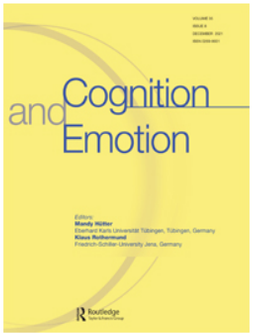

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Linear and non-linear relationships among the dimensions representing the cognitive structure of emotion

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ABSTRACT

While dimensional models play a key role in emotion psychology, no consensus has been reached about their number and nature. The current study sheds a new light on this central issue by examining linear and non-linear relationships among the dimensions in the cognitive emotion structure. The meaning of 80 emotion terms was evaluated on 68 features representing appraisals, action tendencies, bodily reactions, expressions, and subjective experiences by 213 English-speaking US, 156 French-speaking Swiss, and 194 Indonesian-speaking Indonesian students. In a two-dimensional valence and arousal representation, neither linear nor non-linear relationships were observed. In a four-dimensional valence, power, arousal, and novelty representation, both linear (e.g. a positive relationship between valence and power) and non-linear (e.g. a strong positive correlation between valence and power found only for positively valenced emotion terms) relationships were observed. Joy- and sadness-related emotion terms where about as well represented by the two- than by the four-dimensional representation. However, especially anger- and surprise-related terms were only adequately represented by the four-dimensional representation. These findings were generalisable across the three languages. Even though a two-dimensional structure fits the data well in general, four dimensions are needed to sufficiently represent the cognitive structure of the whole gamut of human emotions.

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Cognitive emotion structure; valence; arousal; power; novelty

Dimensional emotion models, which represent variation in the emotion domain in terms of quantitative differences along a few dimensions, play a central role in emotion theorising, such as in the core affect theory of Russell (e.g. Russell, 2003), as well as in both fundamental research, such as on the role of valence and arousal in picture processing (e.g. Olofsson et al., 2008) and applied research, such as on positive and negative affect leading to job performance in the workplace (e.g. Kaplan et al., 2009). Despite the central role of the dimensional approach in emotion research, and psychological research in general, it is surprising that so far no consensus has been reached on the optimal dimensional representation of the emotion domain, allowing a satisfactory degree of differentiation of major emotion terms in different languages. Here, we revisit this long-standing issue by studying linear and non-linear relationships among four dimensions that represent the cognitive emotion structure in three languages (English, French, and Bahasa Indonesia).

Both universalistic biological approaches to emotion (such as Ekman's basic emotion theory, e.g. Ekman & Cordaro, 2011) and relativistic constructivist approaches to emotion (like the conceptual act theory of Feldman Barrett, 2014) expect that the cognitive emotion structure represents fundamental characteristics of the actual emotion domain. According to the universalistic biological model, emotion processes form a part of our biological heritage and result from a phylogenetic evolution. According to this approach, emotions exist before and are independent of

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language and self-consciousness. Emotion processes that are salient in daily functioning are likely to get encoded in language, allowing to differentiate classes of emotion. This lexical approach, also referred to as "sedimentation hypothesis", has also been proposed for personality trait taxonomy (e.g. John et al., 1988). Therefore, the cognitive representation of the emotion domain in terms of verbal labels should mirror fundamental emotional processes. Theoretically, the relativistic constructivist approach is very different from, and in many ways opposite to, the universalistic biological approach. According to the relativistic constructivist approach, emotional processes are the result of meaning-making. Based on pre-existing conceptual knowledge people actively construct their emotional experiences. The relativistic constructivist approach thus reverses the causality: conscious emotional experiences are, at least in part, the result of pre-existing cognitive schemas. A third theoretical tradition, appraisal theory, considers the emergence of feelings and conscious cognitive representation and verbal labelling of emotional experiences, as the outcome of multicomponential processes (involving neurophysiological reactions and motor expression) steered by recursive event appraisals (e.g. Scherer, 2009). Despite important differences among these theoretical traditions, their adherents are most likely to agree on the central importance of the cognitive representation of the resulting emotional experiences and the major role of verbal labelling, essential for emotional sharing via communication. In addition, empirical research on emotion heavily relies on self-reported labelling. Because of this central role, studying the cognitive representation of the emotion domain offers an excellent way to investigate the dimensional structure of the emotion domain. Two-, three-, and four-dimensional representations have been proposed for the cognitive representation of the emotion domain and for each of these representations, there is robust empirical evidence.

Two-dimensional models (valence-arousal)

After first identifying valence and arousal in the cognitive structure in the US (Russell, 1980), Russell and colleagues have identified the same two-dimensional structure in other both western and non-western cultural groups (Russell et al., 1989). Moreover, two-dimensional models have a pre-eminent position in affect and mood models. Several established affect models support a two-dimensional structure both conceptually and empirically: (1) the positive affect – negative affect model of Watson and Tellegen (1985), which assumes that two rather uncorrelated unipolar dimensions, representing negative valence and positive valence, structure the affective domain, (2) the pleasantness-activation model of Larsen and Diener (1992), which differentiates a bipolar negative versus positive valence dimension from a bipolar low versus high arousal dimension, and (3) the tense arousal-energetic arousal model of Thayer (1998), which identifies two different arousal dimensions in the affective domain. Yik and colleagues (Yik et al., 1999) have demonstrated that these three common affect models are psychometrically equivalent with the valence-arousal model of Russell (1980). More recently, Yik et al. (2011) demonstrated that 30 different mood scales could be very well integrated into the valence-arousal model.

Three-dimensional models (valence-power-arousal)

The landmark study of Shaver et al. (1987) identified the three dimensional valence-power-arousal structure in the cognitive representation in the emotion domain in an Anglo-Saxon sample. Using the same methodology of this original study the same three dimensional structure emerged also in other western and non-western cultural groups. This structure could be identified in Italian and in Chinese (Shaver et al., 1992) and in Indonesian (Fontaine et al., 2002). Moreover, this three-dimensional structure mirrors the three connotative meaning dimensions of evaluation, potency, and activation that have been identified when participants are asked to evaluate a representative set of nouns on a representative set of bipolar adjectives that are typical for a language (Osgood et al., 1957). These dimensions were later robustly observed across other Western and non-Western languages (Osgood et al., 1975). Moreover, Mehrabian (1972) also identified these three dimensions in nonverbal communication.

Four dimensional models (valence-power-arousal-novelty)

While most research on the cognitive representation of the emotion domain was done with a similarity paradigm, where participants were either asked to directly rate the similarity between pairs of emotion terms or to sort emotion terms in piles according to their similarity (e.g. Shaver et al., 1987), the four-

dimensional model was identified on the basis of Scherer's (2005) proposal to study the semantic feature profiles of emotion terms. A new assessment method for identifying the meaning of emotion terms – the GRID instrument – was developed (Fontaine et al., 2007). Based on the componential approach to emotions, 142 emotion features were identified representing typical appraisals, action tendencies, bodily reactions, expressions, and feelings that people can have when they experience emotions. Moreover, 24 commonly used, prototypical emotion terms that represent the variability in the emotion domain were selected. Participants have to rate the likelihood that each of these 142 features form a part of the meaning of four randomly selected emotion terms from the set of 24 terms. The contribution of the GRID instrument for studying the cognitive representation of emotion terms is that it allows both to identify the relationships between emotion terms (based on their respective feature profiles) and to identify which emotion features account for these relationships. Using this new instrument, Fontaine et al. (2007) found four dimensions that structure the cognitive representation of emotion domain in three Western languages (English, French, and Dutch). Next to valence (pleasantness/evaluation), power (potency), and arousal (activation), an unpredictability or novelty dimension was identified. This new novelty dimension predominantly (but not exclusively) differentiated surprise-related emotion terms from the other emotion terms.

In an extensive cross-cultural research project using the GRID instrument with 31 additional samples, stemming from 24 additional countries, and representing 20 additional languages (such as Chinese and Japanese), the four-dimensional valence, power, arousal, novelty structure was confirmed (Fontaine et al., 2013). Moreover, recent research demonstrated that the emergence of the novelty dimension does not depend on the specific emotion features or the specific emotion words that were selected for the GRID instrument, as a similar four dimensional structure, including novelty, also emerged in similarity rating research in which the pairwise similarities between the emotion terms were reliably identified (Veirman & Fontaine, 2015). The same structure also emerged with a shortened version of the GRID instrument (the CoreGRID; Scherer & Fontaine, 2013) when investigating the meaning of 80 emotion terms, which allow a more representative mapping of the emotion domain (Gillioz et al., 2016).

Relevance and representativeness

A scientifically trivial account for the differences in dimensionality between the three models can be found in the selection of the emotion terms. Already Gehm and Scherer (1988) suggested that research often fails to identify the power dimension because emotion terms implying high control (such as anger terms) are underrepresented whereas arousal variation is overrepresented. In 1991, Russell hypothesised that if predominantly intra-personal emotion terms are included in a study, a valence-arousal structure is likely to emerge (Russell, 1991). Thus, for identifying the optimal dimensional representation of the emotion domain, it is necessary to work with a relevant and representative sample of emotion terms selected independently from the expected dimensional structure.

To the extent that a lack of relevance and representativeness of the emotion terms can be excluded as an account for the differences between the models, these differences should reveal genuine, valid information about the cognitive organisation of the emotion domain: It would mean that the valence and arousal dimensions are psychologically the two most salient dimensions in the emotion domain, as they are identified across the three different dimensional emotion models described above (hypothesis 1).

Higher-order dimensions

If valence and arousal are indeed the two most salient dimensions in the emotion domain, then the question arises what the role of the power and novelty dimensions is in representing the emotion domain. One possibility is that the power and novelty dimensions are simply two additional, uncorrelated, and less salient dimensions. However, this is not the only possible account. Another account is that the valence-arousal model can be considered an higher-order model that emerges because of linear, and possibly non-linear, relationships between four more specific dimensions that are needed to best capture the variation in the emotion domain. While this latter account has never been investigated in research on the cognitive representation of the emotion domain, three lines of research suggest that the latter could indeed be the case. First, there is the long-standing tradition that investigates possible relationships between valence and arousal in emotional experiences (e.g. Kuppens et al., 2013). Second is the study of affective reactions

to the International Affective Picture System (IAPS) investigating valence, arousal, and dominance (Lang et al., 1999). Third, building on Osgood's seminal work (Osgood et al., 1975), is the research tradition that investigates the affective meaning of words on the dimensions of valence, arousal, and dominance (e.g. Warriner et al., 2013). Across all three research traditions, one linear and one non-linear relationship have been robustly identified. A substantial positive linear relationship has been found between valence and dominance both in the affective reactions to the IAPS pictures (e.g. Lang et al., 1999; Scherer et al., 2006) and in the affective meaning of words (e.g. Warriner et al., 2013). Conversely, a V-shaped relationship between valence and arousal has been found in emotional experiences (e.g. Kuppens et al., 2013), affective reactions to the IAPS pictures (e.g. Kuppens et al., 2013), and in the affective meaning of words (e.g. Warriner et al., 2013). The V shape indicates that the more experiences, pictures, and words tend to deviate from a neutral position on the valence dimension, the more they tend to elicit high arousal.

