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rTMS and the Inhibition of Aversive Encoding Processes: A Pilot Study

Appendix

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S0 Materials

List S0_1

Inclusion and exclusion criteria

- Participants fulfilling all of the following inclusion criteria were eligible for the study:
- Male or female
- Generally healthy
- Age between 18 and 30 years

Participants were excluded if any of the following apply:

- Metal in the head area (e.g., splinters, fragments, clips)
- Implanted neurostimulator (e.g., DBS, epidural/subdural, VNS)
- Cardiac pacemaker or intracardiac lines
- Medication infusion device
- Piercings in the head area (retainers are not an exclusion criterion)
- Tattoos in the head area (if less than 3 months old or older than 20 years)
- History of neurosurgery
- Hearing problems or tinnitus
- Inability to sit still due to tremor, tics, or itching
- History of repeated syncope
- Head trauma diagnosed as concussion or associated with loss of consciousness
- Diagnosis of epilepsy or history of seizures/convulsions in the participant or their close family (parents or siblings)
- Previous TMS session with adverse effects
- Previous MRI session with complications
- History of spinal cord surgery
- Presence of spinal or ventricular shunts
- Positive pregnancy test
- Alcohol or drug use within 48 hours before the study visit
- Regular intake of any medication, particularly CNS-active drugs, within 48 hours before the study visit
- Individual resting motor threshold (rMT) exceeding the safety limits of the rTMS device
- German-speaking

S1 Coding

Table S1_1

Variables and description for analysis

Variable	Description	Type	Possible Values/Range
subject	Subject ID	Numeric (discrete)	205–240
group	Group assignment	Factor (2 levels)	20 Hz online experimental, 20 Hz online sham
age	Participant age	Numeric (continuous)	19–29 years
sex	Biological sex	Factor (binary)	male, female
rMT	Resting motor threshold (% of MSO)	Numeric (continuous)	35–90
valence category	IAPS valence category	Factor (3 levels)	negative, neutral, positive
valence rating	Valence rating at T2 (per val_cat)	Numeric (continuous)	–200 to +200
memory performance	Correctly recalled images at T3 (per val_cat)	Numeric (discrete)	0–14

Note. Valence-related variables (valence rating, memory performance) were recorded separately for each IAPS category.

Table S1_2

Data structure

subject	valence category	memory performance	valence rating	group	age	sex	rMT
ID 1	negative	Integer (0-14)	Continuous (-200 to 200)	Factor (exp/sham)	Integer (years)	Factor (male/female)	% of MSO (35-90)
ID 1	positive	Integer (0-14)	Continuous (-200 to 200)	Factor (exp/sham)	Integer (years)	Factor (male/female)	% of MSO (35-90)
ID 1	neutral	Integer (0-14)	Continuous (-200 to 200)	Factor (exp/sham)	Integer (years)	Factor (male/female)	% of MSO (35-90)
ID 2	negative	Integer (0-14)	Continuous (-200 to 200)	Factor (exp/sham)	Integer (years)	Factor (male/female)	% of MSO (35-90)
ID 2	positive	Integer (0-14)	Continuous (-200 to 200)	Factor (exp/sham)	Integer (years)	Factor (male/female)	% of MSO (35-90)
ID 2	neutral	Integer (0-14)	Continuous (-200 to 200)	Factor (exp/sham)	Integer (years)	Factor (male/female)	% of MSO (35-90)

Note. The final dataset was organized in long format, with each row representing a unique combination of participant and IAPS valence category (negative, neutral, positive). This structure enabled the modeling of within-subject variation across valence conditions. Each participant contributed three observations, one for each valence category, resulting in repeated measures nested within individuals.

S2 Descriptives

Table S2_1

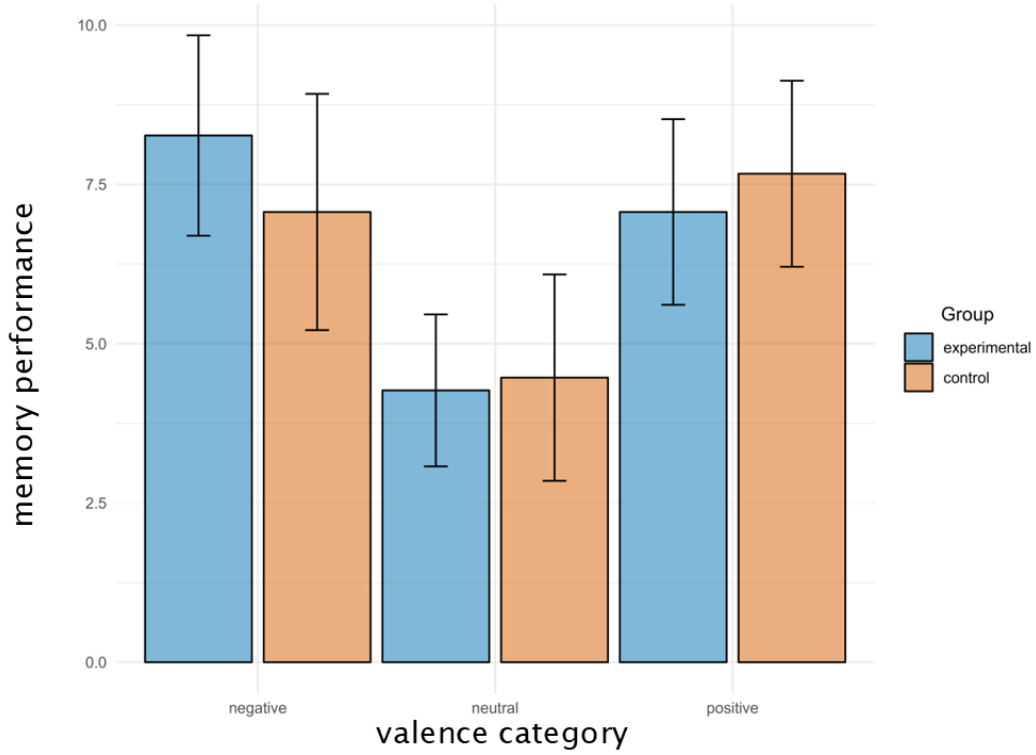
H1: Descriptive statistics of variables after exclusion of multivariate outlier

