Implementation of a longitudinal, artificial language study to investigate morphosyntactic transfer

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Other collaborators

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- Initial heuristics
- Cognitive economy
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LESS Project

Linguistic Economy through transfer Source Selectivity

Transfer in L3 acquisition

Sources

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<u>Sources</u>

L2 by default

L1 and/or **L2**

Transfer in L3 acquisition

Sources

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L2 Status Factor Model (Bardel & Falk, 2012)

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

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

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- 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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    - Acquired by statistical learning (Hudson et al., 2005; Kidd, 2012; Monaghan et al., 2023)
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    - 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 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)

Artificial languages

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

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 L3 Mini-English	No effect	(N400)–P600	No effect
L1 Spanish-L2 English L3 Mini-Spanish	No effect	(N400)–P600	(N400)–P600

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)

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	Case morphology		Adjective position	
Language combination	**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/L*n* 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 yellowe**<u>z</u>**ur and …*
in Spanish and Norwegian	
Differential object marking	*Jessica provided ze **<u>fi</u>**hat and …*
in Spanish	
Verb-object number agreement	*John cleaned**<u>ud</u>** **zer** fiwatch 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)

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
		Mini-English
	L1 Spa, L2 Eng	Mini-Spanish
		Mini-English
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		Mini-English
Verb-object number agreement	L1 Eng, L2 Spa	Mini-Spanish
		Mini-English
	L1 Spa, L2 Eng	Mini-Spanish
		Mini-English

Sessions

- **Session 1. Individual differences** (home-based session)
  - Working memory (digit span), selective attention (Stroop) and implicit learning (serial reaction time)
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- Training only in the new property
- Experiment part contains both properties intermixed

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

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

+ 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

- **No cognates**
- **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
- **Morphemes:** same across the two artificial languages in each site, and ideally across the three mini-languages.
- **Adjectives:** paired by meaning, mostly by antonymy.

