

# Embodied Emotions in Natural Language

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## Abstract:

Emotions are often felt in the body, and embodiment is a prominent mechanism supporting language processing. Here we utilized computational linguistics to map embodied representations of emotions in an English text corpus. The data revealed consistent embodied patterns for emotion categories. Comparison between semantics-derived and self-reported bodily maps of emotions revealed similar, discrete bodily representations of different emotions in texts and self-reports. Hierarchical clustering revealed three clusters: positive emotions within the head and chest, negative emotions within the torso and legs, and negative social emotions mostly within the head. Replication in a Finnish corpus yielded consistent results. These findings show that the bodily organization of emotional experience is reflected in the statistical structure of language, linking linguistic meaning to the subjective bodily experience of emotion.

## Introduction

Emotions are core devices for storytelling. From *The Odyssey* to *Romeo and Juliet* and *The Catcher in The Rye*, we are drawn to the passions, desires, and fortunes of the fictional characters who are brought alive through our ability to transform written text into vivid and affect-imbued mental images of the imaginary worlds and their inhabitants. The core function of emotions is to prepare organisms for action by coordinating activity of the skeletomuscular, cardiorespiratory and endocrine systems to match with the current survival needs (1–4). Emotions are tightly linked with the homeostatic control of the body, and the brain responds continuously to the afferent visceral signals conveyed by the spinal and cranial nerves (5). The insular cortex represents autonomic responses and changes in visceral state and together with the amygdala and medial frontal cortex encodes the subjective emotional feelings, thus serving as the key hub for generating the subjective experience of emotion during both acute survival challenges as well as fictional affect-imbued episodes in written texts (2, 6). Somatosensory cortices are also consistently activated during emotional behavior, and statistical pattern recognition studies have confirmed that an individual’s current emotional state can be reliably “decoded” from the haemodynamic activity in the somatosensory cortex (2, 7).

The bodily changes associated with emotions often trigger the subjective experience of emotion (such as “I am happy”). When hearing about the loss of our loved one we feel heavy-hearted, interpersonal conflicts make our minds blow with rage, while major victories and successes will make us feel proud and excited. Numerous studies have established that different emotions elicit discernible and culturally consistent “bodily feeling fingerprints”, indicative of emotion-specific autonomic engagement (3, 8, 9). These bodily sensations are also translated to emotional language. Misfortunes in love lead to “broken hearts” while excitement and nervousness may bring “butterflies in the stomach”, and a person filled with rage may be “bursting with anger”. Embodied emotion theories propose that emotion concepts are grounded on the brain systems that generate visceral and motor states. When listening to emotional prose, the brain’s emotional and somatosensory circuits closely track the emotional value of the language (10–12) and words describing actions executed with different body parts such as tongue (lick), hands (pick), and feet (kick), activate the somatotopic representation of the corresponding body parts in the motor strip (13). Similarly, sensorimotor activations in the brain’s arm and leg regions are observed while participants process metaphors associated with arm (“she grasped the idea”) or leg (“she kicked the habit”) actions (14), highlighting the somatotopic precision of the embodied metaphor processing.

As bodily sensations associated with emotions influence our decisions from mundane everyday issues to passionate love and political divides (15, 16), understanding how these embodied emotions are expressed in spoken and written language may help clarify how bodily experience is translated into concepts and communication. Although computational linguistic approaches such as sentiment analysis can be used for tracking the general affective value of narratives (17, 18), they do not capture the quantitative associations between the emotional semantics and the textual embodiment patterns and bodily sensations. In other words, we do not know whether i) there exists emotion-specific regularities in the linkage between emotional and bodily language reflects the *de facto* emotion-specific coactivation patterns across bodily systems (3, 9), rather than purely metaphorical communication of emotional states.

### *The current study*

Recently, we have developed a new tool for mapping embodied emotions from texts based on the statistical regularities in co-occurrences between emotion words and different body parts (such as “disgust” → “stomach”; “fear” → “heart”). These regularities can be used for creating statistical parametric bodily maps or “feeling fingerprints” of emotions expressed in language (19). They represent the statistical probability of any given body part and an emotion word occurring in close proximity, thus indicating the semantic embodiment patterns for different emotions. Here we used this computational linguistic approach for mapping semantic representations of bodily emotions in a large English corpus, and compared the semantically derived maps with self-reported bodily maps of emotions. We first identified the occurrence of the most common words pertaining to emotions and body parts from the corpus, and used pointwise mutual information (PMI) embeddings to derive their co-occurrence patterns (19). These patterns were subsequently weighted by embeddings of emotion and body words and mapped on a 3D human model to create quantitative visualizations of the co-occurrence patterns. The weight maps were compared with self-reported bodily topographies of the same emotions from human subjects (n=101). The analytic approach is summarized in Figure 1. We show that a i) broad array (n=14) of emotions are associated with distinct bodily topographies in the written texts, ii) these bodily representations are consistent across occurrences of the emotions across the texts in the corpus and iii) that the bodily representations of emotions derived from the text match well with those reported by human subjects during the corresponding emotions and iv) that the semantic maps also generalize to an unrelated language (Finnish).

