The effect of emotion on voice production and speech acoustics.

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Abstract

The study of emotional expression in the voice has typically relied on acted portrayals of emotions, with the majority of studies focussing on the perception of emotion in such portrayals. The acoustic characteristics of natural, often involuntary encoding of emotion in the voice, and the mechanisms responsible for such vocal modulation, have received little attention from researchers. The small number of studies on natural or induced emotional speech have failed to identify acoustic patterns specific to different emotions. Instead, most acoustic changes measured have been explainable as resulting from the level of physiological arousal characteristic of different emotions. Thus measurements of the acoustic properties of angry, happy and fearful speech have been similar, corresponding to their similar elevated arousal levels. An opposing view, the most elaborate description of which was given by Scherer (1986), is that emotions affect the acoustic characteristics of speech along a number of dimensions, not only arousal. The lack of empirical data supporting such a theory has been blamed on the lack of sophistication of acoustic analyses in the little research that has been done.

By inducing real emotional states in the laboratory, using a variety of computer administered induction methods, this thesis aimed to test the two opposing accounts of how emotion affects the voice. The induction methods were designed to manipulate some of the principal dimensions along which, according to multidimensional theories, emotional speech is expected to vary. A set of acoustic parameters selected to capture temporal, fundamental frequency (F0), intensity and spectral vocal characteristics of the voice was extracted from speech recordings. In addition, electroglottal and physiological measurements were made in parallel with speech recordings, in an effort to determine the mechanisms underlying the measured acoustic changes.

The results indicate that a single arousal dimension cannot adequately describe a range of emotional vocal changes, and lend weight to a theory of multidimensional emotional response patterning as suggested by Scherer and others. The correlations between physiological and acoustic measures, although small, indicate that variations in sympathetic autonomic arousal do correspond to changes to F0 level and vocal fold dynamics as indicated by electroglottography. Changes to spectral properties, speech fluency, and F0 dynamics, however, can not be fully explained in terms of sympathetic arousal, and are probably related as well to cognitive processes involved in speech planning.

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Overview

Since Darwin (1872/1998) wrote about the expression of emotions in humans and animals, the scientific study of emotion has seen numerous but sporadic developments. Darwin's observations and insights provided the inspiration for a large amount of research into facial expressions of emotion, much of which was carried out a century later by Ekman and his collaborators (e.g. Ekman, 1972, 1973b, 1982a, 1984). Such research showed that facial expressions of discrete emotions were universally recognised, spanning widely separated cultures. In developing the Facial Action Coding System (FACS; Ekman and Friesen, 1978; Ekman 1982b), Ekman also provided researchers with a means of precisely quantifying the activity in the facial musculature that expresses each distinct emotion. FACS is now widely used in psychological research on emotions, not just in experiments that focus on facial expression, but also in conjunction with subjective emotion reports as a measure of the presence of a particular emotional state in an experimental participant. These developments have not only led to a much greater understanding of human nonverbal communication and interaction, but also to a better theoretical understanding of the human emotion system as a whole. In particular, research on the facial expression of emotions has been instrumental in shaping one of the dominant theories of emotion, which posits the existence of a limited set of biologically innate emotion response systems that are common to all human beings.

In comparison to facial expression of emotion, the vocal expression of emotion has received relatively little attention. Acted emotion portrayals have been used in a number of emotion judgement studies, with the accumulated findings indicating that at least for such acted expressions, recognition rates are comparable, though slightly lower, than for facial emotion expressions (Scherer, 1989; Banse and Scherer, 1996; Johnstone and Scherer, 2000; van Bezooijen, 1984) and are also recognised extremely well across cultures (Scherer, Banse and Wallbott, 2001). The latter result is particularly relevant for the vocal expression of emotion, because it indicates that the vocal expression of emotion reflects mechanisms that function largely independently of the mechanisms for production of a given spoken language. Only a small, albeit growing number of studies have tried to identify the emotion-specific vocal characteristics that are presumably used by listeners to infer an expressed emotion. In most of these studies, relatively simple acoustical analyses of recordings of speech have failed to discover emotion-specific vocal patterns, although recent efforts employing more sophisticated analysis techniques have met with more success (e.g. Banse and Scherer, 1996; Sobin and Alpert, 1999). The last two studies notwithstanding, it remains unclear exactly which acoustic characteristics carry emotional information in the speech signal, and the degree to which such acoustic markers are reliable across different speakers and listeners, which is one of the reasons that no vocal equivalent of the FACS system has been developed. As a result, the influence of studies of vocal emotion expression on theories of nonverbal behaviour and theories of emotion has been minimal.

One can posit a number of reasons for the apparent lack of interest in the vocal communication of emotion. One possible reason is that until the relatively recent application of computers to digital signal processing, researchers lacked an obvious method for the objective analysis of speech. Even with modern signal processing software, analysis of speech requires a mathematical training that many psychologists don't possess and don't have the time to learn. In addition, in order to properly analyse speech, a high quality recording free of background noise is required. The fact that the speech signal carries both linguistic and non-linguistic (including emotional) information complicates matters, since one must find ways of either separating the various components, or keeping the linguistic component constant while varying the emotional component. Finally, and perhaps most influentially, we seem to possess a far better intuitive knowledge of how faces encode emotions that we do of how the voice encodes emotions. Thus we all know intuitively that people smile by raising the corners of their mouths when they are happy, lower the corners of the mouths when they are sad, and scowl by furrowing their brows when they are angry. We have little such knowledge of people's voices. We say that people raise their voices when they're angry, but they also raise their voices when elated or scared. We can usually tell by listening to the voice the difference between someone who is elated and someone who is angry, but it is difficult to say what the difference is. In short, our knowledge of the vocal expression of emotion is more implicit and thus more inaccessible than our knowledge of the facial expression of emotion.

Studies of emotional expression in the voice are not only fewer than those of facial expression, their results are also less conclusive. Reviews of studies on emotional vocal expression up to the late 1980s (Scherer, 1986; Pittam and Scherer, 1993; Johnstone and Scherer, 2000) concluded that while consistent differences in the acoustical patterns across emotions exist, they seem to indicate a single dimension of physiological arousal. Thus emotions such as anger, fear and joy were all characterised by raised F0 and high intensity, while emotions such as sadness and boredom were expressed with low F0 and low intensity. Reliable acoustic parameters that could differentiate between two emotions of similar arousal seemed, on the basis of the empirical evidence, not to exist. Remarking, however, that the ability of judges to accurately judge expressed emotions, including those with similar arousal levels, meant that such parameters must exist, the authors suggested that a broader set of acoustic parameters would need to be analysed in future research. Supporting this claim, Johnstone and Scherer reviewed some more recent studies in which a more thorough acoustic analysis of acted speech allowed better differentiation of emotions with similar arousal levels.

A question remains, however, about the use of acted speech in most of the studies of vocal emotion expression that have so far been performed. Scherer (Scherer, 1985; Scherer, Helfrich, and Scherer, 1980) has argued that the expression of emotion in speech reflects the effects of two distinct influences on the voice. The most basic is the direct effect of an emotional response on vocal production, termed a push effect by Scherer. This effect might be due to interruption of cognitive processes involved in speech planning and production, perturbation of the physiological systems that not only underlie speech production but also serve to maintain the body in an optimal state for survival (e.g. the skeletal musculature, the lungs), or the activation of specialised neuromotor programs for the vocal expression of emotion. Push effects are expected to be largely involuntary.

Pull effects, on the other hand, are those external influences that can shape vocal production independently of the actual emotional state of the speaker. Such effects include accepted sociocultural speaking styles and vocal display rules (the vocal equivalent to facial display rules, cf. Ekman, 1973a), which will change with the speaking context. In contrast to push effects, pull effects are expected to be more under voluntary control, and can be used strategically with the express purpose of sending a signal to, or evoking a response from cohorts. Such is the case with acted speech. Even those acting techniques (e.g. the Stanislavski technique) that seek to create an emotion as the basis for portraying that emotion reflect both push and pull effects. Thus the presence of emotion-specific acoustic patterns in acted speech, as have been found in previous research, might well be attributable to the adoption by the actors of culturally defined, strategic speaking styles. The question of whether the push effects of emotions on the voice produce well defined, emotion-specific changes to acoustic patterns remains unaddressed. This is the central question of this thesis.

The presence or absence of such emotion-specific effects on the voice is an interesting question not only in terms of emotional expression, but also in terms of theories of emotion in general. Much debate in emotion psychology over the last century has focused on whether emotional responses are well defined and emotion-specific, or whether they are more diffuse, reflecting more general mechanisms of physiological arousal (e.g. Cacioppo, Berntson, Larsen, Poehlmann and Ito, 2000; Davidson, Gray, LeDoux, Levenson, Panksepp, and Ekman, 1994). Given that vocal production is intimately connected with physiology, especially parts of the physiology that subserve more "basic" homeostatic functions such as the respiratory system, it is natural that arguments about whether physiological emotional responses are emotion-specific should parallel similar arguments concerning the emotion-specificity of vocal characteristics. It is perhaps surprising then that until very recently, no attempt has been made to examine physiological and vocal emotional responses together. Scherer (1986), adopting a theoretical stance that favours the presence of differentiated physiological and vocal emotional responses, has suggested a number of ways in which physiological responses lead to changes in vocal production that in turn lead to differentiated acoustic patterns. In an effort to stimulate such an approach, Scherer produced predictions of physiological and acoustic emotional responses that are amenable to empirical testing. In addition to attempting to ascertain whether push effects of emotion on the voice produce differentiated acoustical patterns, this thesis also seeks to test Scherer's predictions, and more generally, to look for correspondence in measurements of vocal and physiological emotional responses.

In order to examine the push effects of emotion on speech, this research adopted the approach of inducing emotional responses in the laboratory using a range of emotion induction techniques. Since efforts to induce emotional physiological responses using passive techniques such as film watching have met with limited success in the past, active emotion-inducing computer tasks and puzzles, designed to be more involving for the participants, were developed. In all tasks, standard sentences, designed to be comparable across emotion conditions, were elicited from participants and recorded using high quality recording equipment. For the second and third experiments, a range of autonomic and somatic nervous system measurements were also made. The specific physiological measures that were chosen were selected either due to their predicted role in the production of speech (e.g. respiration, electroglottogram, zygomatic muscle activity) or their status as indicators of sympathetic or parasympathetic nervous system activity, which plays an important, but distinct, role in both an arousal model of emotional speech as well as in Scherer's theory. In addition, the third experiment included more direct measurement of vocal fold function, using electroglottography, in an effort to better identify the mechanisms underlying changes to the acoustics of emotional speech.

1. Introduction

The importance of vocalisations in affective communication amongst animals was originally noted by Darwin (1872/1998). However, despite the fact that he rated vocal communication alongside facial and postural displays as one of the most prominent means by which animals (including humans) expressed emotions, and despite recent advances in many areas of speech science, there has been a general lack of systematic research into the expression of emotion in speech. Starkweather (1956) demonstrated that the verbal content of speech was not necessary for communication of affective information. Since then perceptual studies of acted emotional speech have used low-pass filtered speech and various masking techniques to eliminate the verbal content of speech, finding the existence of two separate channels of vocal emotion communication, one carrying verbal related content and the other operating independently of verbal content (Lieberman and Michaels 1962; Scherer, Ladd and Silverman, 1984). Studies of acted emotional speech have consistently found that listeners are able to classify the emotional state of the speaker at better than chance levels, when either verbal content is held constant over a number of expressed emotions, or is absent entirely from the speech signal (Johnstone and Scherer, 2000; Banse and Scherer, 1996). Although it has been shown with such studies that the suprasegmental characteristics (i.e. those extending over multiple syllables or words) of speech carry emotional information, the mechanisms underlying such nonverbal transmission of emotion (termed emotional or affective prosody[1]), and the specific suprasegmental acoustic parameters involved, remain to a large extent uninvestigated.

Yet the study of affective prosody is important for a number of fields. In the domain of speech and language science, the phylogenetic and ontogenetic development of spoken language might be better understood given a better knowledge of how the mechanisms of affective prosody interact with those of spoken language (e.g. see Lieberman, 1996). In a more practical context, the growing recognition of affective prosodic pathologies, in which production or perception of affective prosody is impaired (see Baum and Pell, 1999), typically following brain damage, demands a better understanding of affective prosody in order to develop effective treatments and rehabilitation programmes. The study of emotion psychology, in which the focus has long been on subjective feeling, facial expression, and physiological response, also stands to benefit from an improved understanding of affective prosody. For example, an examination of the physiology of emotional vocal production might provide further evidence pertinent to the long running question of whether there exist differentiated, emotion-specific physiological responses (see Cacioppo, Berntson, Larsen, Poehlmann and Ito, 2000; Davidson, Gray, LeDoux, Levenson, Panksepp, and Ekman, 1994).

In what follows, a brief introduction to the mechanisms of speech production is provided, which will serve as a basis for discussing current theory and empirical evidence on the effects of emotion on the voice. This is followed by a summary of empirical findings on the acoustic characteristics of emotional speech. The summary concludes that most results seem to reflect a single dimension of arousal, and that specific vocal characteristics that distinguish between emotions of similar arousal have not been consistently found. The possible methodological and theoretical reasons underlying this lack of measured emotion-specific vocal characteristics are then discussed. Of these, the absence of a theory of the effects of emotion on speech, which could be used to better guide research and compare results, is next addressed. An overview of the ways in which emotion might affect speech production is followed by a review of current emotion theories, in particular their predictions concerning the existence or absence of emotion-specific physiological responses, and the resulting implications for emotional speech production. The chapter concludes with a description of the aims and methodology of this research, including how it attempts to address the problems encountered in previous empirical studies.

Overview of speech production

The human voice is the basic sound which is then modified with the specific features of a language, such as the phonemes representing vowels and consonants, as well as other grammatically significant features such as pauses and intonation. In research on human speech, it is useful to distinguish between short term segmental aspects, which often carry linguistic information, and longer term suprasegmental aspects, which carry a mixture of paralinguistic and non-linguistic information[2]. Non-linguistic information carried by the voice includes indicators of the speaker's age and gender, their regional and educational background and, of central interest here, their emotional state. Although emotions are often also expressed in the linguistic structure and semantic content of speech, the most direct influence of emotions on speech is the way in which they affect suprasegmental characteristics of speech, largely through changes to the physiological mechanisms of voice production.

Speech is produced by the co-ordinated action of three physiological systems, the respiratory system, the vocal (phonation) system and the resonance system. The respiratory system is composed of the lungs, trachea, thoracic cage and its associated muscles, and the diaphragm. By balancing the forces exerted by the air pressure within the lungs with those exerted by the inspiratory and expiratory muscles, the respiratory system provides a regulated air pressure that drives the phonation system.

The phonation system essentially consists of the larynx, a structure that includes the vocal folds and the glottis (the opening between the vocal folds through which air flows from the trachea to the pharynx). During quiet breathing, the vocal folds are far apart and the air flows relatively freely through the glottis. During phonation, the vocal folds are brought close together and put under tension (by the co-ordinated action of a number of laryngeal muscles). The air is thus obstructed, causing air pressure to build up below the vocal folds, eventually forcing them apart. As air starts to flow through the glottis the air pressure between the vocal folds drops (due to the Bernoulli effect), causing the vocal folds to close, whereupon the cycle repeats. The result is a periodic fluctuation in the superlaryngeal air pressure, which corresponds to a sound with a base frequency called the fundamental frequency (f0) and many harmonics, which have frequencies that are whole number multiples of the f0. Any change in the air pressure directly below the larynx (e.g. due to a change in respiratory function), or the tension and position of the vocal folds, will affect how the vocal folds open and close, thus producing variations in the intensity, f0 and the harmonic energy distribution of the sound. For example, when the vocal folds are under heightened tension and subglottal pressure is high due to heavy expiratory effort, the vocal folds will close more suddenly, leading to an increase not only in overall intensity, but also in f0 and the energy in the higher harmonics (Iwarsson, Thomasson and Sundberg, 1998; Hixon, 1987; Ladefoged, 1968). Such a vocal configuration might be expected for certain high arousal emotions, such as anger.

The resonance system, which comprises the rest of the vocal tract, extending from the glottis, through the pharynx to the oral and nasal cavities, then filters the sound. The shape and length of the resonance system, which depends on the configuration of the articulators (the tongue, velum, teeth and lips), determines how certain harmonics are amplified and others are attenuated, giving rise to a highly complicated, radiated speech sound. A relatively small number of specific patterns of attenuated and amplified harmonics, called formants, correspond to the different vowels and vocalised consonants in spoken language (for a more thorough treatment of speech production, see Kent, 1997; Lieberman and Blumstein, 1988). This last stage of speech production, although under greater voluntary control than the preceding stages, is still susceptible to involuntary perturbation. The tension of articulator muscles, the tonus of the walls of the resonance tract and the amount of saliva in the mouth will all have an effect on the amplitudes and bandwidths of the formants. For example, many speakers have dry mouths when anxiously giving public presentations, which could be expected to affect formant amplitudes and bandwidths, although such effects are not yet well understood.

The effects of emotion on speech production

A speaker's emotional state will affect the quality of his or her speech in multiple ways, from the largely uncontrolled changes to the speaker's cognitive and physiological speech production systems which accompany an emotion to the more controlled adoption of emotion-specific, culturally accepted speaking styles. Any study on emotional speech thus needs to consider the multiple determinants of vocal affect expression.

Affective pragmatics

In parallel with the development of spoken language, formalised, prototypical ways of expressing emotions or at least emotional attitudes (such as sarcasm and curiosity) have been established. These affective representations, which could be termed "affective pragmatics", are partly determined by cultural norms, such as rules governing politeness and etiquette in speech, and thus probably vary across cultures and social contexts. In certain social situations speakers might attempt to control or mask the "natural" expression of their internal affective state (e.g. Tolkmitt and Scherer, 1986). For example, whereas vocal expressions of joy uttered amongst familiar friends might be highly animated and loud, the same experienced emotion amongst strangers is likely to lead to a more subdued emotional expression. Another example of a pull effect is the manner in which speakers accommodate to their speaking partners to maintain, increase or decrease communicative distance. The Communication Accommodation Theory of Giles (e.g. Giles, Coupland and Coupland, 1991) suggests that a speaker's communicative style, and thus presumably their speaking style and vocal characteristics, will converge or diverge with that of their speaking partner, depending upon the relationship between the two individuals (e.g. Willemyns, Gallois, Callan, and Pittam, 1997). Affective prosody is also enlisted for strategic social aims, such as inducing favourable behaviours in cohorts or social partners (Scherer, 1988).

It is worthwhile noting, however, that affective pragmatics are most likely not arbitrary acoustic emotional codes. As pointed out by Scherer (Scherer, 1986; Johnstone and Scherer, 2000), such affective signals almost certainly evolved from more involuntary push effects of emotion on speech, and though the form of such expressions might have been shaped through evolutionary pressures, they are unlikely to have strayed too far from their origins, since in doing so they would lose their legitimacy. Indeed, one of the striking things about posed emotional expressions is that they convincingly communicate the real emotion of the speaker. This last point notwithstanding, the research presented in this thesis, being concerned primarily with push effects, was designed to eliminate or control for these more socially-mediated aspects of emotional expression in speech.

Cognitive and attentional constraints

The production of speech starts with the cognitive processes underlying the planning of the content and structure of what is to be said, and activation of the motor commands responsible for driving the speech production systems to produce the appropriate sounds. Although the planning of utterance content and structure is a largely automatic, implicit process, it also draws upon limited capacity, attentional and working memory resources, making it susceptible to interference by extraneous information or processes that also use the same or overlapping resources (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977; Levelt, Roelofs and Meyer, 1999; Baddeley, 1986; Roberts and Kirsner, 2000). The result of such interference will be a change to speech fluency, as well as possible articulatory changes. For example, Lively, Pisoni, Van Summers and Bernacki (1993) showed changes to amplitude, F0, speaking rate and spectral tilt in response to manipulations of cognitive workload placed on speakers.

There are a number of reasons for believing that emotional situations impose demands on attention and working memory. The presence of new and unexpected, potentially significant information has been shown to lead to an orienting response and refocusing of attention towards the novel stimulus (Sokolov, 1963; Öhman, 1992). This fits with the common experience of halting one's speech momentarily when surprised. Emotions such as anxiety seem to adversely affect speech planning and execution, as indicated by reduced speech fluency (Tolkmitt and Scherer, 1986; Scherer, 1986). A large body of literature has shown that anxiety-vulnerable people show a cognitive processing bias towards threatening stimuli that impacts on their performance of unrelated tasks (MacLeod and Rutherford, 1998; Mathews and MacLeod, 1994). The classic demonstration of this is the emotional Stroop task, in which subjects are asked to name the colours of words presented to them in sequence. Colour naming latency, recorded as a measure of performance, is found to be longer for threat-related words than for non-threat related words for subjects high in trait anxiety (see MacLeod and Rutherford, 1998). The explanation is that the threat related words are automatically preferentially attended to and processed in high anxiety subjects, interfering with the colour-naming task.

Although such effects have not been consistently found for people with average trait anxiety but with high state anxiety, the results of Tolkmitt and Scherer (1986) would seem to indicate that state anxiety can still impact on speech planning by causing the reallocation of attention and working memory resources to the processing of other incoming information. In contrast, the impact of other emotions on speech planning is less clear. Experiments such as the emotional Stroop task conducted with depressed subjects have failed to show a similar processing bias (MacLeod and Rutherford, 1998). This result is consistent with the limited evidence showing no increase in speech disfluency for sad speakers (e.g. Banse and Scherer, 1996; Scherer, 1986), although Ellgring and Scherer (1996) did find that an increase in speech rate and a decrease in pause duration corresponded to a decrease in negative mood in depressed patients after therapy. It is feasible that some emotions, such as sadness, might even be characterised by an improvement in speech fluency (relative to the absence of emotion) through the withdrawal from external stimulation and thus the minimisation of extraneous processing, although such a hypothesis is speculative. It must also be noted that any possible disruptive effects of emotion on speech planning will depend upon the content of the speech. Well-practised phrases are likely to be planned and executed largely implicitly/automatically, and thus will not be as susceptible to interference as novel phrases, which require more explicit planning and are thus more dependent on limited working memory resources.

Physiology

The three speech production systems act under the control of both the autonomic nervous system (ANS) and somatic nervous systems (SNS). Whilst motor programs for the production of spoken language, and presumably affective pragmatics, control speech production primarily through the SNS (albeit largely unconsciously), the state of the three systems is also affected by both SNS and ANS activity which is not speech-related, but rather seeks to maintain the body in a state which is optimal for biological functioning (a process termed homeostasis). The respiratory system is under the influence of control mechanisms that ensure a sufficient supply of oxygen to, and discharge of carbon dioxide from the body. The striated musculature, which is instrumental in controlling breathing, larynx position, vocal fold position and tension, and articulator position, is also influenced by actual and anticipated motor needs. Muscles of the mouth and lips, which change the length and shape of the vocal tract, are also used for facial expression. Saliva and mucous production, which affect the resonance of the vocal tract, depend on parasympathetic ANS activity related to digestion.

In situations where the body is in a relatively stable, unchallenging situation, homeostatic requirements do not place restrictive constraints on the functioning of speech production systems. Thus when we speak in everyday life, breathing can be optimised for producing a sustained subglottal pressure in order to vocalise at a well controlled intensity and f0 over the duration of a phrase or sentence, without compromising respiratory requirements (Bunn and Mead, 1971; Shea, Hoit and Banzett, 1998). Likewise, the striated musculature can flexibly adapt to the requirements of speech production, thus producing precise articulation and clear vowel and consonant sounds. When an organism is placed in a situation of great significance for its continued wellbeing, however, as is the case with emotional situations, the influence of the emotion response system upon the three speech subsystems becomes more important. Many emotion psychologists maintain that emotions are accompanied by adaptive responses in the autonomic and somatic nervous systems that serve to prepare the body for necessary action, such as fight or flight (Cacioppo, Klein, Berntson, and Hatfield, 1993; Levenson, Ekman, Heider, and Friesen, 1992; Öhman, 1987; Smith, 1989; Stemmler, 1996). If this is the case, it follows that emotional situations might provoke a pattern of physiological changes that perturbs the speech production systems in some nonarbitrary, differentiated manner. For example, with an emotion such as rage, preparation for conflict might produce increased tension in skeletal musculature coupled with greater respiratory depth, which in turn would provoke a change in the production of sound at the glottis and hence a change to voice quality (cf. Scherer, 1986). The alternative theoretical position is that emotions produce a change in general physiological arousal, with the differentiation between emotions dependent on cognitive, rather than physiological factors (e.g. MacDowell and Mandler, 1989; Schachter and Singer, 1962). A fundamental question addressed by this research is whether the physiological changes that accompany different emotions, and hence the provoked changes in associated acoustic parameters, reflect simply a single arousal dimension or differentiate more specifically amongst emotions. In addressing this question it is useful to briefly discuss the results of previous empirical studies of the acoustic properties of emotional speech.

Evidence on Acoustic Characteristics of Emotional Speech

It is not necessary to provide herein a detailed review of previous empirical studies that have measured the acoustic properties of emotional speech, since such reviews have been made by Frick (1985), Scherer (1986), Pittam and Scherer (1993) and Banse and Scherer (1996). In this section a brief summary of the major findings for the most commonly studied emotions[3] is provided. This section assumes a basic knowledge of acoustic speech analysis – the reader unfamiliar with speech analysis is referred forward to chapter two of this thesis which includes a review of the main principles of acoustic analysis, in particular how they pertain to the study of emotion in speech.

