The long-term effects of reward on spatial priority maps studied with Electroencephalography and Pupillometry.

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Abstract: Knowing how to reinforce some types of behavior, and how to limit other negative behaviors could contribute to more effective strategies in psychological and cognitive treatments. Reward-based learning uses brain plasticity to alter ones behavior by reinforcing some types of behavior while adjusts the behavior for the incorrect type using rewards in this aim. However, the effect of rewards on long-term changes of behavior is not fully estimated. The aim of this study was to investigate whether spatial priority maps during a visual search can be altered in a time period of one week, on healthy human volunteers. This was achieved by introducing a training session paradigm in days 2 and 3 of the experiment where targets on certain spatial locations were rewarded more than others. The effects of reward were evaluated on day 7, using the same paradigm that was presented on day 1. This paradigm was used in a previous study where only investigation of behavioral effects has been reported (Chelazzi et al., 2014) but our study extends it by including electroencephalography (EEG) and pupillometry measures. Our results indicate even though the behavioral results can be versatile, the physiological measures provide clear evidence of the effect of rewards during the training sessions (days 2-3). However, they also show that reward can cause subtly measurable effects on the long term (day 7). Therefore, learning induced from this paradigm, via top-down processing can cause better measurable effects on the short term. These results can give better insight in to reward-based learning mechanisms, which is vital for better designing of behavioral interventions and treatments in addiction and psychological disorders.

Methods

Two different experimental paradigms were used:

a) **Main Task:** An unspeeded report of target item on days 1 , 7 (Baseline and Test task)

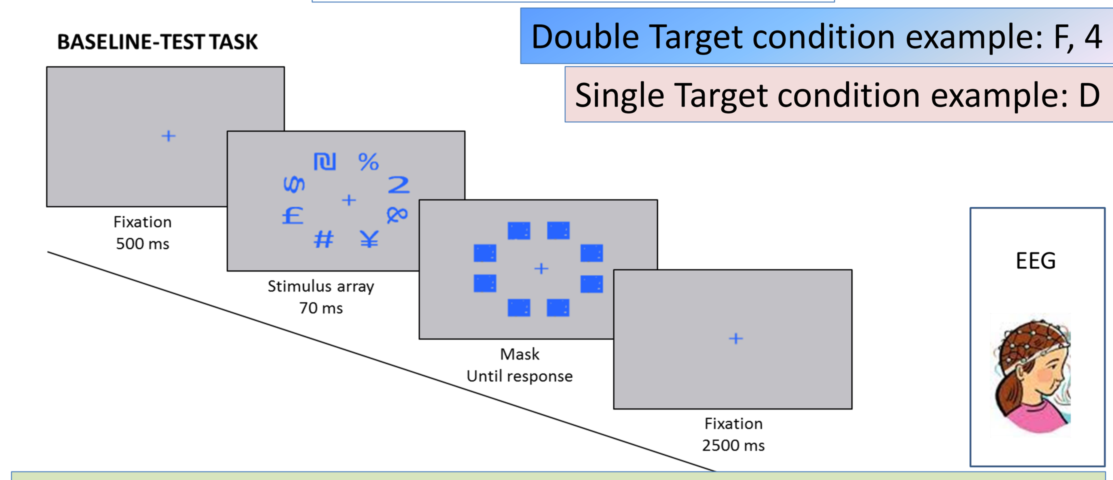
b) **Establishing reward saliency task:** A speeded visual discrimination task on days 2 - 3 (Training task).
*Stimulus design as in Chelazzi et al [3]. E-prime software was used for stimulus presentation.