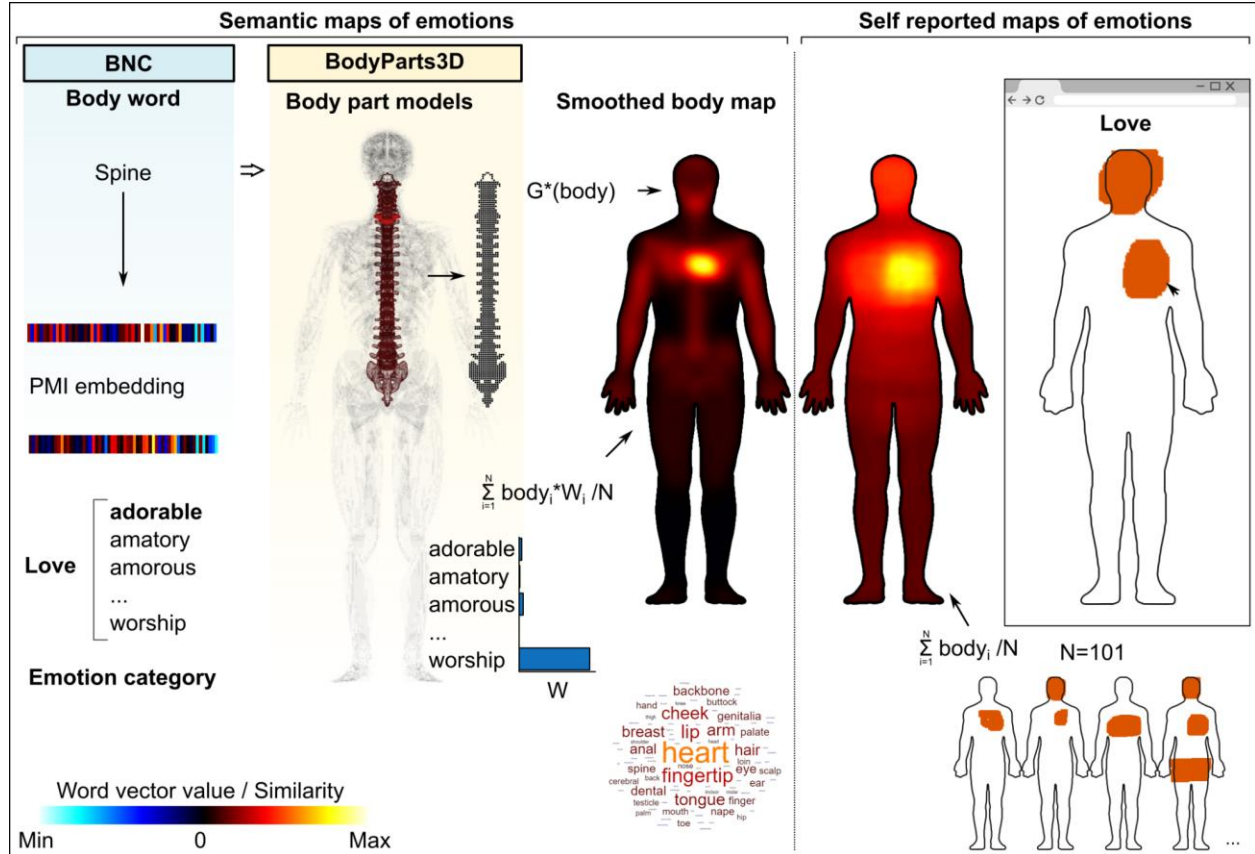


**Figure 1 Semantic and self-reported maps of embodied emotions.** Semantic maps were created based on the cosine similarity of the pointwise mutual information (PMI) embeddings of body and emotions words based on the British national corpus (BNC; English). Similar analysis was repeated using the Finnish National Library's digitized newspaper and periodicals corpus (Finnish) to evaluate generalizability between language families. Self-reported body maps were generated with a web-based tool where participants painted, with the mouse, where in their body they experienced a set of emotion words. A population map was generated to reflect the mean rating and the reliability between subjects was analyzed to evaluate generalizability between individuals.

## Results

We first generated the average semantic maps of bodily emotions based on the British national corpus and analysed their similarity structure (**Figure 2**). The bodily maps reflecting the maximum positive cosine similarity of a body part and all the emotion words belonging to the category revealed a clear categorical structure of the semantic bodily maps of emotions. Cluster analysis revealed three main clusters of the bodily maps. Positive emotions (happiness, love) formed one cluster, whereas negative emotions were split into one cluster consisting of negative social emotions (envy and contempt) while another comprised the basic negative emotions (fear, anxiety, depression, sadness, disgust, anger) and shame. Neutral emotional state, valence-wise ambiguous emotion surprise as well as pride remained independent of the main clusters.

We next tested how well the text-derived bodily maps of emotions correspond with self-reported bodily maps. **Figure 3** shows the resampled semantic and self-report body maps and histograms of the similarity of the semantic vs. self-report map of the same emotion compared to the similarities between the maps of different emotions. Visually the correspondence was on average high, which was also confirmed by the similarity metrics. Similarity between the semantic and self-reported body maps was on average  $r=0.62$  and exceeded 0.5 for all categories except shame, sadness, and disgust.

To evaluate how well the category-wise emotion maps can be distinguished from each other or (i.e. how discrete the semantic and self-reported bodily “fingerprints” of emotions are), we performed nearest neighbor classification based on the semantic and self-report similarity matrices as well as the symmetrized inter-modality matrices. For these analyses, the bodily maps were mapped to vectors with one value for each body word included in the analyses. The accuracies of predicting the emotion categories are shown in **Fig 4** averaged over all emotion categories (**Fig 4A**) and separately for each emotion category (**Fig. 4B**). Corresponding mean confusion matrices across repeated classifications are shown in **Fig. 4C**. This analysis revealed that overall classifier performance exceeded chance level for both semantic and self-reported maps as well as for the cross-modal classification, while classification accuracy was highest for the self-reported maps. Classification accuracy for individual emotions exceeded the chance level for all self-reported emotion maps and for all semantic emotion maps except for envy, indicating discrete bodily representations of emotions in both self-reports and semantics. Finally, cross-modal classification accuracy exceeded chance level for fear, depression, contempt, sadness, surprise, anger, and anxiety, indicating differences in the structural variability across the self-reports and semantic maps across emotions (despite significant spatial correlations across modality-specific maps shown in Figure 2). Equivalent analyses were repeated for the full 2-dimensional body maps (**Figure S1**), this led to poorer performance in the cross-modal classification demonstrating due to the different spatial scales across the modalities (i.e. detailed anatomy in the semantic maps versus approximate sensation localizations in the self-reports).



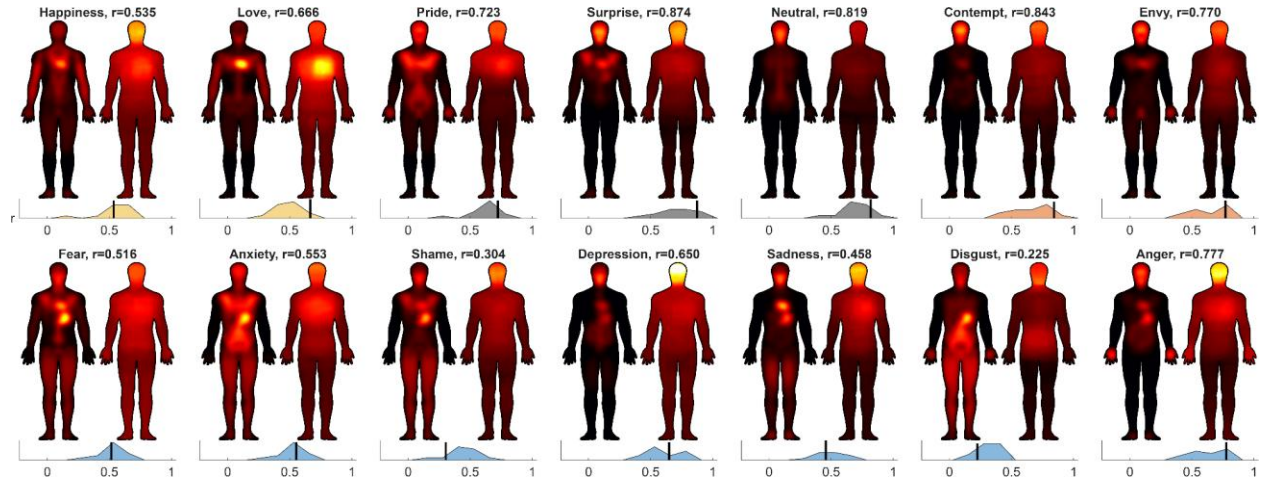


**Figure 3: Semantic and self-report bodily maps of emotions.** For each emotion category, the figure shows the body maps based on semantic cosine similarity of body and emotion words (left) and the self-reported bodily feelings associated with emotions (right) sampled into the same 2D space. The spatial correlation of the semantic vs. self-report maps are shown above each body map. The similarity distributions of the self-report and semantic maps are shown below the body maps with the thick vertical line indicating the similarity of the maps for the same category. The similarity distributions indicate the symmetrized pairwise similarities of the mean of self-report vs. semantic body maps. The order of emotions and the colors of the similarity distributions reflect the clustering solution in Figure 2B.

