THE DO'S AND DON'TS OF DESIGNING & REPORTING NEUROFEEDBACK STUDIES

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UPDATE

Consensus on the reporting and experimental design of clinical and cognitive-behavioural neurofeedback studies (CRED-nf checklist)

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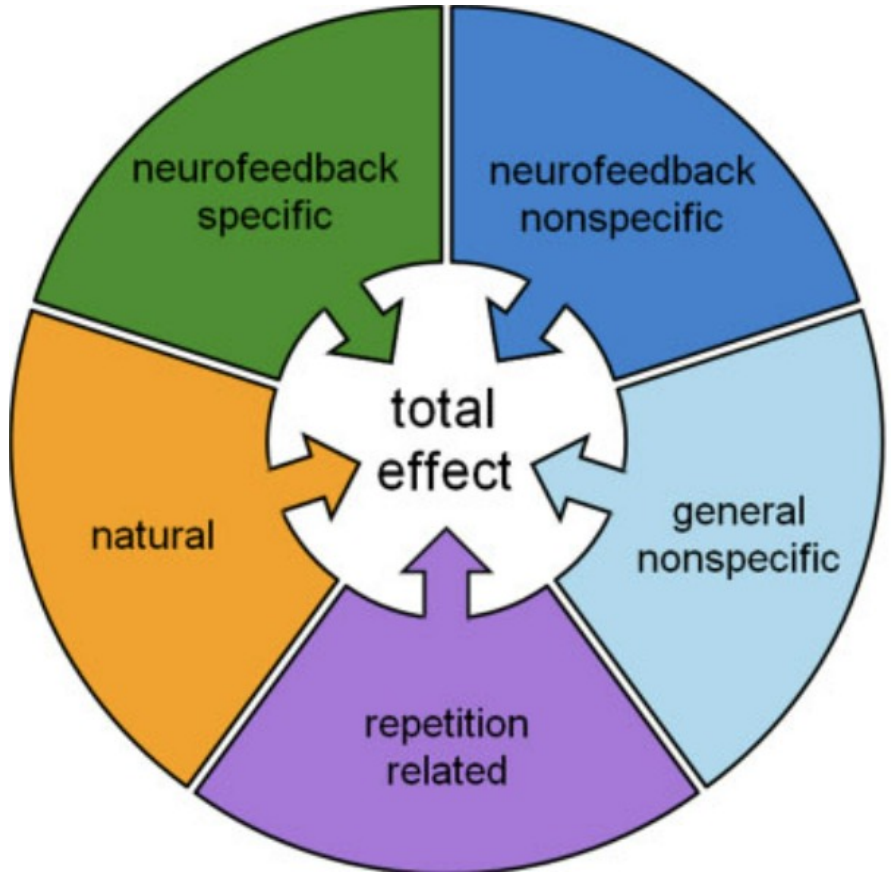


CRED-nf best practices checklist 2020			
Domain	**Item #**	**Checklist item**	**Reported on page #**
Pre-experiment			
	1a	Pre-register experimental protocol and planned analyses	
	1b	Justify sample size	
Control groups			
	2a	Employ control group(s) or control condition(s)	
	2b	When leveraging experimental designs where a double-blind is possible, use a double-blind	
	2c	Blind those who rate the outcomes, and when possible, the statisticians involved	
	2d	Examine to what extent participants and experimenters remain blinded	
	2e	In clinical efficacy studies, employ a standard-of-care intervention group as a benchmark for improvement	
Control measures			
	3a	Collect data on psychosocial factors	
	3b	Report whether participants were provided with a strategy	
	3c	Report the strategies participants used	
	3d	Report methods used for online-data processing and artefact correction	
	3e	Report condition and group effects for artefacts	
Feedback specifications			
	4a	Report how the online-feature extraction was defined	
	4b	Report and justify the reinforcement schedule	
	4c	Report the feedback modality and content	
	4d	Collect and report all brain activity variable(s) and/or contrasts used for feedback, as displayed to experimental participants	
	4e	Report the hardware and software used	
Outcome measures			
Brain	5a	Report neurofeedback regulation success based on the feedback signal	
	5b	Plot within-session and between-session regulation blocks of feedback variable(s), as well as pre-to-post resting baselines or contrasts	
	5c	Statistically compare the experimental condition/group to the control condition(s)/group(s) (not only each group to baseline measures)	
Behaviour	6a	Include measures of clinical or behavioural significance, defined *a priori*, and describe whether they were reached	
	6b	Run correlational analyses between regulation success and behavioural outcomes	
Data storage			
	7a	Upload all materials, analysis scripts, code, and raw data used for analyses, as well as final values, to an open access data repository, when feasible	

Online version of CRED-nf checklist:

https://crednf.shinyapps.io/CREDnf/

Top 3 DOs:

1. **DO** include a **control group**:

- Sham feedback
- Another neural target
- Biofeedback (EMG, HRV)

2. **DO** use a **double-blind** design + use **artifact control**

3. **DO** **pre-register** a study with *a priori* hypotheses on**:**

- **online** changes of target brain activity (*within + between* training sessions)
- **offline** changes of target brain activity (*within + between* training sessions)

What is the similarity & difference between classic **BCI** and **neurofeedback** (NFB)?

