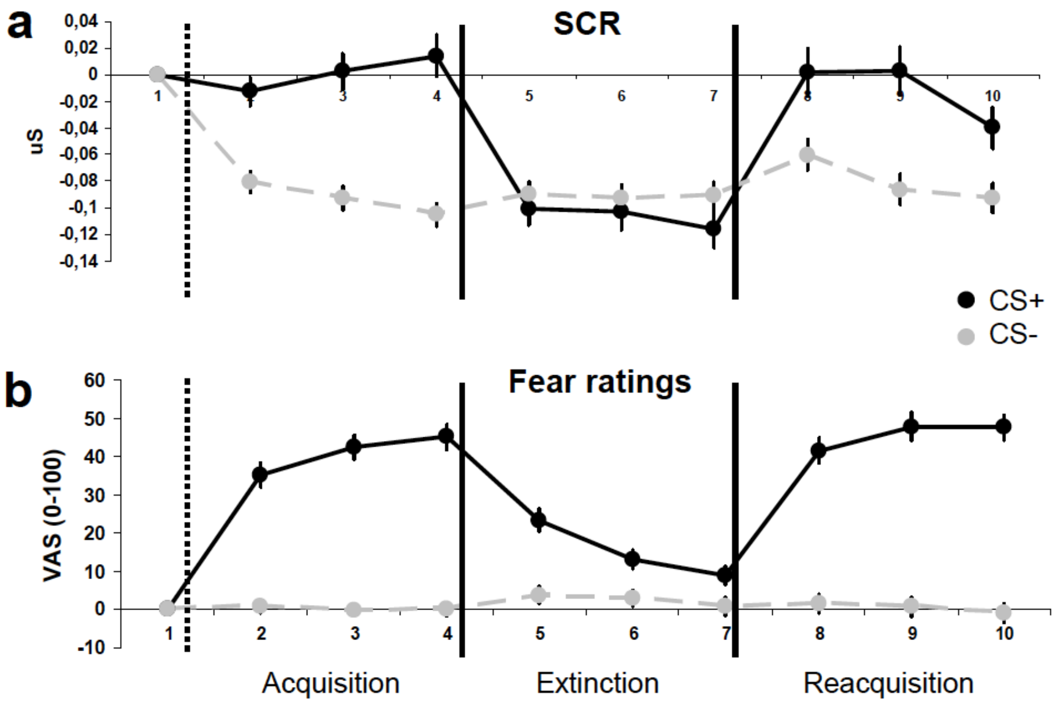
Model-based fMRI

Experiment

Raczka et al, Transl Psychiatry 2011:
Fear conditioning, extinction, re-conditioning
CS+/- = visual, UCS = shock (individual max. tolerable pain)
80% CS+ reinforcement
Measures: SCRs, fear ratings (every 12th trial)



A mathematically explicit model of associative learning

Rescorla-Wagner (1972):

value of outcome (UCS)

$$v(t+1) = v(t) + \alpha\underbrace{(R(t) - v(t))}_{\delta}$$

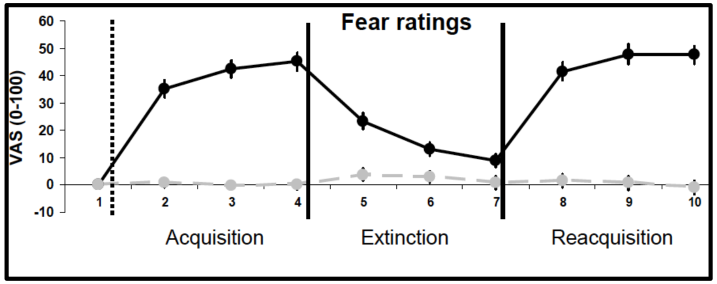
UCS prediction,
value of CS

learning rate

prediction error (PE)

