

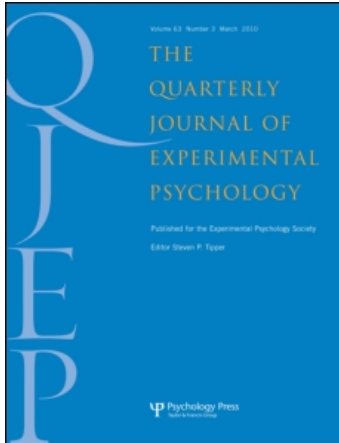
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Work on facial expressions of emotions (Calder, Burton, Miller, Young, & Akamatsu, 2001) and emotionally inflected speech (Banse & Scherer, 1996) has successfully delineated some of the physical properties that underlie emotion recognition. To identify the acoustic cues used in the perception of nonverbal emotional expressions like laughter and screams, an investigation was conducted into vocal expressions of emotion, using nonverbal vocal analogues of the “basic” emotions (anger, fear, disgust, sadness, and surprise; Ekman & Friesen, 1971; Scott et al., 1997), and of positive affective states (Ekman, 1992, 2003; Sauter & Scott, 2007). First, the emotional stimuli were categorized and rated to establish that listeners could identify and rate the sounds reliably and to provide confusion matrices. A principal components analysis of the rating data yielded two underlying dimensions, correlating with the perceived valence and arousal of the sounds. Second, acoustic properties of the amplitude, pitch, and spectral profile of the stimuli were measured. A discriminant analysis procedure established that these acoustic measures provided sufficient discrimination between expressions of emotional categories to permit accurate statistical classification. Multiple linear regressions with participants’ subjective ratings of the acoustic stimuli showed that all classes of emotional ratings could be predicted by some combination of acoustic measures and that most emotion ratings were predicted by different constellations of acoustic features. The results demonstrate that, similarly to affective signals in facial expressions and emotionally inflected speech, the perceived emotional character of affective vocalizations can be predicted on the basis of their physical features.

Keywords: Emotion; Voice; Vocalizations; Acoustics; Nonverbal behaviour

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Humans express emotion via a variety of channels, including the visual and auditory modalities. For example, different emotions are communicated through distinct patterns of facial musculature (Ekman & Rosenberg, 2005). Recognition of the “basic” emotions (fear, anger, disgust, sadness, happiness, and surprise) from photographs of facial expressions is generally good (Ekman & Friesen, 1971), though some emotions are systematically confused (e.g., fear with surprise, anger with disgust; Calder, Burton, Miller, Young, & Akamatsu, 2001). There is also evidence that these “basic” facial expressions are recognized across different cultures (Ekman, 1994; Ekman, Sorenson, & Friesen, 1969; Elfenbein & Ambady 2002; but see Russell 1994). In terms of perceptual processing, the output of a principal components analysis (PCA) of the pixel intensities of photographs of a set of basic facial expressions of emotion has been shown to successfully support automatic facial emotion recognition (Calder et al., 2001). This finding suggests that different emotional states in the face are expressed with specific visual properties, which may in turn reflect candidate visual properties used in human perceptual processing (Calder et al., 2001).

In addition to the face, emotions are expressed using bodily posture, gestures, and vocal cues (Atkinson, Dittrich, Gemmell, & Young, 2004; Atkinson, Tunstall, & Dittrich, 2007; Scherer, 2003). The human voice is a particularly interesting channel, since it simultaneously transmits information about the speaker’s body size, sex, age, social class, geographical origin, and emotional state, often in parallel with linguistic meaning (Karpf, 2006). Research has established that there are vocal correlates of the established facial emotional expressions of anger, fear, disgust, happiness, sadness, and surprise and that these are expressed both in emotional speech (Murray & Arnott, 1993; Scherer, Banse, & Wallbott, 2001) and as nonverbal vocal expressions (Scott et al., 1997).

The main differences between emotionally inflected speech and nonverbal vocal expressions of emotion (e.g., laughs, sobs, or screams) are to do with their production. Speech production

relies on fast, precise, coordinated actions of the supralaryngeal articulators, which are synchronized with the movements of the larynx and the subglottal pressure to ensure that, for example, the onset of voicing is correct at the start of a voiced plosive like /b/. In emotional states, cues associated with voice quality, loudness, and pitch give the emotional speech its affective quality (Murray & Arnott, 1993). Unlike speech production, nonverbal expressions of emotion do not involve detailed supralaryngeal movements—there are no precise articulations. Instead, emotional vocalizations reflect the sound produced at the larynx being shaped by roughly positioned pharyngeal/oral/labial constrictions. A sound like laughter, for example, has been described as more like a way of modified breathing than it is like a way of speaking (Kohler, 2008). An aim of the current paper is to establish the acoustic properties that give nonverbal emotional expressions their affective qualities. Nonverbal emotional vocalizations have been previously characterized as “affect bursts” (Scherer, 1994). This label is not used in the current study since the term “burst” connotes specific acoustic qualities (such as brevity and rapid onsets), whereas the current study sought to empirically investigate acoustic properties in different emotional vocalizations.

Nonverbal vocal expressions have been used in previous experimental, neuropsychological and functional imaging studies of emotional processing (Calder, Keane, Lawrence, & Manes, 2004; Calder, Keane, Manes, Antoun, & Young, 2000; Carroll & Young, 2005; Morris, Scott, & Dolan, 1999; Schröder, 2003; Scott et al., 1997; Warren et al., 2006). Nonverbal vocal expressions of emotion tend to be better recognized than emotional speech stimuli reflecting the same emotion, especially for fear (Scott et al., 1997) and disgust (Banse & Scherer, 1996; Scott et al., 1997). This may be because in some emotional states, a nonverbal expression may be more likely to be produced than emotionally inflected speech (Banse & Scherer, 1996).

In terms of the acoustics of vocal expressions of emotion in the voice, most previous work has investigated emotional speech—that is, spoken

language that is produced with affective cues (Juslin & Laukka, 2003; Murray & Arnott, 1993). A detailed study of the acoustics of emotion in nonsense-speech found that a battery of acoustic measures could be used both to predict judges' ratings of the emotional expressions and to automatically classify the sentences into different emotional categories (Banse & Scherer, 1996). Within this, the study found that different acoustic cues were differentially important for the different emotions. For example, higher ratings for "panic fear" and "despair" were associated with higher mean pitch, while higher ratings for boredom, pride, and contempt were associated with lower mean pitch. Spectral properties were also important: High ratings for "hot anger" were associated with larger differences between the spectral energy from 0–2,000 Hz and from 2,000–5,000 Hz, and higher ratings for "elation" were associated with higher proportions of energy over 1,000 Hz. Lower intensity (which relates to perceptual loudness) was important for the ratings of "shame" and "sadness". A similar pattern, demonstrating important roles for pitch, spectral profile, and loudness as correlates of different affective states in speech has been reported in a more recent study (Juslin & Laukka, 2001), and consequent experimental studies have confirmed that pitch is an important cue in the recognition of emotion in speech (Bänziger & Scherer, 2005).

In contrast, the relationship between the perception of emotion in nonverbal vocal signals and their acoustic profile has not been systematically established. Schröder (2003) investigated the ability of listeners to classify the emotional content of nonverbal vocalizations and to transcribe them. A range of emotional vocalizations were used, including nonverbal vocalizations such as laughter and verbal utterances such as "yuck". Although there was some variability across emotions, the overall recognition rate across the 10 categories was 81%, suggesting that emotions could be recognized well from the nonverbal vocalizations (in contrast, the mean recognition rate in Banse and Scherer's, 1996, study of emotional speech was 55%). Schröder (2003) derived a taxonomy for the classification of such nonverbal

vocalizations of emotion in terms of phonetic transcriptions of their segmental structure, voice quality, and intonation. However, a statistical analysis of the acoustic properties of the sounds was not performed. Schröder's findings suggest that listeners can determine systematic phonological differences between different types of nonverbal emotional signal. However, it remains to be established what the acoustic bases of nonverbal expressions of emotions are, how these differences relate to listeners' ratings of the emotional properties of the sounds, and whether or not these relate to the acoustic bases of emotional inflections in spoken language.

In contrast to the hypothesis that different affective states can be inferred from specific categories of emotional vocalizations, it has been suggested that "speech acoustics provide an external cue to the level of nonspecific arousal associated with emotional processes" (Bachorowski, 1999, p. 55). The emphasis on underlying emotional dimensions, rather than specific emotional categories, follows the argument that both facial and vocal emotional expressions may be better characterized in terms of a limited number of dimensions (e.g., Russell, 1980) rather than a categorical (or "basic") model of emotion (e.g., Ekman, 2003). Typically, dimensional accounts define emotional states in terms of arousal and valence (Russell, 1980) or approach/avoidance (Davidson, 1992). In a series of studies investigating vocal expressions, Bachorowski and colleagues provided support for Russell's dimensional account (Bachorowski & Braaten, 1994; Bachorowski & Owren, 1995), and significant acoustic correlates of affective dimensions such as activation, valence, intensity, and potency have also been determined in emotionally inflected speech (Laukka, Juslin, & Bresin, 2005). Work in the expression of emotion in faces has also shown that the dimensions of perceived valence and arousal have correlates in the statistical patterns of visual information of the facial expressions (Calder et al., 2001). No work so far has determined the extent to which dimensions such as arousal and valence dimensions have acoustic correlates in nonverbal emotional vocalizations.