Similarity :

- BCI & NFB both enable **control** of brain activity in a closed-loop

Difference :

- classic BCI: used for executing a **command** (e.g. to an external device)

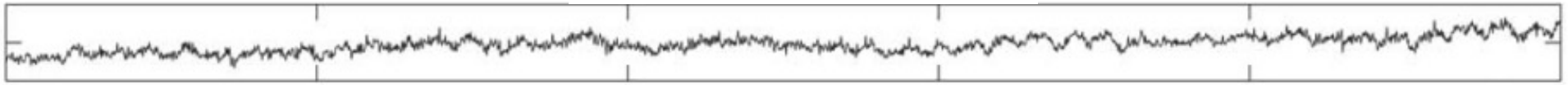
→ "control"

- NFB: used for **lastingly altering** brain activity *as a goal in itself*

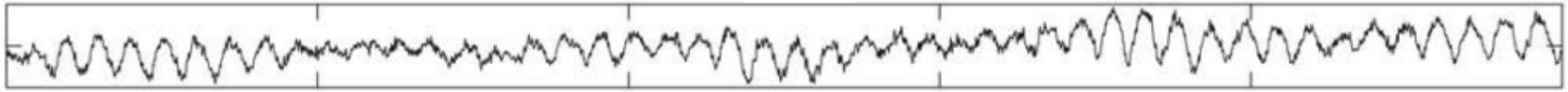
→ "control + plasticity"

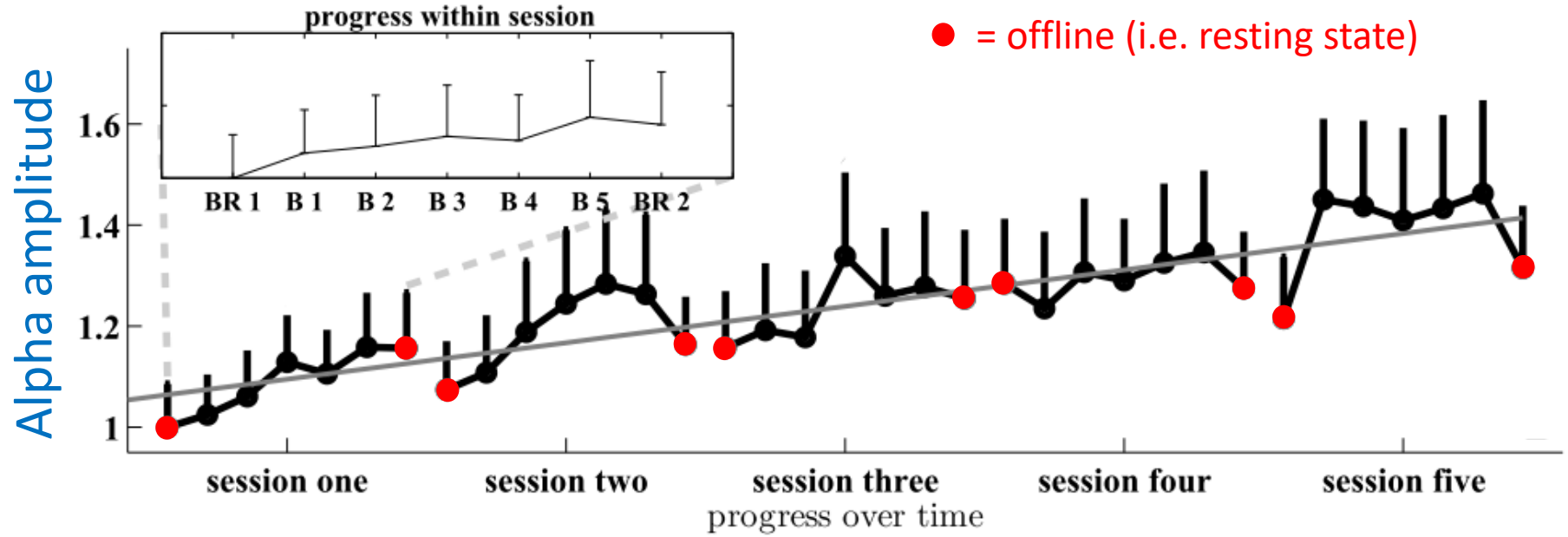
Example 1: Neurofeedback (NFB) up-regulation of alpha rhythm in healthy subjects

