix? ✗

the affix length?

## Affix length




around 100–150 ms

p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

the type of affix? ✗

the affix length?

## Affix length


p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

the type of affix? ✗

the affix length? ✗

## Manual resegmentation

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

the type of affix? ✗

the affix length? ✗

the segmentation?

## Manual resegmentation

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

| | | | |
|---|---|---|---|
| p < .001 | expected direction | Are the differences related to … | the type of affix? ✗ |
| p < .001 | unexpected direction | | the affix length? ✗ |
| p < .01 | weaker effect | | the segmentation? ✗ |

## Type of prosodic integration

## Type of prosodic integration

### The prosodic hierarchy

- U — Phonological utterance
- IP — Intonation phrase
- ϕ — Phonological phrase
- ω — Prosodic word
- Σ — Foot
- σ — Syllable



Hildebrandt 2015, Raffelsiefen 1999, 2007

## Type of prosodic integration

### The prosodic hierarchy

- U — Phonological utterance
- IP — Intonation phrase
- ϕ — Phonological phrase
- ω — Prosodic word
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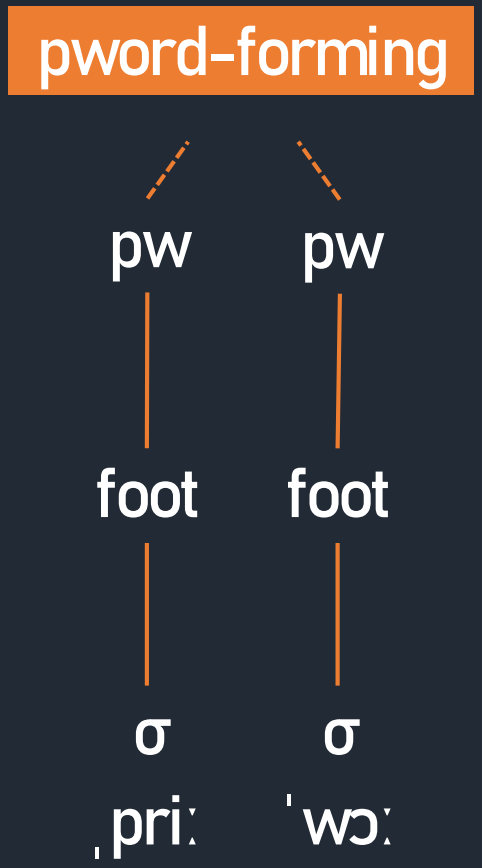
- σ — Syllable



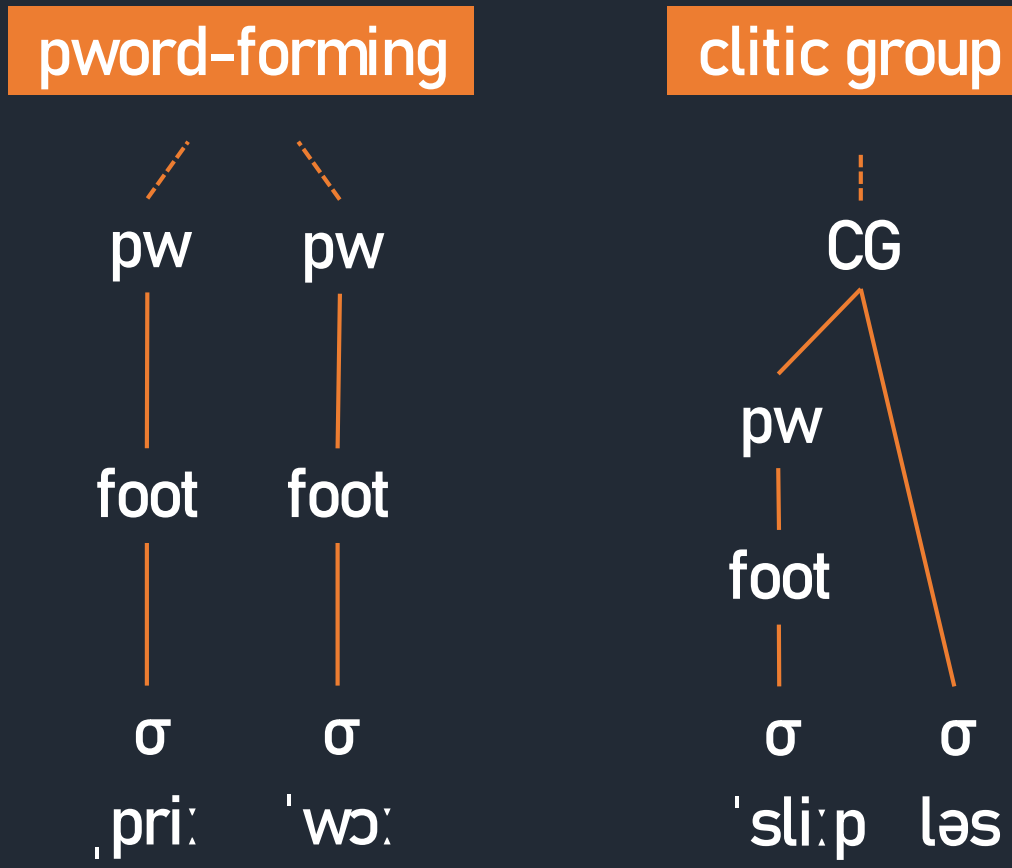
Hildebrandt 2015, Raffelsiefen 1999, 2007