The aim of the current paper was to establish how the acoustic properties of nonverbal emotional vocalizations relate to psychological categories and participants' ratings, across a range of positive and negative emotions. Specifically, we sought to identify patterns of physical properties that were associated with participants' ratings and categorizations of the stimuli, as has been established for emotion in the face (Calder et al., 2001) and for emotion in speech (Banse & Scherer, 1996; Juslin & Laukka, 2001). In the first experiments, categorization and rating paradigms were used to establish that these stimuli were well recognized and to acquire categorization and ratings judgments of the stimuli. Principal component analysis (PCA) was used to investigate whether the perceived arousal and valence might underlie participants' ratings of nonverbal vocal expressions. In the second part of the study, a discriminant analysis was used to establish whether the emotional sounds could be assigned to emotional categories on the basis of their individual acoustic profiles, as has been determined for emotional speech (Banse & Scherer, 1996). The acoustic properties of the emotional stimuli were then used to predict the listeners' ratings of specific emotion categories and of the perceived arousal and valence of the sounds.

EXPERIMENT 1

Method

Stimulus preparation and pilot

Naïve listeners can reliably recognize nonverbal vocal expressions of different negative (e.g., Scott et al., 1997) and positive (Sauter & Scott, 2007) emotional states. In the current study both negative and positive emotions were included. The stimuli thus included exemplars of the commonly studied "basic" emotions (e.g., Ekman, 1992) of fear, anger, disgust, and sadness, and surprise (Ekman & Friesen, 1971) and exemplars of

the positive emotions of achievement/triumph, amusement, contentment, sensual pleasure, and relief (Sauter & Scott, 2007).

Multiple recordings of nonverbal vocal expressions of 10 emotions (achievement/triumph, amusement, anger, contentment, disgust, fear, sensual pleasure, relief, sadness, and surprise) were made in an anechoic chamber.¹ The speakers were two male and two female native British English speakers with no formal performance training. Acted (rather than spontaneous) portrayals are commonly used in studies of vocal signals of emotion (Scherer, Johnstone, & Klasmeyer, 2003). In a review by Juslin and Laukka (2003), 87% of studies on emotional vocalizations used acted portrayals. In the current study, it was of particular importance to obtain recordings of good quality in order to allow the acoustic analyses in Experiment 2, necessitating the use of acted portrayals.

Speakers were presented with appropriate scenarios for each emotion (see Appendix A) and were asked to produce a variety of sounds, but no explicit guidance or exemplars were given as to the precise sort of sounds they should generate (to avoid artifactual stimulus consistency). However, the speakers were instructed not to produce "verbal" items (i.e., signals with lexical identity and overt articulation, such as "phew!", "yippee!", "yuck", etc.). Each speaker produced approximately 15 sounds per category. The sounds were recorded with a Brüel & Kjaer 4165 microphone and were digitized at a 48-kHz sampling rate with 16-bit quantization. This methodology differs from Schröder's (2003) study of nonverbal vocalizations of emotions, where speakers produced only three tokens per emotional class, with two of the three tokens generated by imitation.

All of the stimuli were then pilot tested on 10 participants, who performed a forced-choice task that was procedurally identical to the main study (see below). This method was used to identify and remove the stimuli that were least well recognized; many such stimuli were due to poor production, as the speakers often found it difficult

¹The positive stimuli (achievement, amusement, relief, sensual pleasure, and contentment) have been used in a previous study (Sauter & Scott, 2007). However, none of the data in the current paper have previously been published.

initially to produce some classes of stimuli on command (e.g., sensual pleasure) and also spent some time trying different sounds (e.g., achievement/triumph). The preselection of stimuli based on the results of pilot tests is commonly performed in emotional expression studies (e.g., Banse & Scherer, 1996) to avoid experimenter bias that would arise from a more subjective stimulus selection procedure. A test set of 10 tokens for each category was chosen, on the basis of the recognition scores from the pilot study. To aim for an even stimulus recognition standard, the stimuli for each emotion category were selected to match recognition rates as closely as possible to the overall average recognition rate of 78%. All speakers were represented in each set of stimuli for each emotion, with the exception of Male Speaker 1 for anger and Male Speaker 2 for sensual pleasure. The stimuli used in the categorization and rating tasks were thus 100 nonverbal emotion sounds with equal numbers expressing each of the emotions of achievement/triumph, amusement, anger, contentment, disgust, fear, sensual pleasure, relief, sadness, and surprise. Examples of the stimuli are available at <http://www.icn.ucl.ac.uk/speech/emotion/ehome.html>

Participants

A total of 20 participants (10 males, mean age 21 years) took part in the categorization experiment and another 20 listeners (11 males, mean age 25 years) in the rating tasks. All were recruited from the University College London Psychology participant database. None had taken part in any other studies involving emotional sounds, including the pilot study.

Design and procedure

Categorization task. Each stimulus was played once in random order through headphones from a laptop computer running a Psyscope program (Cohen, McWhinney, Flatt, & Provost, 1993). Participants were asked to categorize each emotional sound by pressing one of 10 number keys (0–9) corresponding to the 10 emotion labels of achievement/triumph, amusement, anger, contentment, disgust, fear, sensual pleasure, relief, sadness, and

surprise. A sheet of paper was provided next to the computer, which gave an example for each emotion label (see Appendix A). Participants were given as much time as they required to make their decision, and no feedback regarding the accuracy of the responses was provided.

Rating tasks. A second group of participants were asked to rate the stimuli. The format and method of presentation in the ratings task were the same as those in the categorization task. There were 12 rating scales, one for each of the 10 emotions, and 2 additional scales for arousal and valence. Each stimulus was presented once in each rating task, with presentation order randomized between participants and between scales. Participants were asked to judge the extent to which each stimulus expressed the given dimension on a 7-point scale. For the valence scale, 1 denoted highly negative valence, and 7 denoted highly positive valence; for all other scales 1 denoted minimum and 7 maximum. The rating scales were completed in a different random order for each participant. Each stimulus was presented 12 times, once for each rating scale. Participants were allowed to take breaks as they wished.

Results

Categorization

Participants were successful at identifying the sounds—that is, the most commonly selected response was the appropriate one for each category of vocal expression. Chi-squared analyses of the raw categorization data revealed that the participants were significantly better than chance at matching sounds and labels for each stimulus type when tested against all other emotions (chance 10%; see Table 1). The confusion matrix for the categorization data is shown in Table 2. The most common errors included anger sounds categorized as signalling disgust, surprise sounds perceived to communicate disgust or relief, and confusions between contentment and sensual pleasure. Another relatively common confusion was the classification of fear sounds as amusement. This was largely due a subset of the fear sounds being

Table 1. *Chi-square values for the categorization of positive and negative emotional vocalizations*

<i>Emotion</i>	$\chi^2(2)$
Achievement/triumph	931.6
Amusement	988.1
Anger	736.1
Contentment	646.4
Disgust	1,396.9
Fear	707.6
Pleasure	730.0
Relief	1,158.4
Sadness	784.4
Surprise	646.4

Note. Bonferroni corrected; all significant at $p < .0001$.

perceived as amused, rather than a generalized tendency across all the fear stimuli.

Ratings

The results from the rating tasks are displayed in Table 3. These were analysed first to establish that the different classes of emotional stimuli significantly affected participants' ratings of the stimuli, and second to test whether sounds expressing the intended emotion (e.g., disgust) were most highly rated on that rating scale. Finally, the rating scales for arousal and valence were analysed with separate repeated measures analyses of

variance (ANOVAs), to determine whether the stimuli were perceived to vary along these dimensions.

The ANOVAs for each rating scale were significant, $F(9, 171) = 75.94$ for achievement/triumph, 76.40 for amusement, 79.75 for anger, 71.01 for contentment, 89.39 for disgust, 64.56 for fear, 65.93 for sensual pleasure, 47.58 for relief, 68.77 for sadness, and 43.07 for surprise; all $p < .0001$, Bonferroni corrected. This indicates that there was significant variation on the emotional rating scales for the different stimulus types.