Main Task: Baseline-Test (Days: 1, 7)

Target Array: F, G, M, D, 2, 4, 7, 9

Double Target condition example: F, 4

Single Target condition example: D

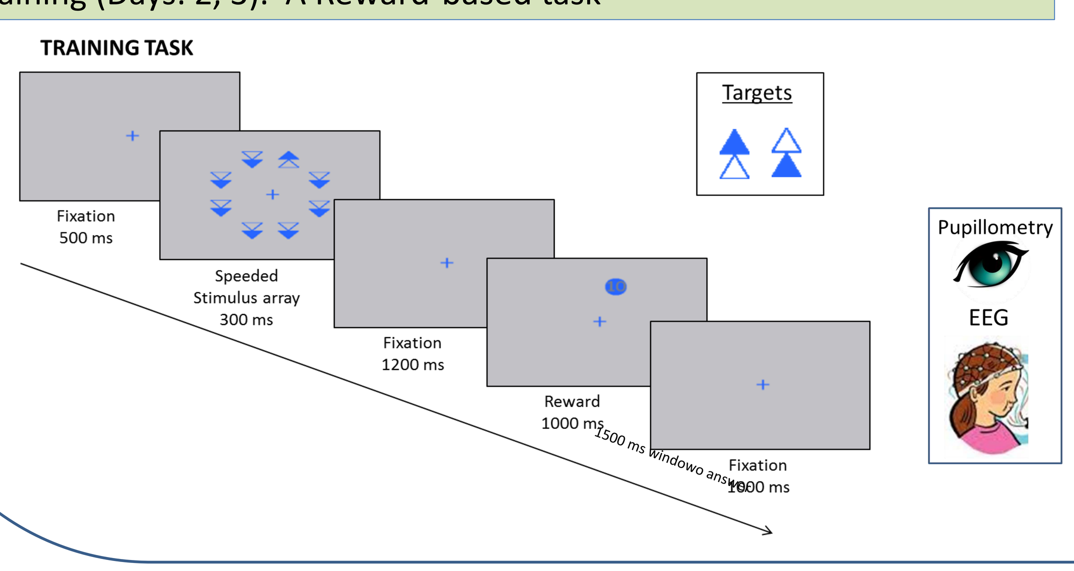


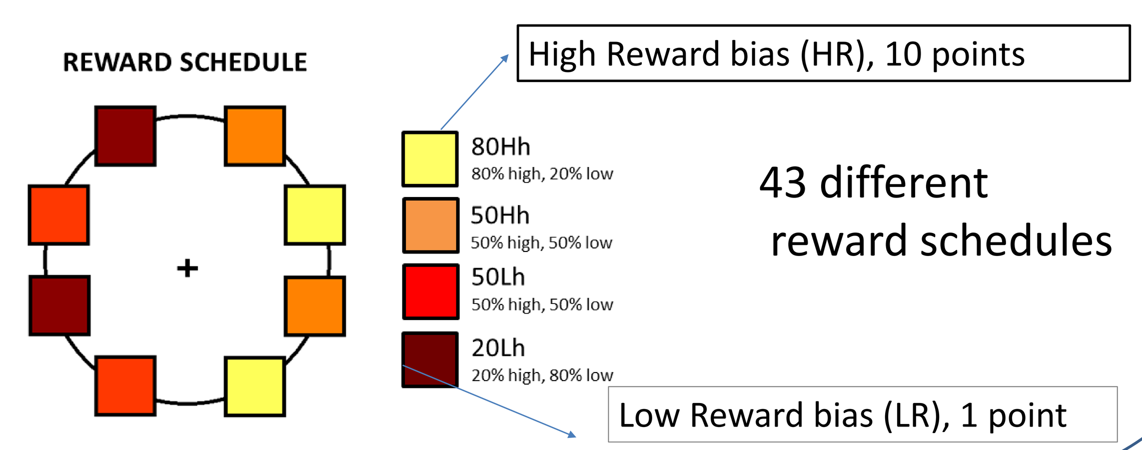
43 participants, aged 18-36 years old. Experiments were conducted at the Cognitive Laboratory, Department of Psychology, University of Oslo.

EEG recordings: 64-channel, Biosemi ActiveTwo System. Referenced to combined left and right earlobe. 2 EOG electrodes. Sampling rate at 2048 Hz. Data filtered 0.05 – 40 Hz., resampled to 256 Hz before further analyses [5]. EEGLAB, ERPLAB and custom made scripts in Matlab environment were used for the analysis.

Pupillometry recordings: Eye pupil diameter was measured with an SMI Eye tracking system, sampling frequency at 60Hz. A chin-rest was used to ensure head stability.