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	blaa
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.

```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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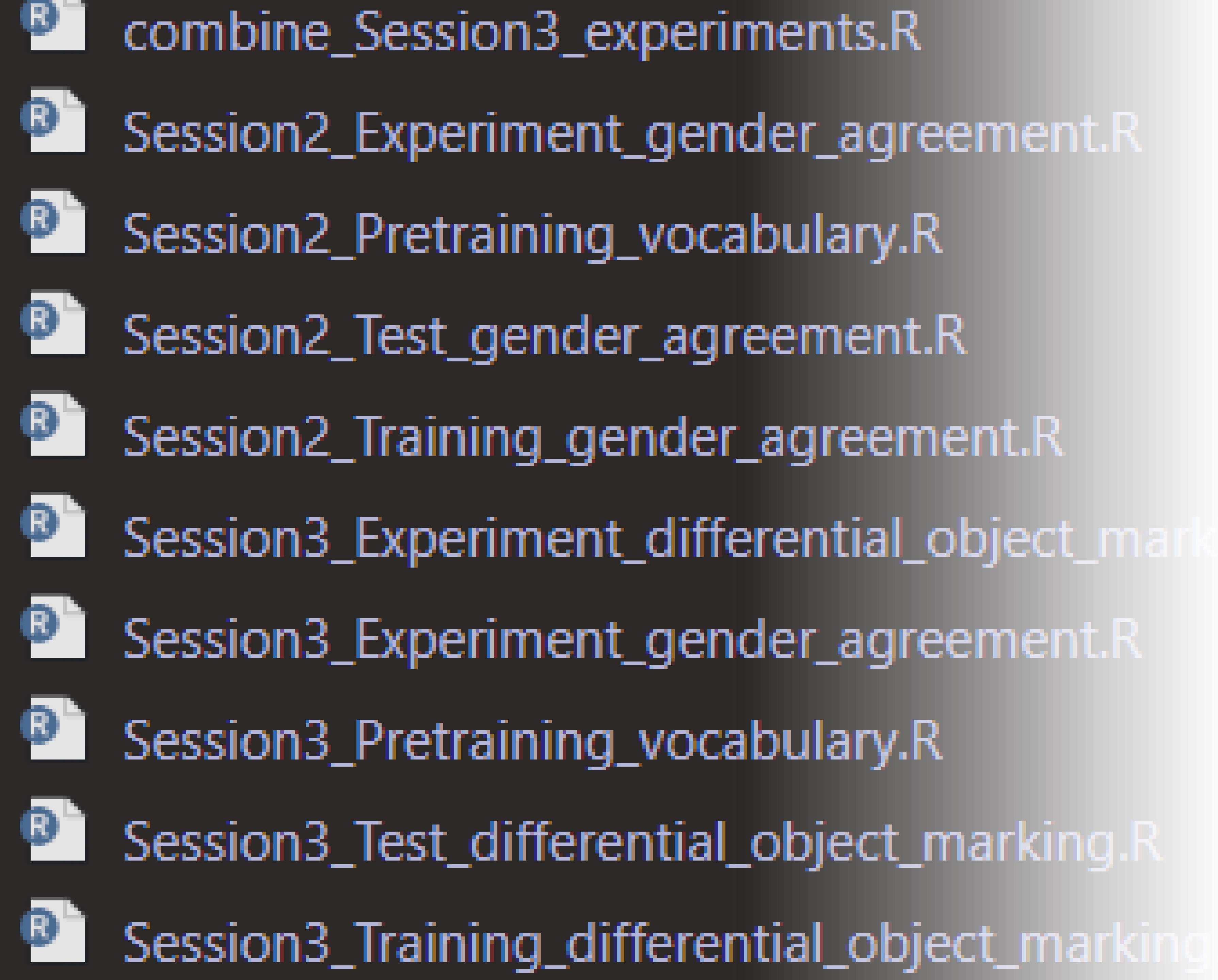
- All stimuli compiled through R scripts



All scripts are run from a core script.

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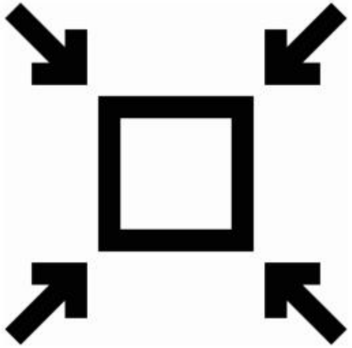
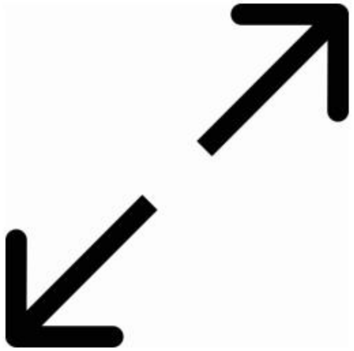
- Minimal components of each language contained in a base file
- Linguistic and visual stimuli finally presented are created by assembling minimal components.
- Several controls exerted on the stimuli to prevent spurious effects. For instance, gender and number are counterbalanced across experimental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

Training

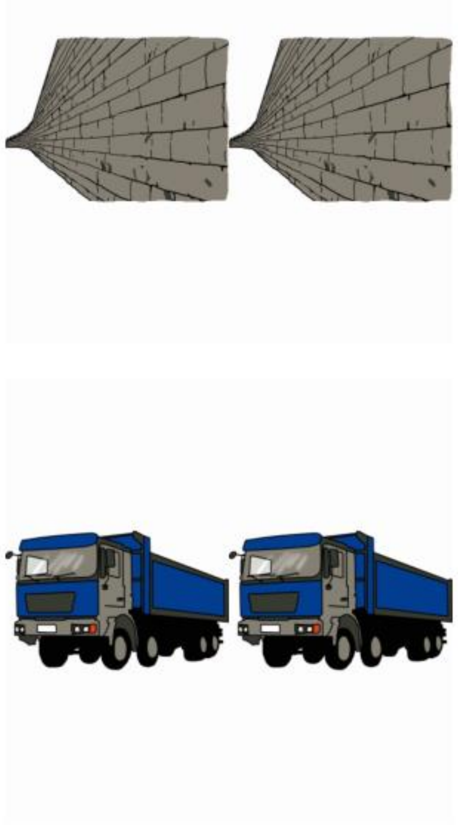


Bordze er litenezu.

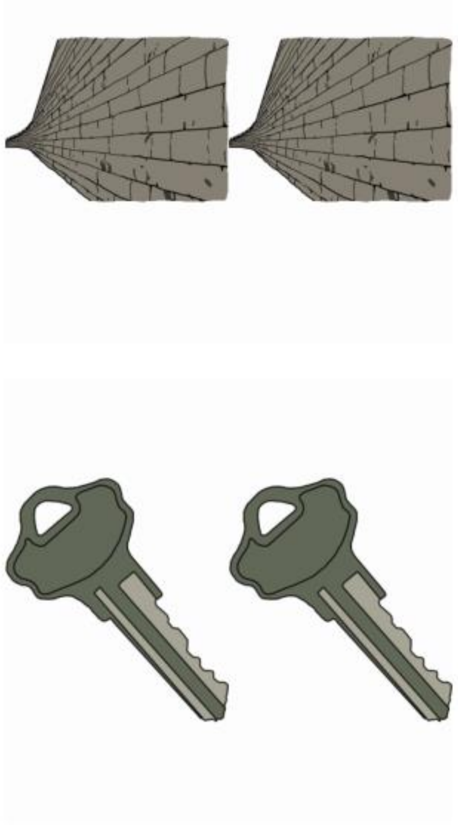


Bordze er storezu.

Training



Veggjer er over lastebiljer.



Veggjer er over noekkeljer.

Test in 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 in 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. Article with gender and number violation
5. Noun with semantic violation (i.e., noun different from image)

Experiment: example stimuli

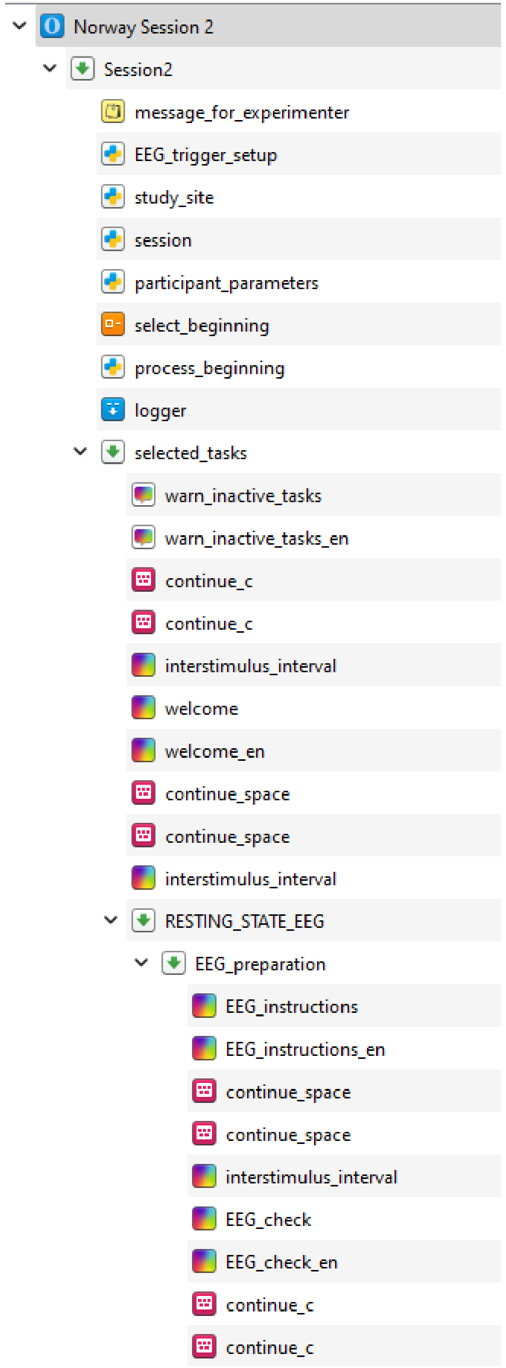
- *zer watch are yellowe**j**ur and zer pencil too* [gender violation]

- *John cleaned ze **fi**hat and ze **fi**watch too* [differential object marking]

- *Jessica provided ze hat and ze wall too* [violation of differential object marking]

Lab sessions

- Detailed information for session conductors



README.txt

File Edit View

== General procedure for lab-based sessions ==