Before



After

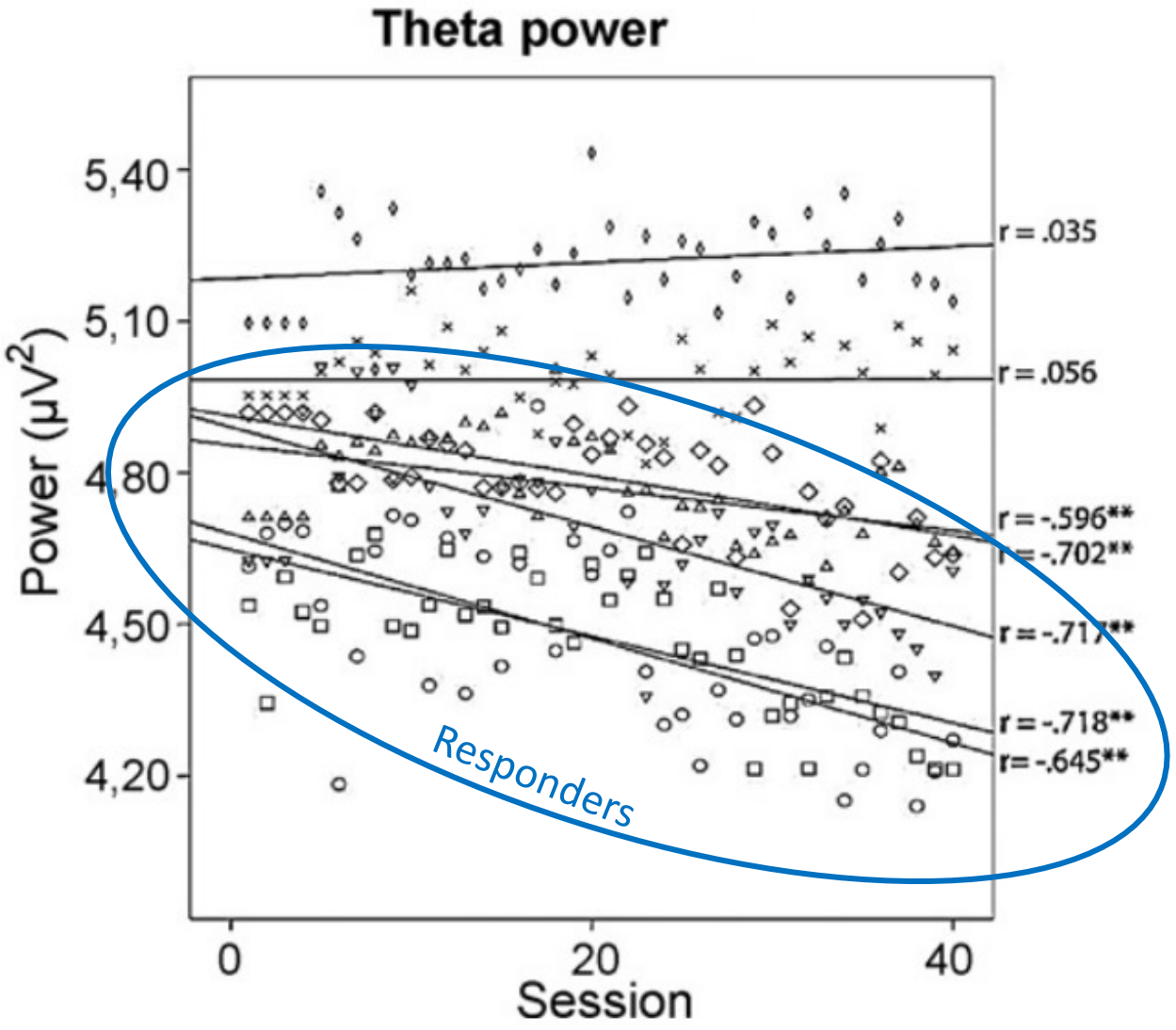




(Zoefel et al 2010)

- Plasticity is **Hebbian** since it occurs **in the direction of NFB training**

Example 2: Neurofeedback (NFB) down-regulation of theta rhythm in autistic children



Neurofeedback improves executive functioning in **autism spectrum disorders**

(Kouijzer et al. 2008)

TOP 3 DON'Ts:

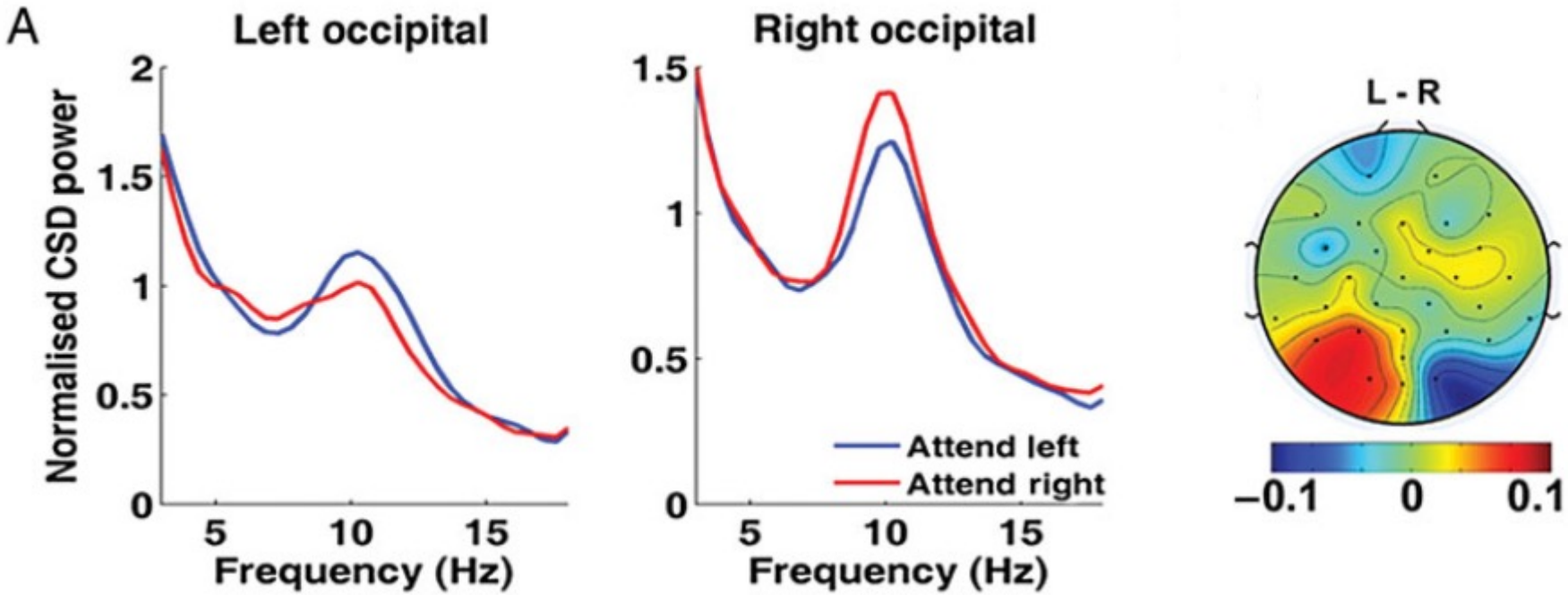
1. DON'T generalise neural features *from* **a healthy population** *to* **a neurological disorder**

Cerebral Cortex February 2016;26:517–529
doi:10.1093/cercor/bhu204
Advance Access publication September 9, 2014