Stress

Although stress is not a single, well-defined emotion, it is useful to start this overview with a look at research on the acoustic indicators of psychological and physiological stress, which were, until recently, the focus of more research in speech science than specific emotions. High stress or high mental workload conditions have generally been found to lead to raised values of fundamental frequency (F0), high intensity and fast articulation (as indicated by low utterance duration). Stress-induced variation in the position or precision of formants has also been reported in some studies. The results for speech under stress are difficult to interpret, however, as changes to these parameters depend on factors such as the speaker's susceptibility to stress and their coping strategy faced with a stressful situation, as well as the type of stress (e.g. cognitive or emotional; see Tolkmitt and Scherer, 1986). Indeed, the term "stress" has typically been used in a haphazard way, and is probably too broad a concept to be useful in the empirical study of emotional speech. For example, the term "stress" has been used to describe the state of speakers in situations likely to cause anxiety, frustration or mental challenge, three states that might well have very different vocal expressions.

Anger and irritation

In general, an increase in mean F0 and mean intensity has been found in angry speech. Some studies also show increases in F0 variability and in the range of F0 across the utterances encoded. Considering that mean F0 is not a singular acoustic measure, it is not clear whether angry speech has a higher F0 level or a wider range of F0 or both. It is possible that those studies that have found increased F0 range and variability have measured "hot" anger, or rage, whereas those studies in which these characteristics were not found may have measured "cold" anger, or irritation, as found by Banse and Scherer (1996). F0 contours tend to be downward directed and articulation rate is generally increased for hot anger. Anger also seems to be characterised by an increase in high frequency energy that, together with the increase in intensity, possibly reflects greater vocal effort leading to more energy in the higher harmonics.

Fear and anxiety

Expected high arousal levels for fear are consistent with convergent evidence showing increases in intensity, mean F0 and F0 floor. The results for F0 range are less consistent, with some, but not all, studies finding F0 range to be large for fearful speech. As with anger, the increased intensity of fearful speech accompanies an increase in high frequency energy. Rate of articulation is also higher. Related emotions such as anxiety or worry also show faster articulation, but data on the other variables is less consistent. Some studies have found an increase in mean F0, but one notable study which made a clear distinction between fear and anxiety (Banse and Scherer, 1996) reported a decrease in mean F0, F0 floor and F0 range for anxiety. A decrease in intensity for anxious speech has also been reported.

Sadness

As with fear, the findings converge across the studies that have included this emotion. Decreases in mean F0, F0 floor, F0 range, and intensity are usually found, as are downward directed F0 contours. Corresponding to the decrease in intensity, voiced high frequency energy seems attenuated, indicating weaker higher harmonics. Rate of articulation also decreases for sadness. Most studies reported in the literature seem to have studied the quieter, resigned forms of this emotion, rather than the more highly aroused forms such as desperation, where correlates reflecting arousal are found, such as increased intensity, increased F0 floor and increased high frequency energy.

Joy and contentment

Joy is one of the few positive emotions frequently studied, most often in the form of elation rather than the more subdued forms, such as enjoyment or happiness. Consistent with the high arousal level that one might expect, there is a strong convergence of findings of increases in mean F0, F0 floor and intensity. F0 range and F0 variability are also found to increase. There is also inconclusive evidence for an increase in high frequency energy and an increase in the rate of articulation. Quieter forms of the emotion, such as contentment, seem to be characterised by relaxed vocal settings, leading to low mean F0, low F0 floor, lower intensity, slower articulation and weaker higher harmonics.

Disgust

As noted by Scherer (1989), the results for disgust tend not to be consistent across the encoding studies. The few that have included this emotion vary in their induction procedures from actor simulation of the emotion to measuring disgust (or possibly displeasure) to unpleasant films. The studies using the former found a decrease in mean F0, whereas those using the latter found an increase of mean F0. Even within studies, little consistency in the acoustic characteristics of digested speech has been found, implying that disgust is simply not well encoded by speakers. This conclusion is echoed in the decoding literature (see Johnstone and Scherer, 2000), where disgust is universally reported to be poorly recognised in speech.

Boredom

Bored speech is generally slow and monotonous, with low F0 floor, low F0 range and variability and slow rate of articulation. Interested speech tends to be the opposite, with large F0 range and increased speaking rate.

It is evident from this brief overview that where there is considerable consistency in the findings, it is usually related to arousal, regardless of the specific quality of the emotion under investigation. Thus rage, joy and fear, all high arousal emotions, are expressed with similar vocal profiles, marked by high F0, F0 range or variability, and intensity. Few, if any, of the studies found acoustic patterns that could differentiate the major non-arousal dimensions of emotional response such as valence and control. This should not, however, be taken as evidence that discrete emotions are not differentiated by vocal cues. Indeed, given the high recognition of emotions in acted speech measured in perception studies, there is reason to believe that emotion-specific acoustic patterns exist.

Problems with previous empirical research

There are several problems with the design and execution of previous studies of affective prosody that might explain why such acoustic patterns which differentiate emotions with similar arousal have not yet been consistently found, and which I have attempted to address in this research:

Acted versus real emotional speech

It is possible that the high recognition rates in perception studies reflect the fact that in such studies, acted emotional speech has always been used. Such acted emotional expressions at least partly reflect the adoption of social or cultural vocal stereotypes, termed “pull effects” by Scherer (1988, 1992). In perception studies this might lead to artificially high recognition rates, as the purpose of acting is, after all, to communicate a desired speaker-state to an audience. Real emotions, in contrast, are likely to be accompanied by changes in the vocal signal which serve no intentional communication purpose, but instead reflect uncontrolled changes to the underlying physiology of speech production that accompany an emotion (termed “push effects” by Scherer, 1988, 1992).

If “real” emotional speech, reflecting the push effects of emotion, were to be judged, emotion recognition scores might be much lower, consistent with the speech characteristics varying on a single dimension of arousal. Unfortunately, the few studies that have attempted some sort of real emotion induction (e.g. Alpert, Kurtzberg and Friedhoff, 1963; Duncan, Laver and Jack, 1983; Simonov and Frolov, 1973), or that have measured “real life” speech recordings, have also been limited almost completely to bipolar inductions, such as high/low stress, or happy versus sad, and thus unsurprisingly have arrived at an arousal explanation for the vocal changes measured. The question of whether the push effects of emotion on speech are limited to the unidimensional effects of general arousal, or if more differentiated emotional vocal profiles exist, is the central question of this research. To address this question, the relatively new technique of using computer games and tasks to induce a range of real emotional vocal responses (as described in chapter two) was used in this research.

Acoustic parameters measured

Another possible reason for inability of previous research to identify acoustic markers of similar arousal emotions is that the number of acoustic parameters that have been measured in most previous studies is very small. Furthermore, the relatively simple acoustic measures employed preclude a finer level of emotion differentiation, because they tend to be exactly those measures that are most affected by physiological arousal. A study by Banse and Scherer (1996) on the acoustic properties of acted emotional speech demonstrated, however, that by using a greater range of acoustic parameters, one can achieve a sizeable increase in the discrimination between different expressed emotions, as measured using techniques such as discriminant analysis. Further improvements should be possible through greater refinement of the acoustic parameters. For example, it remains unclear how the measures of average voiced spectrum used by Banse and

Scherer relate to either vocal tract or glottal waveform characteristics. Measurement of the glottal waveform in conjunction with the voiced spectrum would provide better understanding of the underlying processes involved in emotion encoding. Indeed, ongoing research which makes use of more sophisticated analyses such as formant analysis, spectral and cepstral analysis, intonation scoring, and inverse filtering of the speech signal to arrive at an estimate of the glottal waveform, looks very promising (Bachorowski and Owren, 1995; Klasmeyer, 1998; Klasmeyer and Sendlmeier, 1997; Moziconacci, 1998; Sobin and Alpert, 1999). A number of these techniques were applied to the analysis of speech recorded in this research.

Theory based research

Perhaps the most fundamental problem that has hampered research into emotional speech is the lack of a coherent theoretical framework that would serve to structure empirical investigation, particularly since researchers of emotional speech commonly approach the topic from quite different backgrounds. Thus while speech scientists bring to their research sophisticated models of speech production, their research often wants for a better understanding of emotion psychology. Research by psychologists has suffered from a lack of sophistication in speech production and analysis. As a result, much research to date has been difficult to compare and results difficult to assimilate. As pointed out by Scherer (1986), research needs to be guided by a more thorough theoretical treatment of the psychology and physiology of emotional speech, starting with current knowledge of normal speech production.

Models of emotion and emotional speech

A number of detailed reviews of the history and current state of emotion psychology exist in the scientific literature (e.g. see Cornelius, 1996; Frijda, 1986). This section presents a brief overview of emotion theory, with an emphasis the various theories' predictions concerning physiological responses and their subsequent effects on vocal production.

Darwin (1872/1998) was the first to explicitly recognise the importance of emotion specific vocal and facial expressions in animals, both in terms of their communicative importance and as manifestations of bodily changes that were occurring during emotional episodes. The James-Lange theory of emotion (James, 1884) proposed that emotional situations give rise to specific ANS and SNS activity that is then perceived by the brain through a process of peripheral feedback. The perception of specific patterns of peripheral physiological activity gives rise to the subjective feeling of different emotions. Cannon (1929) argued against a number of specific parts of the James-Lange theory, including the idea that emotions have corresponding, differentiated patterns of peripheral physiological activity. Ever since, theories of emotion have differed with respect to the issue of the specificity of emotional physiological arousal.

Modern theories of general arousal

The study of emotion was marginalised during the dominant period of behaviourism during the first half of the 20th century. It wasn't until the second half of the century that new impetus was given to emotion research, corresponding with the rise of cognitivism. The ideas of cognitive psychology prompted Schachter and Singer (1962) to propose that the physiological arousal that was provoked during emotional episodes was diffuse and undifferentiated. According to Schachter and Singer, the different subjective emotional feelings arise when a perception of the increased general arousal is interpreted in light of the context or situation. Thus when high arousal occurs in a threatening situation, the arousal is interpreted as fear, whereas when the same arousal occurs in response to winning a prize, it is interpreted as joy. Although the empirical evidence for Schachter and Singer's theory has subsequently been criticised both methodologically and conceptually, arguments against the theory's main propositions remain largely theoretical, rather than empirical. In particular, despite much psychophysiology research, evidence for the existence of emotion-specific physiological responses remains inconclusive (Cacioppo, Berntson, Larsen and Poehlmann and Ito, 2000; Ekman, Levenson and Friesen, 1983; Davidson, Gray, LeDoux, Levenson, Panksepp, and Ekman, 1994). A number of dimensional emotion theories, in which emotions are characterised as existing in a two or three dimensional space, hold that emotional physiological arousal is essentially non-specific. For example, Mandler (Mandler, 1975; MacDowell and Mandler, 1989) has proposed that expectancy violation leads to an increase in sympathetic ANS activity, which is perceived and interpreted in a manner similar to the proposals of Schachter and Singer (1962), giving rise to qualitatively different felt emotions.

Modern theories of differentiated physiological response

In contrast with models of non-specific emotional arousal, the theories of Ekman (1984), Tomkins (1962), Izard (1972) posit the existence of innate neuromotor response programs for each of a small number of basic emotions (which might also be combined into "emotion blends" giving rise to a larger number of secondary emotions). According to these theories, the activation of such a program produces a co-ordinated, emotion-specific expressive and physiological response. The proposition that a limited number of biologically innate basic emotions exist, each with a well defined emotional response, is supported by a number of studies that have demonstrated that a small number of expressed emotions are well recognised across widely ranging cultures (Ekman, 1972; 1992). Although some evidence exists for emotion-specific physiological responses (e.g. Ekman, Levenson and Friesen, 1983; Levenson, 1992), it is, however, scarce and inconsistent. Interestingly, some of the stronger evidence for the existence of differentiated physiological responses comes from studies that have used variations of the directed facial feedback task (Ekman, 1979). In this task, subjects are instructed to produce elements of facial configurations corresponding to basic emotions (the instructions are usually implicit, thus avoiding problems with demand characteristics). Subjects not only report greater intensity of felt emotion corresponding to the facial expression produced, but also show replicable effects on ANS activity, presumably due to feedback between the different response systems (e.g. facial and ANS). These results have been debated by Boiten (1996) however, who has suggested that the measured ANS differences reflect the difference in effort required to produce such facial changes. An as yet untested hypothesis would be that similar mechanisms to those proposed by Ekman exist linking the ANS and biologically innate programs for emotion-specific vocal emotion expressions. The research in this thesis, while not directly testing the hypothesis of “vocal feedback”, should lead to a greater understanding of the links between ANS activity and the effects of emotion on vocal expression.

Appraisal theories are another set of theories that posit the existence of differentiated physiological emotion responses. The first cognitive appraisal theories of emotion were put forward by Arnold (1960) and Lazarus (Lazarus, Averill and Opton, 1970). These early theories were followed up in the 1970’s and 1980’s by alternative forms of appraisal theory (e.g. Frijda, 1986; Scherer, 1984; Roseman, 1984; see Scherer, Schorr, and Johnstone, 2001 for an in-depth treatment of appraisal theories of emotion), which all agree on the basic principal that emotions are produced in response to evaluations of a situation and its consequences for the organism’s wellbeing and needs. As pointed out by Gehm and Scherer (1988), there is much correspondence between the different versions of appraisal theory, in particular with respect to the evaluative criteria, or appraisal dimensions, which are thought to underlie most emotions. In addition, a number of appraisal theorists discuss in some detail the link between appraisal outcomes and expressive and physiological responses.

Although appraisal theorists are in broad agreement on the role of cognitive evaluations in eliciting emotions, there is a lack of agreement over how appraisals organise emotional responses, including subjective feeling, physiology, and facial and vocal expression. Smith and Lazarus (1990) make the distinction between a *molecular* level of organisation, in which responses are organised at the level of single appraisals, and a *molar* level of organisation, in which responses are organised around patterns of several appraisals or even more holistic "core relational themes" (CRT; Lazarus, 1991; Smith and Lazarus, 1990). With a molar response, it is the personal meaning attributed (through appraisal) to the situational encounter that leads to an adaptive response, which may be considered a type of “affect program” (Smith and Lazarus, 1990, p. 624). Such an affect program is not inconsistent with the idea of emotion response programs suggested by basic emotion theorists. In terms of vocal production, emotional responses organised at the level of core relational themes would be manifest as well defined, CRT-specific vocal patterns.

Most researchers who have made predictions of the effects of appraisal results on response patterning have, however, done so at a molecular level, i.e., suggesting specific effects of appraisal results separately for each evaluation dimension (e.g. Scherer, 1986; Smith, 1989; Schmidt, 1998; Wehrle, Kaiser, Schmidt and Scherer, 2000).[4] Appraisal theorists have argued that each appraisal dimension provides information to the organism on how best to adapt to a situation or event and prepare for an appropriate course of action. Thus the appraisal of a another person’s actions as conducive or obstructive will lead to preparation for approach or avoidance respectively, whereas appraisal of another person as being controllable or not might lead to preparation for either fighting or submission respectively. It is the preparation for action that constitutes the emotional response. For example, preparation for fighting is predicted to include heightened sympathetic ANS activity and raised skeletal muscle tone, particularly in the upper body (e.g. Scherer, 1986, p. 154). Such action preparations are predicted to cause corresponding changes to vocal production, leading to different vocal-acoustic patterns. Of course, although at least some emotional responses are likely to result from single appraisal outcomes, it seems likely that most measurable emotional response patterns will be combinations of single-appraisal responses occurring simultaneously or cumulatively. It is difficult to envisage ways to empirically test whether an emotional response occurs as a single, co-ordinated molar response, or as a combination of molecular responses. Nevertheless, given a molecular level of organisation, one might be able to find specific acoustic vocal parameters which serve as markers of single appraisals, much in the same way as eyebrow frown and heart rate changes have been linked to appraisals of goal obstruction and anticipated effort (Smith, 1989).

The Component Process Theory of emotion

The theory in which the link between appraisal, physiology and vocal expression has been made most explicit is the Component Process Theory (CPT) of Scherer (1984, 1986). Scherer (1986) has made a number of predictions of how appraisals made by a speaker will lead to specific physiological changes in the vocal production systems, in turn causing modulation of particular acoustic parameters in the speech signal. In the CPT, Scherer proposes that emotional state is the dynamic outcome of a number of appraisals, termed Stimulus Evaluation Checks (SEC's; see table 1.1), that a person[5] continually makes of their environment. Based upon a consideration of the functional requirements of different emotional responses, with a strong emphasis on their phylogenetic development, the theory makes specific predictions of changes to physiological subsystems that correspond to different appraisals. Scherer (1986) has subsequently used knowledge of the physiology of the vocal production system (e.g. Daniloff, Schuckers and Feth, 1980), to make predictions of how each appraisal outcome might modify vocal production and hence the acoustic properties of speech (see Table 4, p. 156 in Scherer, 1986). Scherer acknowledges that such predictions are speculative, based as they are on a theory of emotion which proposes a chain of links between the perception and evaluation of emotion eliciting information and the acoustic changes that result.

Table 1.1. Summary of SEC's in Scherer's Component Process Theory of Emotion (these descriptions are adapted from Scherer , 1986, p. 147).

1. Novelty check. Evaluating the novelty of the current/expected situation - has a change in the environment occurred? A novel situation is expected to cause interruption to current activities and lead to a focusing of sensory attention.

2. Intrinsic pleasantness check. A judgement of whether a given stimulus is pleasant or unpleasant is made on the basis of intrinsic sensory mechanisms and past experiences. Pleasant stimuli will tend to elicit approach behaviour, in contrast to the avoidance of unpleasant stimuli.

3. Goal/need significance check. An assessment is made on the relevance of a particular stimulus to the needs and goals of the organism. Scherer has divided this SEC into four sub-checks, which assess (1) the goal-related relevance of the stimulus, (2) whether or not it is consistent with expectations, (3) whether or not it is conducive to achieving the goal or need and (4) how urgently a response is required. The goal/need significance check is likely to affect organism subsystems involved in preparing the organism for action, such as those responsible for providing energy and oxygen to the muscles.

4. Coping potential check. The overall ability of the organism to cope with a stimulus is assessed in four sub-checks. (1) Identifying the cause of the stimulus enables the organism to evaluate (2) how controllable are its causes or outcomes. Given that the stimulus can or can't be controlled, the organism assesses (3) its power to change or avoid the stimulus and (4) the possibility of adjusting to the final situation. This sequence of sub-checks will influence the type of physiological response prepared for in the preceding SEC. For example, either a (i)'fight" or (ii)'flight" response could be initiated in the case of a (i)controllable or (ii)avoidable stimulus which threatens the organism's goals or needs.

5. Norm/self compatibility check. This check assesses the degree to which a particular situation is consistent with (1) the organism's internal standards (i.e. self-image) and (2) the standards imposed by the organism's external environment (i.e. cultural expectations and rules).

Empirical results discrepant with Scherer's predictions could thus be attributed to a number of possible shortcomings in the theory, including the way emotional information is evaluated, the way these evaluations produce physiological responses, the effects of such physiological responses on vocal production and the manner in which vocal production is translated into an acoustic signal. Concerning the last two aspects, linking physiology with vocal production and vocal production with speech acoustics, Scherer is limited by the state of knowledge in the science of speech production. While much is known about speech production in highly controlled, normative conditions (typically text read aloud in a neutral voice), relatively little is known about speech production in more extreme circumstances. There is still debate over some of the more basic mechanisms by which speech is produced, such as the way subglottal pressure, vocal fold tension and vertical larynx position contribute to F0 control. Rather than being treated as falsifiable hypotheses, Scherer's predictions should thus be seen more as useful principles for guiding and focussing empirical research, as well as lending theoretical precision to the terms and concepts used.

The appraisal methodology in speech research

A small number of studies have been performed to test Scherer's predictions (Scherer, Banse, Wallbott and Goldbeck, 1991; Banse and Scherer, 1996; T.M. Scherer, 2000). The study of Banse and Scherer (1996) differed from previous studies in three important ways. First, a number of spectral characteristics of the voice were measured (these parameters reflect both the dynamics of phonation as well as the resonance of the vocal tract). Second, an effort was made to better define the emotions, with particular attention paid to the different forms of emotions from within the same emotion family, such as anxiety and fear, or contentment and elation. Last, the study aimed at testing theory-driven predictions based upon the CPT.

Banse and Scherer found empirical support for many of the directional predictions, although there remained a number of predictions that were not supported by the data, as seen in table 1.2. Of particular interest were the results for spectral parameters, since these aspects of the speech signal had not been extensively studied in previous research. The prediction of an increase in high frequency energy for anger was supported by Scherer, Banse, Wallbott and Goldbeck (1991), although the same study indicated no significant increase in high frequency energy for fear, contrary to expectations. A sub-analysis of the data from the Banse and Scherer study (Johnstone, Banse and Scherer, 1995) provided evidence that more specific patterns of spectral energy distribution might be specific to particular emotions. Thus even spectral regions above 1000 Hertz could be subdivided into regions with different emotion-specific amounts of energy. These more specific spectral changes would seem to be due mainly to articulation changes than changes to the voice source, which is usually linked to a more uniform spectral energy roll off. Perhaps just as important as the results for specific acoustic parameters, Banse and Scherer were able to demonstrate clear differences in the overall acoustic patterns (i.e. the combined “profiles” of all acoustic parameters) between emotions, including between expressions of emotions of similar arousal levels. Such differences were particularly evident from the results of a discriminant analysis, in which expressed emotions could be classified statistically with an accuracy well above chance, and in line with that of human judges.

In this research, an acoustic analysis approach similar to that of Banse and Scherer (1996) was applied, augmented by the parallel analysis of measures of physiology thought to be implicated in vocal production.

Table 1.2. Predicted and measured standardised vocal parameters for 12 emotions as reported by Banse and Scherer (1996). In each cell, the first symbol represents the predicted value, the second symbol represents the measured value. -,0,+ : low, medium, high values respectively. Symbols in bold indicate a significant difference between the predicted and measured values. ? indicates that no prediction was made.

	Contempt	Boredom	Happiness	Anxiety	Shame	Sadness	Disgust	Cold Anger	Despair	Hot Anger	Panic	Elation
f0	**0** -	- -	- -	+ -	+ -	0 0	+ **0**	0 0	+ +	**0** +	+ +	+ +
energy	+ -	0 -	- -	? 0	? -	- -	+ -	+ +	+ +	+ +	+ +	+ +
LF energy	- **0**	0 +	+ +	- +	- 0	**0** +	- 0	- -	- -	- -	- 0	0 0
duration	? 0	? +	+ -	? -	? 0	+ +	? 0	? 0	- **0**	- -	- -	- -

Based on the results from the Banse and Scherer (1996) study, one might consider that the question “what are the vocal characteristics corresponding to expressed emotions?” is well on the way to being answered. There are, however, a number of caveats. Most importantly, their study was still based upon actors expressing a number of discrete emotions. Banse and Scherer did make efforts to obtain acted speech that was as close to spontaneous emotional speech as possible. Actors were given written descriptions of scenarios that would commonly elicit the target emotion, and were asked to imagine the scenarios as vividly as possible, only producing their renditions when they felt the emotion themselves. The authors claimed that under such conditions, the acted emotional speech would be highly similar to real emotional speech. Given that it is part of an actor's job to make their expressions identifiable to their audience, however, it is likely that such emotional speech reflects affective pragmatics as much as it reflects the more fundamental effects of physiological emotional responses on vocal production. It is clear that research examining speech under real emotional situations is still required. Indeed, the question “what are the mechanisms by which emotion is expressed in the voice?” has barely been touched upon. If the study of Banse and Scherer did much to advance the quantitative knowledge of vocal expression of emotion, its results were less clear with regard to a theoretical understanding of the production process.

Perhaps the biggest problem in interpreting such data is that since the predictions for each emotion were constructed originally from predictions for a number of individual appraisals, it is not possible to identify the sources of the discrepancies. Another problem is that the predictions could be wrong at any of a number of different levels. The emotion-specific patterns of appraisal proposed by Scherer might not match the actual patterns, the predictions of physiological changes resulting from each appraisal outcome might be incorrect, or the predicted way in which vocal characteristics depend upon speech physiology could be at fault.

Nonetheless, by comparing emotions that differ on certain appraisal dimensions, it is possible to make some inferences about the influence of those dimensions on the voice. For example, by comparing the profiles for panic and rage, one can arrive at an estimate of the influence of an appraisal of low versus high coping potential. The observation that high frequency energy is lower in panic than in rage is consistent with the results for anxiety and irritation (see Banse and Scherer, 1996). Thus appraisals of high coping seem to lead to more energy in the high frequencies, which is consistent with greater respiratory force. Similar pairwise comparisons can be made for certain other appraisals, such as guilt versus anger for appraisals of accountability, or elation/rage and contentment/irritation for appraisals of valence. It is clear however, that such inferences are highly conjectural and should be considered as circumstantial evidence, and as providing useful hypotheses for further research. To properly isolate the changes to vocal parameters due to specific appraisals (or specific combinations of appraisals) requires an experimental design whereby appraisals are at least directly measured, and if possible, directly manipulated. This is the approach that has been adopted by the research presented in this thesis.

