A Psycho/neurolinguistic Approach to Cross-linguistic Morphological Processing

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Morphological representation in monolinguals

Study 1

How is morphology represented in lexicon?

“The psycholinguistic literature is generally **lacking detailed descriptions of how affixed words are represented and processed**”

(Marelli and Baroni 2015, p.6)

How is morphology represented in lexicon?

Morphological priming:

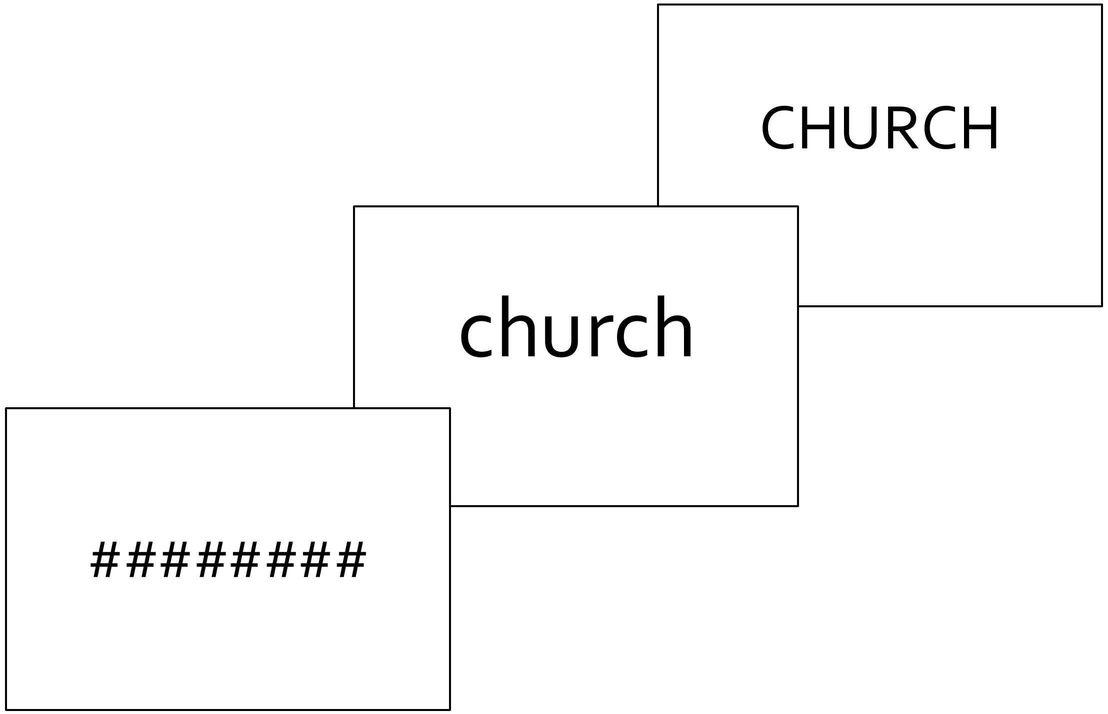
########

church

CHURCH

How is morphology represented in lexicon?

Morphological priming:



“Is this a word?”
Yes (“z”) / No (“m”)

How is morphology represented in lexicon?

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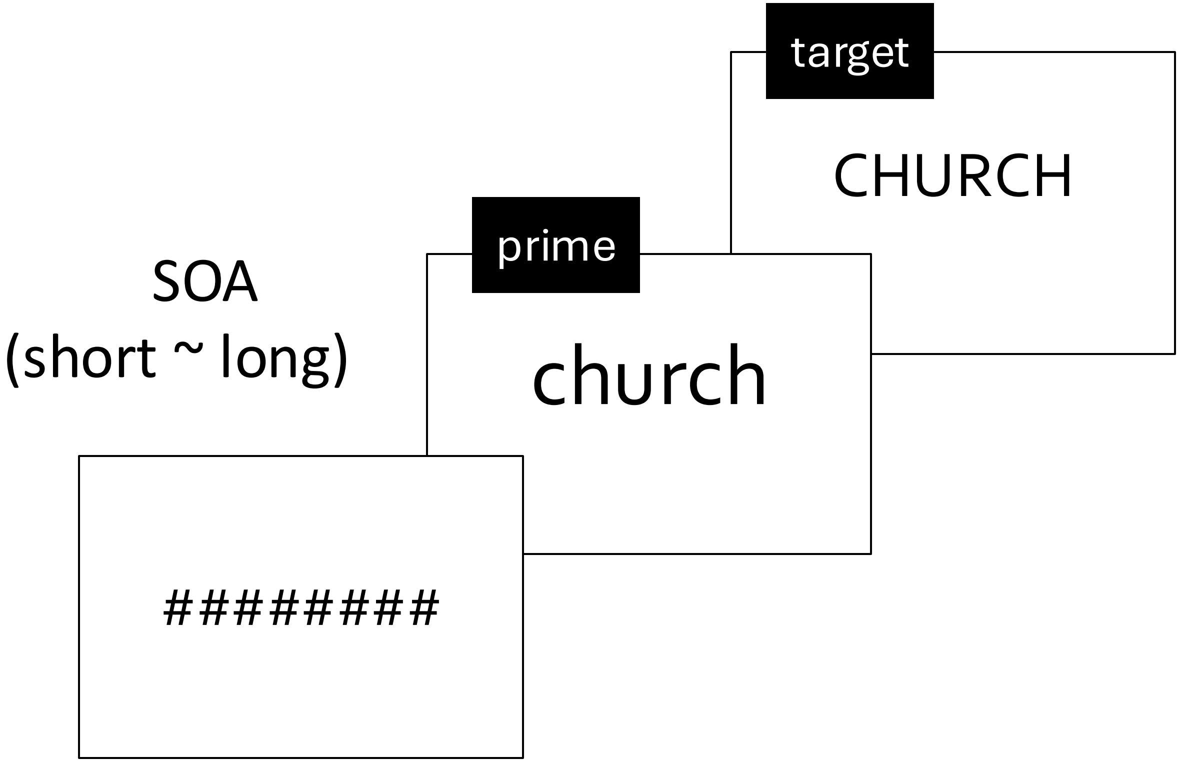

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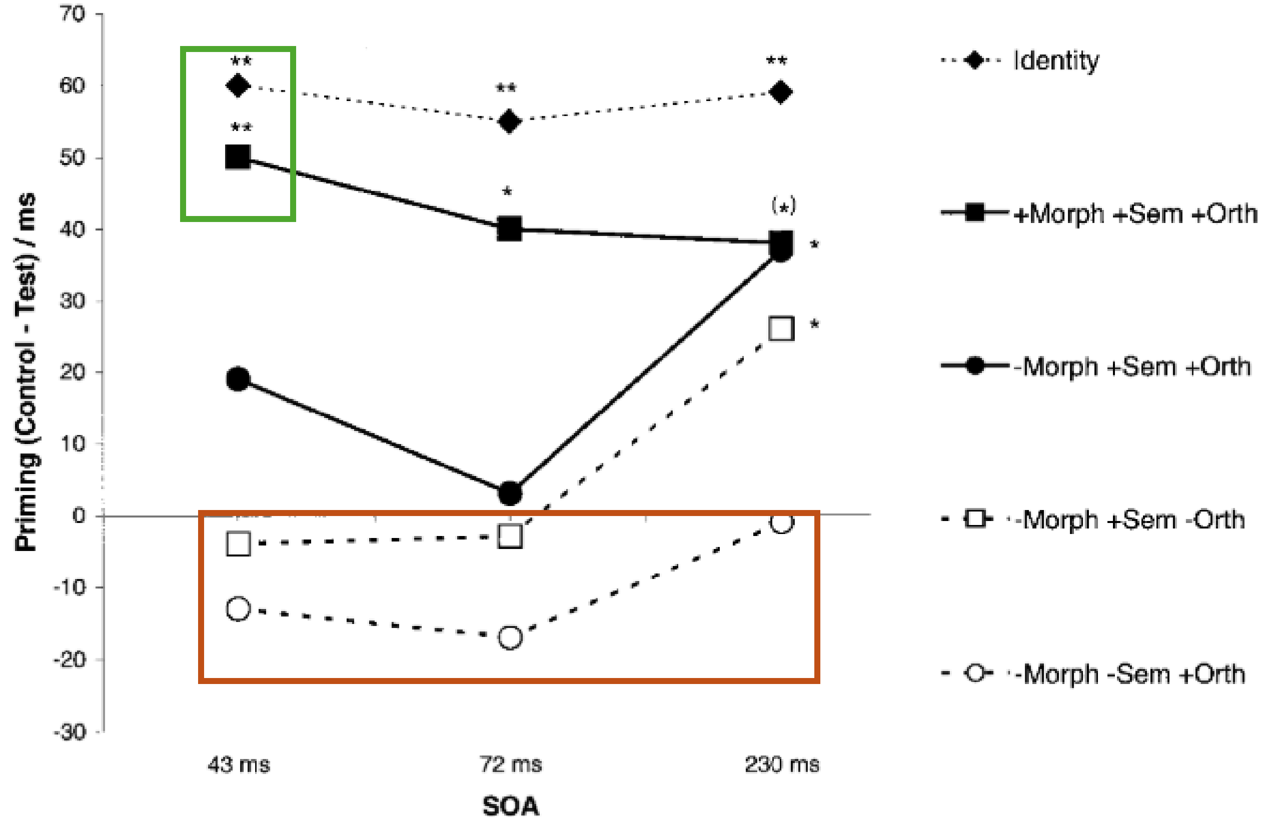


prime	target
church	CHURCH
adapter	ADAPTABLE
screech	SCREAM
cello	VIOLIN
typhoid	TYPHOON

church-CHURCH

adapter-ADAPTABLE "root priming"

screech-SCREAM

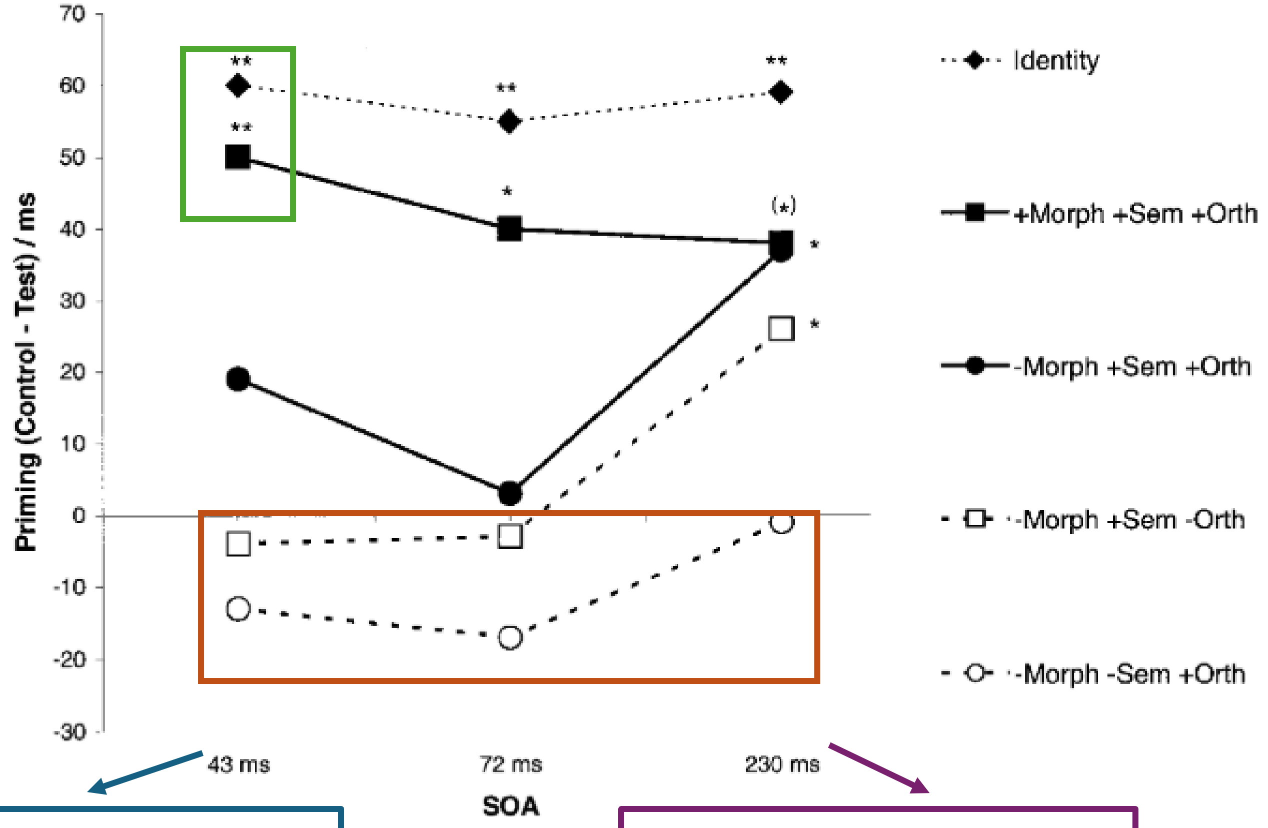
cello-VIOLIN

typhoid-TYPHOON

Rastle et al. (2000)

How is morphology represented in lexicon?

Morphological priming:



prime	target
church	CHURCH
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church-CHURCH

adapter-ADAPTABLE

"root priming"

screech-SCREAM

cello-VIOLIN

typhoid-TYPHOON

Short: participants are unaware of primes

Long: primes are fully visible

Rastle et al. (2000)

How is morphology represented in lexicon?

walk -ed

walk — root priming (o)

turn -ed — affix priming (?)

Piece-based theory

- Affixes are represented as **objects in memory** as roots are

➢ Affixes are expected to show **priming effects**

Affix stripping theory

- Affixes are **stripped off** upon word recognition; they are not objects in memory

➢ No priming effects are expected

How is morphology represented in lexicon?

walk -ed

walk — root priming (o)

turn -ed — affix priming (?)

