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Autonomic specificity of discrete emotion and dimensions of affective space: a multivariate approach

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Abstract

The present study addressed autonomic nervous system (ANS) patterning during experimentally manipulated emotion. Film clips previously shown to induce amusement, anger, contentment, disgust, fear and sadness, in addition to a neutral control film, were presented to 34 college-aged subjects while skin conductance, blood pressure and the electrocardiogram (ECG) were recorded, as was self-reported affect. Both mean of and mean successive difference of heart period were derived from the ECG. Pattern classification analyses revealed emotion-specific autonomic patterning for all emotion conditions except disgust; all emotion conditions exhibited significant patterning using self-report. Discriminant function analysis was used to describe the location of discrete emotions within dimensional affective space using both self-report and ANS variables. Findings suggest that the dimensions of valence and activation portray the structure of self-reported emotion, but that valence is more accurately described as approach–withdrawal when applied to autonomic responses during discrete emotions. The findings provide further support for the existence of emotion-specific ANS activity, and are consistent with a hybrid discrete–dimensional model of affective space.

Keywords: Autonomic nervous system; Electrocardiogram; Emotions

1. Introduction

The issue of emotion-specific autonomic nervous system (ANS) activity is arguably one of the most enduring research topics in psychology. This essential tenet of James' (1884) venerable model of emotion processing holds that basic human emotions have distinct ANS patterns. Although substantial empirical support has accrued for the autonomic discriminability of at least some emotions (e.g. Ekman et al., 1983; Levenson et al., 1990, 1992; Sinha et al., 1992; Stemmler, 1989; Witvliet and Vrana, 1995; see Levenson, 1992, for review), there remains a lack of consensus on the convergence of these results in support of emotion-specific ANS patterns (cf. Cacioppo et al., 1993).

The present study was conducted to address a number of prominent theoretical and methodological issues in this considerable body of literature. First, studies of ANS specificity are either implicitly or explicitly based on a particular structural

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model of affect; this issue is explored in detail in the present investigation. Second, the nature of ANS patterns may vary as a function of the emotion-induction technique and dependent autonomic measures selected; the present study employs a particular method (films) to manipulate affect in conjunction with a broad array of ANS measures. Finally, most research on ANS specificity has been based on univariate analyses; multivariate techniques were used in the current study to detect autonomic patterns. These issues are discussed below, followed by a description of the present study.

1.1. Theoretical issues in ANS specificity research: the structure of affect

The selection of induced emotions is a crucial design feature of ANS specificity studies, and should be guided by a clearly specified theoretical model of affective space. These models generally fall into one of two categories: *discrete* or *dimensional*. Discrete models focus on universal set of 'primary' emotions (e.g. fear, anger or disgust), which are typically seen in terms of their evolutionary adaptive value (Plutchik, 1980). This functional view is consistent with James' (1884) characterization of 'standard' emotions, and portrays emotions in terms of their ability to coordinate multiple behavioral and physiological responses to produce an appropriate response to environmental demand (Levenson, 1988). By contrast, dimensional models describe affective space with a limited number of underlying dimensions.

A prevalent dimensional model is the circumplex, comprising a 2D circular array of affect descriptors (Larsen and Diener, 1992; Russell, 1980) Two dimensions of the affective circumplex have consistently emerged: (1) valence or hedonic tone (positivity or negativity) and (2) arousal or activation (energy level). An alternative dimensional model posits orthogonal axes labeled as positive affect and negative affect, rotated 45° relative to the valence and activation axes (Watson and Tellegen, 1985). In contrast to the circumplex, this model views activation and valence as inseparable, and depicts valence as independent positive and negative factors rather than as anchors of a single bipolar dimension. Both models have accrued considerable empirical support, and their relative merits have been actively debated in the literature (e.g. Feldman Barrett and Russell, 1998; Russell and Carroll, 1999; Watson et al., 1999).