In the current study, it will be investigated whether the strong positive linear relationship between valence and power (Hypothesis 2a), and the non-linear V-shaped relationship between valence and arousal (Hypothesis 2b) can also be found in the cognitive representation of the emotion domain using a relevant and representative set of emotion terms. Additionally, other linear (Research Question 2a) and non-linear relationships (Research Question 2b) will be explored.

A bird versus a frog perspective on dimensional representations

The gain in accuracy by representing the data with a more complex model compared to a simpler one, is typically evaluated across all emotion terms. However, the overall accuracy or increase in accuracy may not hold for specific emotions, or even for whole emotion subdomains. Therefore, it is also interesting to investigate how well the position of individual emotion terms and emotion subdomains is mirrored by a specific dimensional representation. To use a metaphor here, a two-dimensional map of a country represents the distances between cities in that country very well. However, there will be a difference in fit for flat and mountainous areas of the country, with the distances being very well represented for flat areas, and being much less well represented for mountainous areas. The latter distances would be much better represented by a three-dimensional model. Thus, to have a full understanding of the difference between a two- up to a four-dimensional representation of the emotion domain, it is not only important to look at the overall difference in fit between models, but it is also needed to compare how well individual emotion terms and possibly subdomains are represented by these models (Research Question 3).

Robustness and replicability

While there is a general concern for replication in psychological research, there is especially an issue with the replicability of non-linear (and/or interaction) effects (McClelland & Judd, 1993; Open Science Collaboration, 2015). Therefore, we investigate the robustness and replicability of the findings by investigating them in three independent linguistic groups, namely in Swiss French, US English and Indonesian Bahasa Indonesia speakers. US English represents the Germanic language family, Swiss French represents the Romance language family, and Bahasa Indonesia represents the Austronesian language family. The US English and the Swiss French samples represent a Western cultural context and the Indonesian sample represents a non-Western cultural context. Since it has been observed in the literature that when the same research methodology is used, also the same dimensional structure emerges across languages, it is expected that linear and non-linear relationships that are hypothesised to account for the differences between the dimensional emotion models, as well as subdomain differences in the fit with which they are represented will be generalisable across the three languages (Hypothesis 4).

Method

Participants

In total, 156 French-speaking students from the University of Geneva in Switzerland (39 males, mean age = 23.05 years),[1] 213 English-speaking students from the University of California, San Diego, USA (89 males, mean age = 20.34 years), and 194 Indonesian-speaking students from the Universitas Negeri Jakarta, the Binus University, and the Universitas Persada Indonesia (56 males,[2] mean age = 19.87

years) took part in this study. The Swiss participants were paid 15 CHF (approximately 15 USD), the US participants got course credits in exchange of their participation, and the Indonesian participants did not receive any reward for their participation. All participants gave their consent to the study. The research was executed according to the ethical standards of the University of Geneva and got ethical approval by the Human Research Protection Programme of the University of California, San Diego, USA.

Materials

The CoreGRID instrument. The CoreGRID instrument is a short version of the full GRID instrument that was used in previous research (Fontaine et al., 2007, 2013), comprising an empirically-based selection of 68 of the original 142 features used in the GRID instrument representing all five emotion components (10 features for Feelings, 11 for Bodily Reactions, 12 for Expressions, 14 for Action Tendencies, and 15 for Appraisals) (for further details see Scherer & Fontaine, 2013).

Emotion terms. Lists of 80 emotion terms (only nouns) were constructed in each language by adding 56 emotion terms to the 24 already used in the GRID study (Fontaine et al., 2007). The original 24 emotion terms constitute a representative set of emotion terms, and were carefully translated from English in French and Bahasa Indonesian using translation-back-translation and committee approaches. The additional 56 emotion terms were selected in each language separately on the basis of (1) psychologically evaluated prototypicality for the concept of "emotion"; (2) psychologically evaluated prototypicality with respect to the concepts of everyday emotions, aesthetic emotions, moods, emotional attitudes, and affective dispositions; and when available (3) linguistic information about the frequency of use and (4) the cooccurrence of the emotion word with the word "emotion" in extensive linguistic corpuses. See supplemental material for a detailed description of the selection of a relevant and representative set of emotion words in each of the three languages.

Procedure

In each of the languages, the set of 80 emotion terms was divided into eight sets of 10 terms, in such a way that there was large variability between the 10 terms of a single set. Participants completed the CoreGRID questionnaire in their native language using a web-based questionnaire format. Each participant had to rate the likelihood of 68 component features for 10 emotion words by using a 9-point scale ranging from 1 (extremely unlikely) to 9 (extremely likely). The following instructions were presented: "If a speaker of your native language as spoken in your country or region uses the following emotion words to describe an emotional experience, how likely is it that … "

Data analyses

The analyses were executed on the average feature scores per emotion term. Before computing these averages, participants whose feature profile correlated less than .20 with the average feature profile of the other participants were removed per emotion term. They were considered to have a too idiosyncratic interpretation of the meaning of the emotion term to contribute to identifying the shared meaning of that term. On average 1.89% of the Swiss participants, 5.33% of the USA participants, and 6.75% of the Indonesian participants were removed for this reason before computing the average feature scores per emotion term. The average feature scores per emotion term were eventually computed on the basis of on average 19.14 participants in the Swiss sample, 25.36 participants in the USA sample, and 22.65 participants in the Indonesian sample. The reliability (Cronbach's alpha) of the feature profile per emotion term was on average .94 in the Swiss sample, .95 in the USA sample, and .92 in the Indonesian sample.

For further analyses, the units of observation are the 80 emotion terms and the variables are the 68 emotion features. As in the previous studies using the GRID approach, the internal structure of the emotion domain was analysed using Principal Component Analyses (PCA) (Fontaine et al., 2007, 2013; Gillioz et al., 2016). PCA is a reduction technique that makes no assumptions of underlying latent variables that would "cause" the observed emotion structure (as exploratory factor analysis does). PCA fits very well the theoretical assumption of the componential emotion approach, on which the CoreGRID is based. This assumption is that an emotion is a complex process consisting of an interplay between cognitive, motivational, bodily, expressive, and affective processes. Internal constraints in how these components interact are supposed to limit the complexity of the emotion domain. Thus, according to the componential

emotion approach, a low dimensional representation of the emotion domain is an emergent property of a domain characterised by complex underlying processes. The principal components that are generated by PCA will systematically be referred to as "dimensions" in the remainder of the text to avoid confusion with the concept of "emotion components" from the componential emotion approach.

Since the data stem from three different languages, three different PCAs were run to identify each sample structure. In addition, a Simultaneous Component Analysis (SCA) was applied in order to identify a common structure for the three samples at once. SCA is a principal component analysis for variables that have been measured in two or more samples (e.g. Kiers & Ten Berge, 1989). The principal components are computed as the same linear combination of the observed variables in each of the samples in such a way that the variance accounted for across the samples is maximal. Both the SCA and the PCA analyses have been executed with the stand-alone programme MultiBlock Component Analysis (MBCA) (De Roover et al., 2012; https://ppw.kuleuven.be/okp/software/MBCA/). The congruence between the sample-specific structures resulting from the three PCA analyses and the overall structure resulting from the SCA has been compared in three different ways. First, the proportion of variance accounted for by the common structure is compared with the proportion of variance accounted for by language-specific structures. Second, the congruence is computed between the pattern of feature loadings on each of the dimensions in the common structure and the pattern of feature loadings on each of the dimensions in the language-specific structures after (oblique) Procrustes rotation. Following the standard practice in the literature, the congruence measure (Tucker's phi) of .85 is considered fair, of .90 good, and of .95 excellent (e.g. Fischer & Fontaine, 2010; Lorenzo-Seva & ten Berge, 2006). Finally, the coordinates of the 80 emotion terms in each language in the common structure are correlated with the coordinates of these emotion terms in the sample-specific structures after (oblique) Procrustes rotation. These coordinates are computed as the principal component scores of the emotion terms on the two or four principal components generated by the PCA or SCA analyses.

Results

The issue of cross-cultural comparability affects all other research questions and hypotheses. In the absence of cross-cultural similarities, each of the research questions and hypotheses would have to be investigated separately for each cultural group. Therefore, cross-cultural comparability is investigated first when addressing each of the hypotheses.

The two-dimensional representation of the emotion domain

To investigate the central hypothesis that valence and arousal are the most salient dimensions in the cognitive representation of the emotion domain, the analyses start with investigating the cross-cultural comparability of the two-dimensional structure. First, the fit of one- up to nine-dimensional structures is compared. Specifically, one single common structure (computed with SCA across all three groups), and three group-specific structures (computed with PCA separately in each group) were obtained (see Table 1 for the percentages of variance accounted for one- up to nine-dimensional structures, and see Supplemental Material Figure 7 for a visual representation of the Scree Plot of the SCA analysis). In the common as well as in the three language-specific component structures, there is a clear drop in the additional variance accounted for after the second dimension, indicating the presence of two major dimensions. The single common two-dimensional representation accounted for 67.90%, while three separate two-dimensional configurations accounted for 70.42% of the total variance across the three samples. Thus, only 2.52% of the information was lost by working with a single common, rather than three group-specific configurations.

The correlations between the two dimensions with an oblique rotation were very small, not consistent, and not significant ($r = -.13$ in the common structure, $r = -.06$ in the English structure, $r = -.14$ in the French structure, and $r = .15$ in the Indonesian structure). Therefore, the comparability of the two-dimensional structure was further investigated only for the orthogonal model. The two-dimensional culture-specific structures were orthogonally Procrustes rotated to the common two-dimensional orthogonal structure. There was an excellent congruence between the feature loadings in the common structure and in the group-specific structures. For English, the Tucker's phi was .99 and .98, for French they were .99 and .98, and for Indonesian they were .99 and .95, for the first and the second dimension respectively. The position of the 80 emotion terms on the common

Table 1. Percentages of variance accounted for of one- up to nine-dimensional structures for common structures computed with SCA and group-specific structures computed with PCA.