Training (Days: 2, 3). A Reward-based task

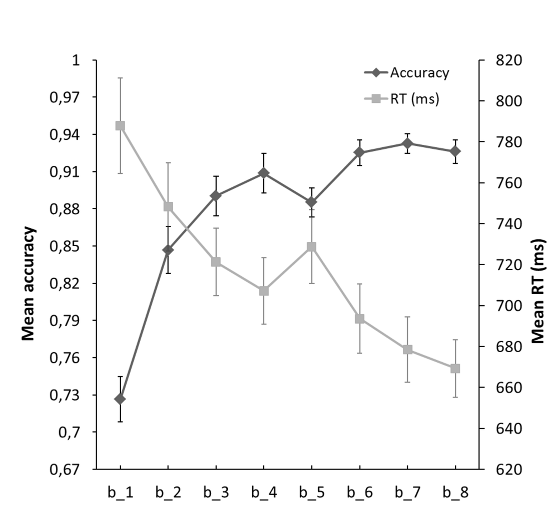




Results

a. Behavioral results

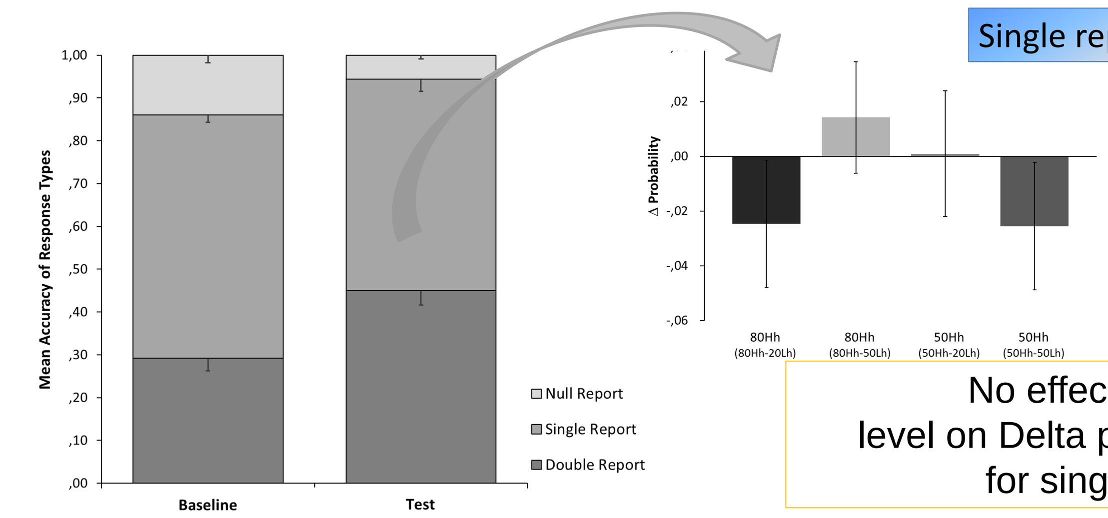
Training (days 2, 3)



2-way ANOVA with factors block : 1-8,
reward level : High – Low.
Accuracy (ACC) increased significantly (p<0.001) with blocks.
Reaction time (RT) decreased significantly with blocks

No effect of reward level on ACC and RT

Baseline-Test (days1, 7)



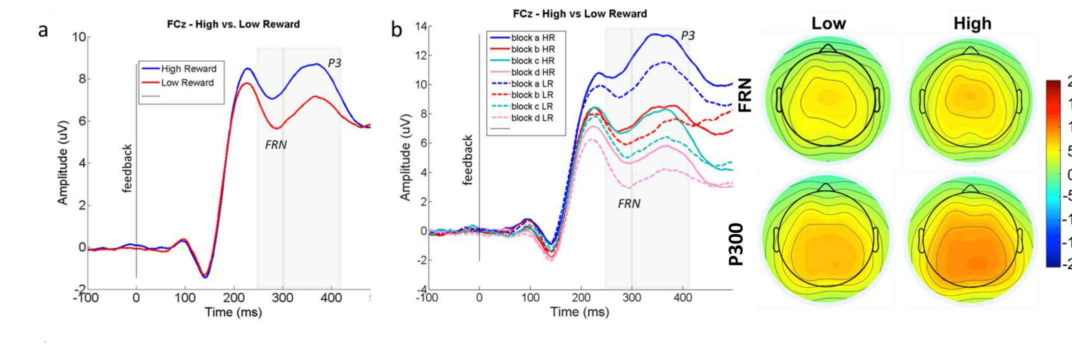
No effect of reward level on Delta probability for single report .

