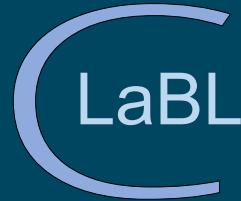




UiT The Arctic University of Norway



The Research Council
of Norway



Unpacking ERP Responses in Artificial Language Learning

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in collaboration with

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Jorge González Alonso

13 February 2025

 <https://osf.io/974k8>



Morphosyntactic transfer

- Initial heuristics
- Cognitive economy
- Facilitative or non-facilitative

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- Third language (L3) context
 - transfer source(s) selected
 - information guiding the selection
 - time course of the selection

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LESS Project
Linguistic Economy through
transfer Source Selectivity

Transfer in L3 acquisition

Sources

Transfer in L3 acquisition

Sources

L2 by default

L1 and/or L2

Transfer in L3 acquisition

Sources

L2 by default { L2 Status Factor Model (Bardel & Falk, 2012)

- L2 by default. Declarative memory for L2 and subsequent languages

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and/or
L2**

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- Property-by-property and only facilitative

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Linguistic Proximity Model (Westergaard et al., 2017)

- Property-by-property, with facilitative and non-facilitative outcomes

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 - Property-by-property and only facilitative
 - Linguistic Proximity Model (Westergaard et al., 2017)
 - Property-by-property, with facilitative and non-facilitative cases
 - Typological Primacy Model (Rothman, 2011)
 - Full transfer from one language, based on overall structural similarity

Morphosyntactic transfer in L3 acquisition

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- **Confounds** when using natural languages: age of acquisition, frequency of use, proficiency level, morphological salience, etc.

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Consider Buzz Lightyear versus Woody
versus humans.

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 - Similar processing signatures (Friederici et al., 2002; Uddén & Mänel, 2018)

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 - Consistency with natural language
 - Acquired by statistical learning (Hudson Kam & Newport, 2005; Kidd, 2012; Monaghan et al., 2023)
 - Similar processing signatures (Friederici et al., 2002; Uddén & Männel, 2018)
 - An extensive training in the artificial language could be necessary for standard syntactic signatures (notably, P600) to appear in ERPs (González Alonso et al., 2020; Pereira Soares et al., 2022).

González Alonso et al. (2020)

- **Participants:** L1 Spanish, L2 English
- **Artificial language groups:** Mini-Spanish ($n = 26$), Mini-English ($n = 24$)
- **Grammatical property:** gender agreement between nouns and predicative adjectives in copular sentences. Example:
 - Mini-Spanish: *Jer mochil son carejur* | *Jer mochil son baratejur*
 - Mini-English: *Jer bag are expensivejur* | *Jer bag are cheapjur*
 - Translation: The bags are expensive | The bags are cheap
- **Session phases:** vocabulary pre-training → grammatical training → test (min. 80%) → ERP experiment → gender assignment task in Spanish

González Alonso et al. (2020)

Artificial languages

MINI-SPANISH				MINI-ENGLISH			
Nouns				Nouns			
Feminine		Masculine		Feminine		Masculine	
<i>mochil, taz, ventan,</i>		<i>cuchil, gor, roper,</i>		<i>bag, cup, window, wall,</i>		<i>knife, hat, closet, truck,</i>	
<i>pared, llave, calle.</i>		<i>camion, reloj, lapis</i>		<i>key, street</i>		<i>watch, pencil</i>	
Adjectives				Adjectives			
<i>amarill-, roj-, pequen-, grand-, nov-, vej-, suci-,</i>		<i>yellow-, red-, small-, big-, new-, old-, dirty-,</i>					
<i>limpi-, barat-, car-, cort-, larg-</i>		<i>clean-, cheap-, expensiv-, short-, long-</i>					
Inflectional affixes				Inflectional affixes			
Feminine		Masculine		Feminine		Masculine	
Singular	Plural	Singular	Plural	Singular	Plural	Singular	Plural
<i>-eju</i>	<i>-ejur</i>	<i>-ezu</i>	<i>-ezur</i>	<i>-eju</i>	<i>-ejur</i>	<i>-ezu</i>	<i>-ezur</i>
Article				Article			
Feminine		Masculine		Feminine		Masculine	
Singular	Plural	Singular	Plural	Singular	Plural	Singular	Plural
<i>je</i>	<i>jer</i>	<i>ze</i>	<i>zer</i>	<i>je</i>	<i>Jer</i>	<i>ze</i>	<i>zer</i>
Copula				Copula			
Singular		Plural		Singular		Plural	
<i>es</i>		<i>son</i>		<i>Is</i>		<i>are</i>	
Conjunction				Conjunction			
<i>y</i>				<i>And</i>			
Adverb				Adverb			
<i>Tambien</i>				<i>Too</i>			
Locatives				Locatives			
<i>arriba, abajo</i>				<i>above, below</i>			
Example sentence				Example sentence			
<i>Je mochil es barategu.</i>				<i>Je bag is cheapeju</i>			
<i>“The bag is cheap.”</i>				<i>“The bag is cheap.”</i>			

González Alonso
et al. (2020)

Pre-training

González Alonso
et al. (2020)

Training

González Alonso
et al. (2020)

Test

González Alonso
et al. (2020)

Experiment

González Alonso
et al. (2020)

**Gender assignment
task in Spanish**

González Alonso et al. (2020)

Hypotheses (based on Rothman et al., 2015) under the assumption that transfer would happen *before* the ERP measurement.

Language combination	L2 Status Factor	CEM	TPM
L1 Spanish-L2 English	No effect	(N400)–P600	No effect
L3 Mini-English			
L1 Spanish-L2 English	No effect	(N400)–P600	(N400)–P600
L3 Mini-Spanish			

González Alonso et al. (2020)

Results

- **Mini-Spanish group:** broadly distributed 300–600 ms positivity, most consistent with attention-related P300.
- **No (N400)–P600**
- **Interpretation:** allocation of attentional resources in preparation for the selection of transfer source(s). In Mini-Spanish, larger focus on word-final gender morphology, consistent with Spanish.

Pereira Soares et al. (2022)

Materials

- (1) Ge. der-NOM.M Koch-NOM.M vs. den-ACC.M Koch-ACC.M
It. il-NOM.M cuoco-NOM.M vs. il-ACC.M cuoco-ACC.M
Lat. magirus-NOM.M vs. magirum-ACC.M
the cook the cook
'The cook'
- (2) Ge. Die-NOM.F Braut-NOM.F vs. die-ACC.F Braut-ACC.F
It. La- NOM.F sposa- NOM.F vs. la-ACC.F sposa-ACC.F
Lat. Nupta-NOM.F vs. nuptam-ACC.F
the bride the bride
'The bride'

Pereira Soares et al. (2022)

Hypotheses (based on Rothman et al., 2015) under the assumption that transfer would happen *before* the ERP measurement.

Language combination	Case morphology		Adjective position	
	TPM	LPM/SM	TPM	LPM/SM
L1 Italian—L1 German (L2 English)—L3 Mini-Latin	No effect	(N400)-P600	(N400)-P600	(N400)-P600
L1 German—L2 English—L3 Mini-Latin	No effect	(N400)-P600	No effect	No effect

Pereira Soares et al. (2022)

Results

- From the abstract: [...] “N200/N400 deflection for the HSs in case morphology and a P600 effect for the German L2 group in adjectival position. None of the current L3/Ln models predict the observed results, which questions the appropriateness of this methodology.”

Our study

- Sites: Tromsø and Madrid
- Several groups per site
- Six sessions
- Three executive functions
- Three grammatical properties
- Several parts per session

Grammatical properties, examples, and presence in natural languages

Gender agreement

Zer watch are yellowezur and ...

in Spanish and Norwegian

Differential object marking

Jessica provided fi ze key and ...

in Spanish

Verb-object number agreement

John cleanedevo fi zer fikey and...

in none of these languages

Wrap-up buffer: ... *and ze watch too*

Sentence wrap-up effects: Real? Dogma? Real?

- Just and Carpenter (1980)
- Stowe et al. (2018)
- Desbordes et al. (2023)
- Meister et al. (2022)

Wrap-up buffer: ... and ze watch too

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Property	Artificial lang.
Gender agreement	Mini-Norwegian
	Mini-English
Differential object marking	Mini-Norwegian
	Mini-English
Verb-object number agreem.	Mini-Norwegian
	Mini-English

Property	Group	Artificial lang.
Gender agreement	L1 Eng, L2 Spa	Mini-Spanish
	L1 Spa, L2 Eng	Mini-English
Differential object marking	L1 Eng, L2 Spa	Mini-Spanish
	L1 Spa, L2 Eng	Mini-English
Verb-object number agreement	L1 Eng, L2 Spa	Mini-Spanish
	L1 Spa, L2 Eng	Mini-English

Sessions

- **Session 1. Individual differences (home-based session)**
 - Working memory (digit span), selective attention (Stroop) and implicit learning (serial reaction time)
 - Language History Questionnaire (LHQ3; Li et al., 2020)

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- + 1 week: **Session 3. Differential object marking + Gender agreement**

- Training only in the new property
- Experiment part contains both properties intermixed

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- + 1 week: **Session 4. Verb-object agreement + Differential object marking + Gender agreement**

- Same mechanism as in the previous session

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- + 1 week: **Session 4. Verb-object agreement + Differential object marking + Gender agreement**

- Same mechanism as in the previous session

- + 1 week: **Session 5. Retest of executive functions** (home-based session)

Sessions

- **Session 1. Individual differences** (home-based session)

- Working memory (digit span), selective attention (Stroop) and implicit learning (serial reaction time)
- Language History Questionnaire (LHQ3; Li et al., 2020)

- + 1 week: **Session 2. Gender agreement**

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- + 1 week: **Session 3. Differential object marking + Gender agreement**

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- + 1 week: **Session 4. Verb-object agreement + Differential object marking + Gender agreement**

- Same mechanism as in the previous session

- + 1 week: **Session 5. Retest of executive functions** (home-based session)

- + 4 months: **Session 6. Retest of all grammatical properties** (Morgan-Short et al., 2012)

- Session ends with control tests on the relevant properties in the natural languages

Creation of the artificial languages

- **Cognates avoided:** lexicons tailored to Norwegian and Spanish sites.
- **Content words (n, adj, adv, v):** translated across the two artificial languages in each site, and ideally across the three mini-languages.
 - Must be picturable (González Alonso et al., 2020; Wendebourg et al., 2025)
 - Adjectives paired by meaning, mostly by antonymy.
- **Morphemes:** same across the two artificial languages in each site, and ideally across the three mini-languages.
- Design and materials described in González Alonso et al. (2025).

Stimulus creation: Phonological and semantic challenges

SPA_noun	ENG_noun	NOR_noun
habitación	bedroom	soverom
mochil	bag	bag
nuez	walnut	valnøtt
perch	hanger	henger
raiz	root	rot
taz	cup	kopp
ventan	window	vindu
aguacate	avocado	avokado
cuchil	knife	kniv
gor	hat	hatt
reloj	watch	klokke
zapat	shoe	sko

malet	suitcase	koffert
mes	table	bord
etiquet	label	merkelapp

blue	bla
white	hvit
first	foerst
last	sist
good	bra
bad	daarlig
easy	lett

Creation of the artificial languages

- Modular framework formed of interoperable components
- Minimal components of each language contained in a base file
- Linguistic and visual stimuli finally presented are created by assembling minimal components.
- Several controls exerted on the stimuli to prevent spurious effects. For instance, gender and number are counterbalanced across experimental conditions. Similarly, words and experimental conditions within the same set appear equally often.

```
# Following González Alonso et al. (2020), create lists to counterbalance
# grammaticality conditions across noun-adjective combinations.
#
# List 1: grammatical, gender violation, number violation
# List 2: gender violation, number violation, grammatical
# List 3: number violation, grammatical, gender violation
#
# In each list, all nouns and all adjectives appear equally often. Furthermore, every
# noun in the initial determiner phrase (here called `noun1`) appears as often in
# singular as in plural. These lists will be administered to different participants.

combinations = 

  # List 1
  combinations %>%
    mutate(list = 'List 1: grammatical, gender violation, number violation',
          grammaticality = rep(c('grammatical', 'gender violation', 'number violation'),
                                each = n()/3)) %>%

    # Ensure every noun1 (i.e., initial determiner phrase)
    # appears as often in singular as in plural.
    group_by(noun1) %>%
      mutate(number = rep(c('singular', 'plural'), each = n()/2)) %>%
      ungroup() %>%

    # Add subsequent lists
    rbind(
      # List 2
      combinations %>%
        mutate(list = 'List 2: gender violation, number violation, grammatical')
```

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- All stimuli compiled through R scripts

- R combine_Session3_experiments.R
- R Session2_Experiment_gender_agreement.R
- R Session2_Pretraining_vocabulary.R
- R Session2_Test_gender_agreement.R
- R Session2_Training_gender_agreement.R
- R Session3_Experiment_differential_object_mark
- R Session3_Experiment_gender_agreement.R
- R Session3_Pretraining_vocabulary.R
- R Session3_Test_differential_object_marking.R
- R Session3_Training_differential_object_marking

All scripts are run
from a core script.

