Affect Bursts: Dynamic Patterns of Facial Expression

Eva G. Krumhuber & Klaus R. Scherer

University of Geneva

Eva G. Krumhuber, Swiss Center for Affective Sciences, University of Geneva, Switzerland; Klaus R. Scherer, Swiss Center for Affective Sciences, University of Geneva, Switzerland.

Eva G. Krumhuber is now a senior research associate at the School of Humanities and Social Sciences, Jacobs University Bremen, Germany.

This research was supported by the Swiss National Science Foundation (FNRS 101411-100367). The authors would like to thank Marc Mehu for FACS coding.

Correspondence concerning this article should be addressed to Eva Krumhuber, Research IV, Campus Ring 1, Jacobs University Bremen, D-28759 Bremen, Germany. E-mail: e.krumhuber@jacobs-university.de

Word count: 8445

Abstract

Affect bursts consist of spontaneous and short emotional expressions in which facial, vocal, and gestural components are highly synchronized. Although the vocal characteristics have been examined in several recent studies, the facial modality remains largely unexplored. This study investigated the facial correlates of affect bursts that expressed 5 different emotions: anger, fear, sadness, joy, and relief. Detailed analysis of 59 facial actions with the Facial Action Coding System revealed a reasonable degree of emotion differentiation for individual action units (AUs). However, less convergence was shown for specific AU combinations for a limited number of prototypes. Moreover, expression of facial actions peaked in a cumulative-sequential fashion with significant differences in their sequential appearance between emotions. When testing for the classification of facial expressions within a dimensional approach, facial actions differed significantly as a function of the valence and arousal level of the 5 emotions, thereby allowing further distinction between joy and relief. The findings cast doubt on the existence of fixed patterns of facial responses for each emotion, resulting in unique facial prototypes. Rather, the results suggest that each emotion can be portrayed by several different expressions that share multiple facial actions.

Affect Bursts: Dynamic Patterns of Facial Expression

Affect vocalizations are primary examples of the nature of emotion as biological, psychological, and social adaptations (Scherer, 1994). Wilhelm Wundt (1900) traced their origin to inarticulate screams and cries accompanying feelings of intense emotion, describing such vocalizations as “sounds of nature” (*Naturlaute*). Goffman (1979) spoke of “response cries,” which he defined as exclamatory, nonlexical, and discrete interjections. The term “affect burst” has become prevalent in recent years when defining brief and discrete outbursts of emotional reactions (Scherer, 1994). Affect bursts have a long evolutionary history as residuals of functional responses to environmental stimuli. They are reminiscent of primitive call systems and closely parallel animal affect vocalizations (Scherer, 1979, 1985, 1988). As a result of physiological push effects and selective pressure for redundant communicative signals, the spontaneous co-occurrence of vocal and facial expression elements is an invariant feature of affect bursts (Scherer, 1994). Affect bursts are therefore classic examples of multimodal phenomena that are highly integrated across modalities (Scherer & Ellgring, 2007b). In this study, we focus for the first time on the analysis of facial patterns in affect bursts expressing different types of emotions.

Previous Research on Affect Bursts

In conceptual terms, affect bursts comprise both nonspeech sounds (e.g., laughter) and interjections with a phonemic structure (e.g., Yeah!; (Schröder, 2003), including raw affect bursts directly arising from physiological changes. These bursts are barely conventionalized and thus relatively universal and language independent. Also included are affect emblems, which are determined by sociocultural norms, and show a high degree of culture and language dependency (Scherer, 1994; see also

Hawk, van Kleef, Fischer, & van der Schalk, 2009). Because the transition between the nonspeech and phonemic structure bursts is continuous, most affect vocalizations can be considered to be mixtures of both (Schröder, 2003). However, the definition of affect bursts excludes verbal interjections that occur within speech (e.g., shit!, good god!). One obvious limitation of emotional expression in speech is that speaking is a highly controlled cognitive and motor process that involves strong articulatory movements of the lower face (Banse & Scherer, 1996; Scherer, 1994). Moreover, affective value may be carried by the semantic content rather than by the affective tone of speech, which imposes linguistic barriers (Belin, Fillion-Bilodeau, & Gosselin, 2008).

Prior research has shown affect bursts to be a highly effective means of expressing emotion. To decipher their meaning, researchers focused their early attempts on the classification and description of different classes of affect bursts (Goffman, 1979; Poggi, 1981). More recent studies have shown that affect bursts can convey a number of different emotions to perceivers. When presented only in the audio modality and without context, several emotion expressions were found to be decoded with high accuracy from affect bursts (Hatfield, Hsee, Costello, & Denney, 1995; Hawk et al., 2009; Sauter & Scott, 2007; Simon-Thomas, Keltner, Sauter, Sinicropi-Yao, & Abramson, 2009). This was the case for both raw and emblematic vocalizations (Schröder, 2003). A few studies have also focused on the acoustic analysis of affect bursts. For example, Kaiser (1962) described affect vocalizations for different emotions with respect to timbre, duration, pitch, and intensity. Belin et al. (2008) measured the acoustic characteristics of a large set of nonlinguistic affect vocalizations, demonstrating consistent differences between vocalization categories of six basic emotions (such as anger, fear, and happiness). This evidence suggests that affect bursts reliably communicate important emotional information.

Until now, most research on affect bursts has been performed by using acoustic parameters. As a consequence, all previous literature on affect bursts has been exclusively on the vocal part of these phenomena (see Scherer, 1994). The present research aims to complement this research evidence by providing the first facial analysis of affect bursts. Given the high degree of multimodal synchronization of the expressive modalities, facial expressions may play an important role in the production of affect bursts. We therefore focused on the facial part of affect bursts and analyzed their occurrence in the expression of anger, fear, sadness, joy, and relief. To avoid any contextual biases such as coarticulation, we selected a sustained vowel for encoding purposes. Produced in the form of affect bursts, the isolated open vowel /a/ (unlike speech samples) allows for sudden and time-bonded effects in the facial and vocal modality. The temporal delimitation of affect bursts makes them also particularly good examples of the expression of discrete emotions (Scherer & Ellgring, 2007b).

Facial Expression of Emotion: Underlying Mechanisms

Considerable evidence suggests that a number of basic classes of discrete emotions exist, such as anger, fear, sadness, or joy. Basic emotion theory (BET; Ekman, 1994, 1999, 2003b; Tomkins, 1962) considers these emotions as primary or fundamental in the sense that they form the core emotional repertoire. Although there is now considerable agreement on the adaptive nature, the components, and the response systems of these emotions, several disagreements still persist regarding the underlying mechanism. According to BET, so-called neuromotor affect programs produce a fixed pattern of facial responses for each of the fundamental emotions (Tomkins, 1962, p. 244) in response to appropriate eliciting events. These emotion-specific facial patterns are prototypical and universal, consisting of characteristic configurations (including allowable variants) of muscle actions as described in the Facial Action Coding System (FACS; Ekman & Friesen, 1978; Ekman, Friesen, & Hager, 2002). Having been triggered by a motor command, all muscle actions are supposed to merge together, leading to a uniform configuration of all emotions with coordinated apexes of the contributing action units (AUs; Ekman, 2003a).

Componential appraisal theory (CAT; Ellsworth, 1991; Roseman, 1991; Scherer, 1984, 1987, 2001, 2009) predicts similar response patterns for discrete or modal emotions (Scherer, 1994). However, in contrast to the assumption of neuromotor programs, it conceives of emotions as dynamically emerging response patterns resulting from a series of evaluation appraisals. Because of the sequential nature of appraisals, emotions are expected to differ in the order in which individual expressive elements are shown, consisting of serial cumulative apexes with different sequences of the contributing action units (Scherer & Ellgring, 2007a). For example, it is argued that brow lowering as an appraisal of goal obstruction occurs earlier in anger than in fear. Rather than assuming a set of tightly organized packages, CAT further proposes that even single facial AUs can carry meaning (related to the underlying appraisal or the action tendencies generated), with the resulting combination allowing extensive individual variability in muscle action configurations (Scherer, 1984).

There is some evidence for the occurrence of individual facial components that characterize basic emotions, but so far most studies have not been able to support the more constraining predictions of BET concerning prototypical AU configurations. For example, in a study by Galati, Scherer, and Ricci-Bitti (1997) involving blind and seeing laypeople, the frequency of complete expression patterns was too low to even allow statistical testing. Carroll and Russell (1997) showed that predicted patterns of complete expressions were rare or nonexistent in emotional episodes of several Hollywood films. In fact, except for happiness, actors mostly used only parts of the full configuration. Similar results have been reported by Gosselin, Kirouac, and Doré (1995), who found that there was low probability of occurrence of prototypes for portrayals of felt and unfelt emotion. Although the facial actions that are suggested to be characteristic of the respective emotion did generally occur, not all of them were shown and other facial actions also occurred. This finding was also demonstrated in a more recent study by Scherer and Ellgring (2007a), which found little evidence for full prototypical patterns for basic emotions but considerable variability of AU configurations.

It could be argued that the encoding procedures used in the aforementioned studies may not have been the most suitable for eliciting complete response patterns, as they would normally be triggered by innate facial affect programs. Specifically, procedures relied on either pure facial encoding tasks (in the absence of voice) or sentence/phrase-length speech samples. Both types of emotion portrayals may be rather contextualized and affected by social norms and expectations, which could override core features of the expression stemming from physiological and expressive responses characteristic of spontaneous emotional states. Moreover, the presence of emotion-specific configurations was examined in different ways. Whereas some studies have looked at individual facial actions that occurred as part of a configuration, others specifically tested for the co-occurrence of AUs. This was done by considering either the whole time course (beginning to end) or only the peak of the expression. Thus, measures varied considerably from more liberal to more conservative. The present research examined expressions resulting from brief bursts of affect in both face and voice, as triggered largely by internal push factors. This approach was selected to minimize the influence of sociocultural norms, thereby facilitating the measurement of emotion-specific facial characteristics. In addition, measures consisting of individual facial actions and AU co-occurrences at various time points were compared to check for the presence of facial prototypes in anger, fear, sadness, joy, and relief.

In contrast to basic emotion theories, dimensional theories (Russell, 1997; Schlosberg, 1954) have conceptualized emotions as interrelated entities that differ only along global dimensions such as valence and arousal. Although the theory does not specify what process governs the categorization of emotions, discrete emotions, including those studied here, have been shown to occupy different regions within a two-dimensional space (Russell, 1980; Russell & Bullock, 1986). The unique order of perceived emotion categories was also demonstrated by Schröder (2003) for affect bursts, showing distinct positions for anger, relief, and elation in the valence-pleasure plane. Snodgrass (1992, as cited in Russell, 1997) found that individual facial actions could even be designated specific attributions of pleasure and arousal, suggesting interpretation of facial movements along these dimensions. Until now, classification of emotions and facial actions has been based upon valence and arousal only within a recognition paradigm.

In the present study, we have made a first attempt to classify the occurrence of facial actions, shown in the context of affect bursts, along the valence and arousal dimension of the underlying emotion. This has the potential not only to contribute to a better understanding of emotion dimensions, but also to allow the differentiation of emotional states that would otherwise be subsumed under the same basic emotion family. According to BET, a number of positive emotions (i.e., joy, relief) do not have a distinctive signal, all sharing the Duchenne smile, which consists of smiling lips and raised cheeks (Ekman, 1989, 1992, 1993). Within a dimensional framework, joy and relief clearly differ from each other on the arousal dimension, with high and low arousal, respectively. Therefore, we investigated whether these various types of positive emotions can be reliably differentiated by unique facial patterns.