Summary

In a review of past research on vocal expression of emotion this proposal has highlighted a number of problems concerning the use of acted instead of real emotional speech, the limited set of acoustic parameters studied, and the failure to adopt a suitable theoretical basis for hypothesis driven research. These deficiencies have made it difficult to conclude one way or the other whether emotional speech is characterised by clearly differentiated, emotion specific acoustic patterns. While there is a limited amount of evidence supporting this proposition, it comes mainly from studies using acted speech. Studies which have examined real, or induced emotional speech, seem to favour the view that the acoustic correlates of emotion represent the single dimension of arousal, but have not included a number of acoustic parameters which might be expected to differentiate between emotions of equal arousal. In the following section, the experimental plan that was designed to address these problems is outlined and justified.

Overview of this research

This thesis describes a series of experiments that were designed to induce real, albeit low intensity, emotional responses in participants, with the aim of measuring the resulting changes to voice production. In light of the difficulties in recording and analysing "real life" emotional speech and the questions surrounding the ecological validity of actor portrayals of emotion, this project made use of interactive computer games and tasks to elicit emotional responses. Using appraisal theory of emotion, specifically the CPT of Scherer (1984, 1986) as a guide, the games and tasks were manipulated along specific evaluative dimensions that are thought to lead to emotional responses. Participants were prompted throughout the tasks and games to pronounce standard-content phrases, which were recorded for subsequent acoustical analysis. The subjective emotional state of participants in response to game and task manipulations was measured by means of subjective rating scales. In the last two experiments, a number of physiological recordings were also made. These were intended to serve as independent indicators of emotional response, as well as providing evidence concerning the physiological mechanisms underlying any observed acoustic changes.

The complexity of the speech production system, together with the relative lack of knowledge of the processes underlying emotional expression and the psychophysiology of emotion, made it impractical for these studies to be based primarily upon the testing of well developed, concrete hypotheses. Well-developed theories of emotional vocal expression that make few unsubstantiated assumptions that could be used to generate such hypotheses simply do not exist. Rather, the approach used in this research paralleled that used in much of speech science, with a focus on the quantitative description of the acoustic properties of speech under specific conditions. On the basis of results from the first experiments, hypotheses were developed that could then be tested in later experiments. In addition, the acoustic changes observed for different induced emotions in these experiments were compared with previous findings for acted emotional speech.

Some hypotheses were nevertheless addressed in this thesis. Most fundamental, both with respect to the vocal expression of emotion and debates on the specificity of emotional response patterning in general, is the hypothesis that changes to the acoustic characteristics of speech reflect simply the unidimensional effects of physiological arousal on speech production. To examine this hypothesis, a number of emotional states and a number of acoustical parameters were measured. It is only by measuring a more complete set of acoustical parameters than has typically been the case in previous research that this hypothesis can be tested. Given an arousal mechanism as the cause of acoustical changes, one would expect the parameters to covary in a systematic manner across all emotional states. Lack of such a covariance would indicate that other mechanisms, which affect each parameter differently, are at play.[6]

The CPT of Scherer also provides a number of hypotheses that were directly addressed by this research. As stated previously, when such hypotheses are not supported by the data, it is difficult to pinpoint the cause of the discrepancy. As such, the hypotheses are not falsifiable in the strict sense. However, given the pressing need for theoretical development in the area of emotional vocal expression, it seems worthwhile to make use of such theory and hypotheses as exist, with the aim of finding weaknesses in the theory on the basis of a comparison with the empirical data.

The first experiment was designed to examine changes to the voice corresponding to two types of event in an interactive computer game, chosen to provoke different probable appraisal outcomes on the most fundamental appraisal dimension in Scherer's CPT, goal congruence. In addition, the sound accompanying each event was manipulated so as to provoke a probable appraisal of high or low intrinsic pleasantness. Immediately following the game events, players were prompted to give a spoken report of the preceding event, using a given standard phrase. Digital recordings of players' speech were analysed, and differences in their acoustical properties compared between the four conditions.

The second experiment was designed to test hypotheses based on the results for goal congruence obtained in the first experiment, and to extend the general approach to an examination of another important appraisal dimension, coping potential. In addition, subjective reports of the player's emotional state, as well as a number of physiological variables, were measured at each manipulated event. Results from acoustical analyses were statistically compared over manipulated appraisal conditions. Subjective, acoustic and physiological variables were statistically analysed, both to test whether converging measures of emotional response could be found, and whether these measures differed across manipulated appraisal conditions.

The third experiment addressed a number of methodological problems apparent in experiment two. Given the lack of acoustic differences observed between the manipulated appraisal conditions, a new computer task was designed to elicit emotional responses in a more controlled manner. In addition to physiological measurements, electroglottal measurements were synchronised with vocal recordings, thus allowing a more precise characterisation of the opening and closing of the vocal folds. The electroglottal measurements were compared both with F0 measures and spectral measures in an effort to understand the basic mechanisms responsible for F0 and harmonic modulation in emotional speech.

[1] The term “prosody” is used throughout this thesis to refer to the broad range of suprasegmental, nonverbal aspects of speech, including intonation, voice quality and aspects of speech fluency such as syllable duration and number and type of pauses.

[2] The distinction between paralinguistic and non-linguistic prosody is subtle and rarely well-defined. “Paralinguistic” usually refers to those prosodic features that compliment the linguistic content of an utterance, without being inextricably bound to linguistic form. For example, when a speaker adopts a sarcastic “tone of voice”, suprasegmental aspects of speech are altered in such a way as to indicate that the speaker’s intentions are in fact opposite to the verbal content of the utterance. Paralinguistic prosody is usually under volitional control and may be learned as part of a culture’s set of speaking norms. In contrast, non-linguistic prosody encompasses the range of suprasegmental variations in speech that bear no connection to the verbal content. Nonlinguistic prosody is often unintentional and may be largely invariant across cultures.

[3] The actual choice of emotions studied in much previous research has been relatively arbitrary, motivated by the interests of the individual researchers (e.g. clinical, technological) rather than by theoretical concerns.

[4] Researchers who have used linear statistical techniques to predict subjective feeling from appraisal profiles (e.g. Frijda, Kuipers, and ter Schure, 1989; Ellsworth and Smith, 1988a,b) also seem to implicitly assume that the effects are due to single appraisal dimensions and their additive effects.

[5] In fact, the component process model of emotion has been proposed as applying not only to humans but at least to higher primates, and possibly animals in general. One of the claims of the theory is that the vocal expression of affect in humans can be traced back to origins common to many animals, and has evolved continuously since (Scherer and Kappas 1988, Scherer 1989).

[6] This line of reasoning actually makes some assumptions about monotonic relationships between underlying mechanisms and measurable acoustic parameters, which will be discussed in chapter 3.

2. Methodological issues

Acoustic analysis of emotional speech

In principle, the encoding of emotion in the voice can be measured at any one of a number of stages, from the physiological changes in various parts of the vocal production system to the perceptual judgement of vocal quality by a listener. The decision of which stage (or stages) is most suitable depends on the specific research project and its goals. In order to be able to integrate and compare data from both vocal encoding and decoding studies however, measurement of the physical (i.e. acoustic) properties of the propagating speech sound is most appropriate. Techniques of acoustic measurement and analysis are also well developed and can be applied using relatively inexpensive, readily available equipment. Many acoustic measures of human speech and vocal sounds have fairly well understood relationships with the perceived aspects of speech. Although the relationships between the physiology of speech production and the resulting acoustic signal are less clear, there exists a large and rapidly expanding literature on the subject (see Borden and Harris, 1994, for an overview of speech production and perception). Acoustic analysis thus allows an objective comparison of studies of emotion encoding in speech with those focused on the decoding, or perception of expressed emotion.

Since speech is a rapidly changing, dynamic signal, most standard acoustic variables are measured over very short speech segments over which it can be assumed that the signal is relatively stable. These segments might correspond to theoretically significant speech features, such as phonemes, diphones or syllables, or alternatively might be chosen for reasons pertaining to the mathematics and practicalities of signal analysis. The measurement of short speech segments is well adapted to research on the linguistic content of speech, since the phonemic content is itself transmitted in short quasi-stable segments. The emotional modulation of speech, however, is expected to be largely *suprasegmental,* since the physiological changes thought to underpin emotional speech are relatively slow[1]. Most research on emotional speech has thus aggregated the short-term acoustic variables over longer time frames (typically single or multiple phrases or sentences) to obtain long-term, suprasegmental measures.

For the sake of this discussion, the acoustic measures of speech have been subdivided into four categories: time-related, intensity-related, fundamental frequency-related and more complicated spectral parameters. The first three categories are linked mainly to the perceptual dimensions of speech rate, loudness and pitch respectively, whilst the fourth category has more to do with perceived timbre and voice quality. The following section presents a brief introduction to the four acoustic categories and their associations with speech production and perception; many texts offer a more detailed treatment of the acoustics of speech (e.g. Borden and Harris, 1994; Deller, Proakis and Hansen, 1993).

Time-related measures

The speech signal consists of a temporal sequence of different types of sounds (those corresponding to vowels, consonants, interjections) and silence, all of which can be carriers of affective information. In practice, however, there exist no clear guidelines as to which basic units of vocal sound are most appropriate for the analysis of emotional speech. The most conceptually simple time-related measures of speech are the rate and duration of both vocal sounds and pauses, which are expected to vary for different expressed emotions. Past research has been limited mostly to measures of overall phrase duration and word rate. Such measures either require that the same phrases are compared across emotions, or that a long enough sample of speech, containing multiple phrases, is measured (in such long speech samples, the duration and word rate differences due to different phrases average out). Similar considerations also exist for measurements of silence. In this research, measures of phrase duration were combined with proportional measures of the duration of voiced (i.e. voiced consonants and vowels), unvoiced (i.e. voiceless consonants, other non-vocal sounds) and silent (i.e. background noise) segments of the speech signal, and compared across experimental conditions.

Intensity-related measures

The acoustic measure that most closely correlates with the perception of the loudness of speech is intensity[2]. Intensity is a measure of the power of a speech signal, and reflects both the sound produced at the glottis, and the amplification and attenuation of harmonics in the vocal tract. It thus varies as a function of vocal effort and tract resonance, both of which might be altered by the effects of emotion on physiology. For example, greater expiratory force, perhaps corresponding to preparation for a fight response, will tend to increase speech intensity by increasing the intensity of sound produced at the glottis. A lack of saliva corresponding to fear will lead to diminished formant amplitudes, thus decreasing speech intensity. The dependence of speech intensity on these two separate mechanisms implies that the interpretation of speech intensity changes with emotion in terms of underlying mechanisms is difficult. Ideally, intensity changes need to be compared with other aspects of the speech signal, such as its spectral composition and, if possible, its glottal source waveform. By examining intensity in combination with these other speech features, it should be possible to better understand the source of intensity changes. This is the approach that was adopted in this research.

Fundamental frequency-related measures

One of the most frequently used vocal cues is fundamental frequency, measured in cycles per second, or Hertz (Hz). F0 is the rate at which the vocal folds open and close across the glottis, and strongly determines the perceived pitch of the voice. It varies continuously and often quite rapidly, as a function of both linguistic and paralinguistic aspects of speech, as well as totally non-linguistic physiological changes. Over the course of a phrase or utterance, F0 can be quantified in terms of its average level or its “resting” level, and the amount in which it varies over time.[3]

A theoretically motivated measure of the resting level of F0 is F0 floor, defined as the lowest F0 value in an utterance.[4] F0 floor is primarily determined by the tone of the laryngeal musculature, in particular the vocal folds, with increased tension leading to higher F0 floor. It is thus reasonable to expect that any changes to laryngeal muscle tone produced as part of an emotional SNS response will have a significant impact on F0 floor. Those emotions characterised by elevated muscle tone, most notably anger and fear, are likely to produce speech with elevated F0 floor, while emotions with relaxed muscle tone, such a sadness, will show low F0 floor. Although mean F0 has been used in a number of studies of vocal affect as a measure of the average, or resting level of F0, its value really reflects the combined effects of F0 floor and F0 range, and thus might not add usefully to an analysis which already includes these variables. If a measure of central tendency of F0 is desired however (e.g. to facilitate comparison with previous studies), median F0 is a more suitable measure than mean F0, given that the distribution of F0 is often skewed and extremely high F0 outliers caused by F0 estimation errors or highly irregular glottal cycles are more common than low F0 outliers.

One measure of F0 variability is F0 range, which is most simply quantified as the difference between the lowest and highest F0 values occurring over the course of an entire utterance. Alternatively, F0 variance, which is correlated with F0 range but also depends on the temporal variability in F0 at shorter time scales, such as those corresponding to syllables, can be measured. Both F0 range and F0 variance depend on both pragmatic and affective-physiological factors. Since adjustments to F0 are the primary carriers of linguistic and paralinguistic intonation, both these parameters vary to a large extent with the linguistic content of the utterance, as well as with pragmatics (including affective pragmatics). Such linguistic and pragmatic changes to F0 are mediated by coordinated adjustments to vocal fold tension, vertical larynx position and subglottal pressure. The effects of emotion on F0 variation are difficult to predict. Emotional changes to muscle tone are likely to be tonic, and thus affect F0 level as described above, rather than F0 variation. It is possible that the major physiological mediator of emotional changes to F0 range and F0 variance is expiratory force. An example is the case of angry utterances, in which powerful expiration will lead to an eventual drop in subglottal pressure (due to exhaustion of the air supply in the lungs), causing a corresponding drop in F0. Conversely, rapid, shallow breathing, as might be expected in fear, should not lead to such differences in subglottal pressure, and hence fearful speech might be expected to exhibit lower F0 range and variance.

In this research, all the aforementioned F0 parameters were measured, both in order to compare results with those previously obtained, as well as to assess their relative independence, and thus their expected utility in future studies of emotional speech.

Another F0-based acoustic parameter that has been found to change with anxiety and stress is jitter, which is the extent to which the fundamental period (i.e. the time for the vocal folds to open and close once) varies rapidly and randomly from one vocal cycle to the next (e.g. Smith, 1977). Based on physiological, acoustical and empirical evidence, the mechanisms that have been suggested to underlie jitter, namely micro-tremors in relaxed skeletal muscle, are questionable (Smith, 1982; Fuller, 1984; Hollien, Geison and Hicks, 1987). The reliability of jitter measurements is also difficult to determine, primarily because accurate measurements of fundamental period are difficult to make on the basis of the acoustic speech signal, and since period measurements have to be adjusted to allow for (i.e. eliminate) slower movements in F0 due to intonation. In this research, jitter was measured in the third experiment, when the availability of electroglottal equipment made the extremely accurate measurement of vocal fold opening and closing possible.

Spectral measures

Many changes to the vocal tract that are postulated to accompany different emotions, such as changes to articulator muscle tension and salivation, will lead to changes in the amount of resonance (formant amplitudes) and the range of frequencies amplified (formant bandwidths). Other changes such as those to expiratory force and tension of the laryngeal muscles are postulated to affect the way in which the vocal folds open and close, and hence affect the spectral slope of the sound produced at the glottis. Such changes to glottal spectral slope will also be manifest in the frequency spectrum of the final speech signal. The major difficulty that thus needs to be solved in the spectral analysis of speech is separating the characteristics of the glottal waveform from the resonant characteristics of the vocal tract and articulators. If certain approximations about the linearity of and interactions between the glottal and resonance systems are made, it is possible to estimate the vocal tract filter characteristics and, through a process of inverse filtering, the glottal excitation, from the acoustic speech signal. This approach has been widely used in speech research to estimate formants and the glottal waveform (e.g. Fant, 1979a, 1979b, 1993; Rothenberg, 1973).

Unfortunately, estimation of the formants of speech with such techniques is a time consuming process riddled with methodological pitfalls, which has rarely been applied to the study of affective speech. In particular, accurate estimation of the formants requires that low noise, linear recordings of speech are made, with no phase distortion. In addition, estimation of formants in spontaneous speech is made less reliable due to the rapidly varying characteristics of vocal tract resonance. Often the formant estimates can vary greatly as a function of the specific parameters that are entered into the estimation program (e.g. number of poles in an all pole model). For these reasons, formant analysis was not applied to the study of emotion in this research.

The aim of glottal waveform analysis is to quantify aspects of the glottal waveform which can be directly related to the physiology and mechanics of the opening and closing of the vocal folds. Its close relationship to glottal physiology makes it a promising candidate for studies on affective speech. Because the same linear predictive technique as used in formant estimation is used to estimate the glottal waveform, the estimate suffers from the same limitations as formant estimates. Specifically, the form of the glottal wave, from which one would like to estimate parameters such as the glottal opening time and closing time, is highly sensitive to both analysis input parameters and recording conditions. Phase distortion during recording is particularly likely to affect estimates of glottal opening and closing times. However, it is possible that more global spectral measures of the glottal waveform estimate are relatively robust and might thus yield useful information about glottal changes accompanying emotion. Some such measures, such as the ratio of F1 to F0 and the spectral slope of the glottal spectrum have been used as indicators of voice quality (Klatt and Klatt, 1990). These measures have thus been included in the present research in an exploratory manner, primarily to see if such measurements are reliable enough to be of use in future research on emotional speech. In the last experiment, these measures were compared with more direct measures of glottal opening and closing characteristics obtained using electroglottography (EGG).

The list of acoustic measures described above is certainly not comprehensive. In addition to using the various types of acoustic measures individually, more complex variables can be obtained by combining two of the three dimensions. Thus, Scherer and Oshinsky (1977) used variations in the vocal envelope, a measure that combines the amplitude and time dimensions, in studying the attribution of emotional state by judges. Although studies are relatively scarce, there is evidence that the temporal pattern of F0 change, that is the form of the intonation contour, may also play an important role in the communication of affect (Cosmides, 1983; Frick, 1985; Mozziconacci, 1995; Mozziconacci and Hermes, 1997; Uldall, 1960). The decision not to include these and other possible acoustic measures in this research was based primarily on the lack of hypotheses concerning their connection to the involuntary effects of emotional responses on voice production (this is particularly true for emotional intonation patterns, which most likely reflect affective pragmatics, cf. Scherer, Ladd and Silverman, 1984; Ladd, Silverman, Tolkmitt, Bergmann and Scherer, 1985), as well as practical problems with their measurement for large numbers of speech samples from different speakers.

Real or induced emotional vocal expressions

Probably the major reason for the relative lack of emotional speech studies that have used emotion induction techniques rather than acted speech is the difficulty of inducing emotions in controlled, laboratory settings. Martin (1990) provides an overview of the techniques that have been used to induce emotions in the laboratory. These include having subjects read and try to imagine emotional stories, view emotional pictures, listen to emotional music, watch emotionally provoking films as well as self-generated techniques such as imagination and recall of past emotional events. A number of problems exist with such methods, however. A common problem with all of these methods is that ethical constraints prevent anything but the induction of low magnitude emotions, which may not provide sufficient power for their differentiation on the basis of vocal cues. It is difficult to see how this problem could be solved by any laboratory technique – examination of anything but mild emotional states is probably limited to either acted emotions, or observational studies of real life events, with the obvious limitations in control and the sound quality of speech recorded.

Besides the limitation to low intensity emotions, however, there are other problems more specific to particular induction techniques. Many of the techniques are essentially passive, with the subject not actively participating as would normally be the case in emotional situations. It could be argued that although many of the subjective qualities of emotions induced by emotional films, music or stories, for example, are similar to those encountered in real life, the physiological response will be muted, because the body does not need to prepare for any expected action. A physiological reaction of sufficient strength to measurably affect speech might require a more active, participatory induction task.

In addition, it is difficult to manipulate the experimental induction in a theoretically guided, consistent manner. Sad films, for example, might contain many things that make them provoke sadness, or might even provoke different forms of sadness. In such cases, comparison between two emotional films, one meant to provoke sadness and the other fear, might be due to some other difference between the films (the difference between films depicting social situations compared to those depicting wild animals, for example). The construction of emotion-inducing stories that have been constructed to differ only along specified dimensions might seem like a solution to this problem, but such artificially constructed stories are unlikely to provoke much emotion in the reader.

Computer games in emotion research

Recently the promise of using computer games and simulations for the induction of moderate intensity real emotions has been demonstrated (Anderson and Ford, 1986; Banse, Etter, van Reekum, and Scherer, 1996; Kaiser, Wehrle, and Edwards, 1994; Kappas, 1997; MacDowell and Mandler, 1989). The advantages of computer simulation over other emotion induction techniques derives from their closeness in many ways to real life. Games and simulations in general allow players to be submerged in scenarios which can be modelled on everyday situations. Furthermore, games allow players to become involved in the types of events which might only happen infrequently (or never) in normal life, but nevertheless produce strong emotional reactions when they do occur. The high level of interactivity involved in game playing is more conducive to emotion elicitation, in particular elicitation of physiological responses, than more passive activities such as watching films. Modern computer games, with their realistic graphics and sound effects, add to this realism and player involvement.

From an experimental viewpoint, computer games have the advantage that they can be played in a controlled laboratory environment, enabling high quality digital recording of speech. Moreover, many of the possibly confounding factors which would be uncontrollable in real life observational studies, or even film-watching inductions, can be manipulated or controlled in a computer game experiment. For example, the social context in which an event is evaluated plays a fundamental role in the emotional response and ensuing behaviours, including expressive behaviours. Using computer games, social factors can either be largely reduced if the experimental focus is on an individual’s emotional response in isolation, or manipulated if the focus is on the effects of the social environment on emotion and expression.

Another major advantage of using computer games as emotion inductors is the ability to change the game in order to systematically manipulate emotion eliciting situations, in accordance with theoretical hypotheses. For example, using appraisal theory as a basis, games can be manipulated in such a way as to provoke appraisals along posited appraisal dimensions. Although there will always be a degree of variability in the way specific events are appraised by different people at different times, a reasonable homogeneity in appraisals is likely when the event characteristics and contextual factors can be well controlled. In addition, it is possible in computer games to encourage the pursuit of specific goals, a factor too often neglected with other induction techniques given that one of the central aspects of appraisal theories is that appraisals are always made with respect to a person's goals and concerns. An example would be the goal of winning more points than all other players in a competition – if such goals are not specified, different individuals will play for different reasons, just as individuals in film watching inductions might watch films with different motivations.

There are still a number of issues than have to be addressed when using computer games in studies of emotion. The most difficult is finding a balance between a game that is interesting and involving enough to induce emotional responses, and one that provides the necessary amount of experimental control. There is a trade-off between experimental control, which is better in games that are very simple, in which only the experimentally manipulated factors vary, and the players' emotional involvement, which tends to increase as the game becomes more varied and includes a greater range of scenarios.[5] In choosing a game as the basis for an experimental study then, it is necessary to find one which is varied enough to be involving (and sustain involvement throughout the experimental session) but not so varied as to swamp the data with effects from uncontrolled sources. Other practical issues also affect game choice. While many games are openly available on the market that include graphic violence and potentially offensive themes, it is ethically desirable not to choose such games for research. In addition, the source code of the computer game must be available to allow for manipulation of game events, as well as the addition of features specific to the research setting, such as report and rating screens and the recording of data files containing subjective ratings and performance data.

The game XQuest (Mackey, 1994), a space-invaders type of game available as shareware on the internet, was chosen for the first two experiments in this research. This specific game was chosen primarily because the PASCAL source code had been made available to our laboratory in Geneva by the game's author, thus allowing the game to be reprogrammed for the sake of experimental manipulations and data collection. XQuest was also chosen for its clear goals (completing each level and accumulating points), as well as being involving enough to elicit mild emotional responses, without being violent or otherwise ethically unsuitable. Despite being an involving and captivating game, XQuest is relatively uncomplicated, thus permitting a high level of experimental control. XQuest is described in more detail in the chapter describing the first experiment (chapter three).

For experiment three, a manual tracking computer task was developed specifically for the collection of standard speech samples under conditions designed to elicit a number of modal emotions. The choice of XQuest had originally been made partly on practical grounds, namely that the game was ready-made and the source code available, thus enabling a prompt start to experimentation. Although the use of the XQuest game in the first two experiments demonstrated the promise of using computer games to elicit emotional speech, it was thought that better control could be achieved with a task programmed “from the ground up”. A more extensive description of the task used in experiment three is given in chapter six.

[1] The voluntary modulation of speech to convey emotion, that is, affective pragmatics, is more likely to occur at a segmental level, in interaction with the linguistic content (see, e.g. Scherer, Ladd and Silverman, 1984; Ladd, Silverman, Tolkmitt, Bergmann and Scherer, 1985). As research leads to more precise hypotheses, particularly concerning affective pragmatics, it will be necessary to examine the acoustic properties of emotional speech at shorter time scales.

[2] The subjective perception of loudness, while highly correlated with the objective measure of intensity, is also influenced by other factors such as the frequency composition of the speech sound, and temporal aspects such as attack and decay of the sound.

[3] Various theories of intonation posit the existence of F0 declination, whereby F0 fluctuates within a range of values defined by an F0 baseline and an F0 ceiling line, both of which drop gradually during an utterance or breath group. The existence of declination in spontaneous, non-read speech however, remains controversial (e.g. Lieberman, 1985).

[4] In practice, F0 floor is measured not on the basis of the single lowest F0 value, but on the basis of a low percentile value (e.g. the 5th) of F0. Similarly, F0 range is usually quantified as the difference between F0 floor and a high percentile value (e.g. the 95th) of F0 (e.g. Banse and Scherer, 1996).

[5] Most emotion theories hold that emotions are responses to events that are relevant to a person’s goals or plans. This implies that for a game to be effective as an inductor of emotions, it must remain relevant to the player, that is, the player must remain involved in the game. To maintain this involvement, it is necessary that the game is comprised of more than simply manipulations of a few experimental factors.

