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SUPPLEMENTARY INFORMATION

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Conceptual knowledge predicts the representational structure of facial emotion perception

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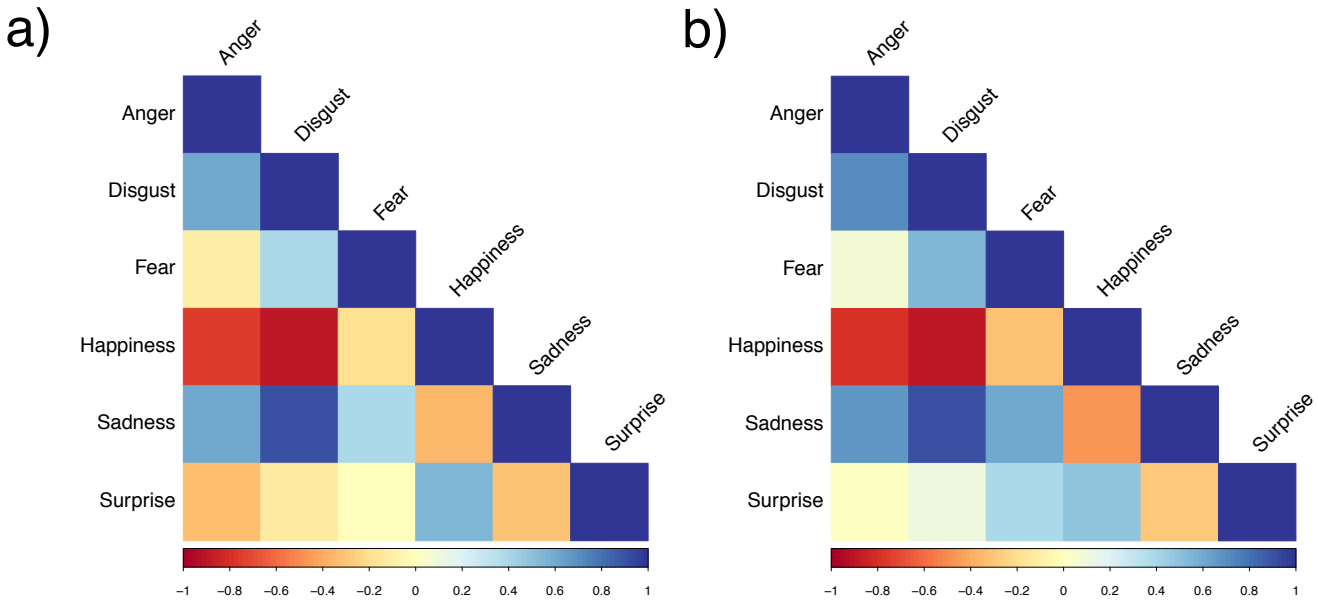
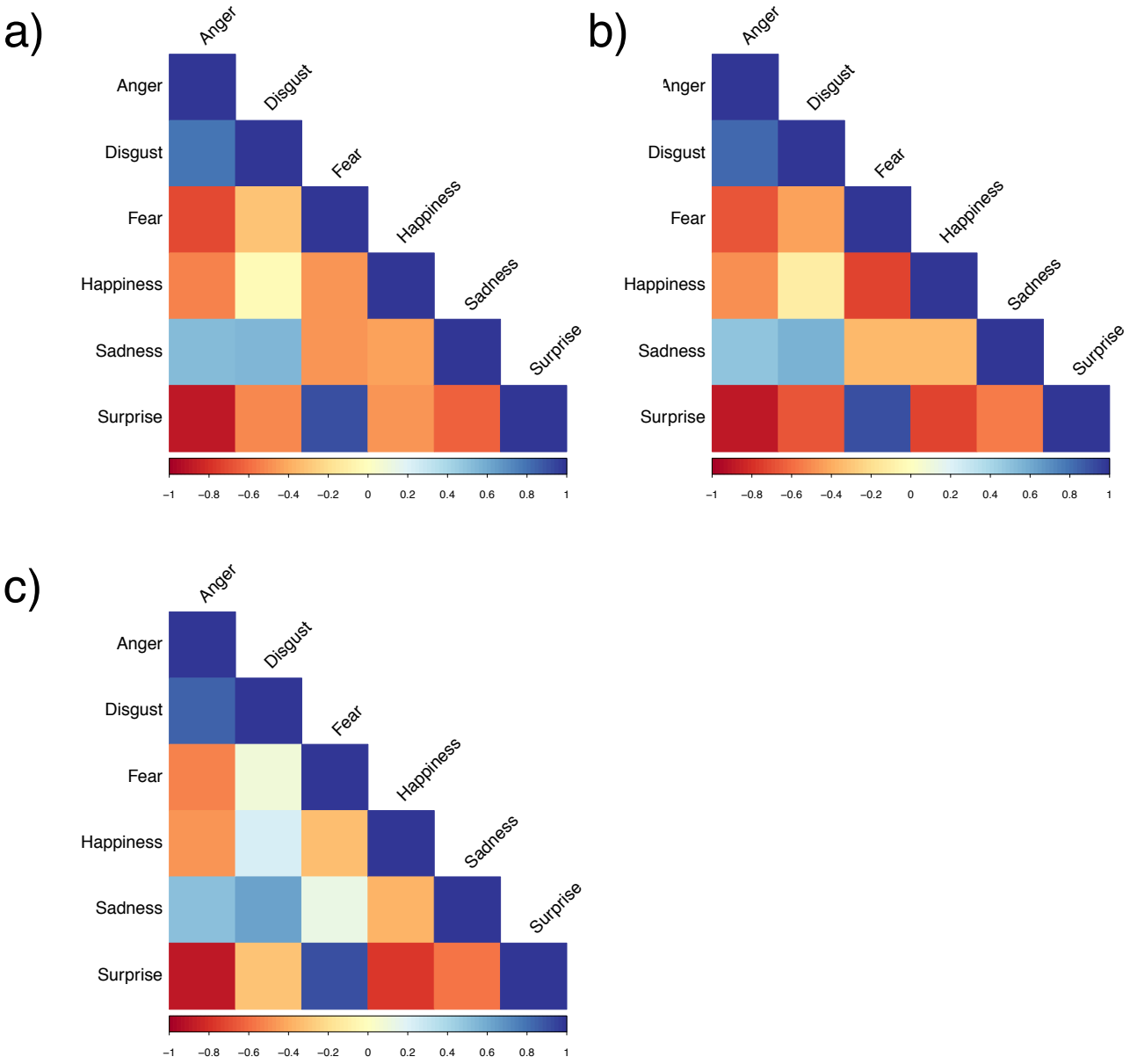
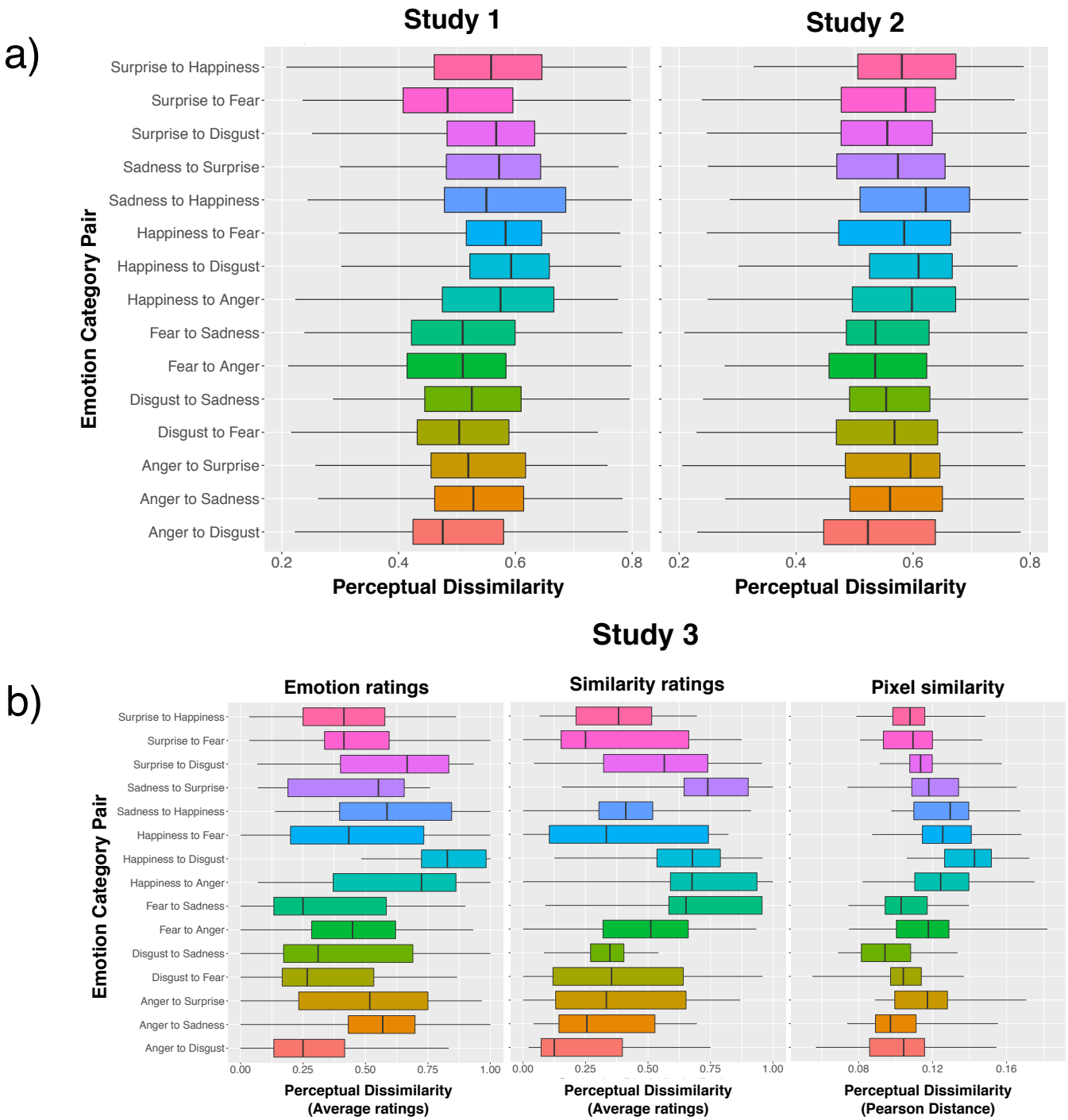