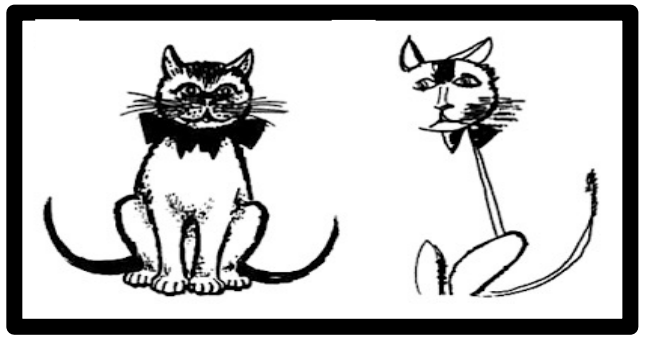
Top-down Modulation of Neural Activity in Anticipatory Visual Attention

Yuelu Liu[1,2], Jesse Bengson[2], Haiqing Huang[1], George R. Mangun[2,3] and Mingzhou Ding[1]

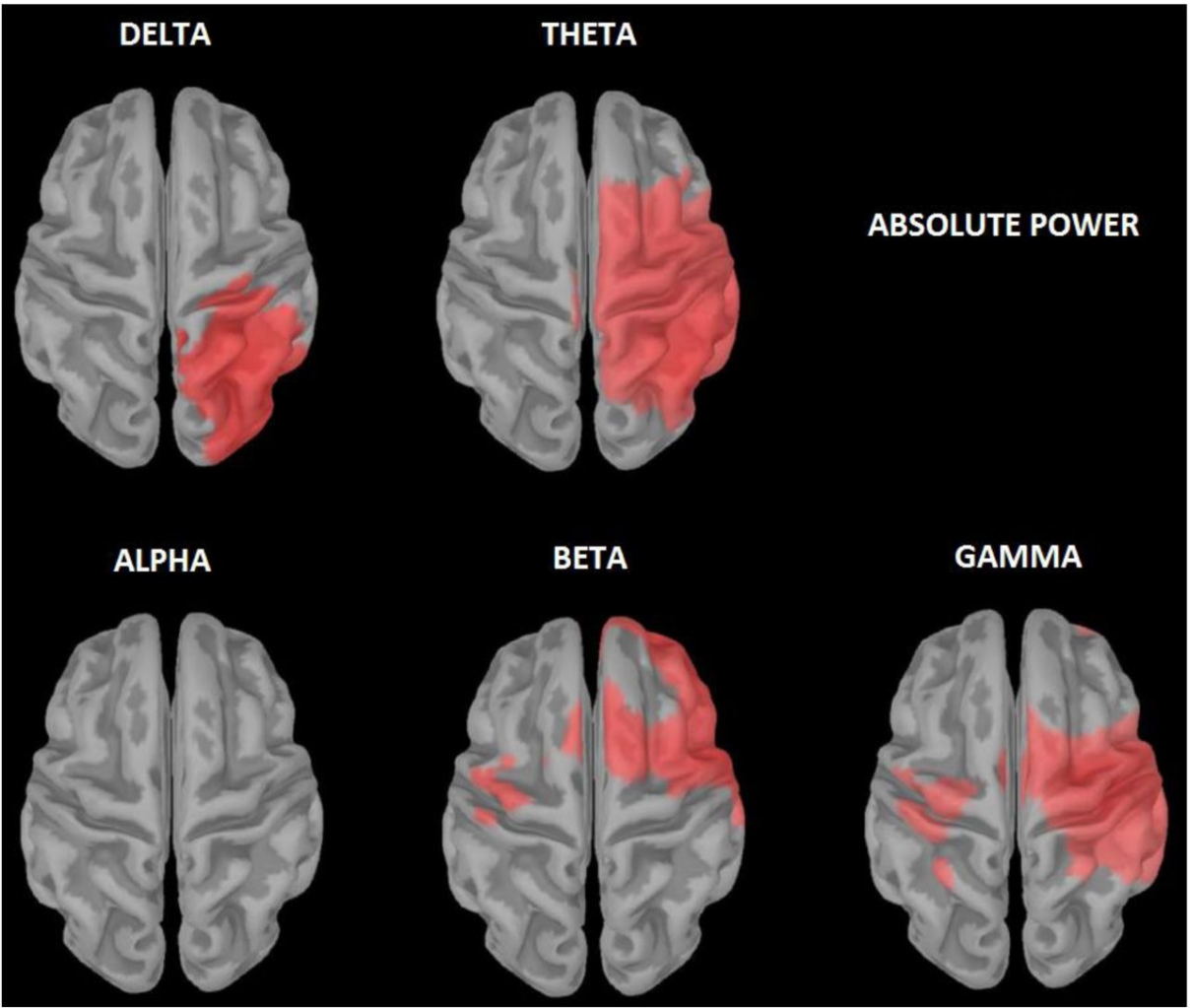
Alpha power



