Language Rehabilitation in Aphasia using an Auditory BCI

Michael Tangermann

Radboud University, Nijmegen, The Netherlands
Data-Driven NeuroTech Lab

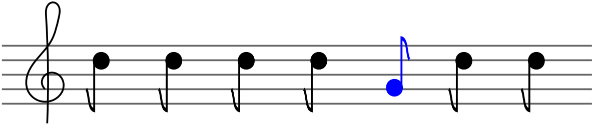
michael.tangermann@donders.ru.nl

Collaboration with Mariacristina Musso, Cornelius Weiller, David Hübner, Pierre LeVan et al.

Radboud University

Auditory Event-Related Potential (ERP) Protocols

- Late ERP components: use a classic **oddball** design
  - Different events/stimuli (in randomized order)
  - Frequent non-target / standard stimuli
  - Rare target / deviant stimuli



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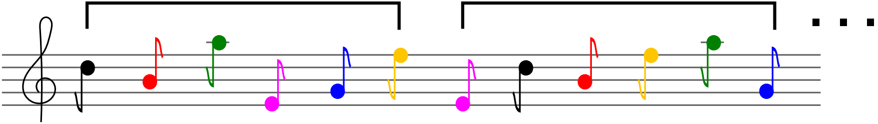

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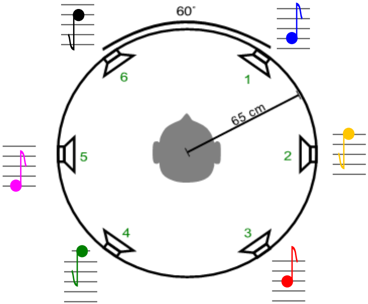
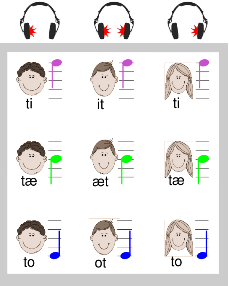
- Late ERP components: use a classic **oddball** design
  - Different events/stimuli (in randomized order)
  - Frequent non-target / standard stimuli
  - Rare target / deviant stimuli
  - Target stimulus can be defined by task instruction

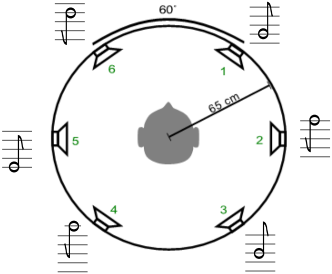


Auditory Brain-Computer Interface (BCI)

Multiple experimental paradigms (**PASS2D, AMUSE**, charspeller) use spatial auditory stimuli. Examples:



(aud)



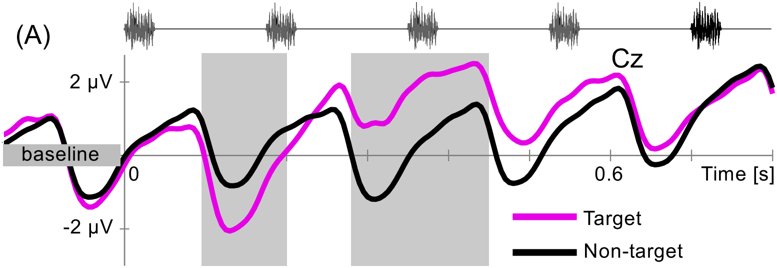
(vid)

[Schreuder et al., PLOS One, 2010], [Höhne et al., Front. Neuroprosthetics, 2011], [Schreuder et al., Front. Neurosci., 2011], [Höhne & Tangermann, J Neural Eng., 2012], [Höhne & Tangermann, PLOS One, 2014]

Auditory ERPs Responses

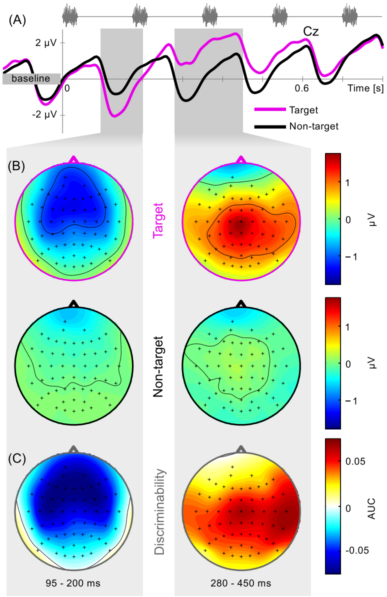
- Use brisk tone stimuli (stimulus onset asynchrony (SOA) of 175 ms)
- Pseudo-randomized sequence of, e.g., 75 non-targets and 15 targets

After averaging out a lot of noise:



Attentive processing of a tone makes a difference!