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- Parallel lists of stimuli used to enable some of the controls
- Open-source software OpenSesame used to present the stimuli and collect responses

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- All stimuli compiled through R scripts
- Present framework facilitates reproducibility and inspection of stimuli, and allows extensions
- Parallel lists of stimuli used to enable some of the controls
- Open-source software OpenSesame used to present the stimuli and collect responses
-  Reproducible, testable, reusable materials available at <https://osf.io/wbjyr>



Stimuli ahead

- Example of stimuli presented next include different mini-languages.
- Mini-languages were distributed between groups. Each participant saw one mini-language only.
- **Semantic information**, particularly using **pictures**, helps in artificial language learning. It boosts **performance**, reduces **perceived effort** and increases **enjoyment** (Wendebourg et al., 2025).

Gender agreement

- Introduced, trained on and tested on in Session 2
- Maintained across subsequent sessions

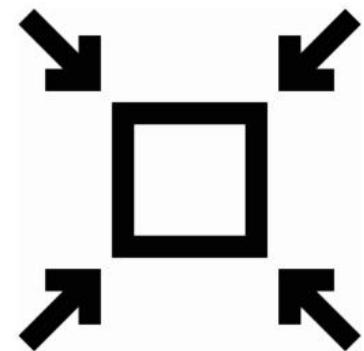
Training in gender agreement



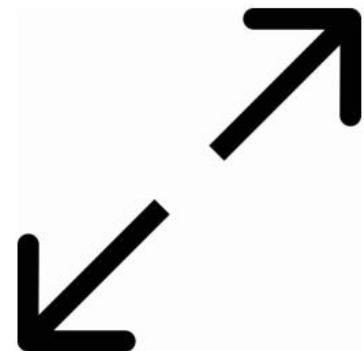
Zer closet are expensivezur.

Zer closet are cheapezur.

Training in gender agreement

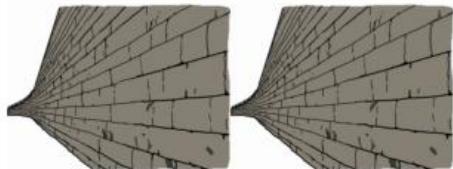


Bordze er litenezu.

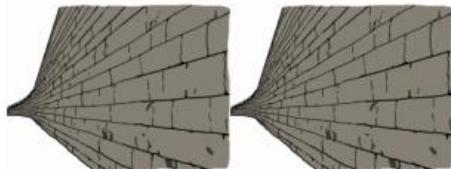


Bordze er storezu.

Locative filler during training



Veggjer er over lastebiljer.



Veggjer er over noekkeljer.

Test on gender agreement - Session 2

Match image to one of five sentences

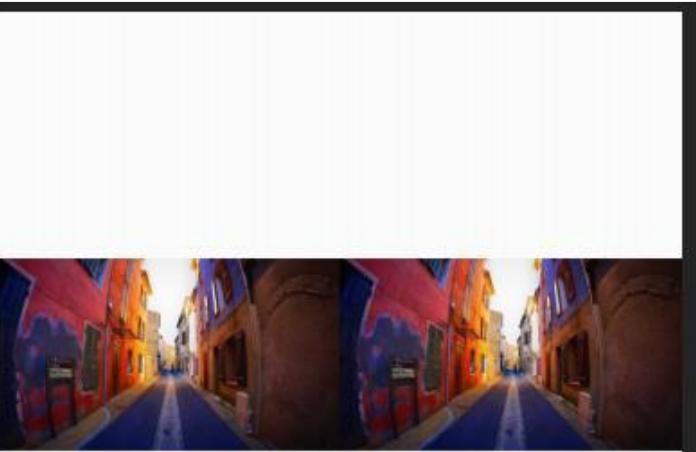
1. Correct
2. Gender agreement violation
3. Number agreement violation
4. Gender and number agreement violation
5. Semantic violation (i.e., opposite adjective)

Test on gender agreement - Session 2

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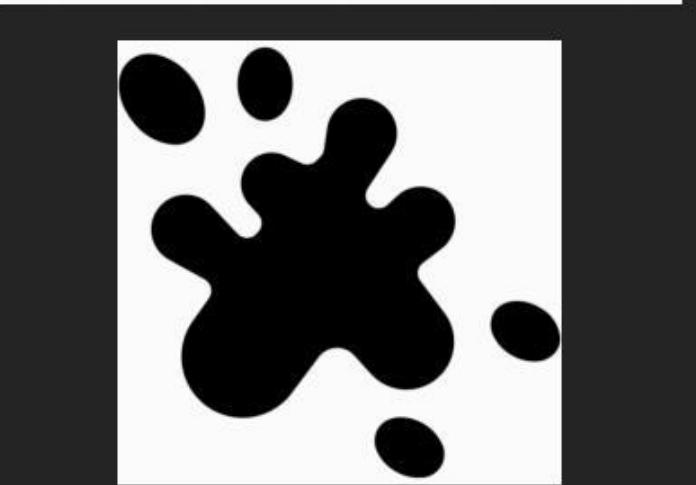
If accuracy < 80%, training and test are repeated.



Jer street are cleanejur.



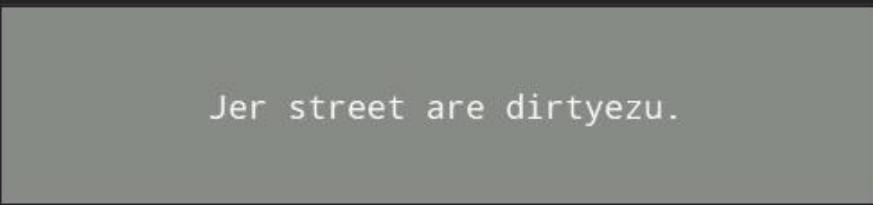
Jer street are dirtyeju.



Jer street are dirtyezur.



Jer street are dirtyejur.



Jer street are dirtyezu.



Differential object marking

- Introduced, trained on and tested on in Session 3
- Maintained across subsequent sessions

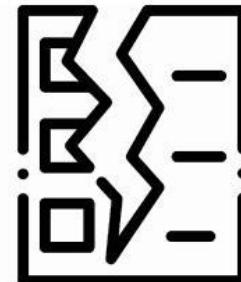
Training in differential object marking

olivia



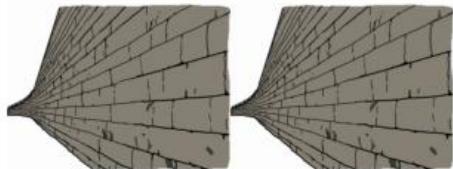
Olivia fixed fi ze closet.

olivia

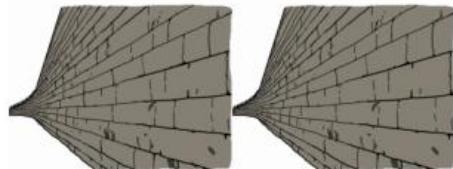


Olivia spoiled fi ze closet.

Locative filler during training



Veggjer er over lastebiljer.



Veggjer er over noekkeljer.

Test on differential object marking - Session 3

Match image to one of five sentences

1. Correct
2. DOM violation (i.e., object noun without DOM)
3. Article with number violation
4. Misplaced article
5. Noun with semantic violation (i.e., noun different from image)

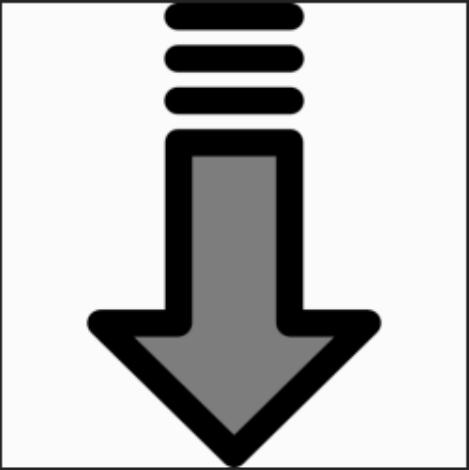
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3. Article with number violation
4. Misplaced article
5. Noun with semantic violation (i.e., noun different from image)

If accuracy < 80%, training and test are repeated.

Amelia



Amelia provided fi ze mug.

Amelia provided fi ze letter.

Amelia provided ze letter.

Amelia provided fi zer letter.

Amelia provided fi zeletter.



Verb-object number agreement

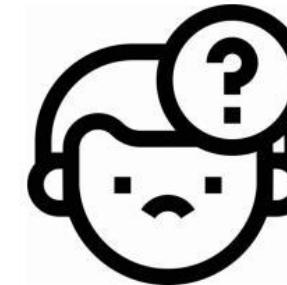
Training in verb-object number agreement

Thomas



Thomas rememberevo fi jer drum.

Thomas



Thomas forgotevo fi jer drum.

Test on verb-object number agreement

Jessica	Jessica rememberedevō fi jer drum.
	Jessica rememberedevō fi je drum.
	Jessica remembered fi jer drum.
	Jessica rememberedevō fi jer box.
	Jessica rememberedevō fi jerdrum.



Test on verb-object number agreement

Jessica

Jessica rememberedevo fi jer drum.

Jessica rememberedevo fi je drum.

Jessica remembered fi jer drum.

Jessica rememberedevo fi jer box.

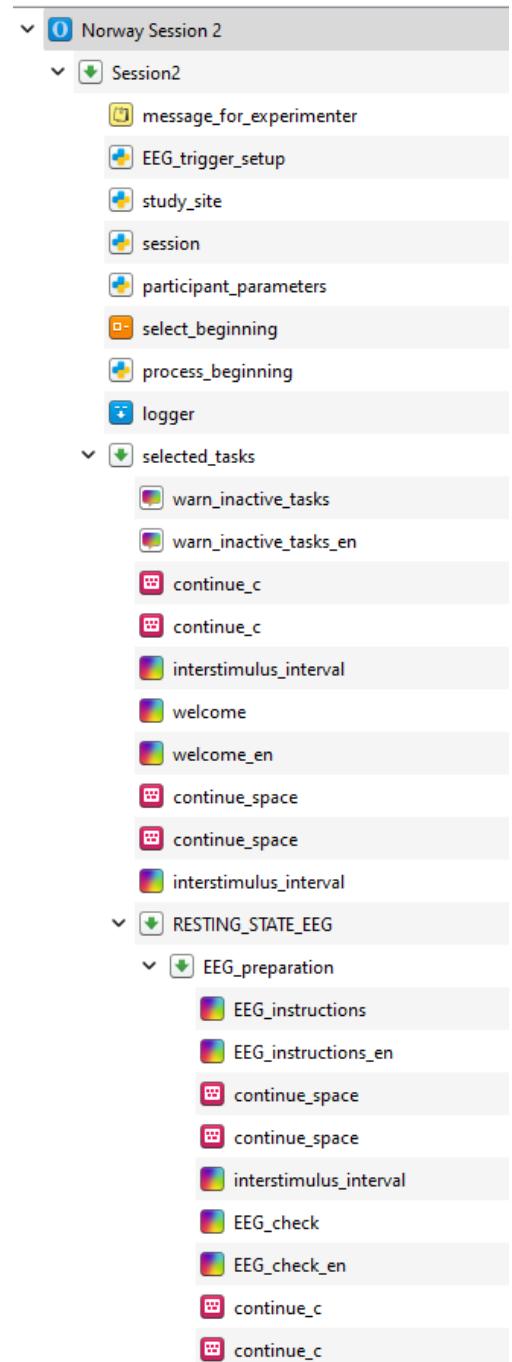
Jessica rememberedevo fi jerdrum.

If accuracy < 80%, training and test are repeated.

Examples of *control* conditions

Lab sessions

- Instructions written in the language corresponding to each artificial language group (e.g., in Norwegian for the Mini-Norwegian group).
- Sufficient written instructions to avoid linguistic influence through spoken explanations.