Aims of the Present Research

This research represents the first analysis of facial expressions based on brief nonlinguistic affect bursts. The focus was on five emotions—anger, fear, sadness, joy, and relief—which were examined for characteristic patterns of facial expression. Although BET predicts that frequent instances of prototypical facial configurations will occur for the basic emotions, CAT proposes more variability, as well as overlap of expressive actions between emotions. The present research aimed to test these contrasting predictions by focusing on both individual facial actions and AU co-occurrences that were shown either during the whole time course or only at the peak of the expression. It was predicted that the more conservative the test became with increasing levels of AU combinations, the lower the frequency of the facial prototypes. This would be expected to be particularly prevalent when testing for the occurrence of AU prototypes (and allowable variants) of BET at the peak level.

A second objective of the present research was to investigate the simultaneity of facial actions. Examination of BET implies that all facial actions merge into a pattern with simultaneous apexes, whereas CAT argues for the cumulative and sequential occurrence of facial expressions. This is the first study to explore the likelihood that expressions of different emotions consist of similar or distinct sequences of facial actions with respect to their apex. In this sense, we examined whether there are significant differences between emotions in the order in which specific AUs reached their apex phase. If facial expressions are the direct result of neuromotor programs, one would expect coordinated apexes with simultaneous actions across emotions.

A third goal of this study was to provide classification of facial expressions along the valence and arousal dimension of the underlying emotion. According to the dimensional approach, specific facial action patterns should be found for positive and negative emotions of high and low arousal. In the present research, we investigated whether facial actions differed significantly as a function of the valence and arousal level of the five emotions. This was done to allow a further distinction between joy and relief, which BET attributes to the same emotion category. In addition, multidimensional scaling was used with the aim of mapping the relationship between facial actions in a two-dimensional space, thereby revealing any similarity or dissimilarity in the AU distributions between emotions.

Method

Emotion Expressions

To obtain full-blown emotional expressions while maintaining control on the type and number of emotional states, we used emotion portrayals by 10 professional actors (5 men, 5 women), which are part of the GEMEP corpus developed by Bänzinger and Scherer (2010). The use of actors has a long history in the study of emotion research (see Banse & Scherer, 1996; Gosselin et al., 1995; Hawk et al., 2009; Scherer & Bänzinger, 2010; Scherer & Ellgring, 2007a, for the use of actor portrayals). Moreover, actors generally have substantial experience with the expression of emotions in the context of recorded performances (including the presence of cameras) due to their stage work. The nature of the emotions to be shown was extensively illustrated with emotion scenarios and brief illustrative descriptions prior to the recording (see Appendix A). To provide valid exemplars of emotional expressions, actors were instructed to immerse themselves into the given scenarios using auto-induction. The procedure generally followed the philosophy of the Stanislavski method, in which an appropriate affective state is elicited by imaging and reexperiencing personal life events and related emotions. In close interaction with a professional director, actors uttered at the apex of the relived emotion a sustained vowel (/a/). This schwa sound /a/ is the most widely produced affect burst under many different circumstances as it corresponds to the most neutral shape of the vocal tract. Thus, whenever someone just opens the mouth without any articulatory effort, this schwa sound will result and is thus adapted to a wide variety of emotional states (Scherer, 1994). Given the multimodal nature of affect bursts, we asked our actors to produce holistic response patterns, allowing for the variation of voice quality (produced by phonatory activity of the glottal muscles) and facial expressions (produced by facial muscles) independently of each other. No priority for one of the channels was given or implied.

For the purposes of the present research, we focused on five emotions that systematically differed in their valence (positive: *M*s > 6.00, negative: *M*s < 3.00) and arousal level (high: *M*s > 7.00, low: *M*s < 5.00; on a linear scale from 0 to 10) as demonstrated by independent ratings of 60 participants (see Mortillaro, Mehu, & Scherer, in prep.): hot anger, panic fear (high arousal, negative valence), elated joy (high arousal, positive valence), relief (low arousal, positive valence), and sadness (low arousal, negative valence). Each of the five emotions was instantiated by 20 portrayals (10 actors x 2 renderings). The two renderings per actor and emotion were chosen with respect to the overall recognizability of the targeted emotions by expert raters from a larger pool of expressions involving several recordings of each of 15 different emotions. For all portrayals mean recognition rates by lay judges (90 students at the University of Geneva; see Bänzinger & Scherer, 2010) were significantly better than chance level (76.45% for anger, 97.40% for fear, 63.90% for joy, 89.60% for relief, and 42.50% for sadness, *p*s < .001) in the audio-visual modality which was set in a conservative fashion at 5.88% (1 out of 17), given the 15 categories of emotion plus ´no emotion´ and ´other emotion´. Similarly good recognition rates were found when portrayals were judged in the vocal (*M*s > 32%) or facial modality (*M*s > 41%), providing evidence of the validity of the portrayals in terms of the intended emotions of the actors.

Facial Coding

Facial activity was scored using the Facial Action Coding System (FACS, Ekman et al., 2002). FACS enables the measurement of all visible facial behavior and describes it in terms of AUs. Besides the type and intensity of each AU, the timing of the AU movement (onset, apex, offset) can be specified. A FACS certified coder manually scored the 100 expressions frame by frame (25 frames/s) and recorded all AUs that occurred within the time intervals. In addition, head and eye positions and movements were coded by using the guidelines provided in the FACS manual. This resulted in a final set of 59 AUs that were retained for statistical analysis. For each portrayal, the onset, apex, and offset phase of the AUs were determined. A new AU was recorded every time that a new onset was observed or when it was seen increasing after a decrease in intensity. However, when an AU was already present at the beginning of the expression, coding had to begin from the first frame. For the purposes of the present research, we focused only on the apex as the time phase of interest. In order for the apex to be scored, the AU had to reach a plateau or peak with no further increase in intensity. Given that actors only had to vocalize an /a/ sound, no bias was introduced by the facial muscle activity related to speech rather than emotion, as the articulatory setting was similar for all portrayals.

Intercoder reliability was checked by a second FACS-certified coder for approximately 25% of the 100 expressions. The subset of expressions was selected to be adequately respresentative of the range of emotions included in the whole set. In total, 26 expressions with a balanced representation across the 10 actors and 5 emotions were coded for reliability. Mean agreement for the presence of AUs was high (Cohen's K = .87). The interrater variability in scoring the apex of an AU was within a 0.5-s tolerance window (see Sayette, Cohn, Wertz, Perrott, & Parrott, 2001) and yielded a Cohen's Kappa coefficient of K = .85.

Data Preparation: Effects of Design Factors on the Observed Frequency of AUs

Overall, one-way analysis of variance (ANOVA) for each of the AUs did not yield significant differences between the two renderings for each actor and emotion. The only exception was AU17 (Chin Raiser), which occurred slightly more often in the first rendering (M = 0.16) than in the second rendering (M = 0.04, p = .046). All other AUs were independent of this factor. We also examined individual differences for AU production for the entire group of 10 actors. As expected, one-way ANOVAs for each of the AUs showed significant differences for some of the AUs (i.e., AU7, AU17, AU20, AU55, AU61; see Scherer & Ellgring, 2007a for similar effects).

However, there was no systematic pattern and none of the actors differed significantly from the others on more than one AU. Thus, we disregard these differences in the Results section.

Results

Occurrence of Individual AUs at Onset, Apex, or Offset Phase

Of 59 AUs, we removed all AU categories for which no instance was observed in our data. This left a total of 45 AUs with one or more instances at any time phase of the expression (onset, apex, or offset). We first tested against the null hypothesis that AUs were used indiscriminately or in a random fashion to encode the five emotions. A multivariate analysis of variance (MANOVA) with the between-subjects factor emotion (five levels) was performed on the 45 AUs. The multivariate main effect of emotion was highly significant, $F(176, 220) = 4.54$, $p = .000$, $\eta_p^2 = .78$. Univariate tests showed significant main effects on 24 of the 45 AUs. Table 1 shows the mean proportions and *F* statistics for the 24 AUs that differed significantly between emotions.

---Table 1 about here ---

For anger, the Upper Lid Raiser (AU5), the Upper Lip Raiser (AU10), the Lower Lip Depressor (AU16), the Lip Stretcher (AU20), the Mouth Opener (AU26, AU27), and Head Forward (AU57) were among the most frequent AUs. An often used action was also the Eyebrow Raiser (AU1, AU2) to iconically signal the novelty of the event (see Ekman, 1979). The high proportion of the Eyebrow Raiser may have been responsible for the moderate occurrence of the Brow Lowerer (AU4). Similarly, Lip Pressing (AU24) and Lip Tightening (AU23), also typically predicted to depict anger, were less frequent or absent, as the production of the open mouth interfered with these AUs, which were often seen with a closed mouth.

All AUs that are predicted to signal fear occurred at high frequency: the Eyebrow Raiser (AU1, AU2), the Brow Lowerer (AU4), the Upper Lid Raiser (AU5), the Lip Stretcher (AU20), and the Mouth Opener (AU26, AU27). In addition, Head Up (AU53), the Lower Lip Depressor (AU16), and the Lip Corner Puller (AU12) were common criteria. Pulling the lip corners backward (AU12) might have functioned as a means to produce the appropriate mouth opening for the desired /a/ sound.

For elated joy, the most frequent AUs were the Eyebrow Raiser (AU1, AU2), the Lip Corner Puller (AU12), the Cheek Raiser (AU6), the Lid Tightener (AU7), the Mouth Stretcher (AU27), and Head Up (AU53). Furthermore, the Jaw Drop (AU26) and the Upper Lid Raiser (AU5) occurred in about half of the expressions. Besides AU6 and AU12, which are predicted for joy, most of the other AUs can be interpreted as signals of elation, which involves components of unexpectedness.

Expressions of relief consisted most frequently of actions involving the Lid Tightener (AU7), the Lip Corner Puller (AU12), the Jaw Drop (AU26), Eye Closure (AU43), and Head Up (AU53). The Cheek Raiser (AU6) was not observed very often. Also, the Mouth Stretch (AU27), which frequently occurred with anger, fear, and elated joy (high arousal emotions), was nearly absent in relief.

For sadness, the proportion of AUs shown was generally low. Among the five predicted AUs, only the Inner Brow Raiser (AU1) and the Brow Lowerer (AU4) occurred at moderate frequency. The predictions concerning the Lip Corner Depressor (AU15), the Chin Raiser (AU17), and the Nasolabial Furrow (AU11) were not supported by the data because of their overall low frequency. However, several AUs that had not been previously predicted were relatively common: the Lid Tightener (AU7), the Jaw Drop (AU26), the Blink (AU45), and Head Up (AU53)[1].

Patterned Co-Occurrences of AUs at Onset, Apex, or Offset Phase

All 24 AU categories that were significant in the preceding analysis were analyzed for co-occurrence with each other. This resulted in a set of 276 AU combinations that occurred during onset, apex, or offset phase. Because of the high number of AU pairs, we examined only those combinations that occurred in at least 50% (10 of 20) of the expressions of one emotion. A MANOVA with the between-subjects factor emotion (five levels) was performed on a final set of 75 AU combinations. On a multivariate level, the main effect of emotion was highly significant, $F(260, 136) = 2.32$, $p = .000$, $\eta_p^2 = .82$. Univariate tests showed that, except for one AU combination (AU2+26, $p = .21$), main effects were significant on all AU combinations. Table 2 shows the mean proportions and *F* statistics for the AU combinations that differed significantly between emotions.

---Table 2 about here ---

As can be seen, the Eyebrow Raiser (AU1+2) was a common combination in anger, fear, and elated joy. However, there was a difference across emotions in the way in which these eyebrow movements co-occurred with other AUs. Characteristic configurations of AUs were found for most of the five emotions. In anger, movements of the outer but also of the inner eyebrow occurred with high proportions with the Lower Lip Depressor (AU16) and the Lip Stretcher (AU20). The latter two AUs, together with the Upper Lip Raiser (AU10), most frequently described the mouth action.

For fear, the Eyebrow Raiser (AU1, AU2) was mainly shown in combination with the Brow Lowerer (AU4) and the Upper Lid Raiser (AU5), thereby providing an emotion-specific signal of fear. As predicted, the movement of the mouth most often involved the Lip Stretcher (AU20) in combination with the Mouth Opener (AU26, AU27). Thus, none of the vertical actions (AU10, AU16) were observed with high frequency with the stretching of the lips in fear.