Although discrete and dimensional models are often presented as mutually exclusive, the most fruitful approach for ANS specificity research may be a hybrid of the two (Levenson, 1988). This approach was employed in a study that illustrated a hierarchical relationship between lower-order discrete emotions and higher-order emotion dimensions (Nyklicek et al., 1997). In this view, emotions of the discrete model represent unique points in dimensional affective space.

1.2. Methodological issues: affect manipulation, ANS sampling and analytic techniques

The choice of affect induction method is also critical in ANS specificity research. Diverse forms include: (a) 'real-life' inductions (e.g. Stemmler, 1989); (b) reading affective statements (e.g. Velten, 1968) or scenarios (e.g. Witvliet and Vrana, 1995); (c) directed facial expressions (e.g. Ekman et al., 1983); (d) imagery (e.g. Lang, 1979); (e) music (e.g. Nyklicek et al., 1997); (f) slides (Lang et al., 1988); and (g) films (Gross and Levenson, 1995). All of these methods have their relative merits, and the types of induction used will vary with theoretical and practical concerns. One such factor is the match of the manipulation with the underlying structural model of affect upon which it is based. For example, the facial action task is intended to induce discrete facial expressions of emotions such as anger or fear (Ekman et al., 1983). By comparison, the targets of dimensionally based affect manipulations (e.g. Velten, 1968) are more diffuse affective states (i.e. quadrants of the circumplex). Thus, the resolution of dimensionally based affect manipulations is theoretically coarser than those based upon discrete models, and it is necessary when addressing some aspect of discrete emotions, as is the case in the present study, to employ a manipulation that is congruent with the latter type. For this reason, films selected on discrete emotion criteria were used in this study.

Furthermore, films were chosen due to their distinct practical advantages: (a) ease of standardization, (b) lack of need for deception and (c) ecological validity (Gross and Levenson, 1995). Finally, because different stimulus situations may evoke dissimilar patterns of somatic responding (Lacey, 1967), it can be difficult to distinguish the physiological effects of emotion from those due to the experimental context of the induction (Stemmler, 1992b; Stemmler et al., 2001). Hence, a relatively neutral ‘context without emotion’ condition was included as a control for these potentially independent sources of variability.

Another relevant issue is the collection of a representative montage of ANS variables. Breadth can be obtained with measures that reflect varying autonomic inputs (Stemmler, 1992a). To achieve this aim, the following measures were employed in the present study: (a) blood pressure (BP), which reflects vascular α-adrenergic (sympathetic) activity as well as cardiac vagal and β-adrenergic input (Smith and Kampine, 1984); (b) skin conductance (SC), which provides a relatively pure sympathetic index that varies with affective arousal (Dawson et al., 2000); (c) heart period (HP), reflecting mixed vagal and β-adrenergic input (Smith and Kampine, 1984) and (d) mean successive differences (MSD) of HP variability, a widely used measure of cardiac vagal control (Friedman et al., 2002).

Finally, to detect coordination of multiple response systems associated with ANS patterning, analytic techniques sensitive to variable configurations must be applied. *Pattern classification analysis* is ideal for this research question because it affords simultaneous consideration of multiple response variables (Fridlund et al., 1984). In this technique, classification functions are generated for each of several output classes (e.g. emotions). Cases are then ‘blindly’ assigned to classes based on a vector of input elements (e.g. ANS responses). The success of the classification functions, and thus the discriminability of the classes based upon respective input elements, is evaluated by testing the percentage of correct classifications against chance level using a standardized normal test statistic (Huberty, 1994).

A secondary aim of this study was to place discrete emotions, with respect to both ANS and self-report variables, in dimensional affective space. To this end, discriminant analysis, which yields a smaller number of discriminant rather than classification functions, was used to generate dimensions (i.e. discriminant functions) that maximally separate groups in multivariate space. Once these functions are identified, group centroids (multivariate group means) can be plotted, thus describing the location of the discrete emotions in dimensional space and facilitating interpretation (i.e. labeling) of the discriminant functions.