Spatial patterns of auditory ERP responses



Classification of Target vs. Non-Target Stimuli

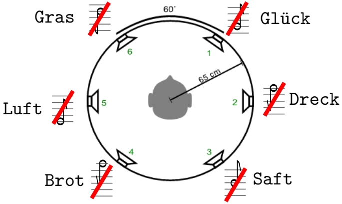
- Discriminative ERPs (textbook):
  1. early negative component (N100-N200)
  2. late positive component (P300a/b)

- Features:
  1. discriminative intervals: average potential per interval and channel
  2. per-epoch covariance matrix $\rightarrow$ Riemannian geometry
  3. raw data

- Classification of target- vs. non-target epochs:
  1. regularized linear discriminant analysis
     [Hübner et al., Frontiers in Human Neurosci., 2018], [Sosulski et al., Neuroinformatics, 2020], [Sosulski et al., J Neural Eng., 2022]
  2. projection into tangent space + logistic regression
     [Kolkhorst et al., IEEE/RSJ IROS, 2018]
  3. deep learning with convolutional neural networks
     [Schirrmeister et al., Human Brain Mapping 2018]
  4. Unsupervised mean-difference maximization (UMM, see poster 3-F-57)

From Tones to Words

Can we replace precise tone stimuli by less well-controlled words?



[Tangermann et al., Verlag Uni Graz, 2014]

Results of first attempt with monosyllabic words:

- Target- vs. non-target word decoding is possible on level with tone stimuli.

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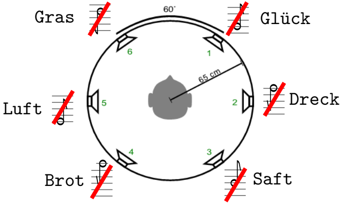


[Tangermann et al., Verlag Uni Graz, 2014]

Results of first attempt with monosyllabic words:

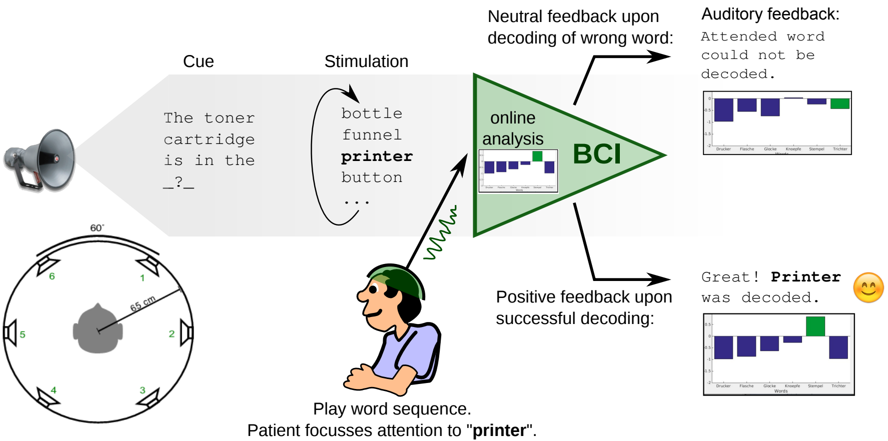
- Target- vs. non-target word decoding is possible on level with tone stimuli.
- Strong inter-individual differences.
- Comparing 6 loudspeakers with mono condition: spatial cues make task much easier.

BCI-Supported Language Training Paradigm for Patients with Aphasia

- Task: attend appearances of target word, ignore non-target words
- Based on AMUSE paradigm [Schreuder et al., PLOS One, 2010]
- Stimuli: 15 iterations of **six bisyllabic words**
- Presentation speed adapted to ability of user
  (SOA of 350 ms or 250 ms)
- **Challenge without overcharging!**
  (faster SOAs, replace words, spatial → mono, ...)

