Investigating language learning and morphosyntactic transfer longitudinally using artificial languages

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- **Workaround:** artificial languages
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    - Similar processing signatures (Friederici et al., 2002; Uddén & Männel, 2018)

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  - 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 cheapejur*
  - 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)

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.

Sessions

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

+ 4 months: Session 6. Retest of all grammatical properties

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

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.

```r
# 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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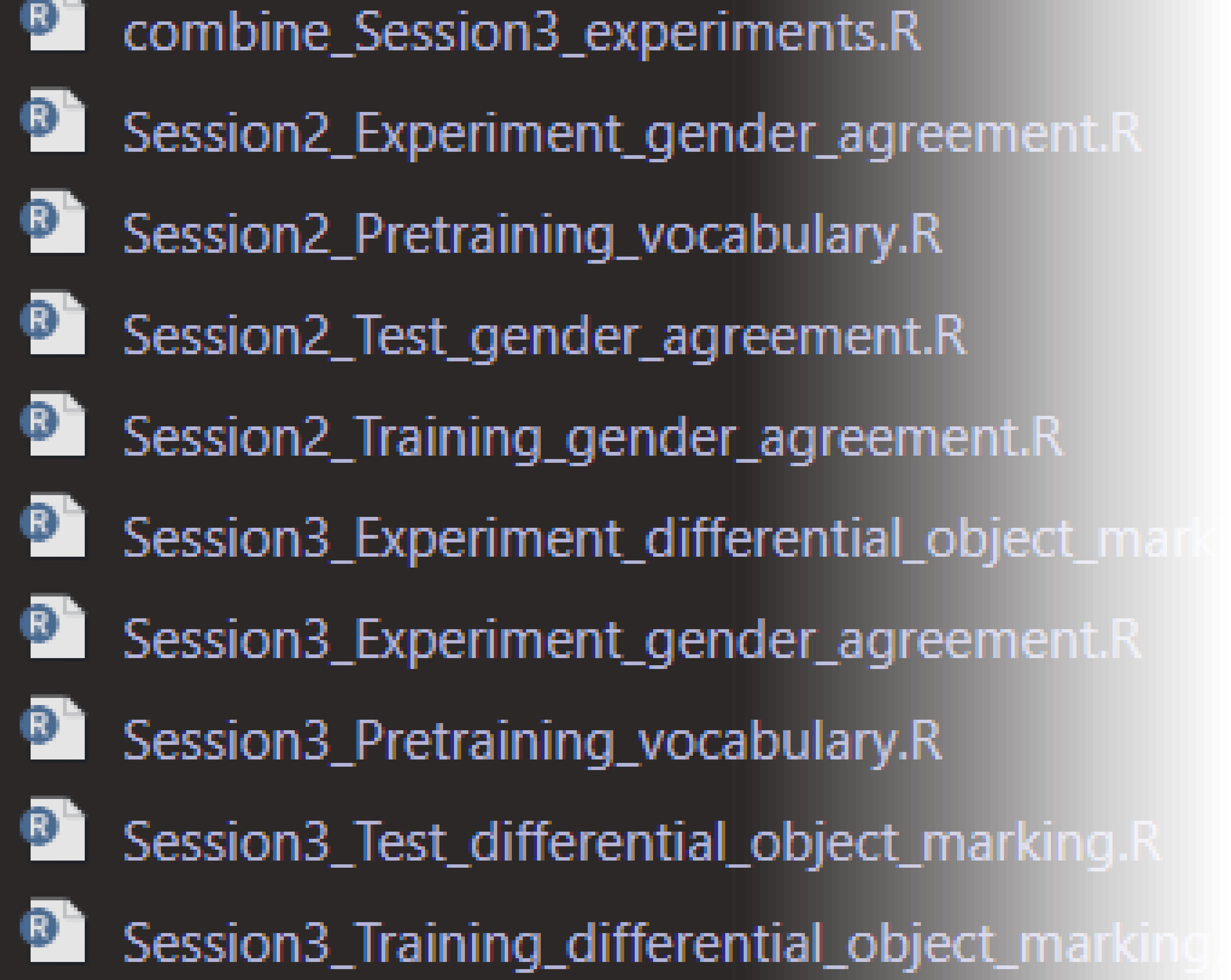
- All stimuli compiled through R scripts



All scripts are run from a core script.