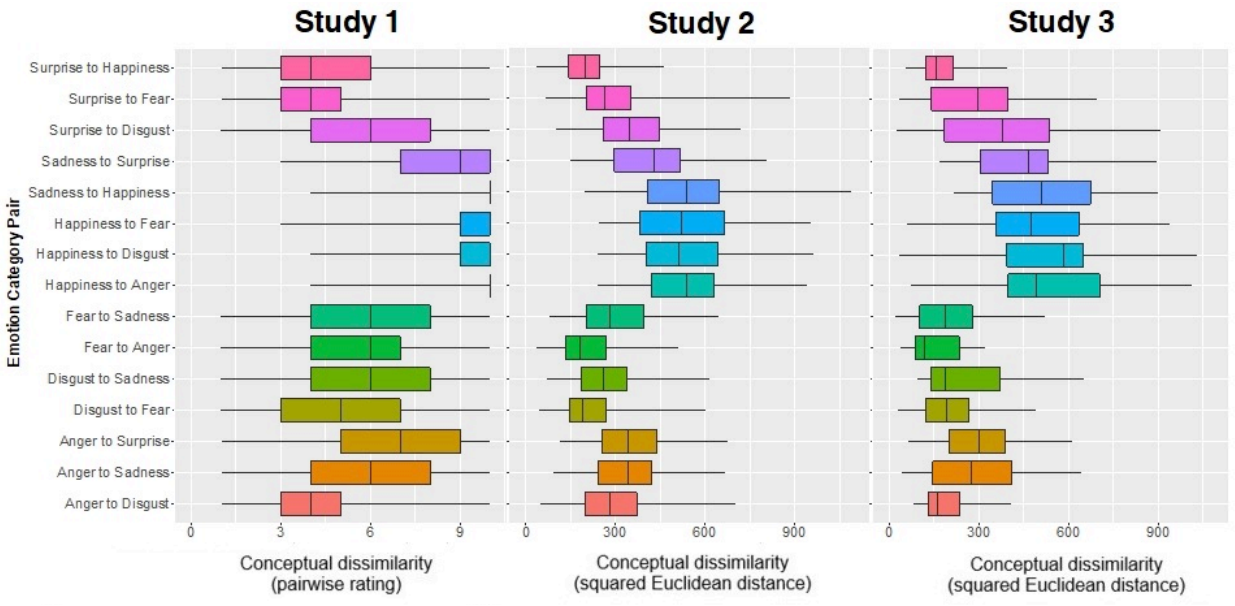
Supplementary Figure 1. Average perceptual DMs for the additional measures of perceptual similarity collected in Study 3.
In Study 3 (N = 368), perceptual similarity was primarily measured as bias in emotion expression (e.g. an Angry CI appearing Disgusted) as judged by independent raters, which is presented in Figure 2. We also assessed perceptual similarity through a) bias in physical appearance (e.g. more subjectively similar in physical appearance) as judged by independent raters, and b) objective physical similarity, as assessed through correlations of the flattened pixel maps of pairs of CIs from a given condition. Note that the average DMs for Study 3 are presented for illustrative purposes only, as each cell under the diagonal included a different set of subjects. Due to the length of the task in Study 3, each participant was randomly assigned to a different condition, where each condition was a given emotion category-pair (e.g. Anger-Disgust).