3. Experiment 1: Computer game induction of emotional speech

Introduction.

As with all of the experiments reported in this thesis, the aims of this experiment were both methodological and theoretical. The methodological aim of this experiment was to develop and test the technique of studying the push effects of emotional response on the characteristics of the voice by recording the speech of players of an experimentally manipulated computer game. The principal theoretical aim was to gather evidence on whether the push effects of emotion on the voice are limited to a simple effect of arousal on the speech subsystems, or whether the effects are multidimensional and reflect factors other than arousal. The experiment also aimed to test Scherer's (1986) predictions of the vocal characteristics resulting from appraisals along the intrinsic pleasantness and goal conduciveness dimensions.

Push effects of emotion on the voice

As discussed in the first chapter, there is little empirical evidence that the voice changes produced by emotional responses reflect anything other than an increase or decrease in general arousal. The lack of such evidence does not necessarily exclude the existence of such non-arousal effects of emotion on the voice however, since the few studies that have been performed on real emotional speech have not examined a wide range of acoustic vocal characteristics, nor have they examined more than one or two different emotions.

In keeping with the experimental approach outlined in the first chapter, this experiment aims at measuring the acoustical changes that are provoked by emotional responses to computer game situations designed to be appraised in specific ways. As this was a first attempt at using such an experimental paradigm, appraisal dimensions were chosen on the basis of theoretical predictions (Scherer, 1986) that they would produce non-arousal changes to the voice as well as the ease with which they could be instantiated within the game. Scherer (1986) suggests that it is likely that the vocal characteristics of emotional speech can be quantified along the three classical emotion response dimensions: activation (or arousal), valence and potency. The little empirical evidence for the existence of three such dimensions in emotional speech (Green and Cliff, 1975) indicates that of the three, activation and valence are more easily identifiable than the potency dimension. For this reason, this experiment focussed on the valence response dimension which, according to Scherer (1986), is affected by appraisals of intrinsic pleasantness and goal conduciveness.

Arguing that appraisals of intrinsic pleasantness or unpleasantness will elicit either innate or learned approach or avoidance action tendencies respectively, Scherer draws upon past research into orofacial behaviour, particularly in response to pleasant or noxious tastes or odours. Thus unpleasant stimuli are predicted to elicit constriction of the pharynx and approximation of the faucal arches, which serve to rejecting noxious stimuli. Combining these vocal tract changes with Laver’s (1980) work on voice quality, Scherer predicts strong resonance in high frequencies following appraisals of unpleasantness. In contrast, stimuli appraised as pleasant are predicted by Scherer to lead to faucal and pharyngeal expansion, which should lead to a damping of high frequency energy. Both pleasant and unpleasant appraisals are also predicted by Scherer to produce facial expressions such as the retraction of the corners of the mouth in smiles and expressions of disgust, although it is unclear how these two types of expression would differently affect vocal characteristics. Tartter (1980; Tartter & Braun, 1994) found that lip retraction in smiling raised second formant frequency, whereas lip protrusion lowered it. It is not clear whether the energy in the second formant is affected by such facial expressions.

Scherer (1986) makes a theoretical distinction between appraisals of intrinsic pleasantness, which has to do with innate, or highly learned evaluation of pleasantness, and goal conduciveness, which involves an evaluation of whether a stimulus or event helps or hinders one to obtain a desired goal or need. An example of this distinction might be when one is offered a medicine that tastes terrible but will cure a bad illness. According to Scherer, the medicine will be appraised as intrinsically unpleasant but goal conducive. The opposite case might be a smoker trying desperately to give up smoking who is offered a cigarette, an event that would be appraised as intrinsically pleasant, but goal obstructive. Despite this theoretical distinction, Scherer predicts that many of the effects of goal conduciveness appraisals on the voice will be similar to those of intrinsic pleasantness appraisals, since the neurophysiological pathways that mediate expressive responses to both appraisals are likely to be the same. Hence goal obstructive events are predicted to produce constricted pharyngeal settings and approximated faucal pillars, leading to fairly high energy at high frequencies, as opposed to less high frequency energy corresponding to wide pharyngeal and faucal settings that result from goal conducive appraisals.

Scherer's (1986) predictions of vocal changes corresponding to a hedonic valence response dimension are in direct contrast to a simple arousal theory of emotional vocal expressions. Scherer predicts that F0 level and mean overall energy of speech will not change as a function of appraisals of goal conduciveness or intrinsic pleasantness. An arousal theory of emotional expression in the voice would predict at least F0 level and mean energy to increase with increasing arousal. Indeed, as discussed in chapter 1, studies that have been carried out on both real and acted emotional speech have almost always measured an increase in F0 and energy for anger, joy and fear and a decrease for boredom and sadness and attributed it to changes in physiological arousal. Other acoustic variables, such as the spectral distribution of energy, might also be expected to change according to an arousal theory, but they would be expected to covary with F0 and energy in a consistent manner.

In summary, by measuring the acoustical properties of speech immediately following game events that are designed to elicit appraisals of intrinsic pleasantness and goal conduciveness, this experiment sought to test the hypothesis that such events provoke changes to the voice that are inconsistent with a simple arousal model of emotional vocal expression. To this end, changes were predicted to the spectral distribution of energy of elicited speech due to the different experimental conditions that would not covary with any changes observed in speech F0 or speech energy. In addition, the specific predictions of Scherer of more high frequency energy under conditions of negative hedonic valence (unpleasant or obstructive) than under conditions of positive hedonic valence (pleasant or conducive), and no valence-dependencies for F0, were also tested.

Method

Participants

Thirty-three volunteer adolescents between the ages of 13 and 15 (27 males and 6 females) were recruited from nearby high schools. Both the schools and parents of all children gave full written consent for the participation of their children based upon a full explanation of the aims and procedure of the experiment. Participants were reimbursed SFr.15 for their participation in the experiment. Adolescents were chosen because they were considered most likely to be familiar with, and get involved in video games, thus making it more likely that emotional responses to the video games would be elicited.

Description of the game

The game XQuest situates the player in a fictional galaxy, filled with crystals, mines and enemies. The general assignment is to gather the crystals which are present in each galaxy. Acceleration of the player's space ship is controlled by moving the mouse, thus leading to a ballistic movement of the ship. This feature makes the game particularly interesting to play. Pressing the left button of the mouse launches bullets in the direction in which the ship is going, which destroy any enemies which are hit. Pressing the right button launches a bomb, if available, which destroys every enemy and mine in the galaxy. Once the player has picked up all the crystals in the galaxy, a gate opens through which the player proceeds to the next galaxy (or game level). Points are awarded for every crystal gathered, completion of a game level within a certain time range, and every enemy destroyed. Depending on the amount of points gained, extra ships are given. The difficulty increases in successive game levels since there are more crystals to pick up, the number of mines increases, the enemies become more numerous and difficult, and the exit to the next game level becomes smaller. The game ends when the player loses all the ships, after which the player starts a new game at the first game level.

Procedure

Upon their arrival in the laboratory, participants were fully informed of the nature of the computer game and how long they would be asked to play for. Participants were then given a demonstration of how to play the game, during which the experimenter played the game and explained the appearance of the different objects (e.g. mines, crystals, player's space ship, enemies), movement of the player's space ship, how to fire bullets and to use the bomb, how to pick up the crystals and how to exit the galaxy when all the crystals had been collected. Players were also shown the emotion rating screen and verbal report screen and how to use them properly. Then they played the game for a

20 minute practice session. During this time, they were given extra instruction and reminders whenever necessary. In order to ensure that all players were sufficiently involved in the game, and to establish a minimal performance level for all players, a selection criterion of reaching at least the fourth game level by the end of 20 minutes practice was used. All players met this criterion. After the practice session, sensors for physiological measures and the microphone were attached. The players were asked to speak aloud in a normal voice while the microphone recording level was adjusted. The experiment started with a 2.5 minute relaxation phase, to establish a resting baseline. Then the game started and participants played for 45 minutes, after which the game halted automatically.

Manipulation of appraisal dimensions

Two appraisal dimensions were operationalised by either manipulating or selecting specific game events. From all possible events in the game which may elicit emotion-antecedent appraisal, two types of events were selected a-priori since it is highly likely that these events would be appraised in a similar way by all players. These events are loosing a ship (by hitting an obstacle or being shot by an enemy) and passing to the next game level after successful completion of a galaxy. In the context of the game, the first type of event is obstructive and the latter conducive in the pursuit of gaining points and progressing to as high a game level as possible. The independent variable goal conduciveness was thus operationalised by selecting situations in which the player’s ship was destroyed (low goal conduciveness) or a game level was successfully completed (high goal conduciveness). The other appraisal dimension which was studied was the intrinsic pleasantness of critical game events. As opposed to goal conduciveness, this appraisal dimension was directly manipulated by playing valenced (i.e. pleasant and unpleasant) sounds. The pleasantness of these sounds, which were equal in duration and average intensity, had been established in an independent pre-test of 15 judges who were asked to rate the sounds on a seven point scale from -3 (very unpleasant) to +3 (very pleasant). The mean ratings are given in table 2.1.

Table 2.1. Ratings of the two sounds used in the experiment as a manipulation of intrinsic pleasantness.

	Mean rating	Std. Dev.
Unpleasant sound	-2.3	1.1
Pleasant sound	2.2	0.8

The appraisal dimensions were manipulated in a 2 (intrinsic pleasantness) x 2 (goal conduciveness) within-subjects design. Thus concurrent with the player reaching the next level or losing a life, either a pleasant or an unpleasant sound was presented.

Vocal reports

Speech was elicited by means of a vocal report pop-up screen, which requested a vocal report of the immediately preceding game events. The report screen, which was designed to seem to the player like part of the game, rather than an intrusion on it, was displayed whenever an experiment-relevant event (i.e. loss of ship or new level) occurred, with the constraint that no more than one screen appeared every two minutes, so that the continuity of the game was not unduly interrupted (see figure 2.1). The players were requested to respond to the screen by pronouncing aloud the identification number, choosing one of the three given reasons for the preceding event, and estimating the percentage chance that they would be successful in the following game level. The pop-up screen provided both strings of isolated letters and connected phrases to be pronounced by the subject. For each presentation the identification number changed, but the first six characters remained constant across all presentations.

Galaxie Franchie!	Galaxy Completed!
Votre rapport s.v.p.	**Your report please**
Identification du vaisseau:	Identification of ship:
AG01813	**AG01813**
Votre compte rendu:	Your account:
Ennemis peu efficaces	**Enemies not very good**
Attaque ennemie	***Enemy attack***
Navigation correcte	**Good navigation**
Mauvais navigation	***Bad navigation***
Chance	**Luck**
Probabilite de franchir la galaxie suivante?	Probability to complete the next galaxy?
X pourcent	**X percent**

Figure 2.1. Vocal report screen used in the experiment (left) and English translation (right). Italics indicate phrases that were displayed in place of the preceding phrases for ship destroyed events.

Emotion self-report

An emotion self-report was obtained using a pop-up screen which displayed a popular French comic strip character (Gaston Lagaffe), expressing eight different emotions (interest, joy, surprise, anger, shame, pride, tenseness and helplessness; see Figure 2.2). The images of the characters, which were used to make the rating screen clearer and easier for the adolescents, were accompanied by the corresponding emotion-labels and a continuous graphic scale on which the felt intensity of each emotion could be indicated by means of clicking and dragging with the mouse. The ratings were converted to 100 decimal values ranging from 0 to 1. The pop-up screen was presented immediately after a random sample of critical game events, but not more often than once every four minutes, so that the continuity of the game was not unduly interrupted.

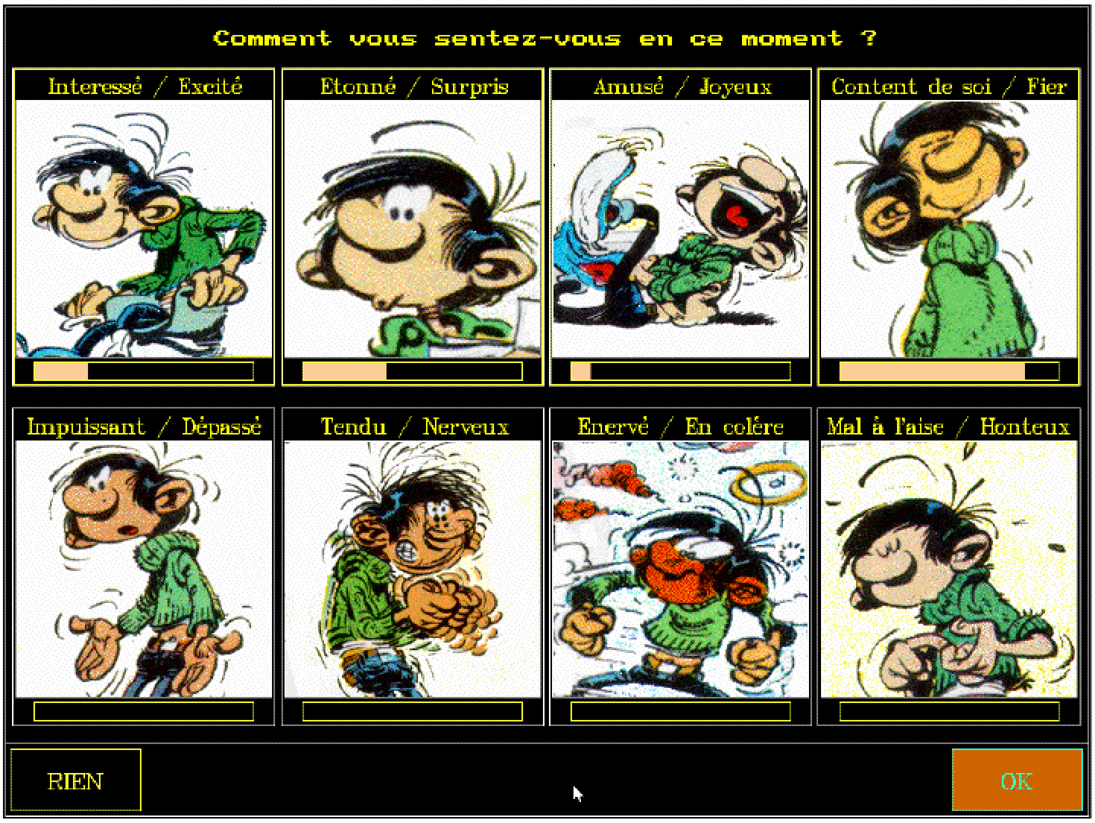


Figure 2.2. Subjective emotion rating screen.

Results

Emotion reports

For each subject, each experimental condition contained on average two observations, the data for which were averaged. Mean reported emotion intensities are shown in figure 2.3. Since the data for all emotions were heavily skewed, and had distributions that could not be corrected with mathematical transformations, they were then analysed with a Friedman test (this is an appropriate non-parametric within-subject test of differences between mean ranks) to determine for each emotion if the reported intensities differed across the four experimental conditions. Reported joy ($\chi^2_{(3, 32)} = 10.0$, p = 0.02), pride ($\chi^2_{(3, 32)} = 29.9$, p < .0005), anger ($\chi^2_{(3, 32)} = 29.2$, p < .0005) and surprise ($\chi^2_{(3, 32)} = 12.3$, p = 0.007) all differed across the four conditions. For these emotions, posthoc two-way Wilcoxon signed ranks tests were used to compare the reported intensities between conducive and obstructive, and pleasant and unpleasant conditions respectively. Joy (Z = 2.0, p = 0.004) and Pride (Z = 4.1, p < 0.0005) were both higher in conducive conditions than in obstructive conditions. Anger (Z = 4.0, p < 0.0005) and Surprise (Z = 3.1, p = 0.002) were both higher in obstructive conditions than in conducive conditions. Surprise was also higher following games events accompanied by pleasant sounds than following events accompanied by unpleasant sounds (Z = 2.4, p = 0.02).

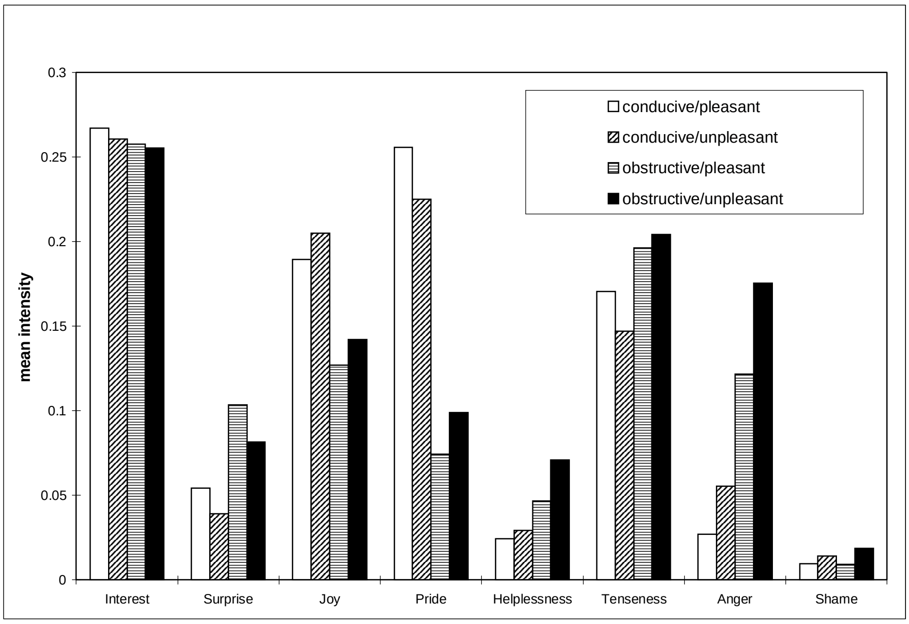


Figure 2.3. Mean reported emotion intensity as a function of experimental condition.

Acoustic Analyses

Sections of the DAT speech recordings corresponding to the prompted vocal reports were identified using timing data recorded in the participants' data log files. These sections were then digitised using 16-bit Kay Computer Speech Laboratory (CSL) 5300B speech analysis hardware and software at 20000 samples/second and stored as separate digital PC sound files. A number of acoustic analyses were then performed on each speech file, using CSL speech analysis software. These are detailed below for each type of analysis.

Fundamental frequency (F0). For each speech file, a three stage procedure was used to extract the F0 contour. The CSL software was first used to mark the onset of each pitch impulse. For each participant, all their speech files were analysed with a set minimum allowed F0 of 150 Hz and a set maximum allowed F0 of 400 Hz. These values are used by the CSL routine to limit the search for pitch impulse peaks in the speech waveform to within the expected range of F0 values for the adolescent participants. The positions of the impulse markers were then visually compared with the speech waveform, and obvious errors were manually corrected. For some participants for which there were many errors, due to F0 being either above the maximum or below the minimum allowed values, the minimum and maximum allowed F0 values were adjusted appropriately and all the participant's speech files were reanalysed and pitch impulses re-inspected. For all participants, a single adjustment of the minimum and maximum allowed F0 values was sufficient to ensure an accurate calculation of pitch impulse markers. Finally, the CSL software was used to calculate the F0 contour for each speech files based upon the pitch impulse markers.

From each calculated F0 contour, the following statistical measures of F0 were calculated: mean F0, standard deviation of F0, F0 5th percentile value and F0 95th percentile value. The two percentile values were calculated as measures of F0 floor and F0 ceiling respectively as reported in Banse and Scherer (1996).

Energy. The mean voiced energy of speech in each speech file was measured by calculating the root mean square (RMS) value of 15 millisecond frames of the speech signal, centred about each pitch impulse marker. The RMS value has advantages over other energy measures since it reflects more accurately the perceived intensity of speech

(Deller, Proakis and Hansen, 1993). A 15 millisecond calculation window is long enough to ensure that the energy is averaged over 2-3 fundamental periods.

Duration and fluency measures. Using the calculated pitch impulse markers, an estimation was made of the length of each utterance, by measuring the time from the first pitch impulse marker to the last pitch impulse marker in each speech file. This technique is inaccurate in so far as it ignores unvoiced sounds at the beginning and end of each utterance, but was nevertheless used since such unvoiced sounds were not expected to vary greatly between experimental conditions (at least compared with the variation expected for voiced parts of the utterance), and since no CSL algorithm could be used for the automatic determination of the onset and offset of unvoiced sounds. A measure of the proportion of each speech utterance that was voiced was made by using the pitch impulse markers to estimate the voiced portions of each utterance and dividing the summed duration of these portions by the estimated total utterance duration. Both measures (i.e. utterance length and proportion voiced) were thus used as an indicator of speech fluency.

Spectral measures. The pitch impulse markers were used to separate each speech file into voiced and unvoiced parts. The average power spectrum of voiced parts of each utterance was then calculated using the CSL software, with a frame size of 512 samples. This thus yielded a power spectrum with 256 frequency bins, each one of width 39.06 hertz. The proportion of energy under 500 Hz, which is a measure of low frequency energy that has been found to vary with different emotions (Banse and Scherer, 1996), was calculated by summing all the frequency bins of the power spectrum below 500Hz, and dividing by the sum of all the frequency bins across the entire spectral range. An equivalent calculation was made of the proportion of energy under 1000 Hz.

Statistical analyses

To determine the effects of the experimental manipulations on the acoustic parameters, each parameter was separately analysed with a univariate mixed-model ANOVA, with conduciveness and pleasantness as two-level fixed factors, and participant as a 30-level random factor. A univariate mixed-model approach was chosen because a number of the acoustic variables measured are known to be highly interdependent, and the aim of these analyses was to identify all the parameters that varied across experimental conditions, rather than only those that contributed uniquely to a single composite dependent variate. Because of the high interdependence[1], no Bonferroni corrections were performed – rather, the intention was to use replication in following studies to verify the results of these analyses.

Pleasantness x Conduciveness interaction. There was very little interaction between the two independent variables. A weak interaction was measured for the F0 ceiling (F(1,30)=2.9, p=0.10). Post-hoc comparisons showed that this was due to F0 ceiling being higher in response to unpleasant than to pleasant sounds that accompanied obstructive events (F(1,30)=4.4, p=0.04), but the lack of such a difference for conducive events (F(1,35)<1). An interaction for F0 standard deviation (F(1,30)=5.0, p=.03) was also due to higher F0 standard deviation in response to unpleasant than to pleasant sounds that accompanied obstructive events (F(1,32)=5.6, p=0.02), but the lack of such a difference for conducive events (F(1,33)<1). These two interactions are illustrated in figure 2.4. No other pleasantness x conduciveness interactions were observed.

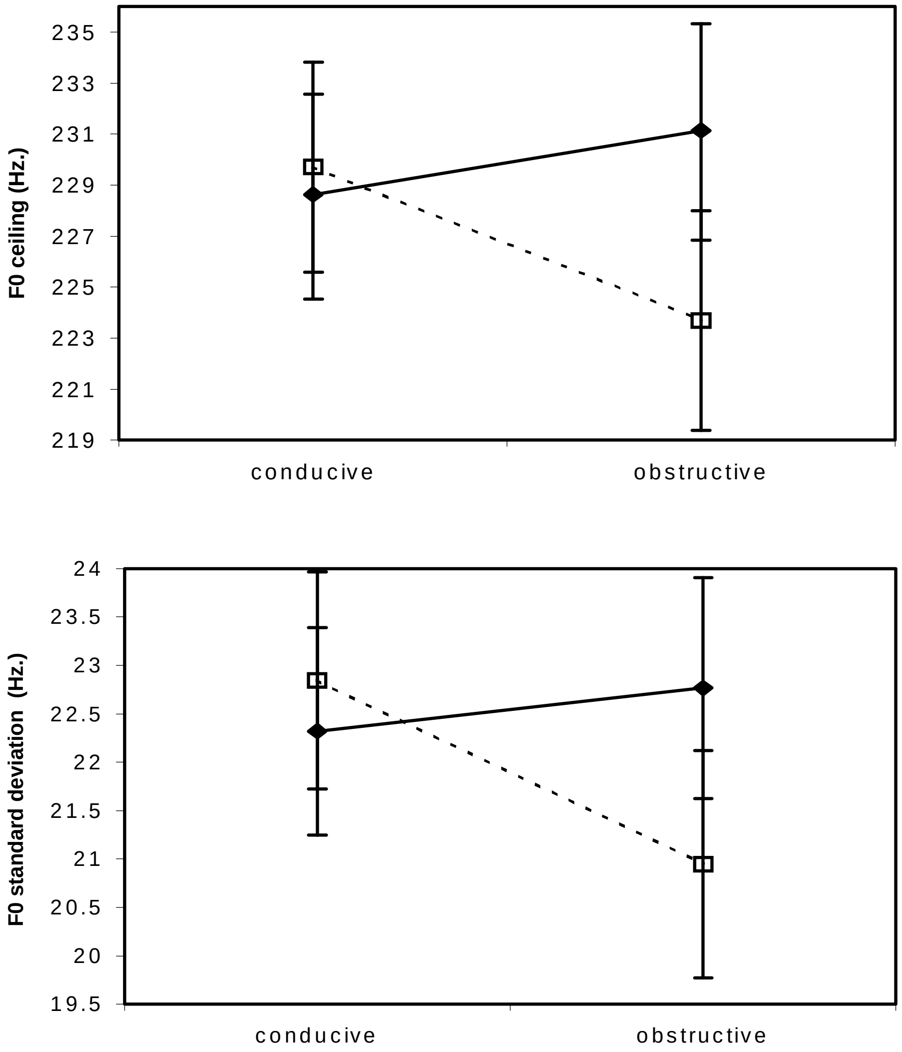


Figure 2.4. Interaction of pleasantness and conduciveness for F0 ceiling (top) and F0 standard deviation (bottom). Solid lines indicate pleasant sounds, broken lines indicate unpleasant sounds. Bars represent 95% within-subjects confidence intervals.