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- 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.
- 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

Test phase in all sessions

1. Grammatical
2. Critical morphosyntactic violation
3. Non-critical morphosyntactic violation
4. Non-critical morphosyntactic violation
5. Semantic violation

Jer street are cleanejur.

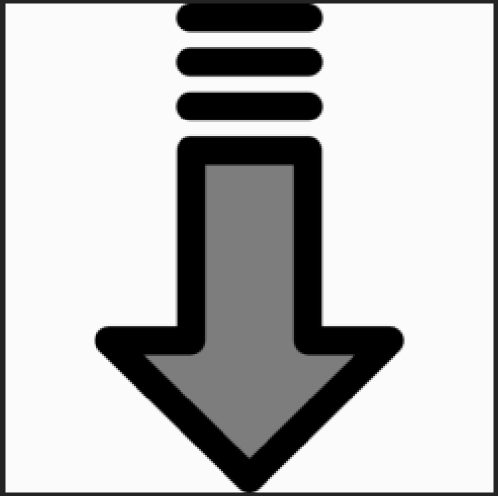
Jer street are dirtyeju.

Jer street are dirtyezur.

Jer street are dirtyejur.

Jer street are dirtyezu.

Amelia



Amelia provided fi ze mug.

Amelia provided fi ze letter.

Amelia provided ze letter.

Amelia provided fi zer letter.

Amelia provided fi zeletter.

Jessica

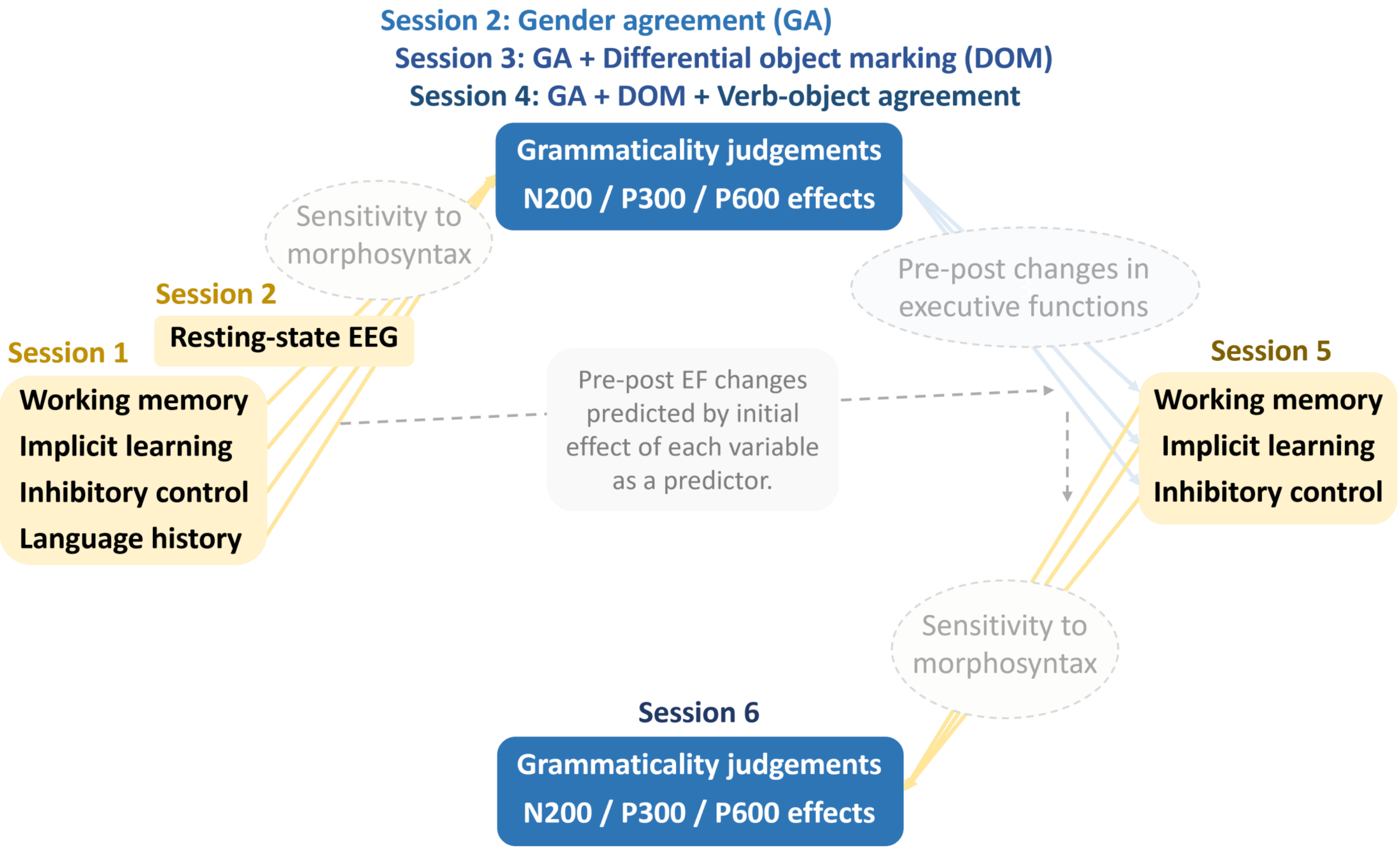
Jessica rememberedevo fi jer drum.

Jessica rememberedevo fi je drum.

Jessica remembered fi jer drum.

Jessica rememberedevo fi jer box.

Jessica rememberedevo fi jerdrum.


Session 2: Gender agreement (GA)
Session 3: GA + Differential object marking (DOM)
Session 4: GA + DOM + Verb-object agreement