Supplementary Figure 2. Visual DMs for the stimuli used in Studies 1 and 2.
Studies 1 ($N = 100$) and 2 ($N = 91$) used a subset of the NimStim face database (Tottenham et al., 2009). To account for any physical resemblance between the stimuli in each category, we included visual control DMs in our regression models. The visual DMs were a) based on the overlap (calculated as the squared Euclidean Distance) between the presence of facial actions (measured with the facial action coding system; FACS), b) based on the overlap between the presence of facial actions that are ostensibly critical for perception of normatively Angry, Disgusted, Fearful, Happy, Sad, and Surprised facial expressions, and c) based strictly on the overlap between the presence of facial actions that are ostensibly critical for perception of the two emotion categories in a given emotion category-pair (e.g., for the Anger-Disgust cell, overlap between the Angry and Disgusted stimuli in facial action units critical for perception of Anger and Disgust).



Supplementary Figure 3. Distributions of perceptual similarity variables for all studies. Box plots are depicted for the perceptual similarity variables in Studies 1-3 (center line, median; box limits, upper and lower quartiles; whiskers, remaining data range). In Studies 1 ($N = 100$) and 2 ($N = 91$), perceptual similarity was measured as average deviation toward the unselected category response on mouse-tracking trials with the two categories in question as response options (e.g. Angry-Disgusted). In Study 3 ($N = 368$), perceptual similarity was measured through two independent rating tasks (emotion ratings and similarity ratings) as well as a measurement of the pixel-wise similarity of the images themselves.



