

Supplementary Material for

Emotional overshadowing: pleasant and unpleasant cues overshadow neutral cues in human
associative learning

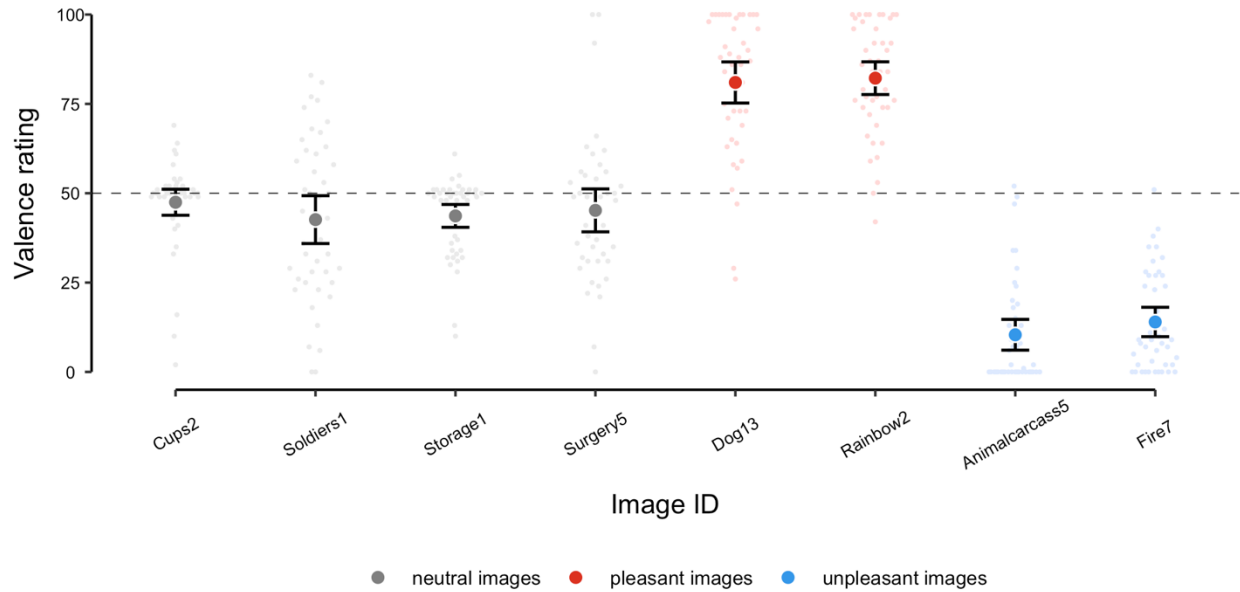
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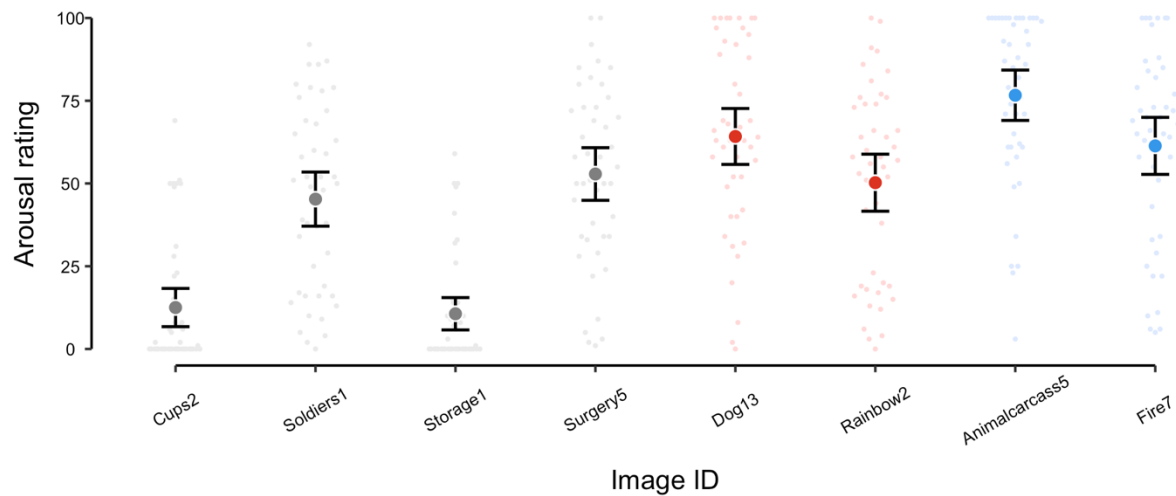
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A) Participant ratings of image valence