		Dimensionality								
Analysis	Group	1	2	3	4	5	6	7	8	9
SCA	Common[a]	48.98	67.90	74.29	78.70	81.14	82.59	83.85	84.83	85.73
	English[b]	48.57	71.94	77.79	81.39	83.13	84.39	85.75	86.80	87.49
	French[b]	48.08	68.66	75.85	80.04	82.33	83.89	85.23	86.38	87.29
	Indonesian[b]	50.28	63.12	69.22	74.68	77.96	79.50	80.58	81.31	82.42
PCA	Common[a]	50.10	70.42	77.35	82.43	85.25	87.08	88.55	89.78	90.83
	English[b]	49.31	73.79	80.02	84.07	86.53	88.26	89.65	90.86	91.77
	French[b]	49.29	70.82	78.49	83.19	85.79	87.69	89.19	90.35	91.38
	Indonesian[b]	51.70	66.65	73.55	80.02	83.42	85.29	86.81	88.13	89.35

[a]Total percentage of variance accounted for across the three groups.
[b]Total percentage of variance accounted for per group.

dimensions and on the sample-specific dimensions (after orthogonal Procrustes rotations) was also virtually identical (see also Supplemental Material Table 1 for the coordinates of the 80 emotion terms in each of the three groups in the common two-dimensional structure). In all three groups and for both dimensions, the coordinates of the emotion terms on the common and the group-specific dimensions correlated .99 or more. It can be concluded that the two-dimensional model was highly comparable between the three samples. It is thus justified to represent the two-dimensional structure across the three samples by a single common structure.

On the first dimension, features like "wanted to undo what was happening", "bad", and "the event had negative, undesirable consequences for the person" had negative loadings and features like "good", "the event was pleasant for the person", and "wanted the ongoing situation to last or be repeated" had positive loadings (see Table 2). Moreover, negatively and positively valenced emotion terms were clearly opposed on this dimension, with terms such as pride and relaxation having positive coordinates and terms such as fury and depression having negative coordinates. On the second dimension features like "slowed heart rate", "slowed breathing" and "spoke more slowly" loaded negatively and "muscles tensing", "rapid heart rate", and "spoke more rapidly" loaded positively. On this dimension, low arousal terms such as relaxation and boredom had negative coordinates, while to high arousal terms such as thrill and outrage had positive coordinates. The coordinates of the English emotion terms in the common two-dimensional structure are represented in Figure 1 (and the coordinates of the French and Indonesian emotion words in the common structure are represented in Supplemental Material Figures 1 and 2 respectively). Thus, both the feature loadings and the emotion term coordinates justified an interpretation of the two most salient dimensions in terms of valence and arousal, confirming the first hypothesis. Moreover, these dimensions are highly comparable between the three cultural-linguistic groups confirming hypothesis 4.

The four-dimensional representation of the emotion domain

As shown in Table 1, compared with the 78.70% of the total variance that was represented by a common four-dimensional structure, 82.43% of the total variance could be represented by three separate four-dimensional structures.[3] Thus, 3.73% of the total variance was lost by working with one common compared to three separate four-dimensional structures.

Since there were substantial correlations between the dimensions in the common structure with oblique rotation (correlations being as high as .65), the common oblique structure was taken as a point of reference. The group-specific structures were obliquely Procrustes rotated towards the common oblique structure. There was good to excellent congruence between the feature loadings in the common structure and in the group-specific structures after these oblique Procrustes rotations. For English, the Tucker's phi's were .98, .95, .97, and .96, for French they were .98, .96, .97, and .94, and for Indonesian they were .97, .93, .94, and .91 for the first up to the fourth dimension respectively. Also, the coordinates of the 80 emotion terms on the common dimensions and the group-specific dimensions (after oblique Procrustes rotation) were highly comparable (see also Supplemental Material Table 2 for the coordinates of the 80 emotion terms in each of the three countries in the common four-dimensional structure). For English the coordinates correlated .99, .99, .99, and

Table 2. Feature loadings in a two-dimensional VARIMAX rotated common structure with SCA and in two-dimensional group-specific structures with PCA after orthogonal procrustes rotation.

	Group							
	Common		English		French		Indonesian	
Feature	V	A	V	A	V	A	V	A
Wanted the ongoing situation to last or be repeated	**.97**	.02	.97	.04	.96	−.03	.97	.06
The event was pleasant for the person	**.97**	.02	.97	.05	.96	−.02	.97	.02
Good	**.97**	.00	.97	.04	.97	−.02	.96	−.02
Smiled	**.96**	.01	.97	.06	.96	−.05	.96	.03
Wanted to sing and dance	**.94**	.04	.95	.09	.95	.01	.93	.04
He person could live with the consequences of the event	**.92**	−.06	.93	−.04	.88	−.09	.95	−.06
The event confirmed the expectations of the person	**.92**	−.08	.88	−.19	.94	−.07	.93	.00
The person could control the consequences of the event	**.91**	−.08	.87	−.05	.94	−.10	.92	−.10
Strong	**.87**	.21	.84	.28	.91	.24	.87	.10
The event was important for and relevant to the person's goals or needs	**.87**	.08	.83	.17	.90	−.01	.86	.07
The person had power over the consequences of the event	**.86**	−.03	.83	−.02	.91	.02	.83	−.10
Calm	**.80**	−.45	.78	−.52	.68	−.64	.93	−.19
The person had a dominant position in the situation	**.79**	.18	.87	.13	.90	.11	.61	.29
The event was important for and relevant to the goals or needs of someone else	**.78**	.04	.64	.08	.83	.02	.85	.01
There was no urgency in the situation	**.70**	−.38	.63	−.61	.80	−.33	.69	−.19
The event had consequences that were predictable	**.64**	−.29	.62	−.46	.58	−.35	.72	−.09
Awake	**.62**	.53	.53	.72	.58	.70	.75	.17
Feeling warm	**.57**	.46	.78	.41	.23	.78	.69	.20
Wanted to comply to someone else	**.42**	−.16	.67	−.20	.03	−.36	.55	.10
The event was caused by the person's own behavior	**.20**	−.12	.27	−.19	.34	−.22	−.01	.07
Restless	**−.57**	.48	−.64	.47	−.18	.88	−.90	.09
Had tears in the eyes	**−.58**	−.23	−.70	−.03	−.54	−.32	−.50	−.32
Wanted to do nothing	**−.66**	−.51	−.57	−.68	−.54	−.58	−.87	−.28
Had speech disturbances	**−.69**	.47	−.66	.64	−.73	.44	−.68	.33
Wanted to oppose	**−.70**	.34	−.66	.32	−.64	.38	−.80	.31
Feeling weak limbs	**−.77**	−.09	−.71	−.07	−.81	−.15	−.79	−.05
Spoke in a trembling voice	**−.80**	.25	−.83	.36	−.86	.12	−.70	.27
The event was uncontrollable	**−.80**	.45	−.80	.43	−.83	.41	−.77	.51
Tired	**−.80**	−.26	−.73	−.50	−.77	−.31	−.90	.02
Wanted to hand over the initiative to someone else	**−.80**	−.12	−.85	−.28	−.84	−.11	−.72	.03
Wanted to damage, hit or say something that hurts	**−.82**	.23	−.84	.22	−.74	.31	−.89	.18
Feeling cold	**−.83**	−.10	−.83	−.36	−.90	−.11	−.76	.17
The event involved the violation of laws or socially accepted norms	**−.83**	.29	−.79	.29	−.83	.31	−.88	.26
Lacked the motivation to pay attention to what was going on	**−.84**	−.19	−.83	−.22	−.75	−.34	−.92	.00
Frowned	**−.84**	.17	−.96	−.12	−.71	.27	−.84	.35
Stomach disturbance	**−.89**	.28	−.88	.33	−.92	.20	−.87	.32
Becoming pale	**−.90**	.06	−.87	.09	−.91	.02	−.91	.08
The event was inconsistent with the person's own standards and ideals	**−.90**	.17	−.92	.11	−.89	.16	−.89	.23
The person was powerless in the situation	**−.90**	.17	−.96	.05	−.96	.07	−.80	.37
Weak	**−.92**	−.19	−.94	−.18	−.94	−.15	−.87	−.25
Wanted to run away in whatever direction	**−.93**	.14	−.91	.22	−.94	.11	−.93	.11
Wanted to disappear or hide from others	**−.95**	−.12	−.94	−.15	−.94	−.11	−.97	−.12
Felt the urge to stop what he or she was doing	**−.96**	.05	−.97	.01	−.94	.19	−.96	−.05
The event had negative, undesirable consequences for the person	**−.97**	.09	−.98	.04	−.96	.09	−.96	.14
Bad	**−.97**	−.02	−.97	−.06	−.98	.00	−.95	−.02
Wanted to undo what was happening	**−.97**	.02	−.97	−.02	−.96	.03	−.97	.05
Spoke more rapidly	.16	**.92**	.20	.93	.10	.93	.17	.91
Rapid heart rate	−.12	**.91**	.01	.95	−.17	.89	−.21	.88
Rapid breathing	−.22	**.90**	−.13	.93	−.27	.88	−.26	.88
Spoke more loudly	.21	**.86**	.24	.87	.31	.84	.09	.88
Muscles tensing	−.50	**.82**	−.44	.84	−.52	.82	−.54	.80
Sweating	−.46	**.75**	−.37	.80	−.45	.76	−.56	.69
Raised the eyebrows	.17	**.73**	.26	.82	.19	.58	.05	.80
The event occurred suddenly	−.23	**.70**	−.23	.81	−.27	.72	−.17	.58
The event required an immediate response	−.38	**.69**	−.38	.80	−.37	.79	−.43	.45
Spoke in a firm voice	.33	**.58**	.15	.42	.55	.64	.30	.66
The event happened by chance	.00	**.58**	.07	.64	−.08	.59	.02	.51
The event was unpredictable	−.43	**.57**	−.43	.67	−.53	.57	−.31	.49
Felt the emotion very intensely	−.13	**.50**	−.20	.65	−.09	.65	−.12	.19

(*Continued*)

Table 2. Continued.

	Group							
	Common		English		French		Indonesian	
Feature	V	A	V	A	V	A	V	A
Had the jaw drop	.10	**.48**	.23	.72	−.18	.27	.26	.44
The event was caused by somebody else's behavior	−.30	**.45**	−.37	.46	−.26	.40	−.27	.47
Wanted to overcome an obstacle	−.12	**.39**	−.03	.50	−.09	.40	−.25	.24
Wanted to tackle the situation	.14	**.37**	.51	.59	.49	.43	−.57	.08
Felt the emotion for a long time	−.10	**−.30**	−.21	−.44	.03	−.37	−.13	−.12
Closed the eyes	−.56	**−.58**	−.58	−.52	−.54	−.59	−.56	−.64
Spoke more slowly	−.25	**−.80**	−.25	−.90	−.13	−.87	−.37	−.63
Slowed breathing	.14	**−.82**	.15	−.93	.30	−.84	−.01	−.69
Slowed heart rate	.16	**−.88**	.12	−.94	.20	−.86	.17	−.82

Note. V = Valence; A = Arousal.

.99, for French they correlated .99, .99, .99, and .99, and for Indonesian they correlated .99, .98, .99, and .96 for the four respective dimensions. It can thus be concluded that all three indicators of fit of the overall four-dimensional model (proportion of variance accounted for, congruence of the patterns of feature loadings, and correlation of the coordinates of emotion terms) pointed in the same direction: The overall structure was highly similar to the group-specific structures, which further confirmed hypothesis 4. This also justified to continue working with the overall four-dimensional structure as a reference point.