t = trial number

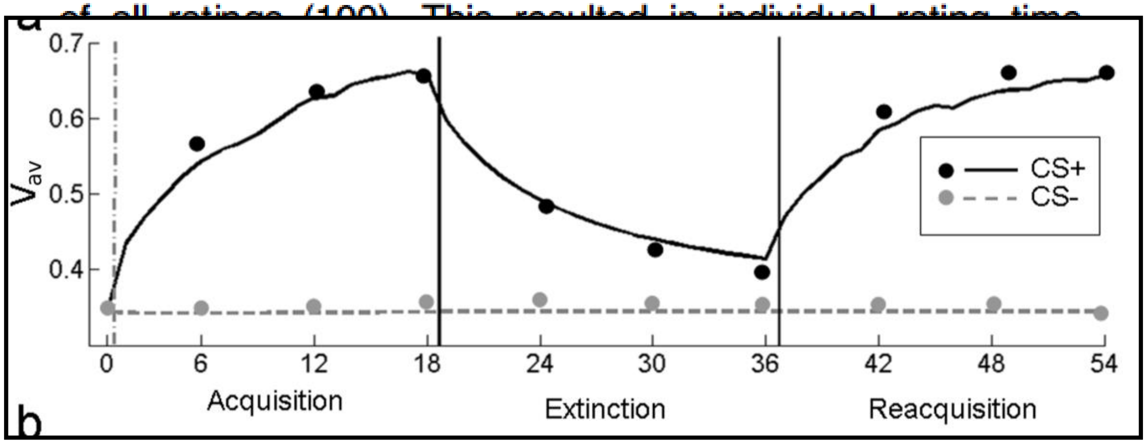
Fitting behavioral data: step 1



Methods. We first range corrected each participants' CS+ and CS− fear rating data (see Supplementary Figure 1a for sample average) according to

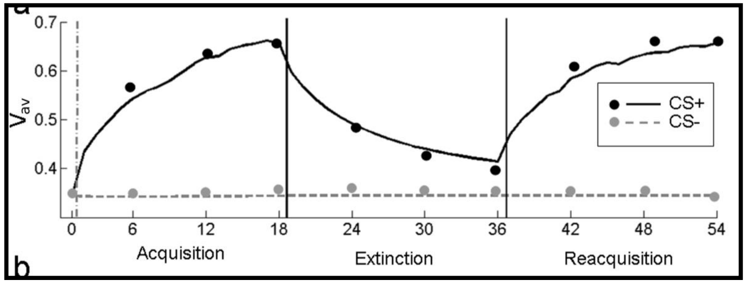
$$x_{\mathrm{i,\,corr,\,CS+or\,CS-}} = (x_{\mathrm{i,\,CS+or\,CS-}} - \mathrm{min})/(\mathrm{max} - \mathrm{min}),$$

with $x_{\mathrm{i,CS+or CS-}}$ $(i = 1,\ldots,10)$ being the successive (CS+ or CS−) fear ratings, min being the sample-wide minimum of all ratings (−58) and max being the sample-wide maximum



Raczka et al., Transl Psychiatry 2011

Fitting behavioral data: step 2



After complete learning, the aversiveness R of the UCS is reflected in the aversiveness of the CS$+$, that is, in the last CS$+$ fear rating after acquisition ($x_{4,\mathrm{corr},\mathrm{CS}+}$). With a partial reinforcement schedule of 80%, a participant's R in paired CS$+$ trials can thus be approximated as $x_{4,\mathrm{corr},\mathrm{CS}+}/0.8$.[40] R in CS$-$ trials (0% reinforcement) was set at each participant's $x_{4,\mathrm{corr},\mathrm{CS}-}$ rating. The same value of R was used for unpaired CS$+$ trials. See the Supplementary Methods for a more

→ individual fixed R values

(requires individual calibration of UCS intensity to similar values)

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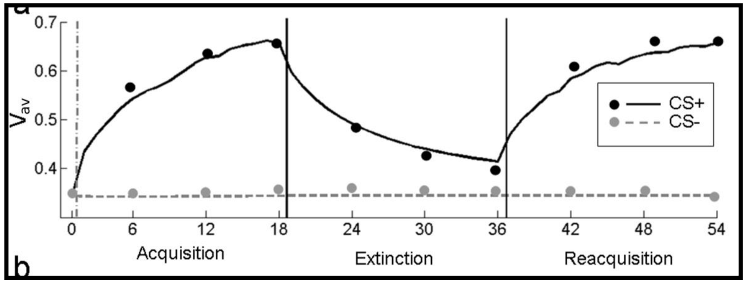
Fitting behavioral data: step 3