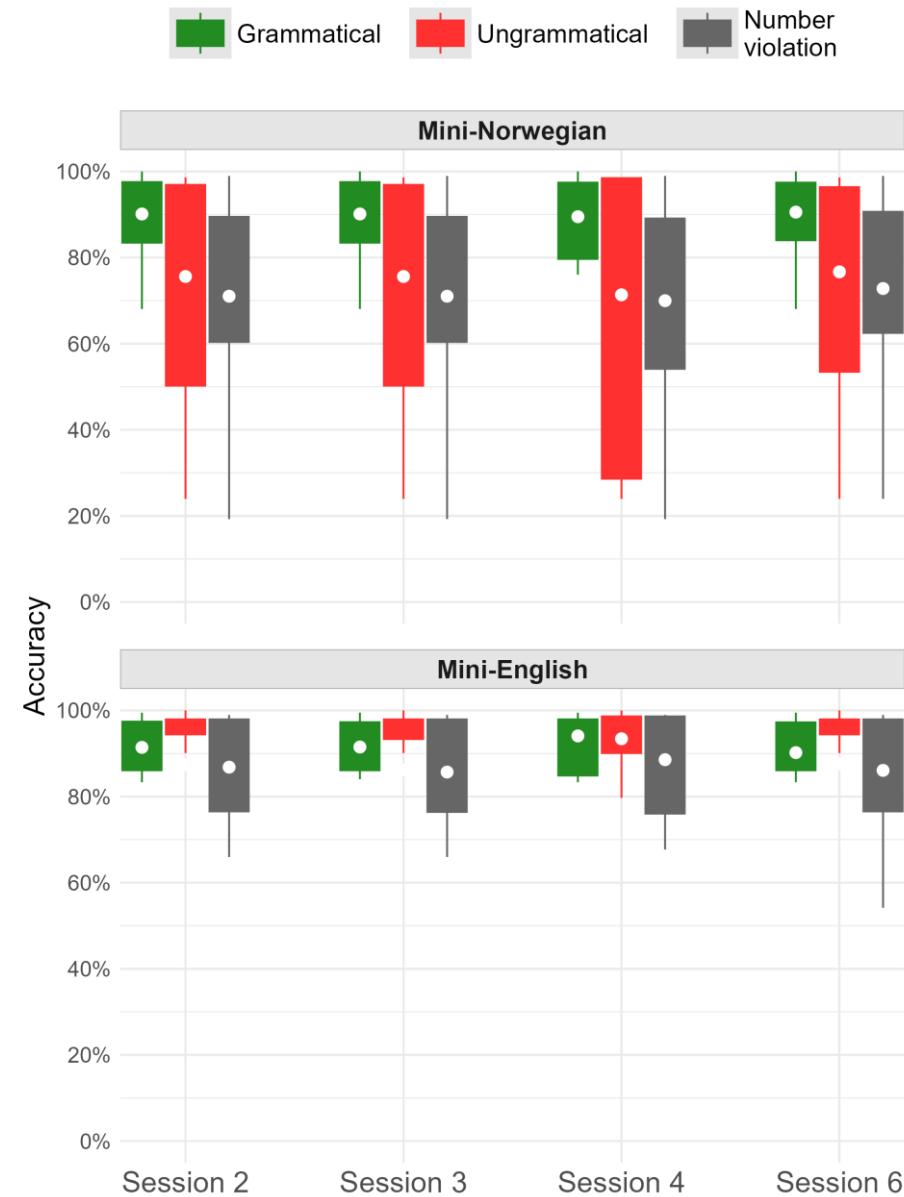


Preliminary results

- ~ 23 participants per mini-language group by Session 5
- ~ 11 participants per mini-language group by Session 6
- Data collection will continue over the next few months.

Accuracy of grammaticality judgements

Accuracy on gender agreement in the experiment

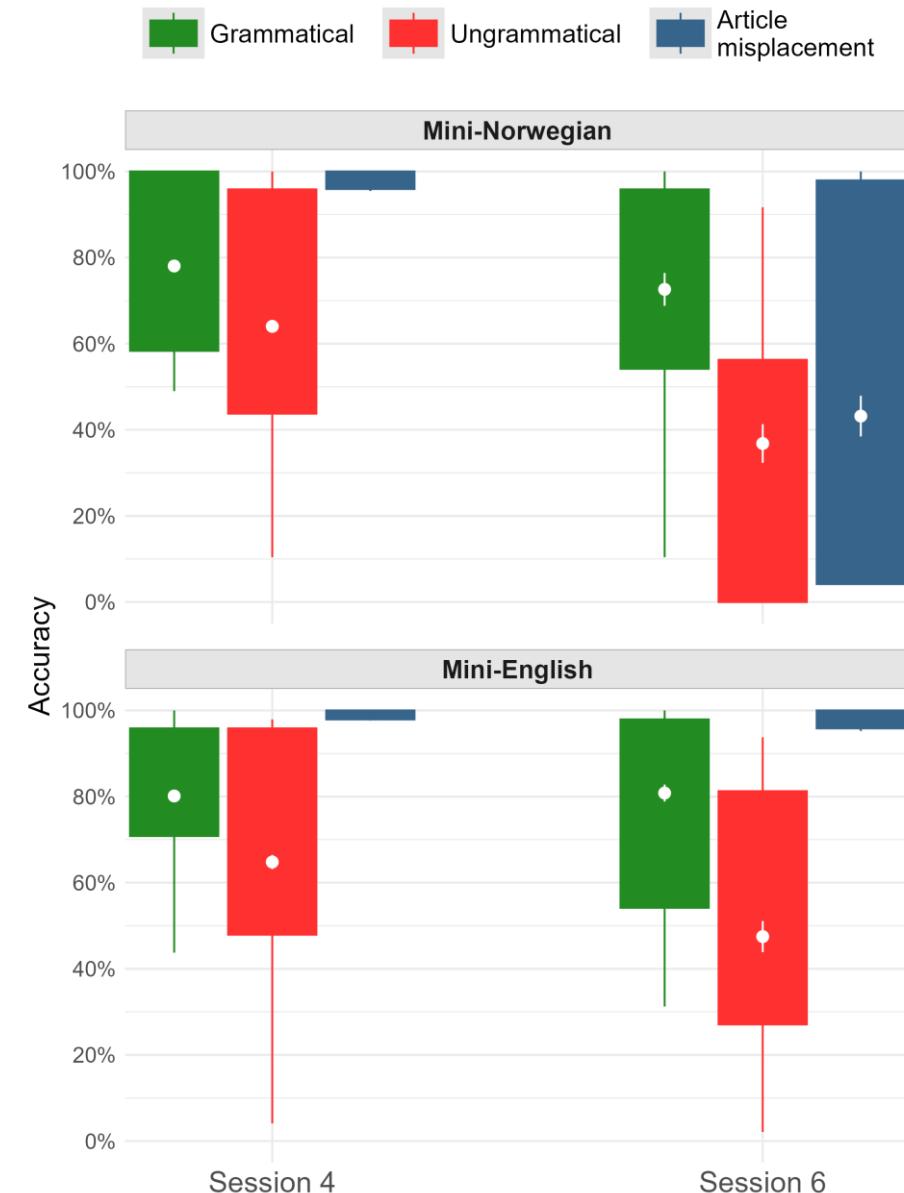


Accuracy on differential object marking in the experiment

Grammatical Ungrammatical Article
misplacement



Accuracy on verb-object agreement in the experiment



Event-related potentials

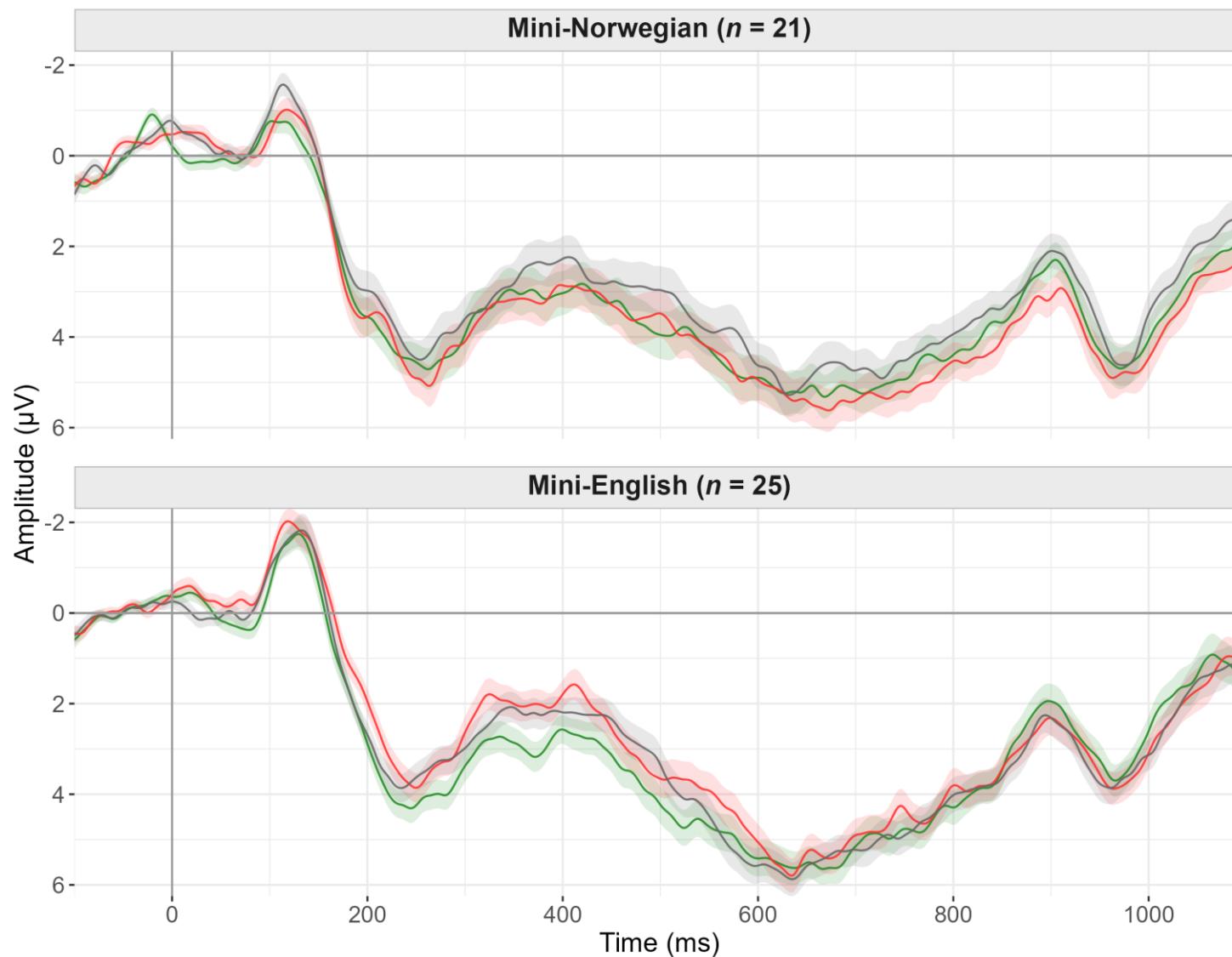
To be presented next...