At the beginning of Sessions 2, 3 and 4, the experimenter starts OpenSesame by opening the program directly (not by opening the session-specific file), and then opens the appropriate session within OpenSesame. This procedure helps prevent the opening of a standalone Python tab. Next, the experimenter opens BrainVision Recorder.

Next, the experimenter fits the participant with the EEG cap, which they will wear throughout the session. To prevent them from being pulled down, please attach the splitter box neatly to the towel on the participant's back.

Next, the experimenter returns to OpenSesame and runs the session in full screen by clicking on the full green triangle at the top left. Next, the experimenter selects a folder to store the logfile. It is important to select the folder corresponding to each session to avoid overwriting existing logfiles. Any prompts to overwrite a logfile must always be refused.

In the first screen, the experimenter can disable some of the tasks. This option can be used if a session has ended abruptly, in which case the session can be resumed from a near checkpoint. In such a case, the experimenter must first note this incident in their logbook, and rename the log file that was produced on the first run (for instance, by appending '_first_run' to the name) to prevent overwriting this file on the second run. Next, they must open a new session and enter the participant ID. Once in the OS session, the first screen allows the experimenter to present only the remaining tasks. Once the session has finished, the first log file and the second one must be safely merged into a single file, keeping only the fully completed tasks.

In the first instructional screen, participants are asked to refrain from asking any questions unless it is necessary, so that all participants can receive the same instructions.