A completely different set of AUs co-occurred with the Eyebrow Raiser (AU1, AU2) in elated joy. Here the inner and the outer brow raiser were mainly shown in combination with the Cheek Raiser (AU6), the Lid Tightener (AU7), the Lip Corner Puller (AU12), the Mouth Stretcher (AU27), and Head Up (AU53). The predicted configuration of AU6 and AU12 occurred frequently. However, the Cheek Raiser (AU6) also often co-occurred with the Lid Tightener (AU7) and this configuration was frequently accompanied by the combined action of AU12, AU27, and AU53.

In relief, the Lid Tightener (AU7) most often co-occurred with the Lip Corner Puller (AU12). Each of those actions was frequently shown in combination with the Jaw Drop (AU26), Eye Closure (AU43), and Head Up (AU53), thereby providing a characteristic pattern of AUs that differed from the configuration of elated joy.

In sadness, none of the selected AU combinations were common, and evidence for the existence of emotion-specific configurations was rare. The predicted pattern of the Inner Brow Raiser (AU1) in combination with the Brow Lowerer (AU4) occurred only with low proportions. Other more often observed configurations consisted of the Inner Brow Raiser (AU1) together with the Lid Tightener (AU7) and of the Brow Lowerer (AU4) together with Head Up (AU53).

Relationship between Emotions for Patterned Co-Occurrences of AUs

Correlational analyses were performed to examine how many of each of the five emotions—anger, fear, joy, relief, and sadness—shared patterned co-occurrences of specific AUs. Specifically, we computed profile correlations in a table organized by sequence of AU combinations in ascending order of AU numbers, with frequency by emotion as entries. As seen in Table 3, AU combinations of anger were significantly and positively correlated with those of fear. In this sense, anger and fear shared similar patterns of AU combinations. A significant but negative relationship was found between anger and joy and between anger and relief. That is, AU combinations of joy and relief were inversely related to those of anger, suggesting that these emotions differed in the co-occurrences of specific AUs. As expected, joy and relief were positively correlated for the pattern of specific AU combinations. Surprisingly, AU combinations of relief were also significantly and positively associated with those of sadness.

---Table 3 about here ---

Occurrence of AU Prototypes at Apex Phase

In the following analysis, for each emotion, we examined the presence of AU patterns that occurred at the apex. This approach differed from the preceding analyses in which the co-occurrence of two AUs was considered at any time of the expression (onset, apex, or offset). For each emotion, we calculated the occurrence of AU prototypes and major variants as predicted by BET (Ekman et al., 2002). In addition, we extracted additional prototypes that were the two most frequent occurrences on each level of AU combination. Table 4 contrasts the mean proportions of AU combinations as predicted by BET with those that occurred as new empirically found prototypes.

---Table 4 about here ---

For anger, only a marginal number of expressions were consistent with BET predictions. Instead, prototypes that included AU1+2 but not AU5 occurred more frequently on most levels of AU combinations (see Figure 1 for exemplars of the empirically found emotion prototypes). Among all prototypes, the most frequent combinations were AU10+20+25 and AU10+16+25, which were shown in roughly half of the anger expressions. For fear, a larger number of expressions matched BET's prototypes and major variants. However, compared with the complexity of activated units, other prototypes occurred more often on each level of AU combination. It is also noteworthy that AU4 was not part of most of those prototypes. Instead, the majority of fear expressions consisted of AU1, 2, 5, 25, and/or 27. In the case of sadness, only one expression (M = 0.05) was consistent with BET predictions. Overall, there were only a limited number of prototypes and the frequency of occurrence was low. For joy, most expressions matched the prototypes of AU6+12 and AU12C/D. However, other prototypes such as AU6+7+12+25, and AU7+12+25 also occurred quite often. AU6+12 and AU12 therefore might be part of a more heterogeneous expression. An interesting finding was that in relief, the occurrence of AU6+12 and AU12C/D was much lower and similar to that of AU prototypes that occurred at higher combination levels (i.e., AU6/7+12+25+53+56). This leads to the conclusion that it is not the same prototypes that apply to both joy and relief. Instead, AU12 at low (A/B) intensity appeared to be the most frequently shown prototype of relief.

---Figure 1 about here ---

Simultaneous or Sequential Occurrence of AUs across Emotions

Overall, emotion portrayals lasted between one and three seconds in total: anger (*M* = 1.76, *SE* = 0.15), fear (*M* = 1.51, *SE* = 0.13), joy (*M* = 2.54, *SE* = 0.29), relief (*M* = 3.10, *SE* = 0.31), and sadness (*M* = 2.65, *SE* = 0.25). In order to standardize the occurrence of AUs across emotion portrayals of different lengths, we used an analog time measure. *M*SecAnlg refers to the relative apex position of AUs averaged across portrayals in an analog time scale from 0 (start) to 1 (end). This parameter indicates, regardless of portrayal length, a standardized apex position, thereby allowing a direct comparison of AU sequences between emotions. For the sequence analysis, we considered 42 of 59 AUs that occurred at their apex phase of the expression. A Kruskal-Wallis H-test was performed on the time scaled data of the 42 AUs. As predicted by CAT, the five emotions differed significantly in the order in which specific AUs reached their apex phase. These differences were significant for the Brow Lowerer (AU4), $\chi^2(4) = 13.17$, $p = .001$; the Lid Tightener (AU7), $\chi^2(4) = 10.19$, $p = .037$; the Upper Lip Raiser (AU10), $\chi^2(4) = 16.91$, $p = .002$; and Lips Part (AU25), $\chi^2(4) = 22.59$, $p = .000$. Table 5 shows the sequential occurrences of AUs at their apex that were shown in at least 50% of the expressions of each emotion. Mann-Whitney U tests were performed to test for significant differences in AU sequences between emotions. As can be seen, in anger and fear, the Brow Lowerer (AU4) occurred at its apex significantly later in sequence than it did in sadness ($M_{SecAnlg} = 0.03$, *ps* < .01). There was no significant difference in the sequential occurrence of AU4 between anger and fear ($p = .114$).

---Table 5 about here ---

For the Lid Tightener (AU7), differences in AU occurrence were found for elated joy, sadness, and anger. Specifically, AU7 reached its apex significantly later in sequence in elated joy than it did in sadness ($p = .018$) and in anger ($M_{SecAnlg} = 0.28$, *p*

= .014). Except for anger, the frequency of the Upper Lip Raiser (AU10) at its apex was generally lower. For both sadness and joy, the sequential occurrence of AU10 was comparable ($M_{SecAnlg}$ = 0.09 vs. $M_{SecAnlg}$ = 0.00, p = .273) and differed significantly from that of fear ($M_{SecAnlg}$ = 0.36, *p*s < .05) and anger ($M_{SecAnlg}$ = 0.23, *p*s < .05). Furthermore, AU10 reached its apex significantly earlier in sequence in anger than it did in fear (p = .042) and in relief ($M_{SecAnlg}$ = 0.59, p = .025). Lips Part (AU25) was a frequent action in all expressions, but differed in the order in which it was shown across several emotions. The sequential occurrence of AU25 was similar for relief and sadness (p = .743). For both emotions, AU25 occurred at its apex significantly earlier in sequence than it did in anger (*p*s < .05) and in fear (*p*s < .001).

From inspection of Table 5, characteristic sequences of AU occurrence were found for each of the five emotions. Anger generally commenced with Head Up (AU53) together with Eyebrow Raising (AU2, AU1) and Neck Tightening (AU21), followed by vertical actions of the mouth (AU16, AU10), Mouth Opening (AU27, AU26), horizontal mouth actions (AU20, AU12) with Brow Lowering (AU4) and Upper Lid Raising (AU5), and finally Head Forward (AU57) and Jaw Sideways (AU30). In comparison, sequences of fear most often started with Brow Lowering (AU4), followed by Mouth Opening (AU25, AU27) with Head Up (AU53), Eyebrow Raising (AU1, AU2), horizontal actions of the mouth (AU12, AU20), Upper Lid Raising (AU5), and vertical mouth actions (AU16). In this sense, Eyebrow Raising as a signal of relevance detection marked the beginning of anger, whereas it followed Brow Furrowing in expressions of fear.

Sequences of joy were generally characterized by Eyebrow Raising (AU2, AU1) with Mouth Opening (AU25, AU27) and Head Up (AU53), followed by Smiling (AU12), Lid Tightening (AU7), and Cheek Raising (AU6). In relief, Lid

Tightening (AU7) occurred before Smiling (AU12) and was preceded by Mouth Opening (AU25, AU26) with Eye Closure (AU43) and then Blinking (AU45) and Head Up (AU53). AU7 may therefore have functioned to signal the peak of arousal in elated joy, whereas it marked the peak of tension release in relief. Sequences of sadness consisted of a limited number of AUs. Most often they started with Lips Parting (AU25), followed by Lid Tightening (AU7), Head Up (AU53) and Blinking (AU45).

Occurrence of AUs across Valence and Arousal

To test to what extent AUs occurrences covary with the valence and arousal level of the five emotions, a MANOVA with the between-subjects factors valence (negative, positive) and arousal (high, low) was performed on the set of 45 AUs described in the preceding analysis (frequency analysis over emotions). Multivariate main effects were found for valence, $F(44, 53) = 10.57$, $p = .000$, $\eta_p^2 = .90$, and arousal, $F(44, 53) = 9.10$, $p = .000$, $\eta_p^2 = .88$. These two main effects were qualified by a significant interaction between valence and arousal, $F(44, 53) = 4.98$, $p = .000$, $\eta_p^2 = .80$. The interaction was significant for 11 AUs. Table 6 shows the mean proportions and *F* statistics for the 11 AUs that differed significantly as a function of the valence and arousal level of the five emotions.

---Table 6 about here ---

As can be seen, the Upper Lid Raiser (AU5) occurred most frequently in high arousal negative emotions and more frequently under high arousal than under low arousal of both negative and positive emotions. This finding suggests an arousal-specific function of AU5 beyond the valence of the emotion. In addition, the Upper Lip Raiser (AU10), the Lower Lip Depressor (AU16), the Lip Stretcher (AU20), and the Neck Tightener (AU21) all occurred at their highest frequency in high arousal negative emotions. They might therefore constitute an arousal-specific cluster of negative valence. The Cheek Raiser (AU6) was shown more frequently in positive than in negative emotions. However, its occurrence was also significantly diminished in low arousal positive emotions, suggesting that AU6 is not part of a unified positive expression, but also varies with the arousal level of the emotion. The Lid Tightener (AU7) was displayed with highest frequency in positive emotions, as well as in low arousal negative emotions, thereby illustrating a more general function of this facial action. Another component of the positive valence cluster was the Lip Corner Puller (AU12), which occurred most frequently in positive emotions. Nonetheless, there was also considerable occurrence of AU12 in high arousal negative emotions. The Jaw Drop (AU26) was the only action that occurred with high frequency and at roughly the same proportions across all valence and arousal dimensions. Its function may therefore be conceived in terms of power and control, indicating either relaxation (low control) or willful opening of the jaw (high control).

Multidimensional scaling (ALSCAL) was used to detect meaningful patterns of AU distributions as a function of the valence and arousal level of the five emotions. AU mean frequencies were plotted by using two-dimensional solutions with good-to-excellent fit indices. Figure 2 illustrates the relative positions of the 24 AUs (that were significant in the frequency analysis over emotions) in the different valence and arousal plots. Inspection of the affective space revealed distinct shapes of AU distributions for high and low arousal dimensions. Specifically, for high arousal, the AU clustering appeared as a boomerang or U shape for positive emotions (Figure 2b) and as an inverse U shape for negative emotions (Figure 2a). For low arousal, mean frequencies of AUs produced more circular-shaped affective spaces with opposite regions of dense AU clustering for negative (Figure 2c) and positive emotions (Figure 2d). Thus, within each arousal dimension, AU distributions for negative emotions seemed to mirror those of positive emotions, thereby demonstrating the impact of valence in the affective space.