- **Midline medial region:** generally representative of other regions in the current data.
- **Per grammatical property**
 - Per **session**

Gender agreement

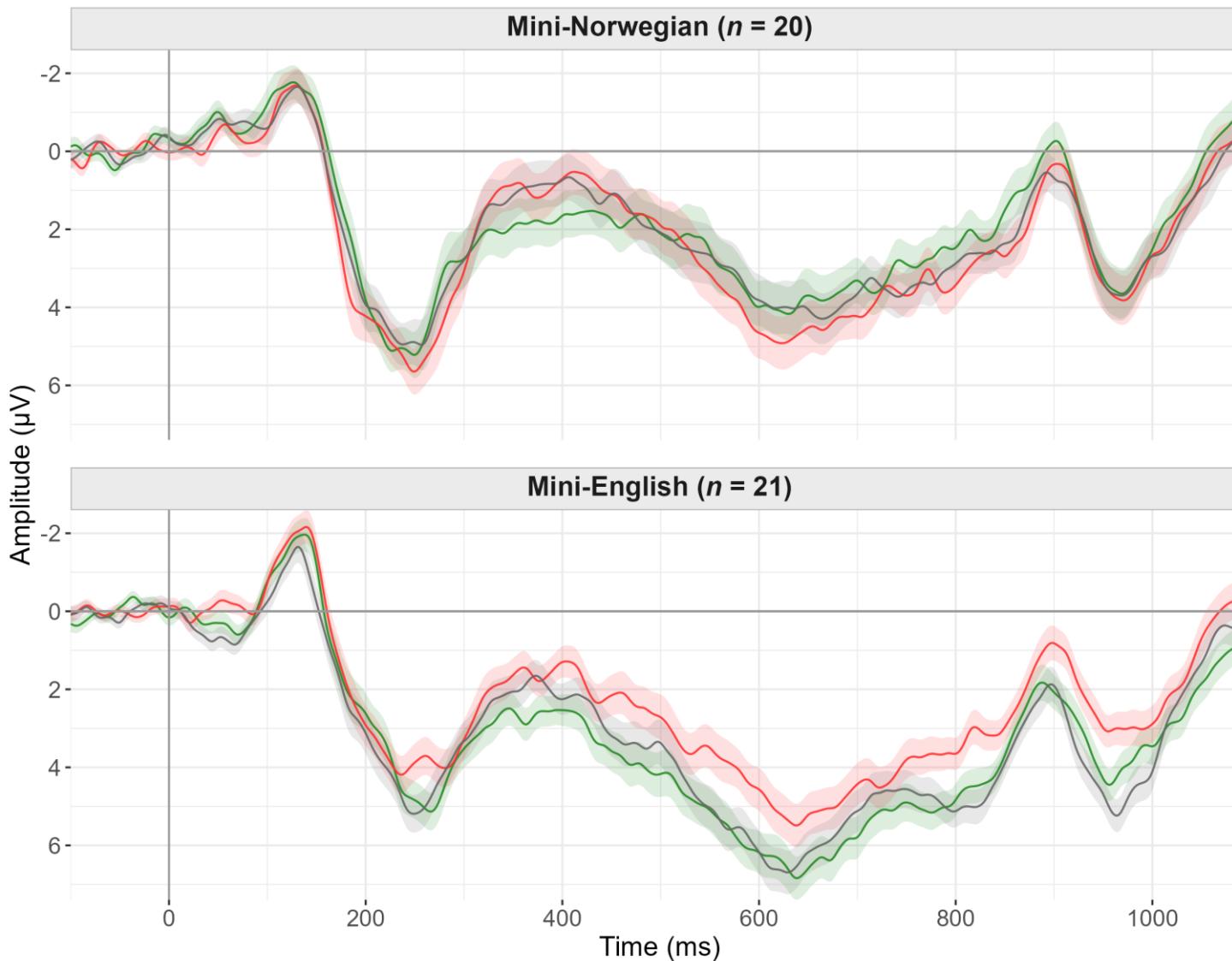
Gender agreement; Session 2; Midline medial region

Grammatical Ungrammatical Number violation



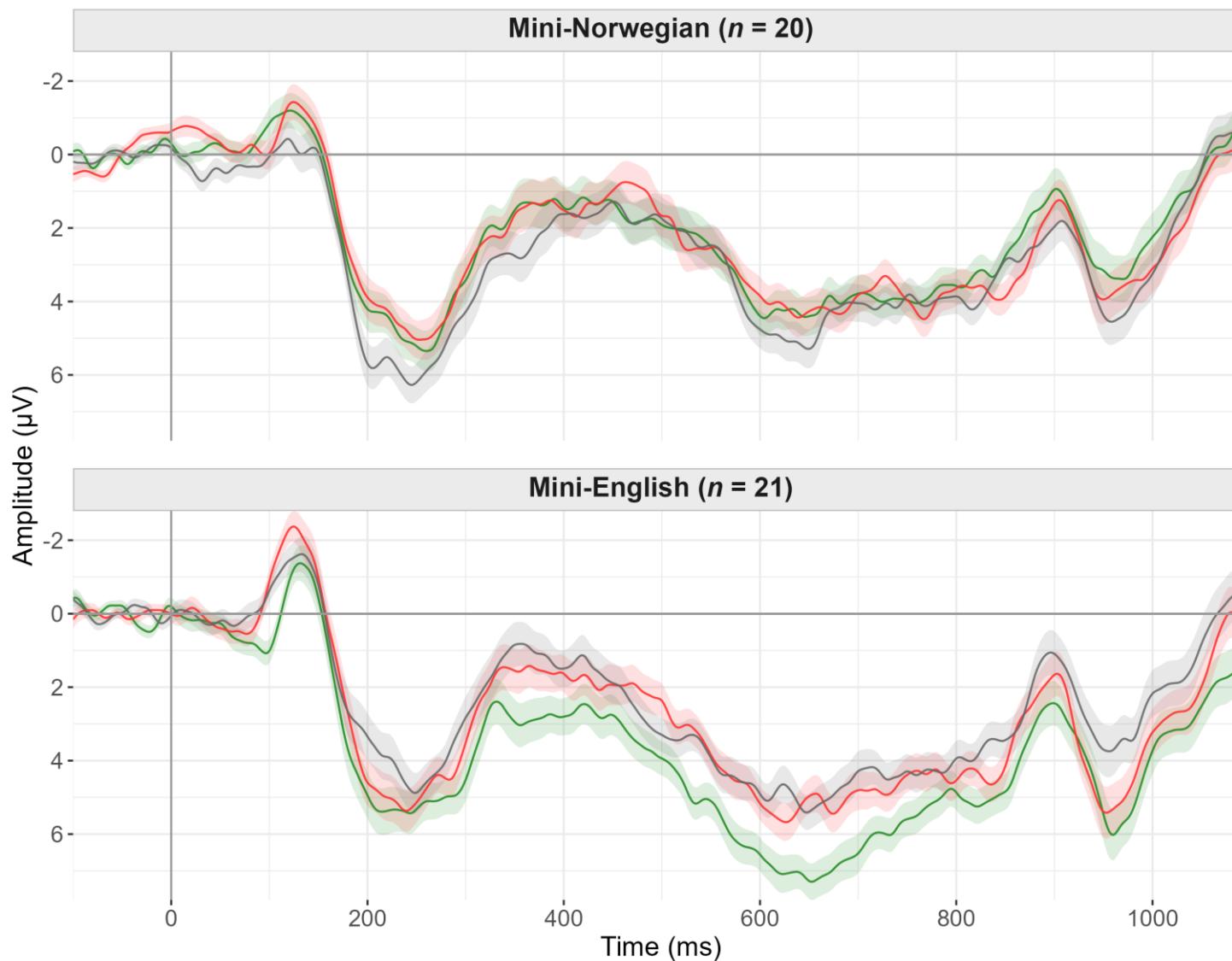
Gender agreement; Session 3; Midline medial region

Grammatical Ungrammatical Number violation



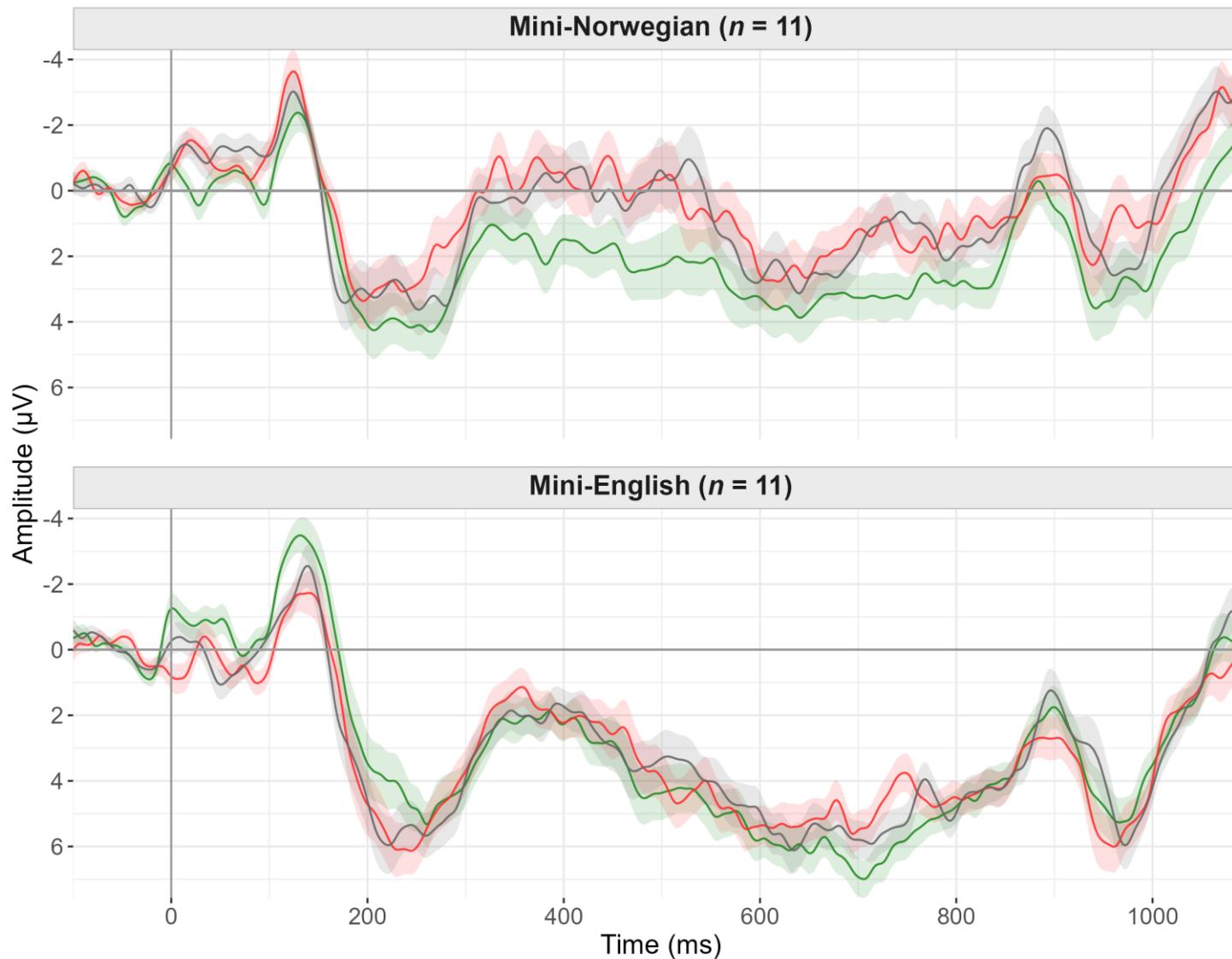
Gender agreement; Session 4; Midline medial region

Grammatical Ungrammatical Number violation



Gender agreement; Session 6; Midline medial region

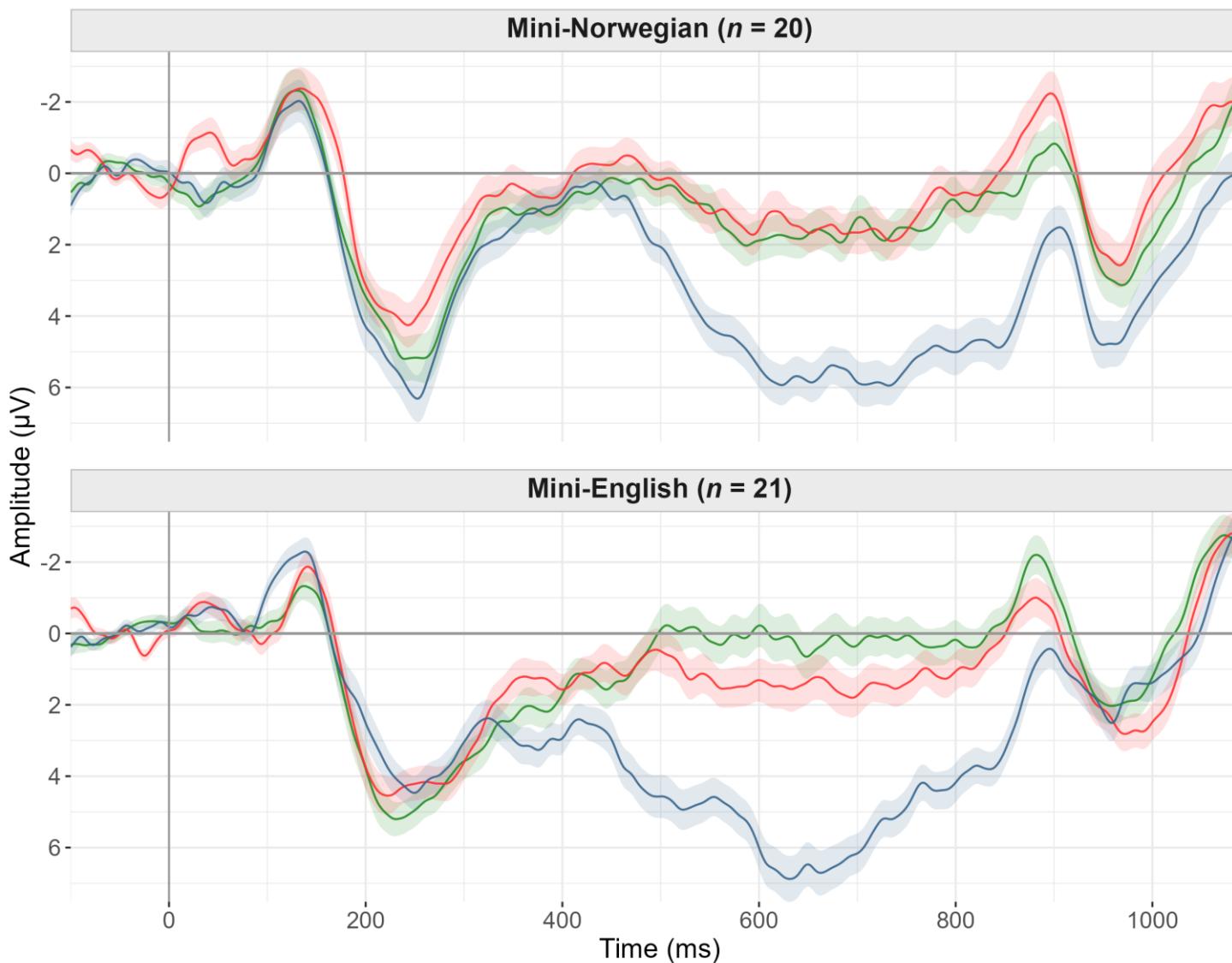
Grammatical Ungrammatical Number violation