$V_{av,CS+}$ and $V_{av,CS-}$ were modeled separately and set at 0.36 ($= x_{1,corr,CS+ or CS-}$; see above) before learning. On the basis of the idea of dissociable neural systems for fear acquisition and extinction (and possibly reacquisition as well), we used three free parameters α_{Acq}, α_{Ext} and α_{RAcq} (one for each of the three experimental phases), which were adjusted to minimize the distance between the change in $V_{av,CS+}$ and $V_{av,CS-}$ and the change in fear ratings $x_{corr,CS+}$ and $x_{corr,CS-}$ using a least-square approach. We did not use CS+ > CS– difference scores, and $V_{av,CS+}$ and $V_{av,CS-}$ were estimated at the same time within the same model. $V_{av,CS+}$ and $V_{av,CS-}$

(worse fits with only one alpha)

Raczka et al., Transl Psychiatry 2011

Fitting behavioral data: results

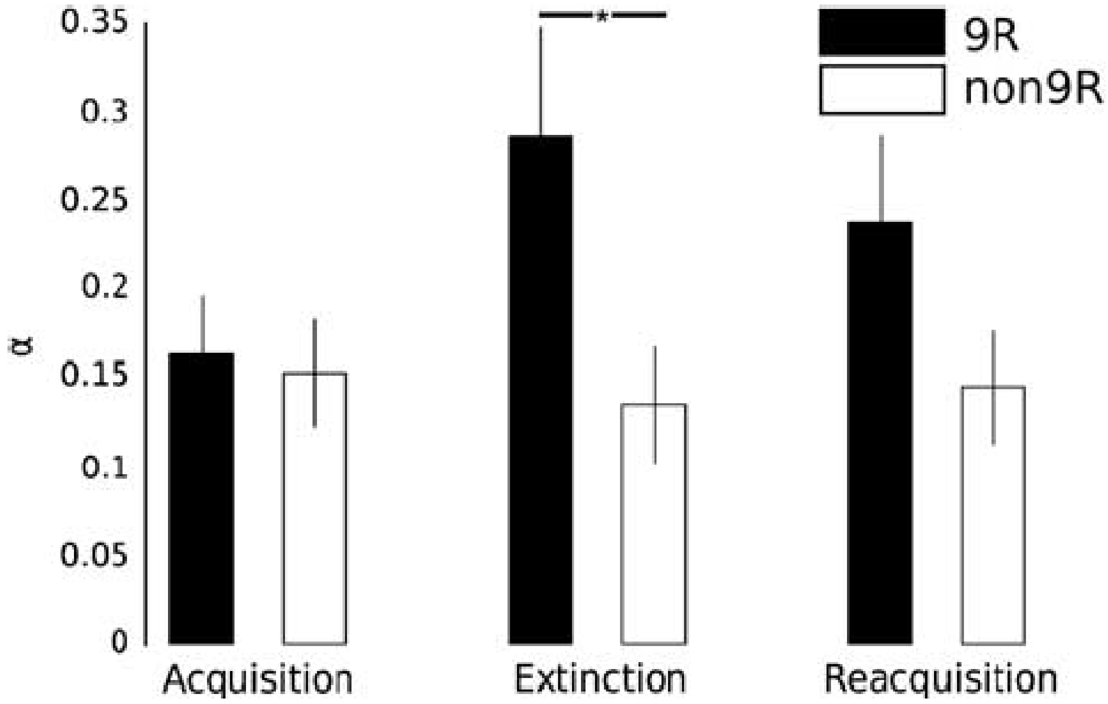


Figure 2 *DAT1* genotype affects learning rates during extinction. Formal modeling of fear rating data showed that 9-repeat (9R) carriers have significantly higher learning rates during extinction than non-9R carriers. Error bars: s.e.m. *$P<0.05$ (F test).