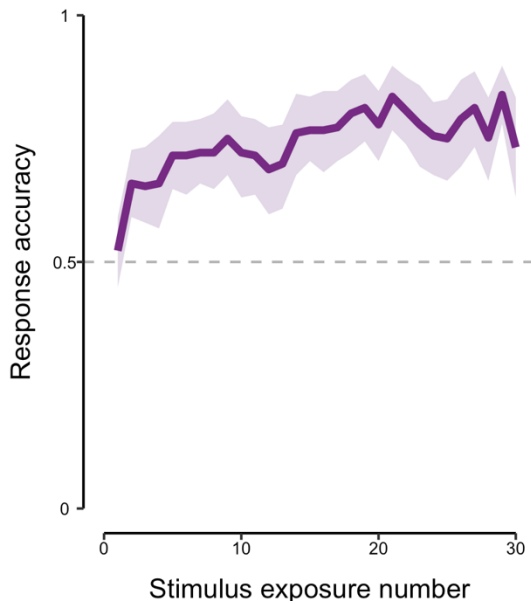


B) Participant ratings of image arousal

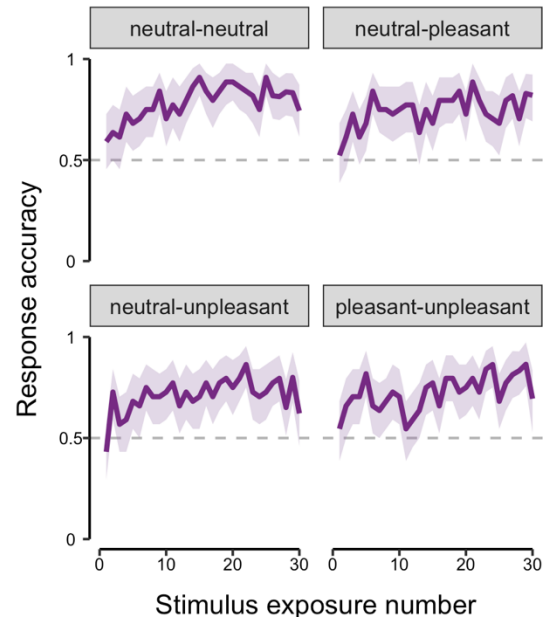


Supplementary Figure S1. Participant ratings of valence (**A**) and arousal (**B**) for each image in each category (grey: neutral-valence images; red: pleasant-valence images; blue: unpleasant-valence images) in the initial exploratory study. Foreground points and error bars denote group means ($\pm$ 95% confidence interval); background points denote ratings from individual participants. The dashed horizontal line in (A) denotes neutral valence (“neither positive nor negative”).