Differential object marking

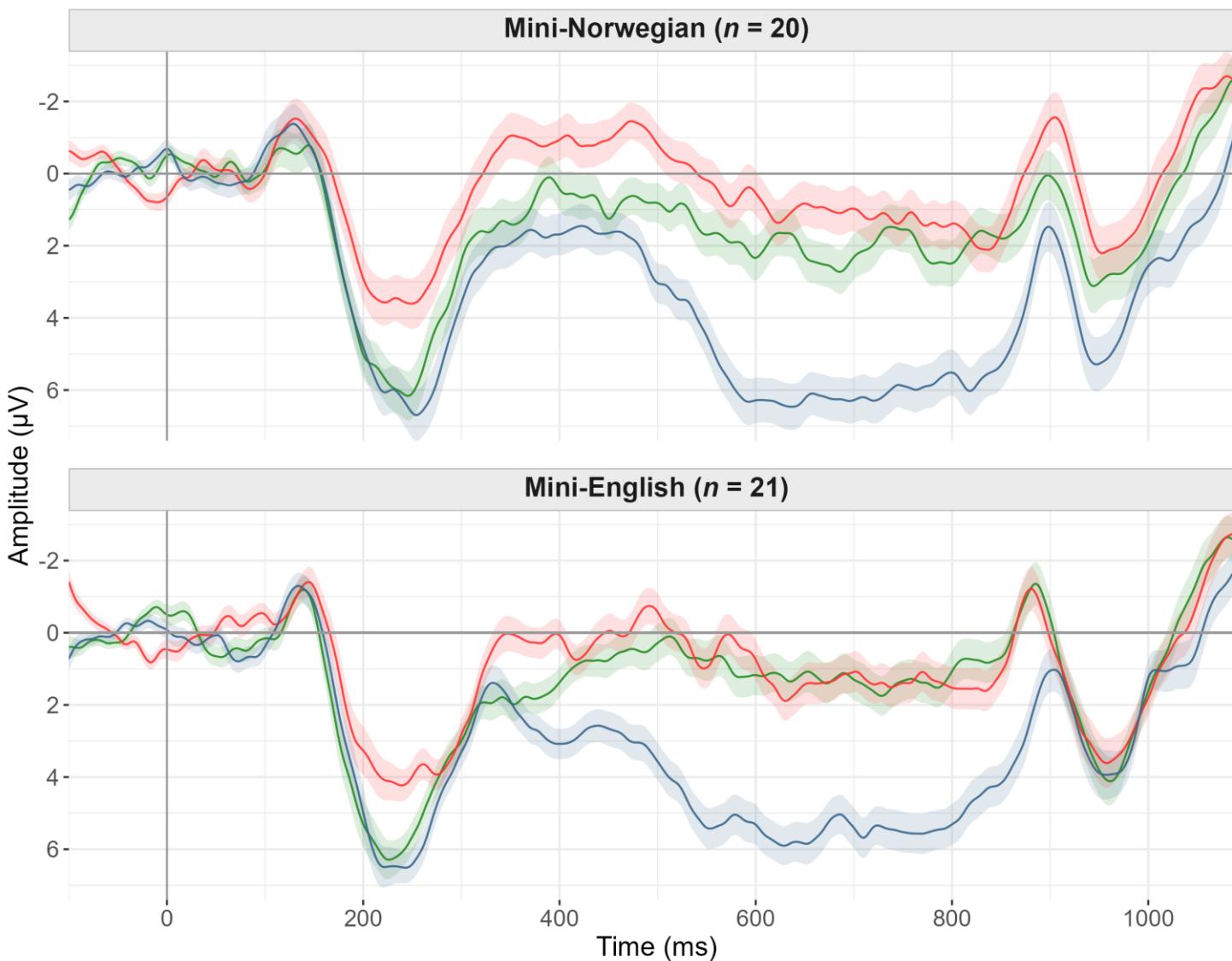
Differential object marking; Session 3; Midline medial region

Grammatical Ungrammatical Article
misplacement



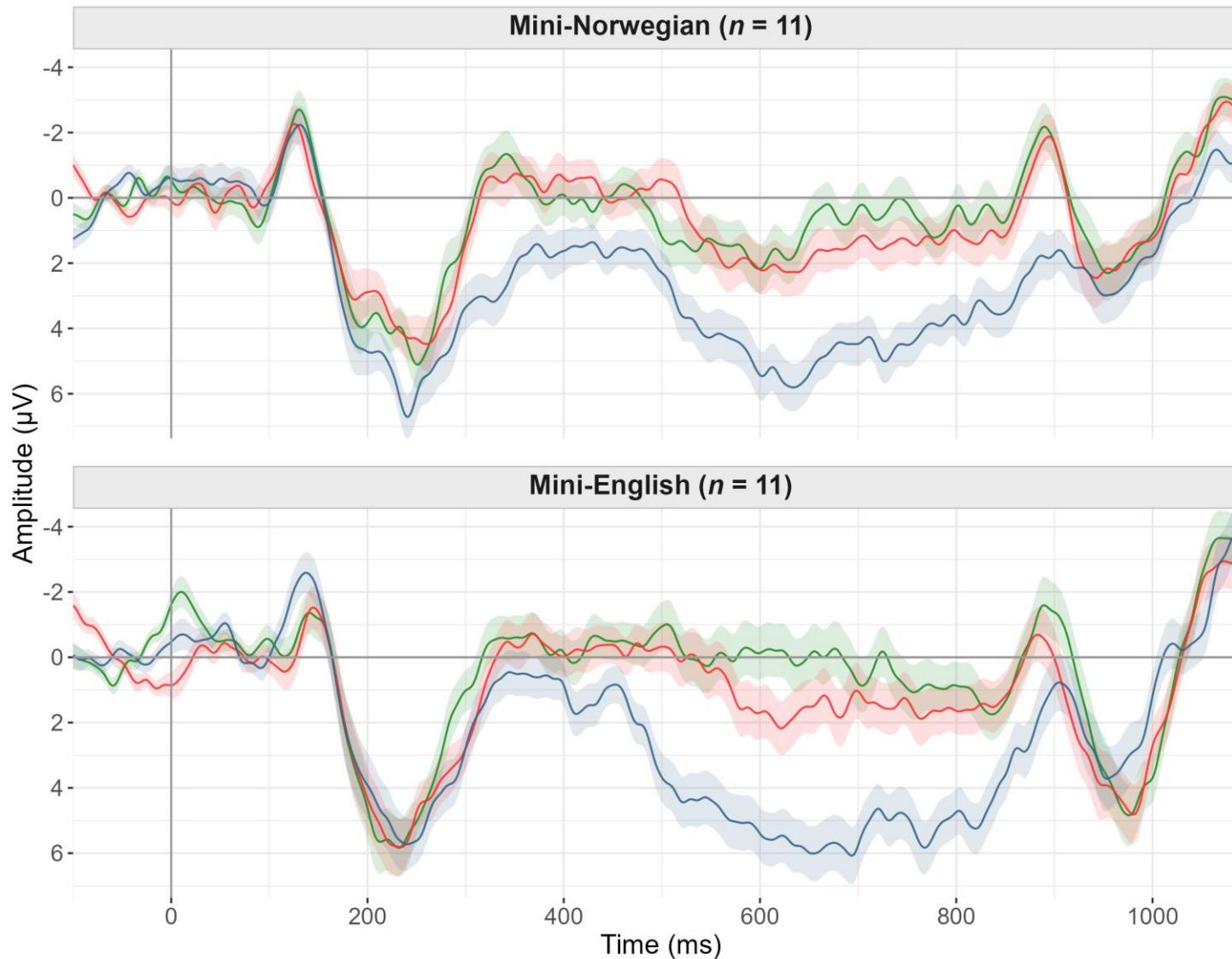
Differential object marking; Session 4; Midline medial region

Grammatical Ungrammatical Article
misplacement



Differential object marking; Session 6; Midline medial region

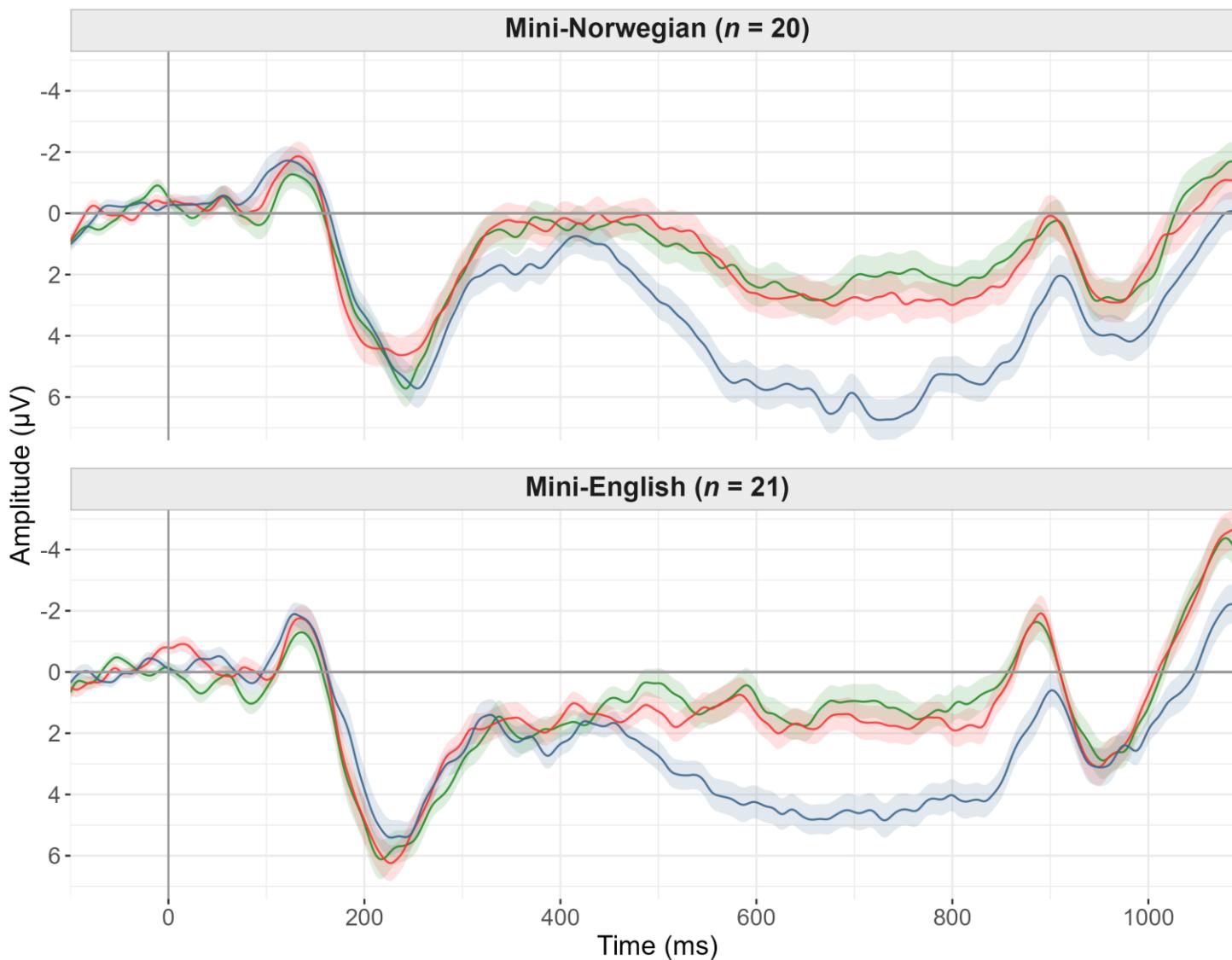
Grammatical Ungrammatical Article
misplacement