Piece-based theory	Affix stripping theory
• Affixes are represented as **objects in memory** as roots are ➢ Affixes are expected to show **priming effects**	• Affixes are **stripped off** upon word recognition; they are not objects in memory ➢ No priming effects are expected

Not conclusive

Exp 1. Study goal

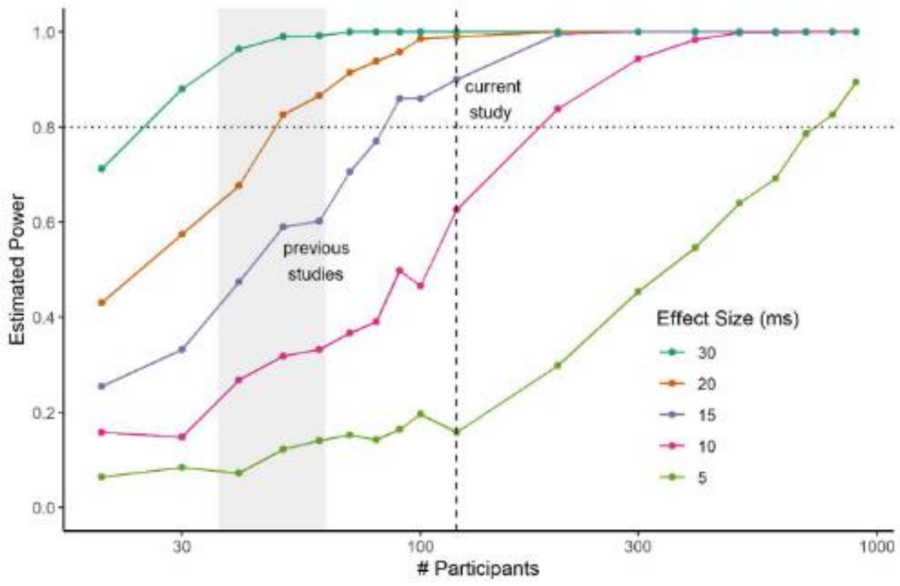
- Does an inflectional affix (English past tense morpheme –*ed*) show priming effects?

Methods

Participants

- 244 English speakers (111 males, age: 32.21 (16-64)) living in the United Kingdom (209 participants) or United States (35 participants)
  - Short SOA (34 ms): 121 participants
  - Long SOA (150 ms): 123 participants

Power analysis of inflectional suffix priming effects at short SOA



Methods

Stimuli

- 150 sets (target=word) and 150 sets (target=nonword) (25 items per condition)

Condition	Prime	Target
+MORPH		
(a) Identity	called	CALLED
(b) Test (suffix overlap)	turned	CALLED
(c) Control	turns	CALLED
-MORPH (orthographical)		
(a) Identity	travel	TRAVEL
(b) Test (letter overlap)	compel	TRAVEL
(c) Control	commit	TRAVEL

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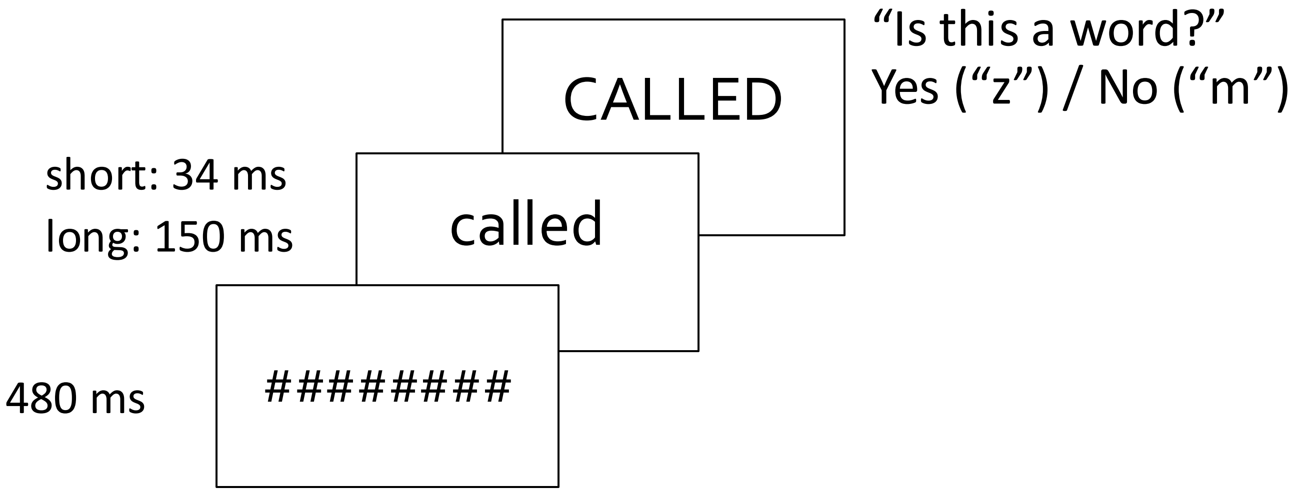
Methods

Procedure



- The experiment was conducted online using Psychopy (version 2020.1.3)
- Data were collected via Prolific

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Methods

Analysis

- Linear regression with **transformed reaction times (RTs)** as a dependent measure and **SOA (short vs long), Condition (Identity, Test, Control), Type (+MORPH vs -MORPH)** and **their interaction**, **prime word length, target word length, prime word frequency and target word frequency** as fixed effects
- Outlier RTs (<200 ms or >2000 ms) were removed (0.8 % of total data)

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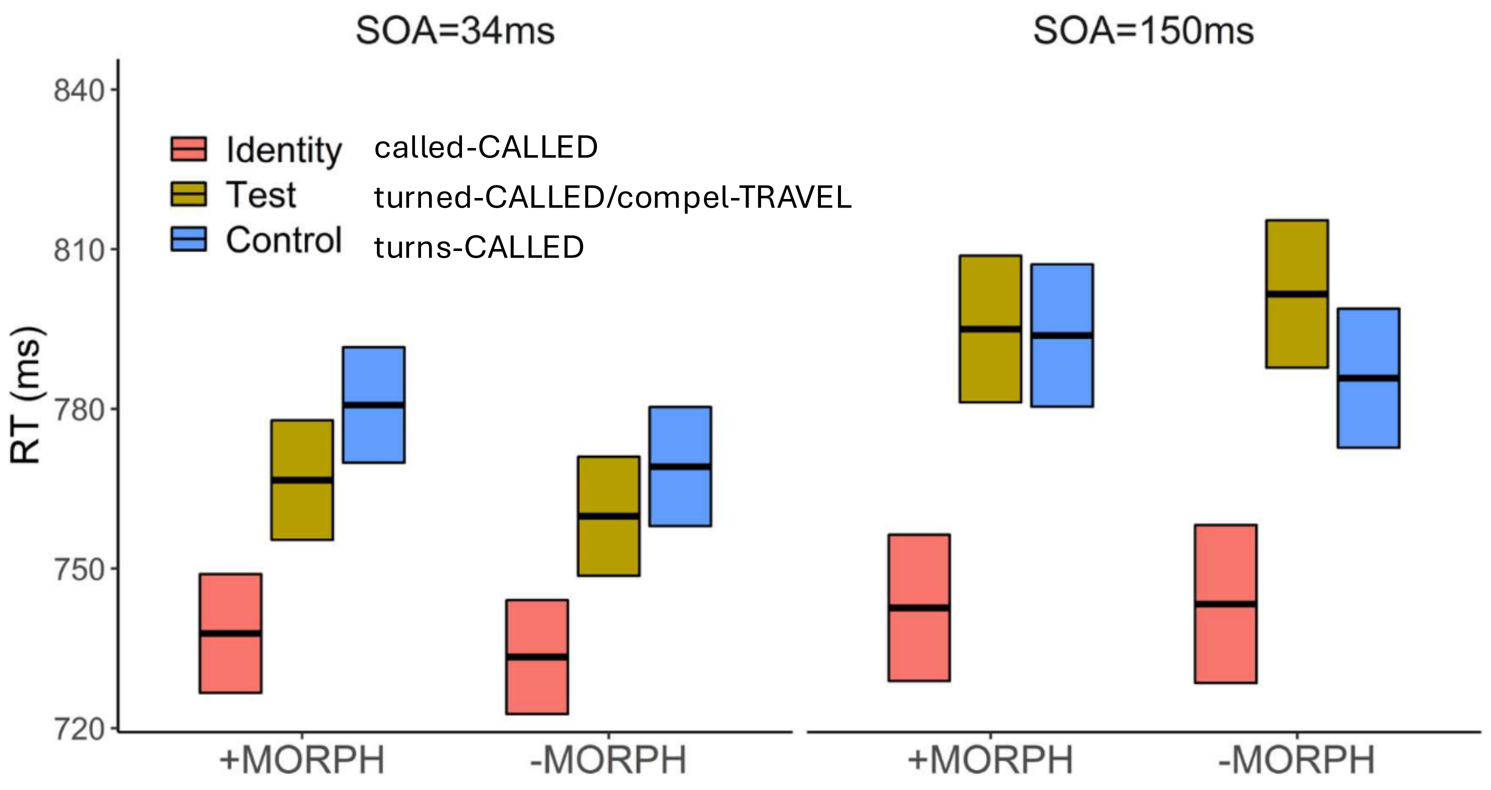
Results



- Robust Identity priming effects (B = 3.37e-5, p < 0.001)
- No statistically significant Test priming effects (B = 5.02e-5, p = 0.303) but interacted with SOA (B = −2.94e-5, p < 0.001)
- ➢ Short SOA: both +MORPH and –MORPH show Test priming
- ➢ Long SOA: -MORPH show inhibitory priming effects

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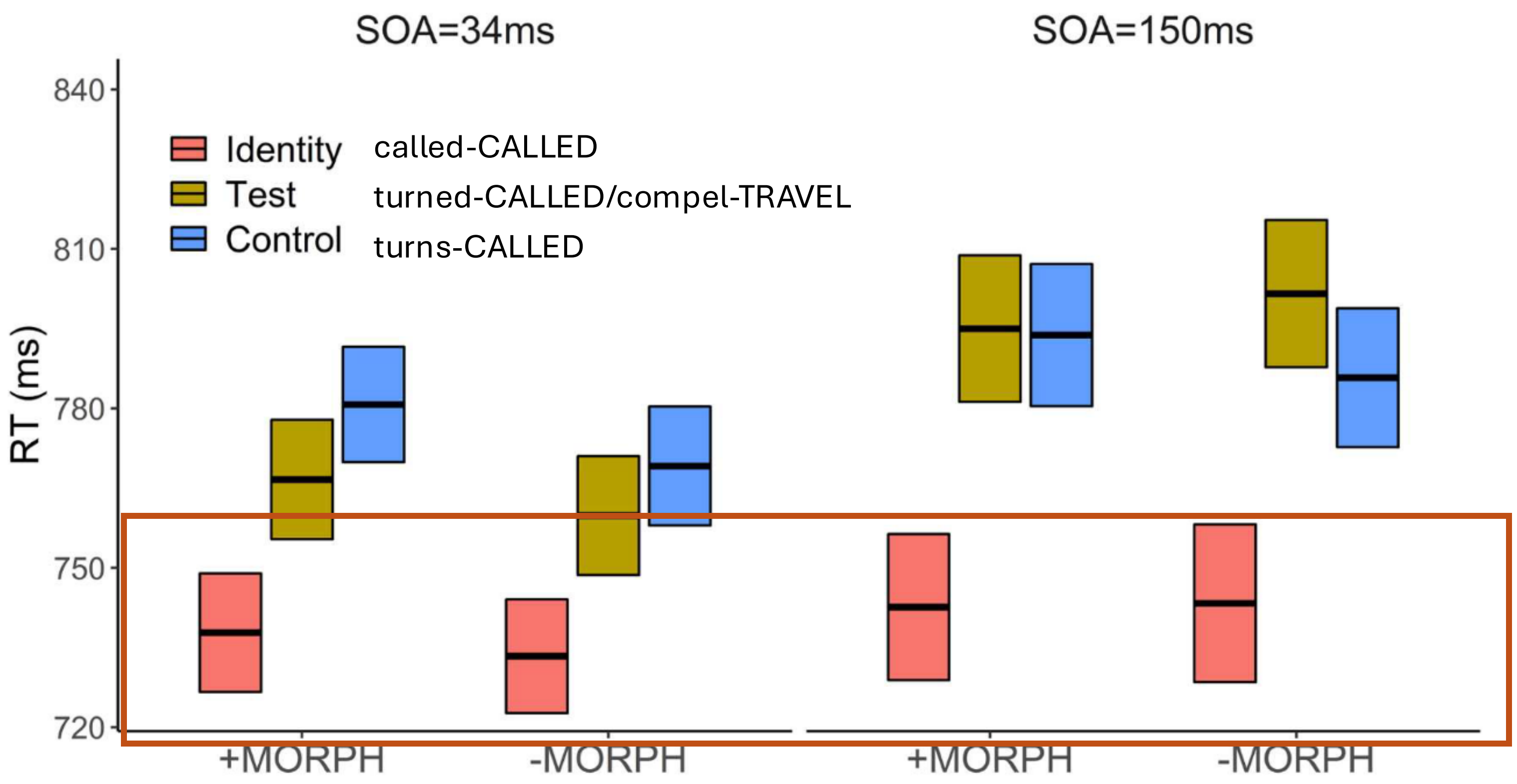