To test whether the "correct" stimulus type for each scale was also rated significantly more highly than the mean of the other emotion classes, planned comparisons were performed for each separate ANOVA, contrasting the sounds expressing the intended emotion (e.g., anger) with the other nine vocal emotional expression conditions. These were significant for each emotional rating scale, $t(19) = 17.20$ for achievement/triumph, 16.68 for amusement, 14.08 for anger, 11.41 for contentment, 19.43 for disgust, 15.52 for fear, 14.20 for sensual pleasure, 8.76 for relief, 19.51 for sadness, and 9.10 for surprise; all $p < .0001$, Bonferroni corrected.

Separate ANOVAs were performed on the ratings for arousal and valence. The results indicated that there was significant variation across both scales with emotional stimulus condition,

Table 2. *Categorization of positive and negative emotional vocalizations*

<i>Stimulus type</i>	<i>Response</i>									
	<i>Ach</i>	<i>Amu</i>	<i>Ang</i>	<i>Cont</i>	<i>Dis</i>	<i>Fear</i>	<i>Ple</i>	<i>Rel</i>	<i>Sad</i>	<i>Surp</i>
Ach	77.0	5.0	1.5	3.5	0.5	2.5	1.5	0.0	0.0	8.5
Amu	0.0	79.5	0.5	6.0	0.0	0.0	7.0	0.5	5.5	1.0
Ang	2.5	1.0	65.5	1.5	16.5	9.5	1.0	1.0	1.0	0.5
Cont	4.0	4.0	2.5	46.0	2.0	0.0	29.0	10.5	1.0	1.0
Dis	0.0	0.5	2.5	0.5	93.5	2.0	0.0	0.0	1.0	0.0
Fear	1.5	13.5	0.5	0.5	1.5	63.0	4.0	1.5	12.0	2.0
Ple	0.0	1.0	0.5	15.0	2.0	0.5	65.0	10.5	3.5	2.0
Rel	1.0	0.0	2.0	3.5	2.5	0.0	2.5	86.0	2.0	0.5
Sad	0.0	0.5	0.5	5.5	2.0	9.5	6.5	6.5	69.0	0.0
Surp	1.5	1.0	4.5	0.0	14.0	10.0	1.0	13.0	1.0	54.0

Note. In percentages. Horizontal rows add to 100. Correct categorizations are shown in bold. Ach = achievement/triumph, Amu = amusement, Ang = anger, Cont = contentment, Dis = disgust, Ple = pleasure, Rel = relief, Sad = sadness, Surp = surprise.

Table 3. Ratings of positive and negative nonverbal emotional vocalizations

Stimulus type	Rating scale											
	<i>Ach</i>	<i>Amu</i>	<i>Ang</i>	<i>Cont</i>	<i>Dis</i>	<i>Fear</i>	<i>Ple</i>	<i>Rel</i>	<i>Sad</i>	<i>Surp</i>	<i>Val</i>	<i>Aro</i>
Ach	6.34	4.7	1.4	4.47	1.19	1.24	4.15	4.46	1.32	4.32	6.17	5.96
Amu	3.81	5.61	1.37	4.02	1.36	1.48	3.77	3.21	1.87	3.17	5.15	4.82
Ang	1.76	1.51	5.5	1.63	3.88	2.83	1.59	1.75	2.06	1.96	2.13	5.2
Cont	3.24	2.52	1.51	5.28	1.45	1.31	4.68	3.65	1.75	2.05	4.64	2.88
Dis	1.34	1.37	2.96	1.52	5.87	1.79	1.37	1.38	1.71	1.87	1.88	4.08
Fear	1.91	2.22	2.04	1.87	2.99	5.11	1.96	1.75	3.21	2.84	2.62	4.93
Ple	2.77	2.32	1.33	5.22	1.35	1.49	5.69	3.77	2.27	2.29	4.81	2.72
Rel	2.97	1.81	1.88	3.45	1.87	1.65	3.39	5.32	2.35	2.23	3.84	2.64
Sad	1.47	1.34	1.52	1.75	2.16	2.71	1.88	1.77	5.05	1.77	2.05	3.05
Surp	2.74	2.16	2.77	2.35	3.17	3.18	2.45	3.03	2.08	4.61	3.31	4.58

Note. 1 = minimum, 7 = maximum. Ratings on own scale are shown in bold. Ach = achievement/triumph, Amu = amusement, Ang = anger, Cont = contentment, Dis = disgust, Ple = pleasure, Rel = relief, Sad = sadness, Surp = surprise, Val = valence, Aro = arousal.

$F(9, 171) = 53.33$ for arousal, and 77.06 for valence, both $p < .0001$.

Principal component analysis. To determine whether a smaller number of dimensions could account for a significant proportion of the variance in participants' ratings, the mean ratings for each stimulus on all of the scales except arousal and valence were subjected to a PCA. Arousal and valence ratings were not included, to ensure that any association between the

resultant factors and these dimensions was not biased. The analysis yielded two factors with eigenvalues over 1, accounting for 53.3% and 15.7% of the variance, respectively. Component 1 correlated highly with the participants' valence ratings ($r = .97$), and Component 2 correlated with the participants' arousal ratings ($r = .87$). Figure 1 shows these two components from the PCA plotted against one another and also a plot of the participants' original ratings on the arousal and valence scales.

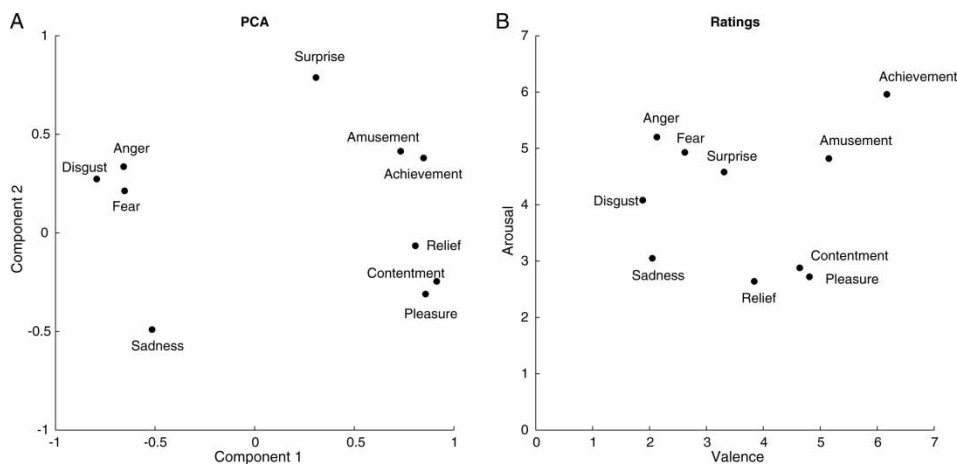


Figure 1. (A) Principal component analysis for positive and negative emotional vocalizations. (B) Average ratings on the dimensions arousal and valence for each category of emotional sounds ($n = 20$).

Discussion

The results from the categorization and rating tasks indicate that the negative emotions fear, anger, disgust, and sadness, the positive emotions achievement/triumph, amusement, relief, and sensual pleasure, and the neutral emotion surprise, have recognizable vocal nonverbal expressions. In contrast, a fifth candidate positive emotion, contentment, was consistently confused with sensual pleasure and was possibly being perceived as a weaker form of sensual pleasure. Although contentment and sensual pleasure are not strongly linked semantically (i.e., they are not synonyms), it is possible that they are associated with generally similar acoustic profiles and are disambiguated on the basis of subtle acoustic cues or by context in real-life situations. Alternatively, it is possible that contentment is simply not a “real” emotional category, or that participants in the current study did not recognize the contentment stimuli reliably because the exemplars used were of less good quality than the other emotion categories.

The PCA indicated that the two dimensions that correlated strongly with valence and arousal accounted for a total of 69% of the variance in the rating data. Notably, the two factors were unequal in their contribution (53% for the factor that correlated with valence ratings and 16% for the factor that correlated with perceived arousal). Previous studies that have applied a dimensional approach to emotional vocalizations have focused mainly on the important role of arousal (see Bachorowski, 1999), while the current study found a dominant role for valence. For example, a study by Bänziger and Scherer (2005) examined the relationship between the pitch contour of emotional nonsense-speech and the perceived level of emotional arousal. While they found a significant relationship between these variables, the study did not report whether there was a relationship with perceived valence. Two earlier studies by Bachorowski and colleagues measured perturbations in pitch and loudness in participants’ speech production during the performance of a difficult task. Their results showed that both the participants’ own arousal and the valence of the

feedback on their performance were reflected in these acoustic cues (Bachorowski & Braaten, 1994; Bachorowski & Owren, 1995).