	experimental		sham			
Sex						
female	n = 8		n = 8			
male	n = 7		n = 6			
Variables	**Mean**	**SD**	**Mean**	**SD**	**W**	***p***
Demographics						
age	23.93	2.55	24.07143	2.53	107	.947
Physiology						
rMT	60.47	13.25	60.14	11.78	107.5	.930
Memory Performance						
overall	19.60	5.78	20.21	6.93	103	.947
negative	8.27	2.84	7.57	2.82	122	.467
neutral	4.27	2.15	4.79	2.75	96.5	.723
positive	7.07	2.63	7.86	2.63	93.5	.628

Note. Descriptives of effective data after exclusion of multivariate outlier subject 212. W = Wilcoxon rank-sum test statistic*s*. *p*-values are unadjusted. $p < .05$ is marked with an asterisk.

Figure S2_1

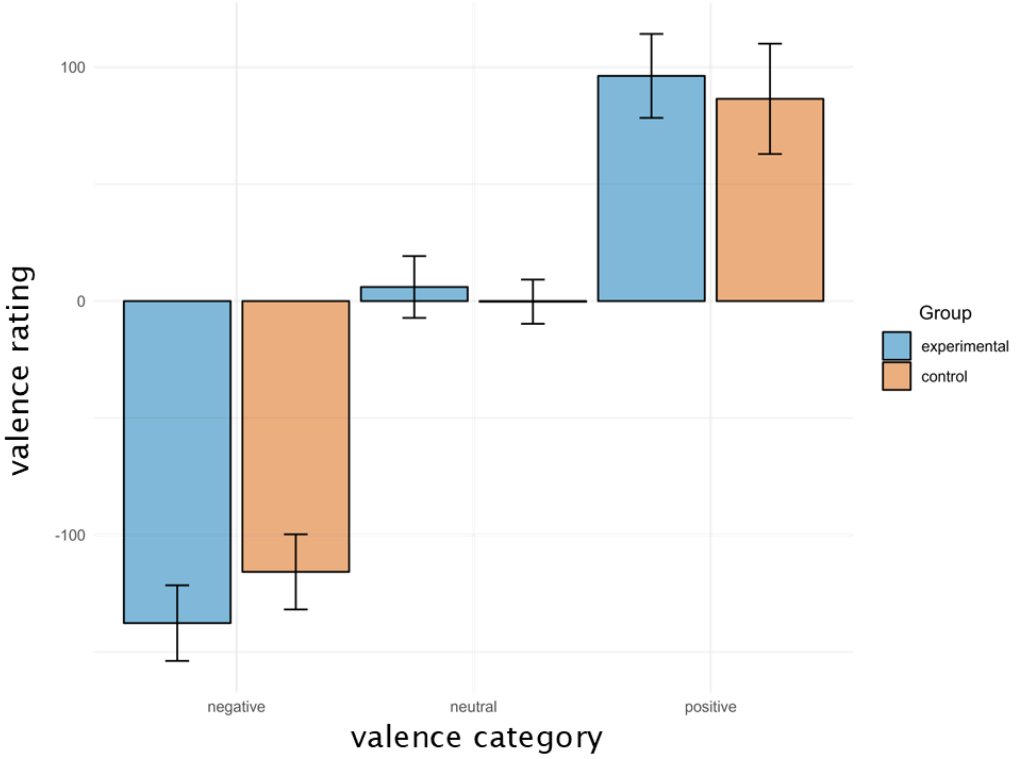
H1: Mean values for memory performance



Note. Mean values for memory performance of participants at T3, separated by group and valence category for the initial sample. Error bars indicate 95% confidence intervals.