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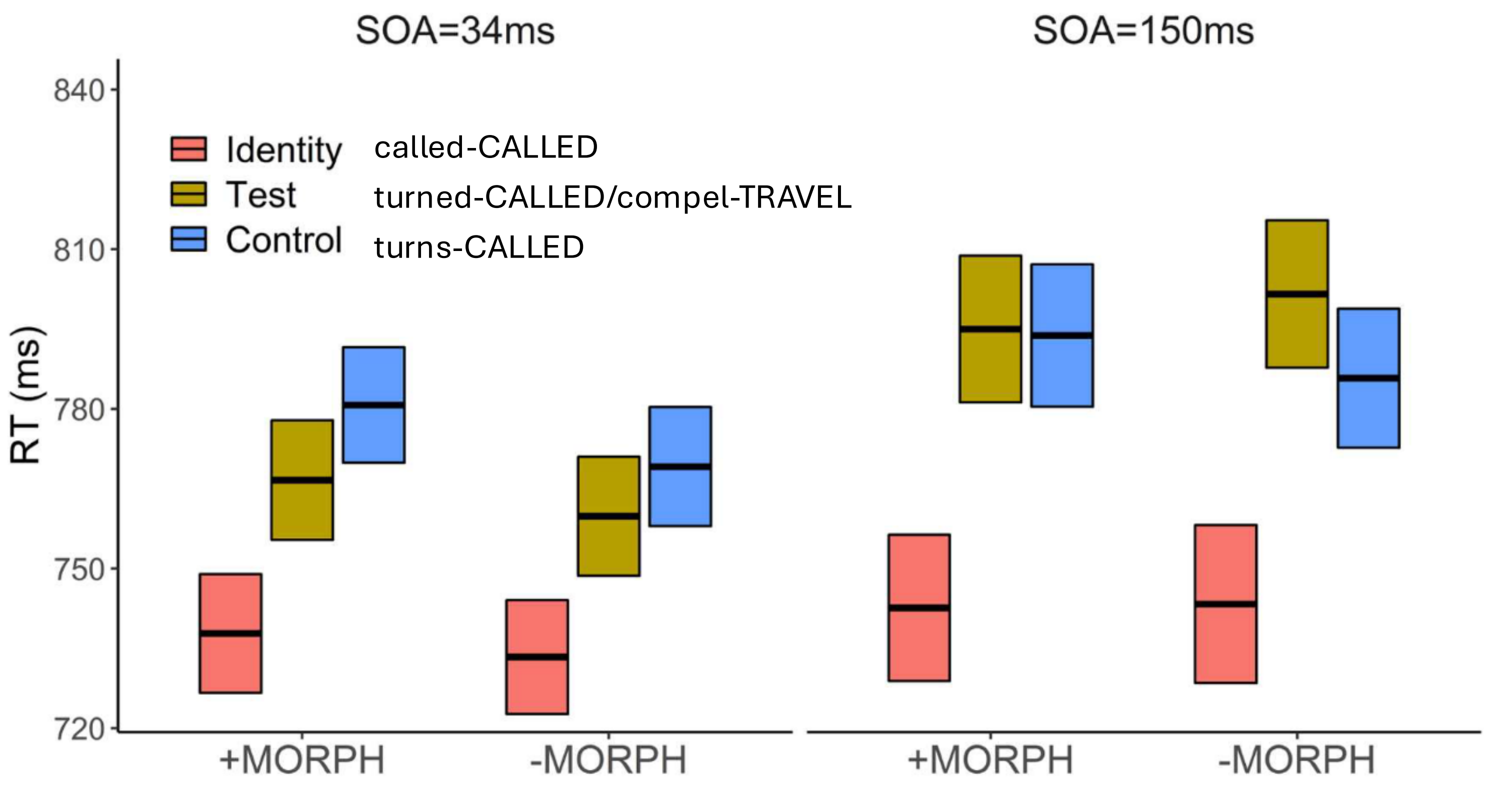

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➢ SOA=34ms (short): both +MORPH and –MORPH show Test priming

➢ SOA=150ms (long): -MORPH show inhibitory priming effects

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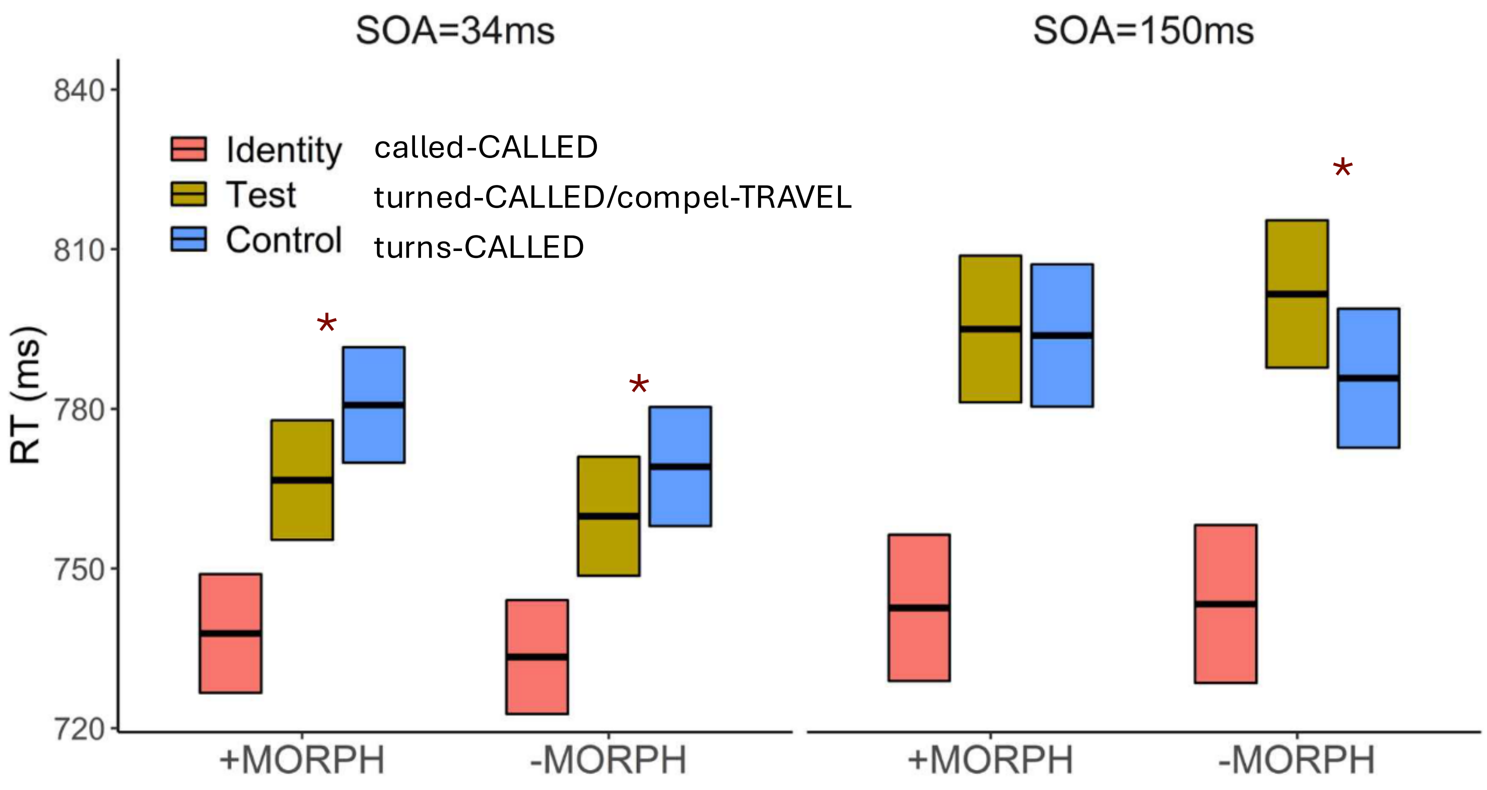

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Discussion

- **Short SOA:** Both **morphological and orthographic overlap** show priming effects
  - Morphological and/or orthographical information is automatically extracted from prime words
  - It is unclear whether the masked priming effect of the past tense morpheme is purely due to morphology

- **Long SOA:** **Orthographic overlap** yields inhibitory priming effects
  - At long SOA where sematic processing comes into play, co-activated words (orthographic neighbors) may become inhibited due to lexical competition

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Exp 2. Meta-analysis: Study goal

- Aggregate across different studies on different languages in a **Bayesian meta-analysis**

- Identify a summary estimate of morphological priming effects of **various types of morphemes (roots, prefixes, and suffixes)**

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Method

Study selection:

- **Studies that examined morphological priming** with a lexical decision task were selected in databases (e.g., Google Scholar, PubMed, PsycINFO, ERIC, EBSCOhost, Scopus, and Web of Science Core Collection)
- **33 papers (81 experiments)** published between 1997-2022
  - Short SOA (30-72 ms): 64 experiments
  - Long SOA (100-300 ms): 17 experiments

Table 4. Number of experiments (number of languages represented across the experiments) included in each group.

		Short SOA	Long SOA	Total	List of languages
Root (hunter-HUNT)		45 (8)	6 (1)	51 (8)	Arabic, Dutch, English, French, German, Hebrew, Serbian, Russian
Prefix (acclaim-ACCUSTOM)		7 (3)	6 (2)	13 (3)	English, French, Spanish
Suffix	Derivational (sheeter-TEACHER)	8 (4)	1 (1)	9 (4)	English, French, Italian, Spanish
	Inflectional (turned-CALLED)	4 (3)	4 (3)	8 (4)	English, Russian, Serbian, Slovene

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Method

A	B	C	D	E	F	G	H	I	J	K	P	R	V	W	X	Y	Z
Group	**Author**	**SOA**	**SOA2**	**Partici**	**Langua**	**Task**	**Total F**	**Length**	**Form_Stimu**	**Forı**	**Form_I**	**Form_**	**Morph_stimu**	**Mop**	**Mor**	**Morph_**	**Morph**
Prefix	Chateau et al 2002 Exp1 HP	45	masked	40	English	lexical de	721.88	NA	violin-violate	beginn	21	20.31	geometric-geoph	3.6	yes	prefix	der
Prefix	Chateau et al 2002 Exp1 LP	45	masked	40	English	lexical de	721.88	NA	NA	NA	NA	NA	acclaim-accusto	2.6	yes	prefix	der
Prefix	Dominguez et al. 2006	200	unmasked	17	Spanish	lexical de	871.33	7.79	reaccion-regalo	beginn	-20	10.17	reaccion-reforma	NA	yes	prefix	der
Prefix	Dominguez et al. 2010 Exp1a	33	masked	36	Spanish	lexical de	688.00	7.77	industria-incapa	beginn	19	12.07	infeliz-incapaz	2.3276	yes	prefix	der
Prefix	Dominguez et al. 2010 Exp1b	132	unmasked	36	Spanish	lexical de	660.67	7.77	industria-incapa	beginn	-14	12.61	infeliz-incapaz	2.3276	yes	prefix	der
Prefix	Dominguez et al. 2010 Exp1c	200	unmasked	36	Spanish	lexical de	651.67	7.77	industria-incapa	beginn	-19	14.73	infeliz-incapaz	2.3276	yes	prefix	der
Prefix	Dominguez et al. 2010 Exp2a	33	masked	36	Spanish	lexical de	628.00	7.30	insulto-industri	beginn	-2	11.29	NA	2.3148	yes	NA	NA
Prefix	Dominguez et al. 2010 Exp2b	200	unmasked	36	Spanish	lexical de	620.67	7.30	insulto-industri	beginn	6	9.94	NA	2.3148	yes	NA	NA
Prefix	Dominguez et al. 2010 Exp3a	33	masked	36	Spanish	lexical de	688.50	7.47	caliza-cachete	beginn	2	8.81	infeliz-incapaz	3.2333	yes	prefix	der
Prefix	Dominguez et al. 2010 Exp3b	200	unmasked	36	Spanish	lexical de	686.75	7.47	caliza-cachete	beginn	-2	9.97		3.2333	yes	prefix	der
Prefix	Giraudo and Grainger 2003 Exp1	43	masked	30	French	lexical de	795.83	5~8	engin-envol	beginn	16	11.29	enjeu-envol	NA	yes	prefix	der
Prefix	Giraudo and Grainger 2003 Exp1	57	masked	30	French	lexical de	775.17	5~8	engin-envol	beginn	6	11.29	enjeu-envol	NA	yes	prefix	der
Prefix	Giraudo and Grainger 2003 Exp1	115	unmasked	30	French	lexical de	766.83	5~8	engin-envol	beginn	0	11.29	enjeu-envol	NA	yes	prefix	der
Suffix	Cho et al. 2022	34	masked	120	English	lexical de	761.27	5.23	travel-compel	end	9.3	6.05	turned-called	2	yes	suffix	inf
Suffix	Cho et al. 2022	150	unmasked	120	English	lexical de	778.32	5.23	travel-compel	end	-15.4	5.58	turned-called	2	yes	suffix	inf
Suffix	Crepaldi et al. 2016 Exp1	42	masked	45	English	lexical de	696.33	4.86	sportel-brothel	end	16	10.25	sheeter-teacher		no	suffix	der
Suffix	Dunabeitia et al. 2008 Exp3	50	masked	30	Spanish	lexical de	770.25	7.17	volumen-certam	end	-2	11.29	brevedad-igualdad		yes	suffix	der
Suffix	Giraudo and Grainger 2003 Exp1	43	masked	30	French	lexical de	795.83	5~8	peuplier-feranie	end	5	11.29	peuplier-feranier	3	yes	suffix	der
Suffix	Giraudo and Grainger 2003 Exp1	57	masked	30	French	lexical de	775.17	5~8	peuplier-feranie	end	1	11.29	peuplier-feranier	3	yes	suffix	der
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Suffix	Marjanovic and Crepaldi 2020 Exp1	36	masked	60	Slovene	lexical de	715.09	4.32	NA	NA	NA	NA	mestam-haljam	2	yes	suffix	inf
Suffix	Marjanovic and Crepaldi 2020 Exp2	36	masked	62	Slovene	lexical de	714.18	4.32	NA	NA	NA	NA	mestam-haljam	2	yes	suffix	inf
Suffix	VanWagenen and Pertsova 2014 Nouns	300	unmasked	36	Russian	lexical de	624.57	NA	fprasonkax-nazi	end	-22	15.31	fkulakax-naZivatax		yes	suffix	inf
Suffix	VanWagenen and Pertsova 2014 Verbs	300	unmasked	36	Russian	lexical de	619.36	NA	patcot-tresot	end	-10	17.58	virnot-tresot		yes	suffix	inf