2. Goals of the present study

A recent study based upon the hybrid discrete–dimensional model of affect addressed a number of the above theoretical and methodological issues (Nyklicek et al., 1997). Key elements of the study include a dimensionally based affect manipulation (music), a broad set of autonomic indices, and multivariate pattern classification analysis. Results yielded ANS patterns that reliably distinguished among four affect conditions. Moreover, both self-report and ANS activity produced a 2D structure consistent with a valence–activation circumplex.

The present study aimed to replicate and extend these findings from the same hybrid discrete–dimensional model, but with an affect manipulation based on a discrete rather than dimensional emotion model. This goal was achieved by including a standardized set of affective film clips as well as a relatively neutral condition, and a broad sample of dependent ANS measures that were analyzed with pattern classification analysis. Thus, comparisons can be made with Nyklicek et al. (1997) in terms of induction type and affect model. It was predicted that the ANS patterns elicited during the induction of amusement, anger, contentment, disgust, fear and sadness would be distinguished from the neutral stimulus condition and from each other.

3. Method

3.1. Subjects

Thirty-four subjects (16 males and 18 females) were recruited via fliers and received their choice of either extra credit or $10 for participation in an experimental session lasting approximately 1.5 h. Subjects were screened on the basis of age (18–26 years old; *M*: 18.7 years; S.D.: 0.88) and health status as determined by questionnaire. Those indicating a history of neurological deficits or cardiovascular disorder, or taking medication for hypertension, depression or anxiety were excluded.

In addition, because the affective characteristics associated with depression or the inability to accurately identify and describe affective states (alexithymia) could interfere with task characteristics, subjects were screened based upon scores on the Beck Depression Inventory-II (BDI-II; Beck et al., 1996) and the Toronto Alexithymia Scale (TAS-20; Bagby et al., 1992a,b). For the BDI-II a cutoff of 19, the upper limit for mildly depressive symptomatology (Beck et al., 1996), was used (*M*: 5.06; S.D.: 3.8; range: 0–14). For the TAS a cutoff of 51, the lower limit for diagnosis of alexithymia (Bagby et al., 1992a,b), was used (*M*: 38.8; S.D.: 7.7; range: 25–51). All screening data were collected via online questionnaire; qualified subjects were contacted for participation in the second stage of the study.

3.2. Materials

3.2.1. Film clips

Standardized films were used to elicit the discrete emotions of amusement, anger, contentment, disgust, fear, sadness and a relatively neutral state (Gross and Levenson, 1995). The clips varied in length ranging from 81 to 203 s (average length 145 s) and were presented on a 42-inch flat-panel television approximately 2 m from the subject.

3.2.2. Questionnaires

Experienced affect was assessed using an 18-item affect self-report (ASR) scale. The ASR is consistent with a hybrid model of affective space and contains items traditional to both discrete (amused, fearful, angry, sad, disgusted and content) and dimensional (good, calm, unpleasant, passive, excited, negative, relaxed, active, positive, agitated, bad and pleasant) models. Responses to all items were based upon a 7-point Likert scale assessing the degree to which the word accurately described affective experience. The discrete portion of the scale is comparable to that used to generate and validate the standardized film set (Gross and Levenson, 1995) and the dimensional portion is based upon an English translation of the scale used by Nyklicek et al. (1997).

3.2.3. Physiological recording equipment

Electrocardiogram (ECG) and SC were recorded with the Ambulatory Monitoring System (AMS; Vrije Universiteit, Department of Psychophysiology, Amsterdam, The Netherlands). SC was recorded using a 0.5 V constant voltage procedure and sampled at 2 Hz. The ECG was analog filtered (high pass 17 Hz) at acquisition and subjected to online auto trigger level R-wave detection resulting in a HP resolution of 1 ms.

BP was recorded from the radial artery of the left wrist using the Vasotrac, a non-invasive semi-continuous BP monitor (Medwave, Arden Hills, MN; see Belani et al., 1999). Previous research has shown the Vasotrac to be very effective in research of this nature in that it can be worn for extended periods without discomfort or excessive intrusiveness (Friedman et al., in press).