## Type of prosodic integration



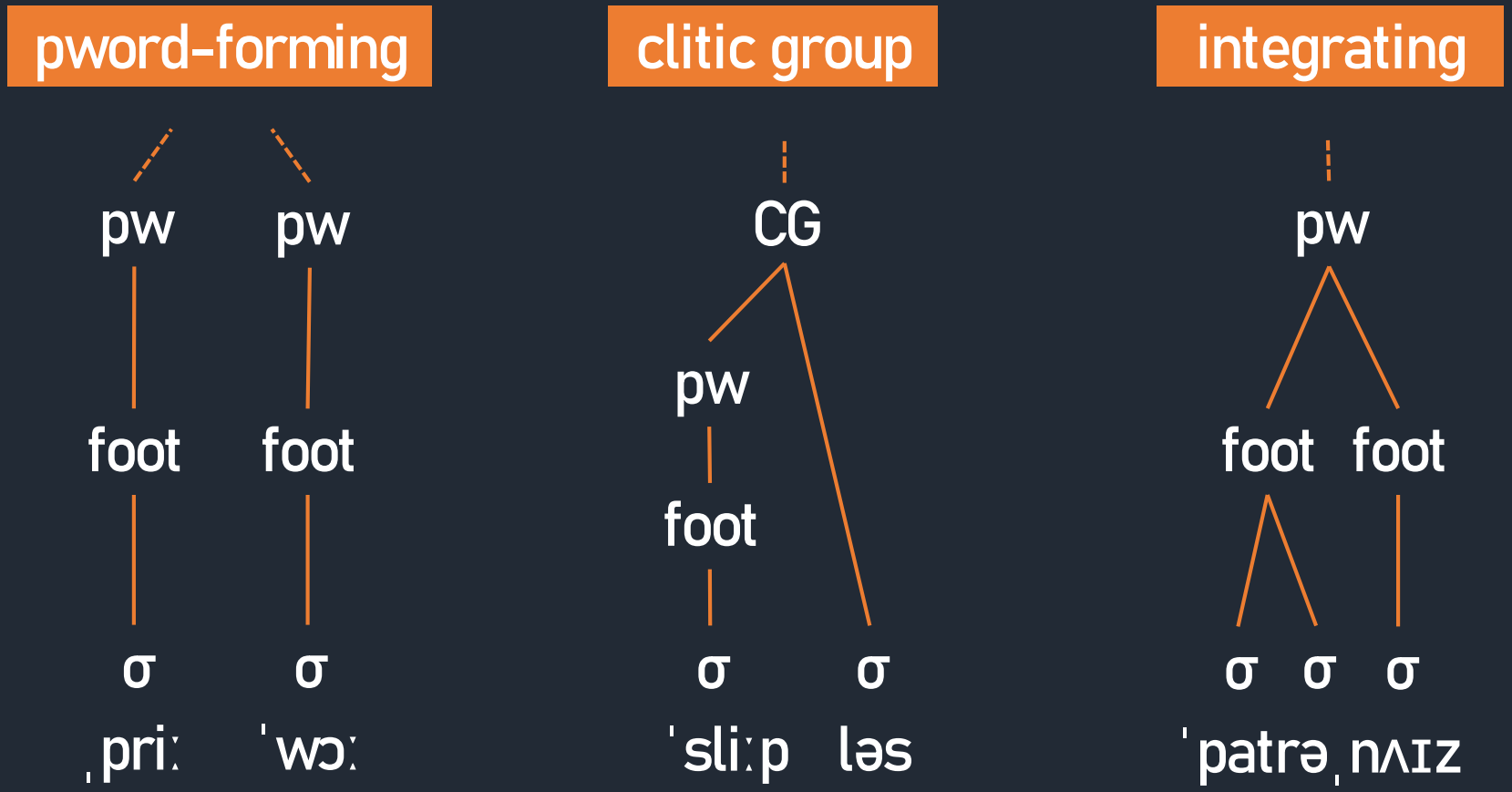

following Raffelsiefen 1999

## Type of prosodic integration




following Raffelsiefen 1999

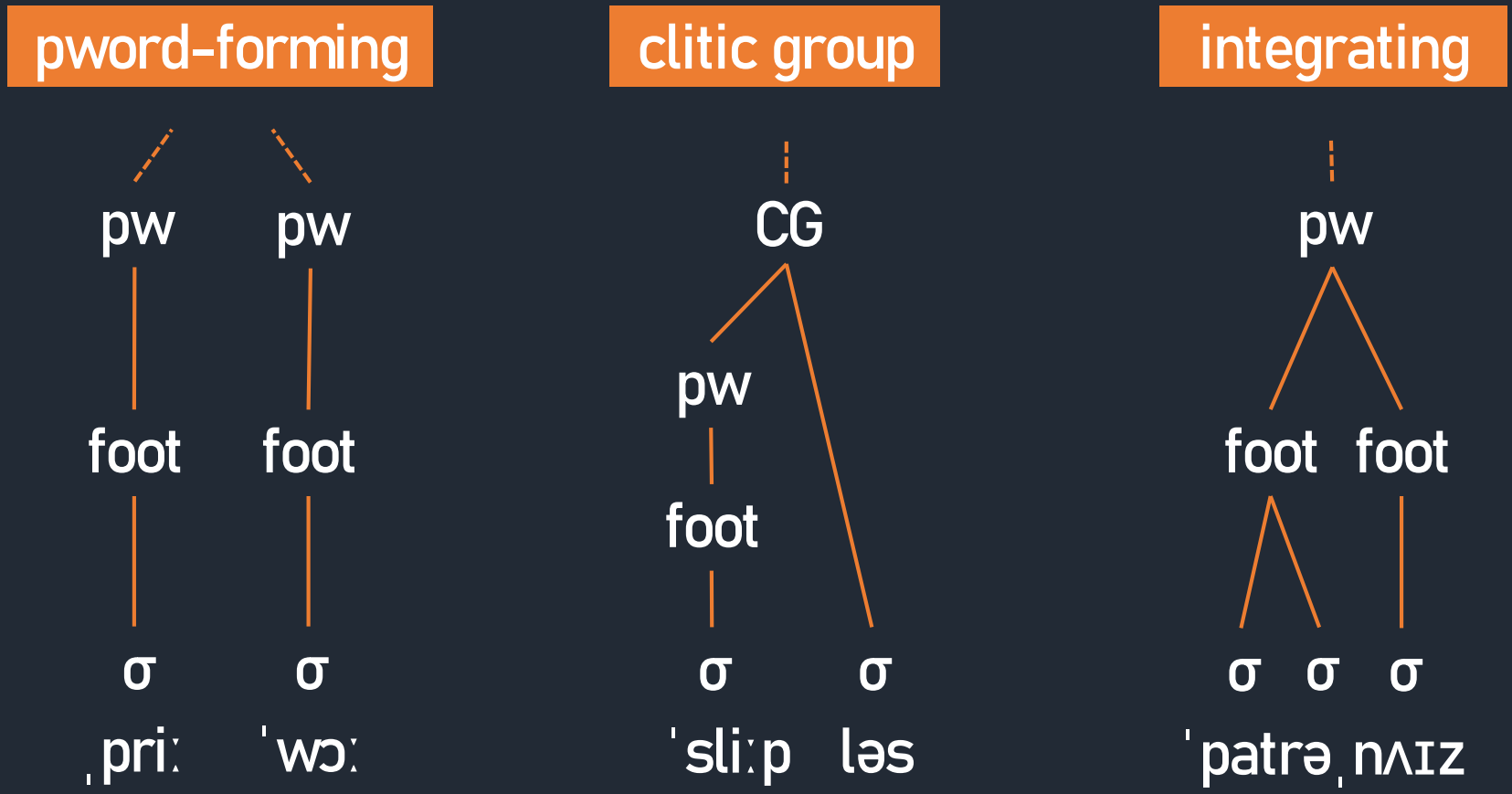
## Type of prosodic integration




following Raffelsiefen 1999

## Type of prosodic integration

more integration




following Raffelsiefen 1999

## Type of prosodic integration

duration longer — duration shorter

### pword-forming


### clitic group


### integrating


following Raffelsiefen 1999

## Type of prosodic integration

duration longer — unclear — duration shorter

### pword-forming


### clitic group


### integrating


following Raffelsiefen 1999

## Type of prosodic integration

duration longer — unclear — duration shorter

### pword-forming


### clitic group


### integrating


following Raffelsiefen 1999

## Type of prosodic integration

duration longer — unclear — duration shorter

### pword-forming


### clitic group


### integrating


following Raffelsiefen 1999

## Type of prosodic integration

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

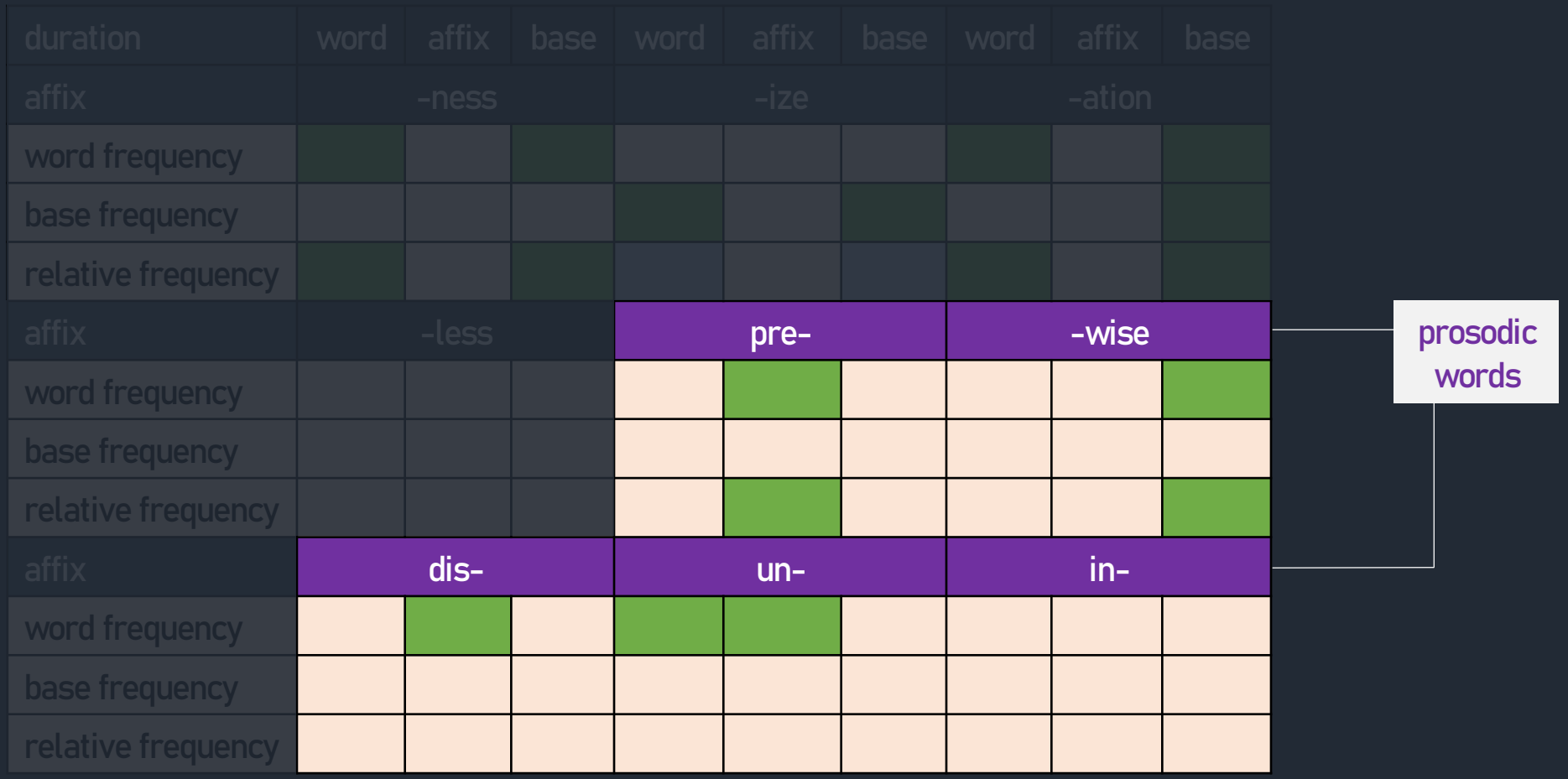
p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

- the type of affix? ×
- the affix length? ×
- the segmentation? ×
- prosodic structure?

## Type of prosodic integration




p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

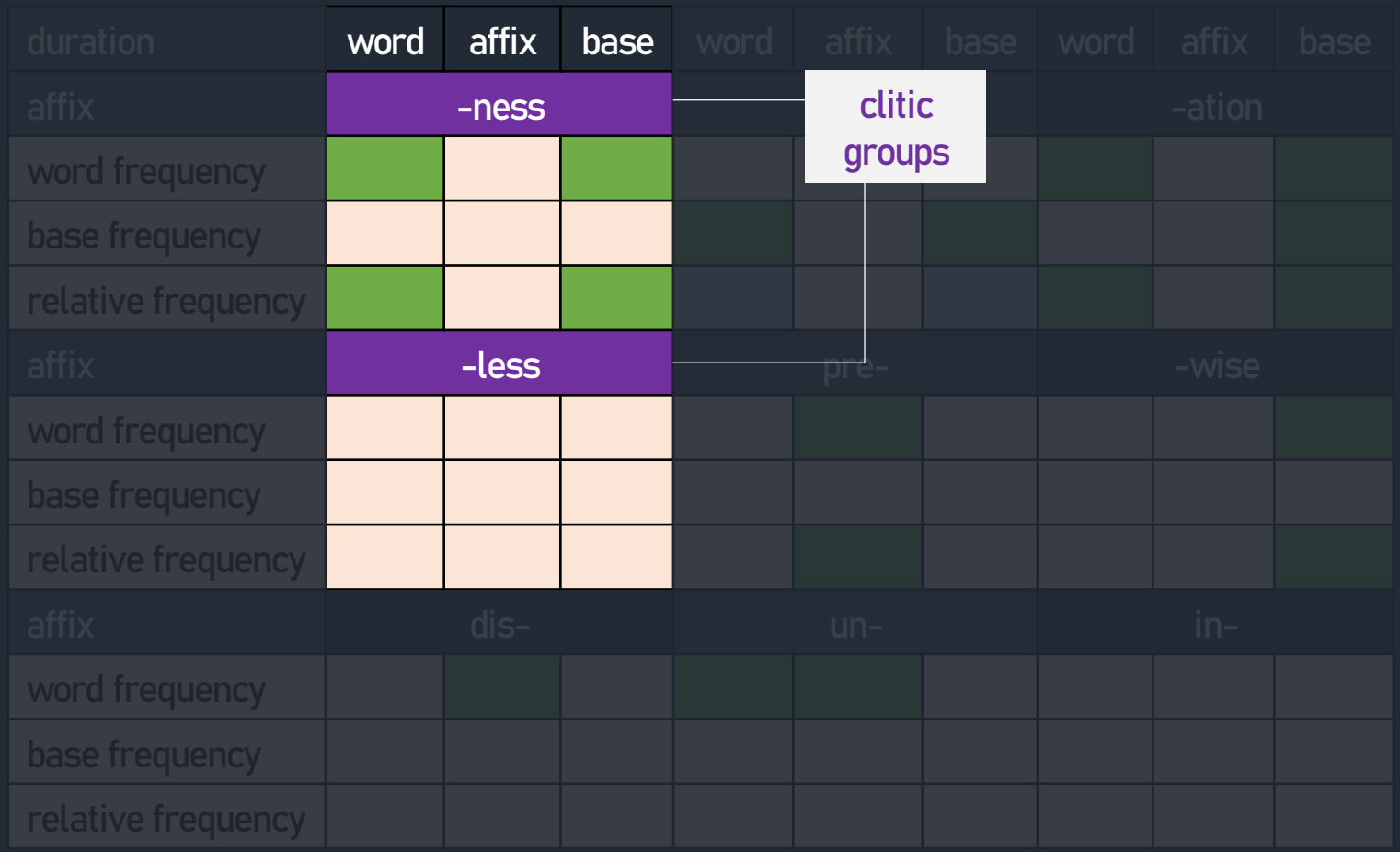
the type of affix? ✗

the affix length? ✗

the segmentation? ✗

prosodic structure?