On the first dimension features like "wanted to oppose" and "the event was inconsistent with the person's own standards and ideals" loaded negatively and features like "smiled" and "wanted to sing and dance" loaded positively (see Table 3). Emotion terms like "frustration", "horror", and "grief" had negative coordinates, while terms like "happiness", "satisfaction", and "enthusiasm" had positive coordinates. On the second dimension, there were negative loadings for features like "closed the eyes" and "feeling weak limbs" and positive loadings for "spoke in a firm voice" and "wanted to tackle the situation". Here, emotion terms like "pride" and "anger" had positive coordinates, while terms like "sadness" and "depression" had negative coordinates. The plot of the English emotion terms on these two dimensions are shown in Figure 2 (and in Supplemental Material Figure 3 for the French and Figure 4 for the Indonesian emotion terms). The third dimension was characterised by features like "rapid heart rate" and "rapid breathing" versus "slowed breathing" and "slowed heart rate", and opposed terms like "relaxation" and "boredom" to terms like "panic" and "rage". On the fourth dimension features like "experienced the emotion for a long time" and "the event was caused by the person's own behaviour" loaded negatively, while features like "had the jaw drop" and "the event happened by chance" loaded positively. On this dimension terms like "regret" and "pride" were opposed to "shock" and "surprise". The coordinates of the English emotion terms on these two dimensions are shown in Figure 3 (and in Supplemental Material Figure 5 for the French and Figure 6 for the Indonesian emotion terms). The feature loadings and the coordinates of the emotion terms in the common structure justified to interpret the four dimensions as valence, power, arousal, and novelty respectively. In the common structure, valence accounted for 47.63%, power for 30.66%, arousal for 23.92%, and novelty for 9.23% of the total variance (note that as the dimensions were correlated these contributions were not independent from one another).

Linear relationships between the four dimensions

Clear evidence was found for linear relationships between the four dimensions, more specifically three relationships were significant in the common and the culture-specific configurations (see Table 4 and Figures 2 and 3 and in Supplemental Material Figures 3–6). As predicted by hypothesis 2a there was a strong positive correlation between valence and power. Moreover, a moderate to small negative correlation between valence and arousal, and a moderate to small positive correlation between arousal and novelty (although this latter correlation was not significant in the Indonesian sample) were observed. By and large, the linear relationships were observed in each of the three cultural groups further confirming hypothesis 4.

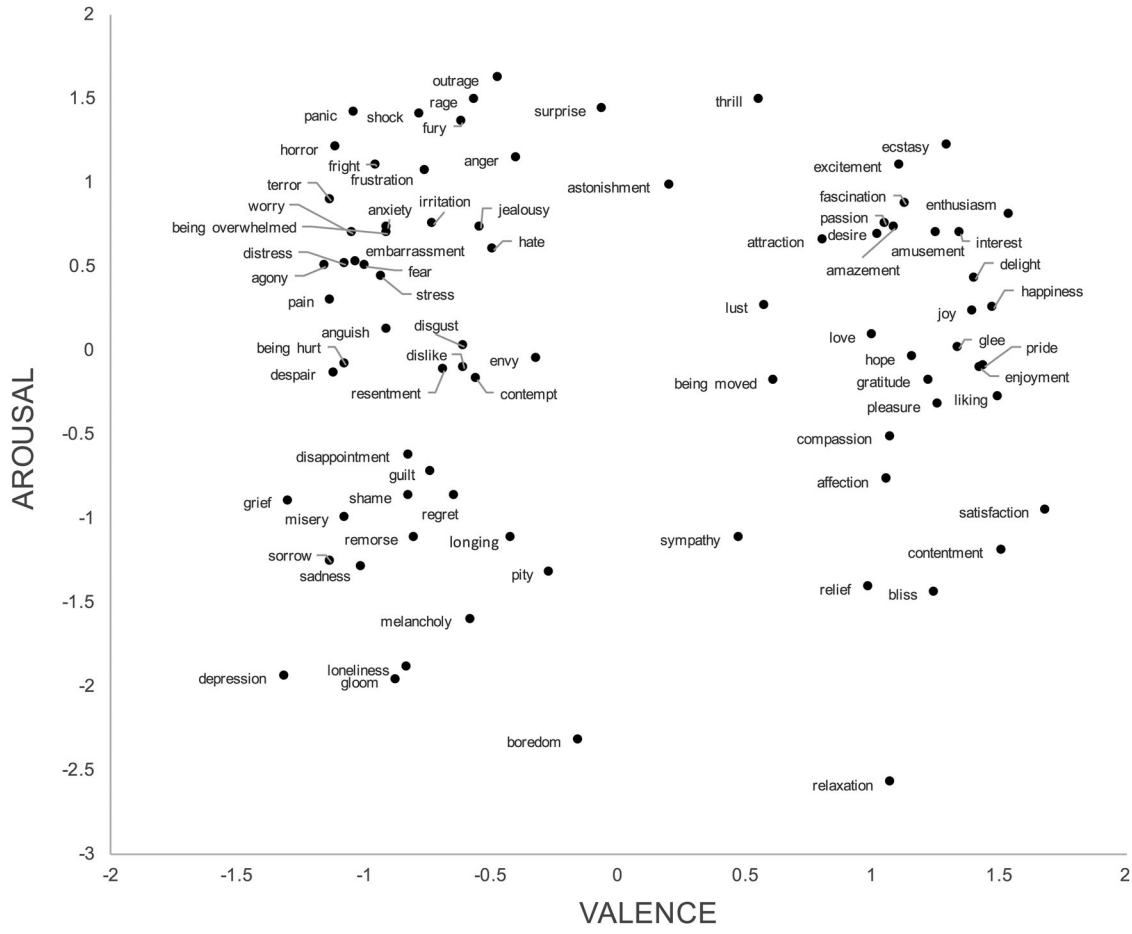

Figure 1. Coordinates of English emotion terms on Valence and Arousal in the common two-dimensional representation.

To investigate the relationships between the two- and the four-dimensional representations, the coordinates of the emotion terms on all dimensions were correlated (see Table 5). Both in the common and the group-specific representations it was observed that the two-dimensional valence dimension related predominantly to the four-dimensional valence, but also to the four-dimensional power dimension. The two-dimensional arousal dimension is related predominantly to the four-dimensional arousal dimension, but related also to the four-dimensional novelty and power dimensions.

Non-linear relationships between the four dimensions

Non-linear relationships between the four-dimensions were investigated by testing the difference in correlations between a dimension and the other three dimensions separately for the 50% lowest and 50% highest scoring terms on that dimension (see Tables 6–9). Moreover, the meaning of these interaction effects was further explored by visually inspecting the pairwise plots of the dimensions (see Panels 1–12 of Figure 4). Three of the non-linear relationships were significant in both the common and at least two of the three group-specific configurations. Some of the other effects were also significant, but because they were small and not well generalisable, they will not be further discussed here.

While there was clear evidence for non-linear relationships, the predicted non-linear V-shaped relationship between valence and arousal was not observed as predicted in hypothesis 2b (see Table 6).[4] The strongest effect was the interaction-effect between valence and power (see Table 6 and Panel 1 of Figure 4). For emotion terms that are low in valence, there was no (or only a small) relationship

Table 3. Feature loadings in a four-dimensional obliquely rotated common structure with SCA and in four-dimensional group-specific structures with PCA after oblique Procrustes rotation.

	Group															
	Common				English				French				Indonesian			
Feature	V	P	A	N	V	P	A	N	V	P	A	N	V	P	A	N
Smiled	**1.02**	−.03	.07	.04	.99	.01	.04	.05	1.01	−.02	.01	.06	.98	.03	.07	.02
The event was pleasant for the person	**1.02**	−.02	.06	.05	.99	.00	.04	.05	1.01	.00	.04	.06	.97	.04	.05	.06
Wanted to sing and dance	**1.02**	−.02	.13	−.01	.98	.01	.09	.02	1.02	−.02	.11	.00	.97	.04	.11	−.02
Good	**1.02**	−.02	.06	.03	.97	.03	.00	.07	.98	.04	.02	.04	1.02	−.03	.06	−.02
Wanted the ongoing situation to last or be repeated	**1.00**	.01	.07	.03	.95	.04	.01	.05	1.00	.01	.04	.04	.97	.07	.09	.01
The event was important for and relevant to the person's goals or needs	**.99**	−.03	.28	−.23	.84	.10	.30	−.25	.96	−.01	.15	−.17	1.00	.00	.26	−.23
Wanted to comply to someone else	**.97**	−0.62	.26	−.20	1.07	−.51	.05	−.03	.49	−.61	.16	−.53	1.03	−.48	.36	.05
The event confirmed the expectations of the person	**.91**	.03	.02	−.12	.75	.14	−.13	−.19	.98	−.02	.04	−.04	.95	.07	.10	−.13
The person could live with the consequences of the event	**.86**	.08	−.02	−.06	.89	.05	−.05	−.01	.79	.11	−.07	−.03	.86	.16	−.02	−.12
The event was important for and relevant to the goals or needs of some someone else	**.83**	.01	.19	−.19	.62	.10	.20	−.24	.71	.18	.03	−.09	.97	−.02	.18	−.20
The person could control the consequences of the event	**.80**	.14	.00	−.18	.87	.05	.14	−.32	.78	.18	−.03	−.21	.81	.15	−.08	−.07
Awake	**.79**	.06	.59	.02	.63	.10	.64	.14	.67	.21	.65	.17	.91	.02	.35	−.21
Calm	**.73**	−.07	−.40	−.01	.63	.03	−.58	.05	.58	−.10	−.63	.07	.93	.00	−.09	−.12
The person had a dominant position in the situation	**.73**	.20	.31	−.31	.77	.22	.29	−.39	.49	.51	.02	−.24	.85	.01	.53	−.29
The person had power over the consequences of the event	**.73**	.19	.07	−.28	.78	.12	.16	−.38	.66	.32	.02	−.24	.76	.16	−.01	−.24
Feeling warm	**.63**	.16	.55	−.15	.50	.47	.27	−.07	.31	.23	.83	−.15	.93	−.08	.42	−.20
There was no urgency in the situation	**.57**	.02	−.36	−.05	.48	−.01	−.63	.00	.53	.19	−.39	−.05	.69	−.03	−.12	−.06
Strong	**.56**	.46	.11	−.10	.42	.59	.05	−.02	.49	.57	.05	−.04	.79	.27	.18	−.24
The event had consequences that were predictable	**.51**	.09	−.10	−.45	.43	.14	−.28	−.44	.33	.15	−.23	−.44	.65	.18	.03	−.33
Stomach disturbance	**−.49**	−.34	.47	−.09	−.53	−.31	.54	−.12	−.58	−.32	.37	−.11	−.51	−.29	.45	.01
The event was uncontrollable	**−.49**	−.19	.49	.11	−.61	−.14	.38	.21	−.52	−.19	.44	.13	−.48	−.15	.57	.08
The event was caused by somebody else's behavior	**−.54**	.39	.13	.31	−.81	.59	−.05	.45	−.59	.48	−.06	.49	−.19	.13	.48	−.01
Wanted to run away in whatever direction	**−.58**	−.34	.31	−.07	−.55	−.37	.43	−.08	−.50	−.46	.33	−.08	−.73	−.21	.17	−.03
Wanted to disappear or hide from others	**−.61**	−.43	.10	−.17	−.58	−.46	.13	−.16	−.50	−.54	.18	−.18	−.77	−.27	.00	−.16
The person was powerless in the situation	**−.65**	−.24	.21	.08	−.79	−.21	.04	.14	−.69	−.30	.10	.15	−.53	−.16	.46	−.01
Lacked the motivation to pay attention to what was going on	**−.66**	−.27	−.03	−.19	−.74	−.17	−.06	−.19	−.55	−.38	−.12	−.25	−.73	−.23	.08	−.08
Tired	**−.69**	−.22	−.08	−.29	−.67	−.20	−.28	−.30	−.62	−.32	−.10	−.31	−.75	−.13	.13	−.22
Felt the urge to stop what he or she was doing	**−.77**	−.21	.12	−.03	−.84	−.17	.09	−.05	−.71	−.21	.21	.07	−.77	−.25	.05	−.10
Bad	**−.84**	−.16	.06	−.13	−.91	−.09	.05	−.14	−.87	−.17	.05	−.10	−.77	−.23	.07	−.11
Wanted to undo what was happening	**−.85**	−.14	.09	−.12	−.83	−.18	.11	−.10	−.90	−.12	.05	−.09	−.81	−.15	.14	−.16
The event involved the violation of laws or socially accepted norms	**−.86**	.11	.24	−.06	−.65	−.07	.37	−.07	−.91	.15	.18	.01	−.92	.17	.23	−.14
The event had negative, undesirable consequences for the person	**−.92**	−.04	.10	−.07	−.95	−.03	.09	−.07	−.97	−.02	.03	−.02	−.83	−.09	.20	−.12
Frowned	**−1.02**	.23	.04	−.06	−.98	−.01	−.04	−.15	−1.21	.57	−.06	−.05	−.81	.07	.30	.04
The event was inconsistent with the person's own standards and ideals	**−1.03**	.17	.06	−.03	−.98	.09	.08	−.02	−1.11	.23	−.04	.03	−.91	.12	.20	−.11
Wanted to damage, hit or say something that hurts	**−1.14**	.41	.05	−.09	−1.14	.42	.11	−.12	−1.20	.55	−.01	−.07	−.96	.16	.13	−.13
Wanted to oppose	**−1.18**	.62	.07	−.11	−1.24	.77	.04	−.09	−1.23	.70	.01	−.10	−.91	.29	.25	−.17
Spoke in a firm voice	−.37	**1.00**	.23	−.13	−.68	1.12	.08	−.21	−.16	.99	.24	−.08	−.08	.83	.49	−.17
Spoke more loudly	−.15	**.71**	.55	.12	−.03	.58	.60	.10	−.17	.84	.45	.12	−.14	.64	.67	.12