3.3. Physiological measures

Systolic (SBP), diastolic (DBP) and mean arterial blood pressures (MAP) were output by the Vasotrac in mm Hg. Mean HP and MSD were derived in milliseconds from the HP time series. MSD was calculated as the mean of the absolute differences between successive HPs. SC was output from the AMS in standard microSiemens (μS) conductance units.

3.4. Procedure

Experimental sessions were conducted in an approximately 8 feet by 15 feet room partitioned by a room divider, resulting in two relatively private areas, an experimenter side and a subject side. All subjects read and signed an informed consent approved by the university Institutional Review Board. Film clips were presented in one of five counterbalanced orders with the constraint that negatively valenced film clips alternated with positively or neutrally valenced film clips. Subjects were randomly assigned to one of the five film orders.

Upon obtaining informed consent, a gender-matched researcher attached transducers and electrodes used to record physiological data. Following application of a mild skin prep (Omni Prep; D.O. Weaver & Co., Aurora, CO; 70% isopropyl alcohol) a modified lead II electrode configuration using three disposable pre-gelled electrodes (Surtrace; ConMed Co., Utica, NY) was used to acquire the ECG signal. Subjects washed their hands with a nonabrasive soap; SC was recorded from the volar surface of the index and middle fingers of the right hand.

Subjects were told they would be watching a number of short film clips with different emotional content and that they were to pay close attention to how they feel as they watched the film clips. After a short period of recording to insure proper equipment functioning, baseline ASR was completed followed by a rest period and the first film. The ASR scale was completed after presentation of each film clip to assess affective responses during the film. Following completion of the scale, a 1-min 'washout' film clip was shown (the second neutral clip from Gross and Levenson, 1995), followed by a 2-min rest during which subjects were instructed to 'sit quietly with your eyes closed and clear your minds of all thoughts, feelings and memories.' The next stimulus presentation then commenced. This procedure was repeated for the remaining six stimulus conditions.

3.5. Data quantification and analysis

Due to differences in film length, physiological measures recorded during the final minute of each film were used for analysis[1]. Likewise, the final minute of the baseline preceding each film clip was used to create change scores for each emotion condition (film clip minus baseline). Subsequent analyses involving physiological measures make use of these change scores. Two subjects were dropped due to equipment failure resulting in missing data.

Two pattern classifications and discriminant function analyses were conducted, the first using ANS variables and the second using dimensional items from the ASR scale. Because the discrete portion of the ASR scale consisted of single items used to assess experienced emotion, multivariate analyses were deemed inappropriate and univariate analyses were used. Specifically, repeated measures ANOVAs, using the discrete ASR items as the repeated variable, were conducted for each emotion condition and significant effects further examined using post hoc paired *t*-tests. In addition, because a goal of this study was to illustrate the need for multivariate analyses in examining patterned autonomic activity, a brief univariate analysis (*t*-tests) was conducted on the ANS variable change scores.

[1] Because the films varied in length, this method necessarily draws data from differing time intervals from the start of the emotion induction. This approach was nevertheless deemed preferable because it allowed for a more complete emotion induction.

3.6. Results

3.6.1. Pattern classification using ANS variables

Pattern classification results using ANS variables are shown in Table 1. Classification rates are presented as both number and percentage (in parenthesis) of observations. Classification hits (i.e. when the predicted emotion condition matches the actual emotion condition) form the diagonal of the classification matrix. Classification accuracies ranged from 17.65 to 61.76%, with an overall correct classification rate of 37.39% (the average of the percentages in the diagonal). The overall average as well as five of the seven individual emotion conditions were statistically significant at the $P<0.005$ level or lower (Table 2).

3.6.2. Pattern classification using ASR variables

Results of pattern classification analysis of dimensional ASR items are shown in Table 3. The overall classification hit rate was 68.07% with individual emotion condition hit rates ranging from 32.35 to 88.24%. Hit rates for both overall classification and each emotion condition were statistically significant at the $P<0.005$ level or lower (Table 4).