Despite the similarity of shape between the two plots in each arousal dimension, the position of AUs varied considerably between the plots. For example, whereas AU12 (Lip Corner Puller) clustered with AU10 and AU21 in the high arousal, negative emotion plot, it was closest to AU1, AU2, and AU6 in the high arousal, positive emotion plot. An interesting finding was that there was also a difference in the clustering of AU12 and AU6 between high and low arousal positive emotions. Instead of a tight coupling of these two facial actions as predicted by BET for positive emotions, the Cheek Raiser (AU6) was considerably distinct in position from AU12, which clustered with AU26 (Jaw Drop) and AU53 (Head Up) in positive low arousal emotions.

---Figure 2 about here ---

Discussion

This study focused on affect bursts as multimodal phenomena of synchronized facial and vocal activity. Whereas previous research had investigated the vocal aspect of affect bursts (i.e., Belin et al., 2008; Hawk et al., 2009; Schröder, 2003), this study is the first to conduct a facial analysis of nonlinguistic affect vocalizations. By using a single vowel /a/, we investigated whether anger, fear, sadness, joy, and relief demonstrated emotion-specific patterns of facial activity. According to BET, prototypical configurations of facial actions should frequently occur for the basic emotions. Although CAT proposes similar AUs, fewer prototypical configurations and greater variability of expression patterns are expected. To test these contrasting predictions, we applied a number of measures, focusing on various time points of the expression.

Results for the occurrence of individual facial actions and AU co-occurrences at the onset, apex, or offset phases showed a reasonable degree of differentiation across basic emotions. Overall, the predicted facial actions occurred quite frequently, and the mean probability of occurrence was higher than had been reported in previous studies (Carroll & Russell, 1997; Galati et al., 1997; Gosselin et al., 1995; Scherer & Ellgring, 2007a). Specifically, results showed that the expected AUs occurred at their highest prevalence for fear and joy, averaging from 80% to 100%. For all emotions, however, facial actions other than those that had been predicted occurred rather frequently. The eyebrow raise (AU1, AU2) was often shown in anger, fear, and joy, suggesting that this may be a more general emotion expression pattern related to the novelty or unexpectedness of the event (Ekman, 1979; Kaiser & Wehrle, 2001; Scherer, 1987). Similar findings have been reported in Carroll and Russell's (1997) analysis of Hollywood movies, namely, that the brow raise, despite its frequent occurrence, was not uniquely or strongly associated with one emotion.

For anger, instead of predicted behavior such as lip pressing (AU24) and lip tightening (AU23), other horizontal and vertical actions of the mouth (AU10, AU16, and AU20) often occurred. The vocal production in affect bursts is likely to have interfered with these facial actions, as they are often seen with a closed mouth. Similarly, the low proportion of AUs in sadness could be attributed to the fact that sadness was portrayed as low-arousal emotion including components of depression. In his established list of affect bursts, Schröder (2003) found only a few affect burst classes that seemed to express sadness. It may well be that this quieter form of sadness is not typically expressed through affect bursts (see also Banse & Scherer, 1996) compared to more aroused variants of this emotion such as despair (involving crying vocalizations, see Hawk et al., 2009). Overall results for patterned co-occurrences of facial actions were in line with predictions, showing significant positive relationships between anger and fear and between joy and relief. These results demonstrate that emotions of each family share similar behavioral patterns. Again, the only exception was sadness, which correlated somewhat higher with relief than with fear and anger, possibly because of the similarity in arousal level.

Testing for prototypical patterns of facial actions at the apex phase showed that there was less convergence on a limited number of prototypes as predicted by BET. Specifically, occurrence of complete or full prototypical patterns was rare. Except for the Duchenne smile (AU6+12) in joy, none of the prototypical configurations occurred frequently. These findings support previous evidence (Carroll & Russell, 1997; Scherer & Ellgring, 2007a) demonstrating that only happiness has stable AU patterns. For all other emotions, the predicted prototypes were shown infrequently and—at best—consisted of subsets of the full pattern. These partial prototypes lacked the presence of predicted single AUs (i.e., AU5 in anger, AU4 in fear) and/or contained additional facial actions (AU1+2 in anger, AU7 in joy) that have not been included before. Overall, there was a tendency for prototype occurrence to decrease when the numbers of AU combinations increased.

These findings cast doubt on the existence of fixed patterns of facial responses for each basic emotion. Instead of tightly organized facial configurations, each emotion was signaled by several different expressions that shared multiple facial actions. In recent years, the validity of prototypes has come under criticism, as most evidence in favor of BET has come from recognition studies with carefully selected portrayals of posed expressions (Russell & Fernández-Dols, 1997; Scherer, 1999; Smith & Scott, 1997). In the present research, we have shown that the strength and prototypicality of the patterning depends on the measure applied. Whereas individual AUs occurred as part of a predicted configuration during the onset, apex, or offset phase reasonably often, the combined activation of all required facial actions at the apex phase was rarely evident. Thus, the more stringent the test became with increasing levels of AU combinations, the lower the frequency of the facial prototypes. In line with previous studies (Carroll & Russell, 1997; Galati et al., 1997; Gosselin et al., 1995; Scherer & Ellgring, 2007a), these findings show that BET predictions concerning a limited number of prototype expressions are not more accurate than the more molecular predictions focusing on individual facial actions. Instead, results seemed to point toward the variability of expression patterns and the meaning of specific facial movements, as suggested by CAT (see Kaiser & Wehrle, 2001; Scherer, 1992).

Another aim of the present research was to investigate the simultaneity of the unfolding of facial actions. According to BET's assumption of neuromotor programs, all facial actions that make up a prototypical expression pattern should be produced simultaneously with coordinated apexes between emotions. Results showed no direct evidence for such coordinated actions. Rather, there were significant differences in the sequential occurrence of facial actions between emotions, with individual facial movements reaching the apex in a cumulative-sequential fashion. Specifically, the basic emotions differed in the order in which certain AUs (i.e., AU4, AU7, AU10, AU25) reached their apex phase. Surprisingly, brow lowering (AU4) did not occur earlier in sequence when shown in anger than when shown in fear. CAT theory states that brow lowering is associated with the perceived goal obstacle (Ellsworth, 1991;

Ellsworth & Scherer, 2003; Smith & Scott, 1997), which is supposed to occur as an early evaluation check in anger (Scherer & Ellgring, 2007a). This assumption has not been subject to empirical testing before and is not necessarily supported by the present findings. Overall, there is evidence for the notion of sequentiality, which questions BET´s premise of comparable ballistic trajectories and coordinated apexes of facial actions (Wehrle, Kaiser, Schmidt, & Scherer, 2000). It remains for future research to determine the extent to which the CAT predictions of sequential evaluation appraisals fit the actual order of facial actions across emotions.

As well as the analysis of emotion-specific patterns, a third goal of the current study was to provide classification of facial expressions within a dimensional approach. Specifically, we wanted to identify whether facial actions that were shown in the context of affect bursts differed significantly as a function of the valence and arousal levels of the five emotions. Results showed valence- and arousal-specific differences between several facial actions. The Upper Lip Raiser (AU10), the Lower Lip Depressor (AU16), the Lip Stretcher, and the Neck Tightener (AU21) occurred most often in negative emotions of high arousal. Although the Lip Corner Puller (AU12) was shown most frequently in positive emotions, there was considerable evidence of this action in high arousal negative emotions. The presence of AU12 corresponding to M. zygomaticus major activation has also been previously reported for emotions such as fear and disgust (Aue, Flykt, & Scherer, 2007; Galati et al, 1997; Larsen, Norris, & Cacioppo, 2003). Its function may be a means of enabling maximum lip corner retraction, which is not possible due to the sole activity of the M. risorius (AU20), particularly with an open mouth and dropped jaw. Such retracting movements have been shown to be part of vocalized bared-teeth displays that phylogenetically constitute one of the oldest facial expressions. Van Hooff (1972, p.

214, Fig. 2) has described this intense vocalized display, including horizontal lip retraction, in monkeys that are subject to threat or strong aversive stimulation. Given the similarity between affect bursts and animal affect vocalizations, the lip retraction in AU12 may be reminiscent of such functional behavior patterns.

There was also a significant difference in the presence of the Cheek Raiser (AU6) between high and low arousal positive emotions. This finding contradicts the assumption of BET that all positive emotions share the same Duchenne smile (AU6+12) expression. Instead, AU6 was specific only for high arousal positive emotions (i.e., joy) and lacked occurrence when displayed under positive low arousal (i.e., relief). Separate emotion-specific patterns were found for joy and relief, suggesting that these two positive emotions differ in their underlying meaning and behavioral elements. It may be the case that a single facial expression does not sufficiently encompass the many meanings of positive emotions. Similar arguments have been made for other positive emotions such as pleasure, elation, and interest (Ricci-Bitti, Caterina, & Garotti, 1996; Sauter, 2010; Wehrle et al., 2000). Multidimensional scaling demonstrated that this dissimilarity between joy and relief was also evident in the affective space. Not only were there distinct shapes of AU distributions for high and low arousal positive emotions, but facial actions also varied considerably in their positions between the plots. Whereas AU6 clustered with AU12 in positive high arousal, it was far from AU12 in positive low arousal. The dimensional approach as applied here allowed, for the first time, a differentiation of emotional states that would otherwise be subsumed under the same basic emotion family. Future studies might be aimed at disentangling these further and at differentiating negative emotions that fall into the same emotion category (i.e., fear and anxiety) but differ on a valence and arousal level.

In this research, emotional expressions as portrayed by professional actors were used as exemplars of five different emotions. It is debated whether such expressions reflect authentic and believable emotions, but given the inherent role of regulation and expression control in everyday behavior, we argue that the degree of naturalness depends on the production strategy (see Banse & Scherer, 1996; Scherer, 2003; Schröder, 2003). To obtain a close approximation of authentic expressions, in our procedure we used the Stanislavski technique, which is based on the auto-induction of emotional states. In an attempt to reexperience and relive the emotions described in brief scenarios, Gosselin et al. (1995) showed that actors can indeed succeed in feeling the intended emotion. The nature of affect bursts as one of the most primitive emotion signals may render emotional portrayals closer to natural expressions. By uttering a single vowel /a/, no attention was diverted to articulatory or semantic aspects, thereby allowing time-bonded and relatively uncontrolled emotional utterances. The sudden and synchronized facial and vocal activity evident in affect bursts may have therefore alleviated some of the difficulties usually associated with acting. Nonetheless, an important avenue for future research remains the study of naturally occurring affect bursts in emotionally charged field situations.

Until now, the limited research effort in this domain has focused predominantly on laughter as the primary affective vocalization. For example, Szameitat, Alter, Szameitat, Darwin, et al. (2009) and Szameitat, Alter, Szameitat, Wildgruber, et al. (2009) showed that emotions such as joy, tickling, taunting, and schadenfreude could be reliably classified and were associated with distinctive acoustic profiles. Bachorowski and Owren (2001) found that voiced laughter led to emotional ratings that differed from unvoiced laughter. The study of emotions in spontaneous nonlinguistic vocalizations is also of relevance for human-computer interaction.

Recent approaches have focused on the automatic detection of laughter in audiovisual streams in order to determine the affective state of the user (Petridis & Pantic, 2008a, 2008b; Truong & Van Leeuwen, 2007). Voice-driven animations strive for the implementation of nonlinguistic articulations in virtual humans, such as laughing or crying (Cosker & Edge, 2009; Cosker et al., 2008). Beyond the importance of such articulations for emotional communication, they may also be indispensable for adding life and realism to such interactions. Unfortunately, most of this work has so far been based only within an audio domain, thereby neglecting the visual information carried by the facial expression of an individual. The present research has been the first of its kind to study the facial component of nonlinguistic affect vocalizations. By analyzing the facial expressions of five emotions in affect bursts, the findings may have relevance not only for advancing theories in emotion research, but also in helping to improve existing technologies in applied fields such as affective computing.