Incidence of double reports increased (p < .001). Incidence of single reports and null reports decreased (both p<0.001)

b. EEG results

Training (days 2, 3)

Feedback Event Related Potentials: High reward (HR) vs Low reward

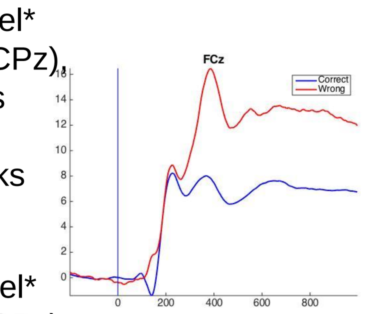


(a) Event-Related Potentials (ERP) for Low and High Rewards, (b) Progression of ERP waveforms with blocks (time) for both HR and LR, and topographic distribution of brain potentials during the peak of the P3 and FRN

FRN: ANOVA with factors: Reward Level* (High Low), Anteriority* (Fz, FCz, Cz, CPz), blocks (1-4)* all p< 0.001 & Interactions Anteriority x Reward Level p=0.032, Anteriority x Blocks p=0.001, RL x blocks p=0.05

P300: ANOVA with factors: Reward Level* (High Low) , Anteriority* (Fz, FCz, Cz, CPz) – blocks (1-4)* & Interactions Anteriority x Blocks, RL x blocks

Correct vs
Incorrect feedback

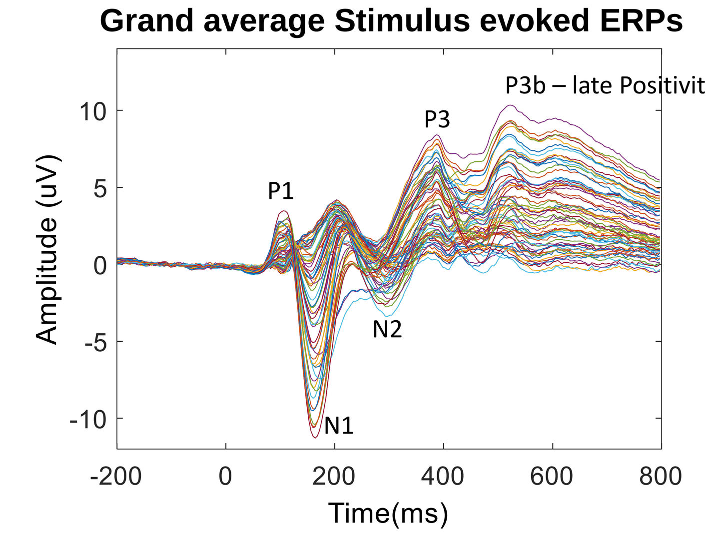


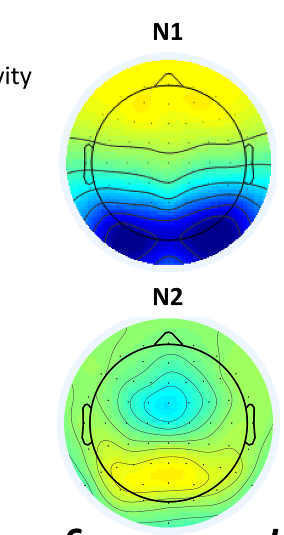
FRN: ANOVA with factors: Accuracy *(Correct, Incorrect) , Anteriority* (Fz, FCz, Cz, CPz) , blocks (1-4)*, N = 32
Anteriority: p<0.001, Accuracy p=0.008, Blocks p<0.001, Anteriority x Blocks p=0.052, Accuracy x Blocks p<0.001

P300: ANOVA with factors: Accuracy *(1 = Correct Incorrect), Anteriority* (Fz, FCz, Cz, CPz) , blocks (1-4)*, N = 32 & Accuracy x Anteriority, Anteriority xBlocks, Accuracy xBlocks gave p<0.001

Are there short term effects of reward?