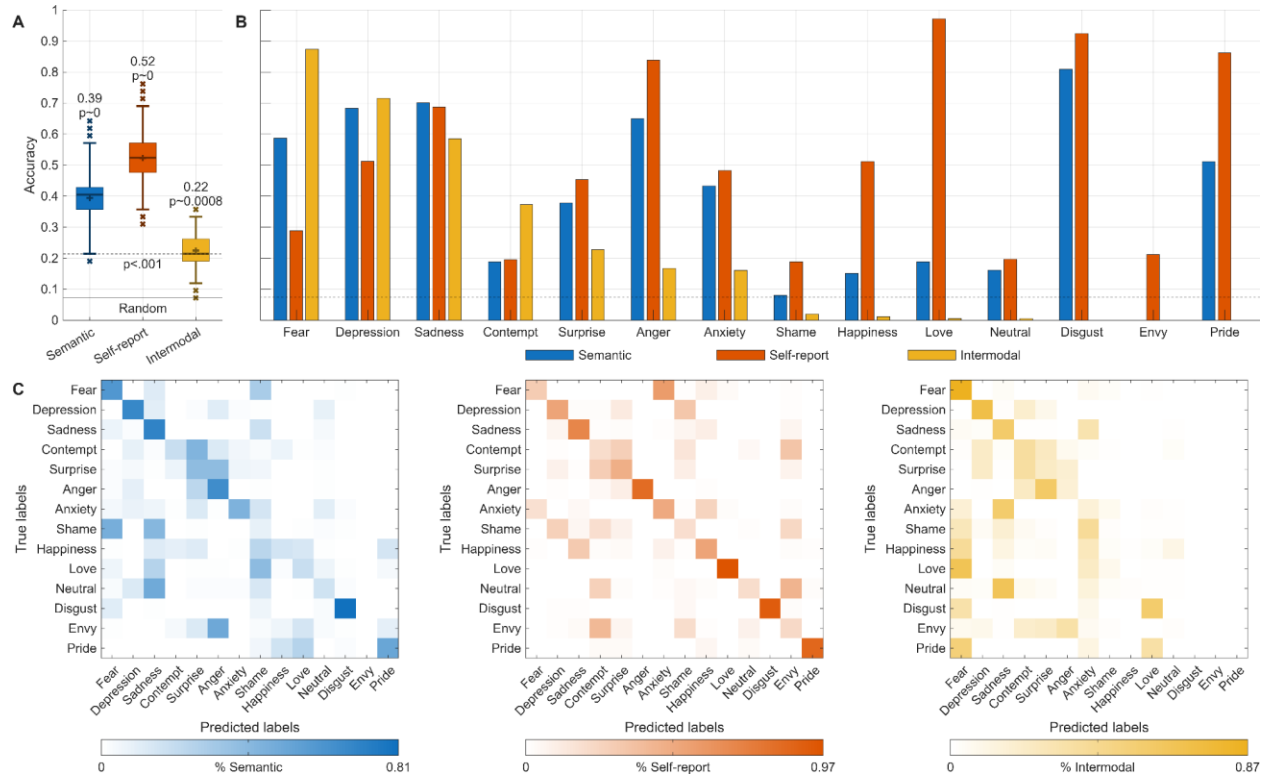


**Figure 4: Classification accuracy for bodily maps of emotions within and across modalities.**

**A:** Overall classification accuracies for semantic maps (blue), self-reported maps (orange) and crossmodal classification. Color coding is indicated in the legend below panel B. Mean accuracies and their probabilities in null analyses are shown on top of the boxplots. **B:** Emotion-specific classification accuracies. **C:** Confusion matrices of semantic, self-report and intermodal classification, respectively. Accuracies are based on 3-fold nearest neighbor classification based semantic, self-report and symmetrized inter-modality correlation matrices and the associated null accuracies with randomized labels. Thresholds based on null analyses are indicated by dashed black lines in panels A and B ( $p < .001$  across iterations, B maximum accuracy across categories). The theoretical random accuracy ( $p = 1/14$ ) is indicated by the solid black line in panel A. Emotions are sorted based on their intermodal identification accuracy (yellow bars).

Although the embodiment of the emotions in the large English corpus matched well with the actual bodily sensations, which are known to be culturally universal (8, 9), it is possible that this linkage is of different magnitude in other languages that potentially have less precise mapping between *de facto* emotions and bodily responses, which would mean that our results would be specific to the English language (19, 20). To address this issue, we conducted a replication analysis for the semantic bodily mapping in Finnish - an Uralic language unrelated to Indo-European languages (including English). We extracted the same years (1960–1993) from the Finnish National Library’s digitized newspaper and periodicals corpus as in the main analysis based on the BNC corpus (see **SI file** for details) and generated the semantic bodily maps using same workflow and parameters as for the English data. This revealed remarkable consistency across the semantic body maps across the languages (mean similarity  $r = 0.59$ ; see **Figure S2**). Prediction accuracy between languages was also significantly above chance level (mean accuracy .31 across emotion categories vs. .07 by chance) and was particularly successful for disgust (.99), surprise (.74) and fear (.62). By contrast, happiness, love, pride and anxiety were confused with other emotion categories (for confusion matrices within and between languages, see **Figure S3**).

## Discussion

Our main findings were that bodily representations of a wide array of emotions ( $n=14$ ) can be automatically derived from a large corpus of written text. These bodily signatures were discrete, as evidenced by the above-chance-level classification of the emotion-specific bodily maps. The semantics-derived bodily maps of specific emotions also corresponded well with those reported by human subjects while experiencing the same emotions. Altogether these data support the discrete representation of embodied emotions in written texts, and highlight how semantic descriptions of emotions in natural language reflect the bodily basis of emotions (3, 8, 21).

### *Bodily maps of emotional semantics*

Analysis of the statistical co-occurrence between body words and emotions yielded distinct maps for the tested emotions. Statistical testing confirmed that the emotion-body word pairings were consistent across emotion word instances for each emotion, indicating regularity in the way different emotions are described in texts (**Fig 1**). Both classic and modern emotion theories posit that subjective emotional feelings are at least partially determined by emotion-related changes in the skeletomuscular, neuroendocrine, and autonomic nervous systems (3, 22, 23). Previous studies based on self-reported bodily sensations evoked by emotions has confirmed that different emotions are associated with distinctive “feeling fingerprints” that are consistent across individuals while they are exposed to a wide array of potentially emotion-evoking material ranging from videos, narrative texts, visual art, and music (3, 8, 24). The present study goes significantly beyond this line of work by revealing that the bodily feeling topographies can be derived computationally from the text corpus. In other words, the links between different emotions and body parts are described consistently across occurrences in texts, indicating a consistent semantic embodiment of emotions. Replication analysis in an independent corpus from an unrelated Uralic language (Finnish) yielded consistent semantic maps of bodily emotions. Although this similarity does not rule out the possibility that the semantic emotional mapping could diverge from the *de facto* sensation patterns in *some* languages, it provides strong evidence against the cultural specificity of our findings, as similar emotional embeddings are consistently observed across distinct languages (Uralic Finnish and Indo-European English) and text corpora. The visceral and autonomic changes of emotions are a universally shared human experience whose efficient communication has warranted shared linguistic reference, thus likely resulting in comparable mappings between emotions and their bodily constituents across languages.