## Type of prosodic integration




p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

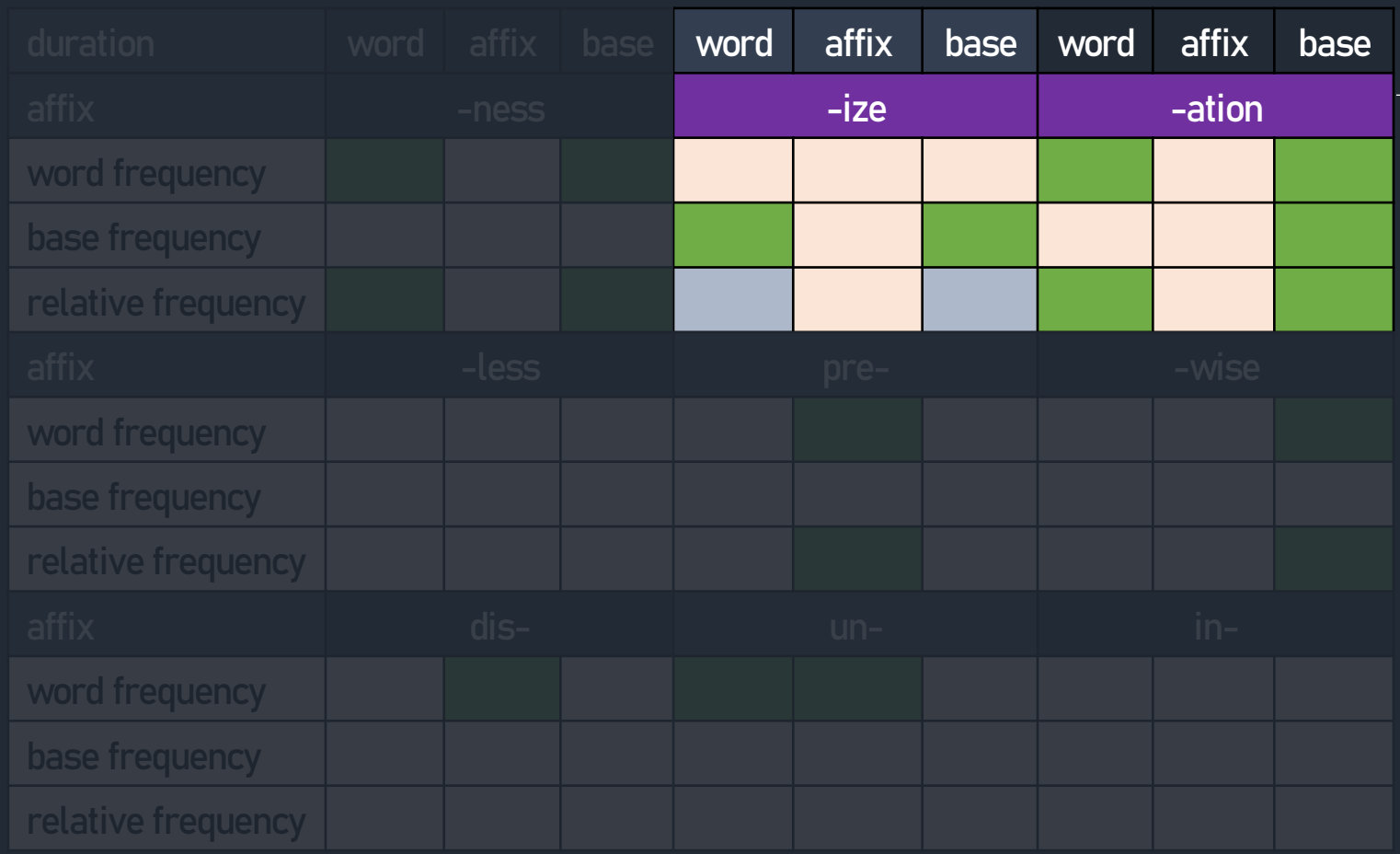
the type of affix? ✗

the affix length? ✗

the segmentation? ✗

prosodic structure?

## Type of prosodic integration




p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

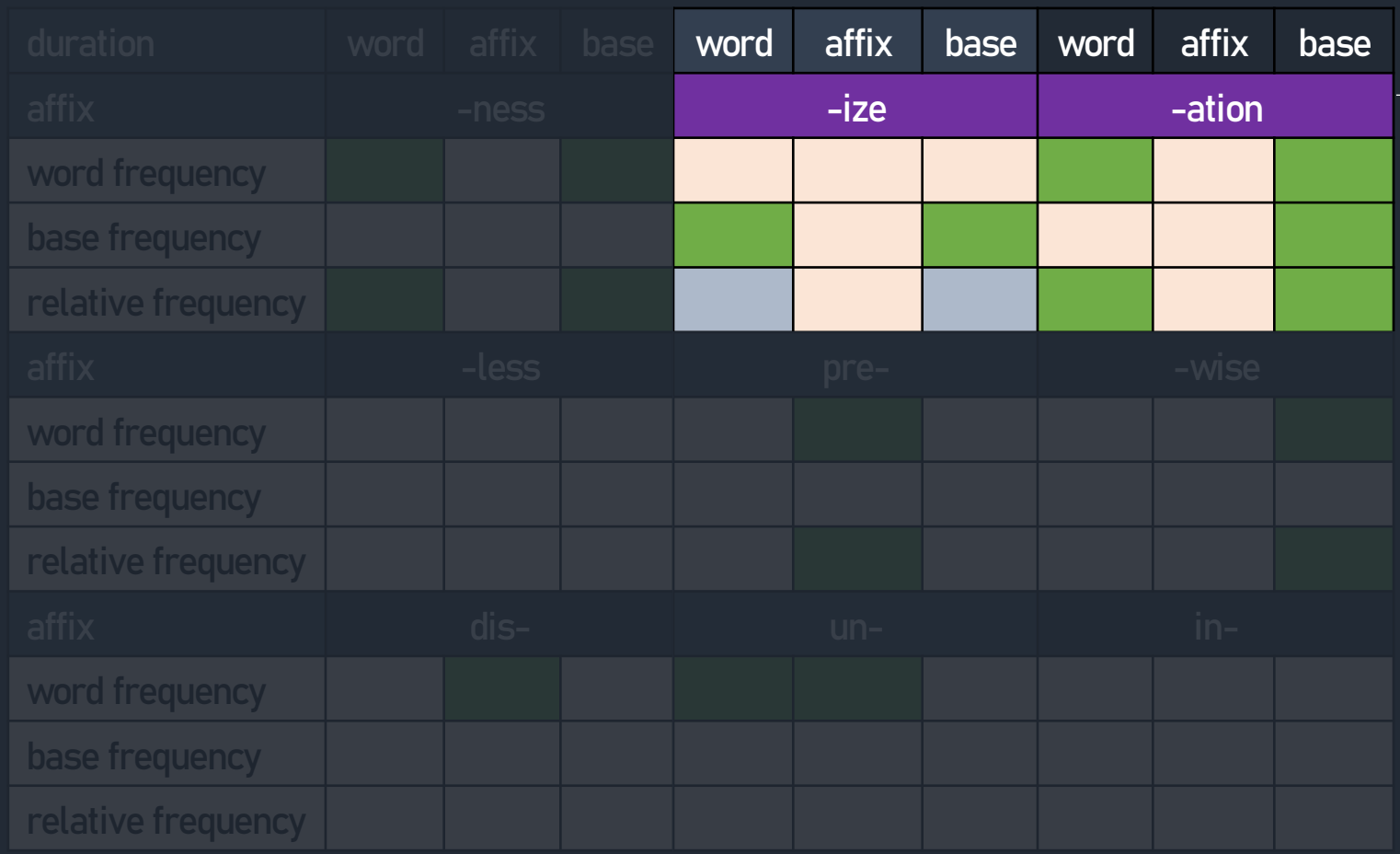
the type of affix? ✗

the affix length? ✗

the segmentation? ✗

prosodic structure?

## Type of prosodic integration




p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

- the type of affix? ✗
- the affix length? ✗
- the segmentation? ✗
- prosodic structure? ✗

## Type of prosodic integration

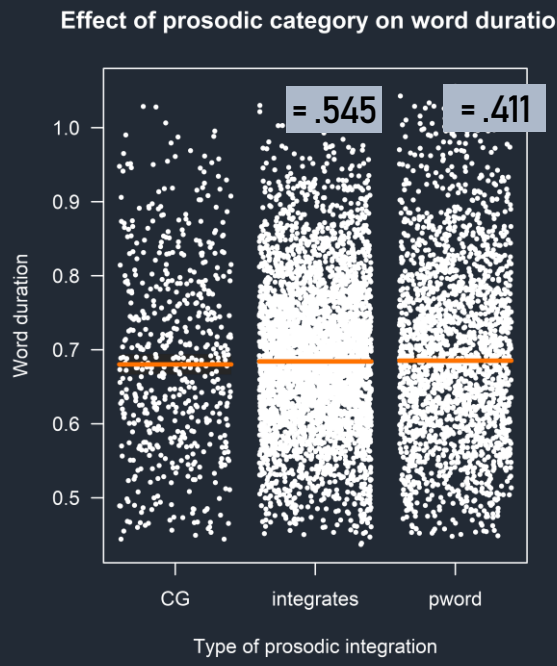
Meta-model including all affixes

- Additional predictor: type of prosodic integration
- Additional covariate: number of timing slots
- N = 7441