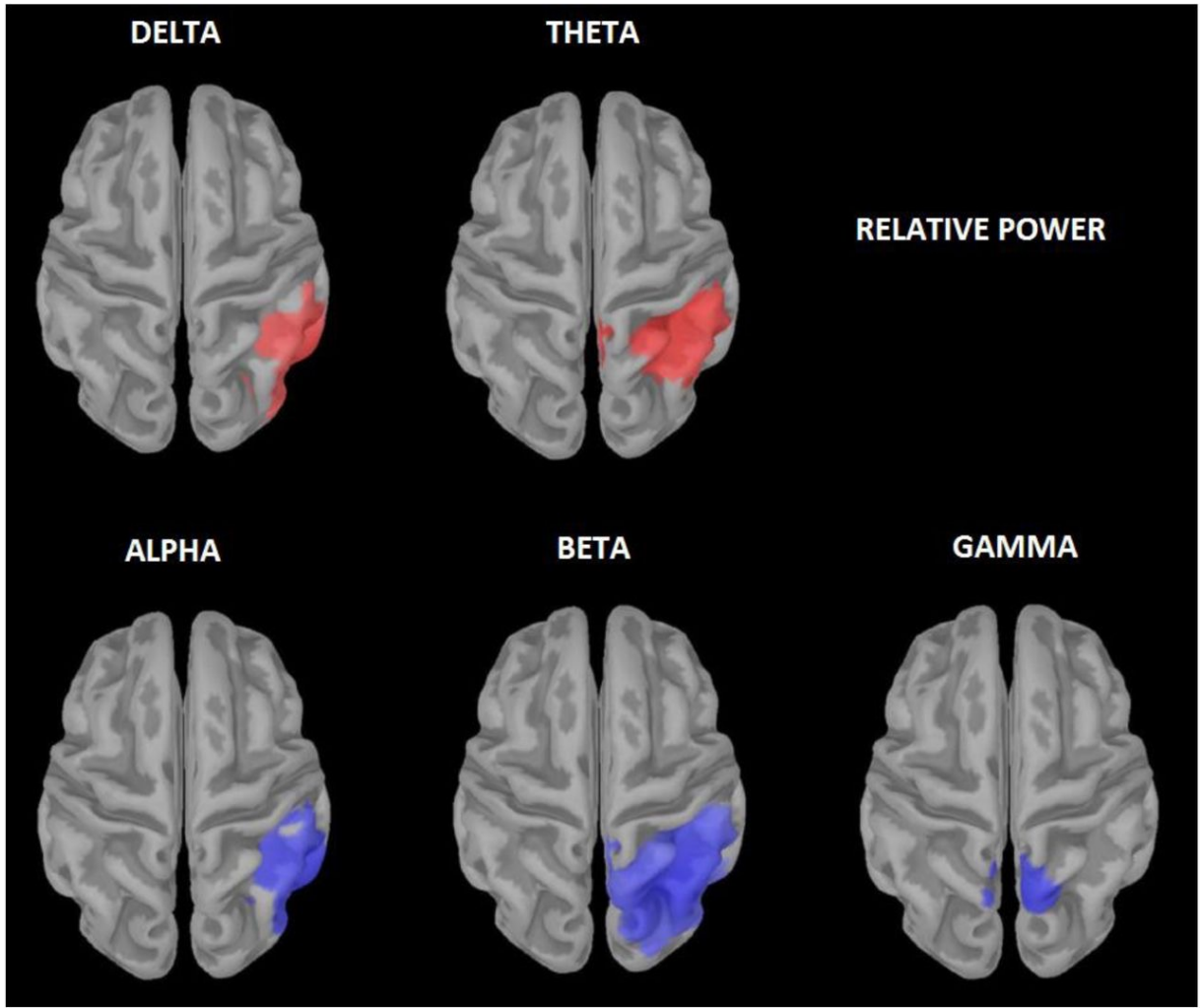
Patients with *left* **visuospatial neglect**
(after stroke in right hemisphere)



Stroke > controls

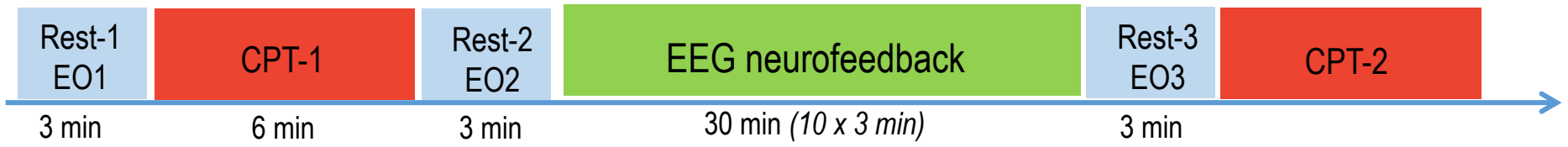


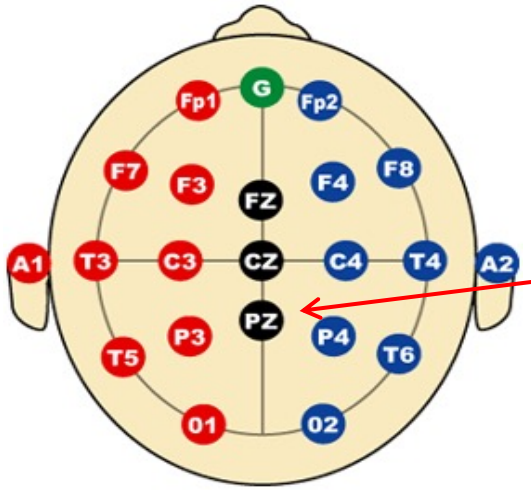
Stroke > controls (Ros et al 2022)