Verb-object agreement

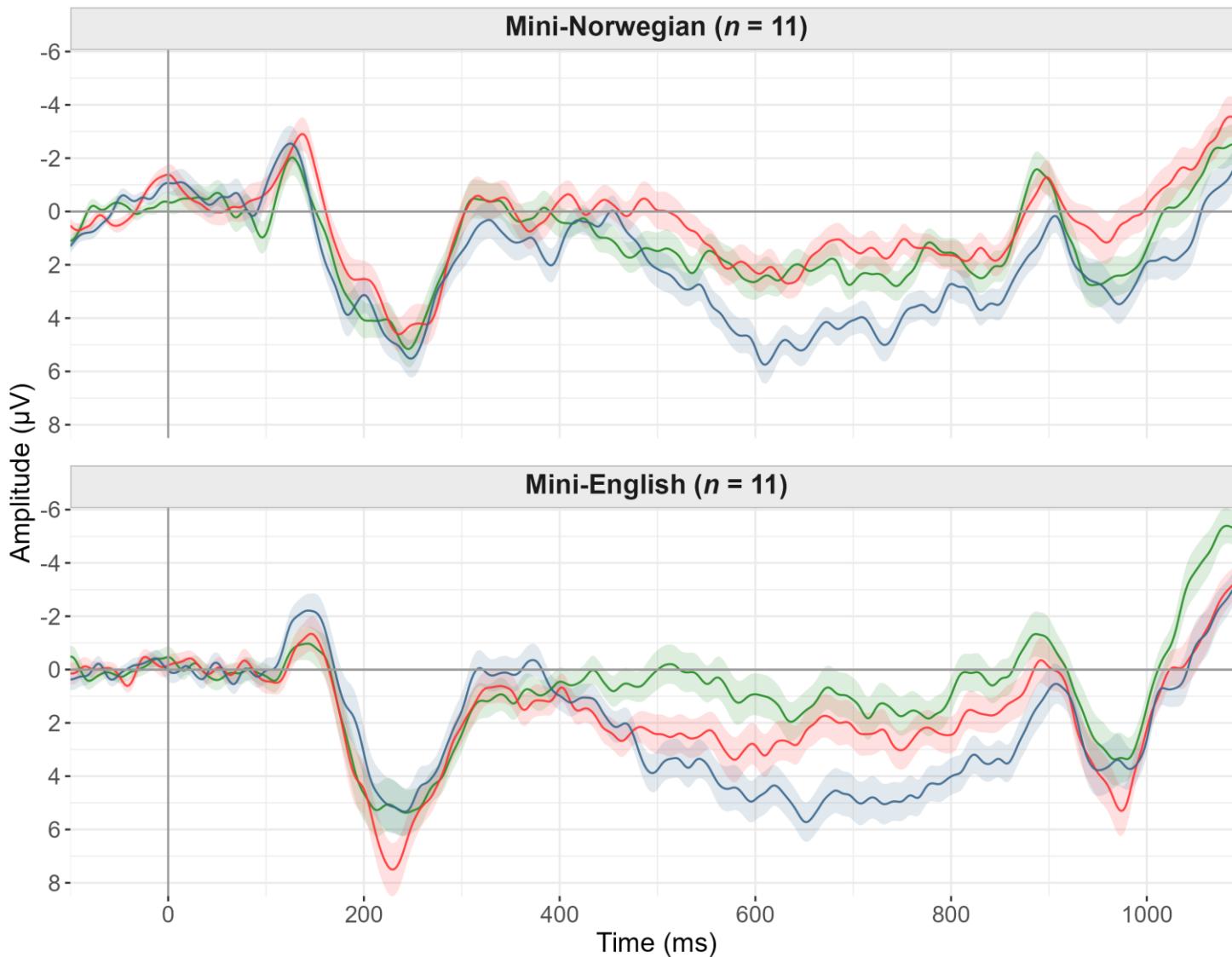
Verb-object number agreement; Session 4; Midline medial region

Grammatical Ungrammatical Article
misplacement



Verb-object number agreement; Session 6; Midline medial region

Grammatical Ungrammatical Article
misplacement



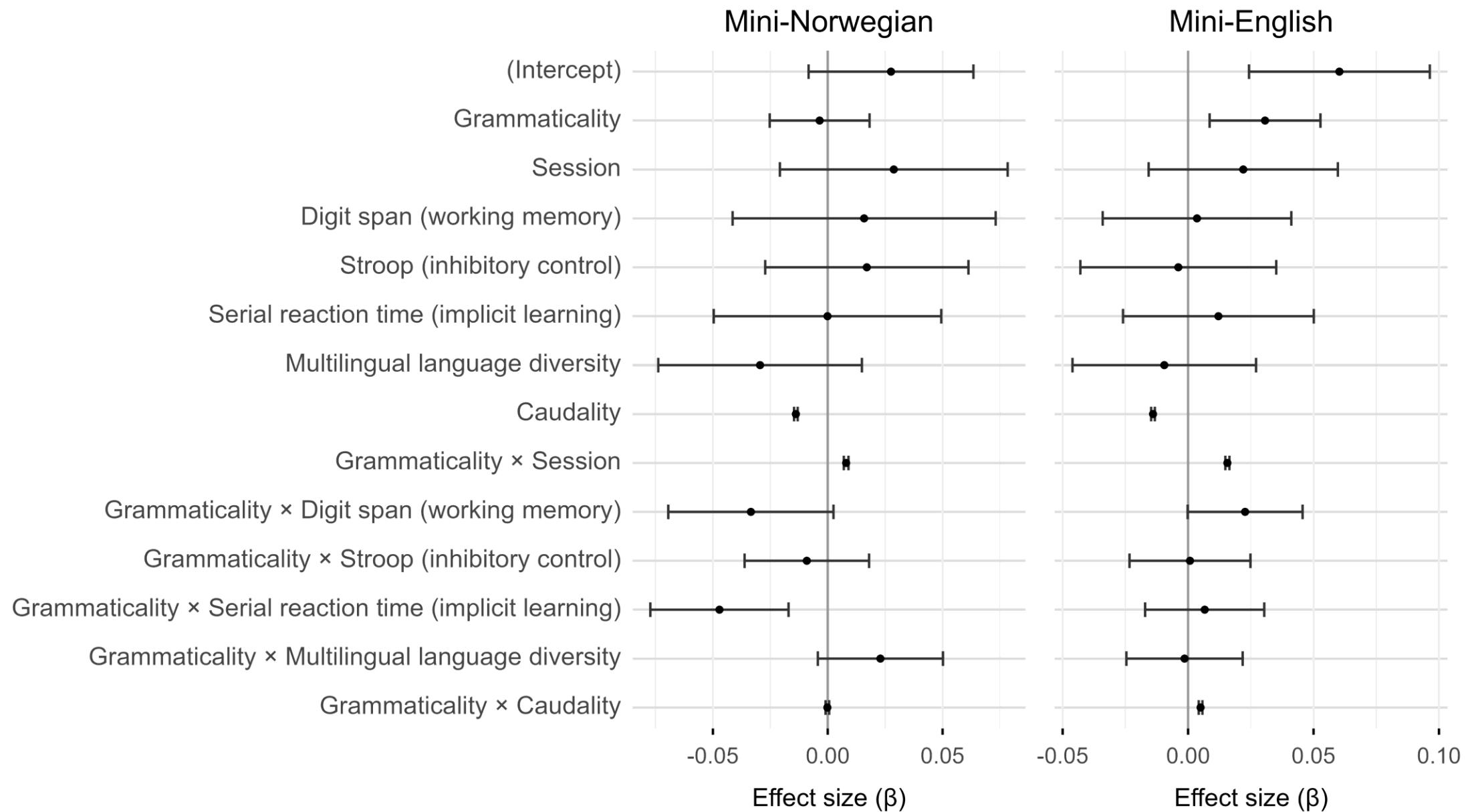
P600-like effect for misplaced articles

- Control effect is informative.
- Data is sensitive enough to detect such a large effect, suggesting data and preprocessing are sound.
- This effect can be compared with the effects of interest, even though smaller effects are expected for the latter.

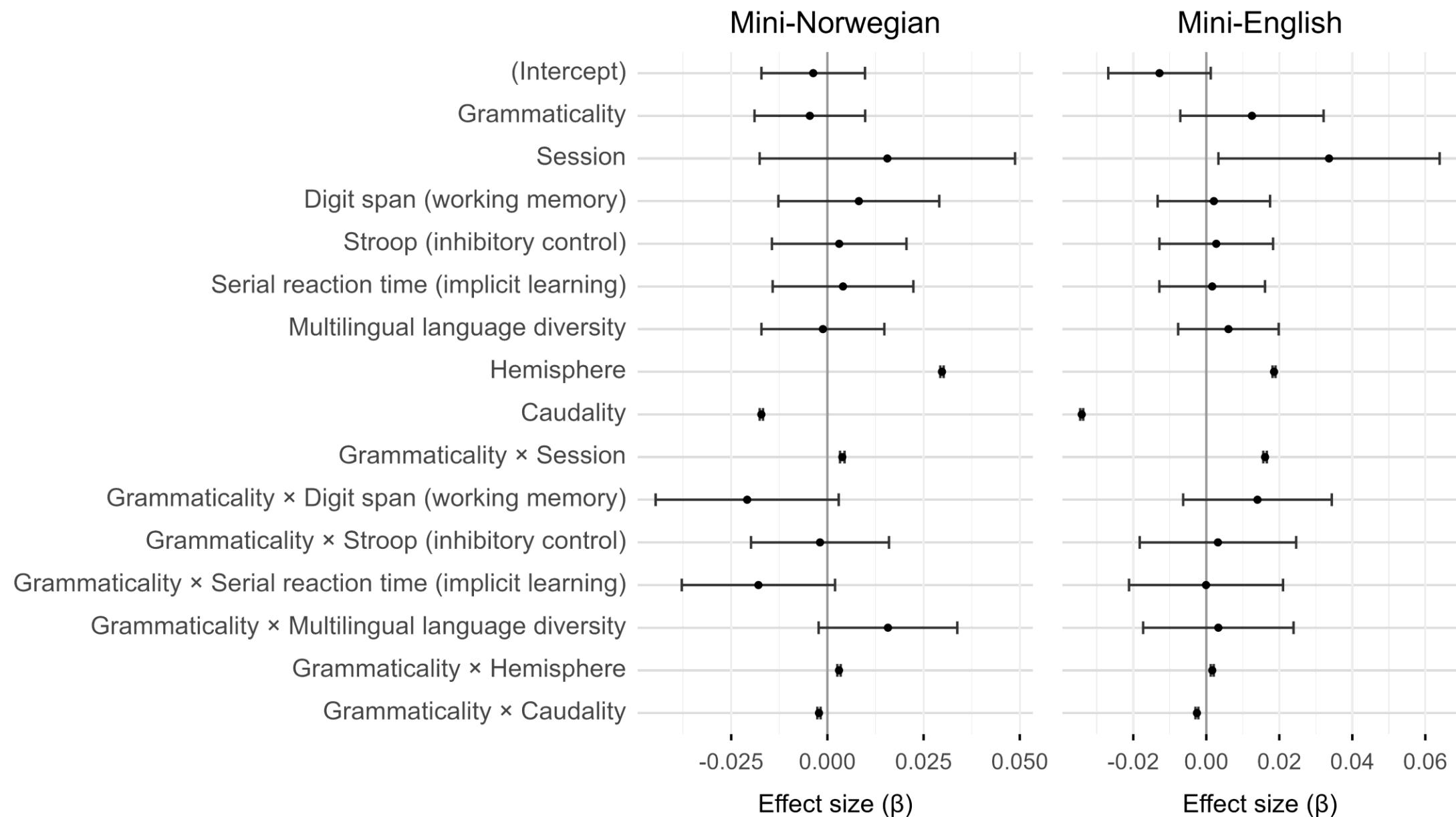
Analysis of ERPs for gender agreement

- Data filtered to **grammatical and ungrammatical conditions** only.
- Categorical predictors numerically recoded in logical ways.
 - Session: 0, 1, 2, 3
 - Grammaticality: -0.5, 0.5
- Dependent and independent variables z-scored (Brauer & Curtin, 2018)
- Trial-by-trial mixed-effects model incl. baseline (Alday, 2019).
- Per **time window** (200–500, 300–600, 400–900 ms).
 - Per **macro-region** (lateral or midline electrodes).