## Type of prosodic integration

Meta-model including all affixes

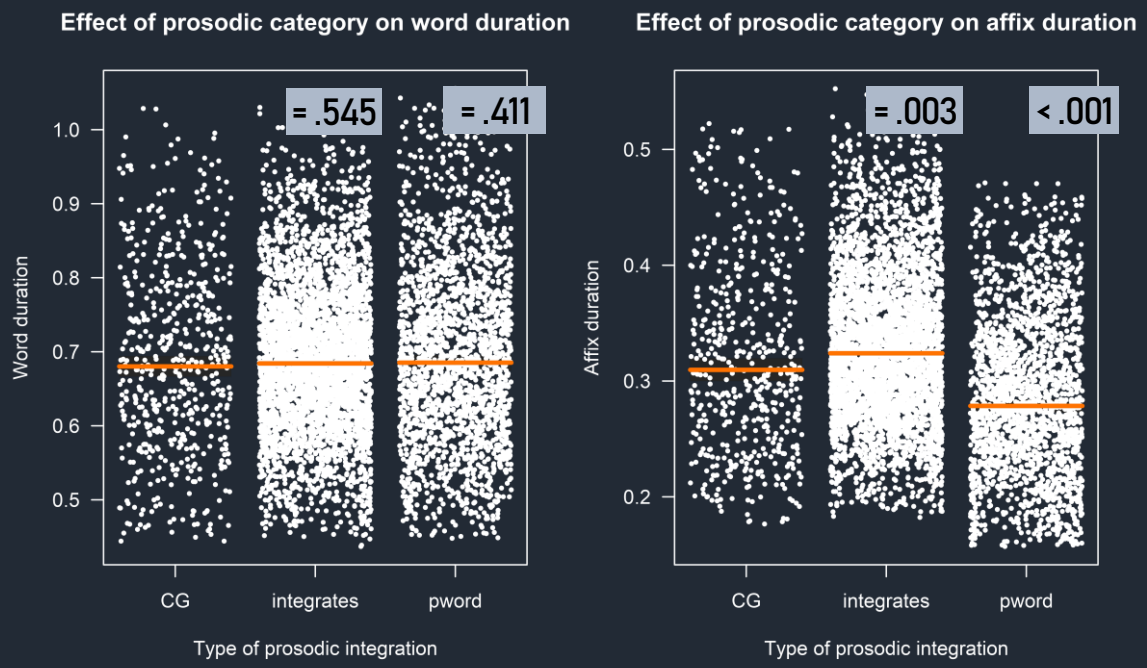
- Additional predictor: type of prosodic integration
- Additional covariate: number of timing slots
- N = 7441



## Type of prosodic integration

### Meta-model including all affixes

- Additional predictor: type of prosodic integration
- Additional covariate: number of timing slots
- N = 7441



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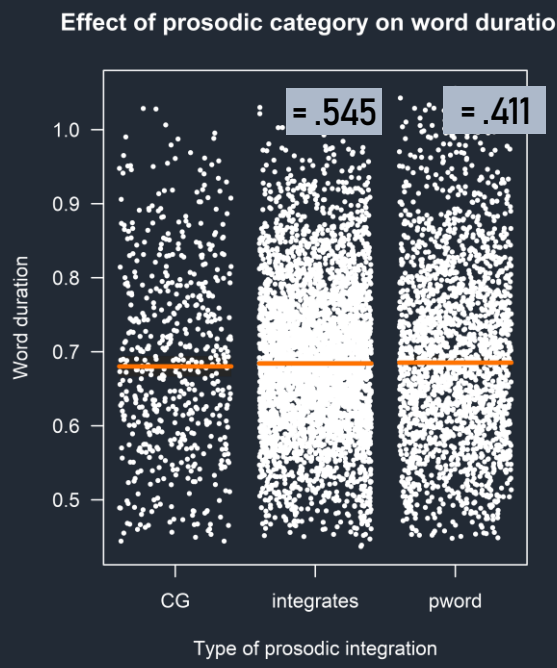
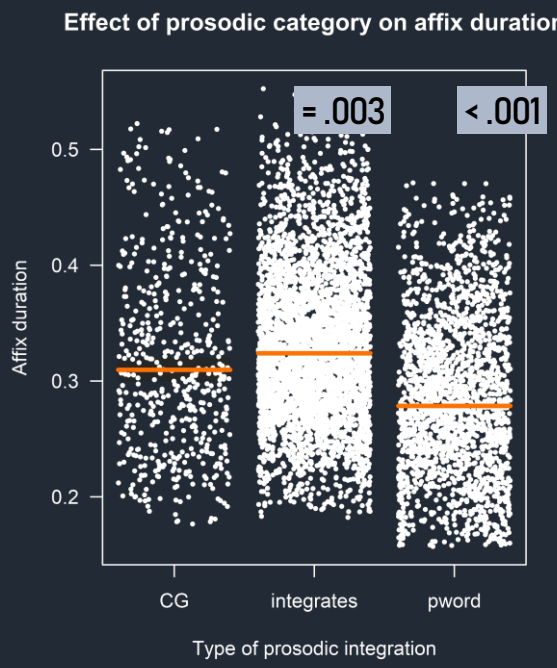
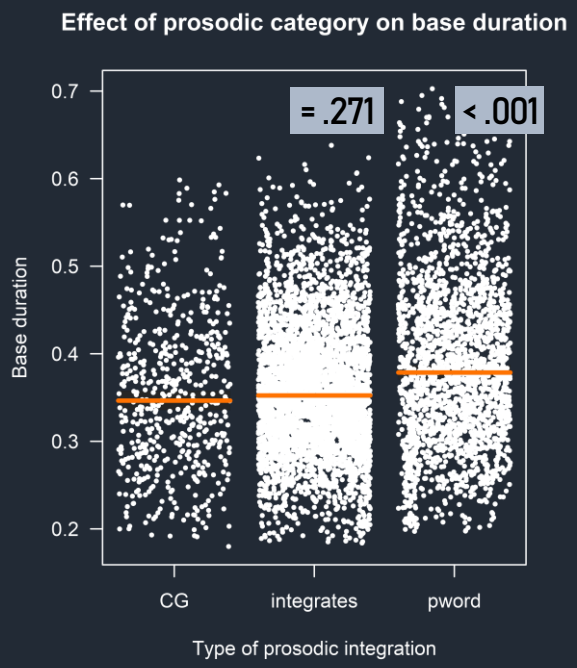
- Additional predictor: type of prosodic integration
- Additional covariate: number of timing slots
- N = 7441



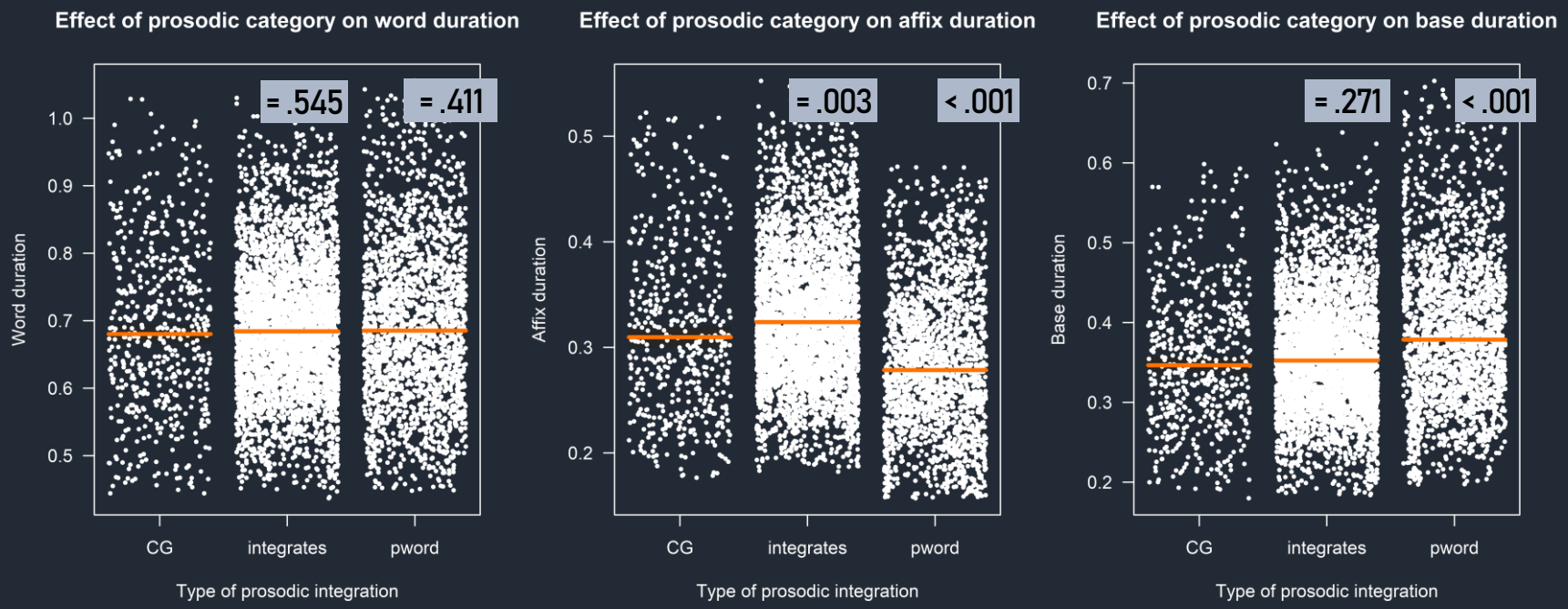



## Type of prosodic integration

### Meta-model including all affixes

- Additional predictor: type of prosodic integration
- Additional covariate: number of timing slots
- N = 7441
- This does not support the predictions of pword integration.



## Summary

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In sum, we have a mixed picture.

- Some results are in line with Caselli et al. 2016:
  - All three frequency measures can independently predict duration.
  - This is evidence for both types of storage in the mental lexicon, as well as for segmentability effects.

## Summary

In sum, we have a mixed picture.

- Some results are in line with Caselli et al. 2016:
  - All three frequency measures can independently predict duration.
  - This is evidence for both types of storage in the mental lexicon, as well as for segmentability effects.

- However, there are also null effects, which require explanation.
  - So far, we cannot attribute the differences to:
    - the domain of durational measurement (word, affix, base)
    - the type of affix (prefix, suffix)
    - the prosodic category (pword, clitic group, integrating).

## Discussion

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Our findings imply that …

- morphological structure can at least partly influence the phonetic output.