Major categorical theories of emotion have argued that different emotions (such as anger, fear, disgust etc) prepare the organisms for different survival challenges, and thus are accompanied by discrete changes in autonomic and neural activity (25–27). Our data provide support for the categorical model of emotions on the level of the semantic descriptors of bodily emotions. Emotion-related language informed by the physiological, emotion-related bodily activations is also consistently discrete across emotions, so that different emotions occur systematically with different constellations of body parts and regions in natural language. The computationally derived “feeling fingerprints” of different emotions are visually saliently different across different emotions. For example, love was profoundly associated with activity in the chest,

disgust with stomach, and anger with upper limbs. This discreteness was also confirmed formally using statistical pattern recognition. All the semantic bodily maps of emotions (except envy) could be classified from each other significantly above chance level, confirming their independence. Semantic descriptions of emotion-evoked bodily changes are thus discrete and consistent within each emotion category, as otherwise successful training of the classifier as well as predicting the emotion categories in the independent test data sets would not have been possible. In other words, writers describe emotion-specific bodily responses differently and categorically depending on the emotion, most likely due to the consistent differences in the emotion-evoked autonomic and visceral activation patterns.

### *Semantic bodily emotions correspond with self-reports*

Our data confirmed that the semantic bodily maps of emotions closely correspond with bodily maps of self-reported emotional experiences gathered from human volunteers. This was evidenced by the high spatial correlations (mean  $r > 0.62$ ) between the semantic and self-reported body maps, suggesting that texts containing references to different emotions also contain semantic descriptions of the same bodily parts that people report being activating when experiencing these emotions (**Fig 3**). Correspondence between the semantic and self-reported body maps was also supported by the cross-classification of the body maps, where the classifier was first trained on the semantic maps and tested on the self-reported maps, or *vice versa*. Overall this approach yielded above chance level mean accuracy of 0.22 against chance level of 0.07, and exceeded a more conservative permutation-based null accuracy of individual iterations (0.21,  $p < .001$ ). However, unlike the within-modality classifiers (train with semantic maps – test with semantic maps and train with self-reported maps – test with self-reported maps) which yielded above chance level accuracy for practically all emotions, the cross-classification accuracy was not equally high for all emotions and particularly shame, contempt and envy (and the neutral emotional state) tended to be misclassified as fear. This likely reflects the overall weak linkage between emotional and bodily semantics for these emotions in the semantic maps. Thus, the mapping of subjective emotional sensations to bodily responses in texts is not perfect and the accuracy is emotion-dependent. Yet, we stress that despite these discrepancies across data types for certain emotions, the semantically derived body maps were discrete and consistent across occurrences of the emotion words.

It could be argued that both the semantic and bodily maps of emotions simply reflect cultural conventions or social schemata in describing the relationship between emotions and body parts through, for example, figurative expressions in English language such as “cold feet” or “butterflies in stomach” (28, 29). For the self-reported body maps this is unlikely given the high consistency of the self-reported emotions (30) and bodily signatures of emotions across cultures and languages (3, 9) even when bodily sensation patterns to non-linguistic emotional material such as music are measured (8). These subjective sensations thus reflect universal sensation patterns brought about by emotion systems, which must be based on biological associations between the emotions and the sensations. Given the i) consistency of the self-reported and semantic maps and ii) consistency in the semantic bodily maps of emotions across languages, we argue that our results show that the conventions of referring to specific body parts in relation to specific emotions in language arise from the consistent mapping between consciously accessible bodily sensations triggered by different emotions, that are in turn reflected in the way we write

about emotions. In other words, our emotions shape the way we write about emotions, rather than vice versa.

### ***Limitations and future directions***

The study was run using English and Finnish corpora with primarily late 20th-century texts. Thus the results may not generalize to other languages. The used corpus contained texts from different genres (English: 85,162,735 words in 1,411 books and 1,208 periodicals, Finnish: 464,019,962 words in 18 periodicals and newspapers), yet we deliberately did not split the data between genres such as fiction versus media articles to ensure generalizability and statistical power. Future studies could extend this work using corpora focused on specific genres such as News on Web and Wikipedia Corpus that contain more selective text sources to address the potential context-dependency of embodied emotions in language. Using corpora spanning longer time windows would also allow investigating whether the semantic embodied representation of emotion varies across time, cultures, as well as text types. Although cultural universality in the bodily experience of emotions has been well established (8, 9) the semantic descriptors of the bodily basis of emotions may not be immutable over time. For example, limited understanding of human physiology and psychology based on religious beliefs in early cultures or the nature of genres of texts in the corpora (e.g., medical, religious, and administrative texts) could affect the way emotions are described in historic texts (31, 32). Finally, the patterns established through the PMI embeddings do not account for the context in which the body parts and the emotions co-occur. For example, statements such as “I was so scared that my heart was racing” and “I was so much in love that my heart was melting” contain similar mutual information between “heart” and the emotion words “love” and “scared” despite the context and the described cardiac physiology being completely different. However, similar unspecificity also applies to the self-reported topographies of bodily emotions (21), and despite this unspecificity the data revealed discrete semantic bodily maps across different emotions, as well as concordance between semantic and self-reported bodily maps.

### ***Conclusions***

We conclude that semantic representations of embodied emotions are discrete and systematically align with subjective bodily experiences of emotion. Thus, the bodily organization of emotional experience is reflected in the statistical structure of natural language. This data-driven approach provides a method for identifying and mapping embodied emotional content in text. Emotions play a central role in stories. They motivate characters’ actions, engage readers, and can shape readers’ interpretations and attitudes (33, 34). Given the centrality of the somatic sensations in generating subjective emotions and decision making (3, 5, 15), this approach makes it possible to use large naturalistic text corpora, including literature, to model the bodily organization of human emotions and provides a basis for predicting how emotional content may be experienced by readers.

## Materials and Methods

### Semantic spaces for body words and emotions

The lists of body and emotion words are based on the hierarchical classification of words in WordNet (20, 21). The list of words relating to the human body was compiled by retrieving all of the words in WordNet with the tag ‘noun.body’, which resulted in an initial list of 3,638 words. We removed words which were related to the body but which were unlikely to appear in everyday language, such as medical vocabulary with Latin and Greek roots (e.g. “oesophagus”) and ambiguous slang terms (e.g. “mug” for “face”). To ensure a sufficient number of unambiguous instances per word, we excluded words occurring in the data for less than 100 times. Finally, we excluded the words whose corresponding anatomical structures or close equivalents were not included as a separate model in the 3D body model (see below) and/or which referred to small parts of the human body (e.g. “belly button”, “eardrum”, “eyelash”). Body parts that could be written as compound words or as separate words (e.g. gall bladder and gallbladder) were merged. This resulted in a list of 93 body words (Table S1). Finally, each of the body words on the final list was linked with the corresponding anatomical structure in the 3D body model.