Video of online training

Single Trial of Training Paradigm



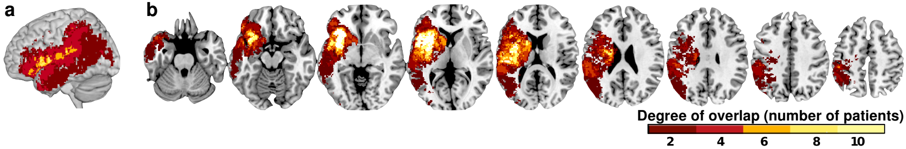
Patients: Demographic and Clinical Data (n=10)

Table 4: **Overview of patient-specific information to demography, stroke, aphasia and comorbidities.**

Demography				**Stroke-related information**									**Aphasia-related information (before training)**			**Others**
	Sex	**Age**	**Edu. age**	**Stroke etiology**	**Stroke risk factors**	**Acute therapy**	**Stroke severity (mRS) at T0, T1, T2**	**Infarct volume (ml)**	**MCA stroke location**	**Additional stroke location**	**Months post-stroke at training start**	**Hemi-paresis (severity)**	**Aphasia severity**	**AAT-based aphasia type**	**Speech apraxia severity**	**Comorbidity**
1	m	76	11	CE, LAA	H,AF,D	ly,mr,s	3/2/2	113	F,T,P,In		10		medium	Broca		
2	m	58	17	LAA	H		4/4/2	13	F,P,In,NC	ACA,AChA	18	severe	mild	anomic	mild	
3	m	71	23	LAA	H,CHD	s	4/3/2	43	F,T,P	ACA	36	mild	mild	anomic		epilepsy, MM
4	m	70	11	EO	H		4/4/3	47	F,T,P,In,		9	severe	mild	Broca		prostate cancer
5	m	60	12	LAA	H,HL,N	ly,mr,s	5/4/2	68	F,T,P,In,NC		27		mild	anomic		
6	m	43	19	LAA	H,HL	ly	3/3/2	125	F,T,P,In,NC	PBZ	10	severe	mild	Broca	medium	epilepsy
7	w	54	23	ICA-D		ly,mr,s	5/4/2	100	F,T,In,NC	ACA	8	mild	mild	anomic		depression
8	m	61	17	ICA-D	H,HL		3/2/1	87	FT,In		149		mild	anomic		
9	m	38	12	CE		he	5/3/3	217	F,T,P,In		21		severe	Broca	mild	
10	m	53	12	CE	H,HL	ly,mr,he	5/5/3	145	F,T,P,In		12	severe	severe	global	mild	depression

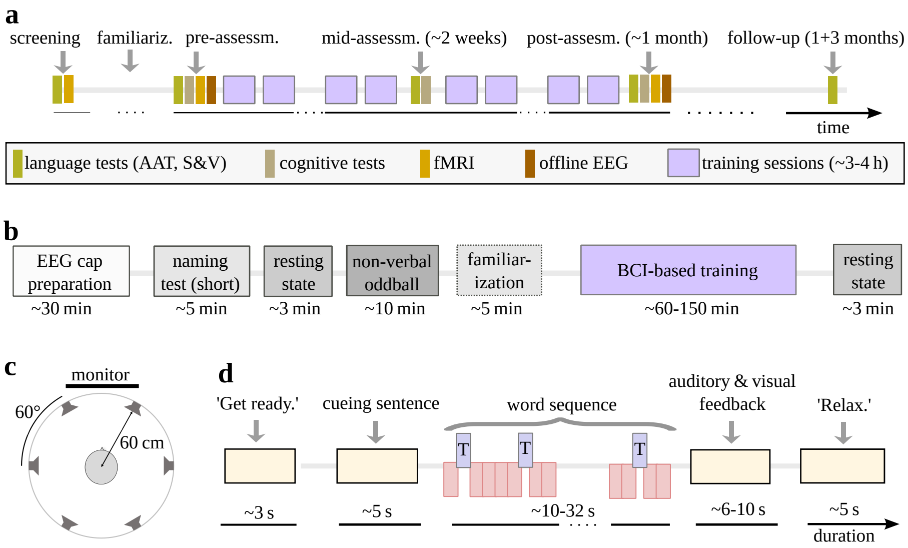
Edu. age refers to the educational age, i. e. the number of years in school and in higher education.
Stroke etiology of (ischemic) stroke subtype: cardioembolism (CE), large-artery atherosclerosis (LAA), internal carotid artery dissection (ICA-D) and embolic undetermined etiology (EO).
Risk factors: atrial fibrillation (AF), coronary heart disease (CHD), diabetes (D), hypertension (H), hyperlipidaemia (HL), nicotine (N).
Stroke severity was assessed with the modified Rankin Scale (mRS) at stroke admission (T0) / discharge (T1) / before training (T2).
Acute therapy consisted of thrombolysis (ly), mechanic recanalisation (mr), ACI Stent (s) or hemicraniectomy (he).
Location of stroke: all patients had an infarct of middle cerebral artery (MCA). Within the MCA, the infarct involved areas from frontal (F), temporal (T), Insula (In), parietal (P), nucleus caudatus/ thalamus (NC) regions.
In some patients, also the anterior cerebral artery (ACA), anterior choroidal artery (AChA) or posterior border zone (PBZ) were affected.
AAT-subtype. Anomic: mild form of aphasia with difficulties to name objects; Broca: partial loss of the ability to produce language (spoken and written); global: most severe form of aphasia heavily affecting comprehension and production.
Apraxia of speech refers to a disorder which affects an individual's ability to translate conscious speech plans into motor plans.
Comorbidity: multiples myeloma (MM).