Analysis:

- **Effect sizes** from each experiment were derived as the RT difference between related vs unrelated conditions
- **Standard error (SE)** was calculated in different ways depending on the information provided by the paper

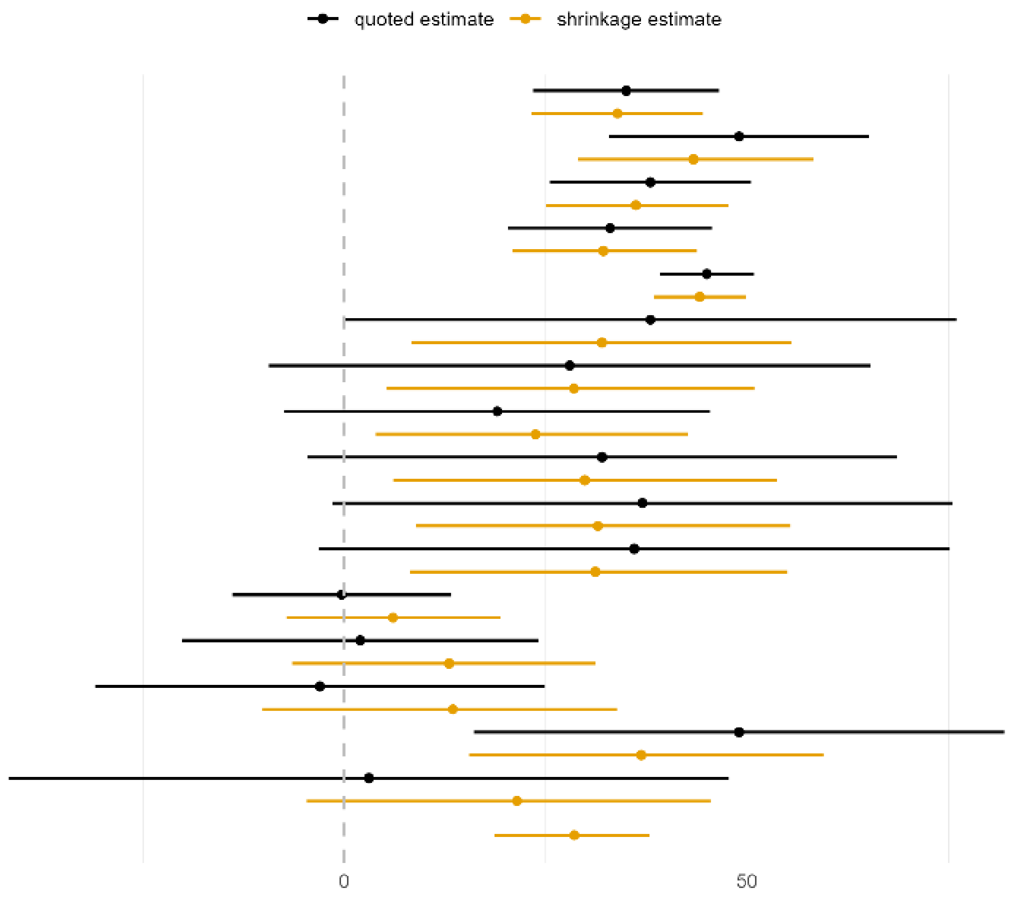
Bayesian meta-analysis was conducted in R by fitting random-effects Bayesian hierarchical models (*brms* package)

Cho et al. (2024) *LCN*

Method

Forestplot of studies with morphological overlap (long SOAs)

Study	Type	N	SOA
Feldman 2000 Exp1B	Root	96	116
Feldman 2000 Exp1C	Root	96	300
Feldman 2000 Exp1E	Root	95	300
Feldman et al. 2004 Exp1b	Root	68	250
Rastle et al. 2000 Exp1 +SEM	Root	24	230
Rastle et al. 2000 Exp2 +SEM	Root	24	230
Dominguez et al. 2006	Prefix	17	200
Dominguez et al. 2010 Exp1b	Prefix	36	132
Dominguez et al. 2010 Exp1c	Prefix	36	200
Dominguez et al. 2010 Exp3b	Prefix	36	200
Giraudo and Grainger 2003 Exp1	Prefix	30	115
Cho et al. 2022	Suffix	120	150
Giraudo and Grainger 2003 Exp1	Suffix	30	115
VanWagenen and Pertsova 2014 Nouns	Suffix	36	300
VanWagenen and Pertsova 2014 Verbs	Suffix	36	300
Lalić 2022 Exp1	Suffix	30	250
Pooled effect			



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Results: Estimated priming effects

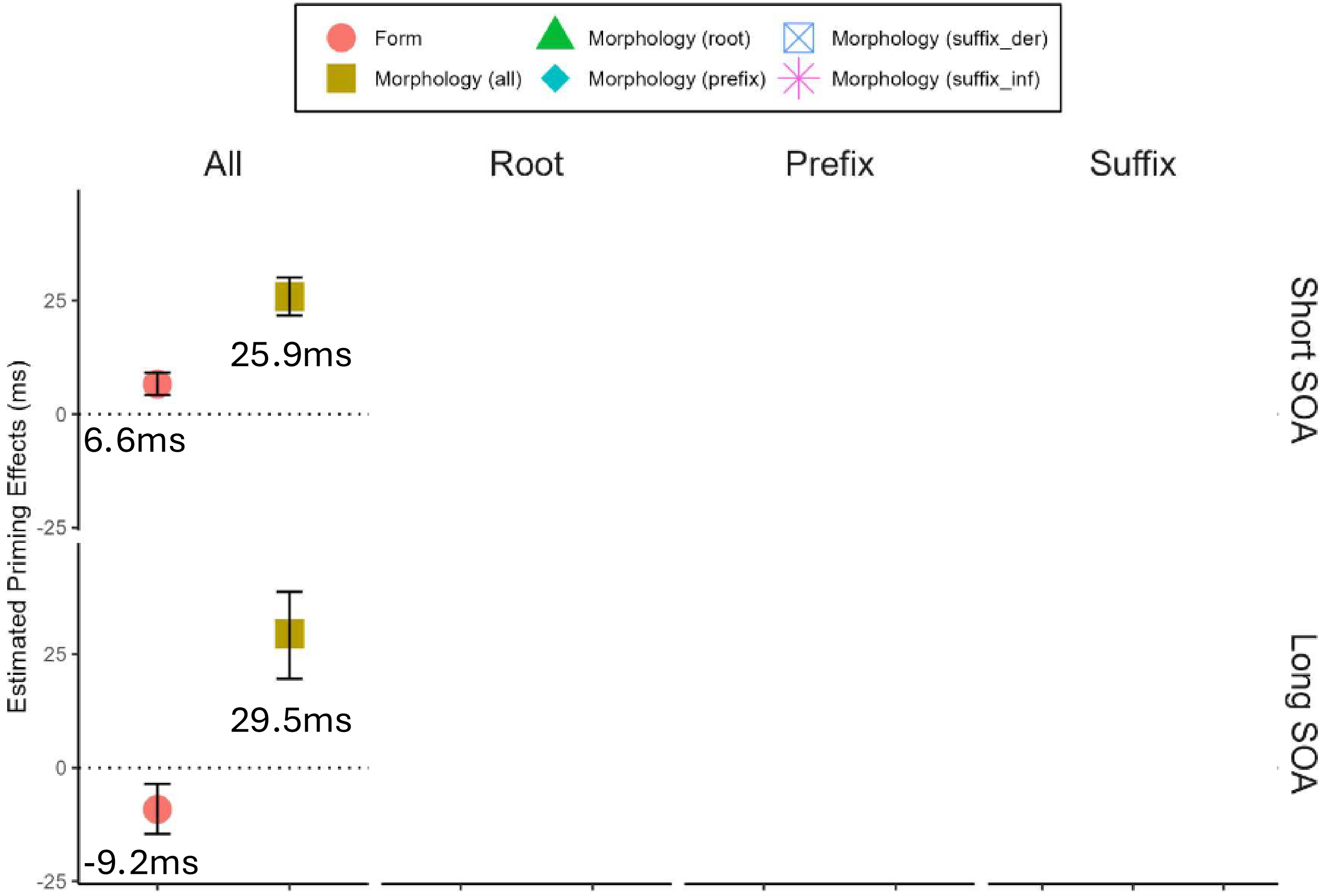

Figure 5. Estimated effect sizes (ms) and 95% Credibility Intervals of form and morphological priming (Root, Prefix, Suffix) at short and long SOAs from a random-effects Bayesian meta-analysis of 81 experiments.

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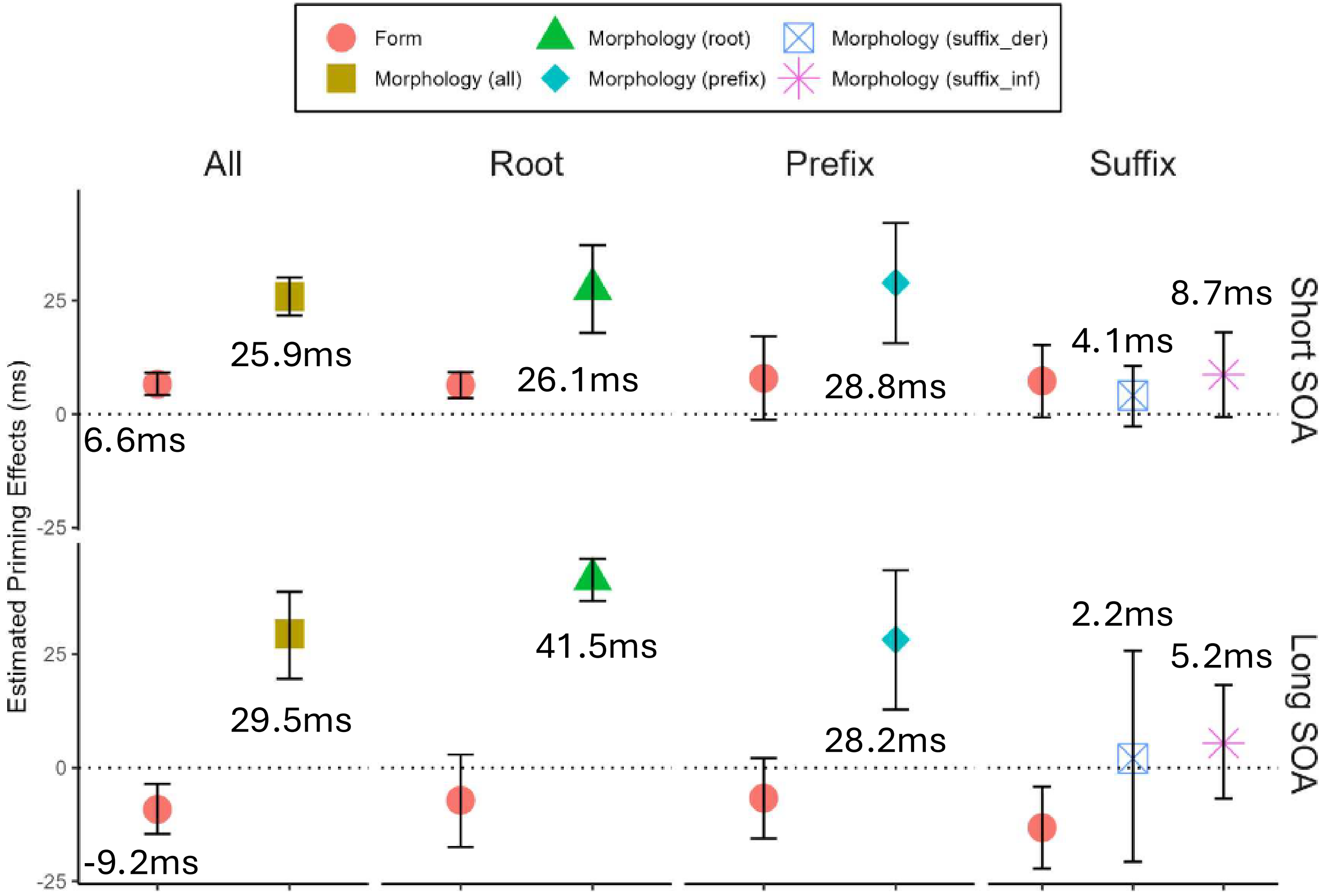
Results: Estimated priming effects



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Results: Morphological-orthographic priming effects

