Visual, sensorimotor and cognitive routes to understanding others' enjoyment: an individual differences rTMS approach to empathic accuracy

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Supplementary Information

1. Analyses of EA scores and RTs

The main ANOVAs reported in the main text showed that rTMS over STS, IFG and TPJ reduced the efficiency of EA task performance, as evidenced by an increase in IE scores. Follow-up analyses were conducted on EA scores and RTs separately (Table S1) to check whether rTMS reduced accuracy, speed or both.

	Experiment 1			Experiment 2		
	sham	**V1**	**STS**	**sham**	**IFG**	**TPJ**
EA scores	0.51 ± 0.11	0.49 ± 0.12	0.44 ± 0.11	0.55 ± 0.10	0.50 ± 0.09	0.48 ± 0.90
RTs	1220 ± 294	1208 ± 330	1288 ± 416	1382 ± 421	1562 ± 636	1523 ± 484

Table S1. Mean ± SD empathic accuracy (EA) scores and response times (RTs) in the rTMS conditions of Experiments 1 and 2. Preliminary *t*-tests ensured that participants in the two experiments did not differ in EA scores ($t_{30} = 1.36$, $P = 0.18$) or RTs ($t_{30} = 1.26$, $P = 0.22$) in the sham (baseline) condition.

1.1. *Experiment 1: reduced efficiency following STS stimulation reflects impaired task accuracy*

The ANOVA conducted on EA scores in Experiment 1 was significant ($F_{2,30}$ = 6.67, P = 0.004; η_p^2 = 0.31) and the data showed strong evidence in favor of an effect of rTMS on EA scores (BF_{10} = 14.571); as shown in Table S1, active rTMS of STS caused a significant reduction in EA scores compared to sham rTMS (P = 0.004; *Cohen's d* = 0.83) and active rTMS of V1 (P = 0.01; *Cohen's d* = 0.75), which in turn did not differ from one another (P = 0.42; *Cohen's d* = 0.20).

The ANOVA on RTs did not reach statistical significance ($F_{2,30}$ = 2.06, P = 0.14; η_p^2 = 0.12) and the data showed weak evidence in favor of the null hypothesis (BF_{01} = 1.600). Inspection of the RTs in Table S1 suggests that responses in the EA task were non-significantly delayed by 68-81 ms in the STS condition relative to the other two rTMS conditions. Thus, disruption of EA task efficiency following STS stimulation was mainly due to a reduction in accuracy. Although non-significant, changes in RTs contribute to ruling out the presence of any speed-accuracy trade off.

1.2. Experiment 2: reduced efficiency following IFG and TPJ stimulation reflects reduced task accuracy and response speed

The ANOVA on EA scores in Experiment 2 was significant ($F_{2,30}$ = 5.70, P = 0.008; η_p^2 = 0.28) and the data showed positive evidence in favor of an effect of rTMS (BF_{10} = 5.872). Table S2 shows that active rTMS of the IFG and the TPJ caused a reduction in EA scores relative to sham rTMS (all P < 0.03; all *Cohens' d* > 0.69). There were no differences in EA scores between the two active rTMS conditions (P = 0.28; *Cohen's d* = 0.22).

The ANOVA performed on RTs was also significant ($F_{2,30}$ = 3.46, P = 0.044; η_p^2 = 0.19; Table S2) although the Bayesian ANOVA showed only weak evidence in favor of an effect of rTMS (BF_{10} = 1.576). Relative to sham rTMS, active rTMS of the IFG significantly increased RTs by 180 ms (P = 0.046; *Cohen's d* = 0.66), whereas active rTMS of the TPJ induced a marginally significant increase of 141 ms (P = 0.059; *Cohen's d* = 0.56). RTs in the two active rTMS conditions did not differ from one another (P = 0.59; *Cohen's d* = 0.12).

Thus, in Experiment 2, rTMS over IFG and TPJ reduced both EA task accuracy and response speed, ruling out that the increase in IE scores was due to any speed-accuracy trade-offs.