Table 1
Pattern classification matrix using ANS variables

Actual emotion condition	Predicted emotion condition							Total
	Amu	Ang	Con	Dis	Fea	Neu	Sad	
Amu	**11** (**32.35**)	2 (5.88)	7 (20.59)	3 (8.82)	6 (17.65)	0 (0)	5 (14.71)	34 (100)
Ang	1 (2.94)	**13** (**38.24**)	7 (20.59)	4 (11.76)	5 (14.71)	1 (2.94)	3 (8.82)	34 (100)
Con	0 (0)	1 (2.94)	**21** (**61.76**)	0 (0)	3 (8.82)	4 (11.76)	5 (14.71)	34 (100)
Dis	5 (14.71)	2 (5.88)	8 (23.53)	**7** (**20.59**)	7 (20.59)	1 (2.94)	4 (11.76)	34 (100)
Fea	0 (0)	0 (0)	7 (20.59)	1 (2.94)	**18** (**52.94**)	2 (5.88)	6 (17.65)	34 (100)
Neu	1 (2.94)	1 (2.94)	13 (38.24)	0 (0)	6 (17.65)	**6** (**17.65**)	7 (20.59)	34 (100)
Sad	1 (2.94)	1 (2.94)	11 (32.35)	1 (2.94)	4 (11.76)	3 (8.82)	**13** (**38.24**)	34 (100)
Total	19 (7.98)	20 (8.4)	74 (31.09)	16 (6.72)	49 (20.59)	17 (7.14)	43 (18.07)	238 (100)

Key: Amu, amusement; Ang, anger; Con, contentment; Dis, disgust; Fea, fear; Neu, neutral; Sad, sadness.

3.6.3. Discriminant analysis using ANS and ASR variables

The ANS variables for each emotion condition that exhibited statistically significant patterning (amusement, anger, contentment, fear, sadness) were entered into a discriminant analysis resulting in 4, the number of conditions minus 1, discriminant functions accounting for 58.29, 26.43, 14.44 and 0.84% of the total variance in the ANS variables. Fig. 1 depicts the first and third ANS discriminant functions as axes against which emotion condition centroids are plotted (the second and fourth functions were not interpretable and are not discussed further). To facilitate interpretation, the data points are rotated 15° in the clockwise direction through multiplication of the matrix of centroid locations with a transformation matrix (Johnson and Wichern, 1992). The factor loadings (i.e. structure *r*'s) for the first and third discriminant functions are presented in Table 5. A similar discriminant analysis, in this case using all six emotion conditions, was conducted using the dimensional ASR variables and five discriminant functions resulted accounting for 66.11, 14.31, 10.32, 6.32 and 2.95% of the total variance in self-reported affect. Fig. 2 depicts the first and second ASR discriminant functions and corresponding condition centroids (the remaining functions were uninterpretable). It is the relative location of the points within discriminant space that is informative, and so the axes are drawn slightly off-center to facilitate interpretation.

3.6.4. Univariate analysis of discrete ASR variables

Repeated measures ANOVA revealed significant within subject differences in discrete ASR variables for each emotion condition (all $P\text{s}<0.0001$; Greenhouse-Geisser correction applied for violations of sphericity). Paired *t*-tests were used to explore the effectiveness of the affect manipulations with respect to the discrete ASR items. For the amusement, contentment, disgust, fear and sadness emotion conditions, ratings on discrete items for the respective conditions were significantly greater than all other discrete items (all $P\text{s}<0.05$). For example, in the amusement condition, the amusement item was greater than the

Table 2
Significance tests for classification using ANS variables

Film	N	Observed	Expected	Z	P
Amu	34	11	4.86	3.01	0.0013
Ang	34	13	4.86	3.99	<0.0001
Con	34	21	4.86	7.91	<0.0001
Dis	34	7	4.86	1.05	0.1468
Fea	34	18	4.86	6.44	<0.0001
Neu	34	6	4.86	0.56	0.2877
Sad	34	13	4.86	3.99	<0.0001
Overall	238	89	34	10.19	<0.0001

See Table 1 for emotion abbreviations.

anger, contentment, disgust, fear and sadness items. In the anger condition, the discrete anger item did not differ from the sadness and disgust items; however, each were greater than the ratings for amusement, contentment and fear (all Ps< 0.0001). Collectively, these results suggest that the manipulations induced their intended emotions, as reported by the subjects.