(*Continued*)

Table 3. Continued.

	Group															
	Common				English				French				Indonesian			
Feature	V	P	A	N	V	P	A	N	V	P	A	N	V	P	A	N
Wanted to tackle the situation	−.23	**.59**	.32	−.38	.06	.73	.42	−.19	−.18	.87	.17	−.31	−.61	.26	.22	−.59
Weak	−.52	**−.52**	.07	−.16	−.62	−.42	.10	−.19	−.53	−.53	.10	−.12	−.50	−.55	-.03	−.15
Wanted to hand over the initiative to someone else	−.37	**−.52**	.16	−.18	−.43	−.58	−.01	−.08	−.41	−.53	.19	−.20	−.36	−.37	.25	−.18
Wanted to do nothing	−.35	**−.54**	−.30	−.07	−.35	−.47	−.49	−.07	−.06	−.75	−.30	.04	−.62	−.40	−.12	−.18
Becoming pale	−.34	**−.60**	.27	.08	−.30	−.67	.29	.15	−.34	−.62	.24	.14	−.50	−.48	.24	.01
Feeling cold	−.33	**−.61**	.12	.04	−.49	−.52	−.18	.03	−.41	−.59	.08	.11	−.23	−.60	.37	.10
Had tears in the eyes	−.10	**−.61**	.10	−.16	−.33	−.44	.21	−.09	−.19	−.52	−.06	−.14	.00	−.70	−.01	−.15
Spoke more slowly	.08	**−.67**	−.56	−.03	−.14	−.39	−.77	−.02	.07	−.54	−.74	.12	.16	−.90	−.31	−.08
Spoke in a trembling voice	−.09	**−.69**	.56	.01	−.32	−.51	.57	.04	−.12	−.75	.48	−.01	−.07	−.67	.51	.11
Closed the eyes	−.09	**−.73**	−.24	−.15	−.07	−.75	−.17	−.10	−.09	−.71	−.31	.01	−.23	−.62	−.36	−.28
Feeling weak limbs	.05	**−.94**	.30	.03	.10	−.98	.35	−.01	−.02	−.91	.23	.10	−.17	−.79	.21	.07
Rapid heart rate	.24	−.03	**1.00**	.02	.21	.06	.96	.03	.21	−.05	1.04	−.05	.11	.00	.93	.16
Rapid breathing	.10	.00	**.97**	.02	.08	.03	.94	.05	.14	−.10	1.04	−.06	−.05	.13	.88	.12
Sweating	−.07	−.13	**.91**	−.08	−.03	−.14	.98	−.13	.00	−.19	.96	−.09	−.31	.01	.75	.02
Spoke more rapidly	.18	.34	**.86**	.00	.25	.23	.88	.02	.14	.32	.92	−.11	.10	.49	.79	.11
Felt the emotion very intensely	.29	−.23	**.78**	−.22	−.04	.03	.82	−.25	.34	−.19	.74	.19	.37	−.28	.61	−.53
Muscles tensing	−.39	.18	**.77**	.04	−.37	.17	.82	−.01	−.37	.13	.80	−.01	−.43	.19	.74	.13
The event required an immediate response	−.14	−.01	**.75**	−.01	−.14	−.07	.74	.22	−.12	.04	.80	.09	−.22	.08	.62	−.34
Had speech disturbances	−.05	−.54	**.68**	.13	−.26	−.29	.73	.10	−.07	−.53	.68	.13	−.07	−.65	.51	.27
Restless	−.31	−.09	**.67**	−.25	−.44	−.06	.72	−.35	.01	.13	.97	−.18	−.60	−.28	.26	−.18
Wanted to overcome an obstacle	−.16	.26	**.60**	−.60	−.14	.34	.67	−.50	−.19	.26	.52	−.52	−.23	.34	.46	−.70
The event occurred suddenly	.16	−.21	**.59**	.53	.07	−.17	.62	.51	.02	−.02	.54	.60	.25	−.40	.57	.55
The event was unpredictable	.02	−.32	**.52**	.49	−.13	−.23	.46	.56	−.22	−.12	.40	.60	.28	−.58	.63	.36
Slowed breathing	.22	−.39	**−.67**	−.08	.07	−.18	−.89	−.02	.19	−.21	−.84	.09	.36	−.67	−.36	−.26
Slowed heart rate	.11	−.27	**−.80**	−.05	.00	−.14	−.92	−.01	−.02	−.10	−.93	.07	.32	−.51	−.62	−.17
Had the jaw drop	.37	−.17	.25	**.72**	.44	−.10	.46	.59	.09	−.17	.04	.81	.44	−.25	.26	.79
The event happened by chance	.44	−.31	.49	**.60**	.42	−.29	.44	.61	.25	−.11	.41	.72	.44	−.43	.52	.55
Raised the eyebrows	.15	.26	.41	**.56**	.22	.23	.44	.55	.42	.02	.39	.65	−.10	.42	.52	.44
Felt the emotion for a long time	.10	−.26	.17	**−.75**	−.15	−.11	.03	−.74	.09	−.21	.03	−.73	.19	−.18	.29	−.72
The event was caused by the person's own behavior	.43	−.20	.38	**−.78**	.65	−.38	.48	−.85	.31	−.05	.14	−.76	.17	.05	.38	−.62

Note. V = Valence; P = Power; A = Arousal; N = Novelty.

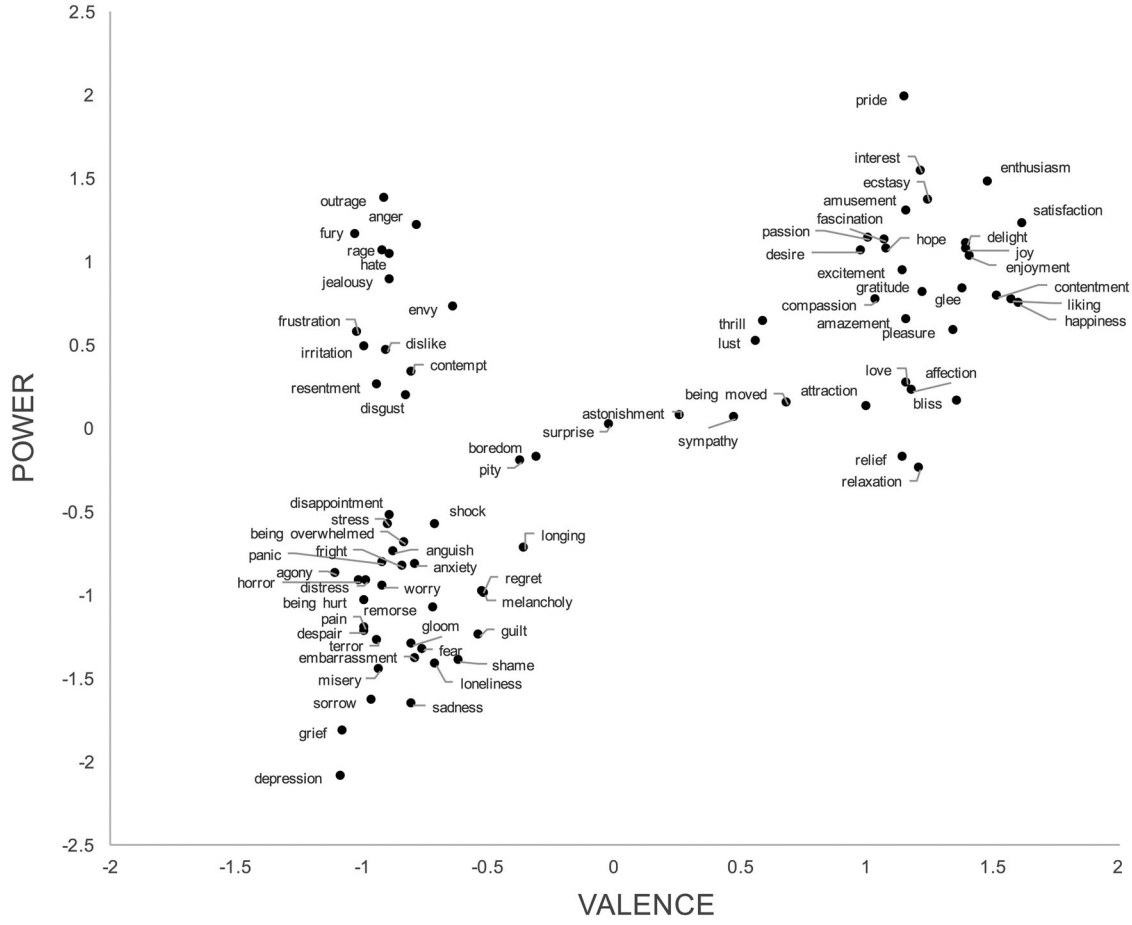

Figure 2. Coordinates of English emotion terms on Valence and Power in the common four-dimensional representation.

between valence and power. Negative emotion terms can be both high and low in power. However, for emotion terms that were high in valence, there was a strong positive relationship between valence and power: The more positive the emotion term, the higher that term tends to score on the power dimension. In both the common and the three sample-specific structures the difference in correlation was significant (see Table 6).