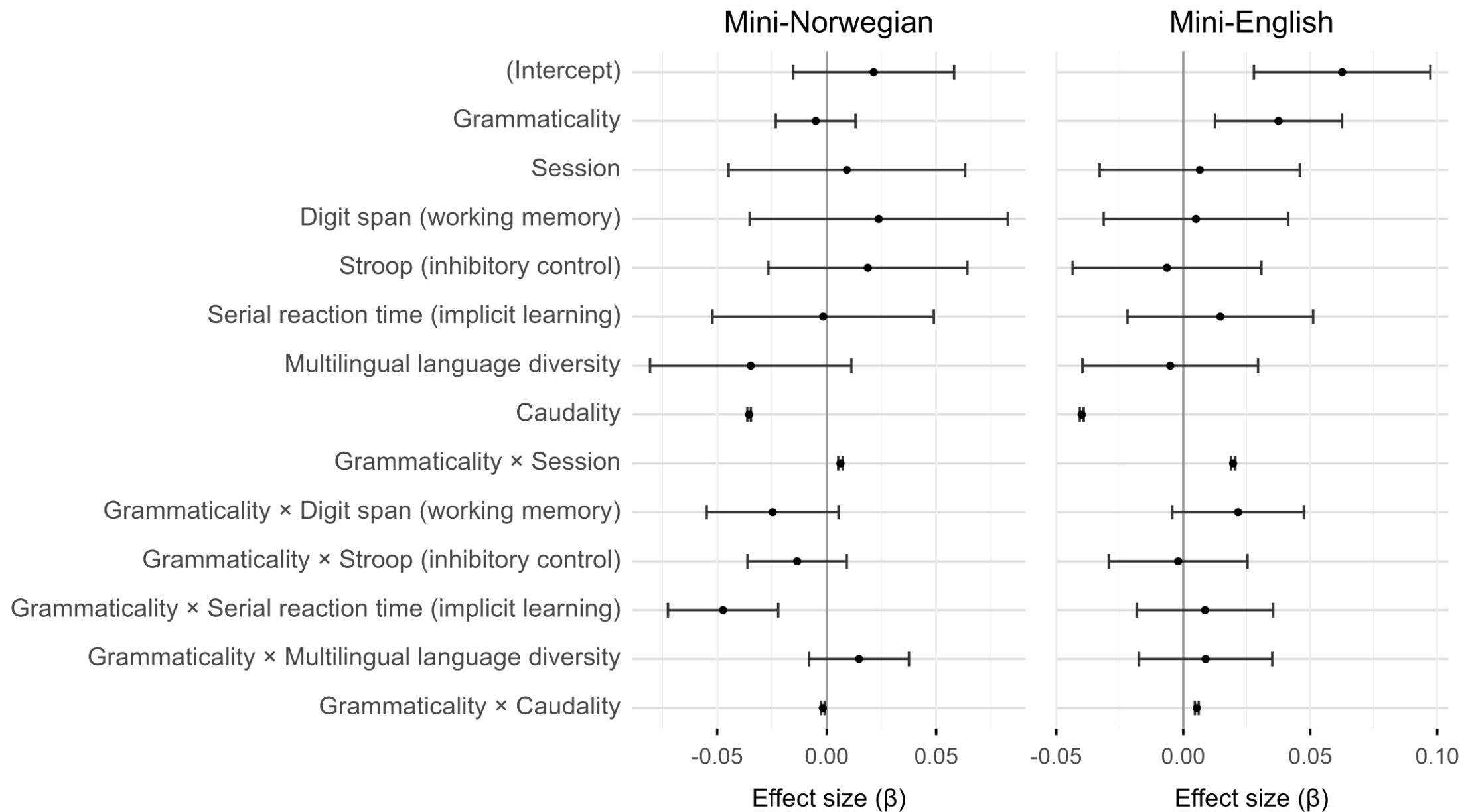
200–500 ms, midline region



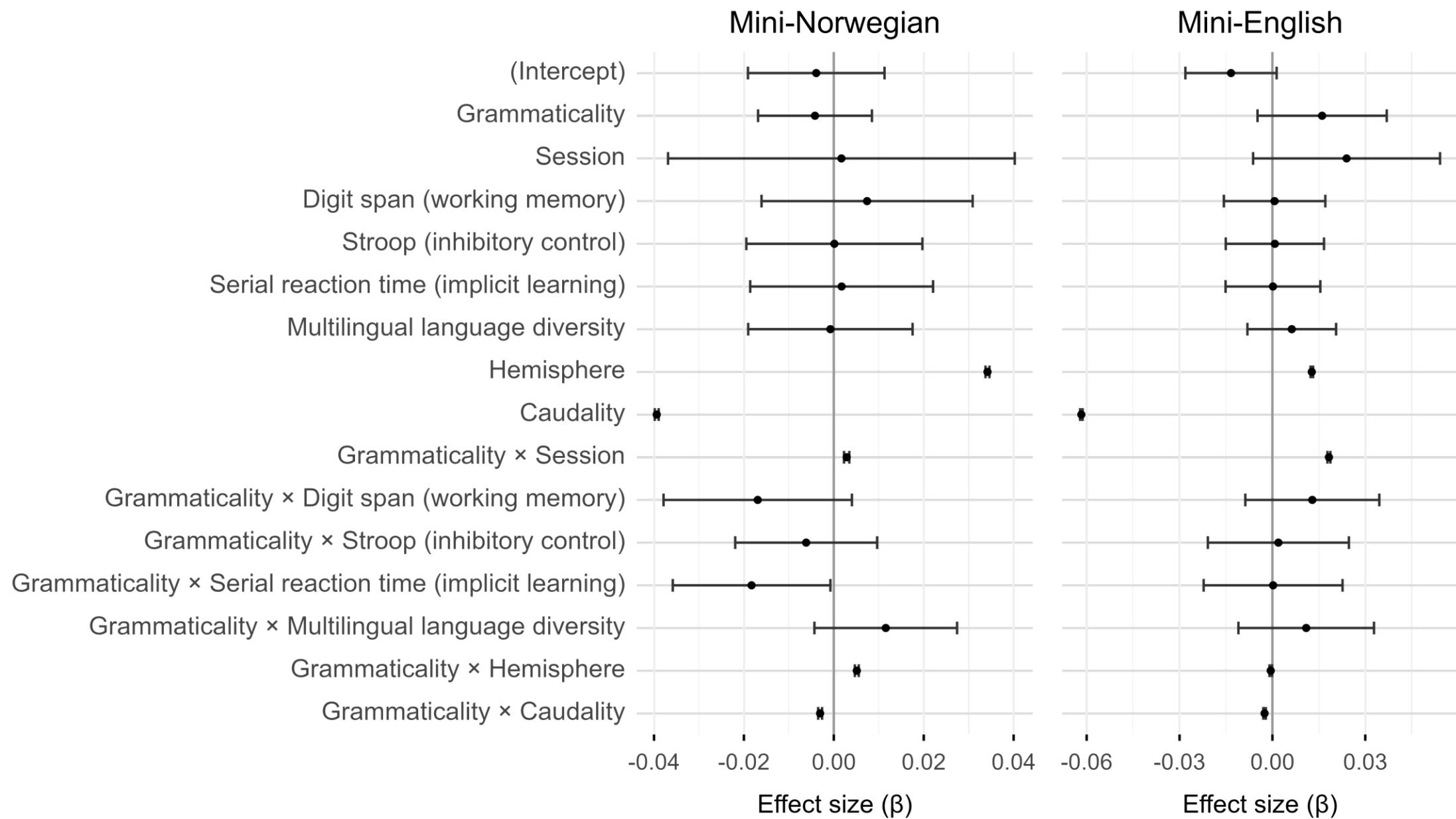
200–500 ms, lateral region



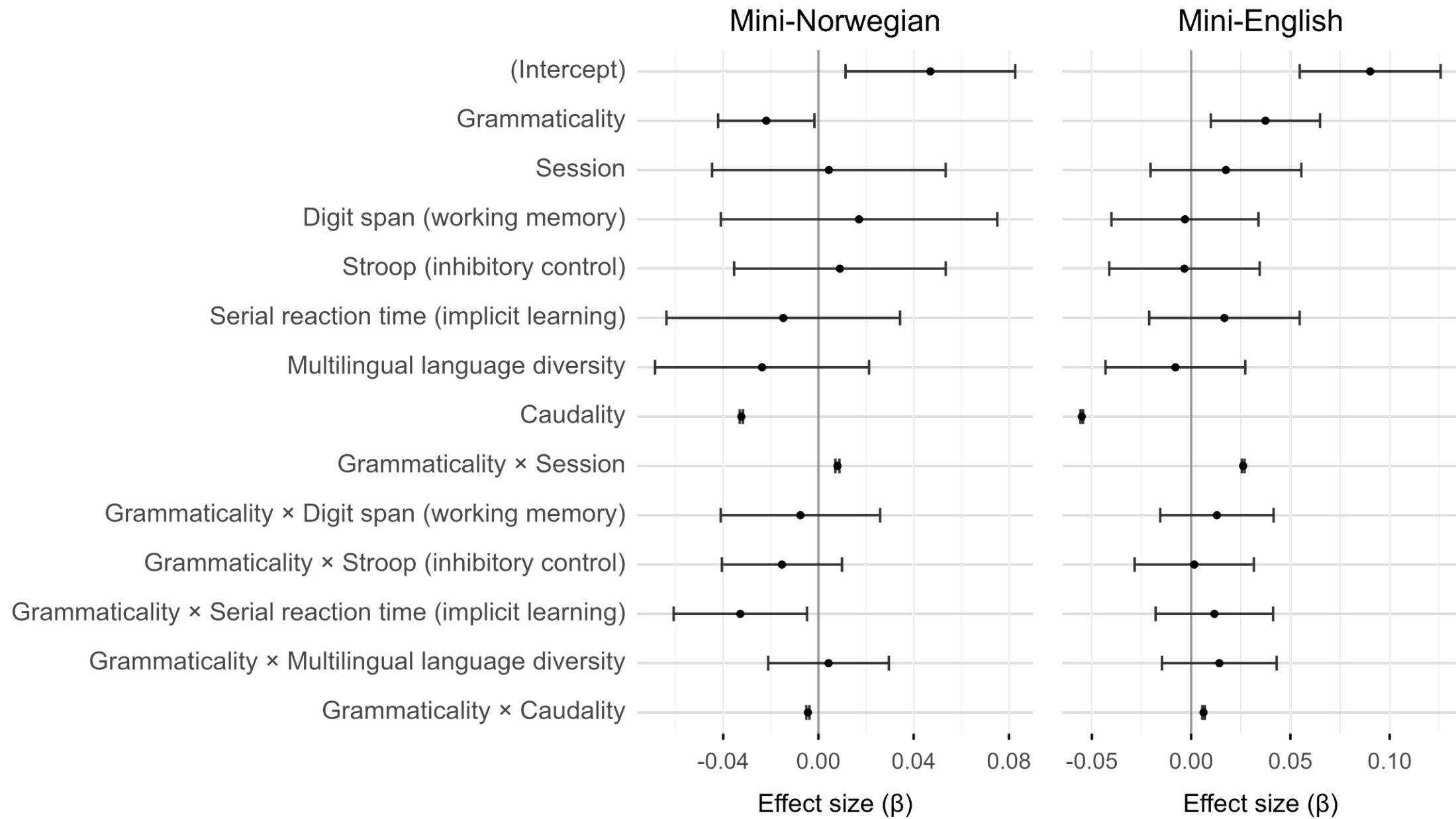
300–600 ms, midline region



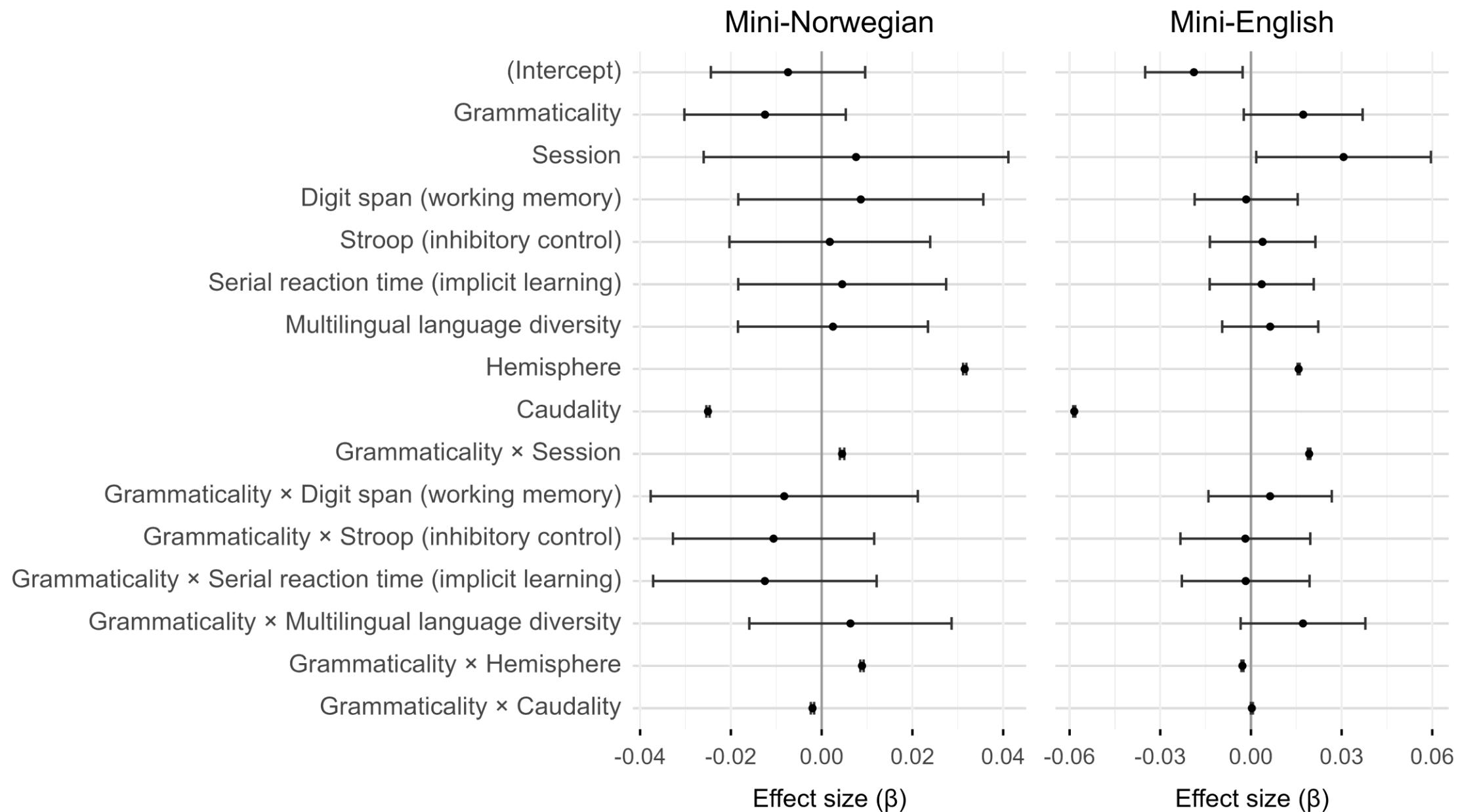
300–600 ms, lateral region



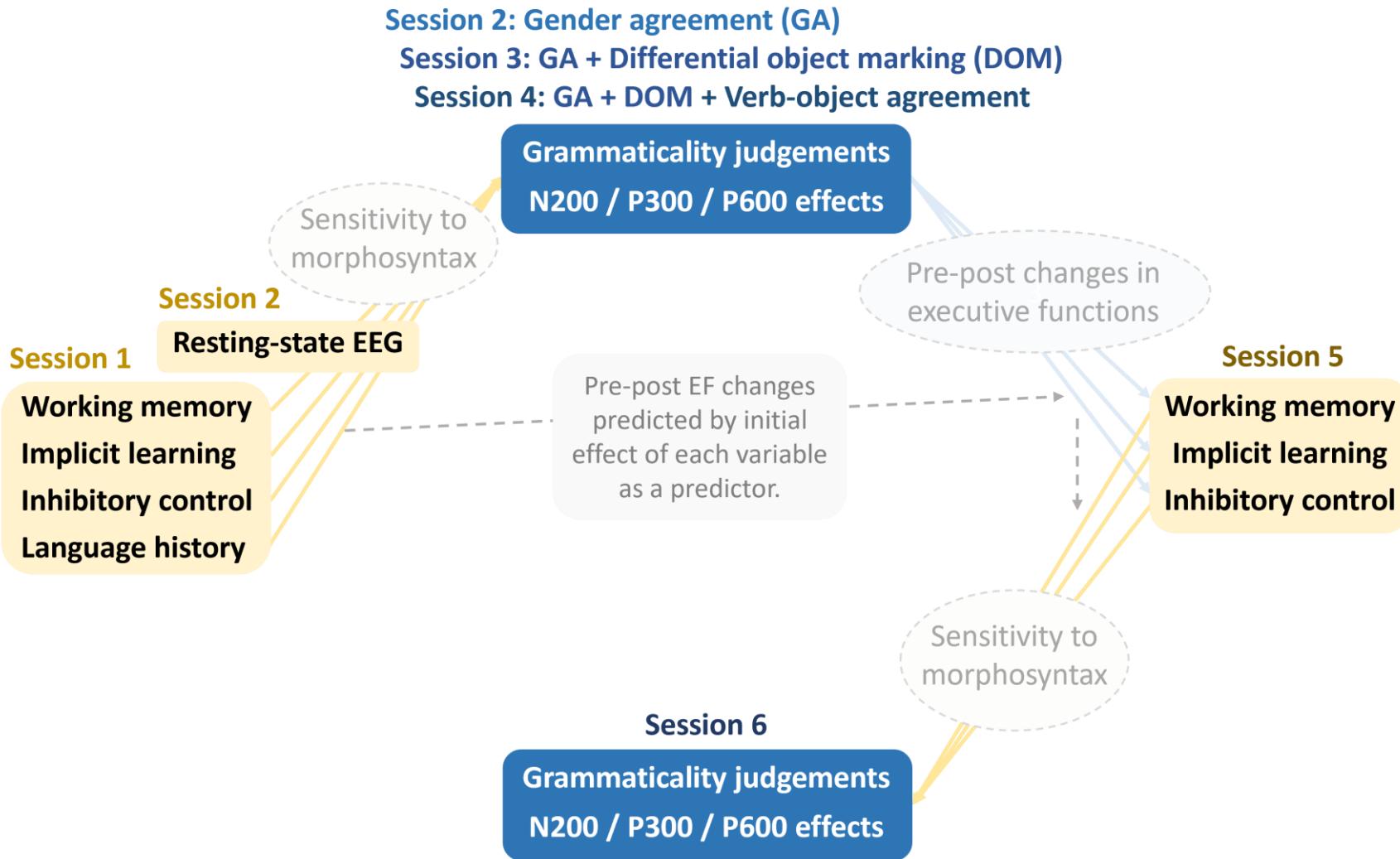
400–900 ms, midline region



400–900 ms, lateral region



Further analyses and hypotheses



Refresher on the Sessions

- **Session 1. Individual differences** (home-based session)

- Working memory (digit span), selective attention (Stroop) and implicit learning (serial reaction time)
- Language History Questionnaire (LHQ3; Li et al., 2020)

- + 1 week: **Session 2. Gender agreement**

- Session begins with resting-state EEG (eyes-open, eyes-closed counterbalanced across participants)

- + 1 week: **Session 3. Differential object marking + Gender agreement**

- Training only in the new property
- Experiment part contains both properties intermixed

- + 1 week: **Session 4. Verb-object agreement + Differential object marking + Gender agreement**

- Same mechanism as in the previous session

- + 1 week: **Session 5. Retest of executive functions** (home-based session)

- + 4 months: **Session 6. Retest of all grammatical properties** (Morgan-Short et al., 2012)

- Session ends with control tests on the relevant properties in the natural languages

Executive functions and rs-EEG

- Primarily methodological analyses focussed on longitudinal stability.
- Analysed first as independent variables, and second as dependent variables.

Longitudinal role of executive functions and rs-EEG

- **Independent-variable analysis:** **longitudinal stability** (i.e., test-retest reliability) of the variables (for similar analyses, see Fuhs et al., 2014; Samuels et al., 2016; Swanson, 2015).
 - First analysis: longitudinal stability of the executive functions and rs-EEG on their own.
 - Second analysis: longitudinal stability of the executive functions and rs-EEG as predictors of language learning and morphosyntactic transfer *over time*.

Longitudinal effects on executive functions and rs-EEG

- **Dependent-variable analysis:** whether cognitive enhancements in each executive function (incl. rs-EEG) induced by language training are consistent with the baseline role of each executive function (incl. rs-EEG).
- Cognitive enhancements analysed relative to the effect of each executive function (incl. rs-EEG) as a predictor of language-learning performance following first exposure—i.e., in the first test on the artificial language.
- Analysis intended to increase the methodological basis for the selection of measures to study training-induced cognitive enhancements (see [Grossmann et al., 2023](#); [Kliesch et al., 2022](#); [Meltzer et al., 2023](#)).