Figure S2_2

H2: Mean values for valence rating

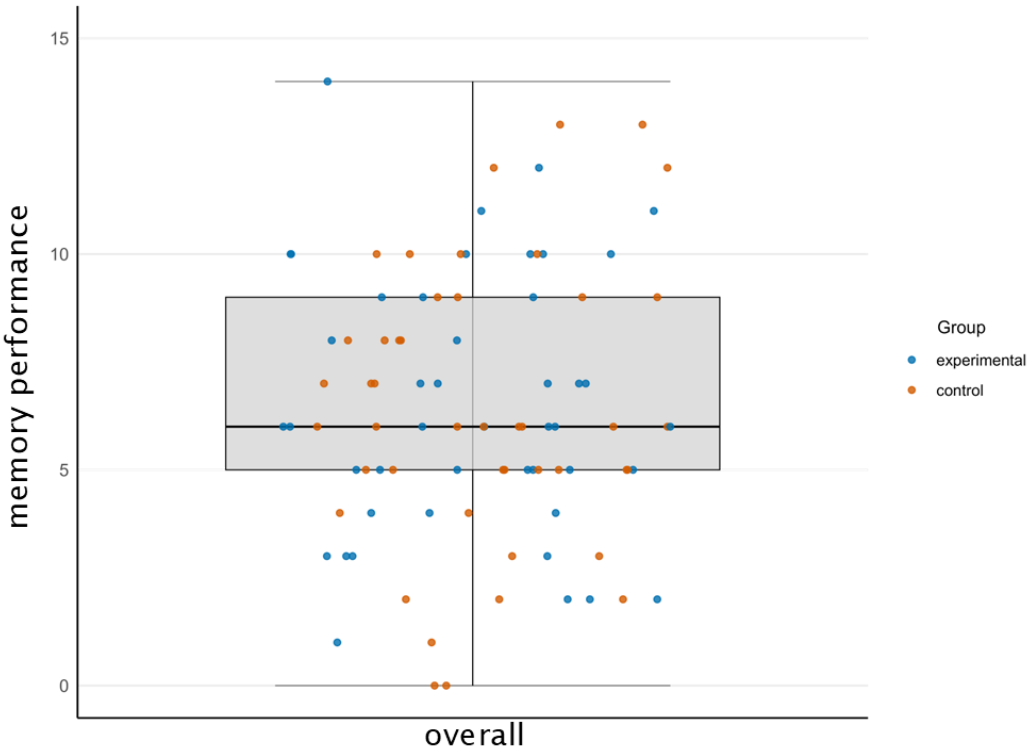


Note. Mean values for valence rating at T2, separated by group and valence category for the initial sample. Error bars indicate 95% confidence intervals

S3 Assumption Testing

Figure S3_1

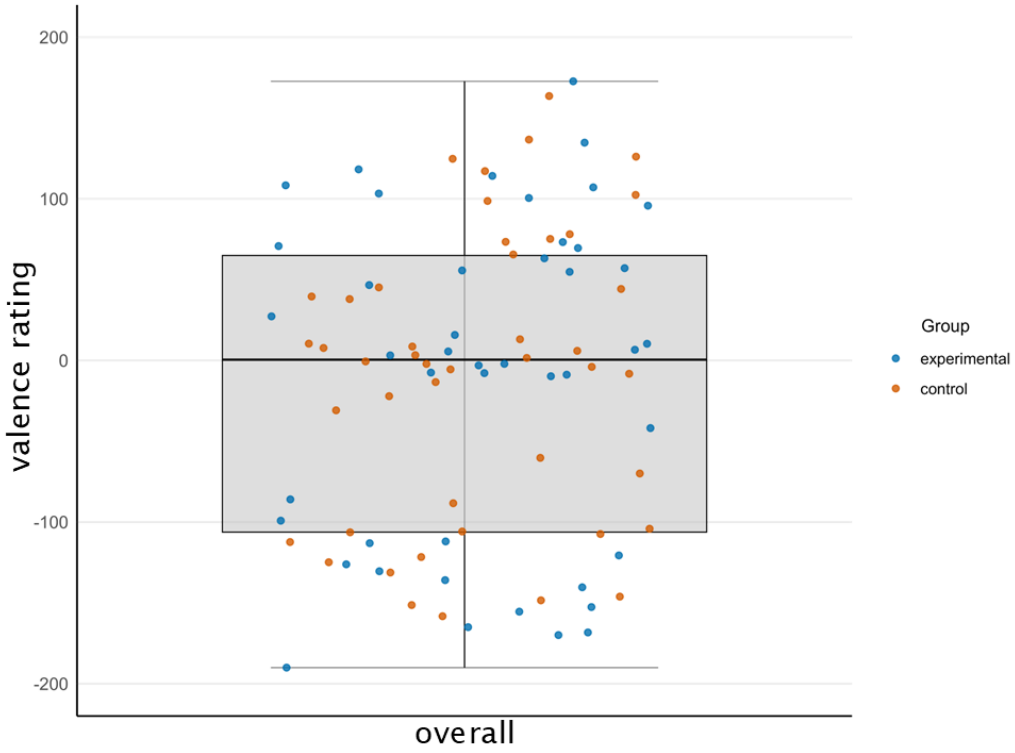
H1: Univariate outliers for memory performance



Note. Boxplot displaying the distribution of memory performance at T3 for the experimental and control groups. Boxes represent the interquartile range (IQR), whiskers extend to 1.5 × IQR, and individual data points are shown with jitter for visibility.

Figure S3_2

H2: Univariate outliers for valence rating



Note. Boxplot displaying the distribution of valence rating at T2 for the experimental and control groups. Boxes represent the interquartile range (IQR), whiskers extend to 1.5 × IQR, and individual data points are shown with jitter for visibility.

Figure S3_3

H1: Multicollinearity Plots

Model	Term	VIF	95% CI		Increased SE
			LL	UL	
P1					
	group	1.56	1.27	2.14	0.64
	valence category	3.74	2.75	5.29	0.27
	group x valence category	4.81	3.48	6.86	0.21
P2					
	group	1.52	1.25	2.08	1.23
	valence category	3.74	2.77	5.24	1.93
	age	1.05	1.00	3.37	1.03
	sex	1.06	1.00	3.29	1.03
	group x valence category	4.74	3.46	6.70	2.18
P3					
	group	1.53	1.26	2.08	1.24
	valence category	3.74	2.78	5.22	1.93
	age	1.08	1.00	2.21	1.04
	sex	1.06	1.00	3.16	1.03
	rMT	1.02	1.00	172.18	1.01
	group x valence category	4.75	3.48	6.68	2.18

Note. VIF = Variance Inflation Factor; 95% CI = 95% Confidence Interval; LL = lower limit; UL = upper limit; SE = Standard Error.