A) Overall learning curve

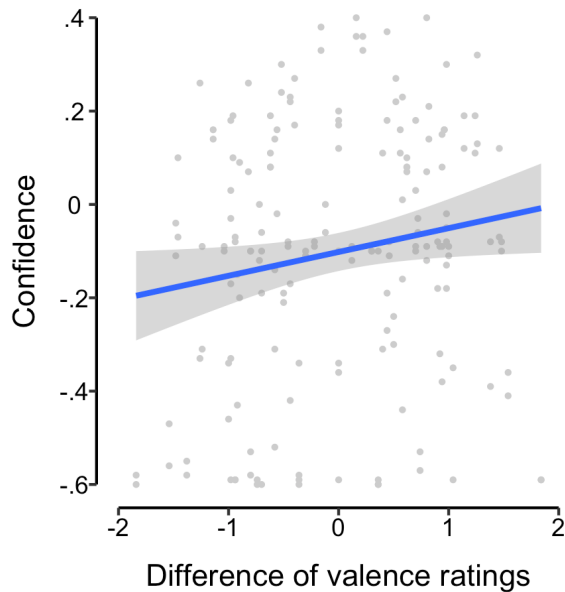


B) Per-stimulus learning curves

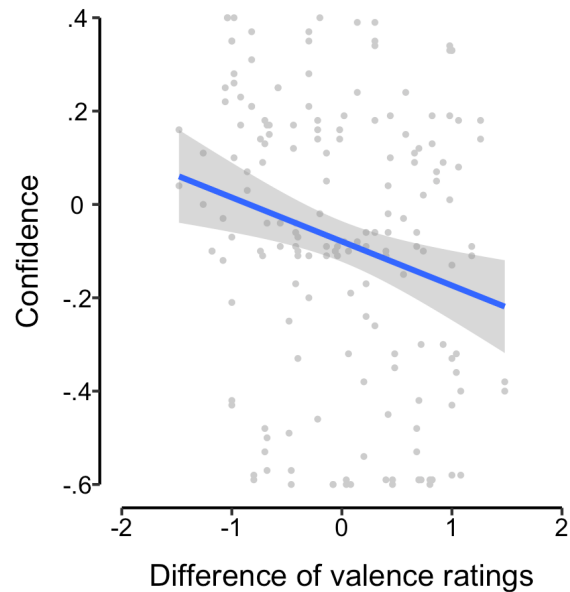


Supplementary Figure S2. Response accuracy as a function of stimulus exposure number during the learning phase of the probabilistic categorisation task for the initial exploratory study. Results are presented overall (**A**) and individually by stimulus type (**B**). Data are mean response accuracy (with a correct response defined as predicting the most likely outcome for a stimulus) $\pm$ 95% confidence interval. The dashed horizontal line denotes chance-level accuracy.