EXPERIMENT 2

Acoustic analyses

In the categorization and ratings experiments, a set of nonverbal vocalizations were identified that could be accurately categorized and rated by naive participants. The second study investigated whether different classes of emotional vocalizations could be distinguished on the basis of their acoustic properties alone and whether the acoustical properties of the sounds reflected aspects of the listeners’ judgements. This has been done for ratings of emotional speech (Banse & Scherer, 1996), with considerable success—acoustic cues that predicted participants’ use of emotional categories were identified, using multiple regression, for 11 out of 14 different classes of emotional speech. Similarly, Juslin and Laukka (2001) measured 20 voice cues of speech with weak and strong intensity in five emotions. They found that participants’ emotional ratings of the sounds could be predicted reliably by the acoustic cues. Work on facial expressions of emotion has also had success in identifying relationships between the statistical constellations of facial images and emotional states. Calder et al. (2001) performed a PCA of the pixel intensities of images of facial expressions of emotions. They found that a set of principal components (PCs) could both categorize individual emotions effectively and capture their rated values on arousal and valence dimensions (see also Dailey, Cottrell, Padgett, & Adolphs, 2002).

In Experiment 2, an acoustic analysis of the nonverbal emotional vocalizations was performed, in order to describe the ways in which sounds from different categories vary on a number of acoustic features. As in previous work (Banse & Scherer, 1996; Juslin & Laukka, 2001), three broad domains of auditory features were analysed: amplitude, pitch, and the spectral properties of the

stimuli. Amplitude cues included measurements of intensity, aspects of the amplitude envelope, and duration. Pitch cues included mean pitch and pitch variation. Spectral cues included the spectral centre of gravity and the variation of the frequencies in the spectrum.

To determine whether these measurements capture sufficient detail of the sounds to classify them, discriminant analysis procedures were employed. In a second set of analyses, the acoustic measurements were used in a series of multiple linear regressions to determine whether linear combinations of these measurements could predict the emotional ratings of the stimuli from Experiment 1. The aim was to identify which patterns of acoustic variation were associated with the perceived emotional contents of the sounds. To summarize, two procedures were used to capture psychophysical properties of the emotional vocalizations: discriminant analysis to assess whether acoustic qualities can sort stimuli on the basis of the actor's intent, and linear regressions to assess whether the listeners' judgements on emotional rating scales could be predicted from acoustic qualities.

Method

Stimulus measurements

Measurements were taken of acoustic parameters from an extended set of 165 sound files from the same corpus as that used in Experiment 1 (16–17 of each emotion) using the Praat program (Boersma & Weenink, 2005). A larger set than the one used in Experiment 1 was selected to increase the power of the discriminant analyses. Only the sounds that were used in Experiment 1 were entered into the regression analyses. All sounds were downsampled to 44.1 kHz and scaled to have the same peak amplitude (0.291 Pa; the mean peak amplitude of the original recordings) prior to the analysis. This was necessary since the wide dynamic range of the original stimuli meant that the recording levels were different across the different emotional conditions. It still permits the analysis of amplitude variation, which is computed across the whole waveform.

The set of acoustic measurements consisted of metrics that are commonly used for describing human vocalizations, in particular speech, and were expected to be broad enough to be applicable across all categories of emotional vocalizations in the current study. In the amplitude domain, duration, standard deviation, and mean intensity (dB SPL scale) were obtained from the waveform. Second, the number of amplitude onsets per sound file was counted, using an algorithm that detects local rises in the smoothed amplitude envelope (Cummins & Port, 1998; Scott, 1993). This gives an estimate of the number of “syllables” (i.e., separate perceptual centres) in a vocalization (Morton, Marcus, & Frankish, 1976). To this end, the signal was first band-pass filtered (Hanning filter centred at 2.2 kHz with a bandwidth of 3.6 kHz), full-wave rectified, and smoothed (Hanning low-pass filter with an 8-Hz cut-off) before obtaining the first derivative of the smoothed envelope. Onsets were then defined as points in time at which (a) a set threshold in the amplitude envelope was exceeded, and (b) the derivative curve had a positive value.

Pitch measurements were based on a derived curve representing change in fundamental frequency as a function of time (using a 75–1,000-Hz analysis window and the autocorrelation method described in Boersma, 1993). From this, pitch minimum, maximum, mean, and standard deviation were obtained. Global pitch movement was defined as the difference between the mean pitch values of the first and last 20% of the sound file. However, pitch movement was discarded as a variable, as this measurement could not be calculated reliably for any of the relief or surprise stimuli (due to their brevity) or for half of the anger stimuli (due to their weak pitch). Finally, the spectral centre of gravity and the standard deviation of the spectrum were computed on the basis of fast Fourier transformations.

Statistical procedure

Discriminant analysis

Discriminant analyses were performed in order to examine whether the measurements from the

acoustic analysis provided sufficient information to statistically distinguish between emotion categories. The independent variables of the models were the acoustic measurements of the 165 nonverbal vocalizations, and the dependent variable was the category of vocal expression. Discriminant analysis identifies a set of functions that minimizes within-category variability and maximizes between-category variability. These functions were used by the model to predict the category membership of each of the stimuli in the set.

As the standard method of discriminant analysis can overestimate the accuracy of the model, the more conservative “jackknife” method was also used. With this method, the category membership of each stimulus is estimated from discriminant functions derived from all other stimuli whose categories were known to the model—that is, a separate analysis is carried out for each stimulus. The performance of the model is measured by the percentage of categorizations made by the model that are correct, assessed both overall and for each category separately. If the accuracy of the model’s classifications is high, this indicates that the independent variables are sufficient to distinguish among the categories. In this case this would indicate that the acoustic measurements of the sounds provided sufficient detail to distinguish among the different emotion classes.

Multiple regressions

In order to determine which acoustic characteristics underlie judgements of each of the emotions, multiple regressions were performed for each of the emotional rating scales from Experiment 1 (achievement/triumph, amusement, anger, contentment, disgust, fear, sensual pleasure, relief, sadness, and surprise). This analysis only included the acoustic measurements of the 100 stimuli (10 per category) that had been rated for every emotion in Experiment 1. The independent variables were the acoustic measurements. These analyses identify which, if any, constellation of acoustic cues significantly predicts participants’ ratings on each of these emotional rating scales. Multiple regressions were also carried out with the participants’ ratings on the arousal and

valence scales from Experiment 1, in order to determine whether the acoustic measurements of the sounds could accurately predict these perceived qualities.

Results

Acoustic analysis and discriminant analysis

The results of the acoustic analysis are displayed in Appendix B. The standard discriminant analysis and the jackknife analysis are shown in the upper and lower sections, respectively, of Table 4. The overall accuracy of the analyses was 56.4% for the standard discriminant analysis and 50.3% for the jackknife analysis (chance = 10%).

Chi-square analyses were performed to test whether the models’ overall performance was better than would be expected by chance. The results indicated that the acoustic measurements provided sufficient information to discriminate successfully between stimuli from different emotion categories for both types of discriminant analyses: $\chi^2(2) = 3,929$ for the standard analysis, 2,953 for the jackknife analysis, both $p < .0001$. In the case of the standard discriminant analysis, performance was lowest for contentment (23.5%) and fear (31.3%) and highest for amusement (76.5%) and surprise (81.3%). In the jackknife analysis, performance was lowest for contentment (29.4%) and fear (25.0%) and highest for achievement/triumph (70.6%).

Sets of chi-square analyses were also performed to examine whether the models performed better than chance in classifying stimuli from each of the emotion categories. For the standard discriminant analysis, the model performed significantly above chance for all emotions: $\chi^2(2) = 673$ for achievement/triumph, 810 for amusement, 392 for anger, 33 for contentment, 209 for disgust, 83 for fear, 436 for sensual pleasure, 548 for relief, 392 for sadness, and 931 for surprise (all $p < .05$, Bonferroni corrected for 10 comparisons). For the jackknife analysis, the model also performed significantly above chance for all categories: $\chi^2(2) = 673$ for achievement/triumph, 436 for amusement, 392 for anger, 69 for contentment, 209 for disgust, 41 for fear, 436 for sensual

Table 4. Results of standard and jackknife discriminant analysis for classification of nonverbal emotional vocalizations from acoustic analysis