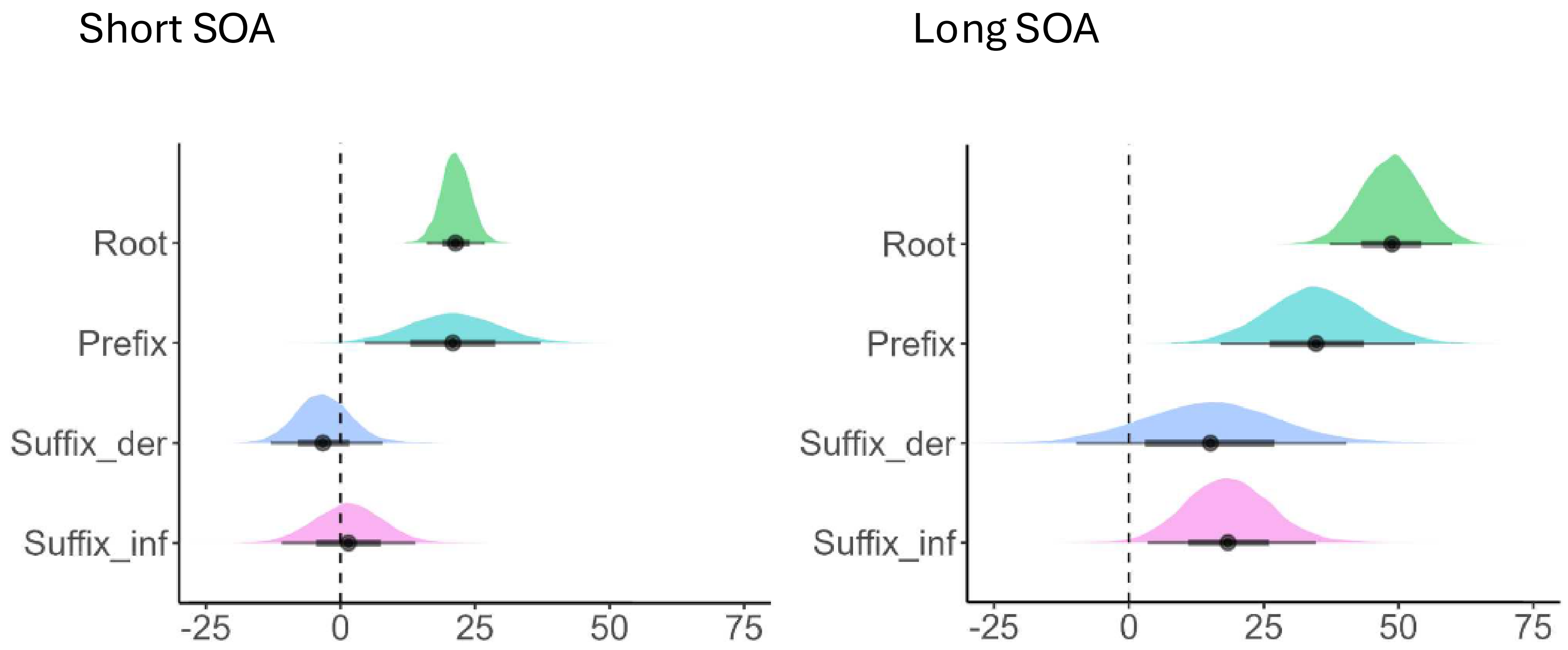

Figure 6. Posterior distributions of differences between morphological priming and orthographic priming for different types of morphemes at short (left) and long (right) SOAs. Bars at the bottom of each distribution indicate 66% and 95% credibility intervals.

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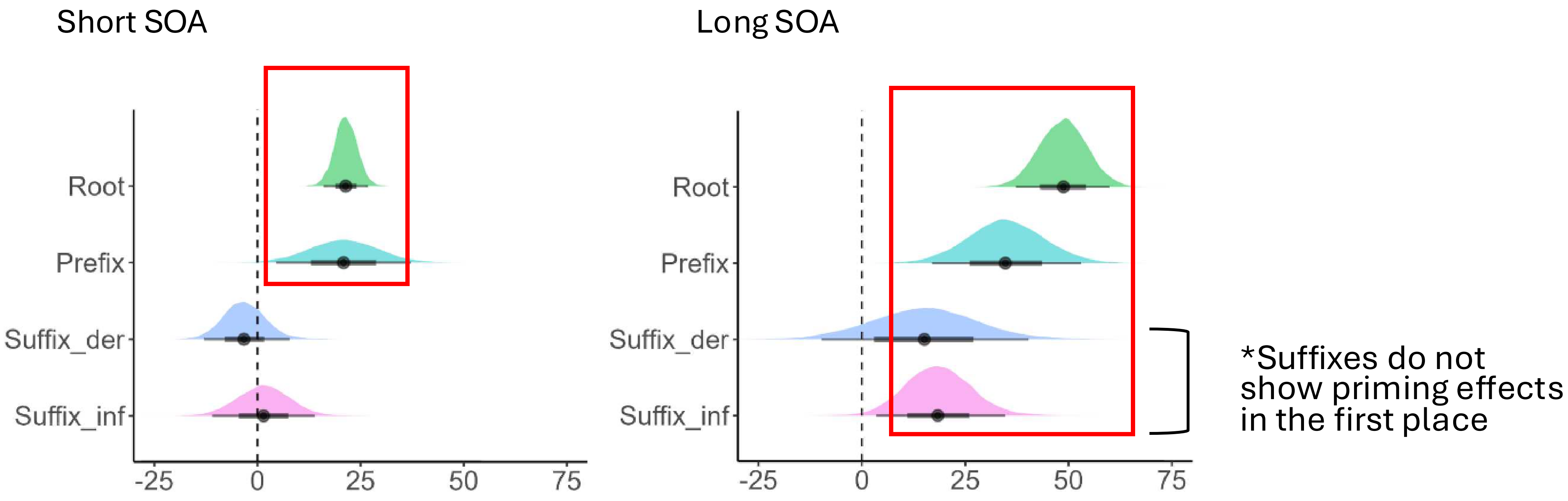
Results: Morphological-orthographic priming effects



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Discussion

- **Robust prefix and root priming** in contrast to **unreliable suffix priming** effects across 81 experiments (~3,600 participants)
- **Prefix priming** indicates that affixes are not stripped off but remain in memory for lexical access in the same way as roots do
- In contrast, **absence of suffix priming** suggests even single-item visual word recognition is sensitive to linear order

be-friend-ed

Its role in lexical access may be masked by the preceding root

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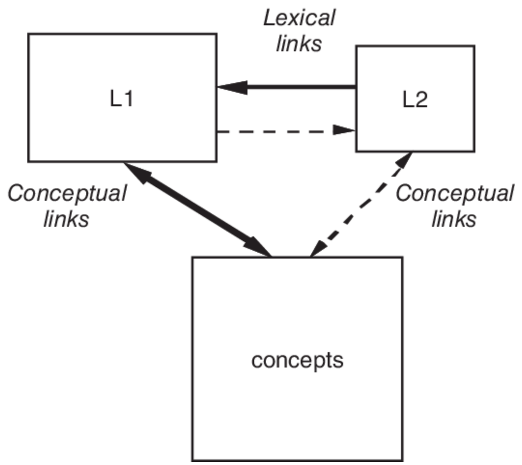
Word and morphological representation in bilinguals

Study 2-3

Study 2. Prefix priming in English-Spanish bilinguals

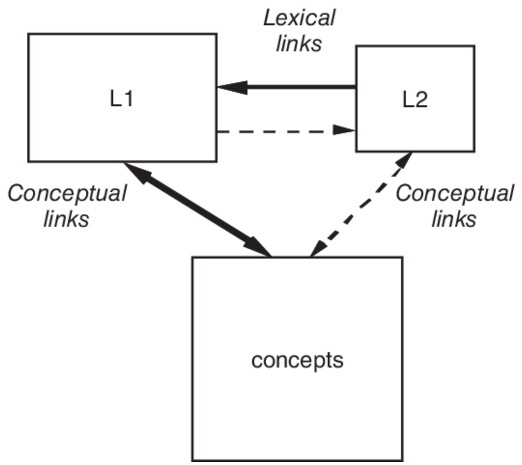
Morphological representation in L2



- L1 and L2 words are linked at the conceptual level (Revised Hierarchical Model)
  - Priming (Dutch and English: De Groot and Nas, 1991, Hebrew and English: Gollan et al., 1997, Chinese and English: Jiang, 1999, Japanese and English: Hoshino et al., 2010, Korean and English: Kim and Davis, 2003)
  - Overlapping brain regions when processing words in English and Chinese (Chee et al., 2000; Ding et al., 2003; Xue et al., 2004)
  - Similar brain activities for English words and Dutch words (Correia et al., 2014, 2015)

Morphological representation in L2

- L1 and L2 words are linked at the conceptual level (Revised Hierarchical Model)



- **Greater overlap or association for cognates** as compared to noncognates, leading to faster recognition (cognate facilitation effect)

- Less is known for **how morphologically complex words are stored** across different languages

➢ *Are cognate prefixes also connected across different languages and show priming effects?*

Cognates

distract – disgustar (dislike)

Morphological representation in L2

- **Age effects:** the degree of sensitivity to L2 morphological structure may vary among bilinguals **depending on their age of L2 acquisition**

e.g., Smaller L2 root priming effects (e.g., geprüft ‘checked’- prüft ‘check’) by late than early bilinguals

2. Study goal

- Test **cognate prefix priming in English and Spanish** and between those languages with early and late English-Spanish bilinguals

Method

Participants

- Experiment 1 (Prime: English-Target: English): 59 English native speakers
- Experiments 2-4: English-Spanish bilinguals

	Early bilinguals	Late bilinguals
Experiment 2 (L1 English-L2 Spanish)		
# participants	69	68
Age of L2 acquisition	2.0 (1.72)	15.2 (5.89)
Experiment 3 (L2 Spanish-L1 English)		
# participants	70	67
Age of L2 acquisition	2.1 (1.98)	14.3 (5.39)
Experiment 4 (L2 Spanish-L2 Spanish)		
# participants	73	69
Age of L2 acquisition	2.1 (1.95)	15.7 (8.07)

Method

Stimuli: 120 word sets and 120 nonword sets (15 items per condition)

Condition	Experiment 1 (English-English)	Experiment 2 (English-Spanish)	Experiment 3 (Spanish-English)	Experiment 4 (Spanish-Spanish)
Identity				
(a) Related	hang-HANG			
(b) Unrelated	erase-HANG			
Prefix				
(a) Related	distract-DISSUADE			
(b) Unrelated	unbend-DISSUADE			
Orthographical				
(a) Related	ignite-IGNORE			
(b) Unrelated	smile-IGNORE			
Semantic				
(a) Related	elect-VOTE			
(b) Unrelated	spend-VOTE			

Method

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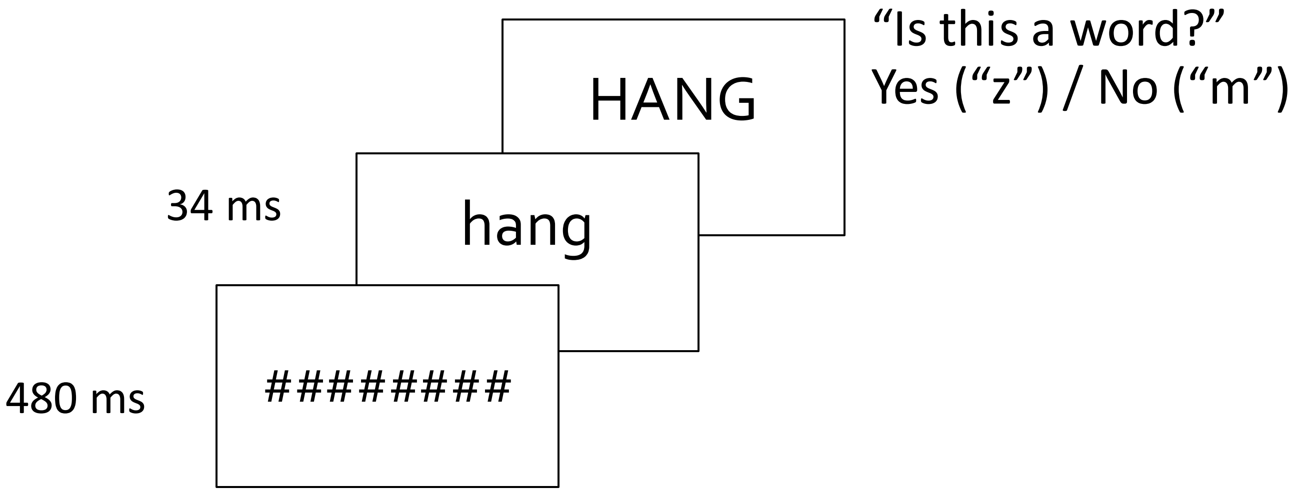
(a) Related	hang-HANG	hang-COLGAR	colgar-HANG	colgar-COLGAR
(b) Unrelated	erase-HANG	erase-COLGAR	borrar-HANG	borrar-COLGAR
Prefix				
(a) Related	distract-DISSUADE	distract-DISGUSTAR	disgustar-DISTRACT	distractir-DISGUSTAR
(b) Unrelated	unbend-DISSUADE	unbend-DISGUSTAR	subrayar-DISTRACT	subrayar-DISGUSTAR
Orthographical				
(a) Related	ignite-IGNORE	ignite-IGUALAR	igualar-IGNORE	ignorer-IGUALAR
(b) Unrelated	smile-IGNORE	smile-IGUALAR	volver-IGNORE	volver-IGUALAR
Semantic				
(a) Related	elect-VOTE	elect-VOTAR	votar-ELECT	votar-ELEGIR
(b) Unrelated	spend-VOTE	spend-VOTAR	gastar-ELECT	gastar-ELEGIR

Method

Procedure



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Cho and Brennan (2025) *BLC*