Left-Hemispheric, Anaemic Infarcts Only, First Stroke

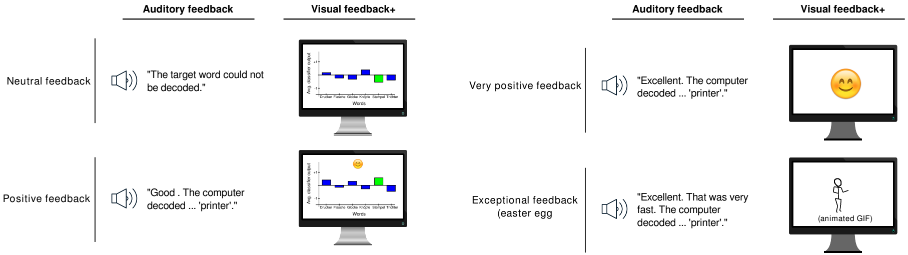


For inclusion / exclusion criteria, see [Musso et al. 2022, Brain Communications].

Intensive Training (≈ 30 hours), Evaluations



Graded Feedback at Trial End



- Feedback shall be supportive!
- Don't blame the patient for bad/wrong classification. (Who made the error is typically unclear...)
- Very positive feedback only if early stopping kicks in.
- Easter egg is shown only for 25% of the earliest possible stops (after 7 iterations).

Results

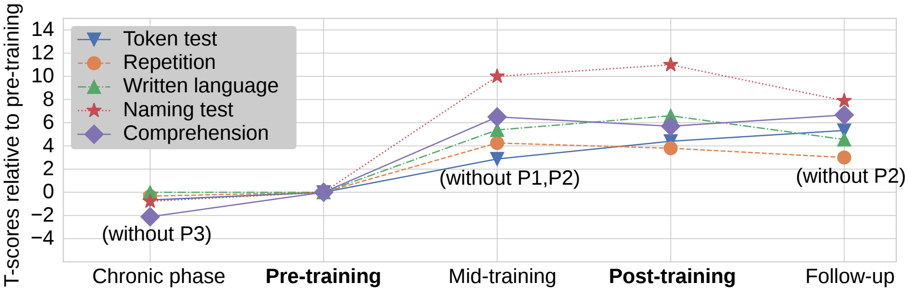
Does it work?

Results: Feasibility and Acceptance

- We **familiarized** the patients with the training prior to the BCI-based training sessions.
- Setup was tedious, but accepted well.
- Session durations were adapted to ability of each patient (typically increases over weeks).
- Difficulty is increased on an individual basis.
- All included patients were capable of doing the training.
- Patients helped recruiting other patients, recommended the training.

Results: Training-Induced Clinically Relevant Language Improvements

Pre vs. post language assessment (Aachener Aphasie Test, AAT):



- 10 points := 1.0 STD in population of patients with aphasia.
  Caveat: effect size computation depends on reference for STD!