At the beginning of the Resting-state part (present in Sessions 2 and 4) and at the beginning of the Experiment part, instructions are presented on the screen that ask participants to stay as still as possible during the following task. The screen contains an orange-coloured square with the letters 'i.s.r', that remind the experimenter to check the impedance and the signal, and finally to begin recording the EEG signal. If the impedance of any electrodes is poor, the experimenter may enter the booth to lower the impedance of the electrodes affected. Otherwise, after validating the signal and the impedance, the experimenter can begin the recording in BrainVision, and press the letter 'C' twice in the stimulus computer. At that point, a green circle will appear, along with instructions for the participant.

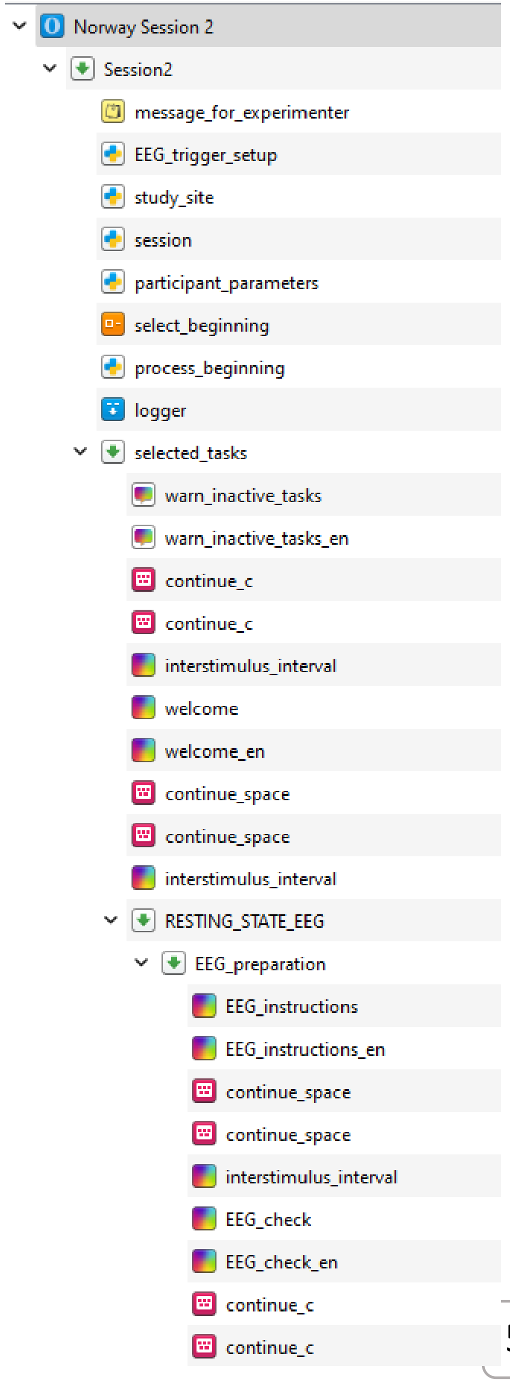
Similarly, at the end of the Resting-state part and at the end of the Experiment part, a screen with a crossed-out R appears to remind the experimenter to stop recording the EEG.

Notice that, at some important stages during the sessions, the letter 'C' must be pressed twice by the experimenter to let the session continue. This protocol provides the experimenter with control when necessary. These moments are signalled by a 'wait a moment' notice for the participant, and by two orange-coloured stripes on the screen. The experimenter should be aware of the use of the letter 'C' at these points, as the requirement is not signalled on the screen to prevent participants from pressing the letter themselves.

During the experiment, it is important to monitor the EEG signal. If it ever becomes very noisy, the experiment must be paused by pressing the ESC key, and the problem must be resolved. If the

Lab sessions

- Detailed information for session conductors
- 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.



Thank you for your collaboration in this study, which consists of several tasks. Before each task, please read the instructions carefully.