Figure S3_4

H2: Multicollinearity Plots

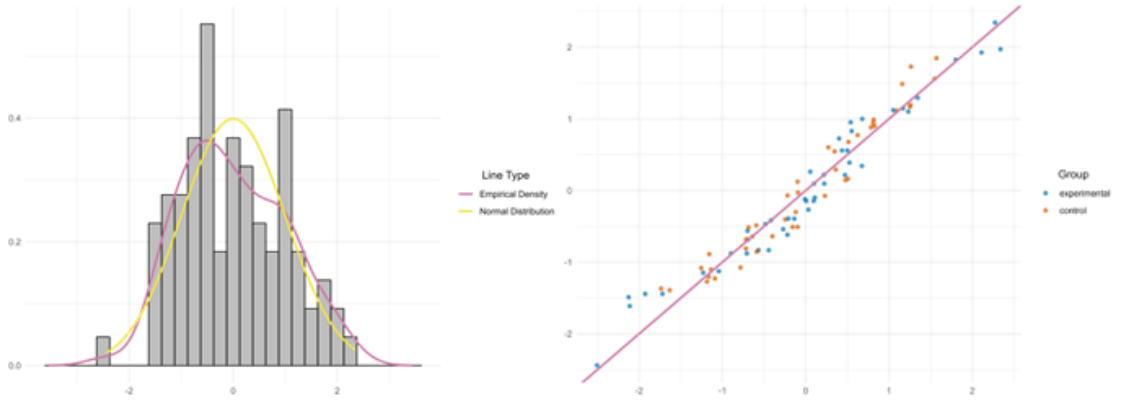
Model	Term	VIF	95% CI		Increased SE
			LL	UL	
S1					
	group	3.00	2.25	4.20	1.73
	valence category	4.00	2.94	5.65	0.25
	group x valence category	8.00	5.68	11.46	2.83
S2					
	group	3.00	2.27	4.16	1.73
	valence category	4.00	2.96	5.60	2.00
	age	1.05	1.00	3.45	1.03
	sex	1.05	1.00	3.55	1.03
	group x valence category	8.00	5.73	11.36	2.83
S3					
	group	3.01	2.28	4.15	1.73
	valence category	4.00	2.97	5.57	2.00
	age	1.08	1.00	2.17	1.04
	sex	1.06	1.00	2.86	1.03
	rMT	1.03	1.00	20.39	20.39
	group x valence category	8.00	5.75	11.31	2.83

Note. VIF = Variance Inflation Factor; 95% CI = 95% Confidence Interval; LL = lower limit; UL = upper limit; SE = Standard Error.