The interaction effect between valence and power also emerged when low and high power terms were analysed separately (see Table 7 and Panel 4 of Figure 4). For emotion terms that were low in power, there was a moderate to strong positive relationship between power and valence. However, for emotion terms that were high in power, there was no relationships between power and valence. The differences in correlation were significant in the common, the English, and the Indonesian structure.

There was also an interaction effect between power and novelty. For emotion terms that were low in power, there was a moderately positive relationship between power and novelty (see Table 7 and Panel 6 of Figure 4). However, for emotion terms that were high in power, there was a negative or no relationship between power and novelty. The difference in correlation was significant in the common, in the English, and the French structures. A visual inspection of Panel 6 of Figure 4, shows the precise meaning of this interaction effect: the more an emotion term was high in novelty, the more the term tended to be neutral in terms of power. Emotion terms that are low in novelty, however, could be characterised by all levels of power.

A visual inspection of the remaining pair-wise plots of the emotion dimensions revealed one more interesting phenomenon: There was heteroscedasticity in

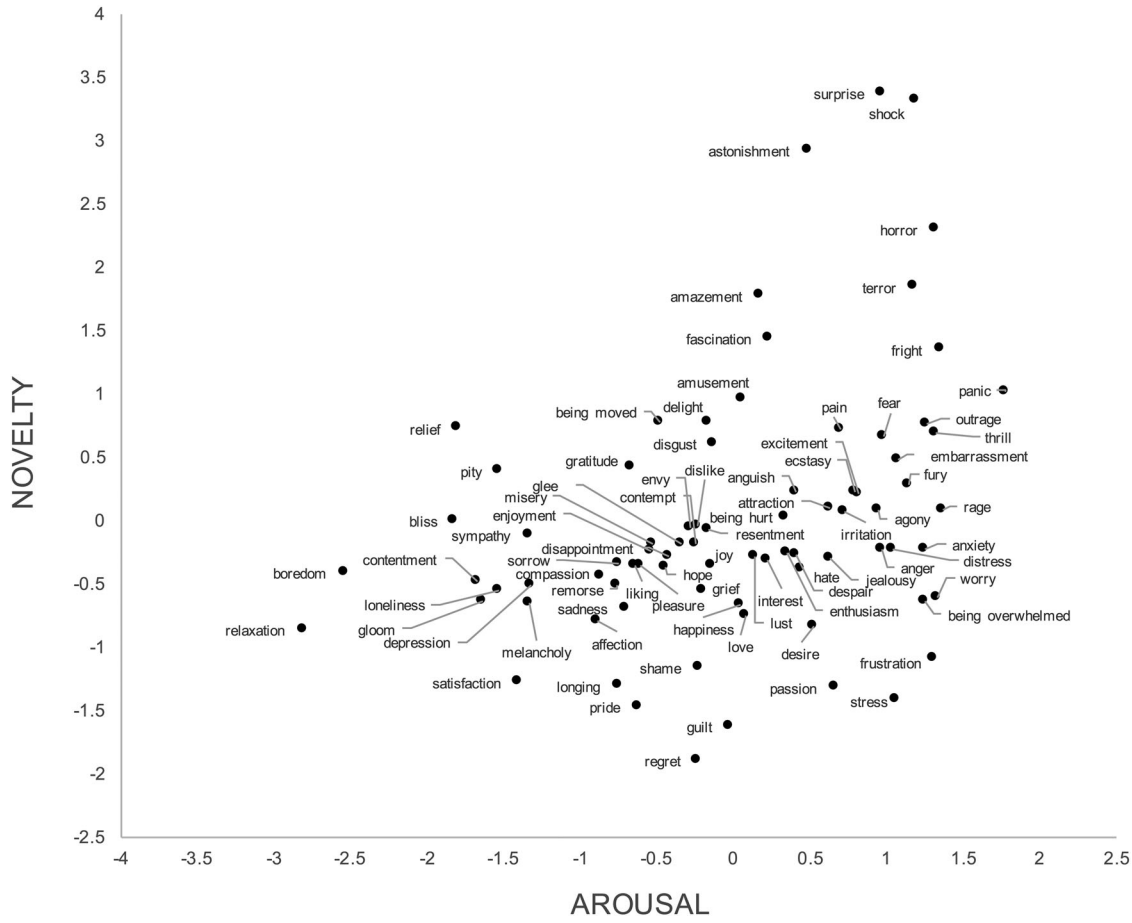

Figure 3. Coordinates of English emotion terms on Arousal and Novelty in the common four-dimensional representation.

the relationship between arousal and novelty (see Panel 9 and 12 of Figure 4). Emotion terms that scored low on novelty show much more variation in arousal than emotion terms that scored high on novelty.

The non-linear relationships were also by and large replicated across the three cultural-linguistic groups, which further confirmed hypothesis 4.

Table 4. Correlations between emotion dimensions in the common four-dimensional oblique structure and in the language-specific four-dimensional structures after oblique procrustes rotation.

	Group			
Dimensions	Common	English	French	Indonesian
Valence-Power	.65**	.64**	.62**	.55**
Valence-Arousal	−.35**	−.23*	−.36**	−.36**
Valence-Novelty	−.06	−.02	−.12	.07
Power-Arousal	.05	.15	.06	−.09
Power-Novelty	.01	.08	−.05	.19
Arousal-Novelty	.36**	.45**	.32**	.16

Note. *$p < .05$, **$p < .01$.

Representation of individual emotion terms in the two- and four-dimensional emotion models

An important contribution of the GRID instrument is that it studies the cognitive representation of the

Table 5. Correlations between dimensions in the two-dimensional and the four-dimensional common structures and in the two-dimensional and the four-dimensional Procrustes-rotated group-specific structures.

	Group			
Dimensions	Common	English	French	Indonesian
Valence_2 – Valence_4	.98**	.99**	.97**	.98**
Valence_2 – Power_4	.76**	.74**	.77**	.70**
Valence_2 – Arousal_4	−.33**	−.24*	−.33**	−.36**
Valence_2 – Novelty_4	−.07	−.04	−.16	.12
Arousal_2 – Valence_4	−.06	−.01	−.20	−.12
Arousal_2 – Power_4	.40**	.41**	.34**	.31**
Arousal_2 – Arousal_4	.92**	.95**	.95**	.90**
Arousal_2 – Novelty_4	.47**	.57**	.41**	.42**

Note. *$p < .05$, **$p < .01$.

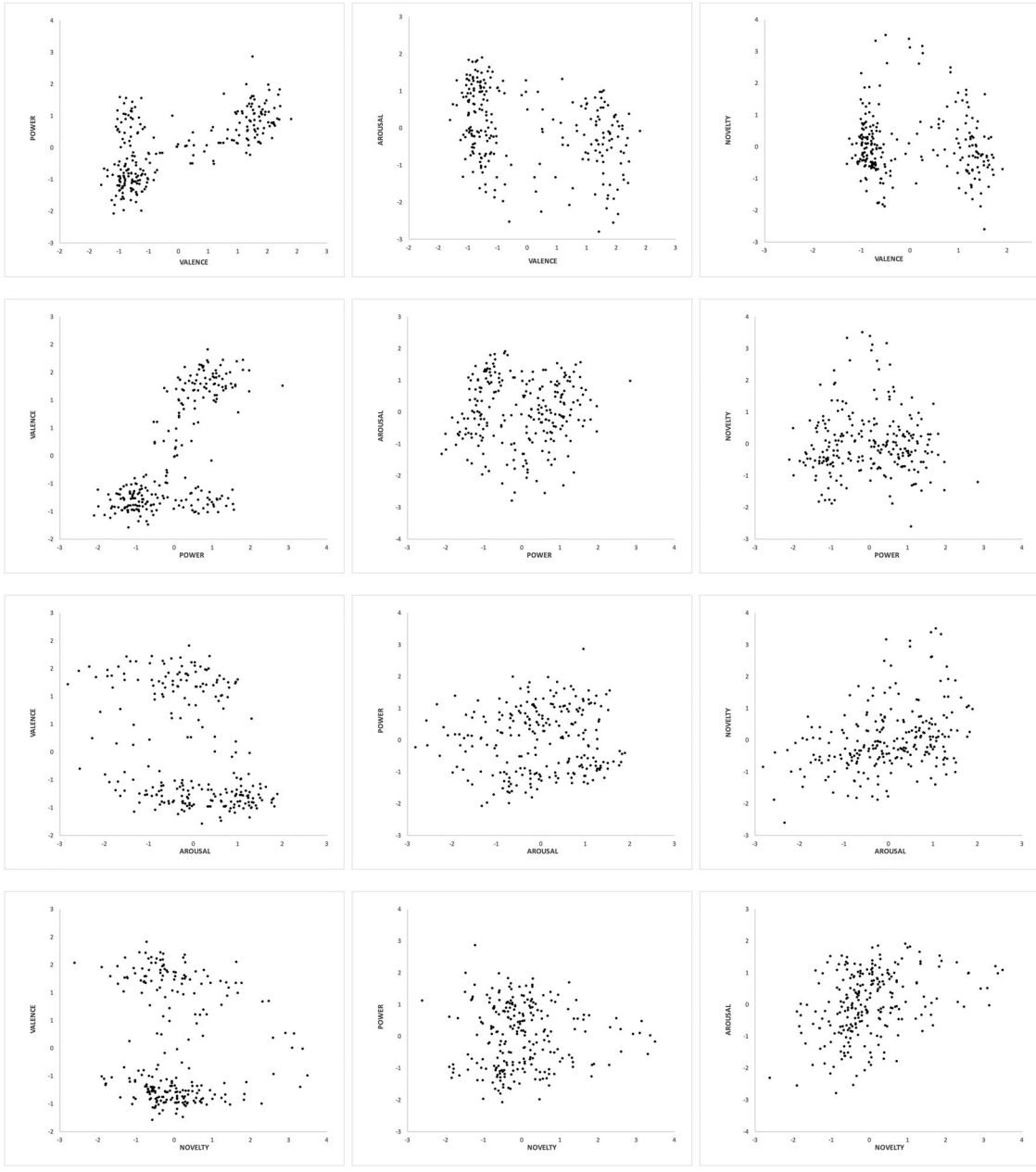

Figure 4. Coordinates of English, French, and Indonesian emotion terms on all pairs of dimensions in the common four-dimensional representation.

emotion domain by directly investigating the feature profile of emotion terms. This approach also offers new ways to study how well individual emotion terms are represented by dimensional models. Within a principal component analysis framework it is possible to predict the scores *of each emotion term on each feature* on the basis of the coordinates on the (two or four) dimensions. The observed feature profile of an emotion term can then be compared with the predicted feature profile derived from the dimensional model. For the present study, the squared correlation between the observed feature profile and the predicted feature profile across the 68 features based on either the two- or the four-

Table 6. Correlations of the valence dimension with the other dimensions in the common four-dimensional oblique structure and in the group-specific structures after oblique Procrustes rotation separately for low and high valence.