Pleasantness. No effects of pleasantness on mean energy (F(1,29)<1), F0 floor (F(1,29)<1), F0 ceiling (F(1,30)=2.1, p=0.15), mean F0 (F(1,29)<1), F0 standard deviation (F(1,30)=1.2, p=0.28) were observed. The proportion of energy below 500 hertz was significantly lower for unpleasant than for pleasant sounds (F(1,31)=7.3, p=0.01). A similar result was found for the proportion of energy under 1000 hertz, which was also lower in response to unpleasant sounds than to pleasant sounds (F(1,29)=4.2, p=0.05).

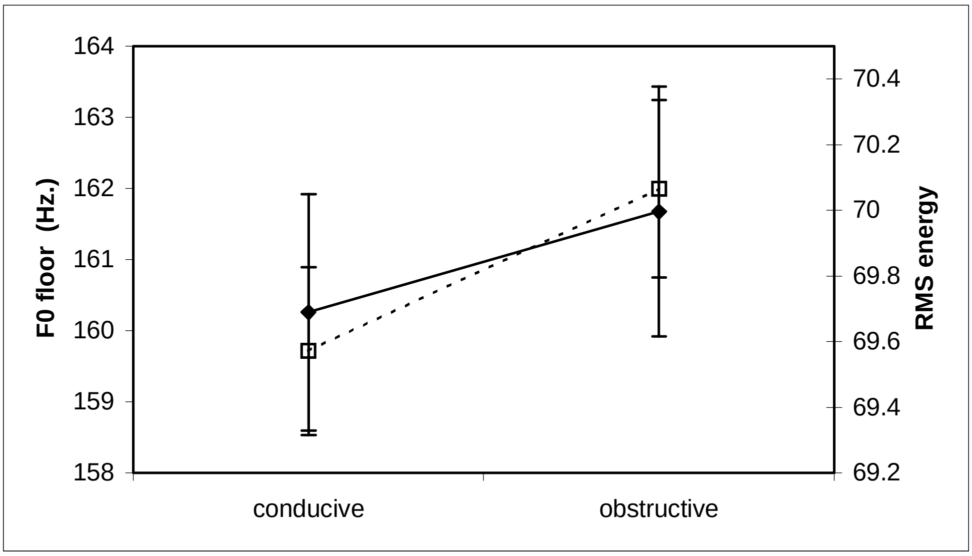


Figure 2.5. Mean voiced energy in decibels (broken line) and F0 floor (solid line) as a function of conduciveness. Bars represent 95% within-subjects confidence intervals.

Conduciveness. The effects of conduciveness on mean energy and F0 floor are shown in figure 2.5. Mean energy was lower for conducive than for obstructive events (F(1,29)=6.4, p=0.02). F0 floor was lower for conducive events than for obstructive events (F(1,30)=4.6, p=0.04), although no effects of conduciveness on F0 ceiling (F(1,30)<1), mean F0 (F(1,29)<1) or F0 standard deviation (F(1,30=1.2, p=0.27) were measured. The effects of conduciveness on the fluency parameters is shown in figure 2.6. The percentage of each utterance that was voiced was lower for conducive than for obstructive events (F(1, 30)=23.4, p<0.0001). Utterance duration was higher for conducive events than for obstructive events (F(1,30)=22.0, p<0.0001). No significant differences due to the conduciveness manipulation were found for the proportion of energy under 500 hertz (F(1,30)=1.8, p=0.19) nor for the proportion of energy under 1000 hertz (F(1,29)=1.3, p=0.27).

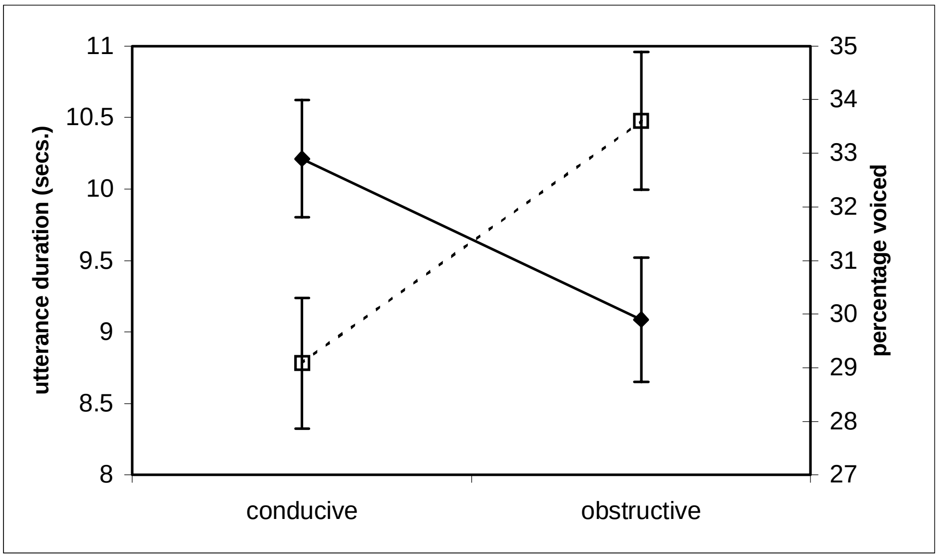


Figure 2.6. Mean utterance duration in seconds (solid line) and the percentage of each utterance that was voiced (broken line) as a function of conduciveness. Bars represent 95% within-subjects confidence intervals.

Interactions with participant. As expected, all of the acoustic parameters differed significantly across participants. More relevant to the current study is whether the ways in which acoustic parameters varied across experimental conditions were participant-dependent. In other words, how stable across participants were the effects of the experimental conditions? The interactions between the random participant factors and the two experimental factors can be used as an indicator of such a dependency. Weak conduciveness x participant (F(29,28)=1.7, p=0.07) and pleasantness x participant (F(29,26)=1.8, p=0.06) interactions were measured for the percentage of each utterance that was voiced. A significant pleasantness x participant interaction was observed for utterance duration (F(29,26)=2.1, p=0.03). No such interactions were measured for the other acoustic parameters.

Data reduction. As mentioned above, the set of acoustic parameters measured in this experiment are not indicators of distinct and independent voice production characteristics, nor even indicators of distinct characteristics of the acoustic signal. There is a large amount of overlap between certain parameters, for example the measures of F0, which is unavoidable since parameters that independently measure distinct acoustic properties are not yet well defined, particularly with respect to the acoustic properties of *emotional* speech. Because of this lack of independence, one can expect the acoustic parameters to be correlated to varying degrees. Table 2.2 lists the pairwise Pearson correlations between all the acoustic parameters measured in this experiment. The parameter values used for the calculation of the correlations were first zero-meaned for each participant. This ensures that the correlations between parameters reflect within-subject variability (i.e. variability due to experimental manipulations) rather than between-subject variability. As can be seen, parameters that are primarily associated with the same specific aspect of the acoustic signal, such as the F0-related measures, tend to be highly correlated. In addition, there are a number of substantial correlations between parameters that are based on different acoustic features, such as the correlations between the F0-related parameters and the measures of spectral energy distribution. It is possible that the latter correlations reflect underlying common characteristics of vocal production, which might be directly affected by emotional responses.

Table 2.2. Pearson correlations between acoustic parameters.

	Mean Energy	Percentage voiced	Duration	F0 floor	F0 ceiling	mean F0	F0 std. dev.	E < 500 Hz	E < 1000 Hz
Mean energy	1.00	.22**	-.06	.33**	.30**	.60**	.14*	-.23**	-.01
Percentage voiced	.22**	1.00	-.69**	.19**	-.03	.09	-.11	.13*	.09
Duration	-.06	-.69**	1.00	-.18**	.06	-.05	.17**	.01	.00
F0 floor	.33**	.19**	-.18**	1.00	.08	.55**	-.41**	.10	.27**
F0 ceiling	.30**	-.03	.06	.08	1.00	.66**	.73**	-.28**	-.44**
mean F0	.60**	.09	-.05	.55**	.66**	1.00	.30**	-.23**	-.13
F0 std. dev.	.14*	-.11	.17**	-.41**	.73**	.30**	1.00	-.30**	-.45**
E < 500 Hz	-.23**	.13*	.01	.10	-.28**	-.23**	-.30**	1.00	.60**
E < 1000 Hz	-.01	.09	.00	.27**	-.44**	-.13	-.45**	.60**	1.00

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

To address this possibility, a principal components analysis (PCA) was used to extract a small number of orthogonal factors that could be linked to specific voice production characteristics. Three, four and five factor solutions were calculated on the basis of the zero-meaned acoustic parameters, which accounted for 73%, 83% and 91% of the within-subject variance respectively. The factors were Quartimax rotated, in order to minimise the number of factors needed to explain the variables and to simplify interpretation. The rotated factor weightings for the three solutions were then examined to determine which of the solutions was most clearly interpretable with respect to current understanding of voice production and speech acoustics. Of the three solutions, the four factor solution provides the most parsimonious explanation of factors. Factor weightings for the four factor solution are shown in table 2.3.

Table 2.3. Factor weightings for a four factor, Quartimax rotated PCA of acoustic variables.

	Component			
	1	2	3	4
mean energy	.74	.13	.11	-.12
Percentage voiced	.13	.01	.91	.13
Duration	-.06	.12	-.91	.08
F0 floor	.81	-.36	.09	.18
F0 ceiling	.41	.82	-.04	-.17
F0 mean	.87	.37	.01	-.08
F0 std. dev.	-.04	.93	-.09	-.20
energy < 500 Hz	-.16	-.08	.06	.92
energy < 1000 Hz	.10	-.38	-.02	.80

The first factor loads most heavily on mean energy, F0 floor and mean F0. These three parameters are all indicators of physiological arousal or excitation, hence the first factor would most appropriately be interpreted as an excitation factor. The second factor loads highly on F0 ceiling and F0 variability, both indicators of F0 variability and range, and would thus be appropriately labeled pitch dynamics. The third factor is most clearly an indicator of fluency, as indicated by a high loading on percentage voiced and a high negative loading on utterance duration. The fourth factor loads highly on the two measures of spectral energy distribution, which have most commonly been linked to vocal fold dynamics and the profile of the vocal tract.

The factor scores were entered into a univariate mixed-model ANOVA, with conduciveness and pleasantness as two-level fixed factors and participant as a 30-level random factor. Scores on the excitation factor were higher for obstructive events than for conducive events (F(1,30)=4.1, p=0.05). There was no difference in the excitation factor between pleasant and unpleasant events (F(1,32)<1), nor were there any significant interactions. For the pitch dynamics factor, no significant difference was observed between events paired with pleasant sounds and those paired with unpleasant sounds (F(1,31)<1), nor between conducive events and obstructive events (F(1,30)<1). A significant interaction between conduciveness and pleasantness (F(1,30)=4.0, p=0.05) indicated that the pitch was less dynamic following pleasant sounds than following unpleasant sounds when accompanied by obstructive events. The fluency factor scores were significantly higher for conducive than for obstructive events (F(1,31)=27.6, p<0.000). The fluency factor did not vary significantly across levels of pleasantness (F(1,31)=1.9, p=0.18), nor was the pleasantness x conduciveness interaction significant (F(1,31)<1), but there was a significant interaction between pleasantness and participant (F(29,24)=2.3, p=0.02), indicating that fluency varied with pleasantness in a participant-dependent manner. The spectral factor scores were significantly lower following unpleasant sounds than following pleasant sounds (F(1,32)=6.9, p=0.01), with no other significant main effects or interactions for this factor.

Discussion

The measured effects of the intrinsic pleasantness manipulation on the acoustic speech signal were limited to the distribution of energy in the spectrum, with a greater proportion of energy in higher frequencies being measured after unpleasant sounds than after pleasant sounds. This result is consistent with the Scherer's (1986) predictions which were based upon a presumed constriction of the faucal pillars and pharynx in response to the appraisal of a stimulus or event as intrinsically unpleasant. Scherer did not predict changes in speech intensity nor F0 due to pleasant or unpleasant appraisals, and indeed no main effects of pleasantness on energy or F0 parameters were measured in this experiment. The measured interaction between pleasantness and conduciveness for F0 ceiling and F0 standard deviation, indicating that for obstructive events only, F0 had a reduced dynamic for pleasant than for unpleasant sounds, was, however, unexpected and is difficult to explain. Scherer's predictions have little to say about the interaction between different appraisal outcomes, other than that the predicted effects of two appraisal outcomes might reinforce or negate each other and thus produce a large or small change to speech acoustics accordingly.

Scherer (1986) predicted that the vocal changes caused by appraisals of goal conduciveness would parallel those of intrinsic pleasantness appraisals. Thus for events appraised as goal obstructive, a voice described as “narrow”, with more high frequency energy is expected, whereas for goal conducive events, a “wide” voice, with greater low frequency energy was predicted. The results of the current experiment do not support these predictions, with no significant spectral differences measured between conducive and obstructive events. Also contrary to Scherer's predictions, conducive events were lower in energy and had a lower F0 level, as indicated by F0 floor, than obstructive events. These latter results, in combination to the higher scores on the excitation PCA factor for obstructive events than for conducive events, suggest that physiological arousal was higher following the destruction of a ship than following the completion of a game level.

Such an arousal dimension is equivalent to the distinction used by Scherer to predict the difference between vocal changes in response to goal discrepant appraisals and those resulting from goal consistent appraisals. According to Scherer, appraisals of goal discrepancy should result in an *ergotropic* shift, whereby the sympathetic branch of the ANS is activated in preparation for probable action, leading to an overall tensing of the skeletal musculature, including the vocal folds, and increased depth of respiration. Such changes are expected to produce increases in F0 level and speech intensity. In situations appraised as goal consistent, a shift towards *ergotropic-trophotropic balance* is expected, in which sympathetic ANS activity is decreased and activity in the parasympathetic branch of the ANS is increased for the purposes of energy conservation and recovery, resulting in a “relaxed” voice with low to moderate F0 and intensity. Indeed, it is probable that the ship destroyed events were more discrepant with expectations than were the new level events, since when passing to a new level in XQuest, players see their ship approaching the exit gate, whereas the enemies that collide with the player’s ship often behave in unpredictable ways. It is thus quite conceivable that the acoustic differences observed between ship destroyed and new level events were due to differences in sympathetic ANS activity produced by appraisals of discrepancy and consistency respectively. Support for this explanation comes from the reports of surprise, which were higher for obstructive events than for conducive events.

Unfortunately, it is not possible to say whether the observed differences between ship destroyed events and level completion events in this experiment were due to a failure on the part of Scherer’s predictions, or a failure of the experiment to isolate the desired appraisal dimension. Although the two events were clearly objectively obstructive and conducive to the main goals of the game, it is not clear that they were appraised as such by participants, nor that they were only appraised along that dimension, and not also appraised along other dimensions such as discrepancy.

The practical problems with asking a player to report their appraisals as they play a computer game include interrupting the flow of game play, as well as changing the very way in which game events are perceived and evaluated (and hence affecting their emotional responses). In addition, most appraisal theorists hold that appraisals often occur unconsciously (e.g. Leventhal and Scherer, 1987; see van Reekum and Scherer, 1997, for a discussion of levels of processing in appraisal) and are thus not accessible for reporting, a problem analogous to that of extracting problem solving techniques from experts in the domain of expert systems research (Berry, 1987). Hence even if subjective appraisal reports had been collected from players, they would not have provided a valid indication of the way players actually appraised events during the game. It would be desirable in future experiments to use a method of estimating participants' appraisals to events which provides a suitable compromise between validity and avoiding interference with the ongoing experiment. Moreover, an effort needs to be made to avoid unwittingly using experimental manipulations that lead to appraisals other than those intended.

Push effects as simple arousal

The hypothesis that push effects on the voice are limited to an arousal dimension was not supported by the results. The fact that manipulations of intrinsic pleasantness produced changes in certain acoustic parameters, while the conduciveness of events produced changes in completely different acoustic parameters, is very difficult to explain within a simple arousal model of emotional vocal response. Such a model would predict that those acoustic parameters affected by general physiological arousal would covary –

that a change in the value of one such variable would be accompanied by a concomitant change in the values of the others, and that for a given pair of variables, the relative direction of change would be constant. Although it is possible that not all such changes would be measurable, since some acoustic parameters might be more sensitive than others, a purely arousal-based model would hold that their relative sensitivity would be constant. In other words, if one experimental condition were to produce a change in parameter A but not in parameter B, one would not expect that in another experimental condition, a change would be observed in parameter B but not in parameter A. This is, however, what the results of this experiment reveal: That variations in the intrinsic pleasantness of an event cause changes to spectral energy distribution, but not to overall energy, F0 level nor fluency, but that changes to the conduciveness of an event produce changes to the latter set of variables, but not to spectral energy distribution.

Although a single-dimension arousal model could be modified to fit such data, a more parsimonious explanation is that emotional changes to the voice reflect two or more dimensions, presumably reflecting two or more underlying mechanisms. This does not come as a surprise, given the evidence and theoretical justification that exists for the existence of at least three dimensions that seem to characterise emotional responses in general: activation, valence and potency. Scherer (1984) has suggested that the three dimensions can be useful in describing the structure of emotional response, although they are of more limited use in explaining the elicitation of emotion. In making his predictions of the acoustic characteristics of speech corresponding to different emotions, Scherer uses such a three-dimensional categorisation, which he proposes corresponds to three dimensions of voice type. Thus Scherer proposes that hedonic valence corresponds to variation in the voice from “wide” to “narrow”, activation corresponds to vocal variation from “lax”, through “relaxed” to “tense, and that potency effects voice along a “thin” to “full” dimension. The different vocal types, which are largely based upon the work of Laver (1980) on vocal settings and voice quality, are also described by Scherer in purely acoustic terms.

Despite the widespread acceptance of a three dimensional description of emotional responses, there is, however, very little empirical evidence supporting such a view with respect to push effects on the voice. Green and Cliff (1975) arrived at a three dimensional description of vocal changes in acted emotional speech, labeling the factors “pleasant-unpleasant”, “excitement” and “yielding-resisting”. The results from the factor analysis in this experiment also provide some support for a three dimensional view of vocal response patterning. A factor that could clearly be related to activation, which consisted of F0 level and mean intensity, was identified. These two acoustic parameters were indeed posited as indicators of the activation dimension by Scherer (1986). In addition, the spectral energy factor, which varied significantly with manipulations of intrinsic pleasantness, seems to match the description given by Scherer for a hedonic valence dimension. The two other factors, F0 dynamics and fluency, do not, however, easily map on to the remaining factor suggested by Scherer, the one of potency. The lack of emergence of a factor that clearly corresponds to the potency dimension is perhaps not surprising, since power, the appraisal dimension most implicated by Scherer in the potency dimension, was not manipulated in the current experiment, and thus might not have varied sufficiently to produce measurable effects in the acoustic data. In addition, Scherer did not include parameters related to speech fluency in his predictions. Nevertheless, at least the fluency factor that was measured in this experiment deserves an explanation, since it varied significantly with goal conduciveness.

One possibility is that fluency is related to the cognitive factors involved in emotional situations, such that situations requiring greater use of cognitive resources "steal" cognitive resources away from speech planning and execution, leading to speech that has more pauses and errors. Such situations are likely to be those appraised as obstructive and needing an urgent response – the type of situations that typically provoke anxiety and fear. The fluency measures from this experiment do not support such a hypothesis however, since obstructive situations provoked speech that was more fluent, as indicated by shorter overall duration and greater voiced percentage. Alternatively, the increase in speech fluency observed for obstructive conditions over conducive conditions could also be the result of increased arousal and excitation, although the low correlations between both fluency measures and the mean energy and F0 measures would seem to cast doubts on this explanation as well.

Conclusions

The results from this experiment indicate the potential of computer games to induce emotional responses which in turn affect the acoustic properties of speech. The main hypothesis of the experiment, that such changes reflect more than the unidimensional effects of physiological arousal on the voice, was supported by the data. In addition, acoustic analyses supported the specific hypotheses put forward by Scherer (1986) concerning the acoustic changes to speech due to appraisals of intrinsic pleasantness. Scherer's predictions of changes to speech due to goal conduciveness appraisals were not, however, supported in this experiment. A possible explanation for the discrepancy is that players did not only appraise events along the two intended dimensions, but also in terms of goal discrepancy.

This experiment has also highlighted a number of methodological and theoretical issues that need to be addressed in future studies. The experiment was successful in eliciting measurable vocal differences between experimental conditions despite the non-negligible delay between the emotion-inducing event and the onset of speech, a result of pausing the game to display the report screen. The measured acoustic differences in speech between the experimental conditions, which in this experiment were small, were presumably what remained of more immediate, possibly larger, acoustic effects. Alternatively, it is possible that the measured effects did not reflect the immediate emotional response to appraisal of the game event, but rather a secondary response, perhaps produced by reappraisal of the event outcome, or even appraisal of the initial emotional response or efforts to control such a response. Given the lack of knowledge of the temporal course of emotional responses (an issue discussed in some depth by Edwards, 1998), it is impossible to say with certainty which of these alternatives is correct. Clearly, it would be preferable in future computer game studies to measure the acoustic changes to speech more immediately after, or even during, appraised game events, although how this can be done without unduly interrupting the game (and thus interfering with the experimental manipulations) is not obvious.

A further issue concerns the difficulty of interpreting acoustic measurements, in particular those that are inconsistent with theoretical predictions, in terms of the their supposed physiological causes. It is difficult to interpret such global energy, F0 and spectral parameters as were measured in this experiment, without any corresponding data on the respiratory and muscular changes that are thought to affect them. Speech production is highly redundant, so that the same or similar acoustic effects can be produced using a variety of vocal settings. Thus acoustic measurements that are consistent with theoretical predictions provide only indirect support for the theory of how those acoustic changes are produced. More problematic still is when acoustic measurements are inconsistent with the predictions, since one can only speculate as to the causes of the discrepancies, as was the case with the goal conduciveness factor in this experiment. The obvious way to solve this problem is by measuring theoretically relevant physiological variables, such as respiration rate and depth, and muscular tension, concurrently with vocal measurements, although such an approach brings with it many new methodological problems.

One of the advantages of using a computer game to test the predictions made by appraisal theories of emotion is that it can highlight ambiguities in the constructs of the theories themselves. Such was the case in this experiment with goal conduciveness, the manipulation of which was questionable on the grounds that goal discrepancy might have also been manipulated. Although this could be considered a purely methodological problem concerning the design of the goal conduciveness manipulation, a closer look at the theory itself reveals a certain amount of confusion between the two appraisal dimensions. Thus while goal discrepancy is sometimes described as an evaluation of discrepancy with the *expected* state of proceedings (Scherer, 1986, p. 147), it is also described as an evaluation of discrepancy with the *desired* state of proceedings (Scherer, 1986, p. 153)[2], which seems to overlap with the goal conduciveness appraisal dimension. In addition to such definitional issues, there is also the possibility that the different appraisal dimensions are interdependent, that is, that the outcome of one appraisal will influence one or more of the others. This possibility is indeed consistent with the outline of Scherer's theory, in which appraisals are postulated to function in a sequential manner, the outcome of one appraisal check feeding forward into the next check in the sequence (Scherer, 2001). Of course, if the different appraisal dimensions do influence one another, it is difficult to see how they can be independently manipulated in an experiment, an issue that is further addressed in the following chapter.

[1] The Bonferroni correction is only applicable when multiple statistical tests are mathematically independent. When multiple tests are highly correlated, the correction is overly conservative.

[2] In the most recent version of his theory, Scherer (2001) has combined appraisal of the discrepancy and goal conduciveness of a situation into one appraisal check.

4. Experiment 2: Acoustic and physiological measurement of emotional speech

Introduction

The first experiment in this thesis highlighted that although a computer game could be effective in eliciting emotional changes to voice quality, concurrent measurements of voice-related physiology are needed to understand the mechanisms underlying such changes. This would seem particularly the case when testing the theoretical predictions of Scherer (1986), since they are based on a model of appraisal-produced physiological responses. The issue of whether emotional vocal changes are unidimensional indicators of arousal, or multidimensional indicators of a more complex physiological response system would also be better addressed by experiments that included physiological measures.

If there exists little prior research on the properties or production of real or induced emotional speech, there exists virtually no such research that has included measures of physiology relative to speech production. There is, however, a large and growing body of research into the physiology of non-emotional speech production. The techniques used in such research vary according to the specific research question being addressed. Much of the research is concentrated on detailed measurements of speech articulation, both in normal speech as well as speech under special circumstances or in special populations (such as stutterers or speakers of particular dialects). Articulatory research uses techniques including electropalatography, X-ray imaging and, more recently, magnetic resonance imaging (MRI) to measure the precise positions of the various articulators during speech production. While such techniques could be applied to research on emotional speech, their invasive nature and high cost precludes them from being easily applied to studies of real or induced emotional speech. The other major area of research into speech physiology focuses on the mechanisms of vocal production centred about the respiratory and laryngeal systems. Such research typically seeks to measure how changes to respiratory function (such as respiratory depth, expiratory force and subglottal pressure) and laryngeal function (such as vocal fold tension, vocal fold abduction and adduction, and larynx position) interact to produce changes to vocal energy, F0 level and dynamics, and vocal spectral characteristics (e.g. Strik and Boves, 1992; Iwarsson, Thomasson and Sundberg, 1996). A variety of techniques are used to this end, including strain gauge measurement of chest circumference, which is an indirect indicator of respiration, measures of oral flow with a pneumotachomask (flow mask), direct intra-oral and subglottal pair pressure measurements, electroglottogram (EGG) and photoglottogram (PGG) measurements of vocal fold opening and closing, EGG measurement of larynx position, and fine wire electromyogram (EMG) measurements of laryngeal muscle activity. Of these techniques, some (PGG, flow mask, intra-oral pressure, fine wire EMG) are too invasive to be usefully applied to studies that seek to induce real emotional speech, while all require specialised equipment of moderate to high cost.