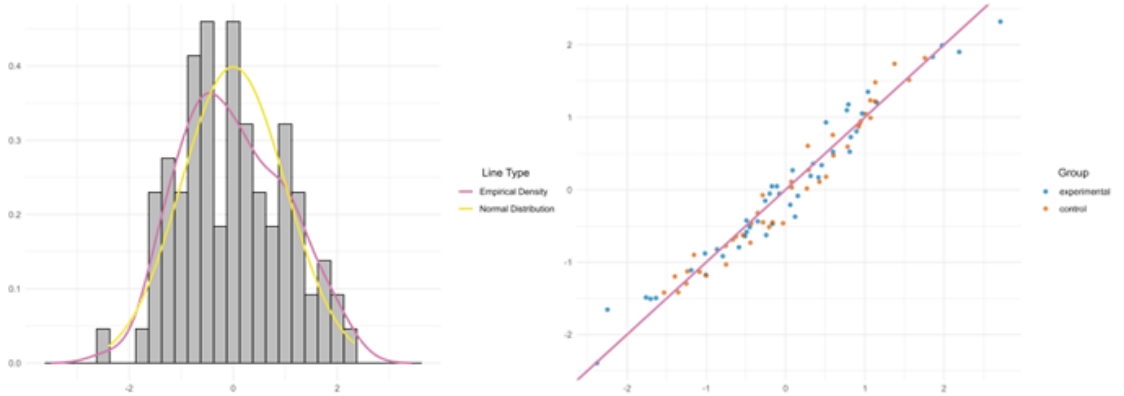
Figure S3_5

H1: Distribution of Errors

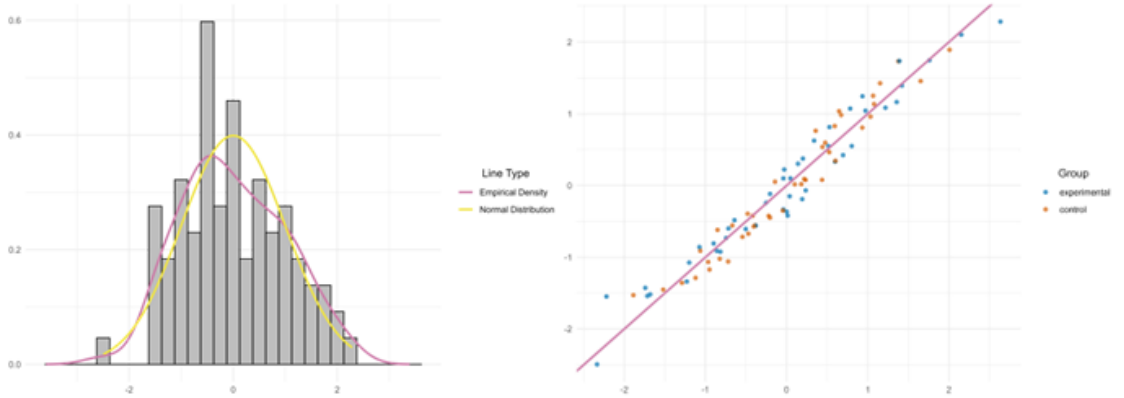
P1



P2



P3



Note. Left: Histograms of standardized KDE (violet) and standard normal distribution (yellow). Right: Q–Q plots comparing residuals to theoretical quantiles. Deviations from normality are visible as departures from the diagonal indicating perfectly normally distributed error structure.

Table S3_1

H1: Normality Testing of Model Residuals

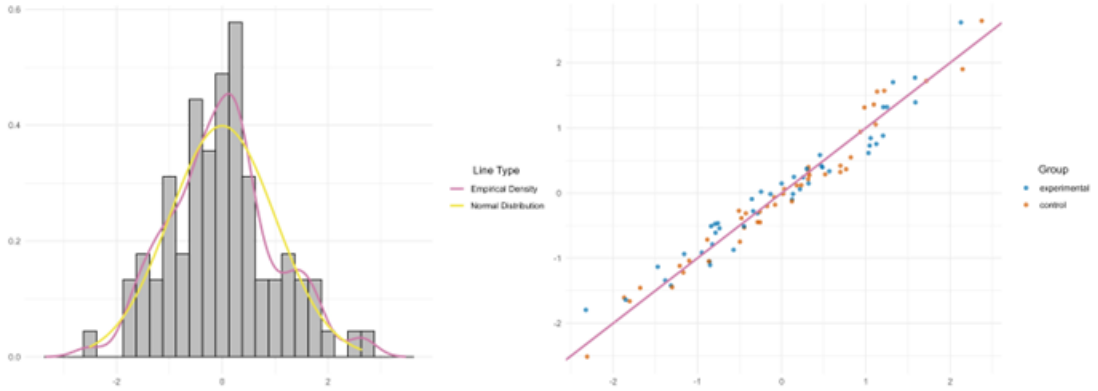
Model	Shapiro-Wilk		Anderson Darling	
	W	*p*	A	*p*
P1	0.99	.480	0.41	.333
P2	0.99	.629	0.30	.553
P3	0.99	.772	0.25	.756

Note. Results refer to the standardized residuals of the three primary analysis models. *W* = Shapiro-Wilk test statistic, *A* = Anderson-Darling test statistic. p-values are unadjusted. p < .05 is marked with an asterisk.

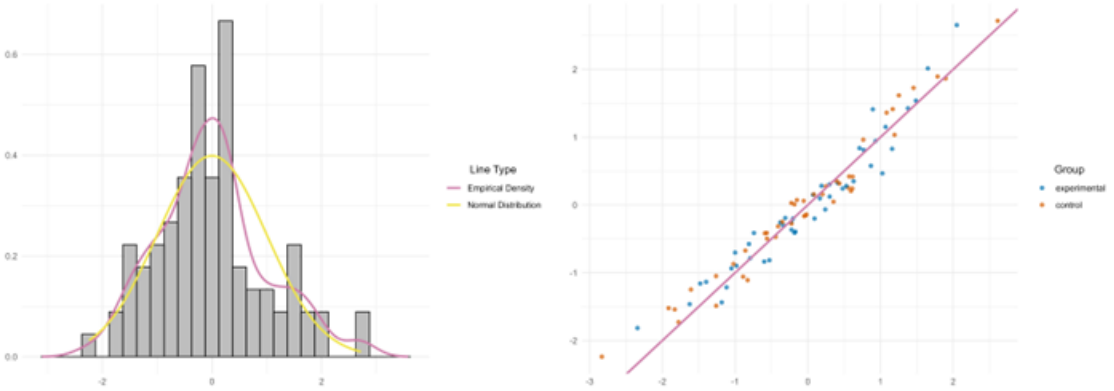
Figure S3_6

H2: Distribution of Errors

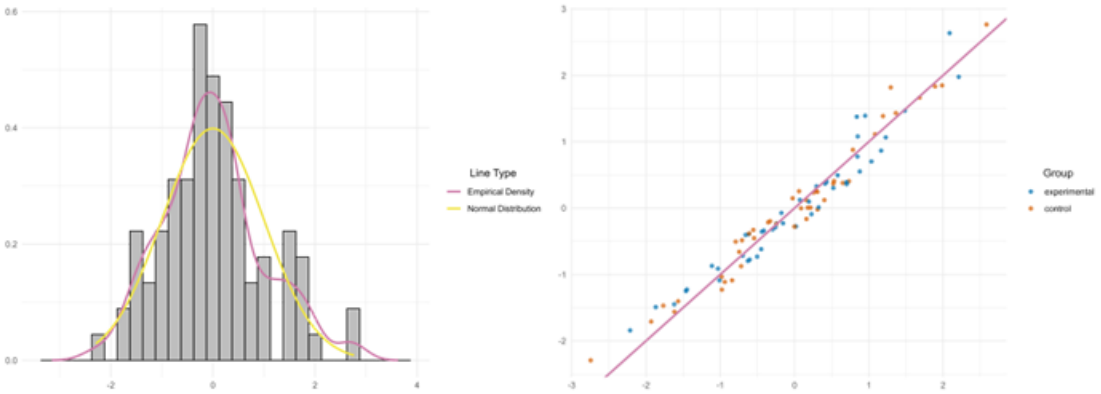
S1



S2



S3



Note. Left: Histograms of standardized KDE (violet) and standard normal distribution (yellow). Right: Q–Q plots comparing residuals to theoretical quantiles. Deviations from normality are visible as departures from the diagonal indicating perfectly normally distributed error structure.