Stimulus type	Classification									
	<i>Ach</i>	<i>Amu</i>	<i>Ang</i>	<i>Con</i>	<i>Dis</i>	<i>Fear</i>	<i>Ple</i>	<i>Rel</i>	<i>Sad</i>	<i>Surp</i>
<i>Standard discriminant</i>										
Ach	70.6	0.0	11.8	0.0	5.9	11.8	0.0	0.0	0.0	0.0
Amu	0.0	76.5	0.0	11.8	0.0	0.0	0.0	0.0	11.8	0.0
Ang	6.3	0.0	56.3	0.0	18.8	12.5	6.3	0.0	0.0	0.0
Cont	0.0	11.8	5.9	23.5	0.0	0.0	29.4	17.6	11.8	0.0
Dis	6.3	6.3	18.8	0.0	43.8	0.0	6.3	12.5	6.3	0.0
Fear	31.3	0.0	25.0	0.0	6.3	31.3	0.0	0.0	0.0	6.3
Ple	0.0	0.0	0.0	11.8	0.0	0.0	58.8	11.8	5.9	11.8
Rel	0.0	0.0	5.9	17.6	0.0	0.0	5.9	64.7	0.0	5.9
Sad	0.0	18.8	0.0	6.3	0.0	0.0	6.3	0.0	56.3	12.5
Surp	0.0	0.0	0.0	0.0	6.3	6.3	0.0	6.3	0.0	81.3
<i>Jackknife</i>										
Ach	70.6	0.0	11.8	0.0	5.9	11.8	0.0	0.0	0.0	0.0
Amu	0.0	58.8	0.0	11.8	0.0	0.0	0.0	11.8	17.6	0.0
Ang	6.3	0.0	56.3	0.0	18.8	12.5	6.3	0.0	0.0	0.0
Cont	0.0	11.8	0.0	29.4	0.0	0.0	29.4	17.6	11.8	0.0
Dis	6.3	6.3	18.8	0.0	43.8	0.0	6.3	12.5	6.3	0.0
Fear	31.3	0.0	25.0	0.0	12.5	25.0	0.0	0.0	0.0	6.3
Ple	0.0	0.0	0.0	11.8	0.0	0.0	58.8	11.8	5.9	11.8
Rel	0.0	0.0	5.9	17.6	0.0	0.0	5.9	58.8	5.9	5.9
Sad	0.0	18.8	0.0	6.3	0.0	0.0	12.5	0.0	50.0	12.5
Surp	0.0	0.0	0.0	0.0	18.8	12.5	0.0	18.8	0.0	50.0

Note. All results in %, correct classifications in bold. All horizontal rows add to 100. Ach = achievement/triumph, Amu = amusement, Ang = anger, Cont = contentment, Dis = disgust, Ple = pleasure, Rel = relief, Sad = sadness, Surp = surprise.

pleasure, 436 for relief, 293 for sadness, and 293 for surprise (all $p < .05$, Bonferroni corrected for 10 comparisons).

Common confusions in the standard discriminant analysis were anger sounds categorized as disgust, contentment sounds categorized as sensual pleasure and relief, disgust sounds categorized as anger, fear sounds categorized as achievement and anger, relief sounds categorized as contentment, and sadness sounds categorized as amusement. The confusions in the jackknife analysis were similar, except that amusement sounds were also categorized as sadness, and surprise sounds were categorized as disgust and relief. This pattern is consistent with that of human participants in Experiment 1, although the human performance was somewhat more accurate (see Table 5 for the most common confusions for

human listeners and discriminant analyses). In particular, confusions for anger, contentment, disgust, sensual pleasure, relief, and surprise were similar for the human listeners and the discriminant models. In contrast, the discriminant analysis errors for sounds of achievement, amusement, fear, and sad sounds differed from those made by humans. Nevertheless, the discriminant analyses clearly demonstrated that the acoustic measurements provided sufficient information to categorize the emotional sounds accurately for all emotion categories and also capture many of the typical confusions. However, they do not indicate what information was associated most with human listeners' perceptual judgements of each category. This relationship was examined using multiple regressions of the acoustic cues and listeners' judgements.

Table 5. Common confusions for human listeners, standard discriminant analysis, and jackknife analysis in the categorization of emotional sounds, showing all categories that comprise over 5% of responses to a given stimulus category

Stimulus	Common confusions		
	Human listeners	Discriminant analysis	Jackknife analysis
Ach	Surp (9)	Ang (12), Fear (12)	Ang (12), Fear (12)
Amu	Ple (7), Con (6), Sad (6)	Con (12), Sad (12)	Sad (18), Con (12), Rel (12)
Ang	Dis (17), Fear (10)	Dis (19), Fear (13)	Dis (19), Fear (13)
Con	Ple (29), Rel (11)	Ple (29), Rel (18), Sad (12)	Ple (29), Rel (18), Sad (12)
Dis	Ang (3)	Ang (19), Rel (13)	Ang (19), Rel (13)
Fear	Amu (14), Sad (12)	Ach (31), Ang (25)	Ach (31), Ang (25)
Ple	Con (15), Rel (11)	Con (12), Rel (12), Sur (12)	Con (12), Rel (12), Sur (12)
Rel	Con (4)	Con (18)	Con (18)
Sad	Fear (10), Ple (7), Rel (7)	Amu (19), Sur (13)	Amu (19), Ple (13), Sur (13)
Surp	Dis (14), Rel (13), Fear (10)	Dis (6), Fear (6), Rel (6)	Dis (19), Rel (19), Fear (13)

Note. For cases where no confusions reached 5%, the most common confusion category is shown. All results in %. Stim = stimulus type, Ach = achievement/triumph, Amu = amusement, Ang = anger, Con = contentment, Dis = disgust, Ple = pleasure, Rel = relief, Sad = sadness, Surp = surprise.

Multiple regressions

The regression analyses were significant for all of the emotional scales (see Table 6). This indicates that the participants' ratings on each of the emotional scales in Experiment 1 could be predicted reliably from the acoustic measurements of the sounds. The variance explained by the acoustic factors ranged from 18% for the sadness and amusement ratings to 36% for the ratings on the fear scale. Clearly, much of the unaccounted variance in the emotion ratings was due to acoustic features that were not captured by the measurements used. Nonetheless, these measurements predicted a significant portion of the participants' ratings on each of the emotion scales.

Table 6 shows the acoustic variables that were revealed by the multiple regression analyses to predict significant amounts of variation for the ratings on each rating scale. A significant proportion of the variance for all the emotion ratings scales was predicted by some combination of acoustic factors, and for eight of the emotions the variance was predicted by a unique constellation of factors. The ratings for "contentment" and "pleasure" were predicted by very similar acoustic patterns. These regressions indicate, as has been described for emotional speech (Banse & Scherer, 1996; Juslin & Laukka, 2001), that the perception

of emotions from nonverbal vocalizations relies on different acoustic profiles, depending on the specific emotion. Specifically, achievement ratings were predicted by a higher mean pitch, more spectral variation, and a lower minimum pitch. Amusement ratings were predicted by a higher number of amplitude onsets and more spectral variation. Anger ratings were predicted by a lower mean pitch, a higher spectral centre of gravity, and less spectral variation. Contentment and pleasure ratings were predicted by longer durations, a lower spectral centre of gravity, and more spectral variation. Disgust ratings were predicted by shorter durations, a higher spectral centre of gravity, and lower spectral variation. A higher spectral centre of gravity and lower spectral variation predicted fear ratings. Relief ratings were predicted by a higher mean pitch, a higher spectral centre of gravity, and more spectral variation. Sadness was predicted by lower spectral variation and lower intensity, although the intensity cue had a p value of .07 (beta value = $-.71$). Finally, surprise ratings were predicted by shorter durations, with a higher pitch minimum and lower pitch mean, and less pitch variation.

As described previously, the acoustic factors can be grouped into three categories—those associated with properties of the amplitude of the sound

Table 6. Summary of results from multiple regression analyses for each of the rating scales from Experiment 1, against the acoustic measures, showing the beta weights and adjusted R^2 values for the ratings of each emotion category

Ac cue	Ach	Amu	Ang	Cont	Dis	Fear	Ple	Rel	Sad	Surp
Dur	.02	-.04	.09	.31**	-.35**	-.1	.32**	.041	.15	-.43**
Amp rms	.46	.19	-.22	.02	-.03	-.24	-.02	-.189	.19	.5
Amp ons	.07	.47**	-.14	.04	.02	-.03	-.03	-.1	-.21	.02
Int	-.11	.07	.22	.37	-.14	.15	.38	.43	-.71 ¹	-.51
P min	-.75**	-.39	.21	-.03	.11	.38	.12	-.39	.24	-.52*
P max	.07	.06	.12	-.21	-.04	.21	-.03	-.22	.19	.28
P mean	.81**	.42	-.46*	.07	-.18	-.24	-.08	.59*	-.17	.59*
P std	-.43	-.32	.15	.2	.32	-.26	.18	-.08	.21	-.55*
Spec cog	-.22	-.1	.68**	-.52**	.45**	.57**	-.51**	-.58**	.06	.12
Spec std	.44**	.3*	-.29*	.39**	-.32**	-.35**	.311*	.63*	-.38**	.04
Adj R^2	.23**	.18**	.28**	.29**	.24**	.36**	.24**	.27**	.18**	.23**

Note. Values are beta weights, except for R^2 . Ac = acoustic, Ach = achievement, Amu = amusement, Ang = anger, Cont = contentment, Dis = disgust, Ple = pleasure, Rel = relief, Sad = sadness, Surp = surprise, Dur = duration, Amp = amplitude, rms = root mean square, ons = onsets, Int = intensity, P = pitch, min = minimum, max = maximum, std = standard deviation, Spec = spectral, cog = centre of gravity, Adj = adjusted.