Supplementary Figure 4. Distributions of conceptual similarity variables for all studies. Box plots are depicted for the conceptual similarity variables in Studies 1-3, showing inter-subject variability in conceptual knowledge (center line, median; box limits, upper and lower quartiles; whiskers, remaining data range). In Study 1 ($N = 100$), conceptual similarity was measured via similarity judgments on a 10-point scale (e.g. "From 1 = not at all to 10 = extremely, how similar do you find the emotions Anger and Fear?"). In Studies 2 ($N = 91$) and 3 ($N = 368$), conceptual similarity was measured as the squared Euclidean Distance (sums of squared distances) between vectors of ratings made for each emotion category on its relationship with a large set of traits including thoughts, bodily feelings, and associated actions.

Supplementary Table 1. Results from Study 1 using stricter versions of the visual similarity control model.

In Study 1 (N = 100), we found that conceptual similarity significantly predicted perceptual similarity, controlling for the visual similarity of the stimuli in each category. However, using a visual similarity model derived from a broad range of FACS-based action units (AUs) may underestimate the similarity of the categories in action units that are more critical for emotion perception (i.e. EMFACS). Therefore, we re-ran the model using two different visual controls derived from subsets of the FACS: a) EMFACS similarity, or overlap in action units deemed critical for emotion perception in general, and b) Strict EMFACS similarity, or overlap in action units deemed critical for perception of the categories in question (e.g., for Anger-Disgust, overlap in the action units deemed critical for perceiving Anger and Disgust). See Methods for more details on EMFACS.

Supplementary Table 1a. Results of the multi-level regression predicting perceptual similarity from conceptual similarity and visual similarity, using a visual similarity model derived from all EMFACS action units.

Model	*B*	*SE*	95% CI	Wald *Z*	% NC	*p*
Conceptual similarity	7.6×10^{-3}	1.1×10^{-3}	[5.6×10^{-3}, 9.7×10^{-3}]	7.17	129.4%	< .0001
EMFACS similarity	4.0×10^{-3}	1.7×10^{-3}	[6.0×10^{-4}, 7.3×10^{-3}]	2.33	42.1%	.02

Supplementary Table 1b. Results of the multi-level regression predicting perceptual similarity from conceptual similarity and visual similarity, using a visual similarity model derived strictly from the EMFACS action units critical for each emotion category in a given category-pair.

Model	*B*	*SE*	95% CI	Wald *Z*	% NC	*p*
Conceptual similarity	7.5×10^{-3}	1.0×10^{-3}	[$5.5x\ 10^{-3}$, 9.6×10^{-3}]	7.18	129.6%	< .0001
Strict EMFACS similarity	4.9×10^{-3}	1.6×10^{-3}	[1.7×10^{-3}, 8.1×10^{-3}]	2.98	53.8%	.003

Supplementary Table 2. Results from Study 2 using stricter versions of the visual similarity control model.

In Study 2 ($N = 91$), we found that conceptual similarity significantly predicted perceptual similarity, controlling for the visual similarity of the stimuli in each category. However, using a visual similarity model derived from a broad range of FACS-based action units (AUs) may underestimate the similarity of the categories in action units that are more critical for emotion perception (i.e. EMFACS). Therefore, we re-ran the model using two different visual controls derived from subsets of the FACS: a) EMFACS similarity, or overlap in action units deemed critical for emotion perception in general, and b) Strict EMFACS similarity, or overlap in action units deemed critical for perception of the categories in question (e.g., for Anger-Disgust, overlap in the action units deemed critical for perceiving Anger and Disgust). See Methods for more details on EMFACS.

Supplementary Table 2a. Results of the multi-level regression predicting perceptual similarity from conceptual similarity and visual similarity, using a visual similarity model derived from all EMFACS action units.