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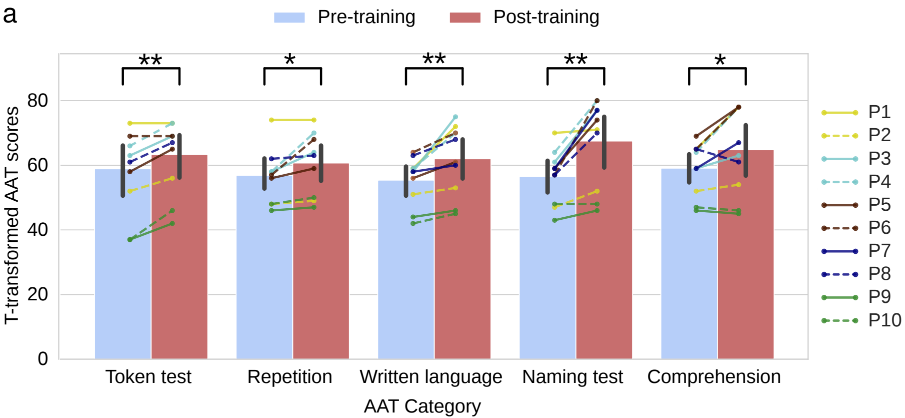
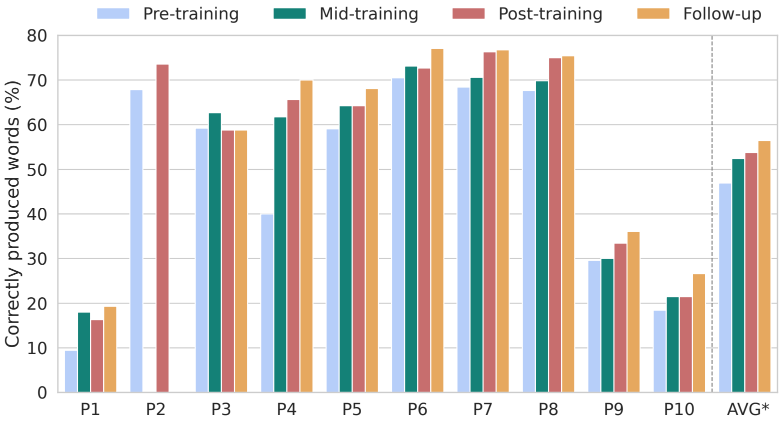


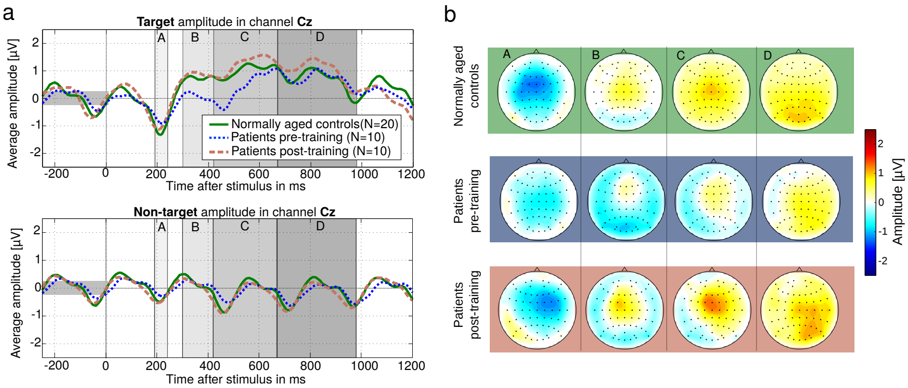
 Training does not involve repetition, written language and other tasks – why could these improve?

Results on Snodgras and Vanderwart Picture Naming Task

Very sensitive test (over 250 items):



Results:
Training-Induced **Stronger and Earlier Target ERPs**



 What may be indicated by earlier ERP responses? What by stronger peak amplitudes?