Table S3_2

H2: Normality Testing of Model Residuals

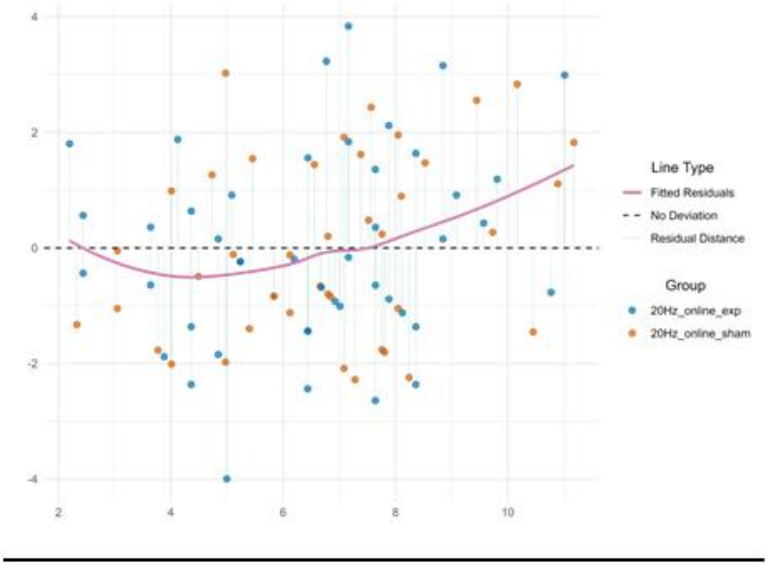
Model	Shapiro-Wilk		Anderson Darling	
	W	*p*	A	*p*
S1	0.99	.536	0.39	.373
S2	0.98	.170	0.644	.090
S3	0.98	.120	0.59	.120

Note. Results refer to the standardized residuals of the three primary analysis models. *W* = Shapiro-Wilk test statistic, *A* = Anderson-Darling test statistic. p-values are unadjusted. p < .05 is marked with an asterisk.

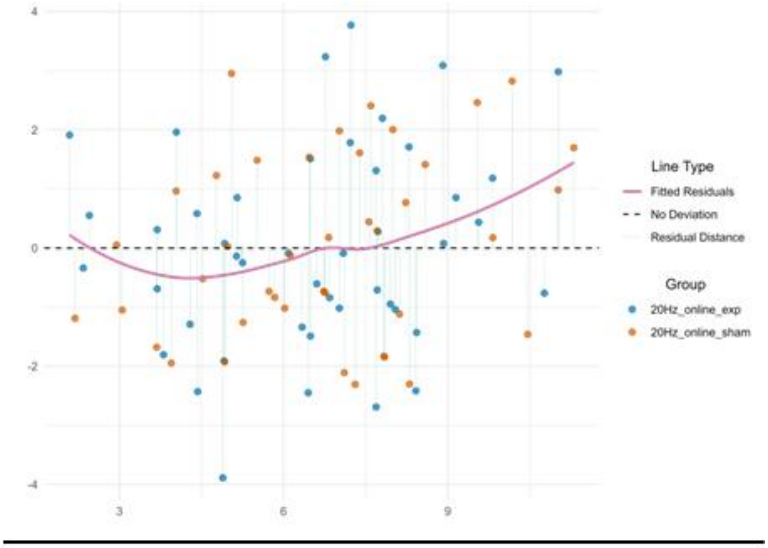
Figure S3_9

H1: Variance homogeneity plots

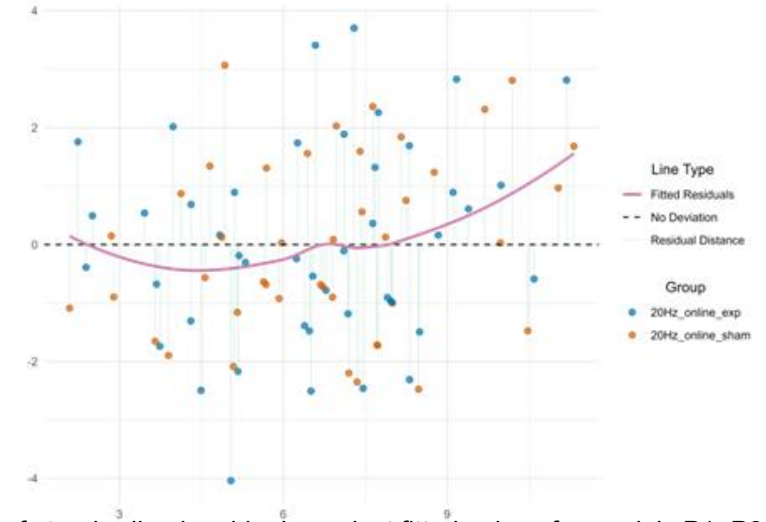
P1



P2



P1



Note. Scatterplots of standardized residuals against fitted values for models P1–P3. The dashed line marks zero residuals; the violet LOESS curve indicates potential deviations from homoscedasticity.