* $p > .05$. ** $p > .01$. ¹ $p = .07$.

(amplitude onsets, amplitude standard deviation, duration, intensity), those associated with pitch information (pitch minimum, maximum, and mean, pitch standard deviation), and those associated with the spectrum of the sounds (spectral centre of gravity, spectral standard deviation). Collapsing predictive acoustic features for each emotional ratings scale into one of these three categories, only the ratings for “fear” were predicted on the basis of just one class of acoustic information (spectral properties). All of the other ratings were predicted by a combination of acoustic properties: anger, relief, and achievement ratings were predicted by spectral and pitch information, surprise on the basis of pitch and envelope cues, and disgust, amusement, sadness, and contentment and pleasure by a combination of spectral and envelope cues. Figure 2 shows a Venn diagram of the three kinds of acoustic cue and how the constellation of acoustic cues associated with the different emotional ratings fits into these three acoustic categories.

Multiple regressions were also carried out for the participants’ ratings on the arousal and valence scales in Experiment 1 (Table 3). The summary of these regressions is shown in Table 7. Both arousal and valence ratings were significantly predicted by subsets of the acoustic measures.

However, the variance accounted for in the arousal ratings was notably much higher than that of the valence ratings: .59 adjusted R^2 for arousal, .18 adjusted R^2 for valence. Arousal ratings were predicted by shorter duration, more amplitude

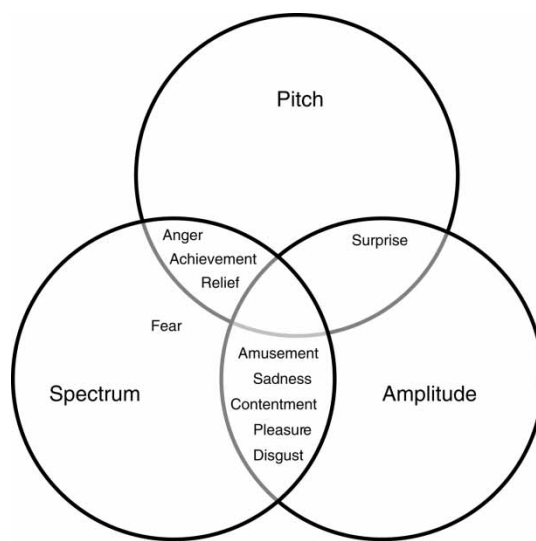


Figure 2. Venn diagram showing which classes of acoustic information are used to predict participants’ ratings for each of the emotional scales.

Table 7. Summary of results from multiple regression analyses for the rating scales "arousal" and "valence" from Experiment 1 against the acoustic measures, showing the beta weights and adjusted R^2 values for the ratings of each category

Acoustic cues	Arousal	Valence
Dur	-.27**	.09
Amp std	.19	.13
Amp ons	.25*	.2
Int	-.23	.28
P min	-.73**	-.33
P max	.34	-.12
P mean	.62**	.39
P std	-.60**	-.09
Spec cog	.62**	-.42**
Spec std	-.14	.45**
Adj R^2	.58**	.17**

Note. Values are beta weights, except for R^2 . Dur = duration, Amp = amplitude, rms = root mean square, ons = onsets, Int = intensity, P = pitch, min = minimum, max = maximum, std = standard deviation, Spec = spectral, cog = centre of gravity, Adj = adjusted.

* $p > .05$. ** $p > .01$.

onsets, lower minimum pitch, higher mean pitch, less pitch variation, and a higher spectral centre of gravity. In contrast, higher valence scores (more positive ratings) were predicted by a lower spectral centre of gravity and higher spectral variation.

Discussion

The results of Experiment 2 demonstrate a mapping between the acoustic properties of the nonverbal vocalizations and their emotional category. In addition, they show that the ratings for different emotions could be predicted on the basis of different constellations of acoustic cues. Within the acoustic cues, spectral measures, especially spectral change, were particularly important in distinguishing the different emotional vocalizations.

Discriminant analyses

Overall, the standard discriminant analysis and the jackknife analysis categorized the emotional

vocalizations with well-above-chance accuracy (56.4% and 50.3% correct, respectively; chance = 10%). This demonstrates that the measurements of the acoustic analysis provided sufficient information for discriminating among stimuli from different emotional categories. The statistical models performed significantly better than chance not only in terms of overall performance but also in classifying stimuli from each of the emotional categories. Furthermore, the pattern of confusions broadly mirrored those found in Experiment 1, although the human performance was better overall. The accuracy of these analyses compares well with previous work using emotional speech (Banse & Scherer, 1996), which reported accuracy rates of 53% for the standard discriminant analysis and 40% for the jackknife analysis (chance = 7%), both of which were close to the human performance at 48%. Furthermore, the performance of the models also mirrored the kinds of errors that were typically made by the human judges.

These findings also parallel those on visual signals of emotions. Calder et al. (2001) used discriminant analyses to determine whether different facial expressions could be discriminated from pixel intensities in these images. Analogous to the present study, they found that the facial expressions were categorized with well-above-chance accuracy, using both standard and jackknife analyses, and that the confusions made by human participants were also captured by the models. Thus, for both facial and vocal expressions of emotions, it is possible to classify emotional expressions in a manner that models human performance on the basis of basic perceptual features.

Multiple regressions

The participants' ratings could be predicted by a particular constellation of acoustic cues for each emotion scale (Table 6). Exceptions were contentment and sensual pleasure, which were predicted by the same constellation of acoustic cues. Indeed, a close acoustic similarity for these two emotional expressions would explain the tendency of human participants in Experiment 1 to confuse them and may be consistent with them not

constituting two different emotion categories (see also Sauter & Scott, 2007).

With the exception of fear, all of the emotion scales were judged on the basis of two classes of acoustic information. The variance explained by the acoustic factors ranged from 18% for the amusement and sadness ratings to 36% for the ratings on the fear scale (Table 6). The unaccounted variance in the emotion ratings was likely due to factors other than the acoustic measurements that were included in the present analysis, such as fine spectral detail. A recent study by Cheang and Pell (2008) examined the importance of a range of acoustic cues including harmonics-to-noise ratio (HNR) for the perception of sarcasm in speech. They found that HNR, together with variation in fundamental frequency, was a reliable indicator of sarcastic speech. Voice quality cues may affect the perception of nonverbal vocalizations in a similar fashion.

These results are consistent with previous findings from studies of emotional speech. Banse and Scherer (1996) regressed acoustic parameters onto participants' use of the emotion categories in a forced-choice task with a range of different emotions expressed in speech (hot and cold anger, panic, anxiety, despair, sadness, elation, happiness, interest, boredom, shame, pride, disgust, and contempt). They found that for most of the emotions, the participants' categorizations could mostly be significantly predicted from the acoustic cues (R values ranged between .16 for cold anger and .27 for happiness, but were not significant for cold anger and disgust). Banse and Scherer also did a reverse set of regressions, to predict acoustic features from the emotion of the sounds. They found that the emotion of the speech sounds predicted a large proportion of the variance for most of the acoustic variables that they measured. Juslin and Laukka (2001) found that a range of acoustic measures significantly predicted the participants' ratings of emotional speech stimuli for five different emotions (anger, disgust, fear, happiness, and sadness). Both of these studies with emotional speech found that, as in the current study, different emotional ratings were associated with different acoustic profiles.

Specifically comparing the emotions common to the three studies enables the comparison of acoustic cues in spoken language and nonverbal vocalizations. For anger ratings, Juslin and Laukka (2001) reported a lower pitch, a higher intensity, more spectral energy over 500 Hz, a higher first formant, and faster attack times for the voice onset. In contrast, Banse and Scherer (1996) reported (for "hot" anger) a higher pitch and more pitch variation, and a higher proportion of spectral energy under 2,000 Hz. In the current study, the anger ratings were predicted by a higher spectral centre of gravity and a lower mean pitch, as in the Juslin and Laukka study. The difference with the Banse and Scherer results may be because of their use of a "hot" anger category. In the current study, lower spectral variation was also a significant predictor of anger ratings.

For disgust, Juslin and Laukka (2001) found that ratings were associated with a lower mean pitch and a downwards pitch inflection, along with more spectral energy over 500 Hz, a higher first formant, and faster attack times for the voice onset. Banse and Scherer (1996) reported an increase in the proportion of spectral energy over 1,000 Hz. In the current study, a higher spectral centre of gravity was also associated with ratings for disgust, consistent with the previous studies on speech. Shorter durations and less spectral variation were also significant predictors for disgust in the ratings of the nonverbal emotional sounds.