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- morphological structure can at least partly influence the phonetic output.
- models that prohibit post-lexical access of morphological information (e.g. Kiparsky 1982, Levelt et al. 1999, Bermúdez-Otero 2018) might have to be revised.



Kiparsky 1982, Levelt et al. 1999, Bermúdez-Otero 2018

## Discussion

Our findings imply that …

- morphological structure can at least partly influence the phonetic output.
- models that prohibit post-lexical access of morphological information (e.g. Kiparsky 1982, Levelt et al. 1999, Bermúdez-Otero 2018) might have to be revised.
- we need to investigate further factors that might cause frequency effects to surface or to not surface.



Kiparsky 1982, Levelt et al. 1999, Bermúdez-Otero 2018

Thank you for listening.

Thank you for listening.


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Thank you for listening.


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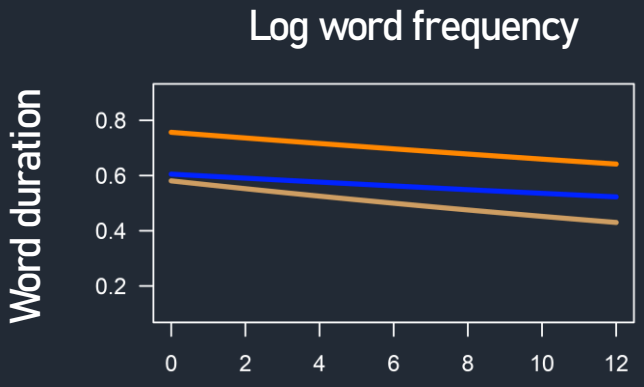
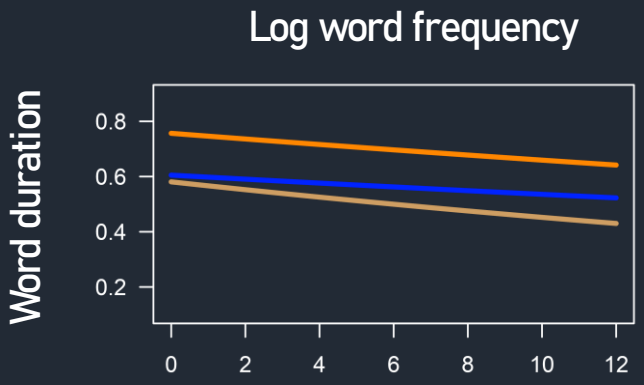
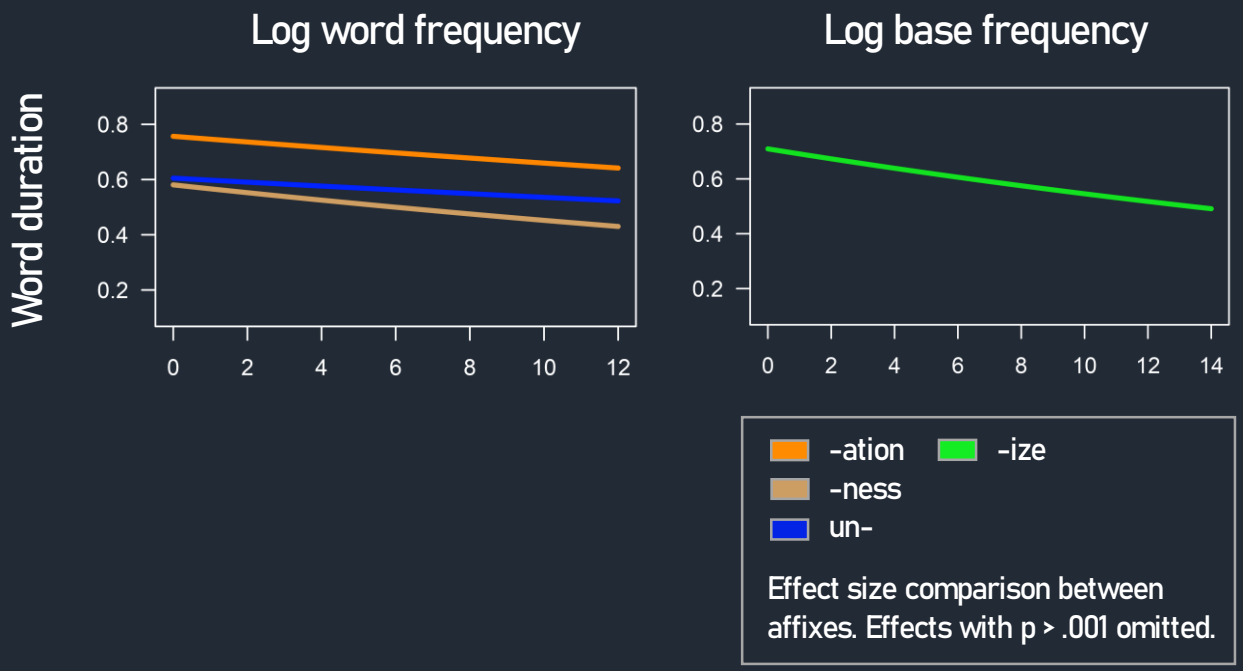
# Appendix

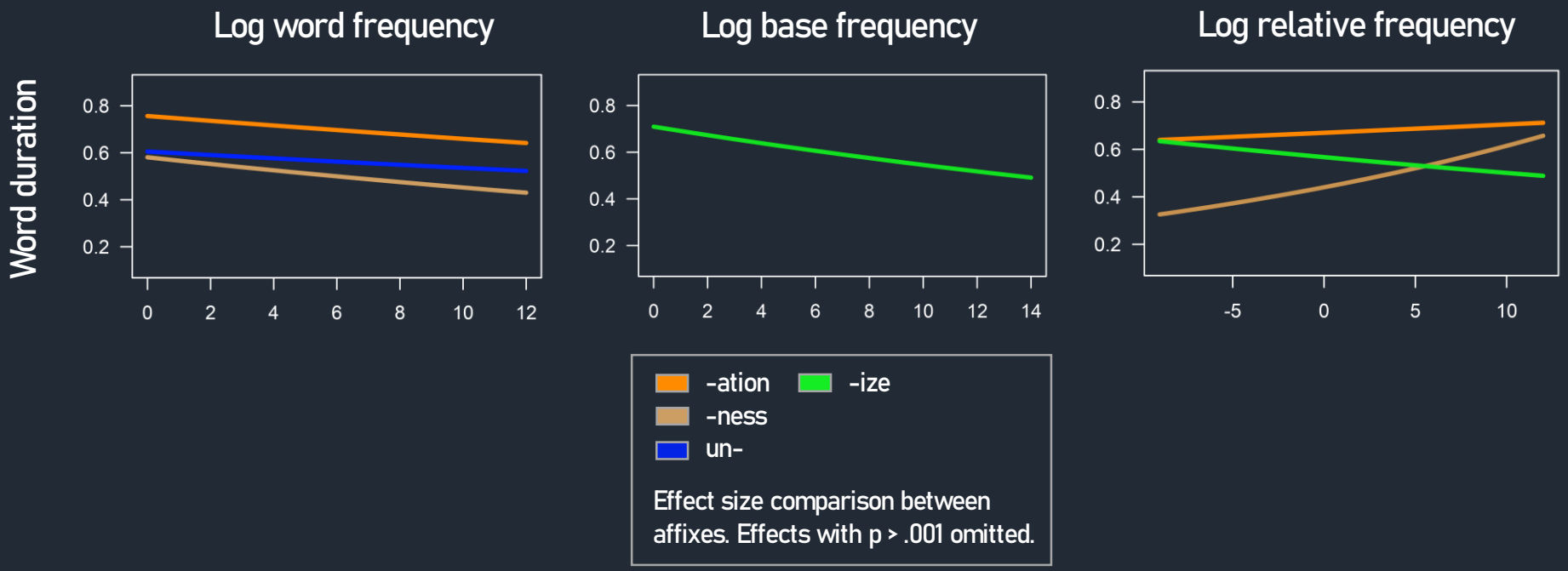

Log word frequency
Word duration
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12