The studied emotion categories (six basic emotions: anger, fear, disgust, happiness, sadness, surprise (25) and seven nonbasic emotions: anxiety, love, depression, contempt, pride, shame, and jealousy) were based on prior work establishing the cultural universality in bodily basis of emotions (9). A complete list of emotion words were derived from WordNet-Affect, which contains a hierarchical semantic representation of different words denoting emotional processes in the English language (35). To limit the lexicon to actual emotion-related expressions, words having an emotional meaning but being used predominantly in their non-emotion-related meaning (such as “blue”) were first removed from the corpus. To use this natural language emotional lexicon with the discrete emotion categories established in affective science, we mapped the relevant emotion words in WordNet-Affect into the fourteen emotion categories used in prior studies on self-reported bodily maps of emotions (9). The emotion words are listed in alphabetical order according to categories in Tables S2–S4.

### Constructing the Finnish corpus

To evaluate the generality of the findings across languages, we performed a replication analysis on a Finnish-language dataset. The Finnish-language data is based on the Finnish National Library’s digitized newspaper and periodicals corpus from which we only used the texts from years 1960 to 1993. We selected 9 newspapers and 11 periodicals and extracted Finnish sentences using the lemma for each word as given in the automatically tagged data files. For body words we used a translation of the list of the English words for this study. The emotion words were taken from the study of Tuovila (36) and supplemented with forms of the words in the data itself and with words from the Finnish WordNet. The words in the same family were normalized into a single lemma and were classified into the same categories as in this study. The final textual data included 464,019,962 tokens and 5,021,572 unique words. More detailed analyses of the Finnish language corpus will be presented in a separate study.

### Text corpus preparation

The textual English-language data was based on the British National Corpus (BNC) of written and spoken texts representing British English from 1960 to 1993. The corpus consists of text samples of generally no longer than 45,000 words spanning a variety of subject fields, registers, and genres.<sup>1</sup> The BNC is one of the major resources in English corpus linguistics due to its size and lemmatized words. While being smaller than e.g. the Wikipedia Corpus (1.9 billion words) and the News on the Web (24.3 billion words), the BNC is not restricted to a single genre (as, e.g., the similarly sized TIME Magazine Corpus or the Corpus of US Supreme Court Opinions) thus making it more representative of natural language use. It also has a defined temporal and geographic restriction, allowing for future comparative research. In line with our prior work (31) we analyzed only the written section of the BNC (85,162,735 tokens). To prepare the texts for the analysis, we combined multi-token body and emotion words in the data into single-token units as described above. We replaced each word within the corpus with its lemma as given in the BNC data, which normalizes different forms of the same word into one character string. Emotion words in the same family were all normalized into a single lemma. For instance, the words *enviable*, *enviably*, *envious*, *enviously*, and *enviousness* were all replaced with *envy*, which appears on the list of emotion words. The final textual corpus included 44,301,237 tokens and 291,318 unique tokens.

### Self-reported bodily topographies of emotions

Self-reported bodily topographies for each emotion were acquired online on the Gorilla experiment platform (gorilla.sc) with the emBODY tool (3). A total of 222 adults fluent in English participated in the experiment. They were recruited through the Prolific service and were compensated for their time. Exclusion criteria included self-reported diagnosed psychiatric and neurological disorders and corresponding medication for the past three months. All participants gave informed consent. Data from 20 participants were excluded because of failed attention checks and one participant had corrupted data, leaving 201 participants (95 female, 106 male, mean age = 36.49,  $sd = 13.32$ , range = [18,78]) for the data analysis. Participants were randomized into two groups ( $N1 = 100$  and  $N2 = 101$ ) and each group was shown either 26 or 27 emotion words out of a larger set of 53 emotions (of which the subset of 14 were analyzed in this study). Each emotion was shown one at a time, and participants were asked to use their computer mouse (or finger if using a tablet) to indicate on a blank human figure the bodily regions whose activity they felt changing when feeling the indicated emotion. Only participants who passed a bot check (rearranging two well-known phrases out of scrambled words) were allowed to take part in the study. An additional attention check was embedded in the bodymap task (“Please indicate that you are paying attention by drawing the letter X on the human figure”). Data from participants who failed the attention test were excluded. Bodily sensation maps were visually inspected for aberrant responses such as scribbling or writing on the bodies, and all responses outside the body were masked out. To reveal regions where statistically significant bodily sensations were experienced for each emotion, mass univariate  $t$ -tests were used to compare pixel-wise activations against zero for each emotion. The pixel intensities in the resulting statistical summary maps ( $t$ -maps) reflect statistically significant bodily changes associated with

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<sup>1</sup> Reference Guide for the British National Corpus (XML Edition), <http://www.natcorp.ox.ac.uk/docs/URG/>

each emotion across subjects. These thresholded statistical maps were then used for comparison with the semantic body maps (see below).

## Data analysis

### Word Embeddings

Word embeddings capture information about the contexts in which a word appears, thus representing the semantic content of a word in numerical format. They therefore allow for comparisons of body words and emotion words in terms of how much the semantic content of various body words aligns with the semantic content of emotion words describing various emotional states. We used the PMI-embeddings toolkit (<https://github.com/asahala/pmi-embeddings>) to create the word embeddings based on the co-occurrences of the words (31). A co-occurrence was defined as two words being present within pre-defined proximity window, and was operationalized as pointwise mutual information (PMI) of the two words. This creates a matrix of the co-occurrences of each word with every other word. Window size of seven words was used to ensure that the higher-resolution vectors have sufficient data to build on. This matrix was then factorized into a lower number of latent dimensions that describe the co-occurrence of the words in the corpus. We used 240 dimensions, as a lower dimensionality was not able to sufficiently represent semantic differences across the body words and the emotion words. This process gave each word a vector representing the sum of all of its co-occurrences in a condensed format.

### Semantic bodily maps of emotions

See **Fig 1** in main text for an overview of the analytic approach. To create the three-dimensional body maps, we used the models from the BodyParts3D project (<https://lifesciencedb.jp/bp3d/>). To match words with 3D maps of body parts, we manually searched for the body part lists of both the BodyParts3D library hierarchy based on synonyms (e.g., backbone – spine) and constituent parts (e.g., vertebra – spine) of the terms identified in the corpus. Body words referring to systems and organs spanning the whole body (e.g., veins) or having broader definition than specific body parts (e.g. limb, skin) were excluded. We then converted the 3D meshes of the body part models to a low-resolution voxel representation in 141 x 101 x 348 (width x depth x height). For visualisation, the arrays were smoothed by a Gaussian kernel (MATLAB smooth function, isotropic 2-voxel standard deviation, kernel array size 9 x 9 x 9 voxels).

To map the emotion-body relations on the 3D body model, we created cosine similarity matrices of the body words compared with the emotion words in the 240-dimensional word embedding space. We then created body maps of emotions by mapping the cosine similarities to the 3-dimensional models of the body parts for each emotion (31) with the distinction that we focused on the maximum positive similarities, rather than extreme positive or negative values. In the cases of overlapping body parts (e.g. arm and forearm), we selected the maximum value for that voxel to create a single 3-dimensional heatmap.