For fearful emotional speech, Juslin and Laukka (2001) reported that a higher pitch, lower pitch variation, lower levels of spectral energy over 500 Hz, a lower first formant, a faster speech rate, and higher proportion of pauses were associated with fear ratings. Banse and Scherer (1996) reported a higher mean pitch for both "panic" and "anxiety" in speech, with lower pitch variation and lower mean energy for the "anxiety" stimuli. In contrast, the most predictive cues for the nonverbal emotional vocalizations in the current study were a higher spectral centre of gravity and less spectral variation. This difference may represent the difference between the kinds of nonverbal screaming sounds produced by the speakers in the current

study and the inflections of fear in spoken language, which appear to be more associated with pitch cues.

For sadness ratings, both of the emotional speech studies (Banse & Scherer, 1996; Juslin & Laukka, 2001) reported an association with lower intensity and higher pitch: There was also an association with lower pitch variation, lower first formant frequency, and more pauses (Juslin & Laukka, 2001), and longer voicing duration and more energy under 2,000 Hz (Banse & Scherer, 1996). Ratings for sadness in the current study were also predicted by less spectral variation and by lower levels of intensity (albeit at a borderline significant, $p = .07$).

These studies vary in a number of ways, other than the use of emotional speech or nonverbal vocalizations to express the emotions: the range of emotions, the number of speakers and their experience (i.e., professional or not), the instructions and scenarios, and the acoustic measurements used. This means that inferences from direct comparisons across the three studies are necessarily somewhat limited. However, there is evidence for both similarities and differences in the ways that listeners rate the acoustic cues used in emotional speech and in nonverbal emotional vocalizations.

Overall, for the emotional categories that could be compared, pitch cues were somewhat less important than spectral cues for the nonverbal emotional expressions, which is a different pattern from that seen for emotional speech. Indeed, all 5 emotions studied in the Juslin and Laukka (2001) paper were significantly predicted by pitch cues, and 7 of the 14 emotion category responses in the Banse and Scherer (1996) paper were predicted by pitch cues. In contrast, in the current study, the ratings of 4 emotion categories (achievement, anger, relief, and surprise) were predicted by pitch cues, while 9 (all but surprise) were predicted by spectral cues. Spectral cues were also important for emotional speech (5 out of 14 emotional conditions in Banse and Scherer's study and for 4 out of 5 emotions in Juslin and Laukka's study). Notably, for the nonverbal vocalizations, it was the measure of *variance* in the

spectral information that was the most important across conditions, with ratings for all of the negative emotions being predicted by lower spectral variance measures, and ratings for all of the positive emotions being associated with a higher measure of spectral variance.

Arousal and valence

Nearly 60% of the variance in the participants' ratings of perceived arousal could be predicted from the acoustic features of the sounds. This provides support for an acoustic "arousal" dimension, consistent with previous claims that vocal cues primarily convey arousal, over and above other dimensions or states (Bachorowski, 1999; Bänziger & Scherer, 2005). These cues are similar to the information indicating high "activation" in a study of the acoustic cues associated with emotional dimensions in emotionally inflected speech (Laukka et al., 2005). Laukka et al. found that higher pitch, higher first formant, and more spectral energy over 500 Hz, as well as higher intensity, were associated with higher activation.

In contrast, there was a somewhat weaker relationship between the acoustic cues and participants' valence ratings for the current study; 17% of the variance was accounted for by the acoustic features of lower spectral centre of gravity and greater spectral variation. This is also consistent with the Laukka et al.'s (2005) study, in which the acoustic cues predicted less variance for the participants' valence ratings than for all of the other rating scales. In their study of emotional speech the cues were higher pitch, lower minimum pitch, and more spectral energy under 500 Hz. Thus, across both speech and nonverbal emotional sounds, a lower frequency emphasis for the spectral profile was associated with more positive valence ratings, but otherwise the cues that predicted valence ratings were different. Across individual emotional ratings, the positive emotions were all associated with high levels of spectral variance, while the negative emotions were all associated with lower levels of spectral variance. This relationship may underlie the role of spectral variation in the prediction of overt valence ratings.

GENERAL DISCUSSION

Recognizing emotions from the voice

Previous neuropsychological research (e.g., Calder et al., 2004; Calder et al., 2000; Scott et al., 1997) has used vocal signals of sadness, anger, fear, disgust, happiness, and surprise that were similar to those used in the current study (i.e., nonverbal, vocal expressions) to investigate emotional impairments following brain injury. However, previous behavioural studies using acoustic analyses to investigate the perception of emotions in vocalizations have exclusively examined emotional speech (Banse & Scherer, 1996; Juslin & Laukka, 2001; Laukka et al., 2005). This study provides the first systematic investigation of positive and negative nonverbal vocal expressions, in terms of recognition rates, confusions, ratings, and their acoustic profiles. Experiment 1 demonstrates that both positive and negative emotions can be identified reliably from nonverbal vocalizations. A previous study reported that a subset of the emotions used in the current study (the positive emotions) could be identified from nonverbal signals (Sauter & Scott, 2007). The current study demonstrates that nonverbal expressions of different positive emotions can be identified in the context of negative emotional vocalizations. Further studies will be needed to determine whether these positive emotions are exclusively expressed by the voice (Ekman, 1992), or whether they are also associated with distinct facial expressions. Recent work has suggested that certain positive emotions, such as pride, may be conveyed by distinct facial and postural cues, which indicates that the differentiation of positive affect signals may indeed not be specific to the vocal domain (Tracy & Robins, 2004). Further work will also be able to establish the extent to which these expressions are recognized in non-Western cultures, as has been investigated for facial cues (Ekman, 1994; Ekman et al., 1969; Elfenbein & Ambady, 2002; Russell, 1994).

The current study has also demonstrated that, with the exceptions of sensual pleasure and contentment, each type of nonverbal emotional vocalization could be automatically categorized by a

discriminant analysis of acoustic measures. In addition, each emotion category had a distinctive acoustic profile. This suggests that, as in the face and emotional speech, different nonverbal emotional vocalizations are associated with distinct physical characteristics. Unlike the studies of emotional speech, where pitch was a dominant cue to emotional ratings, spectral cues—especially spectral variance—was a dominant cue for all but surprise vocalizations.

The previous study of nonverbal vocalizations of positive emotions (Sauter & Scott, 2007) found substantial overlap between sensual pleasure and contentment, a finding replicated in the current study. The rating data from the current study corroborate this pattern, as contentment sounds were rated highly on the pleasure dimension and vice versa. These two emotion categories may have been considered by participants to express variants of the “same” emotion. This interpretation was further supported by the similarities found in the discriminant analyses of the acoustic characteristics of these two stimulus classes. Furthermore, the ratings for contentment and sensual pleasure related in the same way to the same set of acoustic features in the regression analyses. This pattern suggests that the confusion between these two emotions was reflected in similarities of their acoustic profiles. However, this association could be also be due to contentment and sensual pleasure being emotions of relatively low intensity. Previous studies have found that vocal emotions with strong emotion intensity are easier to decode than those with weak emotional intensity (Juslin & Laukka, 2001).

Acoustic cues

The results of the multiple regression analysis indicate that participants’ ratings of achievement, amusement, anger, disgust, fear, relief, sadness, and surprise were associated with different constellations of acoustic features. This relationship between physical stimulus attributes and stimulus ratings has been previously described for the expression of emotions in speech (Banse & Scherer, 1996; Juslin & Laukka, 2001) and in facial expressions (Calder et al., 2001). The

present results also suggest that there is some similarity between the acoustic cues used in the detection and recognition of emotion expressed in speech and nonverbal vocalizations—the ratings for anger, sadness, and disgust shared some acoustic features in the current study and previous work on emotionally inflected speech (Banse & Scherer, 1996; Juslin & Laukka, 2001). However, there were also some differences—for example, fear ratings were associated with different cues for the emotional speech and the emotional sounds. This suggests that the acoustic cues used in the assessment of emotions in speech and nonverbal sounds are not identical.

Within the acoustic profiles for the emotional sounds, spectral variation was an important cue for ratings of all but one of the emotional categories, the exception being surprise. Spectral cues have also been reported to be important in the ratings of emotional speech, along with pitch and pitch variation (Banse & Scherer, 1996; Bänziger & Scherer, 2005; Juslin & Laukka, 2001). Our data suggest that pitch cues also play a role in the perception of emotion from nonverbal vocal cues, but that spectral cues, especially measures of spectral variation (or the absence of such variation), are equally if not more important. As change in the spectral properties of any vocalization can result from movements of the supralaryngeal articulators, as well as by the changes in the sounds produced at the larynx (e.g., from a breathy sound to a normally voiced sound), spectral variation can be considered a rough index of the overall amount of movement associated with the vocalizations (though not what those movements are) and of change in the source sounds produced at the larynx (though not what these changes are). Measures of spectral change have not been reported in emotional speech (Banse & Scherer, 1996; Juslin & Laukka, 2001), possibly because the spectral variation associated with speech production masks any specific changes associated with emotion, or may prevent those changes from occurring.