Effects of neurofeedback on impulsivity in adult ADHD

25 ADHD patients: 34 ± 11 y.o, 14 males
22 Control subjects: 31 ± 7 y.o, 8 males



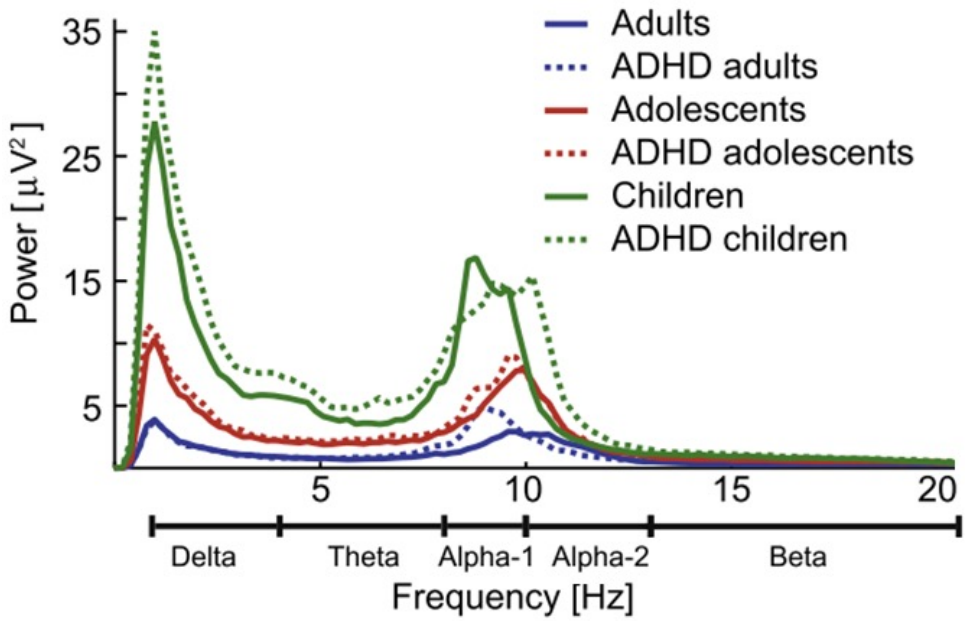


Protocol: reducing *alpha* power (8-12 Hz) at Pz

Deiber et al. 2020
Neuroimage Clinical

Spontaneous EEG in adult ADHD

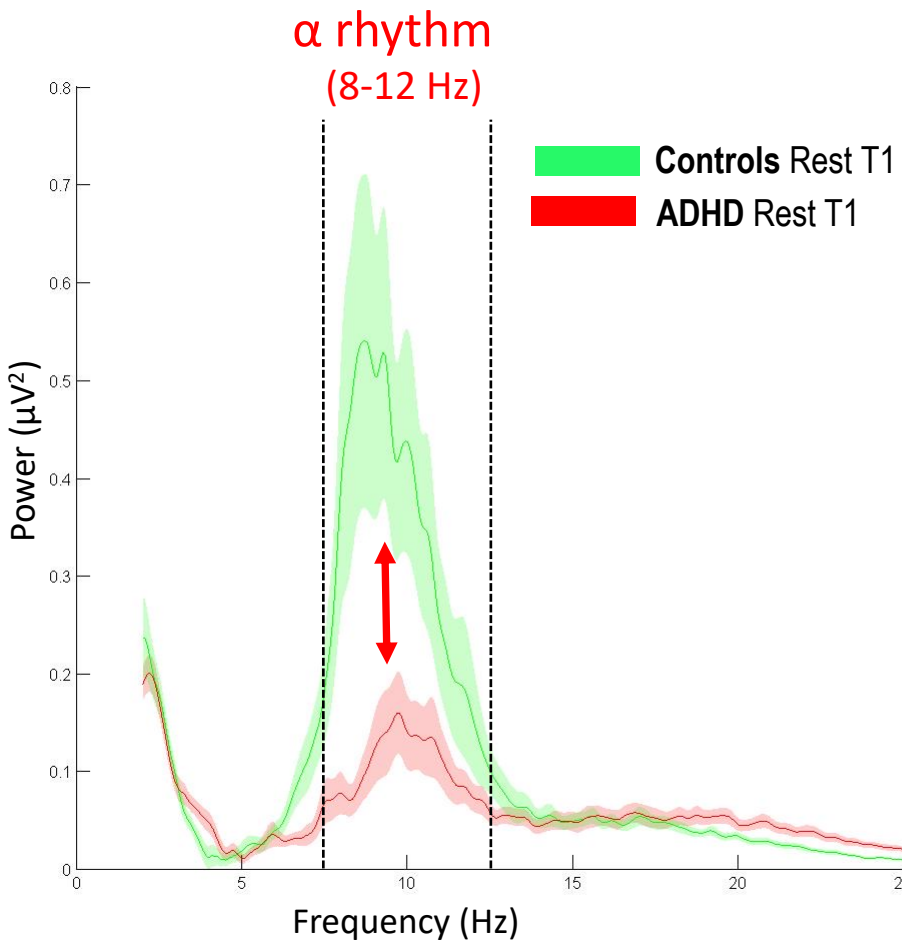
Poil et al. 2014,
Woltering et al. 2012
Koehler et al. 2009