Raczka et al., Transl Psychiatry 2011

Fitting behavioral data: background

Theory:
Extinction mediated by a different learning system than conditioning
Extinction mediated by dopamine-dependent reward system

Assumptions:
DAT 9R: higher phasic extrasynaptic DA concentrations upon DA release

Experimental hypotheses (behavior):
DAT 9R carriers: higher learning rates spec. in extinction

Experimental hypotheses (imaging):
Extinction PE signal in VS
Higher VS-PE in 9R carriers (bec. higher alpha, i.e., higher weights)

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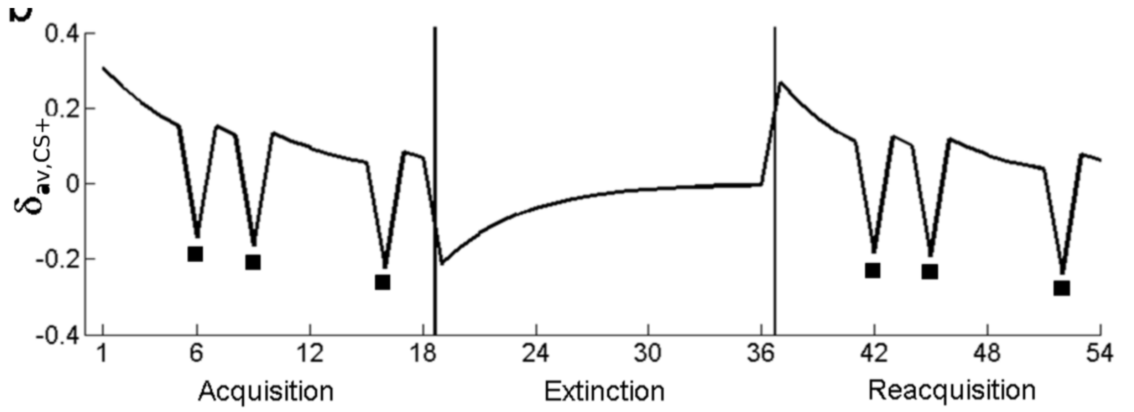
Fitting imaging data: step 1

To prepare the analysis, we used the sample-averaged learning rates $\alpha_{Acq} = 0.16$, $\alpha_{Ext} = 0.21$ and $\alpha_{RAcq} = 0.19$ to derive individual trial-by-trial V_{av} and δ_{av} estimates from the above modeling of the rating data, separately for acquisition, extinction and reacquisition. Averaging of learning rates was necessary to reduce noise in the data that resulted from a limited number of data points for fitting (10 ratings), and thus to obtain robust estimates. An exemplary individual δ_{av} time course is shown in Figure 1b. We emphasize that our



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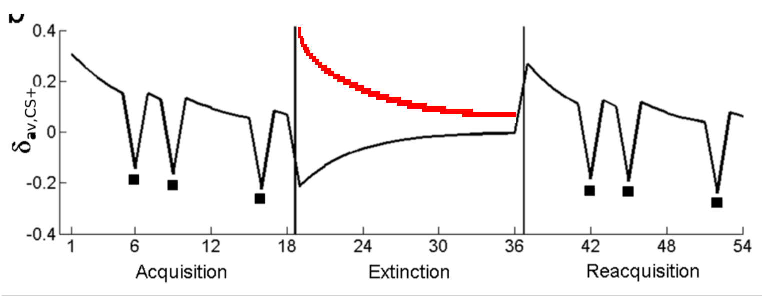
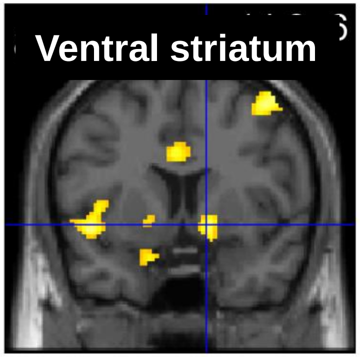
Fitting imaging data: step 2

<u>Regressors (separately for 3 phases):</u>

- CS onsets (CS+/- combined): event-type
- *parametric modulator: indiv. trial-by-trial V estimates*
- CS offsets (CS+/- combined): event-type
- *parametric modulator: indiv. trial-by-trial PE estimates*
- UCSs (events)
- Key presses (events)
- Rating periods (box cars)