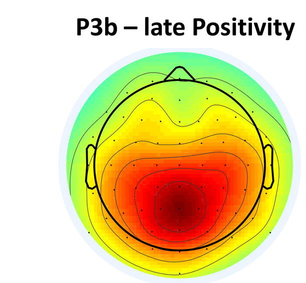
Grand average Stimulus evoked ERPs





N1: ANOVA with factors: Anteriority (Cz, CPz, Pz),
Reward Bias (High, Low) & blocks (1-4)
Anteriority: p<0.001, Reward bias p=0.032, Blocks p=0.012
Interactions Anteriority x Blocks p=0.009,
Reward bias x Blocks not sign. Anteriority x Reward bias not sign.
(similiar results for Anteriority (Fz,FCz,Cz, CPz, Pz, Poz, Oz)

N2: ANOVA with factors: Anteriority (CPz, Pz),
Reward Bias (High, Low) & blocks (1-4)
Anteriority: p<0.001, Reward bias p=0.04, Blocks not sign.,
Interactions Anteriority x Blocks p<0.001,
Reward bias x Blocks not sign. Anteriority x Reward bias not sign.



P3b: ANOVA with factors: Anteriority (Fz, FCz, Cz, CPz, Pz, Poz, Oz),
Reward Bias (High, Low) & blocks (1-4)
Anteriority: p<0.001, Reward bias p=0.024, Blocks p=0.010,

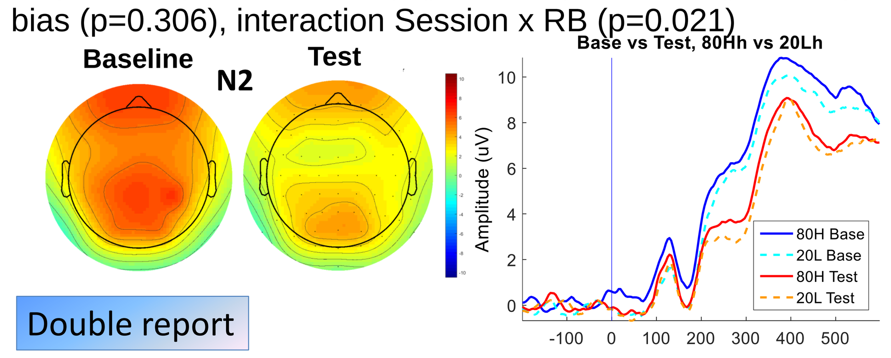
Interactions Anteriority x Blocks p<0.001,
Reward bias x Blocks not sign. Anteriority x Reward bias not sign.

Are there long term effects of reward?

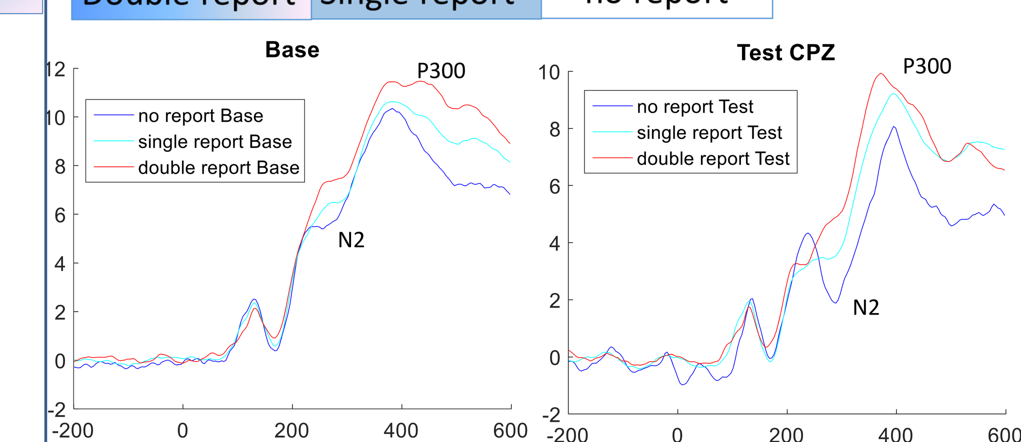
Baseline-Test (days1, 7) Double Target condition