Table 4
Significance tests for classification using ASR variables

Film	N	Observed	Expected	Z	P
Amu	34	29	4.86	11.83	<0.0001
Ang	34	26	4.86	10.36	<0.0001
Con	34	30	4.86	12.32	<0.0001
Dis	34	19	4.86	6.93	<0.0001
Fea	34	20	4.86	7.42	<0.0001
Neu	34	11	4.86	3.01	0.0013
Sad	34	27	4.86	10.85	<0.0001
Overall	238	162	34	23.71	<0.0001

See Table 1 for emotion abbreviations.

3.6.5. Univariate analysis of ANS variables

Of the ANS measures, only MSD and SC showed significant differences between conditions (Table 6). MSD in anger differed significantly from all other conditions, but no other condition effects were found with this variable. SC alone among ANS measures showed any trend of significant differences across conditions. These univariate tests stand in contradistinction to the

Table 3
Pattern classification matrix using dimensional ASR variables

Actual emotion condition	Predicted emotion condition							Total
	Amu	Ang	Con	Dis	Fea	Neu	Sad	
Amu	**29** (**85.29**)	0 (0)	5 (14.71)	0 (0)	0 (0)	0 (0)	0 (0)	34 (100)
Ang	0 (0)	**26** (**76.47**)	0 (0)	3 (8.82)	1 (2.94)	1 (2.94)	3 (8.82)	34 (100)
Con	4 (11.76)	0 (0)	**30** (**88.24**)	0 (0)	0 (0)	0 (0)	0 (0)	34 (100)
Dis	4 (12.12)	3 (9.09)	0 (0)	**19** (**57.58**)	1 (3.03)	0 (0)	6 (18.18)	33 (100)
Fea	8 (23.53)	1 (2.94)	3 (8.82)	1 (2.94)	**20** (**58.82**)	0 (0)	1 (2.94)	34 (100)
Neu	7 (20.59)	1 (2.94)	13 (38.24)	1 (2.94)	1 (2.94)	**11** (**32.35**)	0 (0)	34 (100)
Sad	1 (2.94)	3 (2.94)	2 (32.35)	1 (2.94)	0 (11.76)	0 (8.82)	**27** (**38.24**)	34 (100)
Total	53 (22.36)	34 (14.35)	53 (22.36)	25 (10.55)	23 (9.7)	12 (5.06)	37 (15.61)	237 (100)

See Table 1 for emotion abbreviations.

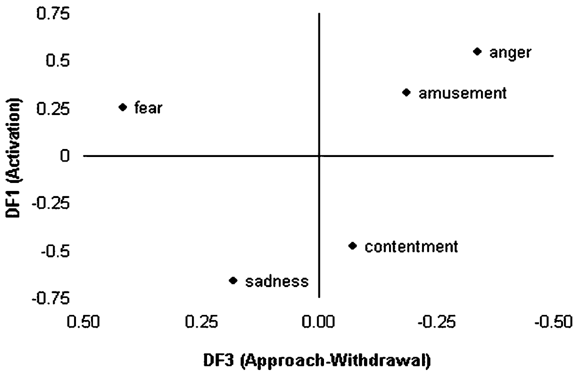

Fig. 1. Group centroids of emotion condition using ANS variables. Discriminant function 1 (vertical axis) is interpreted as activation and discriminant function 3 (horizontal axis) as approach/withdrawal.

multivariate analyses, which revealed clear autonomic discrimination among the inductions.