→ Max. inter-correlation: PE in Cond. and UCS: -0.43

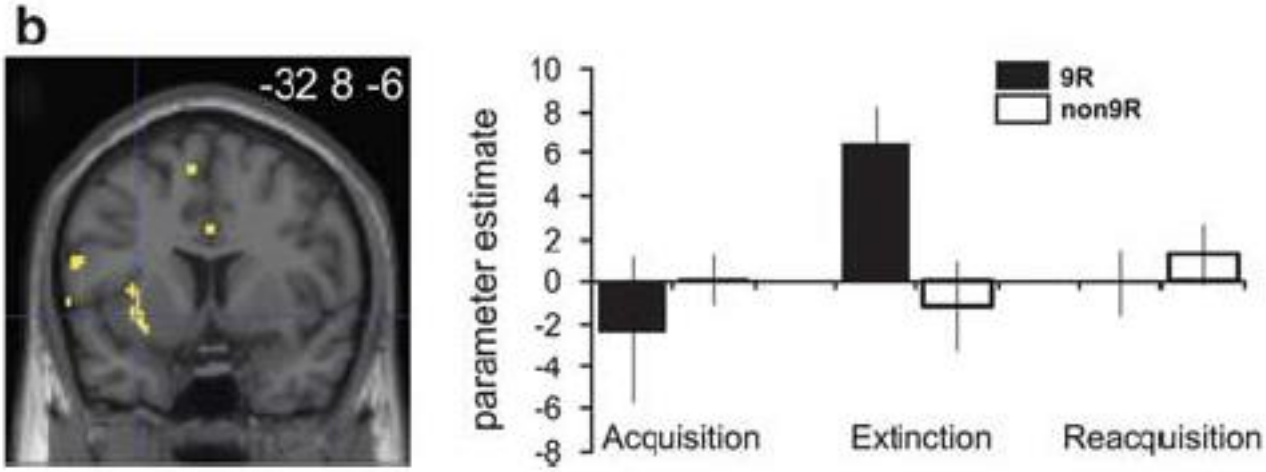




Raczka et al., Transl Psychiatry 2011

Fitting imaging data: step 3

<u>Comparison DAT 9R vs. non9R carriers:</u>
2-sample t-test of PE in Ext.
Small volume correction in a priori VS-ROI from literature



Raczka et al., Transl Psychiatry 2011

Fitting behavioral data: step 2 – addendum

Estimating R

The logic of estimating R from fear ratings while taking into account a given reinforcement ratio (here, 80%) can be illustrated by comparing the present situation to a hypothetical experiment with half as much reinforcement (that is, 40%), the UCS magnitude staying the same. With half as much reinforcement, associative theory predicts that participants will rate half as much fear after full learning (that is, here, the $x_{4,corr,CS+}$ rating). To this effect, dividing $x_{4,corr,CS+}$ by the reinforcement ratio (0.8 and 0.4, respectively) will lead to an identical estimate for R in both scenarios. Assume that in the 80% scenario the $x_{4,corr,CS+}$ rating is 1, then 1/0.8 makes R=1.25. If in the 40% scenario the $x_{4,corr,CS+}$ rating is 0.5 (as associative theory would predict), then 0.5/0.4 also makes R=1.25. Hence, one obtains the same estimate of R, in accordance with an identical UCS magnitude employed in both scenarios. Note that, with partial reinforcement as used here, R must always be larger than $x_{4,corr,CS+}$, because the aversiveness of the CS scales not only with UCS magnitude but also with UCS probability, according to the RW model. Concerning the CS-, there is no need for scaling because reinforcement is absent in 100% of all CS- trials. This allows for using the $x_{4,corr,CS-}$ rating as a direct estimate of the value of no-reinforcement.

Raczka et al., Transl Psychiatry 2011

General take-home message

- Variant of task-based fMRI
- Objective: isolate cognitive processes/operations
- Exploits advantages of parametric designs
- More precise predictions

Extension

- Model choice/model comparison: which is the best model?
- Best fit with simplest possible model (Occam's razor)
  → Penalize number of model parameters
  E.g., Akaike Information Criterion (AIC), Bayes IC (BIC)