References

Aue, T., Flykt, A., & Scherer, K. R. (2007). First evidence for differential and sequential efferent effects of stimulus relevance and goal conduciveness appraisal. *Biological Psychology, 74,* 347-357.

Bachorowski, J. A., & Owren, M. J. (2001). Not all laughs are alike: Voiced but not unvoiced laughter readily elicits positive affect. *Psychological Science, 12*, 252-257.

Banse, R., & Scherer, K. R. (1996). Acoustic profiles in vocal emotion expression. *Journal of Personality and Social Psychology, 70*, 614-636.

Bänzinger, T., & Scherer, K. R. (2010). Introducing the Geneva multimodal emotion portrayal (GEMEP) corpus. In K. R Scherer, T. Bänziger, & E. Roesch (Eds.), *Blueprint for affective computing: A sourcebook and manual (affective science)* (pp. 271-294). Oxford, England: Oxford University Press.

Belin, P., Fillion-Bilodeau, S., & Gosselin, P. (2008). The Montral affective voices: A validated set of nonverbal affect bursts for research on auditory affective processing. *Behavior Research Methods, 40*, 531-539.

Carroll, J. M., & Russell, J. A. (1997). Facial expressions in Hollywood's portrayal of emotion. *Journal of Personality and Social Psychology, 72*, 164-176.

Cosker, D., & Edge, J. (2009). Laughing, crying, sneezing and yawning: Automatic voice driven animation of non-speech articulations. In *Proceedings of Computer Animation and Social Agents* (CASA) (pp. 21-24). Amsterdam, Netherlands: CTIT.

Cosker, D., Holt, C., Mason, D., Whatling, G., Marshall, D., & Rosin, P. L. (2008). Automatic audio driven animation of non-linguistic vocalizations. In

Proceedings of 8th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering (CMBBE). Porto, Portugal.

Ekman, P. (1979). About brows: Emotional and conversational signals. In M. von Cranach, K. Foppa, W. Lepenies, & D. Ploog (Eds.), *Human ethology: Claims and limits of a new discipline* (pp. 169-202). Cambridge, England: Cambridge University Press.

Ekman, P. (1989). The argument and evidence about universals in facial expressions of emotion. In H. Wagner & A. Manstead (Eds.), *Handbook of social psychophysiology* (143-164). Chichester, England: John Wiley & Sons.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion, 6*, 169-200.

Ekman, P. (1993). Facial expression and emotion. *American Psychologist, 48*, 384-392.

Ekman, P. (1994). All emotions are basic. In P. Ekman & R. J. Davidson (Eds.), *The nature of emotion: Fundamental questions* (pp. 15-19). New York, NY: Oxford University Press.

Ekman, P. (1999). Basic emotions. In T. Dalgleish & M. J. Power (Eds.), *Handbook of cognition and emotion* (pp. 45-60). Chichester, England: John Wiley & Sons.

Ekman, P. (2003a). Darwin, deception and facial expression. *Annals of the New York Academy of Sciences, 1000*, 205-221.

Ekman, P. (2003b). *Emotions revealed* (2nd ed.). New York, NY: Times Books.

Ekman, P., & Friesen, W. V. (1978). *The Facial Action Coding System*. Palo Alto, CA: Consulting Psychologists Press.

Ekman, P., Friesen, W. V., & Hager, J. C. (2002). *The Facial Action Coding System* (2nd ed.). Salt Lake City, UT: Research Nexus eBook.

Ellsworth, P. C. (1991). Some implications of cognitive appraisal theories of emotion. In K. T. Strongman (Ed.), *International review of studies on emotion* (Vol. 1, pp. 143-161). New York, NY: Wiley & Sons.

Ellsworth, P. C., & Scherer, K. R. (2003). Appraisal processes in emotion. In R. J. Davidson, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 572-595). New York, NY: Oxford University Press.

Galati, D., Scherer, K. R., & Ricci-Bitti, P. E. (1997). Voluntary facial expression of emotion: Comparing congenitally blind with normally sighted encoders. *Journal of Personality and Social Psychology, 73*, 1363-1379.

Goffman, E. (1979). Response cries. In M. von Cranach, K. Foppa, W. Lepenies, & D. Ploog (Eds.), *Human ethology* (pp. 203-240). Cambridge, England: Cambridge University Press.

Gosselin, P., Kirouac, G., & Doré, F. Y. (1995). Components and recognition of facial expression in the communication of emotion by actors. *Journal of Personality and Social Psychology, 68*, 83-96.

Hatfield, E., Hsee, C. K., Costello, J., & Denney, C. (1995). The impact of vocal feedback on emotional experience and expression. *Journal of Social Behavior and Personality, 10*, 293-312.

Hawk, S. T., van Kleef, G. A., Fischer, A. H., & van der Schalk, J. (2009). "Worth a thousand words": Absolute and relative decoding of nonlinguistic affect vocalizations. *Emotion, 9*, 293-305.

Kaiser, L. (1962). Communication of affects by single vowels. *Synthese, 14*, 300-319.

Kaiser, S., & Wehrle, T. (2001). Facial expressions as indicators of appraisal processes. In K. Scherer, A. Schorr, T. Johnstone (Eds.), *Appraisal processes in* *emotion: Theory, methods, research* (pp. 285-300). Oxford, England: Oxford University Press.

Larsen, J. T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive affect and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology, 40,* 776-785.

Mortillaro, M., Mehu, M., & Scherer, K. R. (in prep.). A dimensional account of multimodal emotion expressions.

Petridis, S., & Pantic, M. (2008a). Audiovisual discrimination between laughter and speech. In *International Conference on Acoustics, Speech and Signal Processing* (ICASSP) (pp. 5117-5120). Las Vegas, CA: IEEE Computer Society Press.

Petridis, S., & Pantic, M. (2008b). Audiovisual laughter detection based on temporal features. In *Proceedings of the 10th International Conference on Multimodal Interfaces* (ICMI) (pp. 37-44). Chania, Greece: ACM.

Poggi, I. (1981). *Le interiezoni: Studio del linguaggio e analisis della mente* [Interjections: Study of language and analysis of mind]. Torino, Italy: Boringhieri.

Ricci-Bitti, P. E., Caterina, R., & Garotti, P. L. (1996). Different behavioural markers in different smiles. In N. H. Frijda (Ed.), *Proceedings of the IXth Conference of the International Society for Research on Emotions* (pp. 297-301). Toronto, Canada: ISRE Publications.

Roseman, I. J. (1991). Appraisal determinants of discrete emotions. *Cognition and Emotion, 5,* 161-200.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39,* 1161-1178.

Russell, J. A. (1997). Reading emotions form and into faces: Resurrecting a dimensional-contextual perspective. In J. A. Russell & J. M. Fernández-Dols (Eds.), *The psychology of facial expression* (pp. 295-320). Cambridge, England: Cambridge University Press, Maison des Sciences de l'Homme.

Russell, J. A., & Bullock, M. (1986). On the dimensions preschoolers use to interpret facial expressions of emotion. *Developmental Psychology, 22*, 97-102.

Russell, J. A., & Fernández-Dols, J. N. (1997). What does a facial expression mean? In J. A. Russell & J. M. Fernández-Dols (Eds.), *The psychology of facial expression* (pp. 3-29). Cambridge, England: Cambridge University Press.

Sauter, D. (2010). More than happy: The need for disentangling positive emotions. *Current Directions in Psychological Science, 19*, 36-40.

Sauter, D. A., & Scott, S. K. (2007). More than one kind of happiness: Can we recognize vocal expressions of different positive states? *Motivation and Emotion, 31*, 192-199.

Sayette, M. A., Cohn, J. F., Wertz, J. M., Perrott, M. A., & Parrott, D. J. (2001). A psychometric evaluation of the Facial Action Coding System for assessing spontaneous expression. *Journal of Nonverbal Behavior, 25*, 167-185.

Scherer, K. R. (1979). Non-linguistic vocal indicators of emotion and psychopathology. In C. E. Izard (Ed.), *Emotions in personality and psychopathology* (pp. 495-529). New York, NY: Plenum Press.

Scherer, K. R. (1984). On the nature and function of emotion: A component process approach. In K. R. Scherer & P. E. Ekman (Eds.), *Approaches to emotion* (pp. 293-317). Hillsdale, NJ: Erlbaum.

Scherer, K. R. (1985). Vocal affect signalling: A comparative approach. In J. Rosenblatt, C. Beer, M. C. Busnel, & P. J. B. Slater (Eds.), *Advances in the study of behavior* (Vol. 15, pp. 189–244). New York, NY: Academic Press.

Scherer, K. R. (1987). Toward a dynamic theory of emotion: The componential process model of affective states. *Geneva Studies in Emotion and Communication, 1*, 1-98.

Scherer, K. R. (1988). On the symbolic functions of vocal affect expression. *Journal of Language and Social Psychology, 7*, 79-100.

Scherer, K. R. (1992). What does facial expression express? In K. Strongman (Ed.), *International review of studies on emotion* (Vol. 2, pp. 139-165). Chichester, England: Wiley.

Scherer, K. R. (1994). Affect bursts. In S. H. M. van Goozen, N. E. Van de Poll, & J. A. Sergeant (Eds.), *Emotions: Essays on emotion theory* (pp. 161-193). Hillsdale, NJ: Erlbaum.

Scherer, K. R. (1999). Universality of emotional expression. In D. Levinson, J. Ponzetti, & P. Jorgenson (Eds.), *Encyclopedia of human emotions* (Vol. 2, pp. 669-674). New York, NY: Macmillan.

Scherer, K. R. (2001). Appraisal considered as a process of multilevel sequential checking. In K. R. Scherer, A. Schorr, & T. Johnstone (Eds.), *Appraisal processes in emotion: Theory, methods, research* (pp. 92-120). New York, NY: Oxford University Press.

Scherer, K. R. (2003). Vocal communication of emotion: A review of research paradigms. *Speech Communication, 40*, 227-256.

Scherer, K. R. (2009). The dynamic architecture of emotion: Evidence for the component process model. *Cognition and Emotion, 23*, 1307-1351.

Scherer, K. R., & Bänzinger, T. (2010). On the use of actor portrayals in research on emotional expression. In K. R Scherer, T. Bänziger, & E. Roesch (Eds.), *Blueprint for affective computing: A sourcebook and manual (affective science)* (pp. 166-178). Oxford, England: Oxford University Press.

Scherer, K. R., & Ellgring, H. (2007a). Are facial expressions of emotion produced by categorical affect programs or dynamically driven by appraisal? *Emotion, 7*, 113-130.

Scherer, K. R., & Ellgring, H. (2007b). Multimodal expression of emotion: Affect programs or componential appraisal patterns? *Emotion, 7*, 158-171.

Schlosberg, H. (1954). Three dimensions of emotion. *Psychological Review, 61*, 81-88.

Schröder, M. (2003). Experimental study of affect bursts. *Speech Communication*, *40,* 99-116.

Simon-Thomas, E. R., Keltner, D. J., Sauter, D., Sinicropi-Yao, L., & Abramson, A. (2009). The voice conveys specific emotions: Evidence from vocal burst displays. *Emotion*, *9*, 838-846.

Smith, C. A., & Scott, H. S. (1997). A componential approach to the meaning of facial expressions. In J. A. Russell & J. M. Fernàndez-Dols (Eds.), *The psychology of facial expression* (pp. 229-254). Cambridge, England: Cambridge University Press, Maison des Sciences de l'Homme.

Szameitat, D. P., Alter, K., Szameitat, A. J., Darwin, C. J., Wildgruber, D., Dietrich, S., & Sterr, A. (2009). Differentiation of emotions in laughter at the behavioral level. *Emotion, 9*, 397-405.