All the physiological measurement techniques listed above are pertinent to speech production in general. In addition, it is likely that other types of physiological measurements that are not usually used in speech production studies, but are commonly used in studies of emotional response patterning, will also prove useful in explaining the mechanisms underlying emotional changes to speech. Measurements such as heart rate and skin conductance are indicators of autonomic nervous system activity (e.g. Bradley and Lang, 2000; Tranel, 2000), which is directly pertinent to arousal-based theories of emotional vocal changes, as well as to the more specific predictions of Scherer (1986). In addition, surface EMG measurements of facial muscles have been suggested and used as indicators of emotion-specific (Ekman, 1972, 1982a) or appraisal-specific (Scherer, 1992; Smith and Scott, 1997) expressive responses, and might thus prove useful when combined with acoustic measurements of the voice. Finally, surface EMG of other muscles might be used as an indicator of general skeletal muscle tension, which is postulated by Scherer (1986) to change with different appraisals and thus affect voice production through changes to laryngeal muscle tone.

This experiment was designed to concurrently measure both acoustic properties of the voice and a set of physiological variables that could be linked either directly or indirectly to emotional voice production. The choice of which physiological variables to measure was decided on the basis of three considerations: a) the expected relevance of the variable to either speech production or to emotional response patterning, based upon current emotion and speech production theory, b) the non-invasiveness of measuring the variable, so as not to interfere with the emotion induction by introducing anxiety and distractions, and c) the cost, availability and ease of use of the equipment necessary to measure the variable. Specific predictions of changes to the physiological measures for the different manipulations are given in the section on this experiment's hypotheses.

Methodological issues

One of the methodological problems discussed in the last chapter concerned eliciting vocal reports some time after a manipulated event occurred in the game, having in the meantime paused the game. When measuring physiological data, this problem is even more relevant, since accurate measurement of physiological data requires a relatively long window of time that is not affected by non-experimental changes in the situation. The mere act of pausing the game will tend to elicit a physiological response, since the player can take that opportunity to disengage from the action and take a break. In so doing, players also often take the chance to readjust their posture, which leads to large movement artifacts in most physiological recordings (due to electrode displacement, strain gauge movement etc.). For these reasons, it was considered desirable in this experiment to collect vocal reports during game play, without any interruption. In this way, the effects of manipulated game events on speech and physiological data could be recorded immediately and relatively freely of artifacts. Therefore, in this experiment, during manipulated game situations, players were requested with an audio prompt to give a vocal report of how they currently felt, using a standard phrase and standard emotion labels that had been rehearsed in a practice session. This technique of collecting speech data also allowed subjective emotion data to be collected for each vocal report, rather than for a subset of manipulated game events as was the case in the first experiment.

Not only were the vocal reports integrated into the game without interruptions, but the experimental manipulations were changed from being single, one-off events (such as losing a ship) to being situations with a prolonged duration (such as battling an enemy). One reason for this change was to provide a suitably long window during which physiological data alone, and vocal and physiological data together, could be recorded. Another reason was that many of the situations that cause emotions in real life tend to be prolonged ones in which the final outcome is uncertain and the emotional response builds up over time, rather than quick events that resolve uncertainty. The slow building up of an emotional response is more amenable to measurement than quick, short lived responses to single events (although the latter do deserve research attention in their own right).

Appraisal dimensions

The primary aim of this experiment was to gather further evidence that emotional vocal changes reflect more than the simple effects of arousal on voice production. It was also intended to extend the findings of the first experiment with respect to Scherer's (1986) predictions, by further studying the appraisal dimension of goal conduciveness as well as examining other appraisal dimensions. A summary of the design of this experiment is presented in table 4.1; the manipulations of appraisal dimensions are further discussed below.

Table 4.1. Factorial design of experiment two, showing manipulations of conduciveness, control and power.

	low power		high power	
	low control	high control	low control	high control
conducive	mine sweeper few bullets ship wobble	mine sweeper few bullets steady ship	mine sweeper many bullets ship wobble	mine sweeper many bullets steady ship
obstructive	mine layer few bullets ship wobble	mine layer few bullets steady ship	mine layer many bullets ship wobble	mine layer many bullets steady ship

Goal conduciveness. The goal conduciveness dimension was examined using a different game manipulation from experiment one. The events used to examine goal conduciveness in the first experiment were problematic because although they clearly did vary along the dimension of goal conduciveness, they might also have varied across other appraisal dimensions, in particular discrepancy. The effects of these events on the voice were thus difficult to unambiguously interpret as either a failure of Scherer’s predictions for goal conduciveness, or as the result of appraisal along a second, unintended appraisal dimension. In addition, neither event meets the criteria of prolonged game situations that would allow physiological and vocal measurements as described in the preceding section. The manipulation of goal conduciveness in this experiment was thus designed to solve these problems. The manipulation consisted of the presence of friends, who sweep up enemy mines, or enemies, who place enemy mines, in a given game level (or galaxy). The friends were intended to provoke appraisals of goal conduciveness, the enemies goal obstructiveness. The manipulation was designed to be as symmetrical as possible, in that the friends and enemies were identical except for their mine sweeping or mine laying behaviour. Given such a symmetrical manipulation, it was not expected that other appraisal dimensions such as discrepancy could account for vocal, physiological or subjective differences between the two conditions.

<u>Coping potential.</u> The other major appraisal dimension included in most appraisal theories of emotion is an appraisal of the expected ability to cope with a given situation, either by attempting to alter the situation itself, avoid the situation, or deal with the situation's consequences. Such an appraisal is thought to be particularly relevant to the choice of an appropriate emotional response. For example, confronted by an aggressor, the decision to stand one's ground and prepare or threaten to fight, as opposed to conceding to the aggressor or running away, will depend largely on appraisal of one's ability to successfully carry out any of the response options. This appraisal dimension also maps fairly well onto the commonly posited emotional response dimension of power or potency. Some appraisal theorists make a distinction between appraisals of one's ability to cope with a situation (e.g. Scherer's (1986) power and control; Smith's (1989) problem-focused coping) and appraisals of one's ability to adjust to its consequences (e.g. Scherer's (1986) adjustment, Smith's (1989) emotion-focused coping). Scherer further distinguishes between appraisals of control, one's ability *in principle* to cope with a situation, and power, one's ability *at the moment* to cope with a situation. For example, this distinction of Scherer can be used to explain why one is frustrated when one can't open a door (low power) that one normally would be able to open (high control), but

resigned when one can’t open a door (low power) that one normally would not be able to open (low control).

In this experiment it was decided to examine the effects of Scherer’s control and power appraisal checks (equivalent to Smith’s problem-focused coping) on the voice. The adjustment appraisal is less amenable to manipulation in a computer game, as it refers to situations in which a person has to come to terms with the consequences of an event by readjustment of their goals, plans or personal image (the term “emotion-focused coping” used by Smith for this type of appraisal is particularly descriptive). Such types of adjustment are almost never needed in computer game play or if they are, they are trivial unless the game is being played in a highly competitive manner with much at stake – a situation that becomes problematic for ethical reasons. Power and control were manipulated in line with the requirements of prolonged manipulations that would allow vocal and physiological recordings to be made without interrupting the game. For the control manipulation, the player’s ship was made to either move in a smooth and consistent manner, as dictated by the player’s movement of the mouse (high control), or in a randomly wobbling manner, so that the player’s movement of the mouse only partially determined the ship movement (low control). There was nothing the player could do, even in principle, to avoid or diminish the random wobbliness of the ship in the low control condition. Power was manipulated by giving the player either a high or low shooting power. Contrary to the control manipulation, the player could make up for low power in the low shooting condition by clicking more frequently on the mouse. Similarly, a player could choose not to shoot at all in the high power condition. It should be noted that although Scherer makes the distinction between control and power, other appraisal theorists do not. The relative merits of either point of view would be tested by whether the two manipulations produced different changes to the voice, as predicted by Scherer (1986).

Interaction between appraisals. One of the possibilities that was briefly discussed in the previous chapter was that different appraisals might interact in their effects on emotional responses. This is particularly likely in the case of goal conduciveness and coping potential, since the notion of coping with a situation would seem to be predicated by the situation being appraised as obstructive (e.g. Lazarus, 1991) – one rarely speaks of coping with a positive situation. If this hypothesis were true, then one would expect manipulations of coping to have an effect on the voice only for goal obstructive situations, but not for goal conducive situations. This experiment was designed in a fully factorial manner to allow such a hypothesis to be tested. Thus with each level that contained enemy mine placers or friendly mine sweepers, players were given either high or low shooting power, and their space ship either moved smoothly or in a wobbly manner, as shown in table 4.1. The hypothesis that coping potential appraisals should only be relevant for goal obstructive situations is intuitively consistent with the requirements of the manipulated game situations. When there are enemies placing mines, one wishes to destroy the enemies by shooting them before they place more mines, and needs smooth ship control to avoid the mines they have already put down. Conversely, when there are friends clearing away the mines, one does not wish to shoot them, and navigation becomes much easier, regardless of ship control.

Other methodological issues. A few changes were made to the experimental design used in the first experiment. Adults (university students), instead of adolescents, were invited to participate, since contrary to initial expectations, they were found in pilot studies to perform better and be more involved in the game than adolescents, and were more readily recruited. In order to standardise the goal of the participants in the game, prizes were awarded to the best performers. This addressed a problem of the first experiment that players might have had goals other than achieving the best score possible, such as simply having fun, destroying as many enemies as possible, or exploring each game level as thoroughly as possible.

Hypotheses

The three appraisal checks that were manipulated - goal conduciveness, control and power - were also chosen because conditions of low conduciveness, low control or low power increase task demands and hence would be expected in an arousal model of emotional response to increase physiological arousal. The hypothesis that vocal changes simply reflect the underlying arousal dimension would thus predict same direction main effects for these three appraisal dimensions on acoustic parameters (although the magnitudes of the effects might differ). Furthermore, the pattern of effects across acoustic parameters, that is, the *acoustic profiles* for the three appraisal dimensions should be the same according to an arousal hypothesis. These three appraisal dimensions are predicted to affect vocal characteristics in different ways according to theories which support differentiated responses, such as the component process theory. Thus a differentiated response hypothesis would predict different patterns of acoustic changes for each of the three manipulated dimensions.

As in experiment one, the second aim of this experiment was to experimentally test the specific predictions of emotion response patterning made by Scherer (1986). Scherer's predictions for appraisals of conduciveness, control and power are now discussed, both in terms of expected acoustic changes to the speech signal, as well as the physiological mediators of such acoustic changes and the associated physiological parameters that were measured in this experiment.

Goal Conduciveness. The primary changes predicted by Scherer (1986) as discussed in the first experiment involve the setting of the vocal tract and facial muscles in either an appetitive or aversive configuration. For conducive situations, this is expected primarily to produce raised low frequency spectral energy, through expansion and relaxation of the vocal tract. Obstructive situations are predicted to provoke the opposite changes, namely an increase in the proportion of high frequency energy due to contraction and tensing of the vocal tract.

Control. Scherer (1986) has predicted that appraisals of control will affect primarily sympathetic arousal, such that appraisals of high control indicating that the player can, in principle, change the situation will lead to increased SNS activity and raised general muscle tension, whereas low control appraisals will lead to lower SNS activity, relatively higher parasympathetic activity and relaxed muscle tension. Thus situations appraised as being highly controllable are predicted to produce higher F0, F0 range and variability and speech with greater amplitude than situations appraised as not controllable. As an independent indicator of sympathetic arousal, measures of finger skin conductance and heart rate were made. Skin conductance, is believed to be innervated only by the sympathetic nervous system as has been found to be a reliable indicator of arousal (Bradley and Lang, 2000). Heart rate is innervated by the sympathetic and parasympathetic nervous systems, both of which can function independently of one another (Berntson, Cacioppo, Quigley and Fabro, 1994). It is thus impossible to make firm inferences about sympathetic arousal based solely on measures of heart rate. Measures of heart rate can be regarded as useful, however, when measured in combination with other sympathetic arousal indicators such as skin conductance. In this experiment, both skin conductance activity and heart rate were expected to be higher for high control than for low control situations. In addition to the autonomic measures, EMG activity was measured over the forearm extensor muscle of the non-dominant arm as an indicator of skeletal muscle tension, and was predicted to be higher for high control than for low control situations.

Power. Appraisals of power are predicted by Scherer (1986) to affect speech primarily through changes to respiration and changes to vocal register. The changes are predicted on the basis of preparation for fight or flight behaviour, corresponding to appraisals of high power or low power respectively. Thus high power appraisals are predicted to produce deep, powerful respiration and the shift to a chest register of phonation. Such changes have been observed in posturing animals in confrontations with social counterparts, and are thought to not only prepare the organism for subsequent action, but also serve to represent the organism as large and powerful (e.g. Morton, 1977; Scherer, 1985)[1]. In contrast, appraisals of low power are predicted to produce fast, shallow respiration and a shift to a head register of phonation, once again both in preparation for escape behaviour as well as serving to represent the organism as small and unthreatening. Acoustically, one would thus expect high intensity and low F0 resulting from appraisals of high power, and low intensity and high F0 resulting from appraisals of low power. In this experiment respiration rate was measured, and respiration depth was estimated, to determine the accuracy of Scherer's predictions of respiratory changes and their effect on the voice in response to power appraisals.

Method

Participants

43 male students of the University of Geneva, aged between 19 and 38 (mean age 24.5) were recruited via announcements describing the experiment as a test of perceptual-motor performance using a computer game. Students of the Faculty of Psychology and Educational Sciences were excluded from participation, in order to

avoid participants' prior knowledge of the game and the subject of interest (emotion psychology) affecting the results. SFr.30 was paid to each participant for the two hour experiment. Additionally, three cash prizes (SFr.500, 350, and 150 respectively) were awarded to the participants with the best three scores. All participants were native speakers of French.

Design and Manipulations

The appraisal checks were manipulated in a Goal Conduciveness (Conducive vs. Obstructive) x Power (High vs. Low) x Control (High vs. Low) fully factorial design. Goal conduciveness was manipulated by the introduction of alien ships which either placed more mines in the galaxy (goal obstructive), or swept the mines from the galaxy (goal conducive). The power of the player was manipulated by diminishing (low power) or augmenting (high power) the number and strength of bullets fired with each mouse button press. Control was manipulated by having the player's ship wobble randomly (low control) or move smoothly and predictably (high control).

Measurements

Subjective feeling. At manipulated points in the game, the participants were asked to provide a report of their current emotional state, by pronouncing out loud "En ce moment, je me sens..." (translation: “at the moment, I feel…”), and then completing the sentence by choosing one or more emotion words and giving an intensity for each one. The player was provided with the sentence and a list of eight emotion words placed above the computer screen in an easy to read, large font, to use as a memory aid. Players could also use their own words in the case that none of the words on the list corresponded to their felt emotion. The felt intensity of the emotion was given by the player by saying an integer from 1 (very little) through 5 (moderately) to 10 (extremely).

Players rehearsed the words on the list before the experiment to facilitate their easy recall during the experiment, thus minimising their need to refer to the list while playing.

Vocal measures. Subjective feeling reports were recorded to a Casio DAT recorder using a Sennheiser clip-on condenser microphone. The standard sentence used at the start of each subjective report was chosen to allow the direct comparison of acoustic tokens from different appraisal manipulations. Most importantly, the phrase was deliberately chosen to be meaningful in the context, as opposed meaningless or "off-topic" phrases as have been used in other studies.

Psychophysiological measures. All physiological measures were recorded continuously throughout the experimental part of the session with Contact Precision Instruments hardware, at a sample rate of 800 Hz. For the EMG measurements, 4 mm Ag-Ag/Cl electrodes were placed over the forearm extensor muscles in accordance with the guidelines provided by Cacioppo, Tassinary and Fridlund (1990). Raw EMG data was sampled with a bandpass filter of 10 - 300 Hz. Skin conductance was measured using 8 mm Ag-Ag/Cl electrodes placed on the tops of the index and third finger. The electrodes were filled with a NaCl paste (49.295 grams of unibase and 50.705 grams of isot. NaCl 0.9%). EMG and skin conductance were measured on the non-dominant arm and hand respectively. ECG was measured using pre-gelled, disposable ECG electrodes placed on the chest according to the Einthoven's triangle. A respiration strain gauge was placed around the abdomen, just below the thoracic cage, to provide an approximate measurement of respiration rate and depth. The respiration signal was highpass filtered at 0.03 Hz.

A digital CPI measurement channel, synchronised with the physiological data, recorded a numerical code corresponding to the different game events of interest, which was output from the game PC parallel port. This channel thus marked the physiological data with the precise onset and offset of each game event, as well as the onset and offset of vocal report screens.

Procedure

The participant was told that the general goal of the experiment was "to examine how your reaction times, mouse movements and physiological responses vary with the nature and complexity of different game events". Participants were then told that the session consisted of two parts: a practice session of 20 minutes during which the participant could get acquainted with the game and (after a break in which the participant was connected to the physiology measuring apparatus), the experimental session. The participant was told that after exactly 45 minutes of the experimental session the game would automatically stop, and that at the end of the experiment the mean score of all games played would be designated that player's final score, to be used in calculating the winners of the prizes.

The training phase consisted of a brief introduction to the game by the experimenter, followed by a 20 minute practice session. The introduction to the game was standardised for all participants, its purpose being to explain in general terms how the game was played, as well as making the participant familiar with the various game objects (e.g. alien ships and mines). The experimenter also demonstrated how to give the verbal subjective feeling reports. During the subsequent practice session the player had to give verbal reports 7-8 times, thus familiarising the player with the procedure while simultaneously allowing the recording level of the DAT recorder to be adjusted.

The experimental phase commenced with a 1.5 minute period of relaxation in which the participant was requested to sit still for the purpose of recording a physiology baseline. The game then started and continued for 45 minutes, after which an exit-interview was completed, and the participant was fully debriefed as to the aims of the study and the data analysis that would be performed.

Results

Subjective emotion reports

Subjective emotion reports were analysed to determine whether players reported feeling different emotions in response to the game manipulations. To test for differences in the different reported emotions between the manipulated events a Friedman test was used, since the distributions of values for all emotions were extremely non-normal and could not be corrected using arithmetic transformations. Significant differences were measured for calm (χ (7, 41) = 13.751, p = .056), contentment (χ (7, 41) = 23.840, p = .001), relief (χ (7, 41) = 13.811, p = .055), and stress (χ (7, 41) = 25.865, p = .001). Inspection of figure 4.1 indicates that higher intensities of calmness were reported in the high control-situations, whereas the level of reported stress increases with low control. Higher levels of stress and irritation were reported for obstructive situations than for conducive situations, and more relief was reported in the conducive situations compared to the obstructive situations. More intense feelings of contentment were associated with high control, particularly in conducive situations.

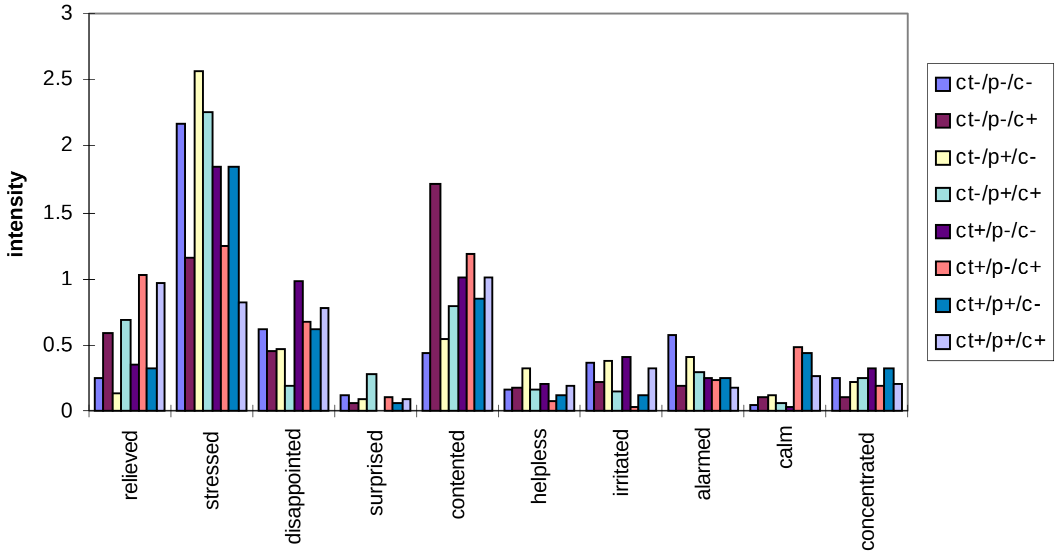


Figure 4.1. Mean reported emotion intensities per event type. c = conduciveness, p = power, ct = control; - = low, + = high.

Acoustic analysis

Vocal data was transferred digitally from DAT cassette to .WAV files on a Pentium PC. The vocal data for each subject was edited so as to save each repetition of "En ce moment, je me sens" to a separate file. All other subject vocalisations were eliminated. Three of the subjects did not always complete the full sentence, but rather used an abbreviated form "Je me sens". For these subjects, if the abbreviated sentence was used more often than the full sentence, the abbreviated form was taken for further analyses - any vocal samples containing the full sentence were edited so that only the words "Je me sens" remained. If the full sentence was more common than the abbreviated form, all the abbreviated samples were eliminated from further analysis. In all, the data of one participant could not be used because he admitted after the experimental session not to be a native French speaker. The vocal data from five other participants could not be analysed because they did not use the standard phrase as requested when making subjective reports. The samples were then low pass filtered and down-sampled to 24kHz for analysis. In this experiment, a custom written software package called LabSpeech was used for the acoustic analysis of speech.[2]

Energy. The root mean square (RMS) signal values for successive 1024 sample frames of each speech file were calculated. The frame RMS values were then used in classification of each frame as voiced, unvoiced or silence (see below). RMS values for frames that were classified as voiced were then averaged to produce a mean RMS energy value for each speech file.

Voiced, unvoiced, silence. For each successive frame of the speech signal, the number of signal zero crossings were calculated. When the RMS energy was above a visually set threshold, and the zero crossings were below a visually set threshold, the frame was designated as voiced. When the zero crossings were above the threshold value, the frame was labelled unvoiced. If both RMS energy and zero crossings were below their threshold values, the frame was labelled silence (meaning background noise only). Although such a simple method has its limitations and there are certainly more sophisticated and better methods available, for good quality signals with low background noise the procedure was found (by visual inspection) to work well.

F0. Voiced frames were centre-clipped at 30% of maximum amplitude and then analysed with an autocorrelation technique. The lag corresponding to the maximum peak in the autocorrelation function was accepted as a valid F0 value if the peak's value was greater than 0.4 and if the lag fell within the pre-set range of allowed F0 values for that speaker. Once the whole speech file had been analysed, outlier F0 values, defined as those differing from any other values by more than 20 Hertz, were excluded. On the basis of the remaining F0 values, a number of summary measures were calculated. These were F0 floor (F0 5th percentile), F0 ceiling (F0 95th percentile), F0 mean, F0 median, and F0 3rd moment.

Spectral analyses. FFT power spectra were calculated for successive 1024 point frames of each speech file. The spectra were then averaged separately for voiced and unvoiced sections. On the basis of these averaged spectra, the proportion of total energy below 500 Hertz and the proportion of total energy below 1000 Hertz were calculated for voiced and unvoiced average spectra.

Physiological analysis

For each manipulated game level, two data blocks were extracted, one consisting of the ten seconds immediately preceding the vocal report prompt, the other consisting of the ten seconds immediately following the vocal report prompt.

EMG. The EMG signal was rectified and smoothed using a digital Butterworth low-pass filter with a cut-off frequency of 4 Hz., after which the signal was down-sampled to 20 Hz. and averaged over five seconds.

Skin conductance. The skin conductance signal was low-pass filtered, with a cut-off of 0.7 Hz, and down-sampled to 20 Hz. before parameter extraction in order to eliminate high frequency artefact spikes introduced by the CPI system. An automated routine enabled the scoring of the number of skin conductance responses within the time block as well as the average skin conductance amplitude, and magnitude (see Dawson, Schell and Filion, 1990). A skin conductance response was scored when the increase in skin conductance level exceeded 0.05 microSiemens. The response amplitude was measured as the amplitude of the largest response occurring during the time block.

ECG. The inter-beat interval (IBI) derived from the R-R interval was calculated using an automatic peak picking routine. Those IBIs shorter than 400 and longer than 1500 were considered as artefacts (caused by player movement or spikes introduced by the CPI hardware) and eliminated from further analysis. For each block, the mean IBI and the standard deviation of IBI was calculated.

Statistical analysis

Each vocal and physiological parameter was analysed with a 2 (control) x 2 (power) x 2 (conduciveness) univariate mixed model ANOVA, with the three experimental factors as fixed factors and participant as a random factor. Since a number of interaction effects were found, these will be discussed first, after which tests of main effects will be presented.