The nonverbal emotional vocalizations associated with lower amounts of spectral change were anger, disgust, sadness, and fear. This lack of spectral variance may reflect reduced movements

of the articulators during the production of these sounds and a consistency (i.e., a lack of change) in the manner of voicing at the larynx. It is possible that the lack of spectral change is associated with a more static facial expression during vocalizations for these negative emotions, which all have correlates in the facial expressions of the four negative “basic” emotions (Ekman & Friesen, 1971). In contrast, ratings of all of the positive emotions, hypothesized to be facially associated with a smile (Ekman, 1992), were predicted by higher amounts of spectral variation. These dynamic spectral profiles may reflect greater change in the movements of the articulators and larynx associated with these emotions—they may all be associated with a smile, but the smile may be less “fixed” in place. Further work investigating both auditory and visual channels together, to identify the kinds of orofacial, articulatory, and laryngeal movements associated with emotional vocalizations, will be able to further delineate how these spectral changes relate to the different expressions.

Arousal and valence

The principal components analysis in Experiment 1 yielded two factors that together accounted for 69% of the variance. The first factor was highly correlated with the participants’ valence ratings, and the second factor was highly correlated with their arousal ratings. Notably, although some emotions that were close in terms of arousal and valence were commonly confused (e.g., contentment and sensual pleasure), this was not consistently the case (e.g., anger and fear were not confused with one another).

Bachorowski (1999) has argued that vocal communication in speech sounds primarily signals the sender’s arousal state and only to a small degree their valence state. In line with this suggestion (see also Banse & Scherer, 1996) the acoustic cues in the model in Experiment 2 explained 58% of the variance of the arousal ratings, but only 18% of the valence ratings. This pattern indicates that the perceived arousal of emotional vocalizations could be better mapped out in terms of their acoustic features than the valence (see also

Banse & Scherer, 1996; Laukka et al., 2005). Nevertheless, the acoustic factors still predicted a significant proportion of the valence ratings, as has been previously described for emotional speech (Laukka et al., 2005). However, the results from the PCA analysis of the ratings data in Experiment 1 contradict the claim that valence is not reliably expressed in the voice. These results suggest that, of these two dimensions, valence is the dominant feature conveyed by these nonverbal emotional vocalizations. The principal component correlating with perceived valence accounted for most of the variance (58.3%) in the model, whereas the component correlated with perceived arousal accounted for only 16% of the variance in the participants' ratings.

One explanation for the discrepancy between the importance of valence in the PCA analysis and the dominant role for arousal in the acoustic analysis could be that the amount of arousal is directly reflected in the acoustics of the voice (Banse & Scherer, 1996), while this may not be that case for valence. Rather, positive or negative valence may represent a conceptual (but not perceptual) distinction between emotion categories, which corresponds less well than arousal to any consistent acoustic mapping. In other words, combinations of perceptual cues distinguish among the individual emotions, and valence ratings may be derived from the knowledge that certain emotions are positive whereas others are negative.

Conceptual properties of the individual emotions may have also had an effect on the relationship between the ratings and the acoustic parameters. The greatest amount of variance accounted for by acoustic factors was 36% (for the fear scale), and the least was 18% (for the amusement and sadness ratings). This difference could be due in part to limitations on the acoustic measures we made. However, there is also the possibility that listeners were making ratings based on their perceptions of the symbolic properties of the stimuli, which might lead to large acoustic differences between items still judged to be similar symbols of the same emotional state (Buck & Vanlear, 2002). Further work with more speakers and possibly contrasting spontaneous

and posed exemplars of emotional states will be able to investigate this further.

Considerations and further studies

An important limitation of the current studies is the reliance on acted emotional vocalizations. Although nonspontaneous expressions are used by most studies in this area of research (see Juslin & Laukka, 2003), this methodology has been criticized for yielding stereotypical portrayals (Bachorowski & Owren, 1995). This is an important point that deserves empirical investigation. However, along with Juslin and Laukka (2001), we consider that acted portrayals, which are not imitated, copied, or directed, are acceptably similar to spontaneous expressions. Furthermore, use of such stimuli avoids the ethical and practical problems associated with attempting to elicit good recordings of spontaneous vocal expressions of emotion. A second limitation is that the current study used only four speakers, although each speaker generated several exemplars. Further work with a greater number of speakers (and possibly trained professional actors) would be able to establish the degree to which the acoustic factors in this study can be generalized (Juslin & Scherer, 2005).

Age-related effects on the perception of facial expressions of emotion have been shown (Calder et al., 2003), and a recent study has suggested that the relationship between acoustic cues and perceived emotions may be also affected by the listener's age (Paulmann, Pell, & Kotz, 2008). This issue needs to be examined in the context of nonverbal vocalizations. Finally, verbal and nonverbal emotional expressions (i.e., emotionally inflected speech and emotional nonverbal vocalizations) need to be directly compared: Which is more efficient as a communicative cue, is this constant across emotional classes, and to what extent do they rely on the same acoustic cues?

CONCLUSIONS

These studies show that the perceptual investigations of emotional expression in the face and in

speech can be applied to nonverbal expressions of emotion. There are accurate recognition and ratings of positive and negative nonverbal expressions of emotion and evidence for valence and arousal dimensions underlying the ratings of emotional sounds. In addition, the perceived emotional character of the sounds can be predicted on the basis of the acoustic features of the sounds, with a different constellation of acoustic cues for each emotion. These acoustic cues show some similarities with the cues that are important in the perception of emotional speech (e.g., aspects of pitch), as well as some significant differences (e.g., aspects of spectral variation). Investigating the ways in which emotions can be expressed vocally, both in speech and in nonverbal expressions, contributes to a multimodal approach to emotional communication.

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APPENDIX A

Scenarios for positive and negative emotions, as well as the dimensions arousal and valence

<i>Emotion</i>	<i>Scenario</i>
Achievement	You get a phone call offering you a job you really want.
Amusement	You are being tickled and find it really funny.
Anger	Someone is deliberately very rude to you.
Arousal	Minimum: You are feeling sleepy. Maximum: You are very awake and alert.
Contentment	You are sitting on the beach watching the sunset.
Disgust	You put your hand in vomit.
Fear	Someone suddenly taps on your shoulder in a dark alleyway.
Pleasure	Your boyfriend/girlfriend is touching you in a sensual way.
Relief	You thought you had lost your keys but find them again.
Sadness	You find out that someone close to you has died.
Surprise	You find out you have been elected as an honorary citizen of a country you have never heard of.
Valence	Positive: You are having an ecstatic experience. Negative: You are experiencing trauma or extreme fear.

APPENDIX B

Acoustic analysis of nonverbal emotional vocalizations

<i>Cue</i>	<i>Emotion</i>										
	<i>Ach</i>	<i>Amu</i>	<i>Ang</i>	<i>Con</i>	<i>Dis</i>	<i>Fear</i>	<i>Ple</i>	<i>Rel</i>	<i>Sad</i>	<i>Surp</i>	<i>Ave</i>
Duration	1	1.6	1.1	1.5	0.7	1	1.2	0.8	1.4	0.3	1.1
Amplitude std	0.1	0	0.1	0.1	0.1	0.1	0.1	0.06	0	0.1	0.1
Amplitude ons	1.5	5.4	1.8	2.6	2.2	2.8	1.6	1.2	2.8	1	2.3
Intensity	73.5	64.9	70.1	69.2	68.3	71.4	70.7	69.7	66.5	68.9	69.3
Pitch min	166	220.6	131.6	99.7	148.3	311.4	128.1	174.5	180.4	278.9	184.6
Pitch max	532.3	693.1	510.6	533.1	675.3	590.4	545.1	400.8	442.5	528.4	545.5
Pitch mean	415.9	359.4	283.2	219.2	352	443.9	243.1	283	274.3	395.6	327.4
Pitch std	95.3	122.3	102.1	134.6	186.9	68	125.3	78.4	66.7	92.5	107.3
Spectral cog	859.4	748.2	1088.7	461.4	784.1	976.7	311.6	482.5	446	793.4	691.2
Spectral std	491.5	879.5	550.7	556.4	630	408.6	327.3	752.4	319.8	521.8	543.7

Note. Acoustic analysis of nonverbal emotional sounds, as mean per category. Units explained in text; std = standard deviation, ons = onsets, min = minimum, max = maximum, cog = centre of gravity; Ach = achievement/triumph, Amu = amusement, Ang = anger, Con = contentment, Dis = disgust, Ple = sensual pleasure, Rel = relief, Sad = sadness, Surp = surprise, Ave = average.