Szameitat, D. P., Alter, K., Szameitat, A. J., Wildgruber, D., Sterr, A., & Darwin, C. J. (2009). Acoustic profiles of distinct emotional expressions in laughter. *Journal of the Acoustic Society of America, 126*, 354-366.

Tomkins, S. S. (1962). *Affect, imagery, consciousness: Vol. 1. The positive affects*. New York, NY: Springer.

Truong, K. P., & Van Leeuwen, D. A. (2007). Automatic discrimination between laughter and speech. *Speech Communication, 49*, 144-158.

Van Hooff, J. A. (1972). A comparative approach to the phylogeny of laughter and smiling. In R. Hinde (Ed.), *Non-verbal communication* (pp. 209-241). Cambridge, England: Cambridge University Press.

Wehrle, T., Kaiser, S., Schmidt, S., & Scherer, K. R. (2000). Studying the dynamics of emotional expression using synthesized facial muscle movements. *Journal of Personality & Social Psychology, 78*, 105-119.

Wundt, W. (1900). *Völkerpsychologie. Eine Untersuchung der Entwicklungsgesetze von Sprache, Mythos und Sitte: Band 1. Die Sprache* [Ethnopsychology: A study of the evolutionary principles of language, myth, and norms: Vol. 1. Language]. Leipzig, Germany: Kröner.

Footnote

[1] Follow-up correlational analyses showed that the variability of an emotion (N deviations of AU predictions) was not significantly associated with the recognition rate of that emotion (*p*s > .05). That is, recognition rates (as reported in the Method section) were not lowered for emotions with greater AU variability.

Table 1

Mean Occurrence of Individual Action Units (AUs) at Onset, Apex, or Offset Phase for Five Emotions and Significance of Difference Between Emotions

AU	Hot anger	Panic fear	Elated joy	Relief	Sadness	*F*	η_p^2
AU1 (Inner brow raiser)	**0.70**$_b$	♦**1.00**$_a$	**1.00**$_a$	0.40$_c$	♦0.45$_c$	11.30***	.32
	.10	.00	.00	.11	.11		
AU2 (Outer brow raiser)	**0.85**$_a$	♦**0.80**$_a$	**1.00**$_a$	0.35$_b$	0.30$_b$	13.00***	.35
	.08	.09	.00	.11	.10		
AU4 (Brow lowerer)	♦0.55$_b$	♦**0.80**$_a$			♦0.40$_b$	17.97***	.43
	.11	.09			.11		
AU5 (Upper lid raiser)	♦**0.70**$_{ab}$	♦**0.80**$_a$	0.45$_{bc}$	0.20$_{cd}$	0.05$_d$	11.72***	.33
	.10	.09	.11	.09	.05		
AU6 (Cheek raiser)	0.15$_{bc}$		♦**0.90**$_a$	♦0.30$_b$	♦	31.00***	.57
	.08		.07	.10			
AU7 (Lid tightener)	♦0.35$_{bc}$	0.20$_c$	**0.85**$_a$	**0.70**$_a$	**0.60**$_{ab}$	6.82***	.22
	.11	.09	.08	.10	.11		
AU9 (Nose wrinkler)	0.20$_a$		0.05$_b$			3.43*	.13
	.09		.05				
AU10 (Upper lip raiser)	♦**0.80**$_a$	0.35$_b$	0.10$_b$	0.10$_b$	0.20$_b$	11.16***	.32
	.09	.11	.07	.07	.09		
AU11 (Nasolabial furrow)		0.35$_a$	0.05$_b$	0.25$_{ab}$	♦	5.29**	.18
		.11	.05	.10			
AU12 (Lip corner puller)	0.50$_b$	0.65$_b$	♦**1.00**$_a$	♦**0.95**$_a$	0.15$_c$	17.65***	.43
	.11	.11	.00	.05	.08		
AU16 (Lower lip depressor)	**0.90**$_a$	0.60$_b$	0.05$_c$		0.10$_c$	32.41***	.58
	.07	.11	.05		.07		
AU20 (Lip stretcher)	**0.80**$_a$	♦**0.85**$_a$	0.15$_b$	0.20$_b$	0.30$_b$	13.83***	.37
	.09	.08	.08	.09	.10		
AU21 (Neck tightener)	0.55$_a$	0.45$_a$	0.15$_b$			10.03***	.30
	.11	.11	.08				
AU23 (Lip tightener)	♦0.40$_a$				0.15$_b$	7.88***	.25
	.11				.08		
AU24 (Lip presser)	♦			0.05$_b$	0.30$_a$	6.27***	.21
				.05	.10		
AU26 (Jaw drop)	♦**0.75**$_{ab}$	♦**0.85**$_{ab}$	0.65$_{ab}$	**0.90**$_a$	**0.50**$_b$	2.77*	.10
	.10	.08	.11	.07	.11		
AU27 (Mouth stretch)	**0.70**$_a$	♦**0.80**$_a$	**0.90**$_a$	0.10$_b$		30.23***	.56
	.10	.09	.07	.07			

Table 1 (continued)

Mean Occurrence of Individual Action Units (AUs) at Onset, Apex, or Offset Phase for Five Emotions and Significance of Difference Between Emotions

AU	Hot anger	Panic fear	Elated joy	Relief	Sadness	*F*	η_p^2
AU29 (Jaw thrust)	0.35_a	0.05_b		0.10_b	0.05_b	4.43**	.16
	.11	.05		.07	.05		
AU30 (Jaw sideways)	0.55_a	0.40_a	0.30_a			8.17***	.26
	.11	.11	.10				
AU43 (Eye closure)			0.30_b	$\mathbf{0.70}_a$	0.30_b	12.52***	.34
			.10	.10	.10		
AU45 (Blink)	0.20_a	0.20_a	0.25_a	0.55_a	$\mathbf{0.55}_a$	3.20*	.12
	.09	.09	.10	.11	.11		
AU53 (Head up)	0.55_a	0.65_a	$\mathbf{0.90}_a$	$\mathbf{0.90}_a$	$\mathbf{0.55}_a$	3.34*	.12
	.11	.11	.07	.07	.11		
AU57 (Head forward)	$\mathbf{0.75}_a$	0.15_b	0.30_b	0.15_b	0.05_b	10.45***	.31
	.10	.08	.10	.08	.05		
AU63 (Eyes up)			0.10_{ab}	0.25_a	0.05_b	3.14*	.12
			.07	.10	.05		

Note. Standard errors appear below the mean values. For readability, zero proportions have been omitted. Means with proportions $\geq$ 0.70 (for sadness $\geq$ 0.50) are printed in bold. ♦ Predicted to signal a particular emotion according to basic emotion theory (Ekman, Friesen, & Hager, 2002).

a,b,c,d = homogeneous subtests based on Newman-Keuls post-hoc comparisons for significant differences between emotions.

***$p < .001$. **$p < .01$. *$p < .05$.

Table 2

Mean Occurrence of Action Unit (AU) Combinations at Onset, Apex, or Offset Phase for Five Emotions and Significance of Difference Between Emotions

AU combination	Hot anger	Panic fear	Elated joy	Relief	Sadness	*F*	η_p^2
AU1+2	**0.70**$_a$	**0.80**$_a$	**1.00**$_a$	0.35_b	0.25_b	11.89***	.33
	.10	.09	.00	.11	.10		
AU1+4	0.40_b	**0.80**$_a$			0.20_{bc}	19.00***	.44
	.11	.09			.09		
AU1+5	0.55_{ab}	**0.80**$_a$	0.45_b	0.15_c	0.05_c	10.59***	.31
	.11	.09	.11	.08	.05		
AU1+6	0.10_b		**0.90**$_a$	0.10_b		51.72***	.68
	.07		.07	.07			
AU1+7	0.30_b	0.20_b	**0.70**$_a$	0.25_b	**0.30**$_b$	3.89**	.14
	.10	.09	.10	.10	.10		
AU1+10	0.60_a	0.35_b	0.10_b	0.05_b	0.05_b	8.48***	.26
	.11	.11	.07	.05	.05		
AU1+12	0.40_c	0.65_b	**1.00**$_a$	0.35_c	0.05_d	16.22***	.41
	.11	.11	.00	.11	.05		
AU1+16	0.65_a	0.60_a				23.88***	.50
	.11	.11					
AU1+20	0.55_b	**0.85**$_a$	0.15_c	0.20_c	0.05_c	14.78***	.38
	.11	.08	.08	.09	.05		
AU1+26	0.50_{ab}	**0.85**$_a$	0.50_{ab}	0.35_b	0.25_b	4.72**	.17
	.11	.08	.11	.11	.10		
AU1+27	0.45_b	**0.80**$_a$	**0.90**$_a$	0.10_c		26.28***	.52
	.11	.09	.07	.07			
AU1+53	0.35_{bc}	0.65_{ab}	**0.85**$_a$	0.35_{bc}	0.25_c	6.00***	.20
	.11	.11	.08	.11	.10		
AU1+57	0.50_a	0.15_{bc}	0.30_{ab}			7.36***	.24
	.11	.08	.10				
AU2+4	0.50_a	0.60_a			0.15_b	12.31***	.34
	.11	.11			.08		
AU2+5	0.55_a	**0.70**$_a$	0.45_a	0.15_b	0.05_b	8.04***	.25
	.11	.10	.11	.08	.05		
AU2+6	0.15_b		**0.90**$_a$	0.10_b		44.64***	.65
	.08		.07	.07			
AU2+7	0.40_b	0.20_b	**0.75**$_a$	0.20_b	0.20_b	6.02***	.20
	.11	.09	.10	.09	.09		

Table 2 (continued)

Mean Occurrence of Action Unit (AU) Combinations at Onset, Apex, or Offset Phase for Five Emotions and Significance of Difference Between Emotions

AU combination	Hot anger	Panic fear	Elated joy	Relief	Sadness	F	η_p^2
AU2+10	0.65_a	0.25_b	0.10_b	0.10_b		10.50***	.31
	.11	.10	.07	.07			
AU2+12	0.50_b	0.45_b	**1.00**$_a$	0.30_{bc}	0.05_c	15.32***	.39
	.11	.11	.00	.10	.05		
AU2+16	**0.80**$_a$	0.55_b				33.69***	.59
	.09	.11					
AU2+20	**0.70**$_a$	0.65_a	0.15_b	0.20_b	0.10_b	9.82***	.29
	.10	.11	.08	.09	.07		
AU2+27	0.60_b	**0.70**$_{ab}$	**0.90**$_a$	0.05_c		26.28***	.52
	.11	.10	.07	.05			
AU2+21	0.50_a	0.45_a	0.15_b			8.85***	.27
	.11	.11	.08				
AU2+53	0.45_b	0.50_b	**0.85**$_a$	0.30_b	0.20_b	5.90***	.20
	.11	.11	.08	.10	.09		
AU2+57	0.65_a	0.15_{bc}	0.30_b			12.32***	.34
	.11	.08	.10				
AU4+5	0.30_b	0.55_a			0.05_c	10.96***	.32
	.10	.11			.05		
AU4+12	0.30_{ab}	0.50_a			0.10_{bc}	8.12***	.25
	.10	.11			.07		
AU4+16	0.50_a	0.45_a			0.10_b	9.78***	.29
	.11	.11			.07		
AU4+20	0.45_b	**0.70**$_a$			0.20_c	14.15***	.37
	.11	.10			.09		
AU4+26	0.40_b	0.65_a			0.05_c	15.82***	.40
	.11	.11			.05		
AU4+27	0.35_b	0.60_a				15.34***	.39
	.11	.11					
AU4+53	0.30_{ab}	0.50_a			**0.30**$_{ab}$	6.66***	.22
	.10	.11			.10		
AU5+10	0.55_a	0.30_b		0.05_c		10.96***	.32
	.11	.10		.05			
AU5+16	0.55_a	0.50_a				15.85***	.40
	.11	.11					

Table 2 (continued)

Mean Occurrence of Action Unit (AU) Combinations at Onset, Apex, or Offset Phase for Five Emotions and Significance of Difference Between Emotions