We then mapped the 3-dimensional body maps to 2-dimensional images by taking the maximum value over the coronal plane of the body. To visualize the 14 main emotion categories, we first

calculated the word frequency-weighted average word embedding vector of all words belonging to the emotion category and created the body map of this vector otherwise identically to the individual emotion maps. For the word frequency weighting, we compared uniform, linear, logarithmic and truncated linear with unit weights for the most frequent 5% of emotion words. For the current results, we selected the truncated linear weighting as it most clearly separated the emotion categories by reducing the effects of infrequent words and not overemphasizing the most frequent words. To ensure similar spatial smoothness between the semantic and self-report maps, we then applied a 2-dimensional Gaussian filter with a standard deviation of 2 pixels in the original resolution of 348x141 pixels. For visualization, the body maps were upsampled by a factor of 5.

### *Comparison of semantic and self-reported body maps*

Both self-reported and semantic body maps were first resampled to a common resolution. We then created a 2-dimensional mask of the skin layer of the body to constrain the analyses to the pixels falling inside the body. To evaluate the similarity of emotion categories, we performed a weighted average linkage hierarchical agglomerative clustering to construct a clustering tree reflecting the similarity of the emotion separately for semantic and self-reported emotions. For visualization of the most consistent cluster, clusters in the tree were color coded with the default threshold (70% of the maximum linkage).

To quantify the similarity of the body maps across modalities (semantic vs. self-report), we calculated the spatial correlation of the heatmap values inside the body mask and plotted the spatial correlation of the maps of the same emotion category and the distribution of correlations with the other emotion categories. As the similarity matrices are not symmetrical and the shared variance of body maps within a modality tended to uniformly affect rows (or columns) of the similarity matrices, we first symmetrized the matrix by calculating the average of the matrix with its transpose. The entries in this matrix reflect the average intermodality similarity of e.g. self-reported happiness map vs. semantic fear map and semantic fear map vs. self-reported happiness map. This simplifies the interpretation of the amount of shared variance between modalities while attenuating the effects of within-modality similarity.

To test for the discriminability of the emotion categories from one another, we performed a 3-fold nearest neighbor classification based on the spatial similarity both within and across modalities. To balance the number of body maps in each category and reduce random variability between participants and unusual emotion words in the classification, we randomly split each category into three equally sized groups of emotions (semantic) or participants (self-report) and created average maps of the three subsets of emotions for each emotion category. To reduce the effects of different spatial specificity and smoothness across the modalities, we first downsampled the 2-dimensional body maps by extracting the maximum values from the 2-dimensional maps of the 92 body parts included in our analyses. This resulted in a vector of 92 values for each map of emotion words and individual self-report ratings of each emotion category. We then created similarity matrices in a 3-fold cross-validation scheme, where we averaged the maps of two of the (“training”) groups and calculated their similarity with the third (“test”) group and selected the label on the highest similarity value for each row of the matrix.

To evaluate the variability, the classification process was repeated 250 times with different random groupings.

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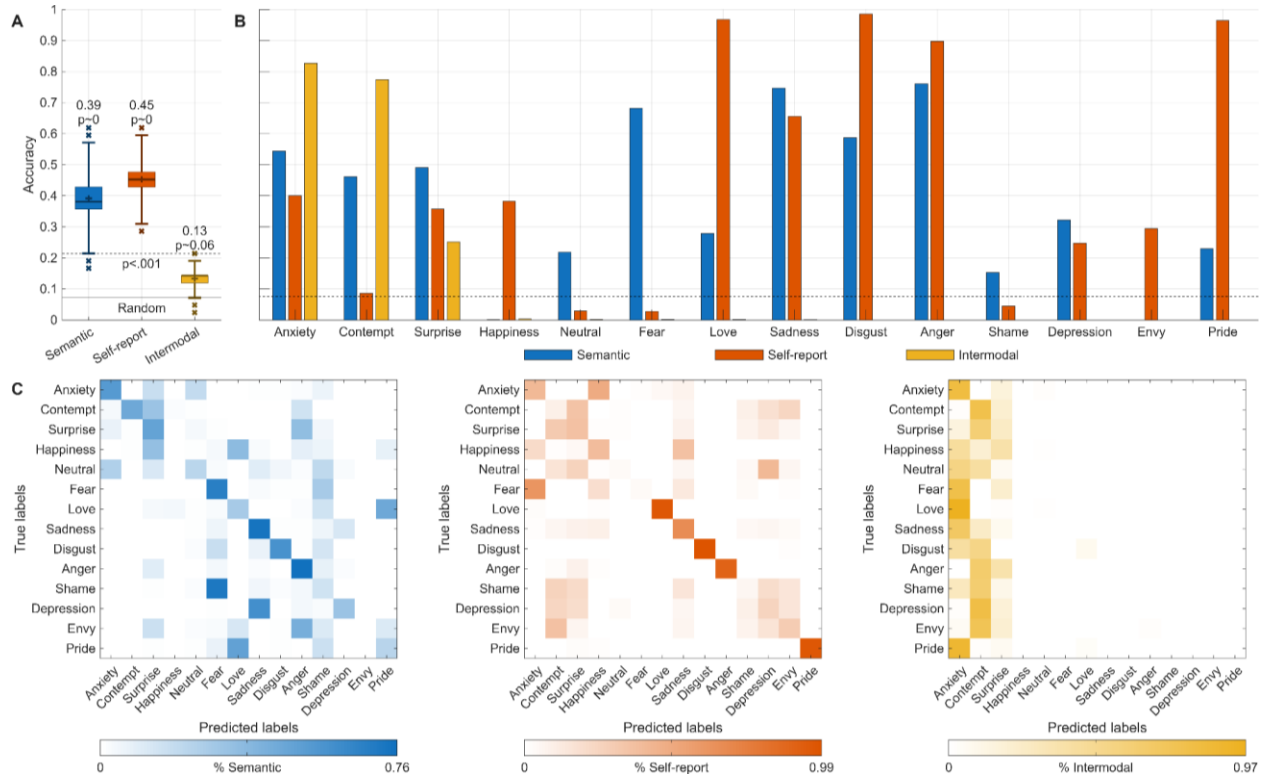
**Competing interests:** Authors declare that they have no competing interests