Method

Analysis

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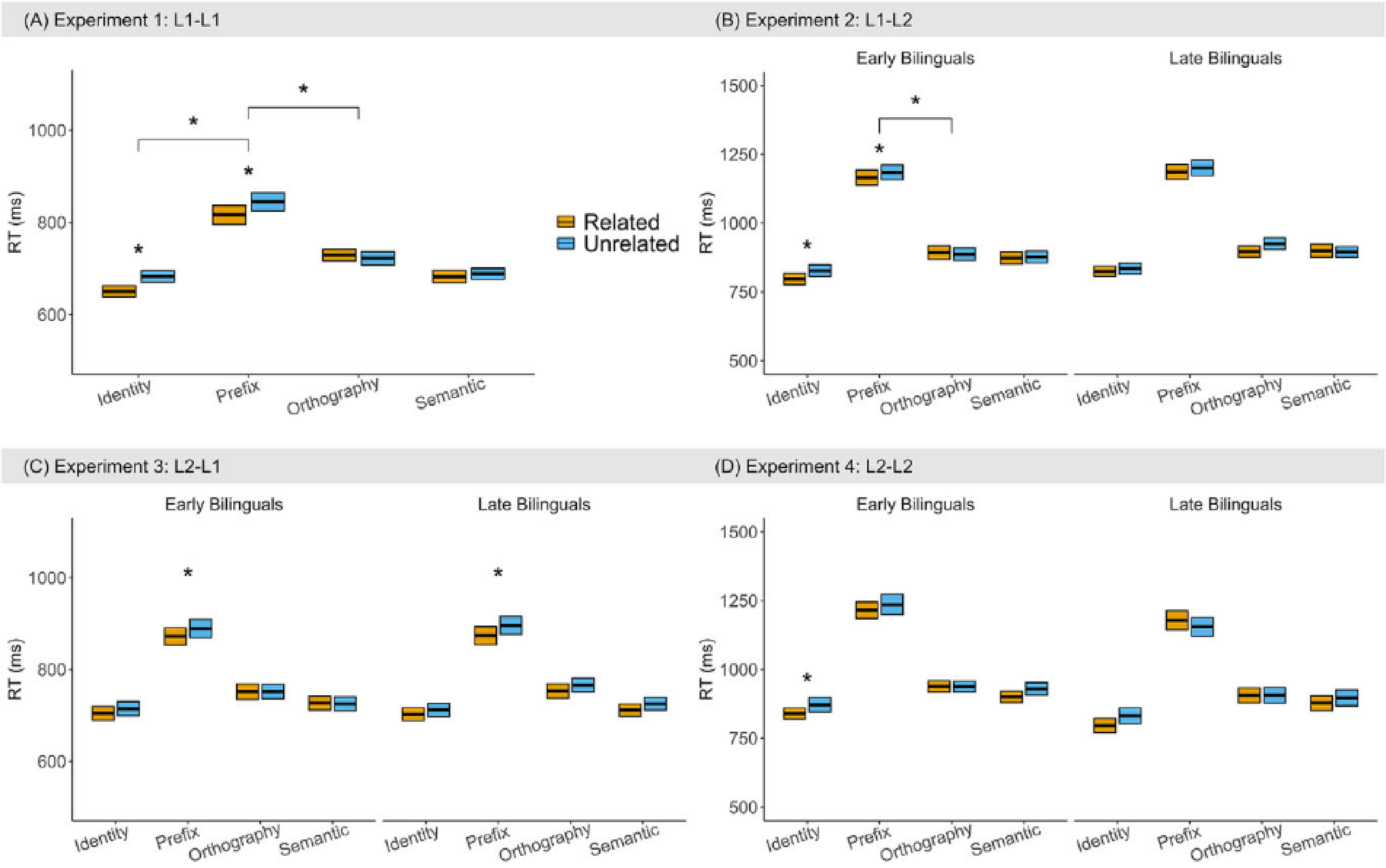
Cho and Brennan (2025) *BLC*

Results



- Experiment 1:

Robust prefix priming in L1

- Experiments 2-4:

L1-L2 cross-language prefix priming among **early bilinguals**, but not late bilinguals

Cho and Brennan (2025) *BLC*

Discussion

- **Only early bilinguals** show cross-languages prefix priming that is dissociated from form-based priming

➢ This indicates that cognate prefixes are mapped onto a shared representation

➢ Consistent with previous literature **on language transfer**, specifically of morphology (Marks et al., 2023; Ramírez et al., 2011; Wang et al., 2022), and convergence (Baptista et al., 2016; Muysken, 2000, 2013; Weinreich, 1953)

dis-

distract — English

disgustar (dislike) — Spanish

Discussion

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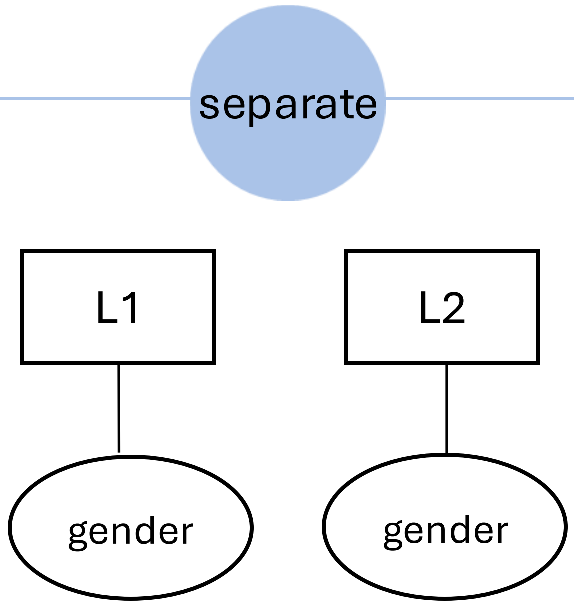
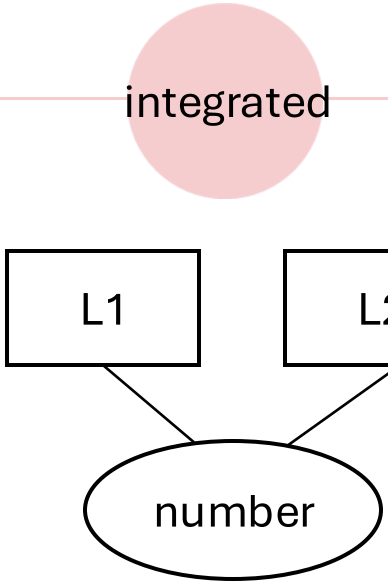
- Absence of cross-languages prefix priming by **late bilinguals** may be due to less sensitivity to L2 morphology

Study 3. Neural decoding of words and grammatical features

Cross-linguistic representation of grammatical features & affixes



Gender systems of the two languages among Italian-Croatian bilinguals are stored separately (Costa et al. 2013)

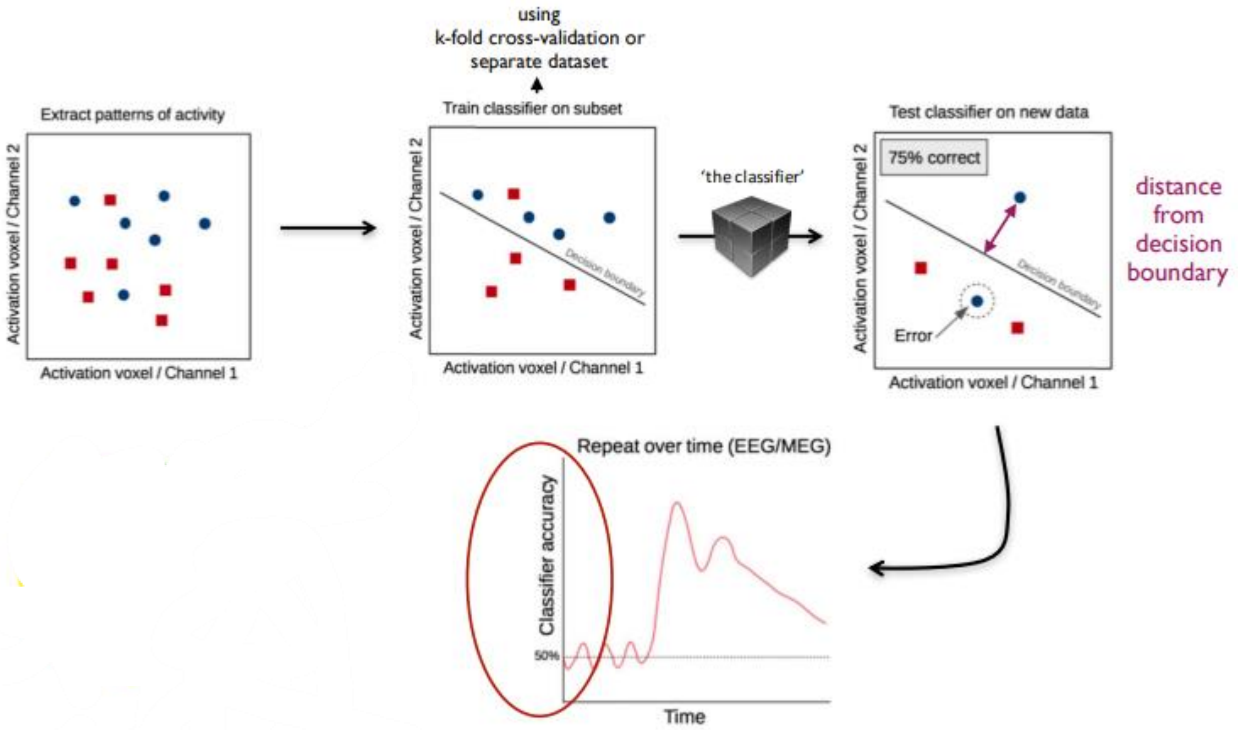


Processing number (Dunagan et al. 2022) and tense (Tang et al. 2021) activates overlapping brain regions across multiple languages (e.g., English, French, Japanese/Chinese)

Neural decoding

A machine learning classifier is trained over the neural data and is tested with unseen data to predict the feature of given stimuli

Has been used for identifying pictured objects, word meanings, grammatical categories, etc.



Grootswagers et al. (2017)

(Carlson et al., 2003; Chan et al., 2011; Cox and Savoy, 2003; Huth et al., 2016; Mitchell et al., 2008; Shinkareva et al., 2011; Simanova et al., 2010)

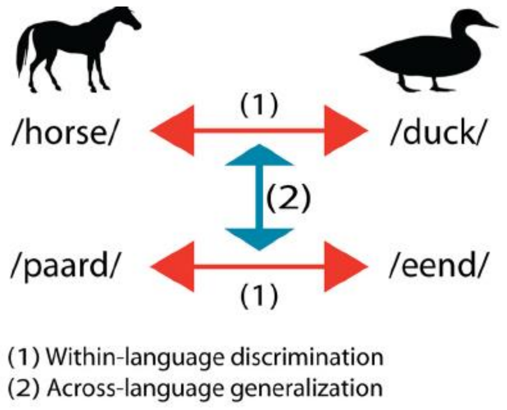
Cross-linguistic neural decoding (Correia et al., 2015)

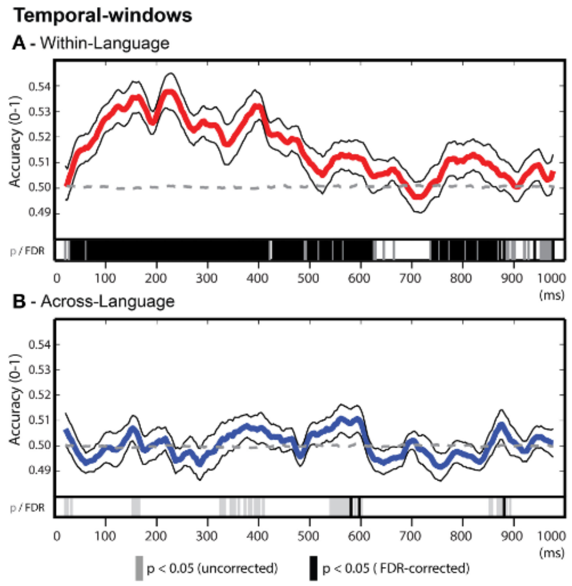
A classifier **trained** on neural data **from one language** is **tested** on neural data **from another language**

Obtained above-chance accuracies between English and Dutch at 550-600 ms and 850-900 ms

- indicates similar brain activities for translation equivalents

Filtering out low frequency bands (<12 Hz) affected accuracies for within-language and between-languages decoding





Study goal

- To test cross-linguistic neural decoding of **words** as well as **grammatical features (number and tense)** with Korean-English bilinguals

Cho and Brennan (2025) *Neuropsychologia*

Method

- **Participants**: eighteen Korean-English bilinguals
- **Stimuli**: eight nouns (plural or singular) and eight verbs (present or past) in English and Korean

Nouns

Singular		Plural	
English	Korean	English	Korean
duck	오리 ori	ducks	오리들 ori-deul
goat	염소 yeomso	goats	염소들yeomso-deul
swan	백조 baekjo	swans	백조들 baekjo-deul
lion	사자 saza	lions	사자들 saza-deul

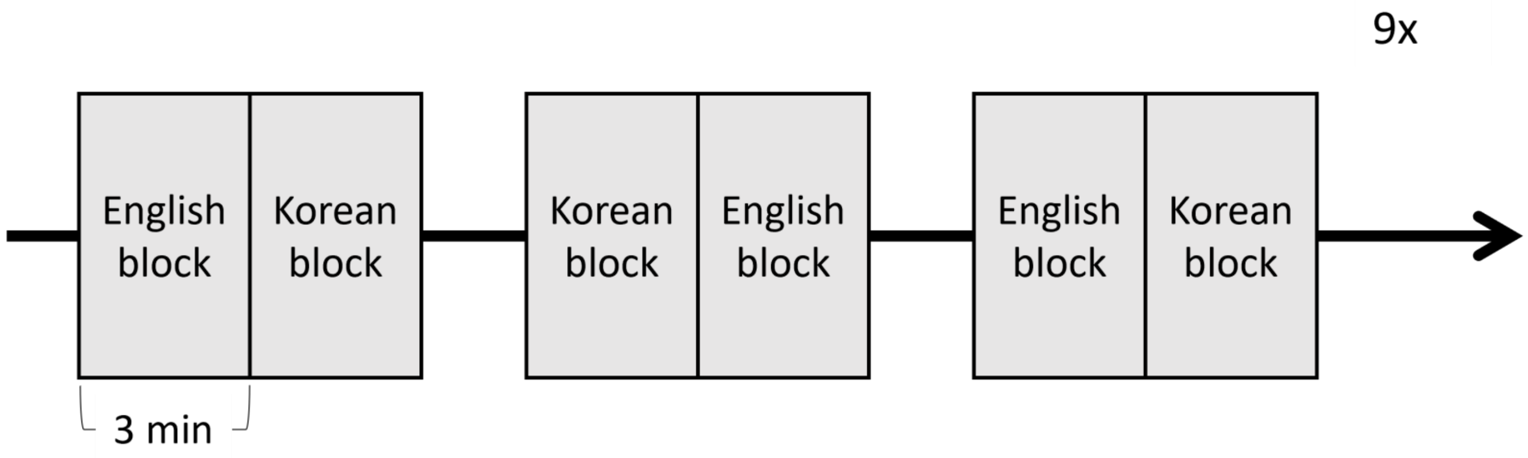
Verbs

Present		Past	
English	Korean	English	Korean
leans	기댄다 gidaenda	leaned	기댔다 gidaessda
cools	식힌다 sikhinda	cooled	식혔다sikhyessda
helps	돕는다 dopneunda	helped	도왔다 dowassda
fills	채운다 chaeunda	filled	채웠다 chaewossda