AU combination	Hot anger	Panic fear	Elated joy	Relief	Sadness	*F*	η_p^2
AU5+20	0.45_a	0.65_a	0.05_b	0.05_b		14.25***	.37
	.11	.11	.05	.05			
AU5+26	0.60_a	0.55_a	0.20_b	0.20_b		7.71***	.24
	.11	.11	.09	.09			
AU5+27	0.35_a	0.60_a	0.40_a			9.33***	.28
	.11	.11	.11				
AU6+7	0.10_b		**0.80**$_a$	0.15_b		28.44***	.54
	.07		.09	.08			
AU6+12	0.15_{bc}		**0.90**$_a$	0.30_b		31.00***	.57
	.08		.07	.10			
AU6+26	0.10_b		0.55_a	0.25_b		9.64***	.29
	.07		.11	.10			
AU6+27	0.15_b		**0.80**$_a$	0.05_b		32.97***	.58
	.08		.09	.05			
AU6+53	0.15_b		**0.80**$_a$	0.25_b		21.85***	.48
	.08		.09	.10			
AU7+12	0.15_b	0.10_b	**0.85**$_a$	**0.70**$_a$	0.10_b	19.63***	.45
	.08	.07	.08	.10	.07		
AU7+26	0.25_{ab}	0.20_{ab}	0.35_{ab}	0.55_a	0.15_b	2.50*	.09
	.10	.09	.11	.11	.08		
AU7+27	0.30_b	0.20_b	**0.75**$_a$	0.10_b		12.40***	.34
	.10	.09	.10	.07			
AU7+43			0.25_b	0.50_a	0.05_b	9.16***	.28
			.10	.11	.05		
AU7+53	0.35_b	0.10_b	**0.70**$_a$	0.65_a	0.25_b	6.73***	.22
	.11	.07	.10	.11	.10		
AU10+16	**0.70**$_a$	0.20_b			0.10_b	17.55***	.42
	.10	.09			.07		
AU10+20	**0.70**$_a$	0.25_b		0.10_b	0.10_b	12.67***	.35
	.10	.10		.07	.07		
AU10+26	0.55_a	0.25_b	0.10_b	0.10_b	0.10_b	5.15**	.18
	.11	.10	.07	.07	.07		
AU10+27	0.60_a	0.25_b	0.10_b			11.56***	.33
	.11	.10	.07				

Table 2 (continued)

Mean Occurrence of Action Unit (AU) Combinations at Onset, Apex, or Offset Phase for Five Emotions and Significance of Difference Between Emotions

AU combination	Hot anger	Panic fear	Elated joy	Relief	Sadness	F	η_p^2
AU10+57	0.55_a					23.22***	.49
	.11						
AU12+20	0.30_{ab}	0.50_a	0.15_b	0.15_b	0.10_b	3.16*	.12
	.10	.11	.08	.08	.07		
AU12+26	0.30_b	0.35_b	0.60_{ab}	**0.85**$_a$		12.18***	.34
	.10	.11	.11	.08			
AU12+27	0.40_b	0.50_b	**0.90**$_a$	0.10_c		18.01***	.43
	.11	.11	.07	.07			
AU12+43			0.25_b	0.60_a	0.05_b	13.15***	.36
			.10	.11	.05		
AU12+45	0.05_b	0.10_b	0.25_b	0.50_a	0.05_b	5.61***	.19
	.05	.07	.10	.11	.05		
AU12+53	0.20_c	0.45_b	**0.90**$_a$	**0.85**$_a$	0.10_c	17.77***	.43
	.09	.11	.07	.08	.07		
AU12+57	0.50_a	0.05_b	0.30_{ab}	0.15_b		6.17***	.21
	.11	.05	.10	.08			
AU16+20	**0.75**$_a$	0.50_b			0.10_c	20.62***	.46
	.10	.11			.07		
AU16+26	0.65_a	0.40_b	0.05_c			15.82***	.40
	.11	.11	.05				
AU16+27	0.65_a	0.50_a				20.29***	.46
	.11	.11					
AU16+21	0.55_a	0.40_a	0.05_b			11.76***	.33
	.11	.11	.05				
AU16+53	0.55_a	0.35_a	0.05_b		0.10_b	8.41***	.26
	.11	.11	.05		.07		
AU16+57	**0.70**$_a$	0.05_b				35.05***	.60
	.10	.05					
AU20+26	0.55_a	0.65_a	0.05_b	0.20_b	0.05_b	10.41***	.30
	.11	.11	.05	.09	.05		
AU20+27	0.55_a	**0.70**$_a$	0.15_b			17.17***	.42
	.11	.10	.08				
AU20+53	0.45_a	0.50_a	0.15_a	0.20_a	0.20_a	2.64*	.10
	.11	.11	.08	.09	.09		

Table 2 (continued)

Mean Occurrence of Action Unit (AU) Combinations at Onset, Apex, or Offset Phase for Five Emotions and Significance of Difference Between Emotions

AU combination	Hot anger	Panic fear	Elated joy	Relief	Sadness	*F*	η_p^2
AU20+57	0.55_a	0.15_b	0.05_b			12.09***	.34
	.11	.08	.05				
AU26+43			0.10_b	0.65_a	0.20_b	14.52***	.38
			.07	.11	.09		
AU26+53	0.30_b	0.50_{ab}	0.45_{ab}	**0.80**$_a$	0.25_b	4.21**	.15
	.10	.11	.11	.09	.10		
AU26+57	0.55_a	0.05_b	0.05_b	0.10_b		11.26***	.32
	.11	.05	.05	.07			
AU27+53	0.40_b	0.55_b	**0.80**$_a$	0.05_c		15.62***	.40
	.11	.11	.09	.05			
AU43+53			0.20_b	0.65_a	0.20_b	12.23***	.34
			.09	.11	.09		

Note. Standard errors appear below the mean values. For readability, zero proportions have been omitted. Means with proportions $\geq$ 0.70 (for sadness $\geq$ 0.30) are printed in bold.

a,b,c,d = homogeneous subtests based on Newman-Keuls post-hoc comparisons for significant differences between emotions.

$^{***}p < .001$. $^{**}p < .01$. $^{*}p < .05$.

Table 3

Pearson's Correlations Between the Five Emotions for the Number of Action Unit Co-Occurrences

	Panic fear	Elated joy	Relief	Sadness
Hot anger	0.47**	-0.38*	-0.55**	-0.11
Panic fear		-0.09	-0.22	0.20
Elated joy			0.42**	0.08
Relief				0.39*

*p < .01. **p < .001, two-tailed.

Table 4

Mean Occurrence of Action Unit (AU) Prototypes at Apex Phase for Five Emotions

	BET predictions	*M*	EF prototypes	*M*
Anger	AU prototypes:		1+2+10+16+20+25	0.15
	4+5+7+10+22+23+25,26	0.00	1+2+7+10+20+25	0.15
	4+5+7+10+23+25,26	0.00	1+2+7+10+16+25	0.15
	4+5+7+23+25,26	0.00	1+2+4+7+10+25	0.15
	4+5+7+17+23	0.00	1+2+10+16+25	0.20
	4+5+7+17+24	0.00	1+2+10+20+25	0.20
	4+5+7+23	0.00	1+2+7+10+25	0.20
	4+5+7+24	0.00	10+16+20+25	0.35
			1+2+10+25	0.35
	Major variants:		10+20+25	0.50
	5+7+10+23+25,26	0.05	10+16+25	0.45
	4+7+10+23+25,26	0.05		
	4+7+23+25	0.05		
	5+7+23+25	0.05		
	4+7+23	0.05		
	5+7+23	0.05		
Fear	AU prototypes:		1+2+5+12+25+27+53	0.25
	1+2+4+5+20+25,26,or 27	0.15	1+2+5+20+21+25+53	0.15
	1+2+4+5+25,26,or 27	0.20	1+2+5+20+25+27+53	0.15
			1+2+4+5+20+25+53	0.15
	Major variants:		1+2+5+12+25+27	0.30
	1+2+4+5+L or R20+25,26,or 27	0.00	1+2+5+25+27+53	0.30
	1+2+4+5	0.20	1+2+5+25+27	0.45
	1+2+5 with or without 25,26,27	0.55	1+2+5+25+53	0.35
	5+20 with or without 25,26,27	0.45	1+2+5+25	0.55
			1+2+25+27	0.50
			1+5+25	0.65
			1+25+27	0.60
			1+2+25	0.60

Table 4 (continued)

Mean Occurrence of Action Unit (AU) Prototypes at Apex Phase for Five Emotions

	BET predictions	*M*	EF prototypes	*M*
Sadness	AU prototypes:		25+26+43+53A	0.15
	1+4+11+15B with or without 54+64,25,or 26	0.00	25+26+53A	0.20
	1+4+15 with or without 54+64,25,or 26	0.05	4+7+25	0.20
	6+15 with or without 54+64,25,or 26	0.00		
	Major variants:			
	1+4+15B+17 with or without 54+64,25,or 26	0.00		
	1+4+15B with or without 54+64,25,or 26	0.00		
	1+4+11 with or without 54+64,25,or 26	0.00		
	11+15B with or without 54+64,25,or 26	0.00		
	11+17 with or without 25,or 26	0.00		
Joy	AU prototypes:		6+7+12+25+53	0.15
	6+12	0.80	6+7+12+25+57	0.15
	12C/D	0.90	1+2+6+12+25	0.15
			6+7+12+25	0.60
			6+12+25+57	0.20
			1+2+12+25	0.20
			1+2+6+12	0.20
			6+12+25	0.75
			7+12+25	0.65
Relief	AU prototypes:		7+12+25+53+56	0.15
	6+12	0.15	6+12+25+53+56	0.15
	12C/D	0.20	12+25+53+56	0.20
	(12A/B)	0.55	7+12+25+53	0.20
			12+25+53	0.35
			7+25+53	0.30

Note. BET = basic emotion theory; EF = empirically found. EF prototypes consist of AU combinations (≥ 3) that occurred in at least three expressions of each emotion. For each AU combination level, the two most frequent occurrences are reprinted. (12A/B) is not part of BET predictions, but was added by the authors of this paper as an additional prototype. Interrater agreement of AU12 intensity: K = .83; AU15 intensity: K = 1.00.

Table 5

Sequential Occurrence of Action Units (AUs) across Five Emotions

	Hot anger		Panic fear		Elated joy		Relief		Sadness	
Sequence	AU	*M*SecAnlg	AU	*M*SecAnlg	AU	*M*SecAnlg	*AU*	*M*SecAnlg	*AU*	*M*SecAnlg
1	AU53	0.18	**AU4**	0.24	AU2	0.21	**AU25**	0.08	**AU25**	0.11
2	AU2	0.18	**AU25**	0.31	**AU25**	0.21	AU43	0.14	**AU7**	0.21
3	AU1	0.20	AU53	0.31	AU1	0.26	AU26	0.17	AU53	0.25
4	AU21	0.20	AU1	0.32	AU27	0.26	AU45	0.26	AU45	0.35
5	AU16	0.22	AU27	0.33	AU53	0.28	AU53	0.27		
6	**AU25**	0.22	AU2	0.33	AU12	0.40	**AU7**	0.29		
7	**AU10**	0.23	AU12	0.33	**AU7**	0.48	AU12	0.52		
8	AU27	0.28	AU5	0.38	AU6	0.50				
9	AU26	0.32	AU20	0.41						
10	AU20	0.36	AU16	0.42						
11	AU12	0.37	AU26	0.44						
12	**AU4**	0.38								
13	AU5	0.39								
14	AU57	0.43								
15	AU30	0.59								

Note. Only AUs that occurred in 50% of the portrayals of each emotion are reprinted. *M*SecAnlg refers to the relative apex position of AUs averaged across portrayals in an analog time scale from 0 (start) to 1 (end). Mean sequences of AUs that differed significantly in the Kruskal-Wallis H-test are printed in bold.