Table S3_3

H1: Testing vor variance homogeneity

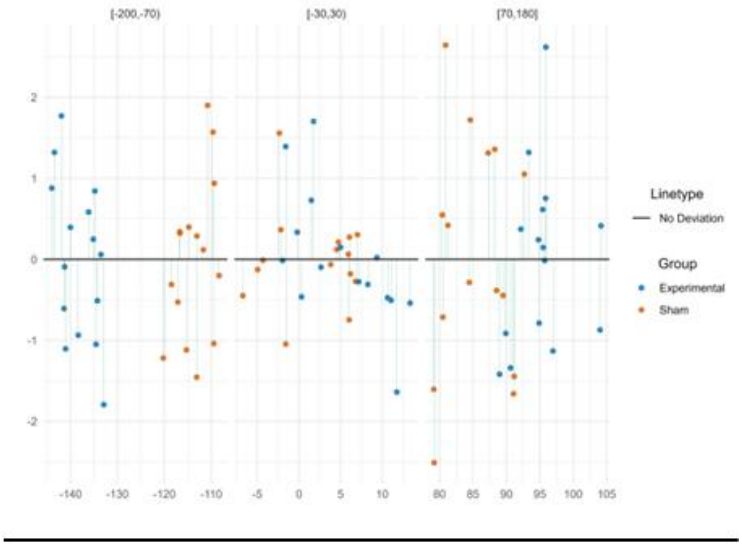
Model	Homoscedasticity	*p*	Interpretation
P1	Yes	0.611	Error variance appears to be homoscedastic
P2	Yes	0.578	Error variance appears to be homoscedastic
P3	Yes	0.631	Error variance appears to be homoscedastic

Note. Homoscedasticity was tested using the Breusch-Pagan method via the check_heteroscedasticity() function. $p < .05$ is marked with an asterisk.

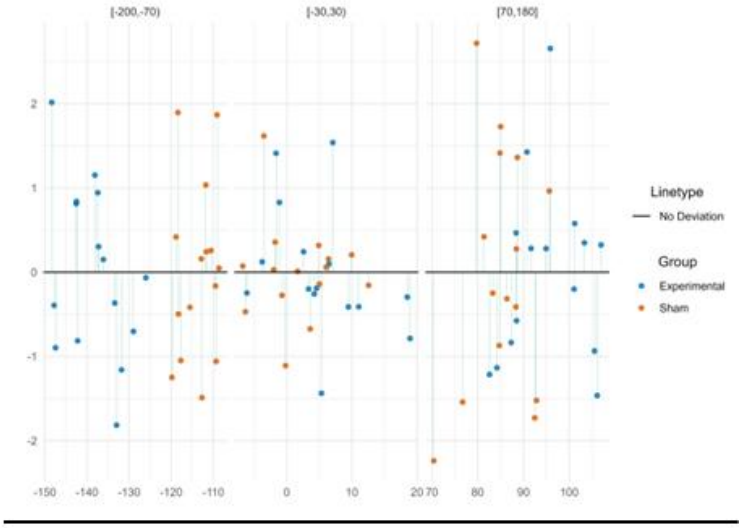
Figure S3_10

H2: Variance homogeneity plots

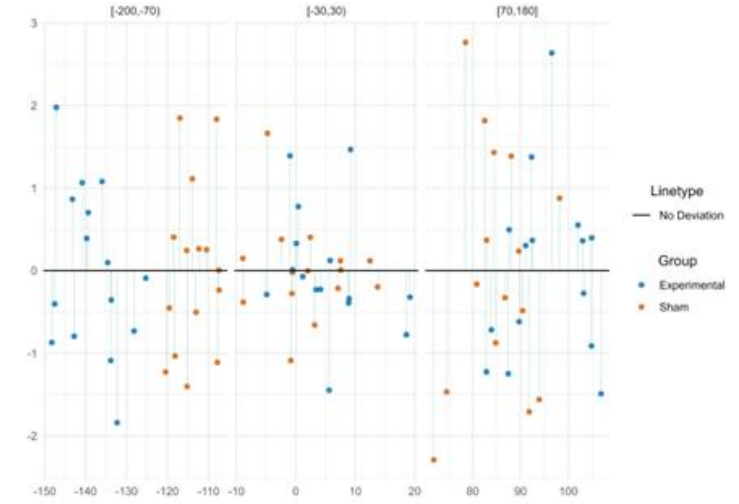
S1



S2



S3



Note. Scatterplots show standardized residuals plotted against fitted values for models S1 - S3. The x-axis is segmented into intervals to allow for a comprehensive visualization of residual distribution across the predictor range. The solid horizontal line marks zero residuals.

Table S3_4

H2: Testing vor variance homogeneity

Model	Homoscedasticity	*p*	Interpretation
S1	No	< .001*	Heteroscedasticity detected
S2	No	< .001*	Heteroscedasticity detected
S3	No	< .001*	Heteroscedasticity detected

Note. Homoscedasticity was tested using the Breusch-Pagan method via the check_heteroscedasticity() function. $p < .05$ is marked with an asterisk.