Conduciveness by power interaction. A conduciveness x power interaction effect on median F0 (F(1,34)=4.2, p=0.05) was due to greater median F0 for obstructive situations than for conducive situations when power was high, but no such difference when power was low (see figure 4.2). The same interaction was evident for mean F0 (F(1,34)=4.7, p=0.04) and although not statistically significant, F0 ceiling varied in the same way (F(1,34)=2.2, p=0.15). A conduciveness x power interaction effect on the proportion of voiced energy in the spectrum below 1000 Hertz (F(1,34)=3.8, p=0.06) was due to lower energy below 1000 Hertz for obstructive situations than for conducive situations when power was high, but no such difference when power was low (see figure 4.3). A conduciveness x power interaction effect on the variability of inter-beat interval (F(1,42)=4.0, p=0.05) was due to greater variability when players had low power than when they had high power in obstructive situations, but no such difference for conducive situations, as shown in figure 4.4. Figure 4.5 shows that a similar interaction effect on skin conductance level (F(1,44)=7.1, p=0.01) was due to a greater skin conductance level when the player had low power than when the player had high power during obstructive situations, but no such difference during conducive situations.

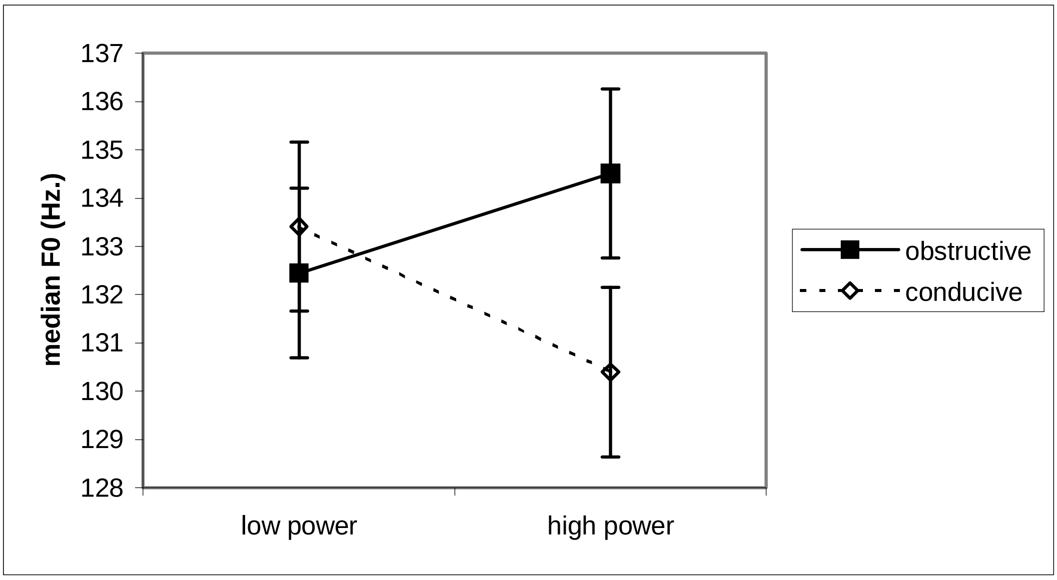


Figure 4.2. Interaction effect of conduciveness and power on median F0. Bars represent 95% within-subject confidence intervals.

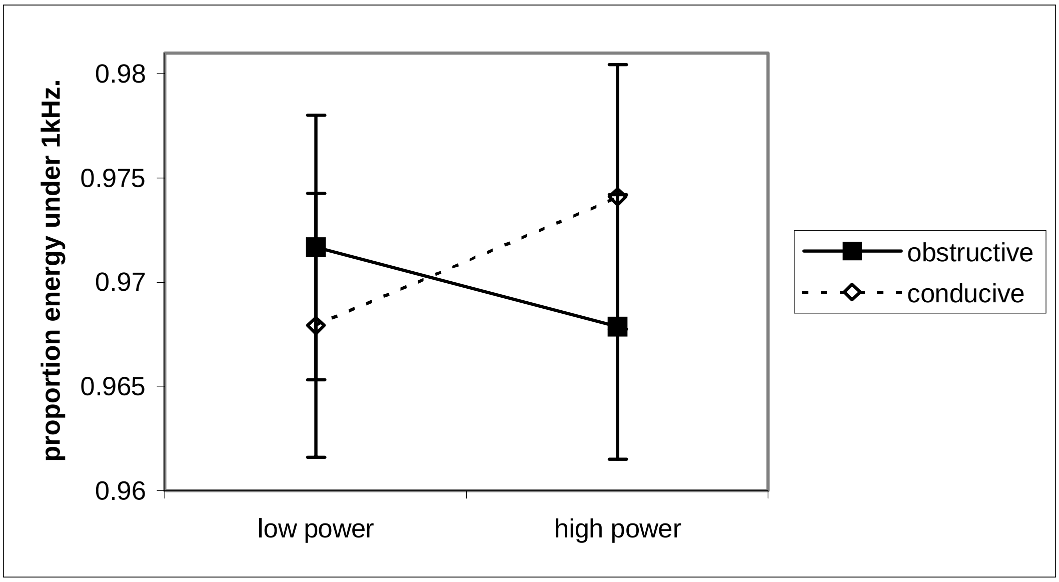


Figure 4.3. Interaction effect of conduciveness and power on the proportion of energy under 1000 Hertz for voiced frames. Bars represent 95% within-subject confidence intervals.

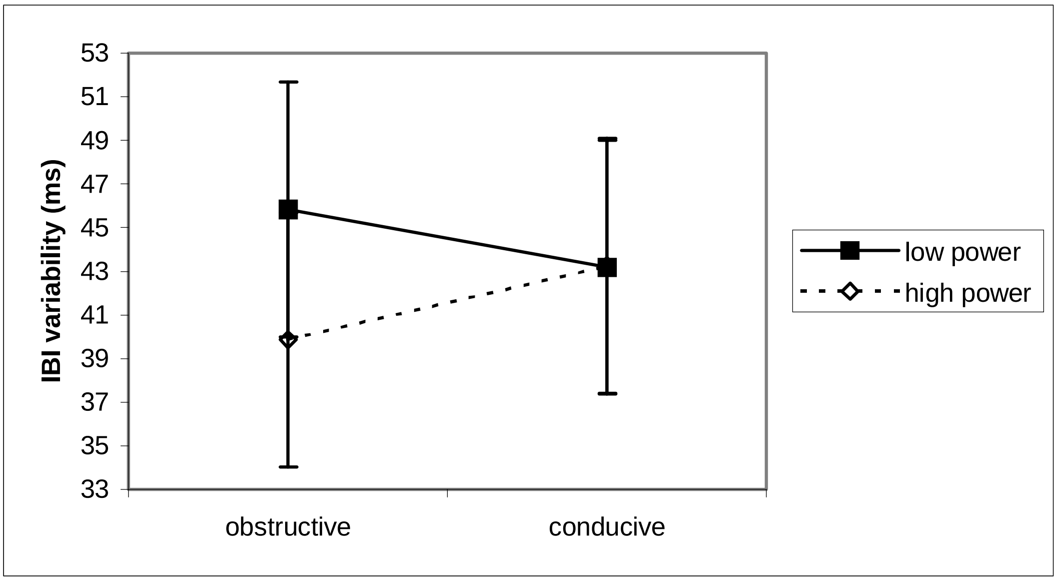


Figure 4.4. The effect of conduciveness x power interaction on inter-beat interval variability. Bars represent 95% within-subject confidence intervals.

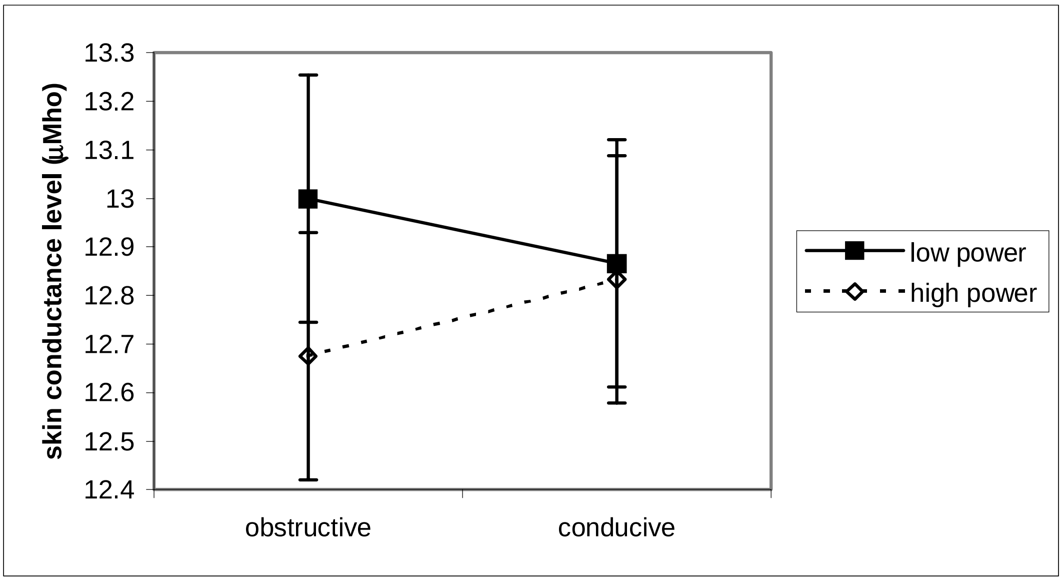


Figure 4.5. Effect of conduciveness x power interaction on skin conductance. Bars represent 95% within-subject confidence intervals.

Conduciveness by control interaction. A conduciveness x control interaction effect on the proportion of the total signal that was unvoiced (F(1,36)=4.2, p=0.05) was due to a greater proportion of unvoiced sounds for low control than for high control situations when the situation was obstructive, but the reversal of the difference when the situation was conducive (see Figure 4.6). The proportion of the signal that was voiced showed a trend for the opposite interaction (F(1,36)=3.2, p=0.08).

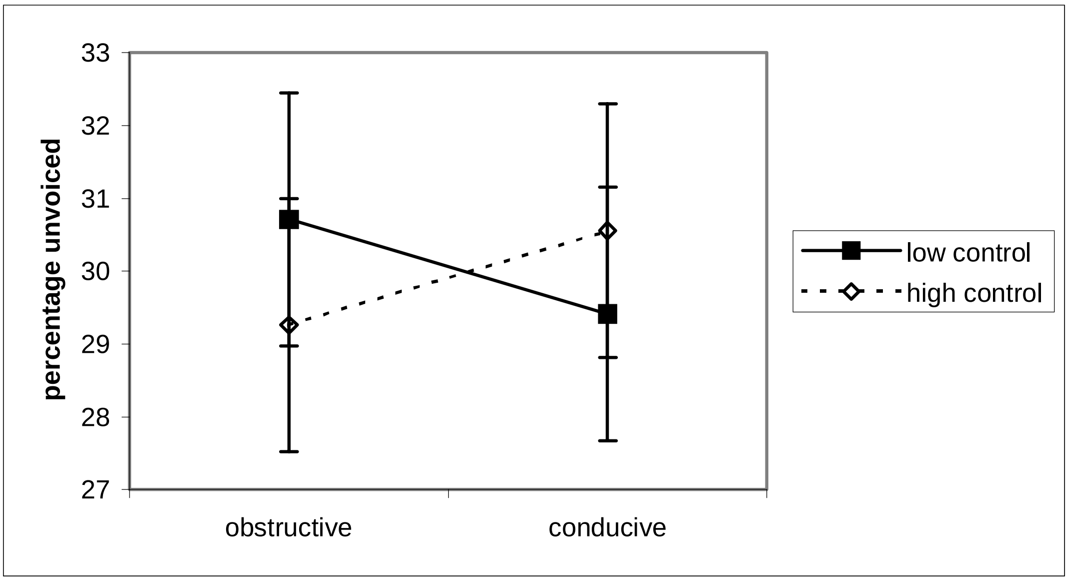


Figure 4.6. Interaction effect of conduciveness and control on the proportion of a phrase that was unvoiced. Bars represent 95% within-subject confidence intervals.

Main effects. Means for the vocal parameters in the different conditions are shown in table 4.1, and those of the physiological parameters are shown in table 4.2. It should be noted that these values are not corrected for between-subject variation, and hence the differences in the means across conditions might not correctly indicate the average size of within-subject differences.

F0 floor was higher in high control conditions than in low control conditions (F(1,37)=3.9, p=0.05). F0 range was significantly greater in low control conditions than high control conditions (F(1,36)=11.7, p=0.002 respectively). Zygomatic muscle activity was significantly greater in low control situations than in high control situations (F(1,43)=6.8, p=0.01). Respiratory period was significantly longer (i.e. respiration rate slower) in low control than in high control conditions (F(1,63)=4.95, p=.03). No other main effects of control were measured.

RMS energy of voiced frames of speech was significantly higher in obstructive situations than in conducive situations (F(1,37)=4.9, p=0.03. The same trend was measured for the RMS energy of unvoiced frames of speech (F(1,37)=3.4, p=0.07). There was a tendency for glottal slope to be greater (i.e. less steep) for obstructive than for conducive situations (F(1,37)=3.6, p=0.07). Skin conductance response amplitudes were higher for obstructive situations than for conducive situations (F(1,44)=5.0, p=0.03. No other main effects of conduciveness were measured.

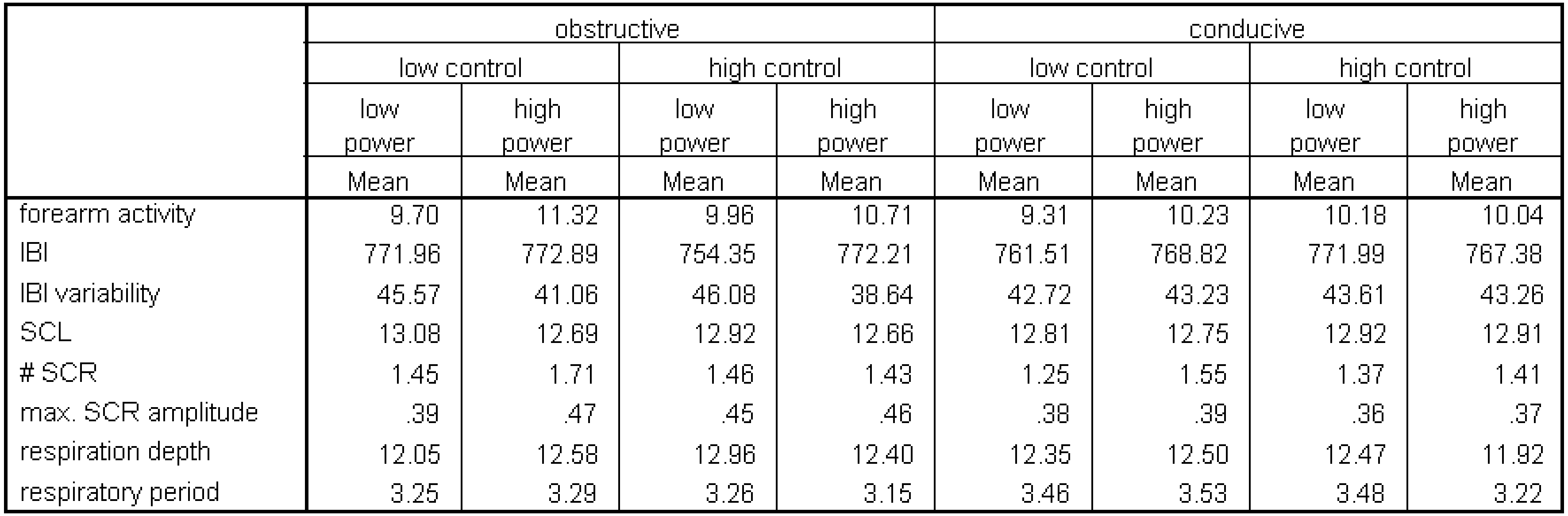
The only main effect of power was on IBI variability, which was significantly higher when players had low power than when players had high power (F(1,45)=5.3, p=0.03). This effect was limited to obstructive situations, as indicated by the significant conduciveness by power interaction for IBI variability and illustrated in figure 4.4.

Correlations between acoustic and physiological variables. Scherer's (1986) predictions are based largely upon the expected effects of physiological emotion responses on vocal production An examination of the scatter plots between pairs of physiological and acoustic variables reveals very few identifiable relationships, as borne out by Table 4.3, which shows the correlations between vocal and physiological variables after the main effect of speaker has been removed. As can be seen, none of the correlations exceed a magnitude of 0.2.[3]

Table 4.2. Mean values for vocal parameters.

	obstructive				conducive			
	low control		high control		low control		high control	
	low power	high power	low power	high power	low power	high power	low power	high power
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
median f0	133.43	135.09	131.50	133.94	133.81	131.06	132.99	129.75
mean f0	134.61	136.07	133.22	135.71	135.64	132.92	134.35	130.93
f0 ceiling	155.73	158.70	154.51	157.82	159.17	155.23	151.99	149.71
f0 floor	118.46	119.14	118.57	120.30	119.50	117.27	118.99	117.58
f0 range	37.27	39.56	35.95	37.52	39.67	37.96	36.15	32.13
voiced energy	1920.74	1934.49	1930.62	1970.82	1916.51	1896.47	1933.18	1919.32
unvoiced energy	728.00	727.57	729.25	742.40	725.79	715.30	730.11	722.69
duration	1240.34	1195.62	1212.48	1177.22	1222.46	1230.84	1196.26	1164.32
prop. voiced	65.02	67.40	68.69	66.90	66.80	67.57	65.36	67.39
prop. unvoiced	31.20	30.19	28.44	30.14	29.83	28.96	31.30	29.80
prop. silence	3.77	2.41	2.87	2.96	3.36	3.47	3.34	2.81
voiced energy < 1kHz	.97	.97	.97	.97	.97	.97	.97	.97
voiced energy < 500Hz	.68	.67	.72	.67	.70	.69	.70	.72
voiced spectral slope	-38.81	-43.23	-36.97	-44.56	-38.84	-42.21	-43.07	-42.59
glottal slope	-7.81	-8.81	-8.22	-9.28	-9.31	-9.17	-9.46	-9.40
unvoiced energy < 1kHz	.47	.50	.45	.48	.44	.47	.47	.46
unvoiced energy < 500Hz	.39	.43	.40	.41	.38	.41	.41	.41
unvoiced spectral slope	-1.70	-1.54	-1.42	-2.14	-1.81	-1.74	-1.94	-1.76

Table 4.3. Mean values for physiological parameters.



	obstructive				conducive			
	low control		high control		low control		high control	
	low power	high power	low power	high power	low power	high power	low power	high power
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
forearm activity	9.70	11.32	9.96	10.71	9.31	10.23	10.18	10.04
IBI	771.96	772.89	754.35	772.21	761.51	768.82	771.99	767.38
IBI variability	45.57	41.06	46.08	38.64	42.72	43.23	43.61	43.26
SCL	13.08	12.69	12.92	12.66	12.81	12.75	12.92	12.91
# SCR	1.45	1.71	1.46	1.43	1.25	1.55	1.37	1.41
max. SCR amplitude	.39	.47	.45	.46	.38	.39	.36	.37
respiration depth	12.05	12.58	12.96	12.40	12.35	12.50	12.47	11.92
respiratory period	3.25	3.29	3.26	3.15	3.46	3.53	3.48	3.22

Table 4.4. Correlations of acoustic with physiological variables after controlling for the random main effect of speaker.

	corrugator	zygomaticus	forearm	inter-beat interval	inter-beat interval variability	skin conductance level	skin conductance response rate	max. SCR amplitude	respiration depth	respiratory period
F0 mean	**0.12**	0.03	-0.10	**-0.12**	-0.06	-0.01	-0.11	-0.08	0.05	0.05
F0 median	**0.13**	0.02	-0.06	**-0.14**	-0.06	0.01	-0.10	-0.05	0.03	0.08
F0 ceiling	0.07	0.09	**-0.16**	-0.03	-0.05	-0.03	-0.09	-0.10	0.02	0.04
F0 floor	0.03	-0.05	-0.06	-0.11	-0.06	-0.01	-0.06	-0.07	0.05	0.02
F0 range	0.05	**0.13**	**-0.13**	0.03	-0.02	-0.03	-0.06	-0.06	-0.01	0.03
voiced energy	**-0.14**	0.06	-0.01	-0.06	0.00	-0.04	0.04	-0.01	-0.08	0.04
unvoiced energy	-0.07	0.05	-0.02	-0.06	0.01	-0.04	0.03	-0.01	-0.05	0.04
duration	0.07	**0.15**	0.00	0.07	-0.08	0.00	0.04	-0.04	-0.06	-0.13
voiced	**-0.12**	-0.06	-0.02	0.02	-0.01	0.07	-0.03	-0.05	0.03	-0.03
unvoiced	0.04	-0.04	0.06	-0.07	0.06	-0.05	0.02	**0.12**	0.02	0.07
silence	**0.13**	**0.14**	-0.04	0.05	-0.06	-0.04	0.01	-0.06	-0.07	-0.03
voiced energy < 1kHz.	0.04	-0.06	-0.03	0.02	0.01	-0.01	0.06	-0.01	0.02	0.02
voiced energy < 500 Hz.	0.03	-0.07	-0.02	0.10	-0.04	0.01	0.10	-0.02	-0.04	0.01
voiced spectral slope	0.10	0.06	-0.04	0.08	0.05	-0.07	0.05	0.07	-0.13	-0.03
glottal slope	0.07	0.09	-0.04	0.03	0.03	-0.05	-0.01	0.05	-0.10	0.02
unvoiced energy< 1kHz	-0.07	-0.02	-0.11	-0.05	-0.06	0.00	-0.05	-0.06	-0.03	-0.03
unvoiced energy < 500 Hz.	-0.03	-0.05	-0.11	-0.05	-0.07	0.00	-0.05	-0.04	-0.02	-0.05
unvoiced spectral slope	**0.16**	-0.06	0.05	0.04	0.09	-0.03	-0.04	0.04	-0.10	-0.04

Discussion

As was discussed in the hypothesis section of this chapter, an arousal theory would predict same direction main effects for each of the manipulations in this experiment. Taken as a whole, the results of this experiment are not consistent with such an arousal hypothesis. While energy of the speech signal was affected by manipulations of conduciveness, F0 range and F0 floor were affected by control manipulations. Median F0, and the proportion of energy below 1KHz changed according to the interaction of conduciveness and power manipulations. As with experiment one, it is difficult to see how general arousal could be responsible for such manipulation-dependent changes to individual acoustic parameters. In particular, the data from this experiment seem to suggest that separate mechanisms mediate changes to energy and fundamental frequency, two aspects of the speech signal that have previously been suggested to covary with physiological arousal.

The physiological data cast further doubt not only on the hypothesis of arousal uniquely mediating acoustic changes, but more generally on the notion of unidimensional physiological arousal. Contrary to what might be expected on the basis of such a notion, the different physiological indicators did not covary across manipulations. Those physiological measurements taken as indicators of autonomic activity do not show consistent covariance; SC response amplitude varied with manipulations of conduciveness, SC level and interbeat interval variability varied as a result of the interaction between conduciveness and power, and respiration rate changed with manipulations of control. As with the acoustic measures, it is difficult to reconcile such a pattern of effects with a model of arousal. Indeed, the very notion of a single dimension of arousal is questionable given current knowledge of the autonomic nervous system. As pointed out by Berntson, Cacioppo, Quigley and Fabro (1994), the two components of the ANS, the sympathetic and parasympathetic branches, cannot be assumed to function antagonistically. Nor can the “net” result of both branches activation at any given moment be mapped onto a single arousal dimension, since the stability and dynamics of the two systems depends upon both individual branches, rather than their net sum. Bernston et al’s arguments focus on the cardiovascular system, but equally pertain to speech production, since both ANS branches enervate multiple organs, some of which impact directly on speech.. It seems likely, then, that a simple arousal model of emotional response needs to be dropped in favour of a more physiologically realistic model that would allow for at least two dimensions of autonomic activity.

Although the data from this experiment do support a theory which posits multiple mechanisms underlying emotional changes to vocal production, they do not show strong correspondence with Scherer's predictions (1986). An increase in F0 floor was found for high control versus low control situations, as predicted, although F0 range was lower in high control situations than low control situations, contrary to prediction. The lower measured proportion of energy below 1000Hz for obstructive situations than for conducive situations under high power situations is in agreement with predictions and replicates similar findings from experiment one, although the interaction effect of power is difficult to explain. Contrary to Scherer’s predictions, but in agreement with results from experiment one, speech energy was higher for obstructive situations than for conducive situations. Coupled with the measured increase in skin conductance response amplitude for obstructive situations compared with conducive situations, the results imply an increased sympathetic arousal in obstructive situations.