4. Discussion

The presence of unique ANS patterns during emotional states, the primary hypothesis of the study, was supported by statistically significant classification using ANS variables. That disgust failed to show significance was likely due to one of two reasons. First, though a diverse montage of ANS variables was used, none specifically indexed gastric activity. Thus, autonomic changes unique to disgust were likely not captured. Second, data suggest that physiological responses to potent disgust film clips may be particularly sensitive to individual differences (e.g. medical vs. non-medical students; Kallenberg et al., 2001).

It was also predicted that emotion conditions would be distinguished from the neutral control. Although classification of the neutral condition did not reach greater than chance levels (i.e. there was no clear pattern identifying the neutral condition), the classification matrix (Table 1) shows that very few observations were misclassified as the neutral condition. In all, only 11 observations (4.6%) were misclassified as neutral, suggesting that the emotion conditions were discernable from neutral, although the reverse may not be true. Patterning of self-report variables was more robust, with

Table 5
Factor loadings for the first and third ANS discriminant functions

	DF1	DF3
HP	0.13	−0.52
MSD	−0.40	0.10
SC	0.58	0.25
SBP	0.13	0.05
DBP	0.02	0.24
MAP	0.12	0.25

significant classifications and higher hit rates for all conditions.

Interpretation of the discriminant analysis is less straightforward. Ideally, the group centroids of a discriminant function reveal the dimension of the data captured by that function. Also, as in factor analysis, factor loadings may shed further light on the relative contribution of variables to individual discriminant functions. Fig. 1 shows the first and third discriminant functions derived from ANS variables and their respective group centroids. Discriminant function 1 (vertical axis) explained 58.29% of ANS variance, and is consistent with the activation dimension of the circumplex; anger, disgust, amusement and fear were separated from contentment and sadness. The third discriminant

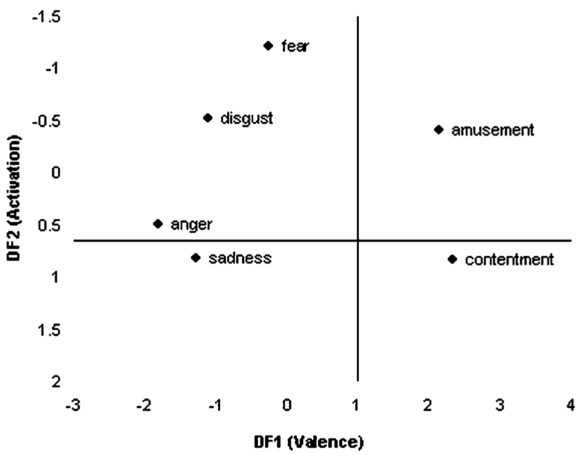

Fig. 2. Group centroids of emotion condition using dimensional ASR variables. Discriminant function 1 (horizontal axis) is interpreted as valence and discriminant function 1 (vertical axis) as activation.

Table 6
Mean change scores and summary of t-tests for ANS variables

HP	−4.83	−4.36	3.02	6.59	8.97	11.55	14.98
	Neu^{A}	Fea^{A}	Sad^{A}	Con^{A}	Dis^{A}	Ang^{A}	Amu^{A}
MSD	−8.66	−3.17	−1.82	−1.29	−0.19	1.24	1.48
	Ang^{A}	Fea^{B}	Con^{B}	Dis^{B}	Neu^{B}	Amu^{B}	Sad^{B}
SC	−0.45	−0.21	−0.11	0.22	0.26	0.44	0.63
	Neu^{A}	Con^{AB}	Sad^{BC}	Ang^{CD}	Fea^{DE}	Dis^{DE}	Amu^{E}
SBP	−0.85	−0.46	−0.32	−0.07	0.30	0.88	1.54
	Neu^{A}	Con^{A}	Sad^{A}	Ang^{A}	Fea^{A}	Dis^{A}	Amu^{A}
DBP	−1.25	−0.75	−0.64	−0.16	0.16	0.20	0.42
	Neu^{A}	Con^{A}	Ang^{A}	Sad^{A}	Amu^{A}	Fea^{A}	Dis^{A}
MAP	−1.25	−0.63	−0.30	−0.18	0.61	0.73	0.91
	Neu^{A}	Con^{A}	Sad^{A}	Ang^{A}	Dis^{A}	Fea^{A}	Amu^{A}