Table 6

Mean Occurrence of Action Units (AUs) as a Function of the Valence and Arousal Level of the Five Emotions

	Negative valence		Positive valence			
AU	High arousal	Low arousal	High arousal	Low arousal	*F*	η_p^2
AU5 (Upper lid raiser)	0.75_a	0.05_c	0.45_b	0.20_c	6.69*	0.06
	.07	.09	.09	.09		
AU6 (Cheek raiser)	0.08_c		0.90_a	0.30_b	17.23***	0.15
	.05		.07	.07		
AU7 (Lid tightener)	0.28_b	0.60_a	0.85_a	0.70_a	6.34*	0.06
	.07	.10	.10	.10		
AU10 (Upper lip raiser)	0.58_a	0.20_b	0.10_b	0.10_b	4.65*	0.05
	.07	.09	.09	.09		
AU11 (Nasolabial furrow)	0.18_a		0.05_a	0.25_a	7.36**	0.07
	.05		.07	.07		
AU12 (Lip corner puller)	0.57_b	0.15_c	1.00_a	0.95_a	5.81*	0.06
	.06	.08	.08	.08		
AU16 (Lower lip depressor)	0.75_a	0.10_b	0.05_b		19.27***	0.17
	.05	.07	.07			
AU20 (Lip stretcher)	0.83_a	0.30_b	0.15_b	0.20_b	11.53**	0.11
	.06	.09	.09	.09		
AU21 (Neck tightener)	0.50_a		0.15_b		5.35*	0.05
	.06		.08			
AU24 (Lip presser)		0.30_a		0.05_b	6.66*	0.06
		.05		.05		
AU26 (Jaw drop)	0.80_{ab}	0.50_b	0.65_{ab}	0.90_a	9.35**	0.09
	.07	.10	.10	.10		

Note. Standard errors appear below the mean values. For readability, zero proportions have been omitted.

a,*b*,*c* = homogeneous subtests based on Newman-Keuls post-hoc comparisons for significant differences between emotions.

***p < .001. **p < .01. *p < .05.

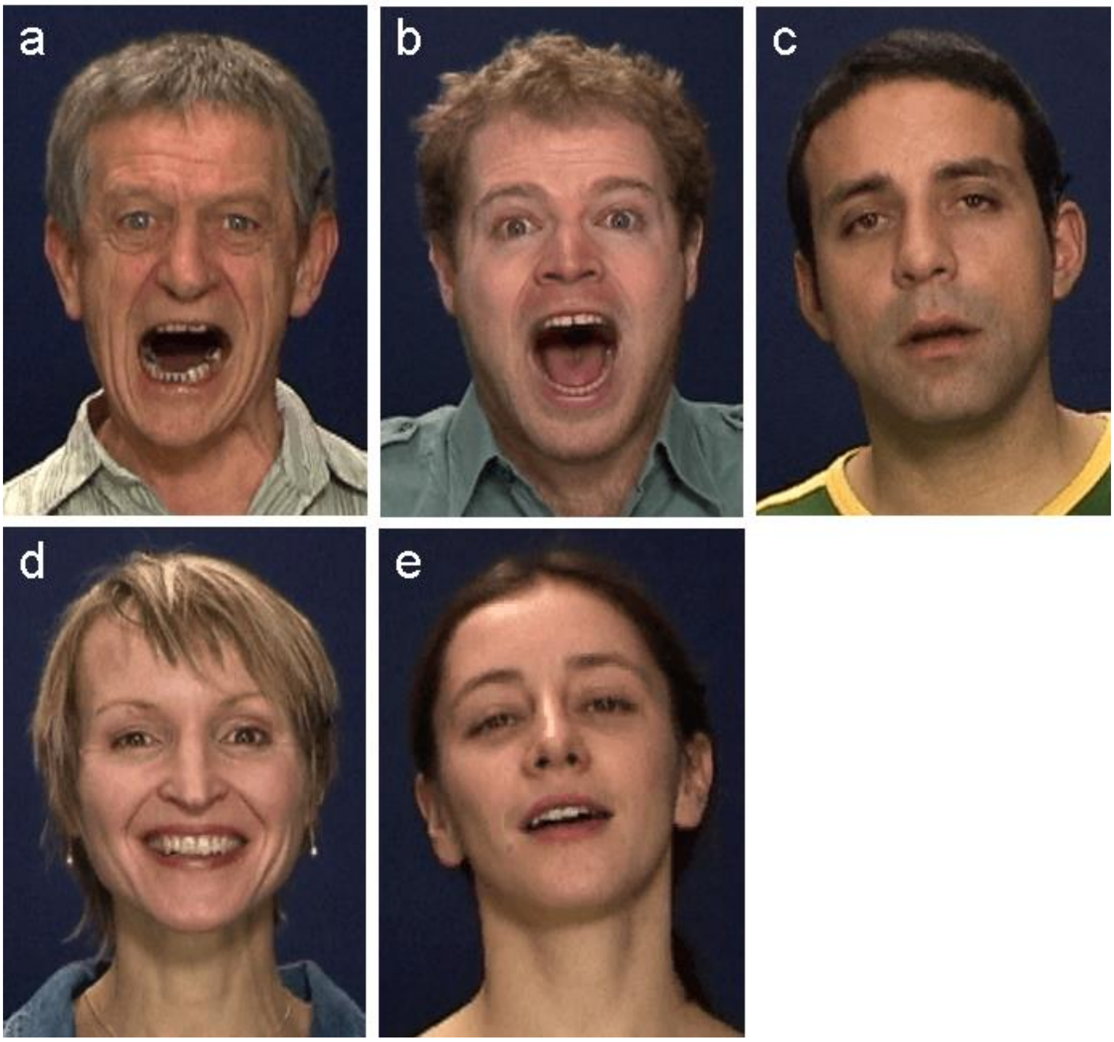

Figure 1. Exemplars of empirically found emotion prototypes at the apex phase for a) hot anger, b) panic fear, c) sadness, d) elated joy, and e) relief. All images have been taken from the GEMEP corpus (Baenziger & Scherer, 2010) and are reproduced by permission of the actors.

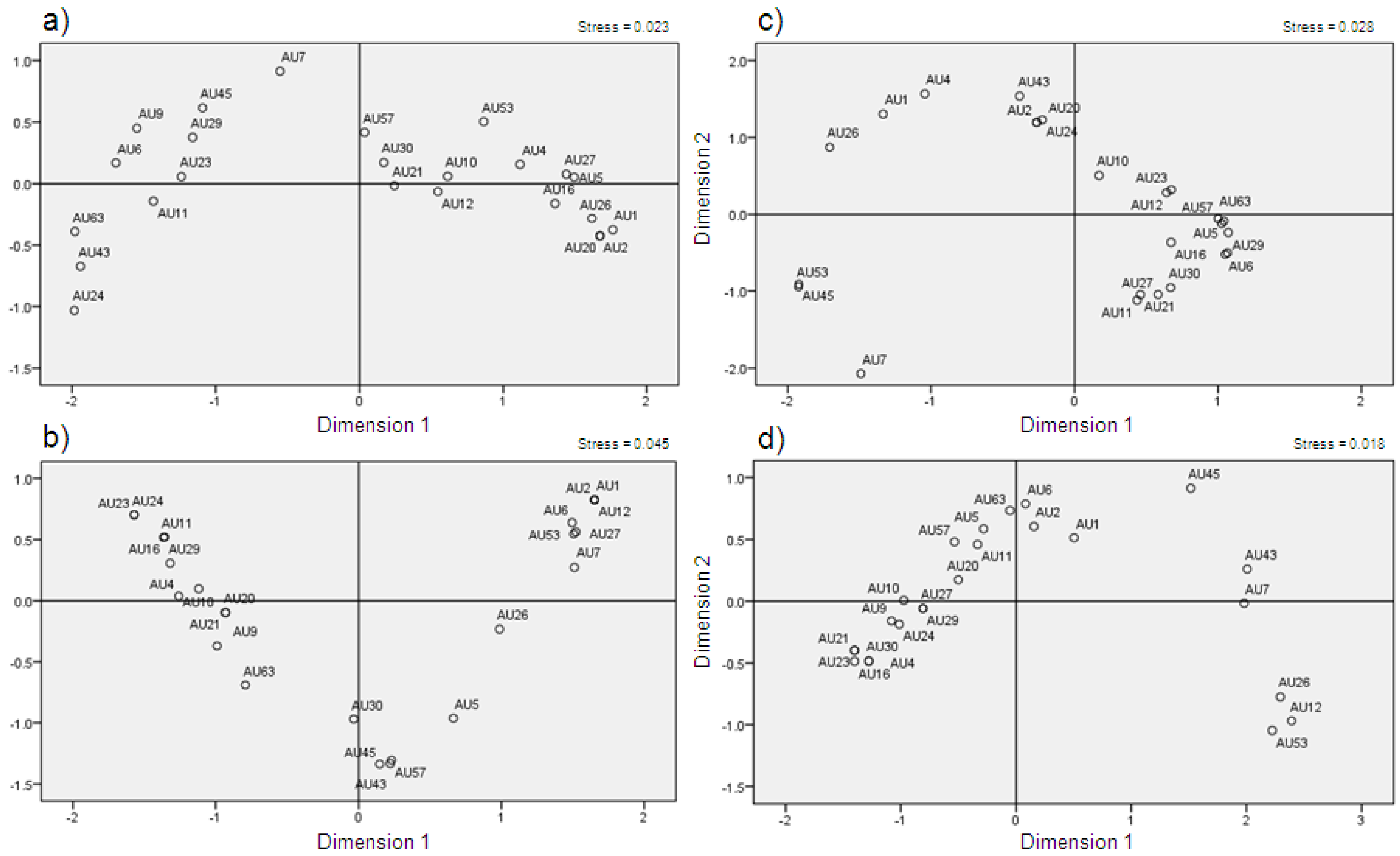

Figure 2. Multidimensional scaling plots of action unit mean frequencies for a) high arousal, negative valence, b) high arousal, positive valence, c) low arousal, negative valence, and d) low arousal, positive valence.

Appendix A

Illustrative descriptions and Example Scenarios of Five Emotions as Provided to Actors

Emotion	Definition	Example Scenario
Hot anger	Extreme displeasure caused by someone's stupid or hostile action	During a stay abroad I have sublet my apartment. On my return I find that my apartment has been left in a terrible state by the occupants, who have not kept any of the promises they made when they signed the contract to sublet. Some of my property is missing and the rent has not been paid. I am furious at these irresponsible people, and I express what I feel to a friend who is with me and who has seen the extent of the damage.
Panic fear	Being faced with an imminent danger that threatens one´s survival or physical well-being	I am driving my car on a narrow mountain road. Suddenly, the brakes stop responding. My car picks up speed, and I feel I can no longer stop it. In a matter of seconds, it is likely to veer off the road and over the precipice.
Elated joy	Feeling of great happiness caused by an unexpected event	I have just won a huge sum in the lottery. I wasn't expecting it, as I had bought the ticket by chance while out having coffee with a friend. I am overwhelmed with joy when I discover this, and go to break the news to my partner (my parents, my children).
Relief	Feeling reassured at the end or resolution of a difficult or dangerous situation	I am driving home. At one point, I look in the rear-view mirror to catch a glimpse of some unusual movement in the traffic behind me. Suddenly I feel a bump in the front – it seems I hit something. I wonder immediately what it could have been, as I saw nothing. I am afraid I may have hit a pedestrian who stepped out too quickly in front of my car. Very alarmed, I stop and get out... and then I see that I hit a rubber marker. There is no damage to the car. I am very relieved that I was worried about nothing.
Sadness	Feeling discouraged by the irrevocable loss of a person, place or thing	After several years of marriage, my husband/wife has decided to leave me. Things were not good between us for a long time now. But I had hoped that a solution could be found. I received the divorce papers this morning. This time, it's really the end of our marriage. I know that there's nothing which can be done now.