Single report

N2: An ANOVA (reward bias (80Hh vs. 20Lh), session (baseline vs. test)) and Anteriority (AFz Fz, FCz, Cz electrodes) on the N2 mean amplitudes gave: Anteriority (p=0.0001), Session (p<0.001), Reward bias (p=0.306), interaction Session x RB (p=0.021)

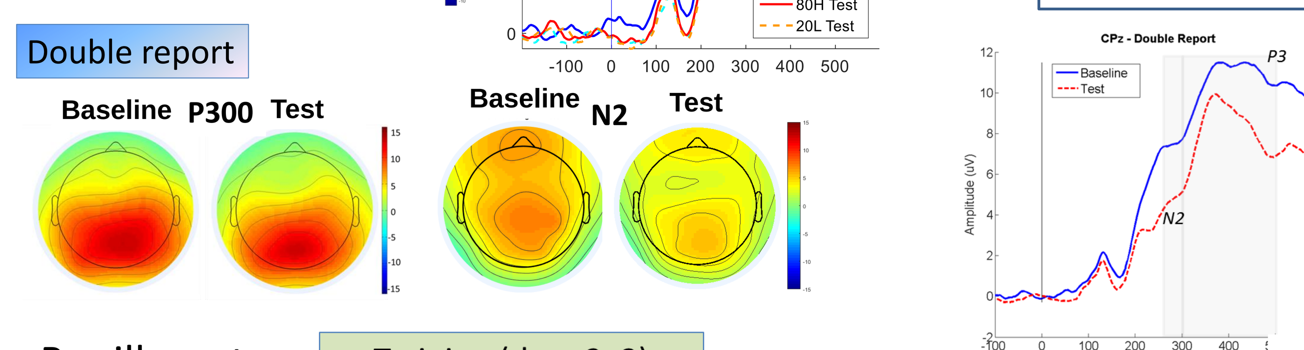


Double report Single report no report



P300: An ANOVA with factors: Condition(Double, Single, none report), Anteriority (AFz Fz, FCz, Cz, CPz, Pz, POz, Oz) & session (baseline vs. test) Anteriority (p<0.001), Condition (p<0.001) Session (p<0.001), interactions Anteriority x Session (p<0.001); Condition x Session (p=0.027)
N2: Anteriority (p=0.003), Condition (0.047), Session (p<0.001), interactions Anteriority x Session (p<0.001), Condition x Session (p=0.032)

Double report

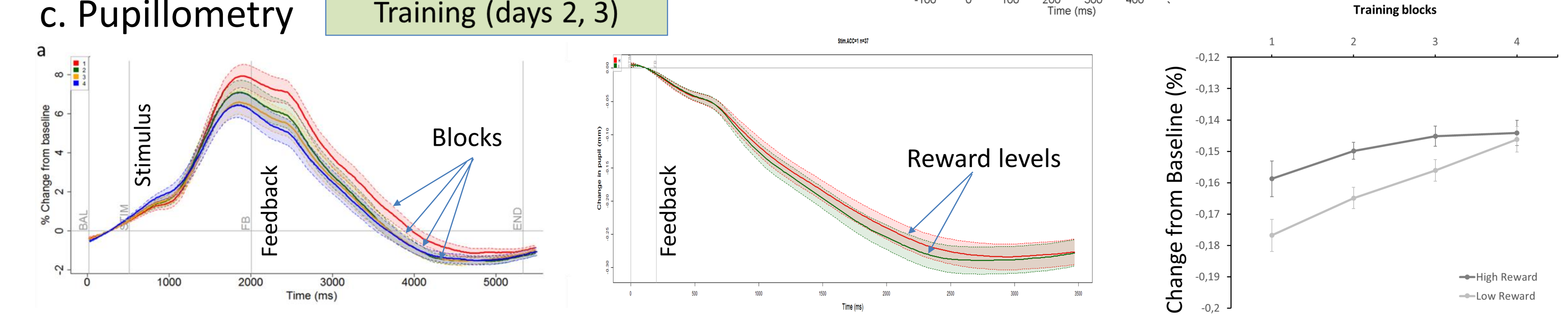


N2: An ANOVA with factors: Anteriority (Fz, FCz, Cz, CPz, Pz, POz) & session (Baseline vs. Test)) gave: Anteriority (p=0.008), Session (p<0.001), interaction Anteriority x Session (p<0.0001)