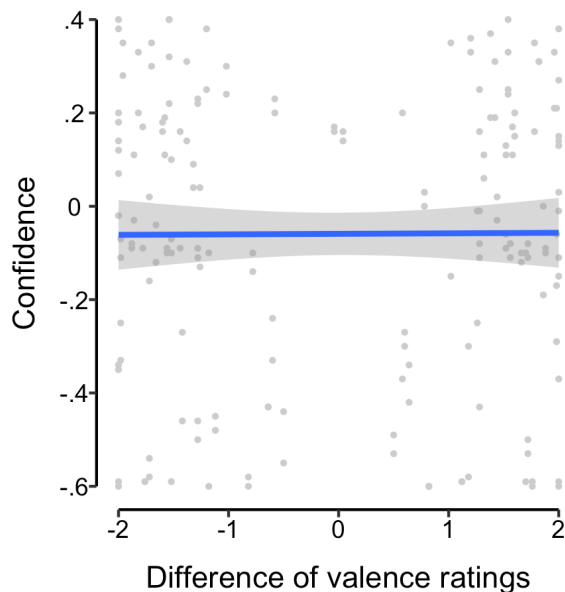
A) Pleasant/neutral stimulus



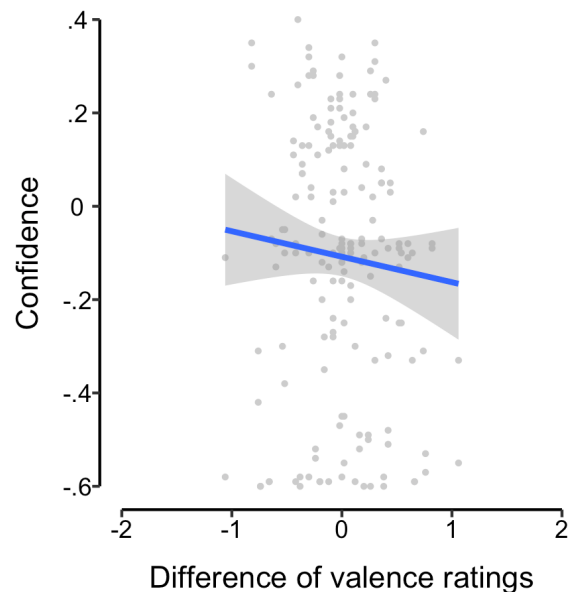
B) Unpleasant/neutral stimulus



C) Pleasant/unpleasant stimulus



D) Neutral/neutral stimulus



Supplementary Figure S3. The association between the difference in valence ratings between the two images in a stimulus (x-axis) and participants' confidence regarding reported cue-outcome associations (y-axis). There was a significant positive association between valence difference and confidence for the pleasant/neutral stimulus (A), a significant negative association for the unpleasant/neutral stimulus (B), and no significant association for either the pleasant/unpleasant stimulus (C) or the neutral/neutral stimulus (D). Regression lines indicate the linear association of best fit and its 95% confidence interval. Each background point represents one self-report by one participant. Data are presented for the initial exploratory study only.

Supplementary Table S1a. Overview, mixed-effects Bayesian regression of image valence ratings

Fixed effects	Participant-wise random effects
- Intercept	- Random intercept
- Image type (reference-coded, <i>neutral</i> as reference)	- Random slopes for:
	- Image type

Note: valence ratings were standardised between -1 and 1 prior to analysis, such that a rating of 0 represents the mid-point of the rating scale.

Supplementary Table S1b. Coefficients for analysis of image valence ratings, exploratory study

Coefficient	β (SE)	95% Bayesian HDI	
Intercept	-0.11 (0.03)	[-0.17, -0.04]	*
Image type (<i>pleasant</i>)	0.74 (0.05)	[0.63, 0.84]	*
Image type (<i>unpleasant</i>)	-0.65 (0.04)	[-0.74, -0.56]	*

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S1c. Coefficients for analysis of image valence ratings, replication study

Coefficient	β (SE)	95% Bayesian HDI	
Intercept	-0.07 (0.01)	[-0.09, -0.04]	*
Image type (<i>pleasant</i>)	0.69 (0.03)	[0.64, 0.74]	*
Image type (<i>unpleasant</i>)	-0.68 (0.02)	[-0.73, -0.63]	*

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S2a. Overview, mixed-effects Bayesian regression of image arousal ratings

Fixed effects	Participant-wise random effects
- Intercept	- Random intercept
- Image type (reference-coded, <i>neutral</i> as reference)	- Random slopes for:
	- Image type

Note: arousal ratings were standardised between -1 and 1 prior to analysis, such that a rating of 0 represents the mid-point of the rating scale.

Supplementary Table S2b. Coefficients for analysis of image arousal ratings, exploratory study

Coefficient	β (SE)	95% Bayesian HDI	
Intercept	-0.39 (0.05)	[-0.50, -0.29]	*
Image type (<i>pleasant</i>)	0.54 (0.08)	[0.39, 0.69]	*
Image type (<i>unpleasant</i>)	0.77 (0.08)	[0.63, 0.92]	*

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S2c. Coefficients for analysis of image arousal ratings, replication study

Coefficient	β (SE)	95% Bayesian HDI	
Intercept	-0.42 (0.02)	[-0.46, -0.37]	*
Image type (<i>pleasant</i>)	0.55 (0.04)	[0.47, 0.62]	*
Image type (<i>unpleasant</i>)	0.75 (0.04)	[0.68, 0.83]	*

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S3a. Overview, mixed-effects Bayesian logistic regression of learning data

Fixed effects	Participant-wise random effects
- Intercept	- Random intercept
- Stimulus type (reference-coded with <i>neutral/neutral</i> as reference condition)	- Random slopes for:
- Per-stimulus exposure number (z-scored)	- Stimulus type
- Stimulus type $\times$ exposure number	- Per-stimulus exposure number
	- Stimulus type $\times$ exposure number

Note: The dependent variable was accuracy, coded as 1 if the participant predicted the most likely outcome shape for a given stimulus and 0 if they predicted the less likely shape.