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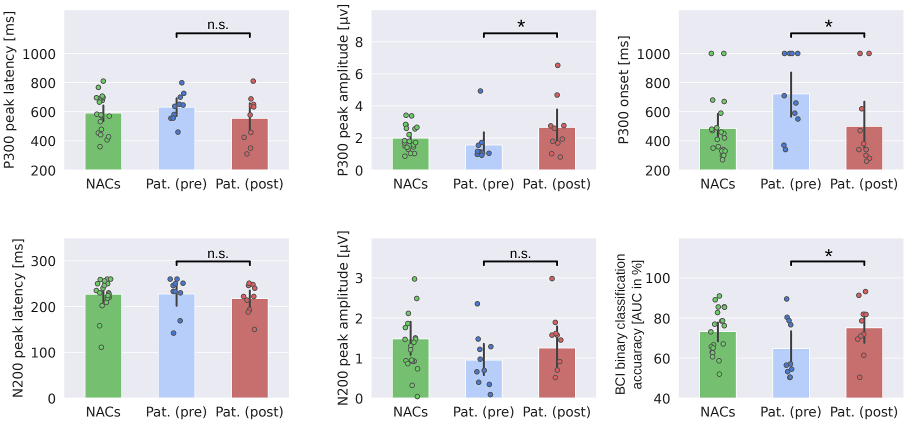

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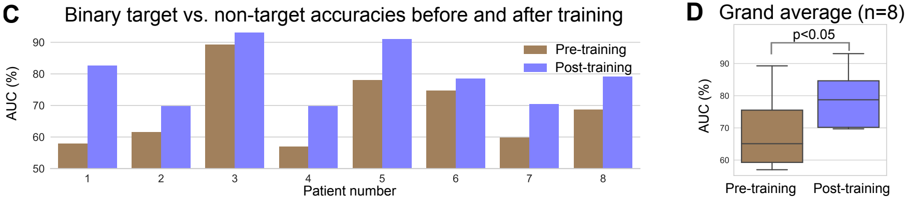
Results **(n=8)**:
Improved Target-/Non-Target Classification

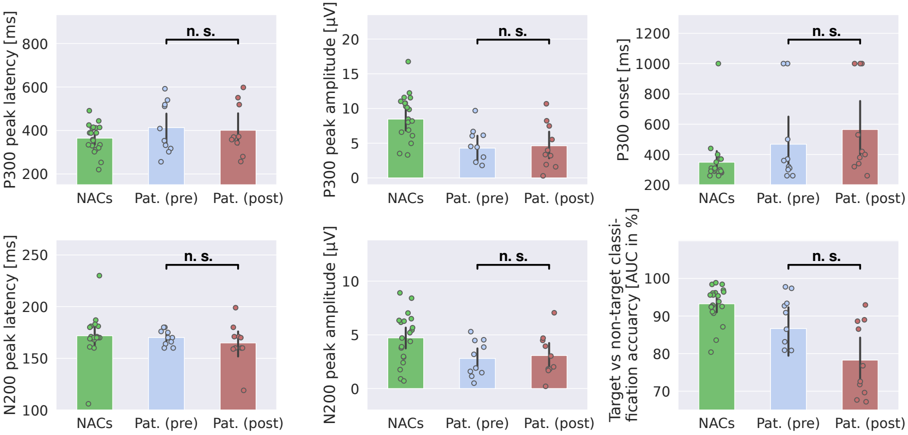


 How do you interpret the improved classification performance?
Could this information be used during the rehabilitation training?

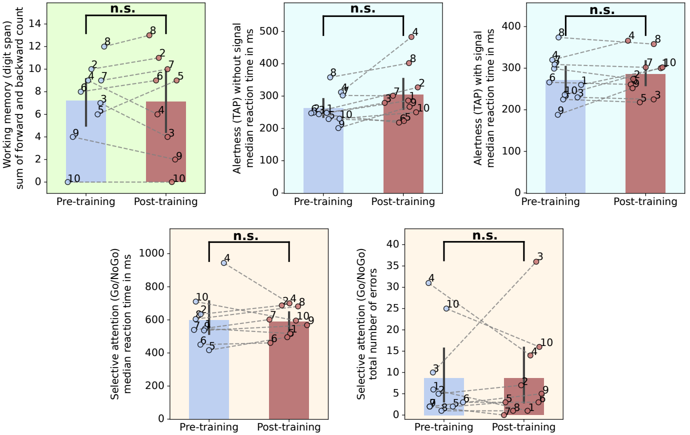
Results

What is **not improved** by this BCI-supported training?

Results: No Signif. Change of Auditory Oddball ERPs



Results: No Sign. Effect on Neuropsychological Tests



 BCI-based training seems to act relatively specific upon language. Is this good or bad?