P300: An ANOVA with factors: Anteriority (AFz Fz, FCz, Cz, CPz, Pz, POz, Oz, Iz electrodes) & session (Baseline vs. Test)) gave: Anteriority (p<0.0001), Session (p<0.001), interaction Anteriority x Session (p<0.0001)

c. Pupillometry

Training (days 2, 3)



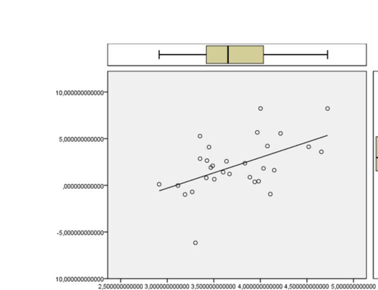
(a) Stimulus – locked pupil responses: Statistically significant changes with subsequent blocks (p=0.001), but not for the reward level.
(b) Feedback – locked pupil responses: Statistically significant changes with subsequent blocks (p=0.001), and between high and low reward (p<0.001) and for the interaction blocks x Reward Level (p=0.008)

d. Correlations pupil diameter with feedback ERPs

Pupil	FRN	P300
Baseline Stimulus (-200 to 0 ms)	Yes (electrodes Pz, Poz, Oz, Iz) – Correct	Yes (electrodes Pz, Poz, Oz, Iz)
Baseline Stimulus (0 to 300 ms)	Yes (electrodes Pz, Poz, Oz, Iz) – Correct	Yes (electrodes Pz, Poz, Oz, Iz)
Baseline Feedback (-200 to 0 ms)	Yes (electrodes Pz, Poz, Oz, Iz) – Correct	Yes (electrodes Pz, Poz, Oz, Iz)
Evoked Stimulus Dilation	NO	
Evoked Feedback Dilation	Yes (all electrodes)	Yes (electrodes Pz, Poz, Oz, Iz) – Correct

Evoked Pupil after feedback 1000 – 1750 ms, with FRN mean amplitude.

	Correct (r ; p)	HR	LR	Wrong
CPZ	-0,391*; 0,016	-0,352*;0,028	-0,390*;0,017	0,012;0,475
CZ	-0,364*; 0,024	-0,351*;0,029	-0,328*;0,038	-0,012;0,476
FCZ	-0,362*;0,025	-0,357*;0,026	-0,328*;0,039	-0,028;0,441
FZ	-0,353*;0,028	-0,343*;0,032	-0,325*;0,040	0,073;0,350
Iz	-0,366*;0,023	-0,288*;0,062	-0,425**; 0,010	-0,171;0,183
Oz	-0,471**;0,004	-0,400*;0,014	-0,515**;0,002	-0,139; 0,233
POZ	-0,422**;0,010	-0,350*;0,029	-0,477**;0,004	-0,059;0,378
PZ	-0,419*;0,011	-0,350*;0,029	-0,454**;0,006	-0,041;0,416



Conclusions: The Behavioral results did not show effect of reward (Base vs Test). ERP results have shown a distinct change in feedback ERP waveforms after High or Low reward during Training.

References:
[1] Thomson KG and Bichot NP, A visual salience map in the primate frontal eye field, Prog Brain Res 124: 251-262, , 2005
[2] Fecteau JH, Munoz DP, Salience Relevance and firing: a priority map for target selection. Trends Cogn Sci, 10 382:390, 2006
[3] Chelazzi et al, Altering Spatial Priority Maps via Reward-Based Learning, J Neurosci, 18;34(25):8594-604, 2014
[4] Laeng B, Sirois S, Gredeback G, Pupillometry: A window to the Preconscious, 7: 18-27, 2012
[5] Luck S., An introduction to the event related technique, MIT Press, 2005; (second edition) 2014.