S4 Inferential Results

Table S4_1

P2: Results of Mixed Effects Regression Analysis

Variable	Estimate	SE	95% CI		*p*	Bootstrapped R^2
			LL	UL		
Fixed Effects						
(Intercept)	8.09	4.24	-0.36	16.54	.060	-
sham	-0.71	1.00	-2.71	1.29	.479	0.011
neutral	-4.00	0.71	-5.41	-2.59	< .001*	0.181
positive	-1.20	0.71	-2.61	0.21	.094	0.038
age	0.02	0.17	-0.32	0.36	.926	0.002
sex	-0.42	0.84	-2.10	1.25	.615	0.005
sham x neutral	1.21	1.02	-0.81	3.24	.236	0.016
sham x positive	1.49	1.02	-0.54	3.51	.148	0.025
Model P2						0.302
Random Effects						
SD (Intercept: subj)	1.88	0.37	1.29	2.76		-
SD (Residual)	1.94	0.19	1.60	2.34		-

Note. Results from the linear mixed-effects regression analysis of Model P2 testing H1. Fixed effects were tested using the Kenward–Roger approximation for degrees of freedom. Marginal R^2 values were computed via nonparametric bootstrapping with 1,000 simulations (nsj method). SE = standard error; CI = confidence interval; LL = lower limit; UL = upper limit. *p*-values are unadjusted. $p < .05$ is marked with an asterisk.

Table S4_2

P3: Results of Mixed Effects Regression

Variable	Estimate	SE	95% CI		*p*	Bootstrapped R^2
			LL	UL		
Fixed Effects						
(Intercept)	8.09	4.24	-0.36	16.54	.060	
sham	-0.71	1.00	2.71	1.29	.479	0.009
neutral	-4.00	0.71	-5.41	-2.59	< .001*	0.182
positive	-1.20	0.71	-2.61	0.21	.094	0.031
age	0.02	0.17	-0.32	0.36	.926	0.002
sex	-0.42	0.84	-2.10	1.25	.615	0.005
rMT	0.04	0.02	-0.01,	0.08	.114	0.052
sham x neutral	1.21	1.02	-0.81	3.24	.236	0.015
sham x positive	1.49	1.02	-0.54	3.51	.148	0.022
Model P3						0.322
Random Effects						
SD (Intercept: subj)	1.88	0.37	1.29	2.76	-	-
SD (Residual)	1.94	0.19	1.60	2.34	-	-

Note. Results from the linear mixed-effects regression analysis of Model P3 testing H1. Fixed effects were tested using the Kenward–Roger approximation for degrees of freedom. Marginal R^2 values were computed via nonparametric bootstrapping with 1,000 simulations using the nsj method. SE = standard error; CI = confidence interval; LL = lower limit; UL = upper limit. *p*-values are unadjusted. $p < .05$ is marked with an asterisk; $p < .01$ with a double asterisk

Table S4_3

S1: Results of Mixed Effects Regression Analysis

Variable	Estimate	SE	95% CI		*p*	Bootstrapped R^2
			LL	UL		
(Intercept)	-137.65	7.53	-153.81	-121.49	< .001*	-
sham	21.90	10.62	0.15	43.65	.049	0.048
neutral	143.67	9.15	124.05	163.30	< .001*	0.658
positive	233.91	14.11	203.65	264.18	< .001*	0.836
sham x neutral	-28.18	12.69	-54.17	-2.18	.035	0.037
sham x positive	-31.70	22.61	-78.01	14.60	.172	0.030
Model S1						0.901
Random Effects						
SD (Intercept: subj)	2.61e-09	0.35	0.00	9.93	-	-
SD (Residual)	30.04	0.19	24.94	33.43	-	-

Note. Results from the linear mixed-effects regression analysis of Model S1 testing H2. Fixed effects were tested using the Kenward–Roger approximation for degrees of freedom. Marginal R^2 values were computed via nonparametric bootstrapping with 1,000 simulations using the nsj method. SE = standard error; CI = confidence interval; LL = lower limit; UL = upper limit. *p*-values are unadjusted. $p < .05$ is marked with an asterisk; $p < .01$ with a double asterisk.

Table S4_5

S3: Results of Mixed Effects Regression Analysis

Variable	Estimate	SE	95% CI		*p*	Bootstrapped R^2
			LL	UL		
Fixed Effects						
(Intercept)	-99.00	29.47	-162.19	-35.81	.005	-
sham	21.85	10.74	-0.1727	43.87	.052	0.054
neutral	143.67	9.15	124.05	163.30	< .001*	0.656
positive	233.91	14.11	203.65	264.18	< .001*	0.835
age	-1.38	1.14	-3.86	1.10	.251	0.020
sex	5.11	5.32	-5.97	16.19	.348	0.009
rMT	-0.13	0.17	-0.50	0.23	.440	0.003
sham x neutral	-28.18	12.69	-54.17	-2.18	.034	0.038
sham x positive	-31.70	22.61	-78.01	14.60	.172	0.078
Model P1						0.901
Random Effects						
SD (Intercept: subj)	2.61e-09	0.35	0.00	9.93	-	-
SD (Residual)	30.04	0.19	24.94	33.43	-	-

Note. Results from the linear mixed-effects regression analysis of Model S3 testing H2. Fixed effects were tested using the Kenward–Roger approximation for degrees of freedom. Marginal R^2 values were computed via nonparametric bootstrapping with 1,000 simulations using the nsj method. SE = standard error; CI = confidence interval; LL = lower limit; UL = upper limit. *p*-values are unadjusted. $p < .05$ is marked with an asterisk; $p < .01$ with a double asterisk.