	Group											
	Common			English			French			Indonesian		
Dimensions	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}
Valence-Power	.07	.73**	−6.57**	.11	.81**	−4.37**	.35*	.79**	−3.04**	−.14	.60**	−3.59**
Valence-Arousal	−.13	−.09	−0.31	.05	.11	−0.26	−.02	−.31	1.29	−.28	−.05	−1.02
Valence-Novelty	−.10	−.14	0.31	.21	.10	0.49	−.26	−.07	−0.84	−.11	−.26	0.67

Note. *$p < .05$, **$p < .01$.

dimensional models was computed.[5] This squared correlation can be interpreted as the proportion of variance in the observed feature profile that can be accounted for by the dimensional model. To investigate how much better an emotion term is represented by a four- compared to a two-dimensional model, the difference between the squared correlations in the four- and the two-dimensional model was computed. This measure can be interpreted as the proportion of variance in the feature profile that is additionally accounted for by going from a two- to a four-dimensional representation.

The feature profiles of the individual emotion terms could be very well predicted based on the four-dimensional valence, power, arousal, and novelty model: 81.38% of the variance in the observed profiles could be predicted on average for the English emotion terms, 80.44% for the French emotion terms, and 75.70% for the Indonesian emotion terms. By using only the valence and arousal dimensions of the two-dimensional model 70.00% of the variance in the observed profiles could be predicted on average for the English emotion terms, 65.28% for the French emotion terms and 64.17% for the Indonesian emotion terms. Thus, on average 11.38%, 15.15%, and 11.53% was gained respectively for English, French and Indonesian by going from a two- to a four-dimensional representation. The gain of information, however, was not evenly distributed between emotion terms (see Table 10 for the English terms, and Supplemental Material Tables 3 and 4 for the French and Indonesian terms respectively). The third research question must thus be answered affirmatively: For some emotion terms, there was no gain of information at all, while for others there was a huge gain of variance accounted for (up to 51% in English, 67% in French, and 47% in Indonesian). A close inspection of all emotion terms revealed the following three broad trends: (1) both surprise-related emotion terms (e.g. astonishment and surprise in English, stupéfaction and étonnement in French, perasaan terkejut and ketakjuban in Indonesian) and anger-related emotion terms (e.g. hate and anger in English, rancœur and colère in French, and kebencian and kekesalan in Indonesian) were substantially better represented in the four- than the two-dimensional model, (2) both joy-related (e.g. contentment and enjoyment in English, amusement and satisfaction in French, kesukacitaan and keriangan in Indonesian) and sadness-related terms (e.g. loneliness and melancholy in English, mélancolie and depression in French, patah hati and kesedihan in Indonesian) were almost as well represented in the four- and the two-dimensional model, and (3) and fear-related terms (e.g. fear and worry in English, anxiété and angoisse in French, kegugupan and perasaan was-was in Indonesian) took an intermediate position. They tended to be better represented in the four- than the two-dimensional model, but the difference was not as pronounced as for surprise- and anger-terms. We thus observe that across the three groups very similar emotion terms fitted much better the four than the two-dimensional representation, confirming hypothesis 4.

Table 7. Correlations of the power dimension with the other dimensions in the common four-dimensional oblique structure and in the group-specific structures after oblique Procrustes rotation separately for low and high power.

	Group											
	Common			English			French			Indonesian		
Dimensions	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}
Power-Valence	.56**	.12	3.92**	.65**	.13	2.77**	.46**	.19	1.31	.41**	−.07	2.18**
Power-Arousal	.09	.28**	−1.51	−.03	.26	−1.27	.16	.33*	−0.78	.35*	.35*	0.00
Power-Novelty	.30**	−.25**	4.32**	.41**	−.08	2.22*	.34*	−.37*	3.19**	.31	−.11	1.85

Note. *$p < .05$, **$p < .01$.

Table 8. Correlations of the arousal dimension with the other dimensions in the common four-dimensional oblique structure and in the group-specific structures after oblique Procrustes rotation separately for low and high arousal.

	Group											
	Common			English			French			Indonesian		
Dimensions	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}
Arousal-Valence	−.36**	−.51**	1.96*	−.02	−.41*	1.79	−.06	−.43**	1.72	−.28	−.36*	0.38
Arousal-Power	.09	.28**	−1.51	.25	−.26	2.24*	.17	−.31	2.12*	−.27	−.05	−0.98
Arousal-Novelty	.43**	.25**	1.56	.09	.26	−0.76	.11	.05	0.26	.35*	.02	1.49

Note. *$p < .05$, **$p < .01$.

Discussion

Valence and arousal as the two most salient dimensions in the emotion domain

Great care was taken to select a representative set of emotion terms independent of any possible dimensional structure of the emotion domain. With these representative sets of emotion terms, there is strong evidence that valence and arousal are the two most salient dimensions in the emotion domain as was predicted by hypothesis 1.

Linear and non-linear relationships between valence, power, arousal, and novelty

The current research was also capable to identify which properties of the four-dimensional valence-power-arousal-novelty structure are likely to account for the emergence of valence and arousal as the two most salient dimensions. This is the first research to investigate both linear and non-linear relationships between dimensions in the cognitive representation of the emotion domain. The following clear-cut results emerged:

Linear relationships. As predicted in hypothesis 2a, a strong positive correlation was observed between valence and power. Moreover, two smaller linear relationships emerged. There was a tendency for novelty to be positively related to arousal. Also, a negative relationship was observed between valence and arousal. The negative relationship was mainly due to the fact that high arousal negative terms, such as panic and rage, scored higher on the arousal dimension than the high arousal positive emotion terms, such as excitement and ecstasy. Possibly the difference with experience research has to be attributed to the fact that these extreme high arousal terms are typically not included in assessment instruments for emotional experience.

Non-linear relationships. There was strong evidence for the presence of non-linear relationships between the emotion dimensions. The strongest non-linear relationship was between valence and power: while there was a strong positive relation between valence and power for positively valenced emotion terms, there was no relation between valence and power for negatively valenced emotion terms. Two smaller non-linear effects were also identified between novelty and arousal and between novelty and power. Novelty was positively related to arousal (the more novel, the more aroused), but not vice versa; and the higher a term scored on novelty the more neutral its position on power, but not vice versa.

While finding very strong support for the presence of non-linear relationships in general, no evidence was found for the non-linear V-shaped relationship between valence and arousal, as predicted in hypothesis 2b. As to emotion concepts, there are emotion terms to refer to both low arousal negative emotion processes (e.g. sadness) and low arousal positive emotion processes (e.g. relief). It is interesting to note that while Kuppens et al. (2013) did find an overall V-shaped relationship between valence and arousal at sample level, they also observed huge variations between participants within the sample. Apparently, when it comes to the emotion lexicon, there are emotion terms to refer to any combination of valence and arousal.

Representation of individual emotion terms. The current research is the first to study the impact of representing the emotion domain by a four- rather than a two-dimensional structure at the level of the individual emotion terms. There was clear evidence that surprise and anger terms, and to some extent also fear terms, were substantially better represented in the four- than in the two-dimensional structure. The third research question thus must be answered affirmatively. These results further substantiate the findings by Scherer (2005, pp. 719–720), that the fear- and anger-related emotions are completely intertwined in a narrow region of the two-dimensional valence-arousal space (see also Figure 6).

Table 9. Correlations of the novelty dimension with the other dimensions in the common four-dimensional oblique structure and in the group-specific structures after oblique Procrustes rotation separately for low and high novelty.

	Group											
	Common			English			French			Indonesian		
Dimensions	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}	r_{low}	r_{high}	z_{diff}
Novelty-Valence	−.10	.07	−1.30	.19	.00	0.83	.10	−.13	0.99	.13	−.01	0.61
Novelty-Power	.02	−.09	0.84	.36*	−.18	2.40*	.19	−.32*	2.25*	.24	.13	0.49
Novelty-Arousal	.28**	.22*	0.49	.09	.26	−0.76	.11	.05	0.26	.35*	.02	1.49

Note. *$p < .05$, **$p < .01$.

The two-dimensional model for the cognitive representation of the emotion domain. The linear and non-linear relationships between the emotion dimensions allow together for a very straightforward explanation for why valence and arousal emerge as the two most salient dimensions in the emotion domain. In the two-dimensional structure, the valence dimension captures already a lot of the variation between emotion terms in power, and the arousal dimension captures some information about both the novelty and the power dimension. Moreover, because of non-linear relationships between the emotion dimensions, the loss of information in the two-dimensional model is not evenly distributed across all emotion terms and thus does not strongly affect the overall fit of the two-dimensional structure.

The current findings allow to make clear predictions as to when each dimension will emerge on the basis of the proportion (1) of positive emotion terms compared to negative emotion terms, (2) of anger terms compared to fear and sadness terms, and (3) of surprise terms. Because there is a strong positive relationship between valence and power for positive emotion terms, one can expect that the higher the proportion of positive emotion terms, the less likely a separate power dimension will be identified. Since there is no relationship between valence and power for negative emotion terms, and especially anger terms deviate from the overall positive relationship between valence and power, the higher the proportion of anger-related terms, the more likely a power dimension will be identified. Finally, the higher the proportion of surprise terms, the more likely the novelty dimension will emerge.

The representation of the different emotion subdomains is not only relevant for predicting which cognitive emotion structure will emerge, but also for predicting which structure will emerge when people are asked to rate actual emotional episodes using affect and mood scales. As reported in the introduction, it is robustly observed that a broad variety of actual affect and mood scales show a valence-arousal structure (or a psychometric equivalent structure) (see Yik et al., 2011). However, these scales typically consist of as many positive as negative terms, and contain few anger and surprise terms, which makes the emergence of a separate power and novelty factor rather unlikely. Thus, based on the current findings a better representation of the anger and surprise emotion subdomains are called for when assessing the full domain of emotional experiences.