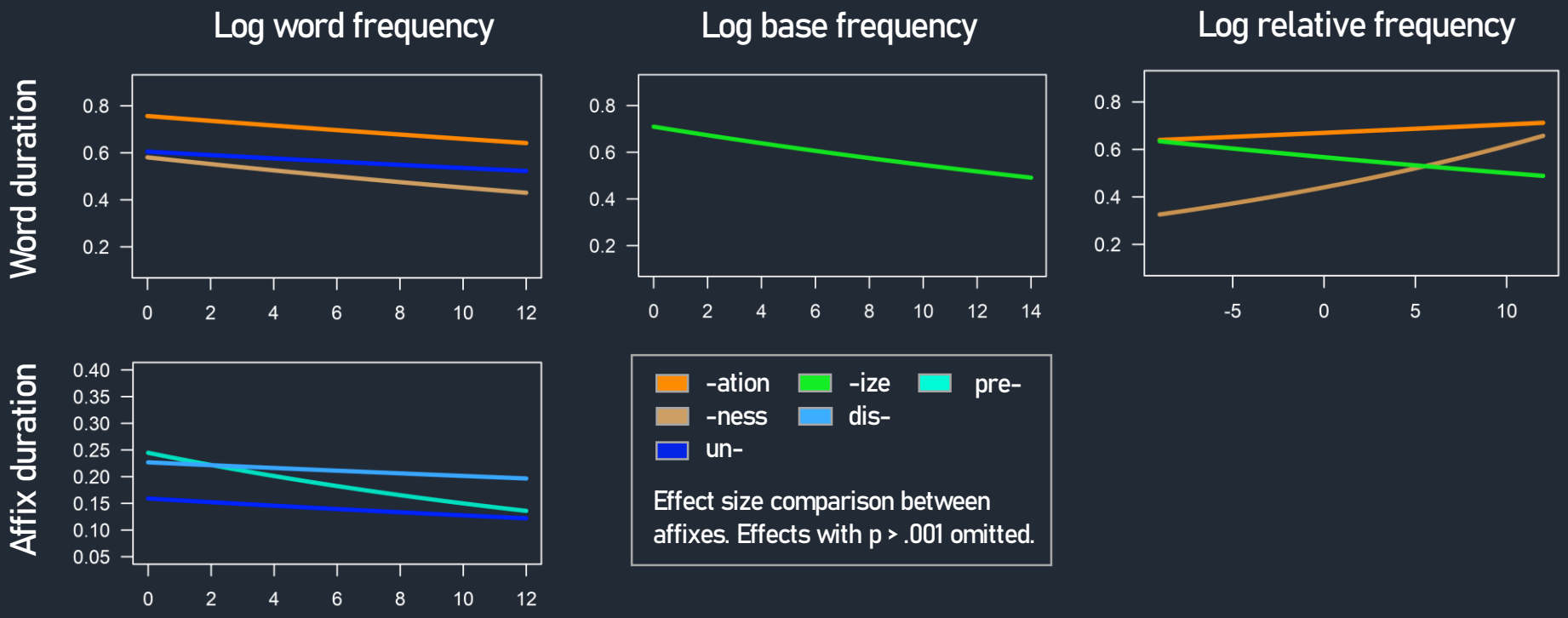


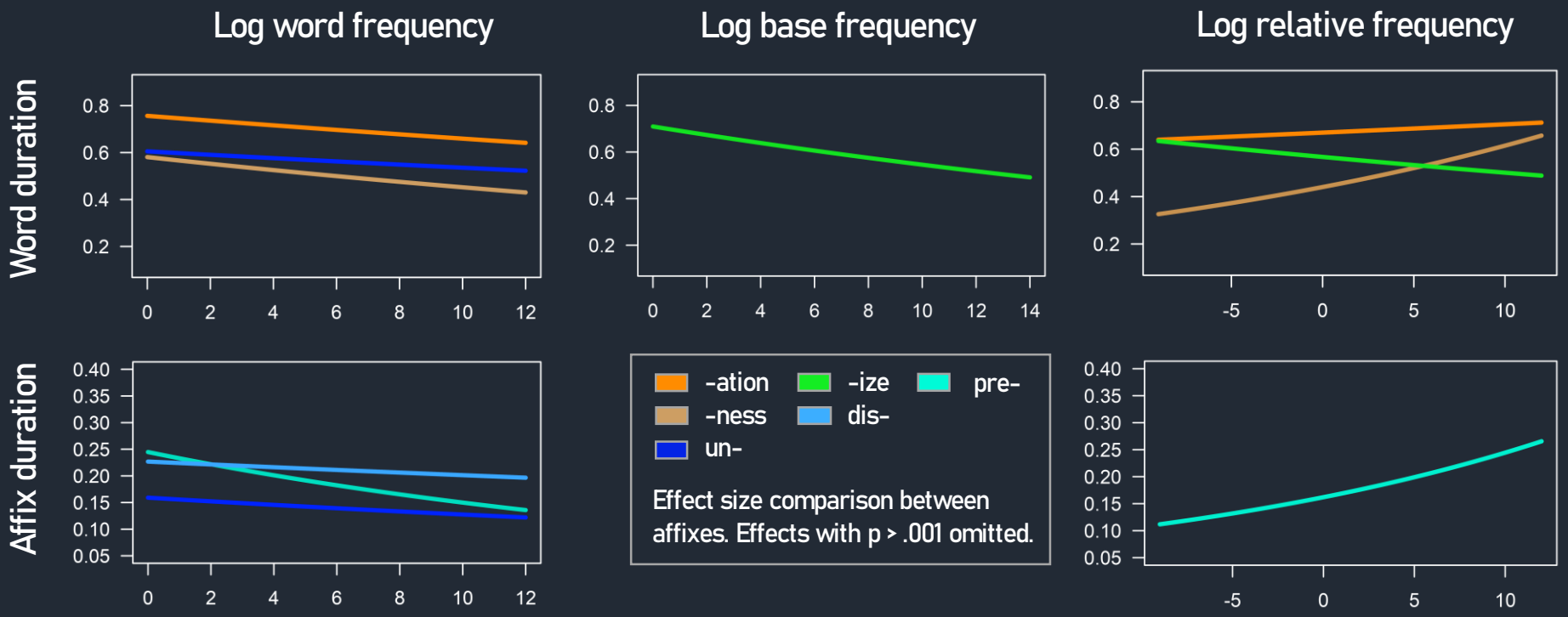

-ation
-ness
un-

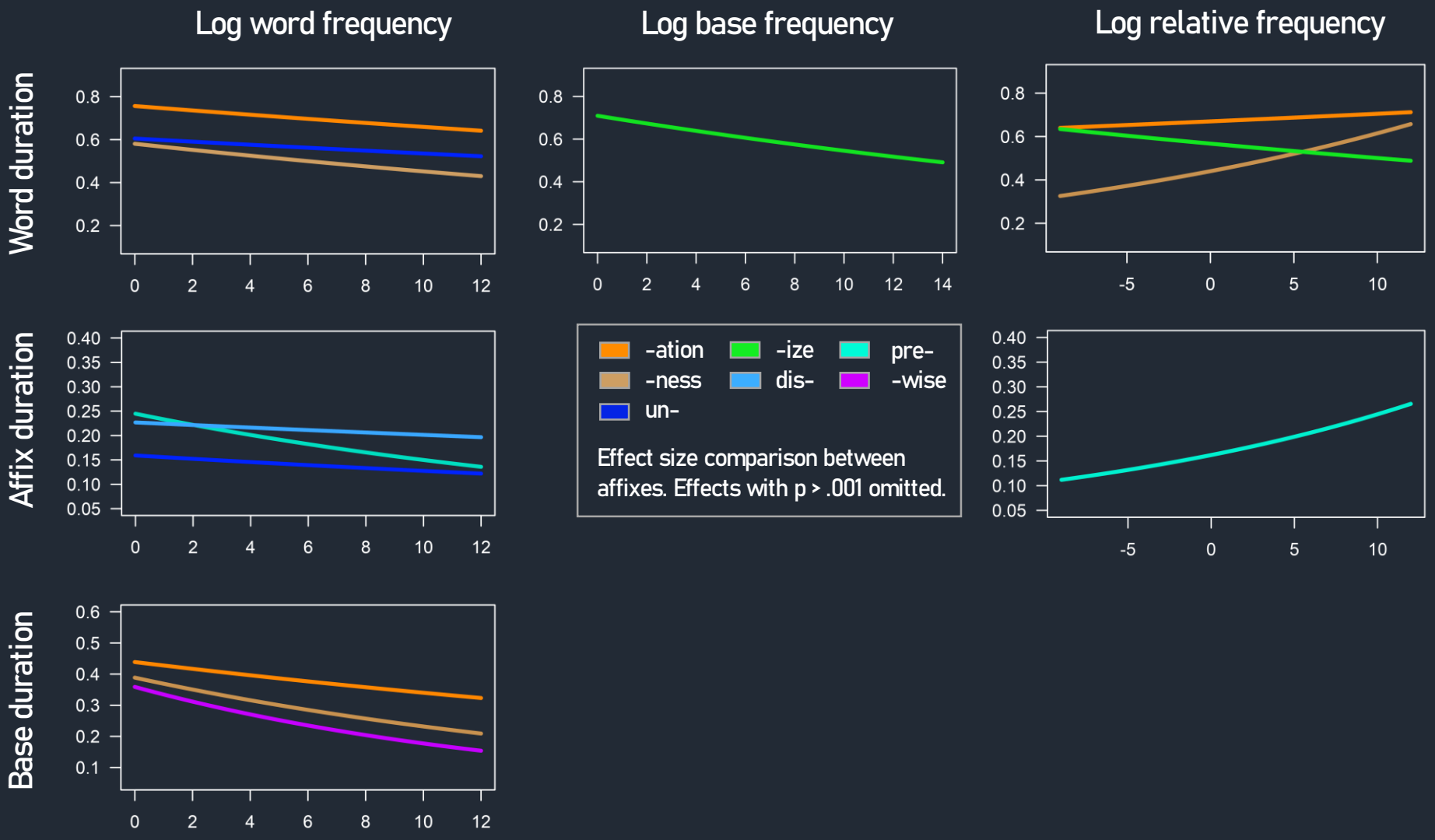
Effect size comparison between affixes. Effects with p > .001 omitted.


Log word frequency
Log base frequency
Word duration
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
14
-ation
-ness
un-
-ize
Effect size comparison between affixes. Effects with p > .001 omitted.


Log word frequency
Log base frequency
Log relative frequency
Word duration
0.8
0.6
0.4
0.2
0 2 4 6 8 10 12
0 2 4 6 8 10 12 14
-5 0 5 10
-ation
-ness
un-
-ize
Effect size comparison between affixes. Effects with p > .001 omitted.


Log word frequency
Log base frequency
Log relative frequency
Word duration
Affix duration
0.8
0.6
0.4
0.2
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0 2 4 6 8 10 12
0 2 4 6 8 10 12 14
-5 0 5 10
-ation
-ness
un-
-ize
dis-
pre-
Effect size comparison between affixes. Effects with p > .001 omitted.