# Supplementary Materials

## **Supplementary materials include**

Figs. S1 to S3  
Tables S1 to S4  
Data S1

**Fig. S1.**

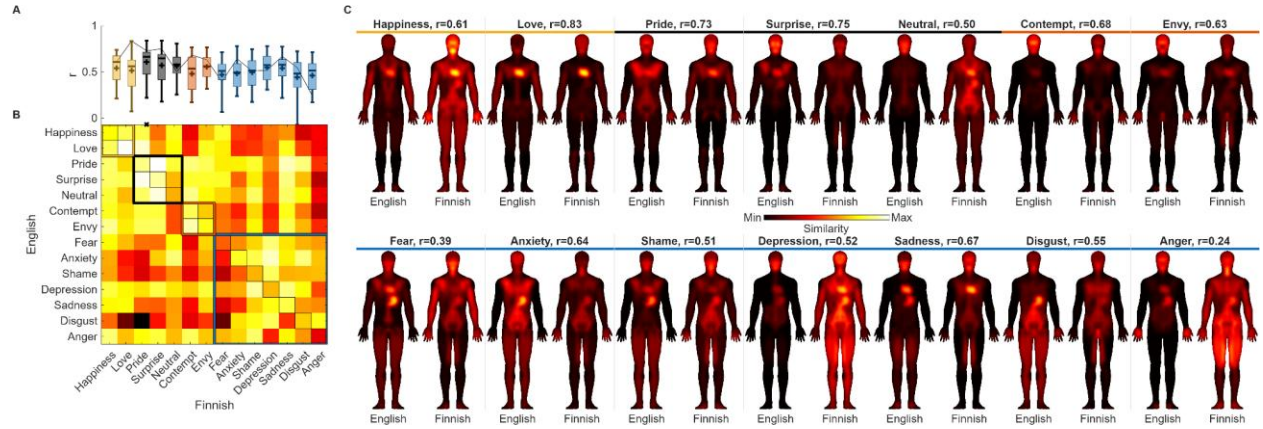


**Classification accuracy of emotions based on full body maps.**

**A:** Overall classification accuracies for semantic maps (blue), self-reported maps (orange) and crossmodal classification. Color coding is indicated in the legend below panel B. Mean accuracies and their probabilities in null analyses are shown on top of the boxplots.

**B:** Emotion-specific classification accuracies. **C:** Confusion matrices of semantic, self-report and intermodal classification, respectively. Accuracies are based on 3-fold nearest neighbor classification based semantic, self-report and symmetrized inter-modality correlation matrices and the associated null accuracies with randomized labels. Thresholds based on null analyses are indicated by dashed black lines in panels A and B (A  $p<.001$  across iterations, B maximum accuracy across categories). The theoretical random accuracy ( $p=1/14$ ) is indicated by the solid black line in panel A. Emotions are sorted based on their intermodal identification accuracy (yellow bars).

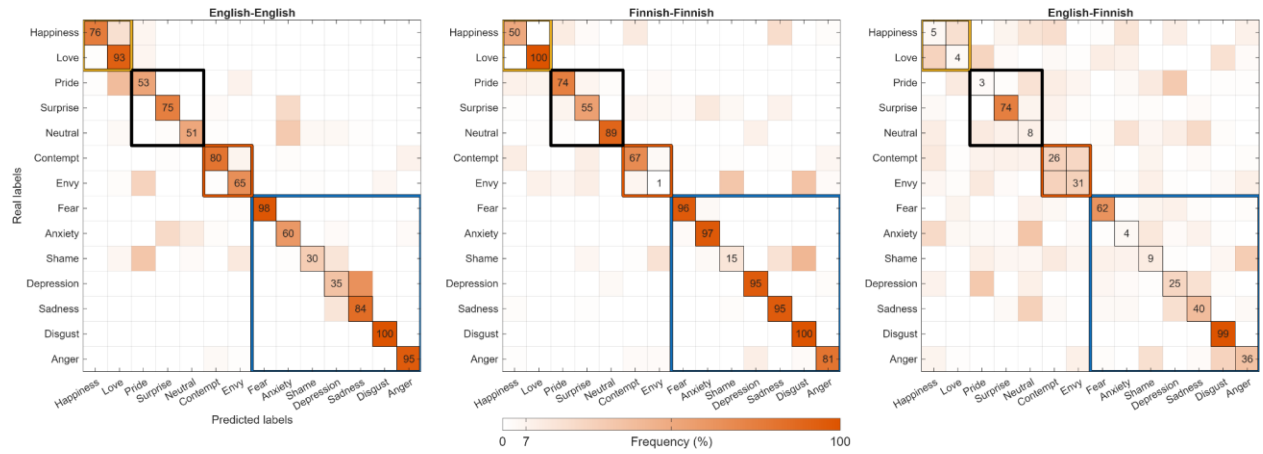
**Fig. S2.**



***Semantic body maps for the English and Finnish corpora.***

**A:** Cross-linguistic similarity distributions across emotions. **B:** Cross-linguistic similarity matrix for the semantic bodily maps of emotions. **C:** Bodily maps of semantic emotion categories for English and Finnish corpora with pairwise similarity values. The black-to-yellow colour coding body maps show the maximum positive cosine similarities between body parts and the emotion words included in each emotion category.

**Fig. S3.**



**Generalization of embodied emotions within and between languages.**

Confusion matrices of body maps of subsets of emotions between categories in the English (left), Finnish (middle) and between English vs. Finnish (right) corpora. The similarity is based directly on the cosine distances emotion words belonging to the 14 categories and the subset of body words that were shared between the two corpora (i.e. Finnish corpus contained words whose translation matched an English body word).

**Table S1.**

|             |           |           |          |            |             |
|-------------|-----------|-----------|----------|------------|-------------|
| abdomen     | anal      | ankle     | anus     | arm        | armpit      |
| back        | backbone  | belly     | bladder  | bowel      | brain       |
| breast      | brow      | buttock   | cerebral | cheek      | chest       |
| chin        | colon     | dental    | ear      | elbow      | eye         |
| eyeball     | eyebrow   | eyelid    | face     | finger     | finger nail |
| fingertip   | fist      | foot      | forearm  | forefinger | forehead    |
| gallbladder | genitalia | groin     | gum      | hair       | haircut     |
| hairstyle   | hamstring | hand      | head     | heart      | heel        |
| hip         | incisor   | intestine | jaw      | kidney     | knee        |
| knuckle     | leg       | lip       | liver    | loin       | lung        |
| molar       | mouth     | nape      | nasal    | neck       | nose        |
| nostril     | palate    | palm      | pancreas | pelvis     | penis       |
| prostate    | rib       | scalp     | shin     | shoulder   | skin        |
| skull       | spine     | spleen    | stomach  | testicle   | thigh       |
| throat      | thumb     | thyroid   | toe      | tongue     | tooth       |
| torso       | waist     | wrist     |          |            |             |

Full list of words relating to the body. There are 93 words, listed alphabetically.