Robustness and replicability

Although almost two thirds (56 of the 80) of the emotion terms were selected independently in each of the three cultural-linguistic groups, very strong cultural similarities were observed: The two-dimensional structure, the four-dimensional structure, the linear and non-linear relationships, and how well emotion subdomains are represented in the two- and the four-dimensional structure are highly comparable between the three groups as predicted by hypothesis 4. Since the three cultural-linguistic samples are not representative for language and cultural groups across the world, and as they are predominant female student samples, one has to be careful deriving strong conclusions about the relationship between culture and the cognitive representation of emotions. Still, as the Indonesian sample was very different from the English-US and French-Swiss samples both in terms of language family and cultural background, these results give first evidence that the relationships between the two- and the four-dimensional representations are likely to be robust and replicable across a wide range of cultural groups.

Explaining the linear and non-linear relationships

The identification of both linear and non-linear relationships means that the four-dimensional

Table 10. Proportion of emotion profiles across 68 features predicted on the basis of the common four-dimensional structure (R^2_4), the common two-dimensional structure (R^2_2), and the difference in prediction between both (R^2_{Diff}) for the English emotion terms.

Emotion term	R^2_4	R^2_2	R^2_{Diff}
Astonishment	.83	.32	.51
Surprise	.92	.49	.44
Hate	.78	.35	.42
Envy	.60	.19	.41
Anger	.92	.55	.37
Dislike	.79	.42	.37
Shock	.93	.61	.32
Contempt	.78	.46	.32
Jealousy	.73	.43	.30
Resentment	.78	.49	.29
Frustration	.84	.56	.28
Regret	.70	.43	.28
Stress	.80	.55	.25
Guilt	.71	.46	.25
Fury	.88	.64	.23
Irritation	.75	.54	.22
Outrage	.90	.68	.22
Disgust	.67	.46	.21
Rage	.85	.65	.19
Pride	.90	.71	.19
Terror	.89	.71	.18
Fear	.88	.70	.18
Horror	.91	.74	.17
Amazement	.87	.71	.16
Relief	.89	.74	.15
Passion	.85	.71	.14
Shame	.75	.61	.14
Being moved	.48	.36	.12
Embarrassment	.68	.55	.12
Worry	.79	.69	.10
Fright	.85	.75	.10
Being overwhelmed	.79	.70	.09
Fascination	.90	.81	.09
Desire	.84	.75	.09
Pity	.62	.54	.08
Panic	.89	.81	.07
Love	.76	.69	.07
Anxiety	.78	.72	.07
Longing	.62	.56	.06
Boredom	.76	.70	.06
Pain	.81	.76	.05
Attraction	.59	.53	.05
Disappointment	.80	.76	.05
Excitement	.85	.80	.04
Thrill	.74	.69	.04
Distress	.81	.77	.04
Bliss	.90	.86	.04
Despair	.89	.85	.03
Lust	.41	.37	.03
Delight	.94	.91	.03
Gratitude	.83	.80	.03
Happiness	.90	.87	.03
Sympathy	.59	.56	.02
Amusement	.90	.88	.02
Satisfaction	.89	.87	.02
Grief	.82	.80	.02
Enthusiasm	.93	.91	.02
Interest	.85	.83	.02
Affection	.80	.78	.02
Pleasure	.81	.79	.02
Glee	.89	.88	.01
Sadness	.93	.91	.01
Ecstasy	.87	.86	.01
Agony	.81	.80	.01
Depression	.91	.89	.01
Hope	.72	.70	.01
Joy	.93	.92	.01
Gloom	.93	.92	.01
Misery	.92	.91	.01
Liking	.93	.92	.01
Sorrow	.83	.82	.01
Relaxation	.87	.86	.01
Melancholy	.91	.90	.01
Compassion	.79	.78	.01
Loneliness	.90	.89	.01
Remorse	.75	.74	.00
Enjoyment	.89	.89	.00
Contentment	.93	.92	.00
Anguish	.71	.72	.00
Being hurt	.78	.79	−.01

emotion space is not fully colonised with emotion words: Some subdomains are not (e.g. low arousal and high novelty) or much less (e.g. high valence and low power) represented by emotion words than other subdomains. From the perspective of the lexical sedimentation hypothesis this phenomenon can be explained as the result of genuine characteristics of emotion experiences. If there are no or hardly any emotion terms for some subdomains in the dimensional representation, this would mean that these emotions either do not exist or are unlikely to occur. Scherer et al. (2006) have advocated to study the appraisal processes underlying the emotions denoted by the different emotion terms, i.e. explaining the location in dimensional space by the specific configuration of appraisal outcomes. The current finding that the four-dimensional emotion structure is not fully colonised by emotion terms can be used as a rich source for formulating specific hypotheses on the relationships between real-life emotion appraisals and other emotion-related processes. The position of the emotion terms in the four-dimensional space suggests three specific hypotheses: namely that there are implication relationships between (1) valence and power appraisals, (2) novelty and power appraisals, (3) novelty and arousal appraisals.

The interaction effect between the valence and the power dimension could be attributed to an implication relationship between valence-related and power-related appraisals. The current structure seems to indicate that when an event and/or its consequences are appraised as positive, then the event

also triggers appraisals of control and power. Thus, power would not only be appraised when a person is successful (or expects to be successful), because he or she actively shapes the events or its consequences, but would be appraised automatically as long as events develop in a way the person wants them to develop. The reverse, however, is not true: the appraisal of control or power does not mean that the event or its consequences are positively appraised. Such an asymmetrical appraisal mechanism might explain why the experience of positive emotions can counter-balance the experience of negative emotions, as for instance proposed by the broaden-and-build theory by Fredrickson (2001). A decreased level of self-efficacy elicited by negative emotional experiences can be recharged by positive emotional experiences even if they do not imply actual control and power over the events that cause the positive experiences.

The second and the third non-linear effect imply novelty. They could be explained by an implication relationship between novelty and arousal appraisals and/or between novelty and power appraisals. When an event is appraised as sudden and unexpected, the meaning of that event for the person is not clear. Thus, the event is initially interpreted neutrally in terms of control and power. However, as a sudden and unexpected event potentially requires quick action, this appraisal would be automatically elicited and the body would become prepared for action. The reverse relationships would not be true. An event appraised as neutral in terms of control and power need not occur suddenly and unexpectedly, and when an event calls for quick action, it need not occur suddenly and unexpectedly.

Economy, robustness, and parsimony

The final question to be discussed is which dimensional model of the emotion domain is to be preferred: the two-dimensional valence-arousal model or the four-dimensional valence-power-arousal-novelty model? Two important heuristic criteria favour the two-dimensional valence-arousal model: its economy and its robustness. Two-thirds of the information in the cognitive representation is already covered by the two-dimensional model. The four-dimensional model, which adds two dimensions (entailing a 100% increase in the complexity of the model), only leads to a 15.91% increase in variance accounted for. The two-dimensional model is also very robust. It is found both in the dimensional structure of emotional experiences and in the cognitive representation of emotions. Furthermore, there is the heuristic of parsimony (also known as Occam's razor) for choosing between models (e.g. Gauch, 2003). This heuristic principle entails that when there exists a simpler model, the simpler model is to be preferred if it can explain the same phenomena equally well. It can be argued that from the perspective of parsimony the two-dimensional structure is to be preferred because it requires fewer distinctions and interactions. However, the hic is the "if". Compared to the two-dimensional model, the four-dimensional model does not just represent all parts of the emotion domain a bit better, but it has a very strong impact on the adequacy of the representation for some subdomains. The map metaphor referred to in the introduction can be applied here. For flat areas, the map works perfectly, but the more hilly the area, the more deviations there are between the distances represented on the map and reality. If a substantial part of a country consists of high mountains, a simple two-dimensional map is misleading. This is precisely the problem observed here for the cognitive organisation of the emotion domain, where anger and surprise constitute very salient "hilly areas". Anger, surprise, and fear are considered central for the domain of emotions in both basic emotion theories, like Ekman (e.g. Ekman & Cordaro, 2011) and Izard (e.g. Izard, 1977), and in appraisal theories, such as Lazarus (e.g. Lazarus, 1991), and Scherer (e.g. Scherer, 2009). Moreover, the action tendencies involved in anger (fight) vs. fear (flight) vs. surprise (approach or avoidance) are obviously very different indeed. Because the two-dimensional representation does not adequately map the differentiation between these central types of emotion (for example, anger- and fear-related terms are very close to one another in the circumplex model), it cannot be considered a parsimonious model that adequately explains the phenomenon under investigation.

Obviously, the question about which model is to be preferred also depends on the use or application of the model. When the purpose is to focus on the valence and arousal dimensions, using a two-dimensional model is justified and parsimonious. However, one must assure that these two dimensions are measured in their pure form. By just working with an overall two-dimensional model, one runs the risk to work with imprecise combinations of valence, power, arousal, and novelty. Depending on the precise distribution of the emotion terms, the first dimension can

be combination of valence, power, and arousal, and the second a combination of arousal, power, and novelty.

Conclusions

Four dimensions are needed to comprehensively represent the cognitive structure of the whole gamut of human emotions. A two-dimensional representation fits the data well in general and seems parsimonious, but misrepresents anger and surprise emotions. Both linear and non-linear relationships between the four emotion dimensions can account for this phenomenon.

Notes

1. Preliminary results of the French-speaking sample only looking at the four-dimensional representation with orthogonal dimensions has been reported in Gillioz et al. (2016).
2. The uneven distribution in terms of gender, with women substantially outweighing men is a limitation of the current study. However, previous research using a similarity rating approach between emotion terms found no significant gender difference in an adolescent, a student, and a community sample with respect to the cognitive structure of emotions (Veirman & Fontaine, 2015). Apparently women and men are quite alike when it comes to cognitively representing the emotion domain. Gender differences are probably more likely to be found in the proneness to experience and express certain emotions.
3. In addition, exploratory investigations of higher-dimensional structures were performed. However, these higher-order dimensions were difficult to interpret and had very few features that exclusively defined the respective dimensions.
4. Since all four dimensions are bipolar dimensions with a meaningful zero point (not positive, not negative; not strong, not weak; not relaxed, not aroused; not expected, not novel), doing separate analyses for terms that score below or above the zero point on each dimension has intuitive appeal. An additional regression analysis has been executed with the coordinates on the arousal dimension being the criterion and the coordinates on the valence dimension (in step 1) and the squared coordinates on the valence dimension (in step 2) being the predictors. The squared coordinates in the second step, however, did not add any information [$F(1,237)=1.321$, $p=.252$, $\Delta R^2=.005$], which confirms the absence of a V-shaped relationship.
5. For this computation, the feature scores have first been standardized across emotion terms. This computation is not to be confounded with the communalities of the features in the principal component structure.

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