Log word frequency
Log base frequency
Log relative frequency
Word duration
Affix duration
-ation
-ness
un-
-ize
dis-
pre-
Effect size comparison between affixes. Effects with p > .001 omitted.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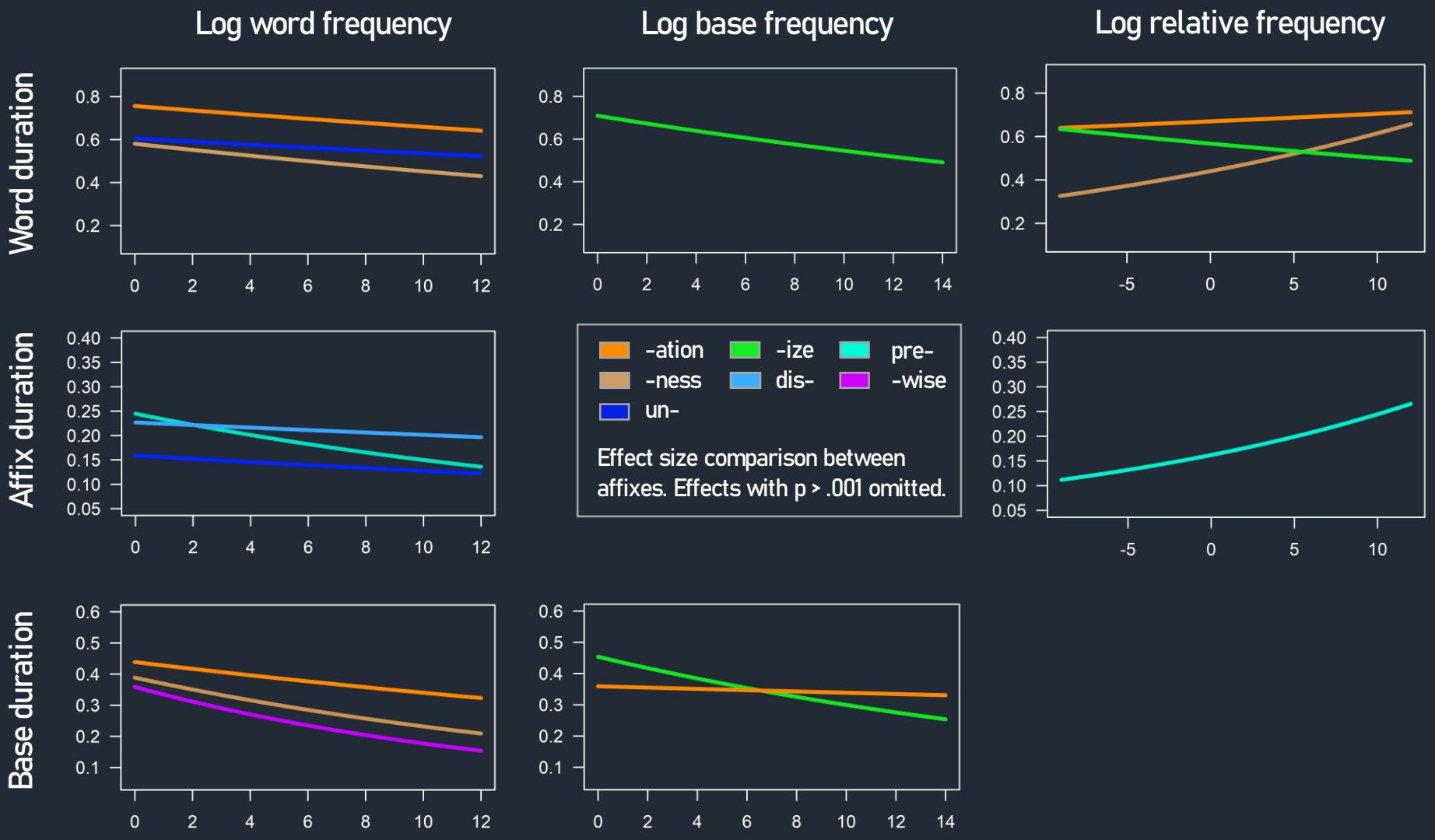
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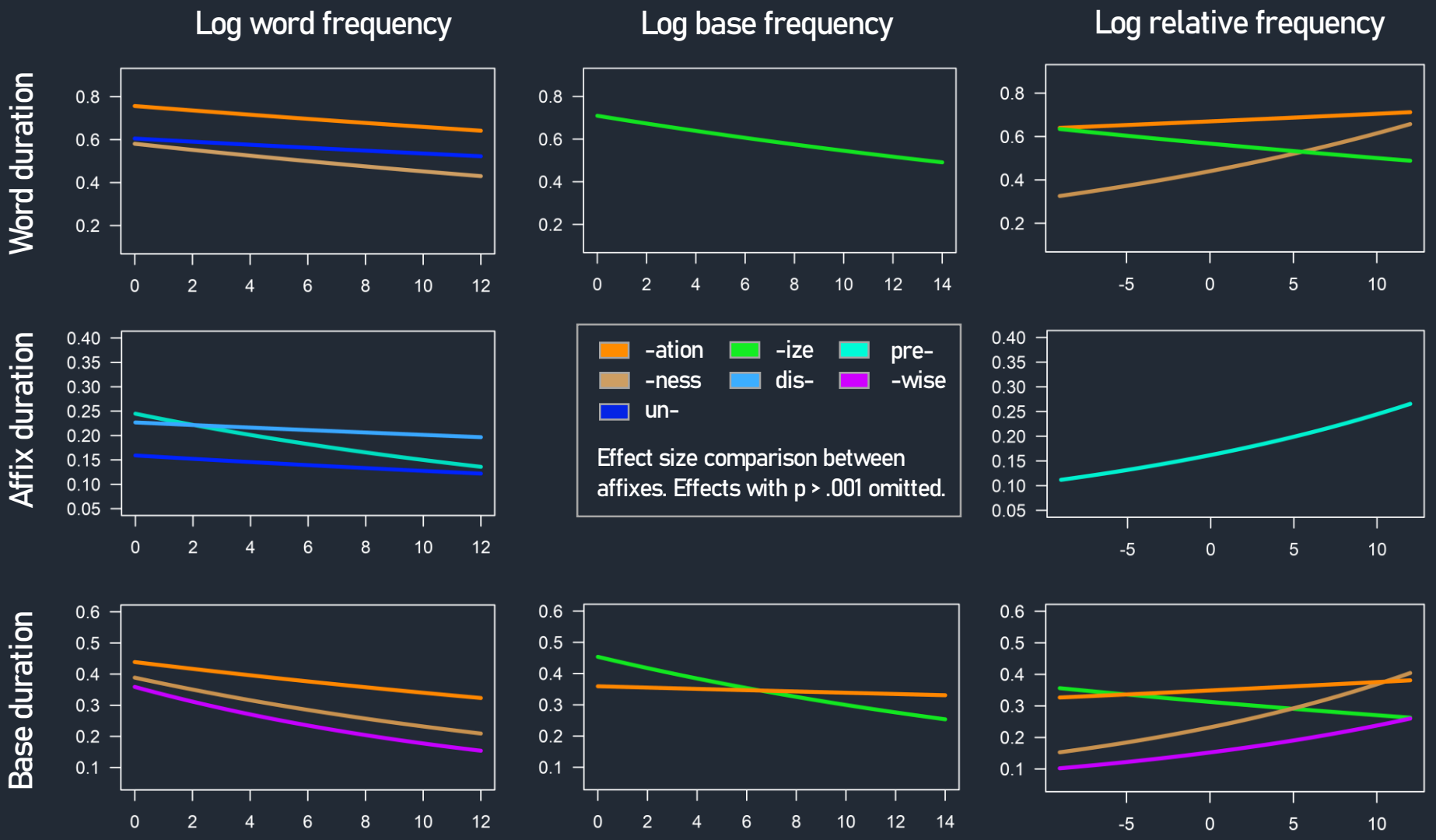
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# Informativity

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

- the type of affix? ✗
- the affix length? ✗
- the segmentation? ✗
- prosodic structure? ✗
- affix informativity?

## Informativity

Measured in two ways:

## Informativity

Measured in two ways:

Semantic information load score

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Semantic information load score

5-point Likert scales coded for:

- clearness of semantic meaning
- type of base: free vs. bound root
- semantic transparency
- productivity

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Affix-specific semantic segmentability hierarchy

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Affix-specific semantic segmentability hierarchy

H: The higher the semantic information load, the longer the duration.

## Informativity

Measured in two ways:

Semantic information load score

Conditional affix probability $C_{aff}$

5-point Likert scales coded for:

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- productivity

Affix-specific semantic segmentability hierarchy

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- productivity

Affix-specific semantic segmentability hierarchy

H: The higher the semantic information load, the longer the duration.

### Conditional affix probability $C_{aff}$

Affix probability given preceding word:

| SUFFIX EXAMPLE | | PREFIX EXAMPLE | | |
|---|---|---|---|---|
| A | B | A | B | C |
| *random* | *ize* | *her* | *pre-* | *...* |

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$$C_{aff} = \frac{Freq(AB)}{Freq(A)}$$

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# Informativity: Semantic information load score

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

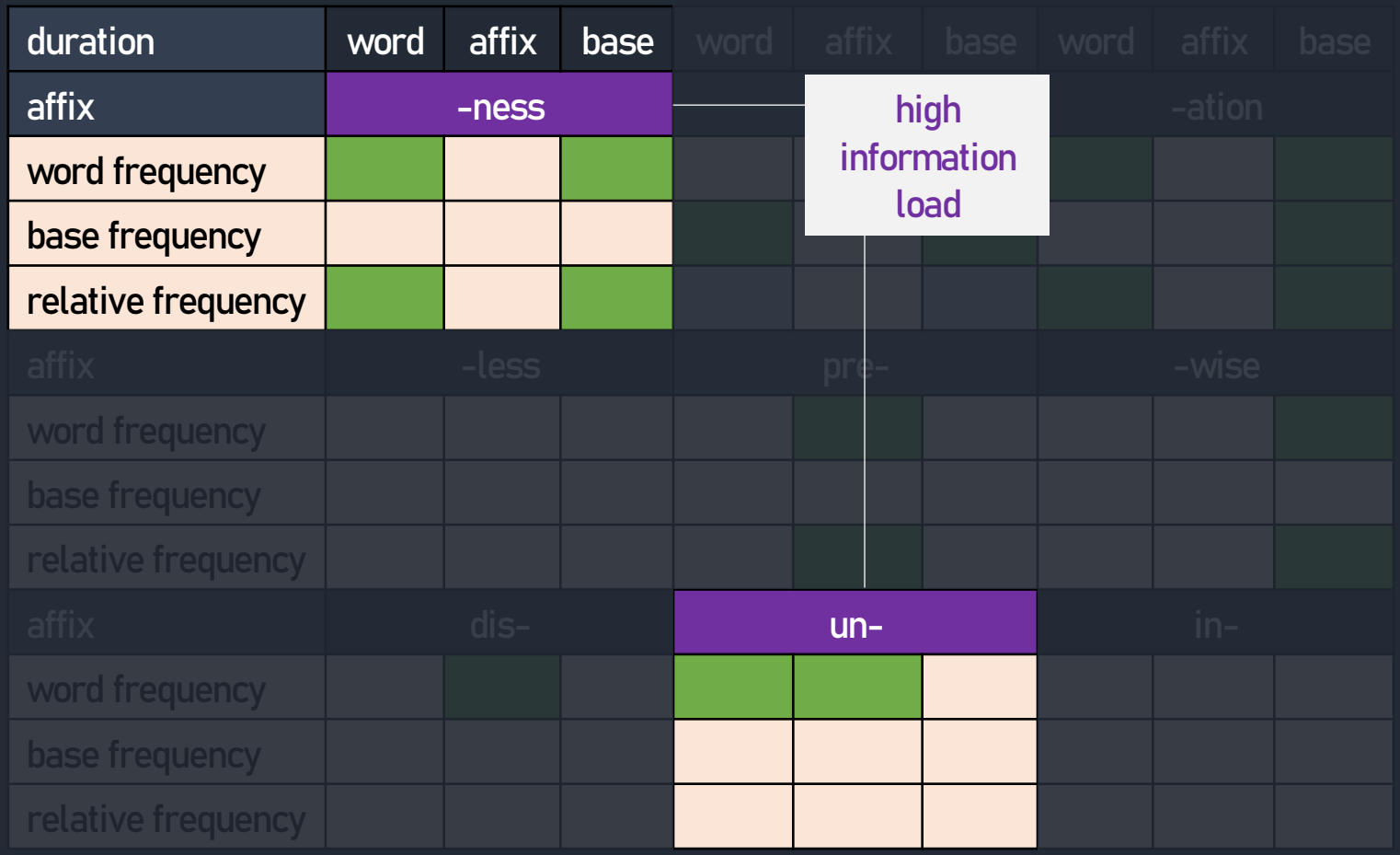
p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

- the type of affix? ×
- the affix length? ×
- the segmentation? ×
- prosodic structure? ×
- affix informativity?