2. Contrasting IFG and TPJ involvement in the efficiency of EA task performance

The analysis of IE scores across the entire sample showed that rTMS of STS, IFG and TPJ similarly disrupted EA task efficiency. This effect was associated with a reduction in EA scores and, only in the cases of IFG and TPJ stimulation, with an increase in RTs. This indicates that IFG and TPJ are particularly effective at interfering with EA task performance, thus supporting the pivotal roles of sensorimotor and mentalizing networks in EA.

However, in Experiment 2, the investigation of individual differences in baseline EA task efficiency showed relationships of different signs between IE scores in the sham rTMS condition (i.e., the predictor) and the interferential effects induced by IFG and TPJ stimulation (dependent variables). In another analysis, we sought to further examine the relationships between these variables, and Experiment 2 provided the opportunity to test these relationships within the same sample of participants. To test the roles of sensorimotor and mentalizing mechanisms in optimal EA task performance, we examined the unique contributions of IFG and TPJ to the efficiency of baseline EA task performance. That is, we tested whether the interferential effects induced by targeting these regions (difference in IE scores between sham rTMS and active rTMS) predicted the efficiency of baseline EA task performance (indexed by IE scores in the sham rTMS condition). The regression model was significant and showed a large effect size (*Adjusted* $R^2 = 0.39$, $F_{2,12} = 5.43$, $P = 0.021$; $f^2 = 0.90$; see Figure S1). TPJ interference was a significant predictor of baseline EA task efficiency ($\beta = -0.48$, $t_{13} = -2.24$, $P = 0.045$), pointing to the unique contribution of TPJ to EA abilities. The negative relationship indicates greater TPJ interference in high-performers, pointing to the key contribution of TPJ in achieving efficient EA task performance. IFG interference showed a non-significant positive relationship with IE scores at baseline ($\beta = 0.39$, $t_{13} = 1.80$, $P = 0.097$), suggesting a trend for greater IFG interference in low performers.

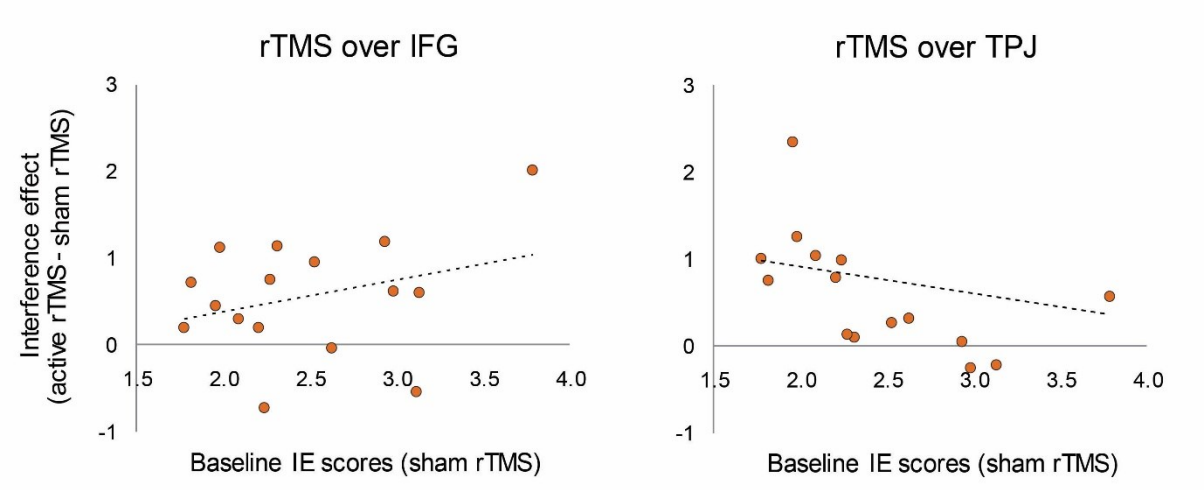

Figure S1. Scatterplot showing the linear relationship between baseline IE scores (sham rTMS) and the interference effects induced by IFG (left panel) and TPJ (right panel).