- **Increased alpha** in adult ADHD suggests **cortical hypo-activation**

EEG results

At baseline (T1): ADHD vs controls

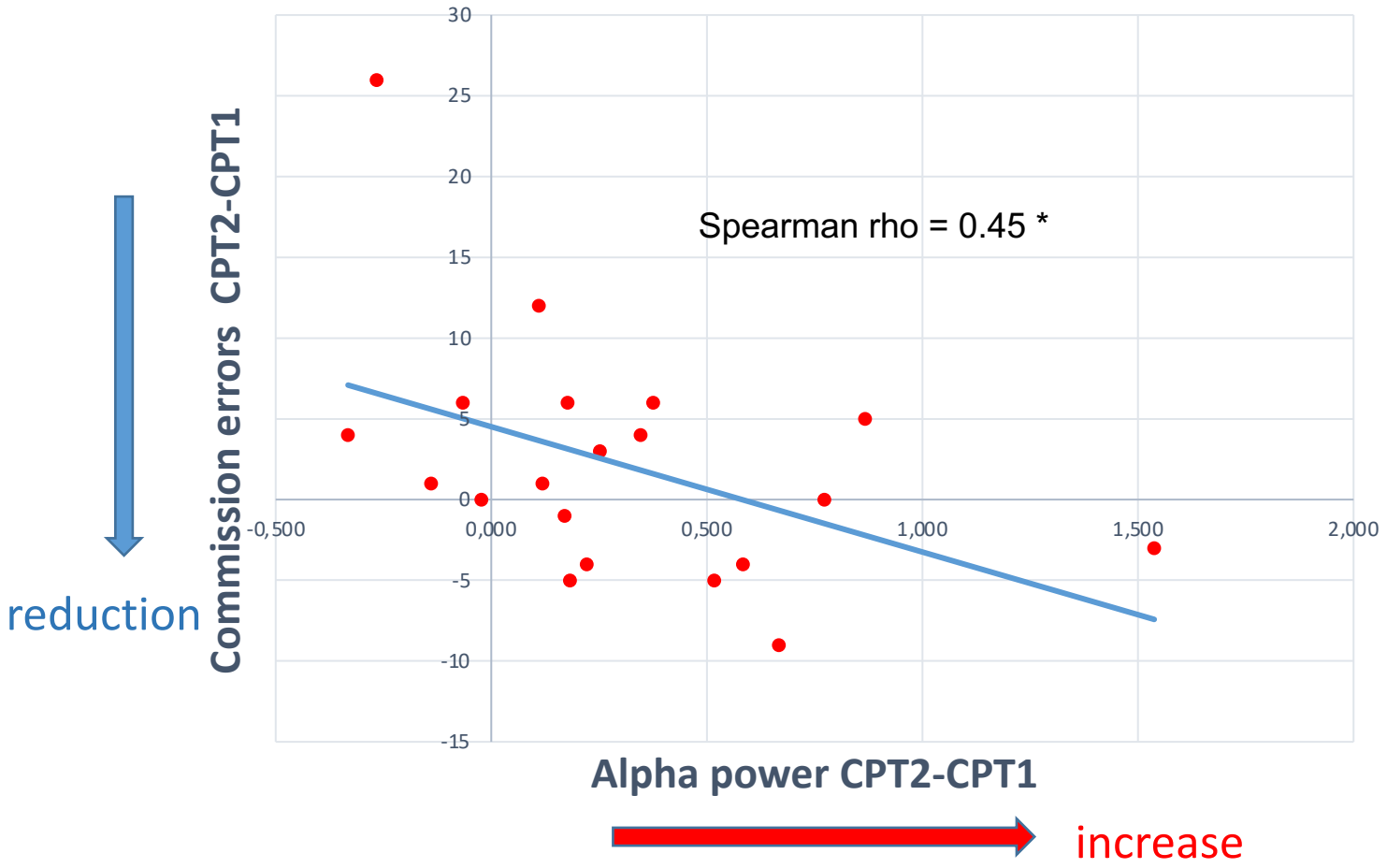


- Decreased alpha in adult ADHD suggests **cortical hyper-activation**

- Alpha rebound after NFB

Deiber et al. 2020
Neuroimage Clinical

Correlation between alpha power & impulsivity

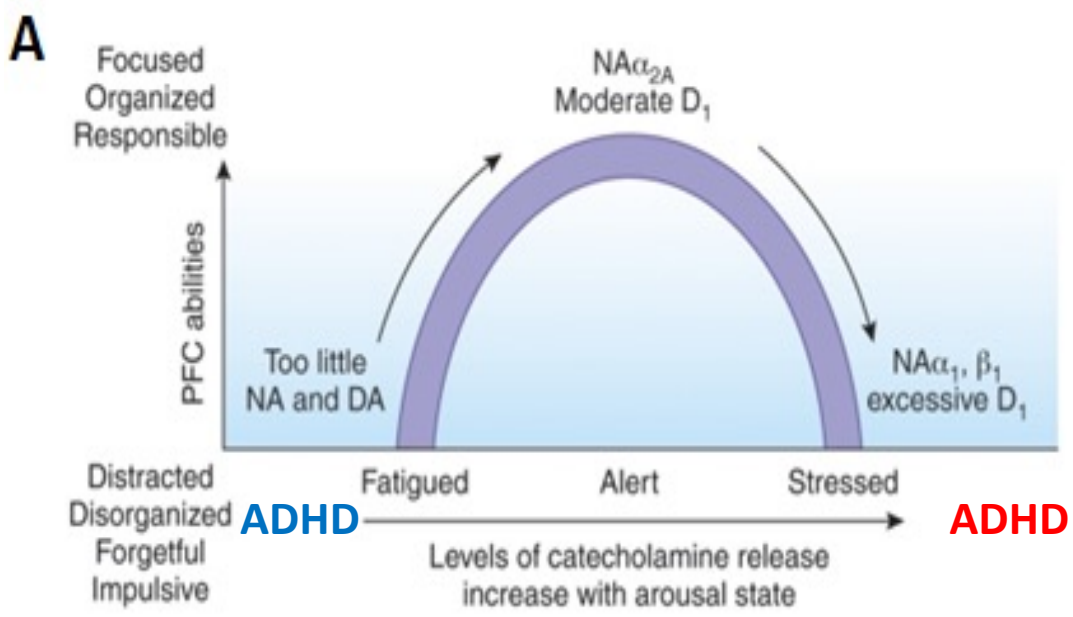


↑ alpha during Go/NoGo after neurofeedback

↓ commission errors

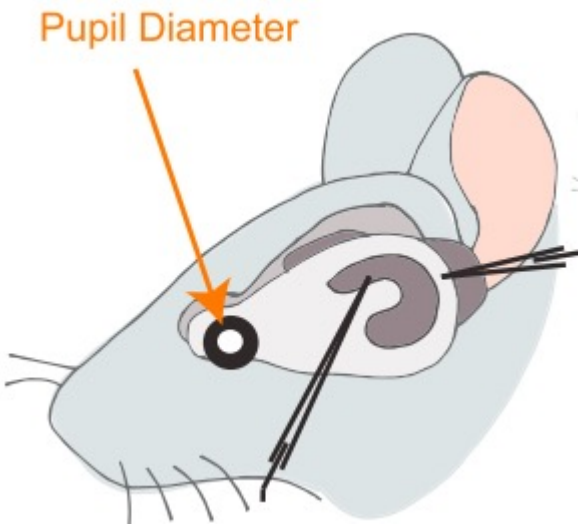
Deiber et al. 2020
Neuroimage Clinical

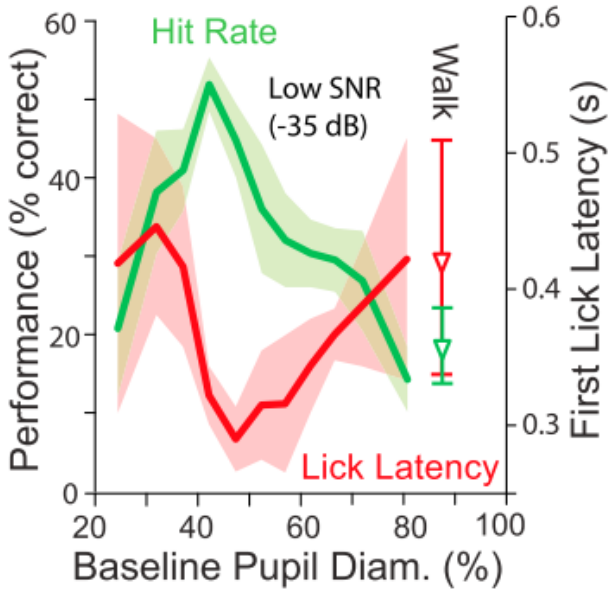