Supplementary Table S3b. Coefficients for analysis of learning data, exploratory study

	Coefficient	β (SE)	95% Bayesian HDI	
Intercept		1.92 (0.25)	[1.46, 2.41]	*
Stimulus type (<i>pleasant/neutral</i>)		0.10 (0.27)	[-0.40, 0.67]	
Stimulus type (<i>unpleasant/neutral</i>)		-0.52 (0.21)	[-0.92, -0.11]	*
Stimulus type (<i>pleasant/unpleasant</i>)		-0.16 (0.27)	[-0.68, 0.39]	
Exposure number		0.67 (0.14)	[0.39, 0.97]	*
Exposure number $\times$ stimulus type (<i>pleasant/neutral</i>)		0.14 (0.21)	[-0.24, 0.58]	
Exposure number $\times$ stimulus type (<i>unpleasant/neutral</i>)		-0.15 (0.14)	[-0.41, 0.14]	
Exposure number $\times$ stimulus type (<i>pleasant/unpleasant</i>)		0.09 (0.18)	[-0.23, 0.46]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S3c. Coefficients for analysis of learning data, replication study

	Coefficient	β (SE)	95% Bayesian HDI	
Intercept		1.99 (0.15)	[1.71, 2.29]	*
Stimulus type (<i>pleasant/neutral</i>)		0.54 (0.16)	[0.22, 0.87]	*
Stimulus type (<i>unpleasant/neutral</i>)		0.57 (0.16)	[0.26, 0.90]	*
Stimulus type (<i>pleasant/unpleasant</i>)		0.63 (0.18)	[0.29, 0.99]	*
Exposure number		0.92 (0.09)	[0.75, 1.11]	*
Exposure number $\times$ stimulus type (<i>pleasant/neutral</i>)		0.33 (0.12)	[0.11, 0.57]	*
Exposure number $\times$ stimulus type (<i>unpleasant/neutral</i>)		0.25 (0.12)	[0.03, 0.49]	*
Exposure number $\times$ stimulus type (<i>pleasant/unpleasant</i>)		0.29 (0.12)	[0.06, 0.53]	*

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S4a. Overview, mixed-effects Bayesian regressions of learned contingencies (applies to all models reported in Tables S4-S7)

Fixed effects	Participant-wise random effects
- Intercept - Queried shape (reference-coded with <i>square</i> as reference condition) - Confidence rating for corresponding compound stimulus (i.e., for each simple cue, what was the confidence rating for the compound it was originally presented within?) - Anxiety (GAD-7; z-scored) - Valence difference (between this cue image and the other cue with which it was paired during learning) - Arousal difference (between this cue image and the other cue with which it was paired during learning) - Anxiety $\times$ Valence difference - Anxiety $\times$ Arousal difference	- Random intercept - Random slopes for: - Queried shape - Confidence rating for corresponding compound stimulus - Valence difference - Arousal difference

Note: - Valence and arousal differences were each based on participant-specific image ratings