# Informativity: Semantic information load score




p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

- the type of affix? ✗
- the affix length? ✗
- the segmentation? ✗
- prosodic structure? ✗
- affix informativity?

# Informativity: Semantic information load score

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

low information load

p < .001 expected direction

p < .001 unexpected direction

Are the differences related to ...

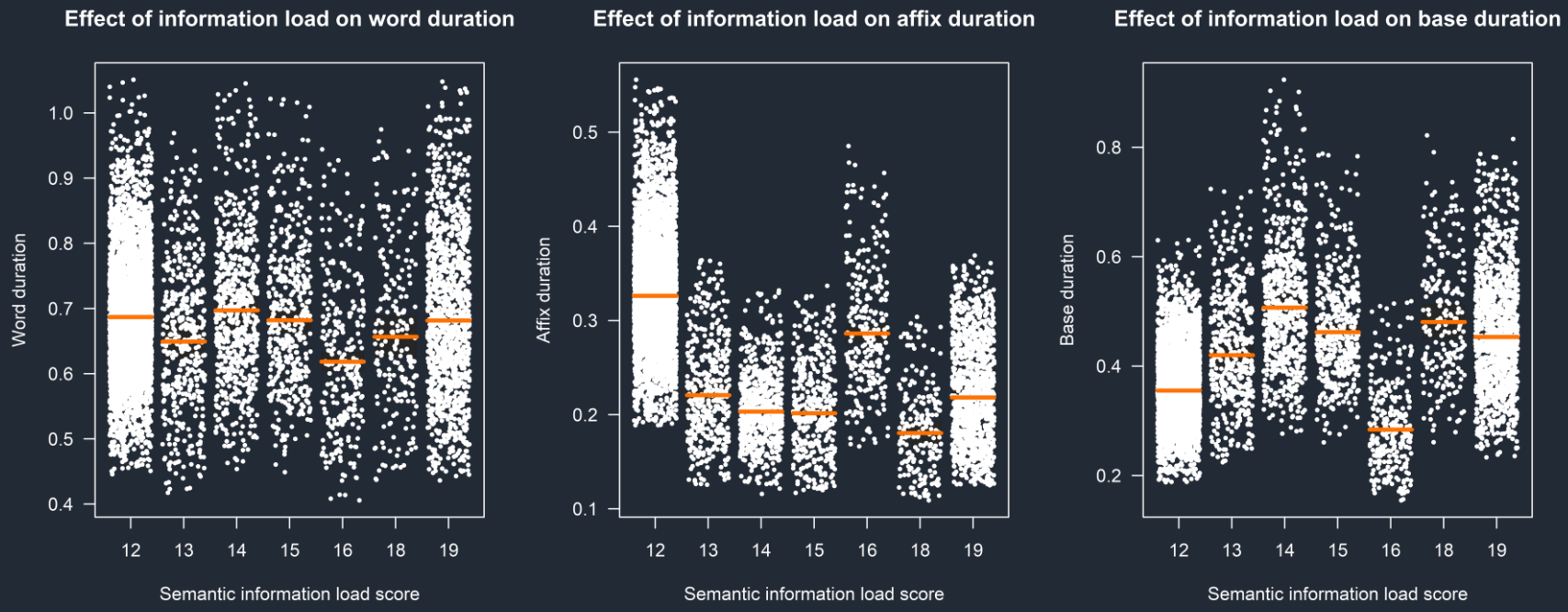
- the type of affix? ✗
- the affix length? ✗
- the segmentation? ✗
- prosodic structure? ✗
- affix informativity?

# Informativity: Semantic information load score

## Meta-model including all affixes

- Additional predictor: semantic information load score
- Additional covariate: number of timing slots
- N = 7441

- This does not support the predictions of semantic information load.



# Informativity: Conditional affix probability

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | -less | | | pre- | | | -wise | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |
| affix | dis- | | | un- | | | in- | | |
| word frequency | | | | | | | | | |
| base frequency | | | | | | | | | |
| relative frequency | | | | | | | | | |

p < .001 expected direction

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- affix informativity?

# Informativity: Conditional affix probability

| duration | word | affix | base | word | affix | base | word | affix | base |
|---|---|---|---|---|---|---|---|---|---|
| affix | -ness | | | -ize | | | -ation | | |
| affix probability | | | | | | | | | |

| affix | -less | | | pre- | | | -wise | | |
|---|---|---|---|---|---|---|---|---|---|
| affix probability | | | | | | | | | |

| affix | dis- | | | un- | | | in- | | |
|---|---|---|---|---|---|---|---|---|---|
| affix probability | | | | | | | | | |

p < .001 negative correlation

Are the differences related to ...

- the type of affix? ×
- the affix length? ×
- the segmentation? ×
- prosodic structure? ×
- affix informativity? ×

## Results: Updated

In sum, we have a mixed picture.

- Some results are in line with Caselli et al. 2016:
  - All three frequency measures can independently predict duration.
  - This is evidence for both types of storage in the mental lexicon, as well as for segmentability effects.

- However, there are also null effects, which require explanation.
  - So far, we cannot attribute the differences to:
    - the domain of durational measurement (word, affix, base)
    - the type of affix (prefix, suffix)
    - the prosodic category (pword, clitic group, integrating)

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    - the type of affix (prefix, suffix)
    - the prosodic category (pword, clitic group, integrating)
    - the informativity of the affix (information load, probability).

# Prosodic word diagnostics

# Prosodic word diagnostics

## The prosodic hierarchy

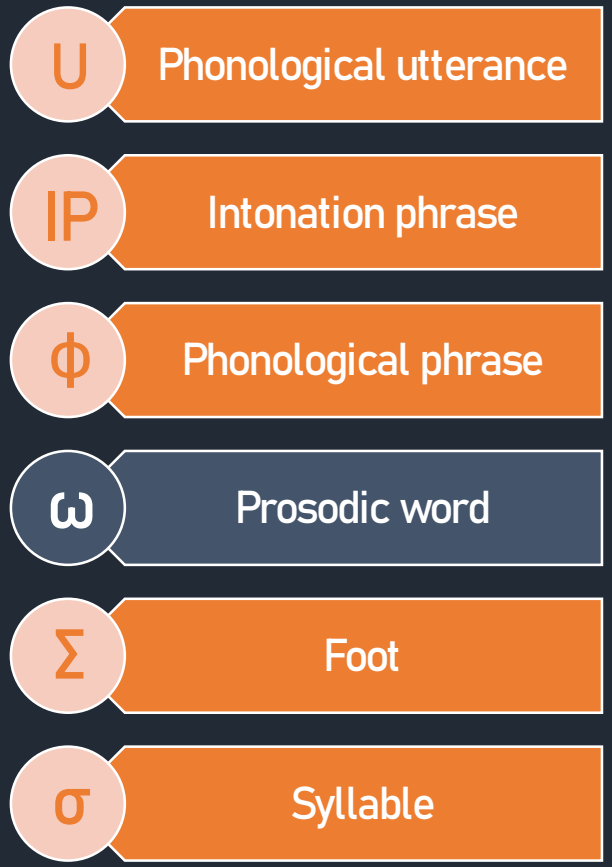
- U — Phonological utterance
- IP — Intonation phrase
- ϕ — Phonological phrase
- ω — Prosodic word
- Σ — Foot
- σ — Syllable



Hildebrandt 2015, Raffelsiefen 1999, 2007

# Prosodic word diagnostics

## The prosodic hierarchy




## Some pword-diagnostics

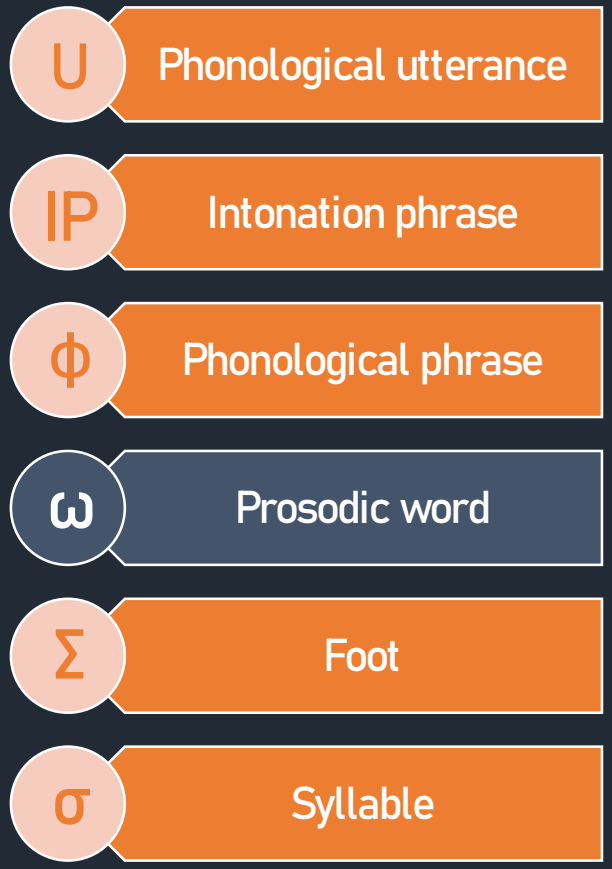
- onset or coda conditions, LOI-violations
- ambisyllabicity
- stress and relative prominence
- trisyllabic laxing, vowel reduction
- minimal word requirements
- compositionality, type of base



Hildebrandt 2015, Raffelsiefen 1999, 2007

# Prosodic word diagnostics

## The prosodic hierarchy

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## Morpho-prosodic alignment

- A morpheme cannot include multiple pwords, but a pword can include multiple morphemes.



Hildebrandt 2015, Raffelsiefen 1999, 2007