Grammaticality judgements
N200 / P300 / P600 effects
Sensitivity to morphosyntax
Session 2
Resting-state EEG
Session 1
Working memory
Implicit learning
Inhibitory control
Language history
Pre-post EF changes predicted by initial effect of each variable as a predictor.
Pre-post changes in executive functions
Session 5
Working memory
Implicit learning
Inhibitory control
Sensitivity to morphosyntax
Session 6
Grammaticality judgements
N200 / P300 / P600 effects

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 any cognitive changes in each executive function (incl. rs-EEG) 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

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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)

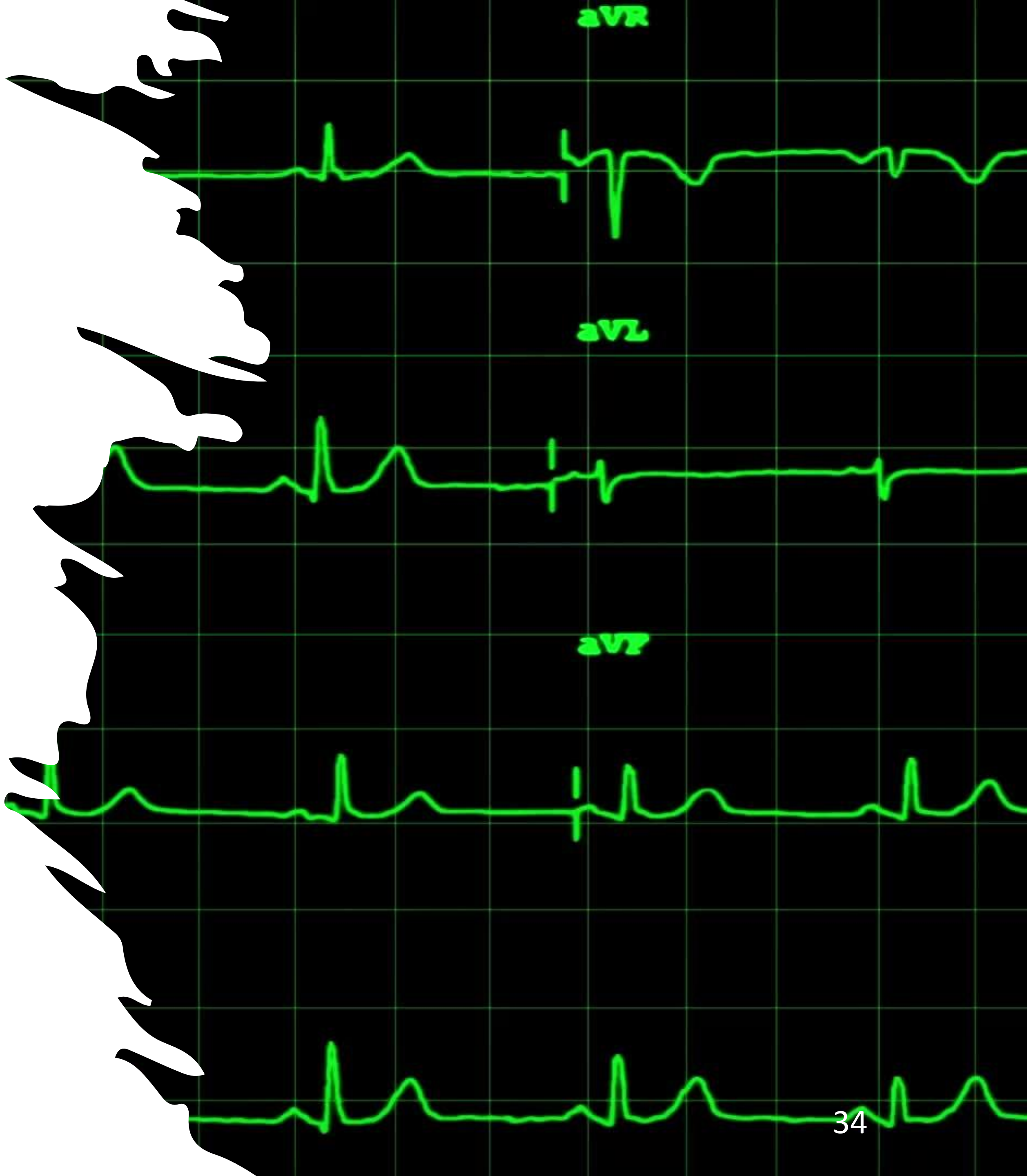
Hypothesis 2: greater executive functions (overall , incl. rs-EEG)

→ 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.



Main references (others available upon request)

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