Supplementary Table S4b. Analysis of cue images from pleasant/neutral stimulus, exploratory study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.06 (0.03)	[-0.12, -0.01]	*
	Queried shape	0.03 (0.02)	[-0.02, 0.07]	
Confidence rating for corresponding compound stimulus		0.57 (0.09)	[0.38, 0.75]	*
	Anxiety	-0.03 (0.02)	[-0.07, 0.02]	
Valence difference between cues in compound		0.06 (0.02)	[0.02, 0.10]	*
Arousal difference between cues in compound		-0.01 (0.02)	[-0.05, 0.04]	
	Anxiety $\times$ Valence difference	0.04 (0.02)	[0.001, 0.08]	*
	Anxiety $\times$ Arousal difference	0.01 (0.02)	[-0.03, 0.06]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S4c. Analysis of cue images from pleasant/neutral stimulus, replication study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.03 (0.01)	[-0.06, -0.01]	*
	Queried shape	0.01 (0.01)	[-0.01, 0.03]	
Confidence rating for corresponding compound stimulus		0.64 (0.04)	[0.55, 0.72]	*
	Anxiety	-0.003 (0.01)	[-0.02, 0.01]	
Valence difference between cues in compound		0.02 (0.01)	[0.004, 0.04]	*
Arousal difference between cues in compound		-0.0004 (0.01)	[-0.02, 0.01]	
	Anxiety $\times$ Valence difference	0.003 (0.01)	[-0.01, 0.02]	
	Anxiety $\times$ Arousal difference	0.01 (0.01)	[-0.01, 0.02]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S5a. Analysis of cue images from unpleasant/neutral stimulus, exploratory study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.05 (0.02)	[-0.09, -0.01]	*
	Queried shape	0.01 (0.02)	[-0.04, 0.05]	
Confidence rating for corresponding compound stimulus		0.64 (0.10)	[0.45, 0.84]	*
	Anxiety	0.03 (0.02)	[-0.01, 0.07]	
Valence difference between cues in compound		-0.07 (0.03)	[-0.13, -0.01]	*
Arousal difference between cues in compound		0.03 (0.02)	[-0.01, 0.07]	
	Anxiety $\times$ Valence difference	0.03 (0.03)	[-0.03, 0.09]	
	Anxiety $\times$ Arousal difference	0.03 (0.02)	[-0.01, 0.06]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S5b. Analysis of cue images from unpleasant/neutral stimulus, replication study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.02 (0.01)	[-0.04, -0.01]	*
	Queried shape	0.01 (0.01)	[-0.01, 0.03]	
Confidence rating for corresponding compound stimulus		0.63 (0.05)	[0.53, 0.74]	*
	Anxiety	-0.02 (0.01)	[-0.03, .0001]	
Valence difference between cues in compound		-0.03 (0.01)	[-0.06, -0.001]	*
Arousal difference between cues in compound		0.01 (0.01)	[-0.02, 0.03]	
	Anxiety $\times$ Valence difference	-0.01 (0.01)	[-0.03, 0.02]	
	Anxiety $\times$ Arousal difference	-0.01 (0.01)	[-0.03, 0.01]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S6a. Analysis of cue images from pleasant/unpleasant stimulus, exploratory study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.02 (0.03)	[-0.09, -0.04]	*
	Queried shape	0.001 (0.03)	[-0.05, 0.05]	
Confidence rating for corresponding compound stimulus		0.49 (0.14)	[0.21, 0.78]	*
	Anxiety	-0.01 (0.03)	[-0.08, 0.06]	
Valence difference between cues in compound		0.004 (0.01)	[-0.01, 0.02]	
Arousal difference between cues in compound		0.02 (0.02)	[-0.02, 0.06]	
	Anxiety $\times$ Valence difference	0.03 (0.01)	[0.01, 0.05]	*
	Anxiety $\times$ Arousal difference	-0.01 (0.02)	[-0.05, 0.03]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S6b. Analysis of cue images from pleasant/unpleasant stimulus, replication study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.01 (0.01)	[-0.03, -0.01]	*