Conclusion [Musso et al. 2022, Brain Communications]

- Novel language training paradigm for chronic stroke patients
  - exploits information about ongoing brain state
  - intensive, challenging, individualized
  - rather complex technical setup
- Patients accept the training and recommend it to others.

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- Training is effective
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- Generalized training effect
  - several aspects of language are improved
  - improvements for items not trained

Challenge 1 — find an answer to this question:

Why is the BCI-supported training effective?

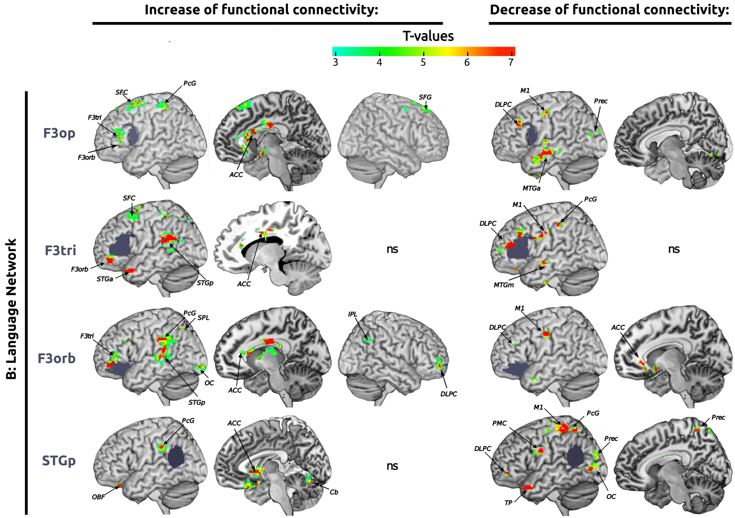
Hypothesis 1: Language processing is sped up.
(This is supported by earlier ERP responses.)

Hypothesis 2: Patients are supported (by reinforcing feedback) to find an individually useful strategy of how to activate their language network.

$\rightarrow$ **The answer could allow to provide more informative feedback.**

Functional Connectivity Enhanced in Language Network, Reduced in Default Mode Network

(resting state fMRI, sorted by blue/gray ROIs/seeding areas)



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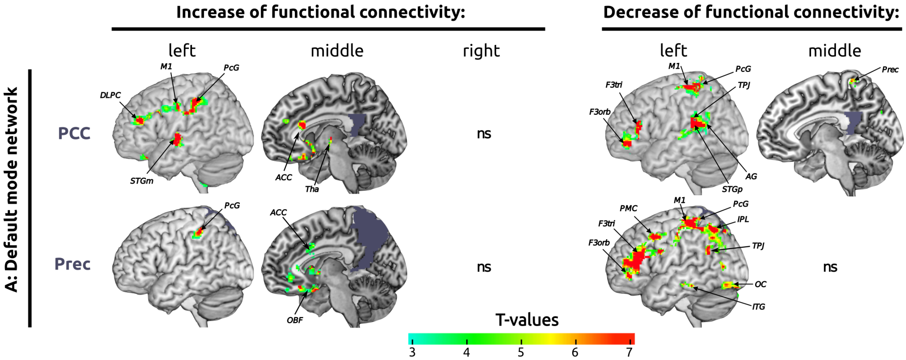

Further challenges...

- Individualization done properly (task difficulty, feedback etc.)
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- Reduce the technical complexity of the protocol, enhance robustness

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- Find a clinical partner that has
  - sufficient number of patients, not a lot of competing studies
  - sufficient research interest
  - openness to neurotechnology
- Organize the patient
  - scheduling
  - communication with patient, convince family members, GPs, language therapists, physiotherapists etc.
  - mobility: Daily commute to lab possible? Housing? Inpatient?
- Train up technical assistants / nurses / ...
- Receiving support for ethics and regulatory affairs

Aphasia Rehabilitation: Ongoing and future work

Increase our understanding:

- RCT with non-BCI control condition
- Identify suitable patient groups
- Functional and structural connectivity analyses

Increase usability:

- fewer EEG channels, simulated spatial directions with headphones
- re-implementation in Python, internationalization

Make the training more efficient:

- individualized training strategies: shorten? predictors?
- better classification → more informative feedback