- Pre-post effects not analysed in absolute terms due to lack of control group ([Sala & Gobet, 2017](#)).

Language learning:

Analyses and hypotheses

Language learning

- Hypothesis 1: greater executive functions (overall, incl. rs-EEG) → better language learning
- Exploratory analysis: relative importance of the four executive function measures
 - Hypotheses to be set a priori where possible
- Hypothesis 2: greater executive functions (overall, incl. rs-EEG) → greater longitudinal improvements in language learning due to better accumulation of knowledge
- Hypothesis 3: longitudinal retests in the grammatical properties → better language learning

Morphosyntactic transfer:

Analyses and hypotheses

Standardised numeric predictions

- Effect sizes standardised between 0 and 10
- Visualisation of numerous comparisons across conditions and models
- Pave the way towards computational models with numeric predictions

Standardised numeric predictions

- Effect sizes standardised between 0 and 10
- Visualisation of numerous comparisons across conditions and models
- Pave the way towards computational models with numeric predictions

Norway site predictions

Property	Artificial lang.	L2SFM	CEM	LPM	TPM
		L2 default	prop. by prop.	prop. by prop.	full transfer
Gender agreement	Mini-Norwegian	0	10	5-10	10
	Mini-English	10	10	0-5	0-2
Differential object marking	Mini-Norwegian	0-3	0-3	0-2	0-2
	Mini-English	0-3	0-3	0-3	0-3
Verb-object number agreem.	Mini-Norwegian	0-3	3	0-6	0-5
	Mini-English	0-3	3	0-3	0-3

Spain site predictions

Property	Group	Artificial lang.	L2SFM	CEM	LPM	TPM
			L2 default	prop. by prop.	prop. by prop.	full transfer
Gender agreement	L1 Eng, L2 Spa	Mini-Spanish	10?	10	5-10	10
		Mini-English	10?	10	5-7	0
	L1 Spa, L2 Eng	Mini-Spanish	0	10	5-10	10
		Mini-English	0	10	0-5	0
Differential object marking	L1 Eng, L2 Spa	Mini-Spanish	8?	8	5-8	8
		Mini-English	8?	8	0-5	0-2
	L1 Spa, L2 Eng	Mini-Spanish	0	8	5-8	8
		Mini-English	0	8	0-5	0-2
Verb-object number agreement	L1 Eng, L2 Spa	Mini-Spanish	0-5?	0-3	0-4	0-3
		Mini-English	0-5?	0-3	0-2	0-2
	L1 Spa, L2 Eng	Mini-Spanish	0-3	0-3	0-4	0-3
		Mini-English	0-3	0-3	0-3	0-2

Executive functions and morphosyntactic transfer

- Hypothesis 1: greater executive functions (overall, incl. rs-EEG) → greater precursors of transfer (N2, P3)
- Hypothesis 2: greater executive functions (overall , incl. rs-EEG) → greater signatures of transfer (P600)

Longitudinal effects in morphosyntactic transfer

- Hypothesis 1: any signatures of transfer (esp. P600) more likely to occur in **later** sessions.
- Hypothesis 2: any signatures of transfer (esp. P600) should **persist** in subsequent sessions.

Thank you

Questions and feedback very welcome.

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