We would like to provide all participants with the same input. Therefore, please refrain from asking us any questions unless it is necessary.

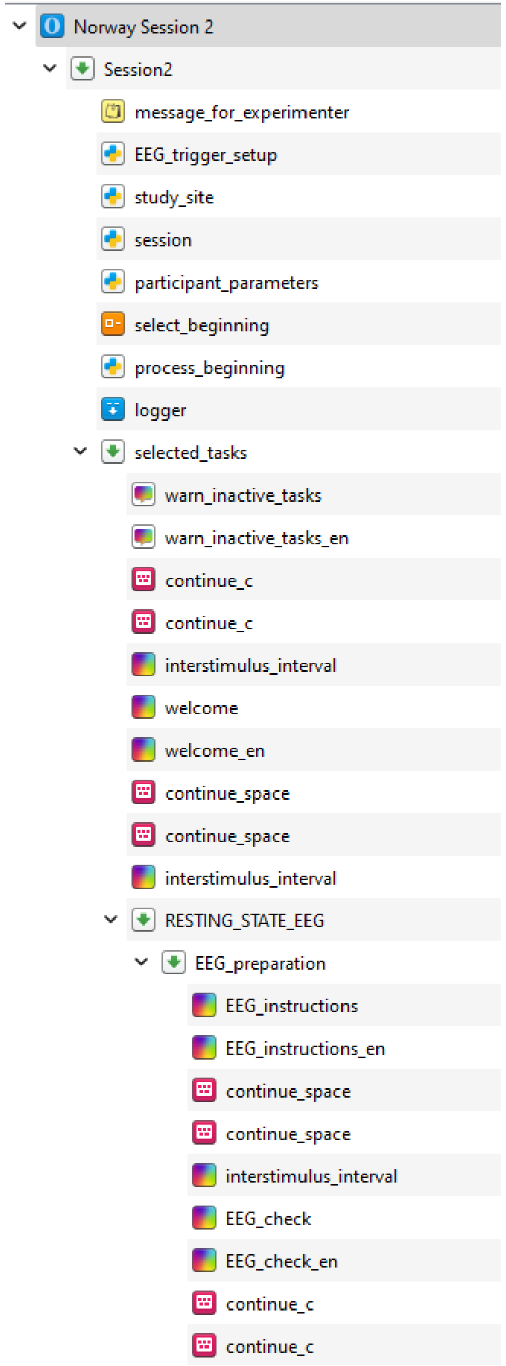
Please press the space bar twice to begin.

We will now record your brain waves while you are resting with your **eyes closed**. Please look right under the arrow at the bottom of the screen, close your eyes, and remain in this way until a **beep** sounds. The duration of the task is five minutes, but you don't have to worry about time because you will hear the bip at the end.

To begin the task, press the space bar twice.

Lab sessions

- Detailed information for session conductors
- 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.
- Integrated checkpoints to verify EEG signal remotely



Once you are comfortable, please maintain your posture so that the EEG signal stabilises. When the signal is valid, a new screen with a green circle will appear.

Contingency measures to reduce session time

CAUTION: Begin session from the part selected below?

ONLY SELECTED BY THE EXPERIMENTER

Participant: 143

- [ ] Resting-state EEG (default)
- [ ] Pre-training
- [ ] Training
- [ ] Experiment

Click to confirm or to begin from Part 1 if nothing selected

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)
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+ 1 week: Session 2. Gender agreement

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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
  - Minor caveat: limited variation due to accuracy threshold in the tests. That is, participants can only do the experiment if they pass the test with a minimum of 80%.

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.

Thank you

- References and further information available upon request.
- Questions and feedback very welcome.