	Queried shape	-0.01 (0.01)	[-0.03, 0.01]	
Confidence rating for corresponding compound stimulus		0.55 (0.06)	[0.44, 0.66]	*
	Anxiety	0.01 (0.01)	[-0.01, 0.02]	
Valence difference between cues in compound		0.01 (0.01)	[-0.001, 0.01]	
Arousal difference between cues in compound		0.02 (0.01)	[-0.001, 0.04]	
	Anxiety $\times$ Valence difference	0.004 (0.003)	[-0.01, 0.003]	
	Anxiety $\times$ Arousal difference	-0.01 (0.01)	[-0.03, 0.01]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S7a. Analysis of cue images from neutral/neutral stimulus, exploratory study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.06 (0.02)	[-0.11, -0.02]	*
	Queried shape	0.02 (0.02)	[-0.02, 0.07]	
Confidence rating for corresponding compound stimulus		0.68 (0.08)	[0.53, 0.83]	*
	Anxiety	0.01 (0.02)	[-0.03, 0.05]	
Valence difference between cues in compound		-0.05 (0.04)	[-0.14, 0.03]	
Arousal difference between cues in compound		-0.003 (0.02)	[-0.05, 0.05]	
	Anxiety $\times$ Valence difference	0.05 (0.05)	[-0.06, 0.16]	
	Anxiety $\times$ Arousal difference	0.0003 (0.02)	[-0.04, 0.05]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S7b. Analysis of cue images from neutral/neutral stimulus, replication study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.05 (0.01)	[-0.08, -0.03]	*
	Queried shape	-0.01 (0.01)	[-0.01, 0.03]	
Confidence rating for corresponding compound stimulus		0.60 (0.06)	[0.49, 0.72]	*
	Anxiety	-0.01 (0.01)	[-0.03, 0.01]	
Valence difference between cues in compound		0.02 (0.02)	[-0.01, 0.06]	
Arousal difference between cues in compound		0.003 (0.01)	[-0.01, 0.02]	
	Anxiety $\times$ Valence difference	0.02 (0.02)	[-0.02, 0.06]	
	Anxiety $\times$ Arousal difference	-0.0001 (0.01)	[-0.02, 0.02]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S8a. Coefficients for aggregate regression analysis, initial exploratory study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.05 (0.02)	[-0.09, -0.01]	*
	Queried shape	0.01 (0.01)	[-0.01, 0.04]	
Confidence rating for corresponding compound stimulus		0.50 (0.06)	[0.38, 0.63]	*
	Anxiety	0.004 (0.02)	[-0.04, 0.04]	
Valence difference between cues in compound		-0.003 (0.01)	[-0.02, 0.01]	
Arousal difference between cues in compound		-0.004 (0.01)	[-0.03, 0.02]	
Difference in absolute valence between cues		0.08 (0.02)	[0.03, 0.12]	*
Anxiety $\times$ valence difference		0.03 (0.01)	[0.01, 0.04]	*
Anxiety $\times$ arousal difference		0.01 (0.01)	[-0.02, 0.03]	
Anxiety $\times$ difference in absolute valence		0.03 (0.02)	[-0.01, 0.08]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero

Supplementary Table S8b. Coefficients for aggregate regression analysis, replication study

	Coefficient	β (SE)	95% Bayesian HDI	
	Intercept	-0.03 (0.01)	[-0.05, -0.02]	*
	Queried shape	0.002 (0.01)	[-0.01, 0.02]	
Confidence rating for corresponding compound stimulus		0.51 (0.03)	[0.44, 0.58]	*
	Anxiety	-0.01 (0.01)	[-0.03, 0.01]	
Valence difference between cues in compound		-0.001 (0.01)	[-0.01, 0.01]	
Arousal difference between cues in compound		0.01 (0.01)	[-0.004, 0.02]	
Difference in absolute valence between cues		0.02 (0.01)	[0.003, 0.03]	*
Anxiety $\times$ valence difference		-0.002 (0.01)	[-0.01, 0.01]	
Anxiety $\times$ arousal difference		-0.001 (0.01)	[-0.01, 0.01]	
Anxiety $\times$ difference in absolute valence		0.01 (0.01)	[-0.01, 0.02]	

Note: * denotes coefficients for which the Bayesian 95% HDI excludes zero