Cho and Brennan (2025) *Neuropsychologia*

Method

- **Procedure**: participants read each word a total of 36 times in each language (English and Korean) while their EEG is recorded
  - A total of nine runs with English and Korean blocks alternating orders
  - Each block = each word x 4 times



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Analysis and Results

Words (four nouns and four verbs) and grammatical features (number and tense):

1. ERP analysis (300-600 ms and 600-800 ms)
2. Decoding
3. (Time-frequency analysis)

ERP analysis

- EEG data were epoched (-300 ~ 1,000 ms) and analyzed with ANOVAs in the time windows of **300-600 ms** and **600-800 ms**

Lexical

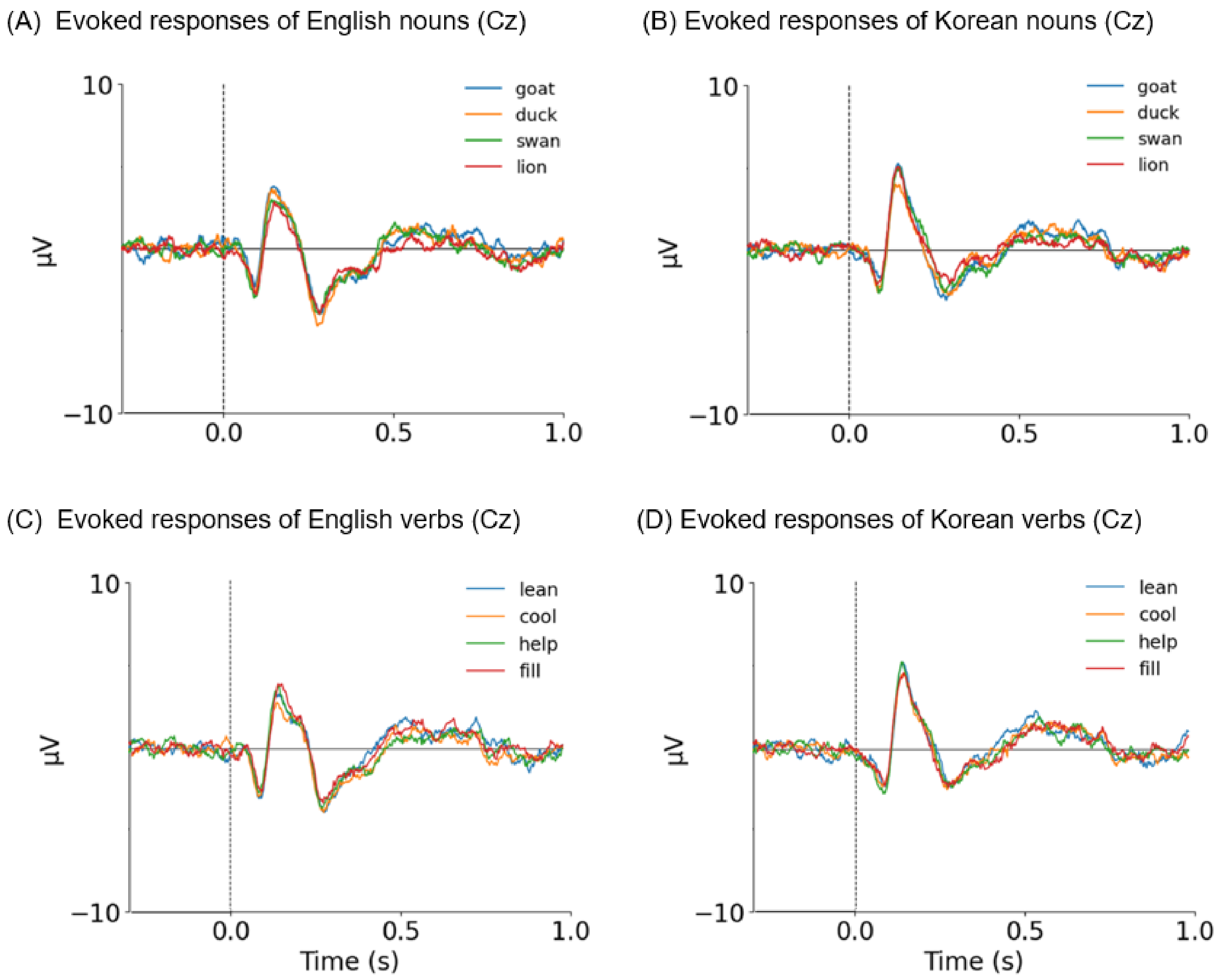
Grammatical

- Fixed effects: **Word type** (four levels for nouns and verbs, two levels for number and tense), **Hemisphere**, **Anterior-posterior orientation**
- Corrected for multiple comparisons

Results: ERP analysis

Words

- No statistical differences among nouns and verbs (both 300-600 ms and 600-800 ms) for both languages



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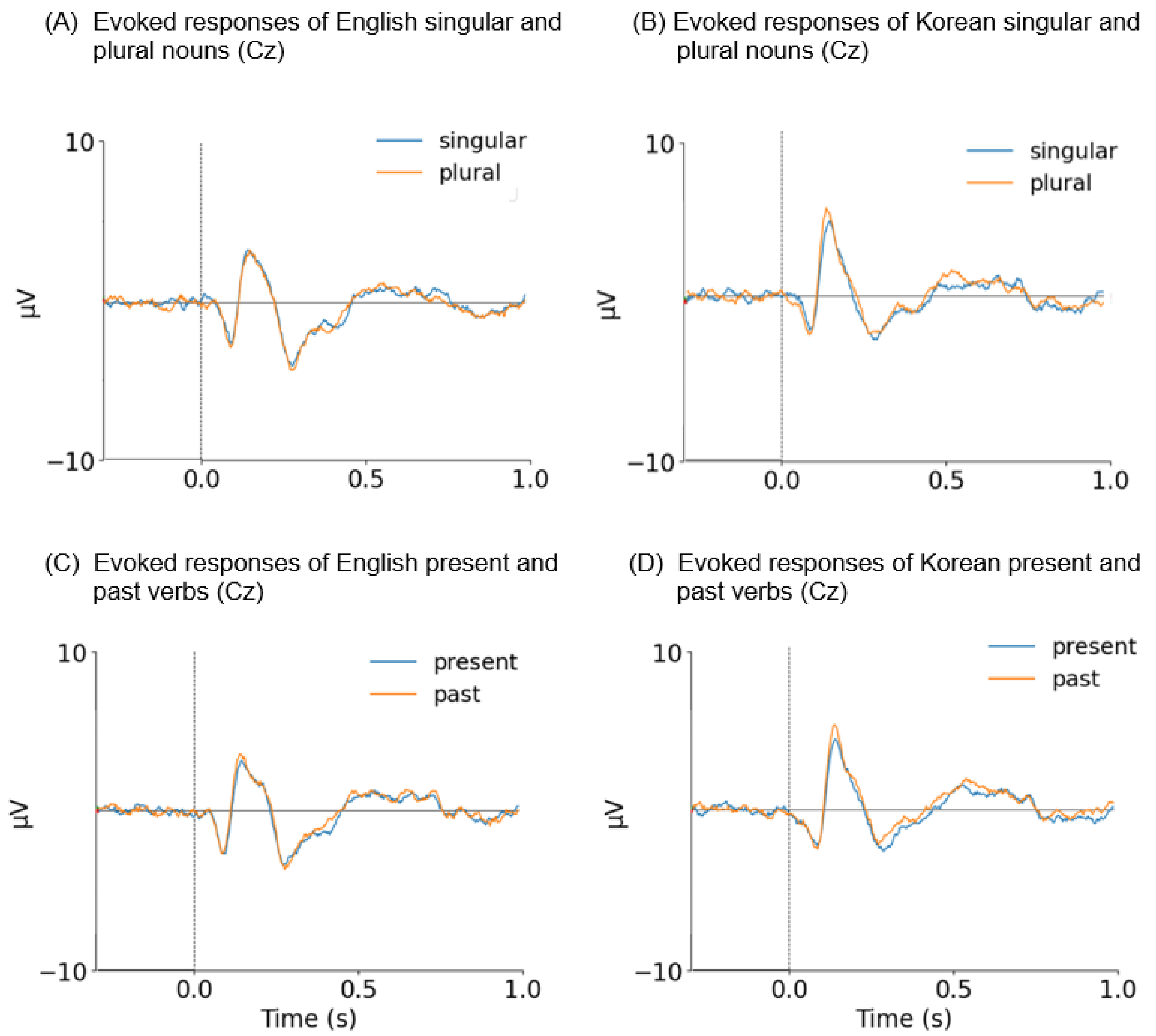
Results: ERP analysis

Number and tense

- No statistical differences for the number feature
- Korean past tense yielded more positive amplitudes in the anterior ($p < 0.001$) and central ($p < 0.001$) regions



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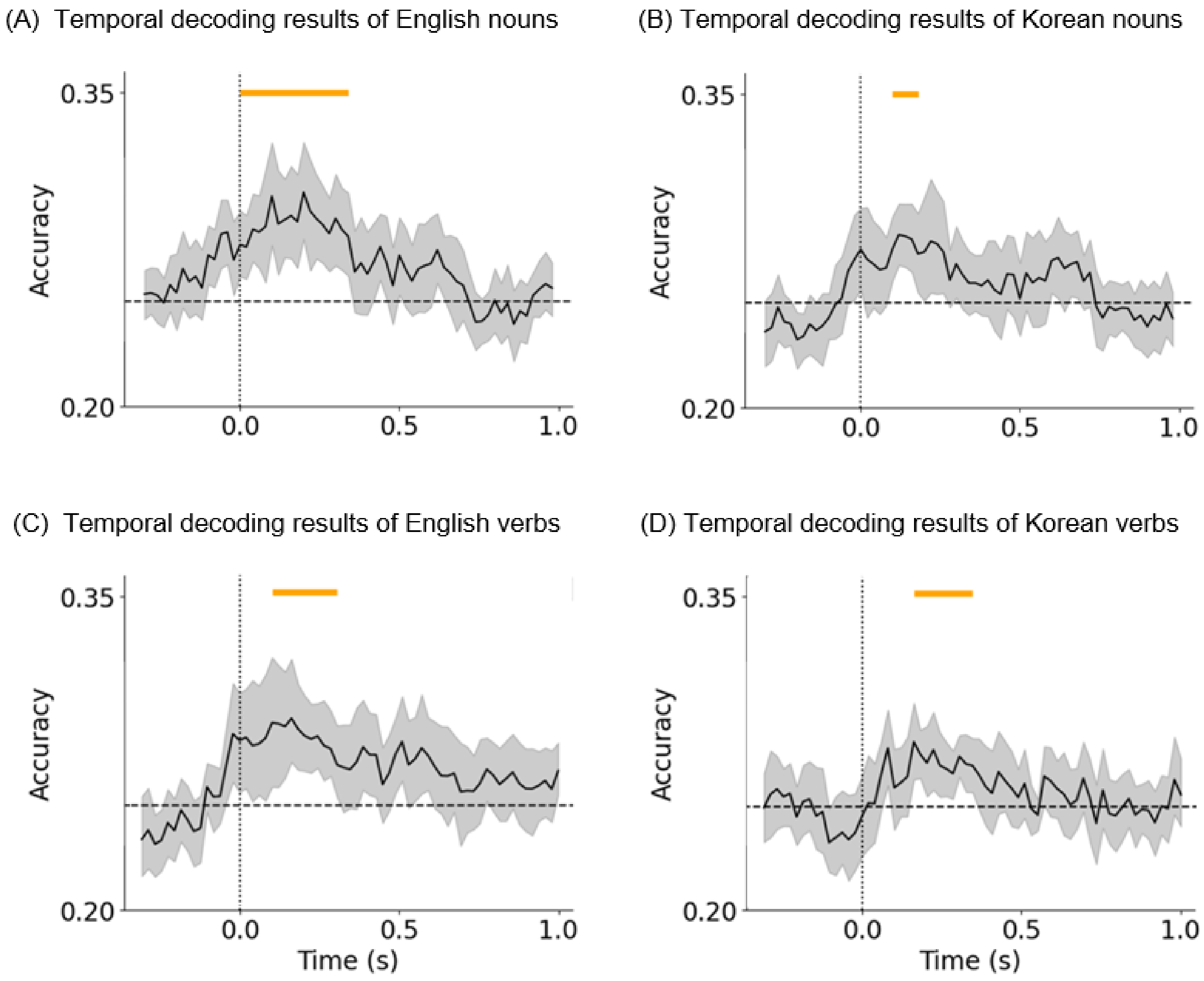
Decoding

- Epoched EEG data were trained with an LDA (linear discriminant analysis) classifier
- Data used for training and testing: 200 ms-long window moving by 20 ms intervals
- **Within language:** results based on five-fold cross validation
- **Between languages:** trained on one language and tested on the other
- Statistical testing: cluster-based permutation test

Results: Within-language decoding

Words (chance=0.25)