A general framework linking behavioral arousal, cortical activation, and optimal performance → "Yerkes-Dodson" law



Arnsten et al 2009, McGinley et al 2015

Inverted-U relationship between CNS arousal and performance

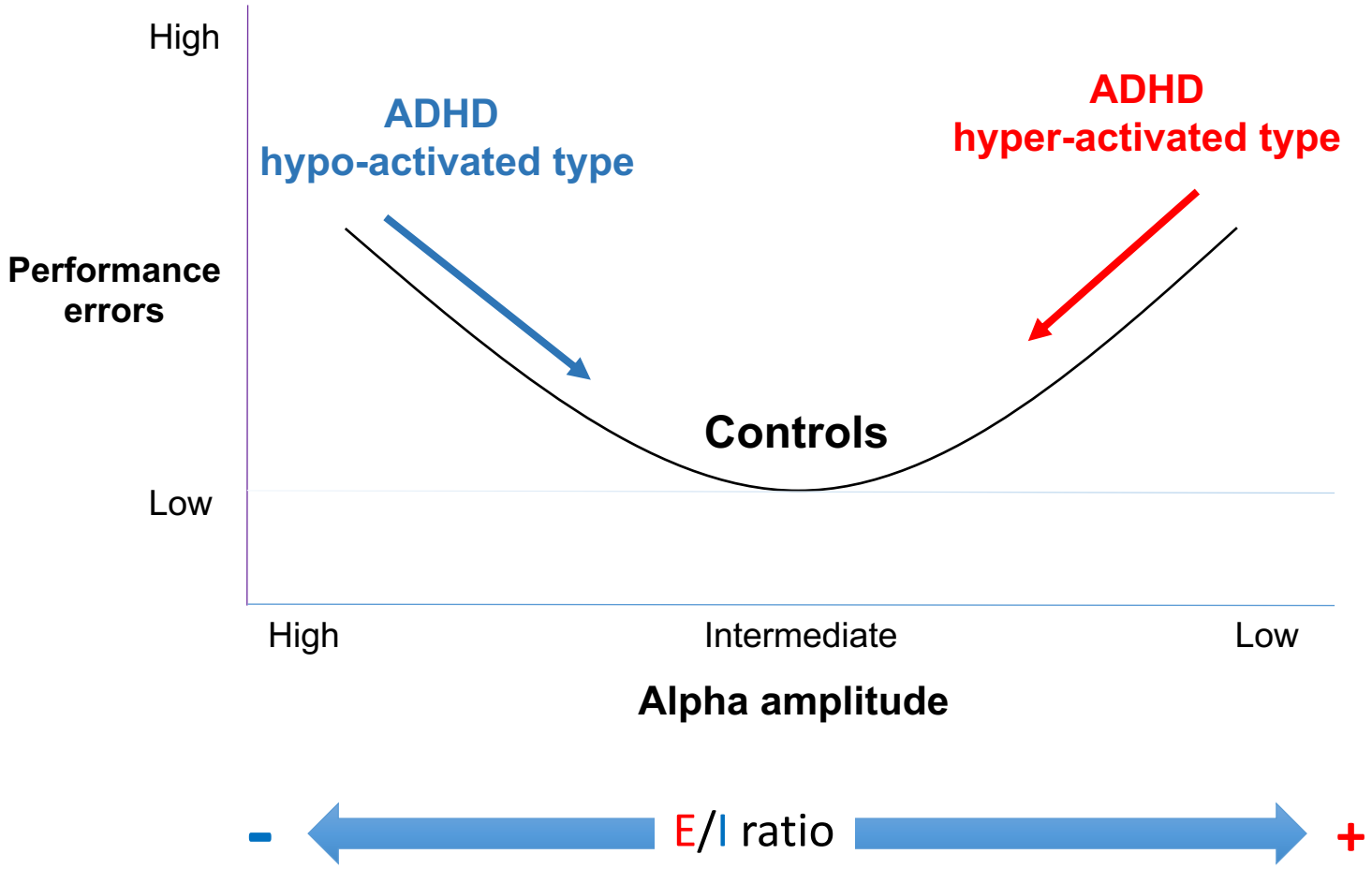




McGinley et al 2015

Theoretical model of neurofeedback mechanism:

Homeostatic normalization of E/I balance in adult ADHD



TOP 3 DON'Ts:

1. DON'T generalise neural features *from* **a healthy population** *to* **a neurological disorder**

2. DON'T expect **homogenous neural features** within the same neurological disorder

3. DON'T expect only Hebbian changes in the neural feature, but also **homeostatic** effects.