**Table S2.**

| <b>Anger</b>      |                |                |                   |                                  |
|-------------------|----------------|----------------|-------------------|----------------------------------|
| aggravate         | anger          | annoy          | bad\$\$\$temper   | bedevil                          |
| beset             | bother         | chivvy         | choleric          | choleric                         |
| crucify           | dander         | discourage     | displeasure       | dudgeon                          |
| dun               | enraged        | exacerbate     | exasperate        | frustrate                        |
| fury              | harass         | hassle         | high\$\$\$dudgeon | huffy                            |
| ill\$\$\$temper   | incensed       | indignant      | infuriate         | irascible                        |
| ire               | irritate       | livid          | mad               | miffed                           |
| nark              | offense        | outrage        | peevish           | pesky                            |
| pester            | pique          | pissed         | pissed\$\$\$off   | provoke                          |
| quick\$\$\$temper | rage           | rile           | see\$\$\$red      | short\$\$\$temper                |
| sulk              | tantrum        | temper         | torment           | umbrage                          |
| vex               | wrath          |                |                   |                                  |
| <b>Anxiety</b>    |                |                |                   |                                  |
| abash             | anxiety        | apprehension   | chagrin           | discomfit                        |
| discompose        | disconcert     | embarrass      | nervous           | queasy                           |
| uneasy            | unquiet        | upset          | worry             |                                  |
| <b>Contempt</b>   |                |                |                   |                                  |
| contemn           | contempt       | despise        | disdain           | scorn                            |
| <b>Depression</b> |                |                |                   |                                  |
| beset             | cast\$\$\$down | cheerless      | chivvy            | deject                           |
| demoralise        | depression     | despair        | despondence       | disconsolate                     |
|                   |                |                |                   | down\$\$\$in\$\$\$the\$\$\$mouth |
| discourage        | disheartened   | dismay         | dispirited        | h                                |
| downcast          | downhearted    | downtrodden    | dysphoria         | gloom                            |
| grim              | harass         | hassle         | heartsick         | helplessness                     |
| low\$\$\$spirited | oppressed      | provoke        | tyrannous         | unhappy                          |
| <b>Disgust</b>    |                |                |                   |                                  |
| abhor             | abominable     | churn\$\$\$up  | detest            | disgust                          |
| distaste          | foul           | gross\$\$\$out | hideous           | horrid                           |
| horrific          | horror         | loathe         | nausea            | noisome                          |
| obscene           | odiously       | offense        | outrage           | queasy                           |
| repel             | repugnant      | repulse        | revulsion         | sick                             |
| sick\$\$\$of      | tired\$\$\$of  | vile           | wicked            | yucky                            |

Words relating to emotions in the study according to their emotional category. There are 393 words, and fourteen emotion categories altogether. Each category presents the words alphabetically as they are represented in the BNC data. This table lists words for the first 5 emotion categories, in alphabetical order.

**Table S3.**

| <b>Fear</b>         |                   |                   |                  |                   |
|---------------------|-------------------|-------------------|------------------|-------------------|
| affright            | afraid            | alarm             | alert            | anxiety           |
| appal               | apprehension      | atrocious         | awful            | bashful           |
| cliff\$\$\$hanging  | consternation     | cower             | crawl            | creep             |
| cringe              | cruelty           | daunt             | diffident        | dismay            |
| dread               | fawn              | fear              | fearsome         | foreboding        |
| frighten            | grovel            | hangdog           | hardhearted      | heartless         |
| hesitance           | hideous           | horrendous        | horrible         | horrid            |
| horrific            | horrify           | horror            | hysteria         | intimidate        |
| mercilessness       | nail\$\$\$biting  | outrage           | panic            | panic\$\$\$attack |
| panic\$\$\$stricken | pitilessness      | pity              | premonition      | presentiment      |
| ruthlessness        | scare             | scare\$\$\$away   | scare\$\$\$off   | self\$\$\$doubt   |
| shudder             | shy               | stage\$\$\$fright | suspense         | terrified         |
| terror              | timid             | timorous          | trepid           | unassertive       |
| unconcern           | uneasy            | unkind            | unsure           | worry             |
| <b>Happiness</b>    |                   |                   |                  |                   |
| blithe              | euphoria          | happy             | jubilant         | merry             |
| mirth               |                   |                   |                  |                   |
| <b>Jealousy</b>     |                   |                   |                  |                   |
| covet               | envy              | jealous           |                  |                   |
| <b>Love</b>         |                   |                   |                  |                   |
| adorable            | amatory           | amorous           | ardour           | beneficed         |
| beneficent          | beneficially      | benevolence       | calf\$\$\$love   | care              |
| charitable          | devotion          | enamour           | endearingly      | enjoy             |
| fond                | good\$\$\$hearted | kindly            | love             | loyalty           |
| openhearted         | puppy\$\$\$love   | romantic          | sympathy         | warmheartedness   |
| worship             |                   |                   |                  |                   |
| <b>Neutral</b>      |                   |                   |                  |                   |
| aloofness           | apathy            | detached          | dreamy           | emotionless       |
| impassive           | indifferent       | lackadaisical     | languor          | lassitude         |
| listlessness        | passionless       | stolidity         |                  |                   |
| <b>Pride</b>        |                   |                   |                  |                   |
| conceit             | congratulate      | egotism           | exult            | jubilant          |
| pride               | proud             | rejoice           | self\$\$\$esteem | self\$\$\$love    |
| self\$\$\$pride     | triumph           | vanity            |                  |                   |

Words relating to emotions in the study according to their emotional category, similar to Table S1. This table lists words for the emotion categories 6–11, in alphabetical order.

**Table S4.**

| <b>Sadness</b>     |                    |                      |                  |                      |
|--------------------|--------------------|----------------------|------------------|----------------------|
| aggrieve           | attrition          | bad                  | bereaved         | bereft               |
| compunction        | contrite           | deplorably           | desolation       | dismal               |
| distress           | doleful            | dolour               | dour             | drab                 |
| dreary             | forlorn            | glowering            | glum             | grief                |
| grief\$\$\$tricken | grievous           | guilt                | guilt\$\$\$trip  | guilty\$\$conscience |
| hangdog            | hapless            | heartache            | heartbreak       | heartrending         |
| joyless            | lamentably         | loneliness           | lowness          | melancholy           |
| misery             | misfortunate       | moody                | morose           | mourning             |
| pathetic           | penance            | penitent             | pity             | plaintive            |
| regret             | remorse            | repent               | sad              | saturnine            |
| self\$\$\$pity     | shame              | shamefaced           | somberness       | sorrow               |
| sour               | suffering          | sulk                 | sullen           | tearfulness          |
|                    |                    | world\$\$\$weariness |                  |                      |
| weepiness          | woe                | s                    | wretched         |                      |
| <b>Shame</b>       |                    |                      |                  |                      |
| abase              | abash              | ashamed              | awkward          | bashful              |
| chagrin            | confuse            | conscience           | discombobulation | discomfit            |
| discompose         | disconcert         | discredited          | disgraceful      | dishonourable        |
| embarrass          | guilt              | hangdog              | humble           | humiliate            |
| ignominious        | inglorious         | mortify              | opprobrious      | put\$\$\$off         |
|                    | self\$\$\$consciou |                      |                  |                      |
| scandalous         | s                  | self\$\$\$hatred     | shame            | shamefaced           |
| shameful           | sheepish           | shock                | uneasy           | unenviable           |
| upset              |                    |                      |                  |                      |
| <b>Surprise</b>    |                    |                      |                  |                      |
| admire             | amaze              | astonish             | astound          | awe                  |
| awful              | baffle             | besot                | bewilder         | dazed                |
| dumbfound          | dumbstruck         | flabbergasted        | flummox          | mystify              |
| nonplus            | perplex            | puzzle               | staggering       | stun                 |
| stupefy            | stupid             | surprise             | thunderstruck    | vex                  |
| wonder             |                    |                      |                  |                      |

Words relating to emotions in the study according to their emotional category, similar to Table S1. This table lists words for the emotion categories 12–14, in alphabetical order.

**Data S1.**

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