- Within-language decoding of nouns and verbs yielded above-chance accuracies in 0-300 ms



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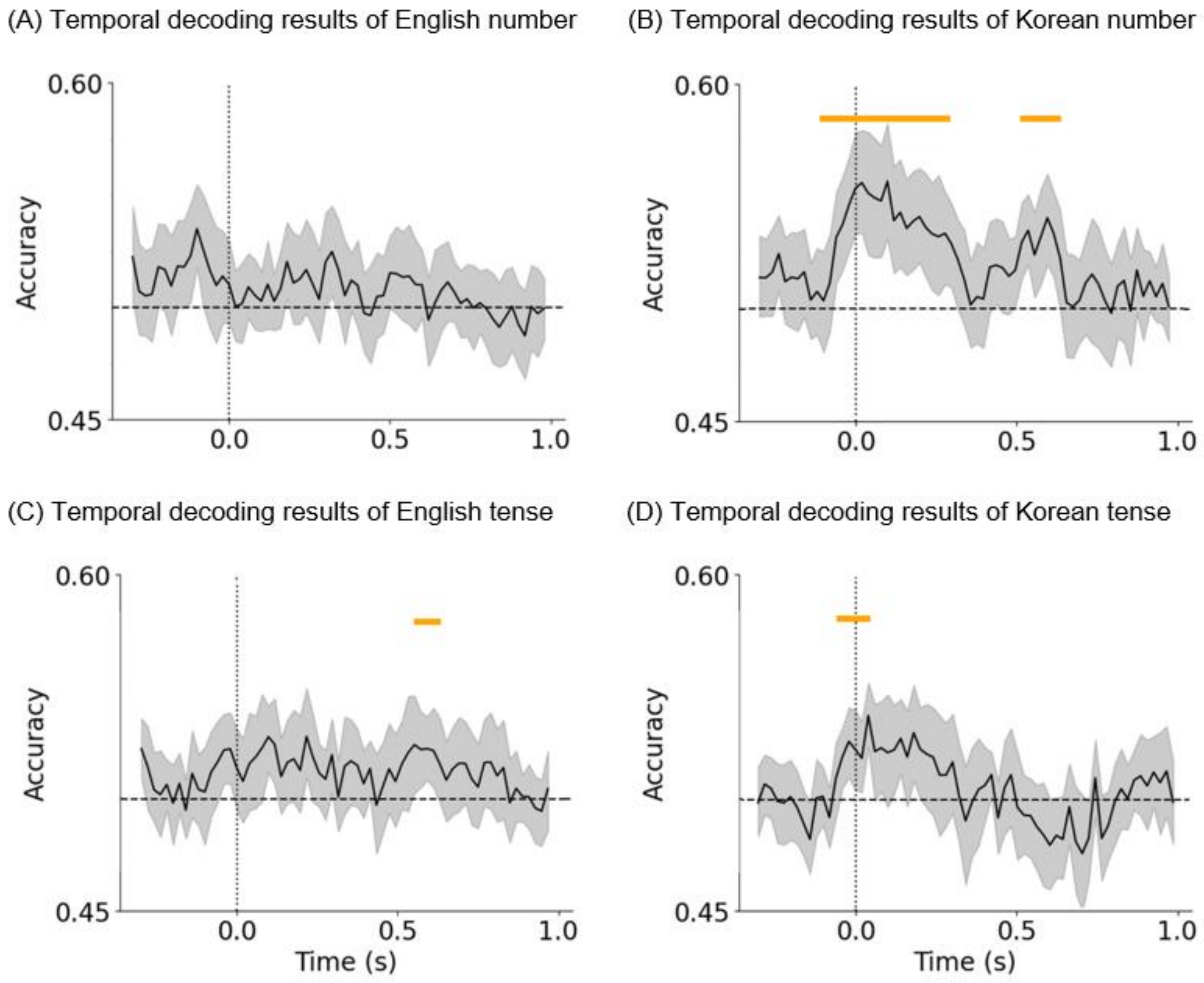
Results: Within-language decoding

Number and tense (chance = 0.5)

- Number: above chance in Korean -60-300 ms and 460-600 ms
- Tense: above chance in English (560-620 ms) and Korean (-40-40 ms)



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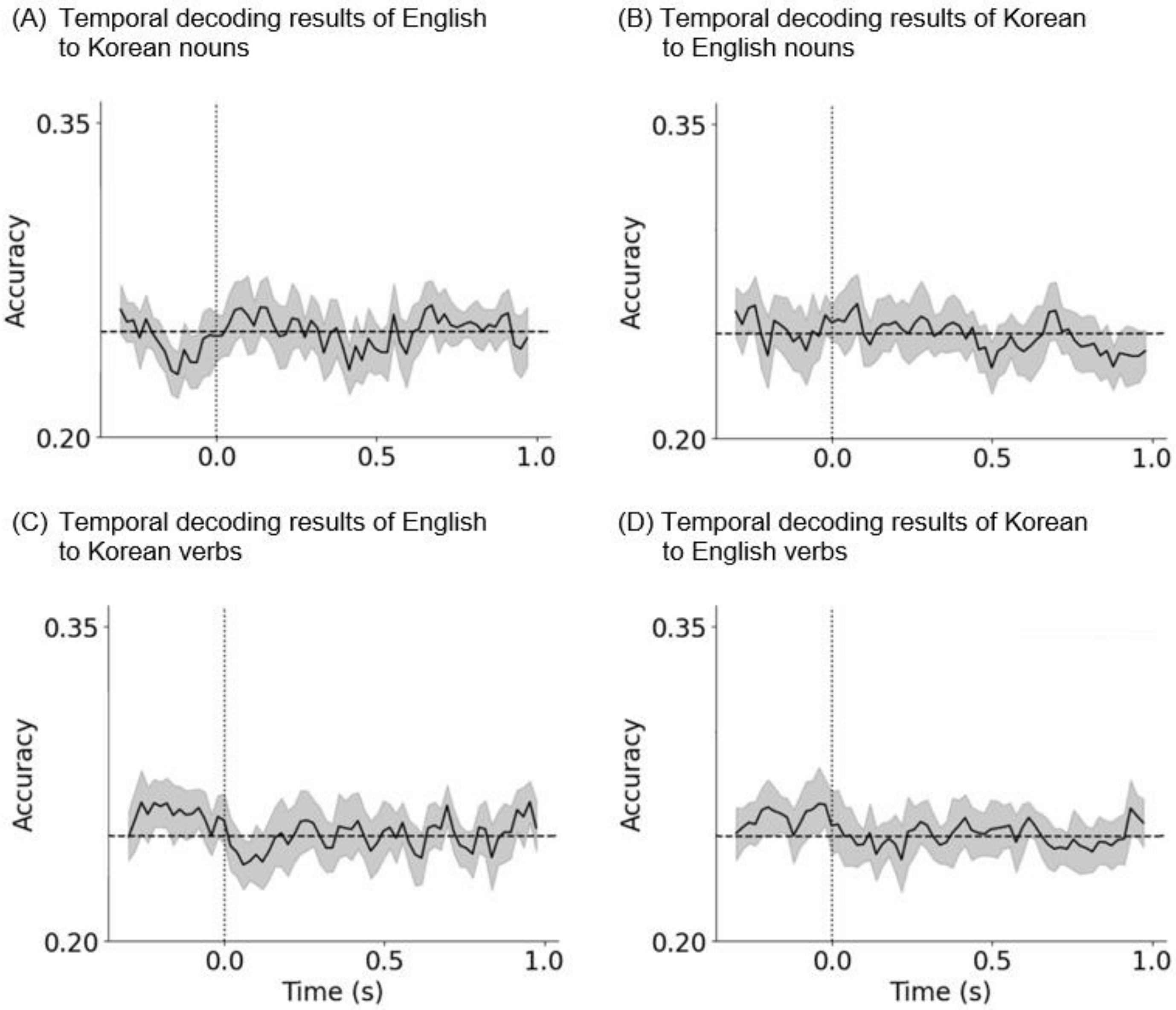
Results: Between-languages decoding

Words (chance=0.25)

- No above-chance accuracies



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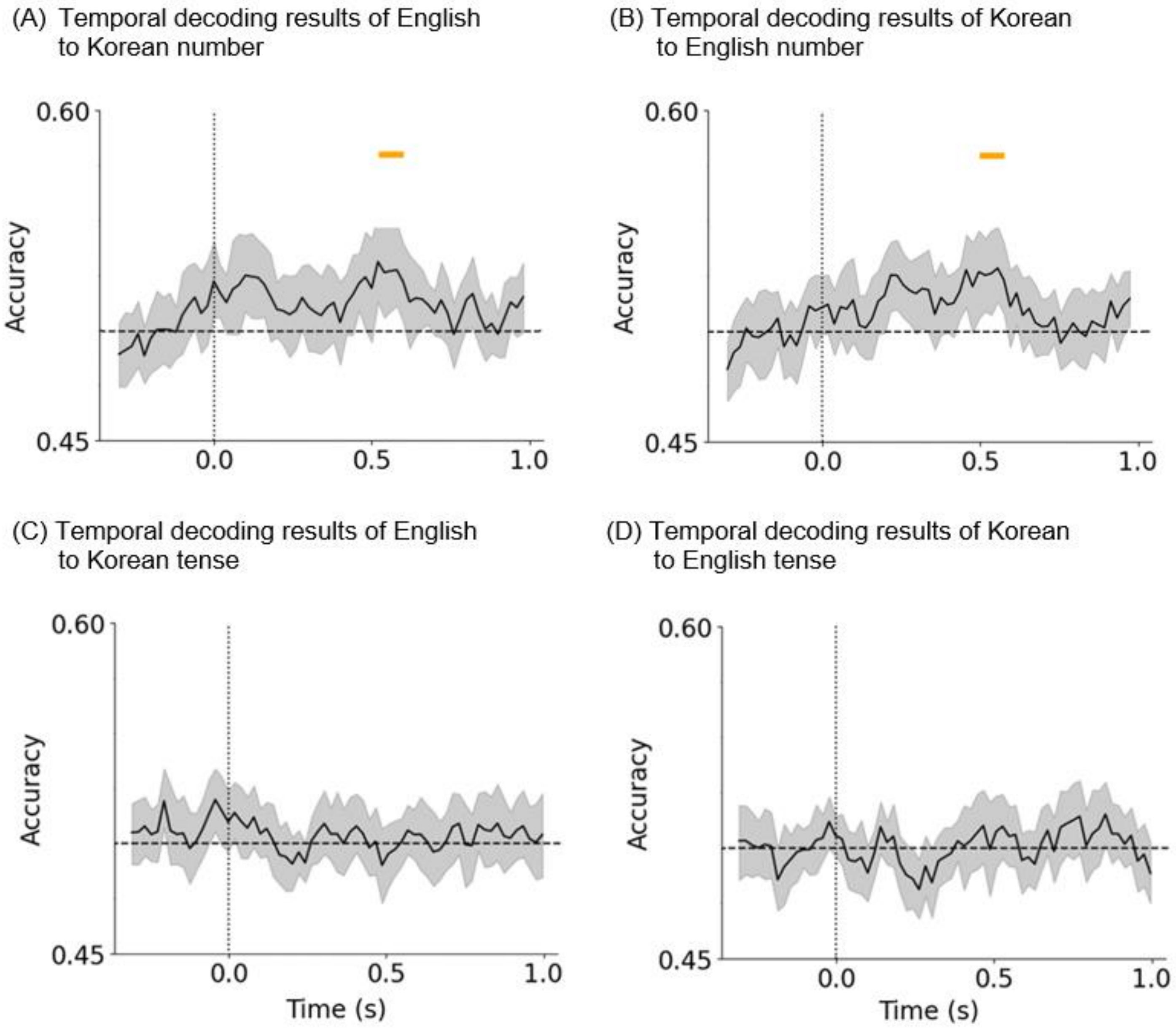
Results: Between-languages decoding

Number and tense (chance = 0.5)

- Number: above chance both directions in 500-600 ms
- Tense: no above-chance accuracies



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Discussion

- **Within-language neural decoding** is successful for nouns, verbs, and tense for both languages and for number for Korean

➢ Advantage of the multivariate analysis over traditional ERP analysis

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  It may reflect processing of low-level visual properties (~100 ms), lexicality (150-200 ms), and semantic properties (300-600 ms)

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  It may reflect processing of low-level visual properties (~100 ms), lexicality (150-200 ms), and semantic properties (300-600 ms)

➢ Time windows for decoding of **grammatical tense** are different for the two languages

  May be due to different processing mechanisms for inflectional suffixes (English) versus stem conjugation (Korean).

Discussion

- **Between-language neural decoding** yields above-chance accuracies for number but not words and the tense feature

➢ Consistent with previous fMRI study that reports **crosslinguistic similarities in processing number** in English, Chinese and French (Dunagan et al., 2022)

Discussion

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➢ Consistent with previous fMRI study that reports **crosslinguistic similarities in processing number** in English, Chinese and French (Dunagan et al., 2022)

➢ **Lexical items (nouns and verbs)** in two languages may share some conceptual representations, but not to the extent for a classifier to learn patterns from for successful decoding from scalp EEG

Thank you!

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Study 1: Cho, J. & Brennan, J. R. (2025). Decoding of lexical items and grammatical features in EEG: A crosslinguistic study. *Neuropsychologia.* https://doi.org/10.1016/j.neuropsychologia.2025.109150.

Study 2: Cho, J. & Brennan, J. R. (2025). Cross-linguistic representation of prefixes for early and late bilinguals. *Bilingualism: Language and Cognition.* https://doi.org/10.1017/S136672892400107X.

Study 3: Cho, J., Pires, A., & Brennan, J. R. (2024). How large are root and affix priming effects in visual word recognition? Estimation from original data and a Bayesian meta-analysis. *Language, Cognition, and Neuroscience.* https://doi.org/10.1080/23273798.2024.2384051.

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