Model	*B*	*SE*	95% CI	Wald *Z*	% NC	*p*
Conceptual similarity	6.6×10^{-5}	1.7×10^{-5}	[3.3×10^{-5}, 9.9×10^{-5}]	3.90	70.1%	< .0001
EMFACS similarity	3.0×10^{-3}	1.5×10^{-3}	[1.0×10^{-4}, 6.0×10^{-3}]	2.02	36.3%	.043

Supplementary Table 2b. Results of the multi-level regression predicting perceptual similarity from conceptual similarity and visual similarity, using a visual similarity model derived strictly from the EMFACS action units critical for each emotion category in a given category-pair.

Model	*B*	*SE*	95% CI	Wald *Z*	% NC	*p*
Conceptual similarity	6.4×10^{-5}	1.7×10^{-5}	[3.1×10^{-5}, 9.7×10^{-5}]	3.80	68.3%	.0001
Strict EMFACS similarity	4.3×10^{-3}	1.6×10^{-3}	[1.2×10^{-3}, 7.4×10^{-3}]	2.69	48.4%	.0072

Supplementary Table 3. Correlations between average conceptual and perceptual representations across all 3 studies.

Supplementary Table 3a. Correlations between the average conceptual similarity values in Studies 1 (N = 100), 2 (N = 91), and 3 (N = 368). In Study 1, conceptual similarity was measured using pairwise similarity ratings. In Studies 2 and 3, conceptual similarity was calculated by measuring the overlap between conceptual ratings of word and phrase stimuli for each emotion category.

	Study 2	Study 3
Study 1	.93	.91
Study 2		.97

Supplementary Table 3b. Correlations between the average perceptual similarity values in Studies 1 (N = 100), 2 (N = 91), and 3 (N = 368). In Studies 1 and 2, perceptual similarity was measured using computer mouse-tracking. In Study 3, perceptual similarity was measured using emotion judgments of independent raters, similarity judgments of independent raters, and correlations between the flattened pixel maps of pairs of classification images.

	Study 2	Study 3 (emotion judgments)	Study 3 (similarity judgments)	Study 3 (pixel similarity)
Study 1	.80	.81	.56	.72
Study 2		.82	.66	.74
Study 3 (emotion rate)			.85	.92
Study 3 (similarity rate)				.96

Supplementary Table 4. Percent agreement with EMFACS.

In Studies 1 ($N = 100$) and 2 ($N = 91$), we found that conceptual similarity between emotion categories significantly predicted how similarly those categories were perceived. To ensure that this effect did not reflect a confound of the stimulus set (e.g., stimuli in the Anger condition actually appeared more Disgusted), we coded the degree to which our images displayed the "correct" facial action units for each category, as determined by the EMFACS coding system, a subset of FACS which isolates action units critical for emotion perception (see Methods). Across all emotion categories, we found substantial agreement. Moreover, we controlled for any spurious overlap by using visual control models based on FACS and EMFACS as additional predictors in our regression models.

Emotion	Percent agreement
Anger	80.0%
Disgust	78.8%
Fear	80.5%
Happiness	92.8%
Sadness	79.8%
Surprise	99.3%
Overall	85.9%

Supplementary Table 5. Studies 2 and 3 word and phrase stimuli.
The top 40 words and phrases from a pre-test on MTurk in which participants were asked to "list the top 5 thoughts, bodily feelings, and actions" associated with each emotion category. These were used as stimuli in the conceptual rating tasks in Studies 2 ($N = 91$) and 3 ($N = 368$).

Emotion features
Crying
Smiling
Nausea
Yelling
Shaking
Shock
Heart racing
Grossness
Frowning
Jumping
Wide eyes
Upset
Vomiting
Laughing
Heat
Excitement
Sweating
Sickness
Loving
Depression
Calm
Tense
Avoidance
Slumping over
Screaming
Clenching fists
Lonely
Pain
Frustration
Gasping
Warmth
Hiding
Rage
Punching
Anxious
Headache
Gagging
Turning away
Lethargic
Jaw grinding