See Table 1 for key. *Note:* Emotion conditions sharing the same superscript do not differ; p's < 0.05 for all significant differences.

function (horizontal axis) explained 14.44% of the variance and initially seems to track the valence dimension of the circumplex. However, the dimension is more accurately described by the approach–withdrawal nature of the respective emotion conditions with anger, contentment and amusement separated from sadness and fear. In particular, the disparate locations of anger and fear along this dimension support this interpretation. That is, though both anger and fear are negative emotions, anger is associated with approach, and fear with withdrawal (cf. Harmon-Jones and Allen, 1998). This view is consistent with research on hemispheric asymmetry in affect, which maps frontal EEG activity onto the basic motivational dimension of approach–withdrawal (for review, see Davidson, 1992). Furthermore, this interpretation fits well the notion that the functional role of emotion is to coordinate biobehavioral responses to environmental demands.

Factor loadings for these ANS discriminant functions (Table 5) suggest that SC and MSD contribute much to function 1. The contribution of SC to this dimension converges with the consistent association of SC with the arousal content of affective stimuli (e.g. Lang et al., 1993). The variables contributing to discriminant function 2 are less clear, but HP appears to contribute greatly along with modest contributions by DBP, MAP and SC. The importance of cardiovascular measures to function 2, interpreted as approach–withdrawal, is also consonant with the view of an emotion as a system response organizer.

Discriminant analysis using the dimensional ASR variables yielded two interpretable functions, the first explaining 66.11% and the second 14.31% total variance. As can be seen in Fig. 2, the first discriminant function (vertical axis) is consistent with a valence factor, with amusement and contentment located higher on the dimension relative to anger, sadness, disgust and fear. The second discriminant function (horizontal axis) maps onto activation, with amusement, fear, disgust and anger falling higher than contentment and sadness.

Despite success in describing the structure of self-reported affect, the valence–activation circumplex may not fully capture the 'autonomic space' of discrete emotion. Rather, a modified circumplex, with valence reconceptualized as approach–withdrawal, may be more appropriate. This finding is inconsistent with the single extant study that addressed these issues from a dimensional multivariate perspective (Nyklicek et al., 1997). Only one high activation-negative affect condition was included in that study, and so separation along an approach–withdrawal dimension cannot be detected. In contrast, the present study included two such emotions (anger and fear), and thus was able to capture this dimension. Additionally, the dimensions that distinguish among discrete emotions may differ from those underlying the general affective states delineated by the circumplex; the latter may mirror the dimensions of self-report, whereas those separating discrete emotions might incorporate motivational qualities.

Finally, the validity of films as an emotion-induction technique was supported along several lines. First, the film clips used in this study were effective at eliciting distinct response patterns with both autonomic and self-report variables. It is further compelling that a valence–activation circumplex was found in experienced emotion despite that the films were selected on discrete emotion criteria (Gross and Levenson, 1995). This concordance between affect theories provides additional support for the use of a hybrid discrete–dimensional model. The present study also replicated the essential findings of Nyklicek et al. (1997) in regard to ANS patterning, and hence suggests that films and music are both effective emotion manipulations. Future research might compare these findings to other widely used techniques such as slides or imagery.

In sum, the present study adds both empirically and conceptually to the body of literature that provides evidence of emotion-specific ANS patterning. The current findings support the validity of films as an emotion-induction technique, and point to the value of acquiring a broad range of ANS measures that are analyzed with appropriate multivariate techniques. Finally, data sampled from different components of emotion (i.e. physiological and self-report) speak to theoretical issues in the structure of affect. Specifically, the results illustrate the utility of a hybrid discrete–dimensional model of emotion in two ways: (1) by locating self-reported discrete emotions within an affective space described by a dimensional circumplex model; and (2) by describing the location of emotion-specific ANS activity within an affective space described by a circumplex with the valence dimension reconsidered as approach–withdrawal.

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