Interestingly, Scherer’s predictions are based upon an additive model, in which the effects of individual appraisal checks on the voice add together cumulatively, largely independently of the other appraisal dimensions. For example, the predicted effects of appraisals of conduciveness on the spectral characteristics of speech are the same regardless of the outcome of other appraisals such as control or power. This experiment, however, found manipulated dimensions to interact in their effects on the voice. A conduciveness by power interaction effect found for median F0 indicated greater median F0 for obstructive situations than for conducive situations when power was high, but no such difference when power was low. It is tempting to explain this effect by suggesting that when players have high shooting power, they actively engage in defeating enemies, leading to an increase in muscle tone and an associated increase in median F0 relative to when friends are present. Conversely, when players had low power, they might have disengaged from dealing with enemies, having decided that they could not do so effectively. Such effects of task engagement and disengagement on F0 have been found in comparable manipulated game situations in other studies (Kappas, 2000). A similar interaction effect on heart rate variability, in which, for obstructive situations, heart rate variability was lower when players had high power than when they had low power, supports such an explanation. An increase in mental workload, as might be expected with increased task engagement, has been linked to reduced heart rate variability without a corresponding effect on heart rate (Lee and Park, 1990), as observed in this experiment for high versus low power in obstructive situations. The observed conduciveness by power interaction effect on skin conductance level, which was due to a higher skin conductance level when the player had low power than when the player had high power during obstructive situations, but no such difference during conducive situations, might seem to contradict the heart rate and median F0 data. The latter result seems to point to *lower* sympathetic arousal when players had high power in obstructive situations, although the lack of a corresponding drop in heart rate suggests that this is not the case.

Given that the measurement of tonic skin conductance level over a ten second window is unreliable, the result for skin conductance level should not be given too much weight.

An interaction effect was also found for the relative proportion of utterance voiced and unvoiced, such that for obstructive situations, utterances were relatively more voiced when players had high control than when they had low control, whereas for conducive situations the effect was reversed. Although an effect of conduciveness on the same fluency measures was also found in experiment one, it is difficult to interpret the interaction with control in this experiment.

Conclusions

This experiment replicated some of the results from experiment one, particularly the inability of a simple arousal model of emotional response to explain emotional changes to vocal production. In addition, the effects of the goal conduciveness dimension on speech energy, median F0 and spectral energy distribution were also consistent with results from experiment one. The results of this experiment were not, however, consistent with Scherer’s essentially additive predictions of the effects of different appraisals on the voice, indicating instead that such appraisal dimensions interact in producing physiological and vocal changes.

The predictions of Scherer (1986), as well as the assumptions of other researchers of emotional speech, are based largely upon the expected effects of physiological emotion responses on vocal production. Although comparing the effects of manipulations on the acoustic measures with the corresponding effects on physiological measures has been helpful in the preceding paragraphs, it cannot be ignored that in general the correlations between acoustic and physiological parameters were very low. Such low correlations cast doubt on the assumption than emotional changes to vocal production reflect predictable effects of emotional physiological responses. At least in this experiment there was no consistently clear linear mapping between physiological measures and acoustical measures of speech[4]. Because speech production is highly redundant (i.e. the same or similar acoustic effects can be produced using a variety of vocal settings), it might prove impossible to use the voice as a “readout” of emotional state or underlying appraisals. Given the complexity of speech physiology, emotion physiology and the difficulty in measuring the two within an emotion induction experiment, however, it is clearly too early to draw firm conclusions. For example, the fact that most effects on acoustic measures in this experiment resulted from interactions of manipulated appraisal dimensions and that for a number of cells in the design neither acoustic nor physiological measures differed, could have led to decreased correlations. Indeed, the restricted range of variation of all the measured parameters in such an induction paradigm is likely to restrict the correlation between different parameters.

To address these problems, two changes were made to the basic design of the last experiment of this thesis. In an attempt to increase the size of effects, and thus the range of variability in vocal and physiological parameters, the induction technique was changed from event manipulations in the XQuest game to a computerised tracking task with reward and punishment feedback. This task was programmed “from the ground up”, thus allowing more focused and controlled manipulations and more seamless integration of vocal reports. Electroglottography, which is a technique used to measure the opening and closing characteristics of the vocal folds, was also introduced as a more direct measure of vocal physiology than the physiological measures so far taken.

[1] It could be argued that such a representational change to respiration and phonation reflects a pull effect on the voice rather than a push effect (e.g. Scherer, 1985). Nevertheless, given that the prediction made by Scherer (1986) and tested here is that such representational functions are the product of evolutionary pressures and thus highly automatic and innate, they are considered in this thesis to be push effects.

[2] LabSpeech was designed around the type of analyses that were thought to be relevant to the semi-automatic analysis of a large number of speech samples as is often required in psychology research, but is not readily available in other speech analysis software. It is available for download at the author’s web site and is free for non-commercial purposes.

[3] It must be noted that the correlations have been calculated by aggregating the observations across all speakers. Since there are multiple observations per speaker, the assumption of independent observations that is used in testing the significance of correlations is violated, despite having first factored out the main effect of speaker. In the correlations presented here, a conservative criterion of $p<0.01$ has thus been applied in designating which correlations are significant.

[4] Of course, it is possible that the relationship between physiological and acoustic changes is nonlinear, and possibly nonstationary. Techniques such as nonlinear regression or neural network modeling could be applied to identify such relationships, although the increased degrees of freedom involved in such techniques also necessitates a larger number of observations than were available in this experiment. It is also possible that relationships between physiological and acoustic measures show complex time dependencies, which could be identified using mathematical functions such as cross power spectral density functions, although longer samples of speech and physiology data than recorded in this experiment would need to be recorded.

5. Electroglottal measurements of emotional speech

Introduction

This experiment was motivated largely by the finding in the first two experiments that average spectral energy distribution, as indicated by the relative proportion of energy under 1000 Hz, differed significantly as a function of experimental manipulations. This dependence of spectral energy distribution on emotional response is consistent with similar findings in studies of acted emotional speech (Banse and Scherer, 1996). The effects of emotional response on spectral energy distribution might be due in part to differences in the configuration of the vocal tract, as suggested by Scherer (1986). For example, changes to precision of articulation and therefore the amplitude and bandwidth of formants, restriction or contraction of the faucal arches and changes to the amount of mucous and saliva in the vocal tract will all have an impact on the resonance of vocal harmonics.

It is also possible, however, that emotional changes to spectral energy distribution are caused by changes to vocal fold vibration patterns. Much work on voice source modeling and estimation has pointed to the relationship between the manner in which the vocal folds open and close and the dynamics of glottal air flow (e.g. Titze, 1994; Sundberg, 1994). The glottal air flow in turn strongly determines the relative strength of vocal harmonics feeding into the vocal tract (e.g. see Fant, 1993). For example, when vocal folds open and close abruptly, the result is proportionately more power in higher harmonics, and thus proportionately more high frequency energy in the speech signal (all other resonant characteristics being equal) than when the vocal folds open and close slowly and smoothly. Such variations in vocal fold function, categorised into a range of laryngeal settings, have been described phonetically by Laver (1980, 1991). They make up part of a broader system for describing and categorising laryngeal and articulatory voice quality settings, although such settings have more often been the focus of research on pathological changes to voice quality rather than more subtle vocal changes. Scherer (1986) also makes reference to appraisal-mediated changes from “tense” to “relaxed” vocal settings, although the link between vocal settings, vocal fold dynamics and spectral aspects of the resulting acoustic signal are not made explicit. The two possible sources – vocal folds and vocal tract - of spectral changes to emotional speech, make the results from experiments one and two difficult to interpret. A method of independently measuring the emotion-provoked changes to vocal tract resonance and vocal fold dynamics is necessary to resolve such ambiguity.

Electroglottography (EGG) is a technique that can be applied to better understand the link between vocal fold dynamics and the spectral characteristics of emotional speech. With EGG, a small, high frequency electric current is passed between two surface electrodes placed on either side of the speaker’s neck, at the level of the larynx. Since the electrical impedance of the path between the two electrodes will change as the glottis opens and closes, a measurement of the impedance can be used as an indicator of glottal opening and closing.

Figure 5.1 shows the acoustic and EGG signals from recording of an extended [a] vowel (the “a” sound in the word “father”). As can be clearly seen, the EGG signal is free of resonance from the vocal tract, which is apparent in the acoustic signal as rapid fluctuations occurring in between successive vocal excitations. In fact, aside from its application to measuring vocal fold dynamics, the EGG signal allows for an extremely precise measurement of F0 and F0 perturbation.

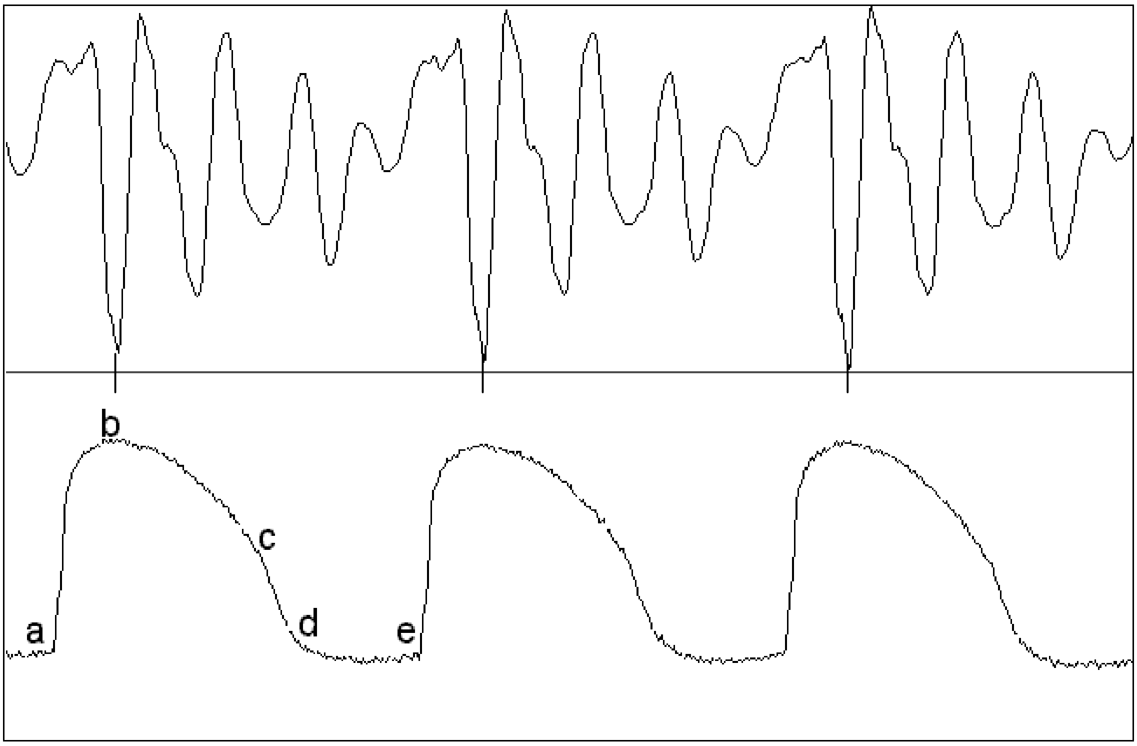


Figure 5.1. Acoustic (top) and EGG (bottom) signals from recording of an extended [a] vowel. Marks on the horizontal axis indicate fundamental periods. Symbols on the EGG signal indicate the instant of glottal closure (a), instant of maximum vocal fold contact (b), instant of glottal opening (c), instant of maximum minimum vocal fold contact (d) and instant of glottal closure for subsequent glottal period (e).

Although the exact relationship between the size of the glottal opening and the electrical impedance is not linear, the EGG signal is inversely proportional to the contact area of the vocal folds (Childers & Krishnamurthy, 1985), and as such serves as a useful indicator of vocal function. It is at least reasonable to assume that the temporal characteristics of the measured EGG signal are good indicators of the temporal aspects of glottal opening and closing. The magnitude of the EGG is a less valid measure of the relative area of the glottal opening, although in the absence of alternative estimates (other than invasive measurements such as photoglottography) it remains the best approximate indicator.

Glottal analysis of imagined emotions.

This experiment was carried out to develop a set of analysis procedures for extracting the main features from the EGG signal, as well as a test of the feasibility and applicability of EGG analysis to the study of emotional voice production. In particular, it was intended to apply such analysis to the final experiment of this thesis, in which computer tasks and games would be used to induce emotional speech. To be assured of high quality speech recordings, which were known to vary across different emotional states, an imagination/acting procedure was used. Speakers were asked to imagine themselves in specific emotional states and then to pronounce aloud two short phrases and the sustained [a] vowel. Rather than recording expressions of extreme emotions such as rage, elation and fear, seven non-extreme emotions (tense, neutral, happy, irritated, depressed, bored, anxious) corresponding to those that could realistically be induced with computer tasks and games, were selected for study.[1]

Method

Participants

Speakers were eight research workers and postgraduate students (two males and six females) studying emotion psychology at the University of Geneva. The familiarity of the speakers with emotion psychology was seen as an advantage in this pilot study, as they were more readily able to follow the emotion imagination procedure and produce emotional (albeit possibly stereotypical) vocal samples.

Equipment

Speech was recorded with a Casio DAT recorder using a Sony AD-38 clip-on microphone to one channel of the DAT. EGG recordings were made with a Portable Laryngograph onto the second DAT channel.

Procedure

Speakers were seated in front of a computer display at a comfortable viewing distance. They were told that the experiment consisted of being presented with a number of emotion words on the computer screen. When each emotion word was presented, they were to try to imagine themselves in a situation that would provoke that emotion. They were asked to imagine the situation as vividly as possible and try to actually feel the emotion. When they felt that they were involved in the imagined situation as much as possible, they were to click the mouse, whereupon they would be presented with a list of phrases on the screen. Speakers were instructed to read aloud all the phrases on the screen, while still trying to feel the imagined emotion. The order of the seven emotions (tense, neutral, happy, irritated, depressed, bored, and anxious) was randomised across speakers. For each emotion, each speaker was asked to pronounce the phrases “Je ne peux pas le croire!” (“I can’t believe it!”), “En ce moment, je me sens…<emotion>” (“at the moment, I feel…<emotion>”; speaker completed the phrase with the appropriate emotion term), and the extended [a] vowel. Each phrase was pronounced twice by each speaker in each emotion condition.

Results

Acoustic and glottal analyses

The samples from each subject were acoustically analysed using LabSpeech. In contrast to the F0 measures made in the previous experiments, which were based upon an autocorrelation analysis of the acoustic speech signal, in this experiment F0 was calculated on the basis of the low-pass filtered EGG signal. First the EGG waveform was high-pass filtered to remove low frequency fluctuations due primarily to larynx movement. Next, a peak-picking algorithm was applied to the differentiated EGG waveform to locate the instants of glottal closure, which are typically the points of maximum positive gradient in each glottal period. Those sections of the EGG signal displaying successive glottal closures corresponding to a frequency within the preset permitted F0 range were designated voiced, and the F0 values saved. All other segments were labeled non-voiced. RMS energy of voiced segments and the mean proportion of energy under 1000 Hertz for voiced segments were calculated from the acoustic speech signal as in experiment two.

Glottal opening, closing, open and closed times were calculated from the EGG signal following guidelines given by Marusek (1997). Each glottal period, as demarcated by successive instances of glottal closure, was analysed to identify closing, closed, opening, and open times, as depicted in figure 5.2. An amplitude criterion of 90% of total period amplitude was used to determine the onset and offset of closed phase. The onset of glottal open phase was located using the equal level criterion as described by Marasek (1997, section 12), which is the point at which the glottal signal drops to a level equal to the level at the instant of glottal closure. These values were then converted to quotients by dividing each by the total glottal period. The use of quotients, rather than absolute times, was preferred since quotients give a better measure of the shape, rather than the length, of the glottal EGG waveform. Such shape parameters were hypothesised to correspond to spectral acoustic measures such as the proportion of energy under 1000 Hertz. In addition, because quotients are normalised to the length of each glottal period, they can meaningfully be averaged across glottal cycles and compared between conditions.

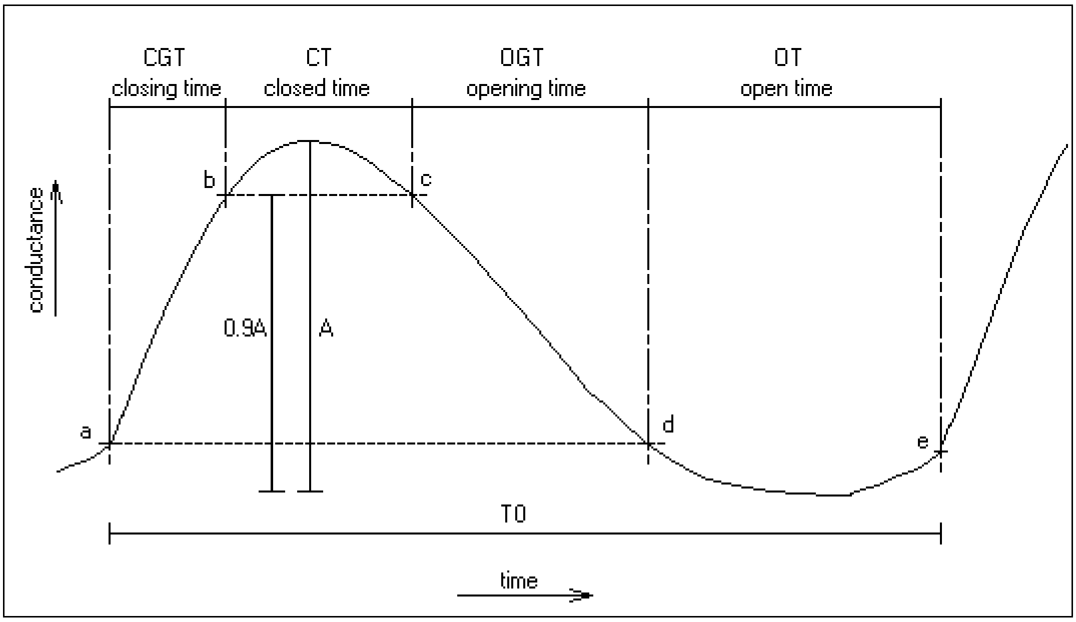


Figure 5.2. Stylised example of a glottal cycle measured with EGG, showing how the cycle is divided into four segments, based upon the point of maximum curvature (a), points of positive-going (b) and negative-going (c) 90% amplitude threshold, point of equal value to preceding point of maximum curvature (d) and point of maximum curvature of following glottal cycle (e). (A = amplitude, T0 = glottal period).

Very low frequency EGG energy was also calculated as a potential measure of larynx movement. The low frequency EGG energy is manifest as a slow waveform upon which the faster fluctuations of glottal cycles are superimposed. In this experiment, low frequency EGG energy was isolated by using a low pass filter with a frequency cut-off of 10 Hz. The RMS power of the resulting waveform was then calculated.

A measure of jitter, the short-term, random period to period variation in F0, was also calculated. For the jitter calculation, a quadratic curve was fitted to a running window of five successive F0 values on the F0 contour using a least mean squares curve-fitting algorithm. The quadratic curve was then subtracted from that section of the F0 contour. This served to remove long term, prosodic F0 movements, which would otherwise contaminate jitter measurements. Jitter was then calculated as the mean of the magnitude of period to period variation in the residual F0 values.

Statistical analysis

All acoustic and glottal parameters were tested with univariate mixed effect ANOVA's, with emotion and phrase as fixed factors and speaker as a random factor. The results are presented below organised by vocal parameter.

Median F0. Median F0 differed significantly across emotions (F(6,78)=17.5, p<0.000), and was categorised by high values for happy speech and low values for depressed and bored speech. The middle curve in Figure 5.2 shows the emotion profile for median F0.

F0 ceiling. The emotion profile for F0 ceiling is shown in Figure 5.3, top curve. The F0 ceiling varied significantly across emotions (F(6,78)=11.3, p<0.000), and was characterised by a higher value for happy speech than for the other expressed emotions.

F0 Floor. F0 floor varied significantly with emotion (F(6,78)=7.3, p<0.000) in much the same way as median F0, with relatively high values of F0 floor for happy speech, and low values for depressed and bored speech (see Figure 5.3, bottom curve).

Voiced RMS energy. The RMS energy of voiced segments of speech was significantly different across emotions (F(6,78)=16.5, p<0.000), as shown in Figure 5.4. In particular, voiced energy was high for happy and irritated speech and low for depressed speech.

Jitter. Jitter values varied significantly with emotion (F(6,54)=2.9, p=0.013), with jitter values being highest for bored and depressed speech and lowest for tense speech (see Figure 5.5).

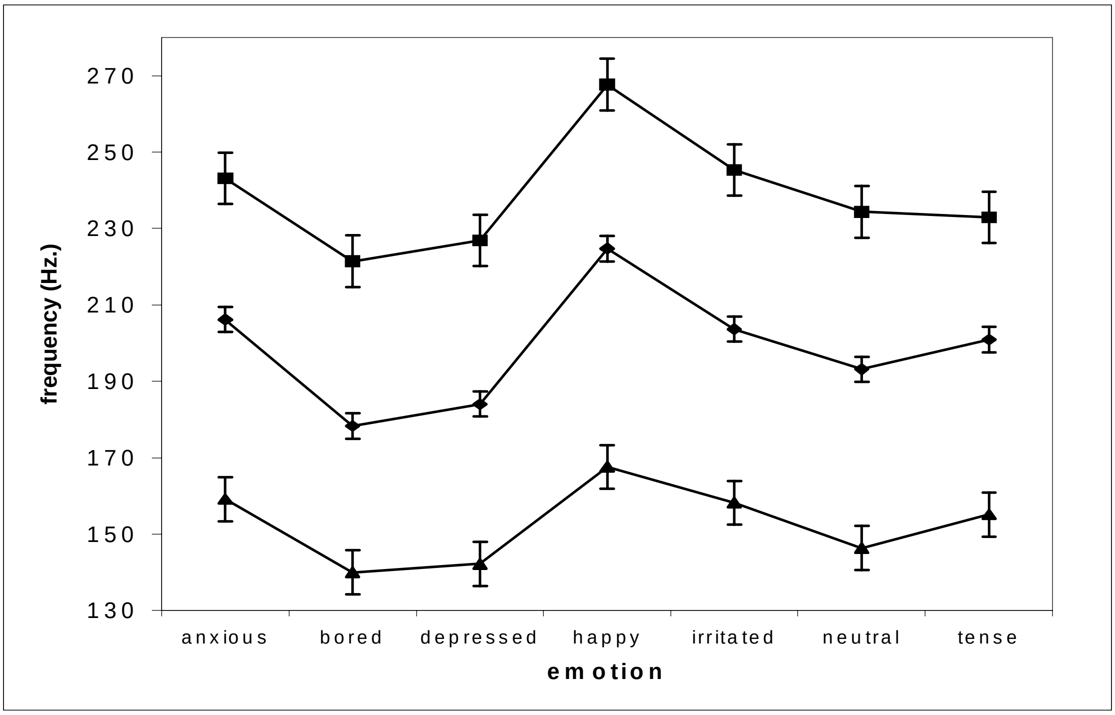


Figure 5.3. Mean values for F0 ceiling (top), median F0 (centre) and F0 floor (bottom), shown as a function of emotion. Bars represent 95% within-subjects confidence intervals.

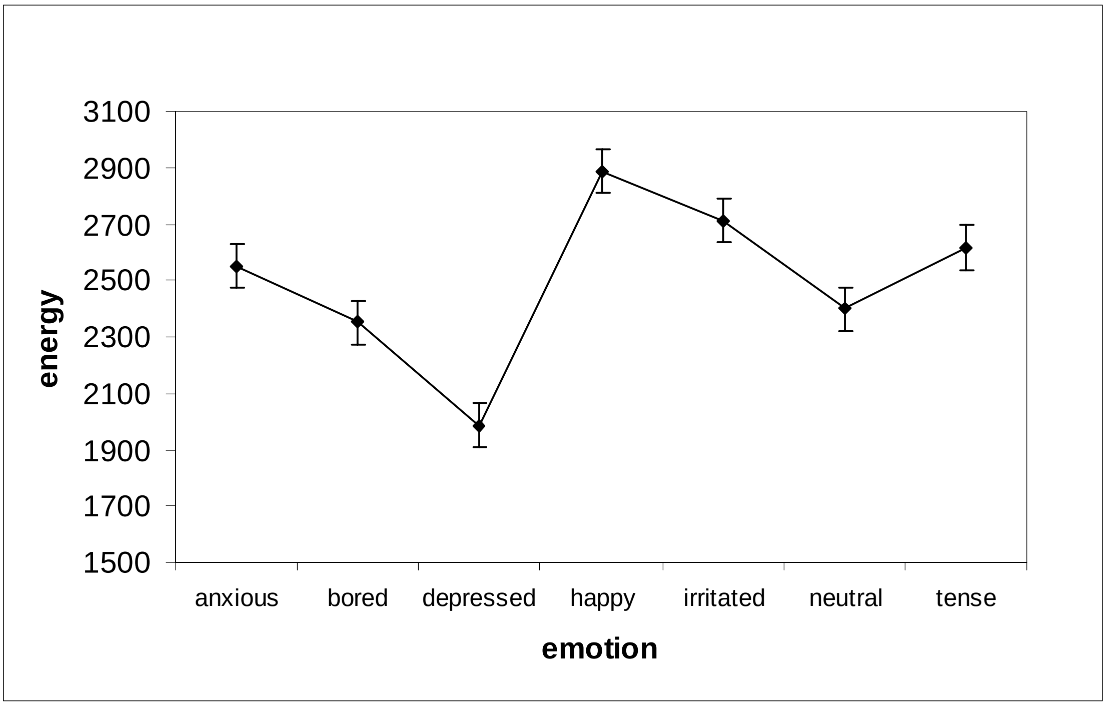


Figure 5.4. Mean values for RMS Energy, shown as a function of emotion. Bars represent 95% within-subjects confidence intervals.

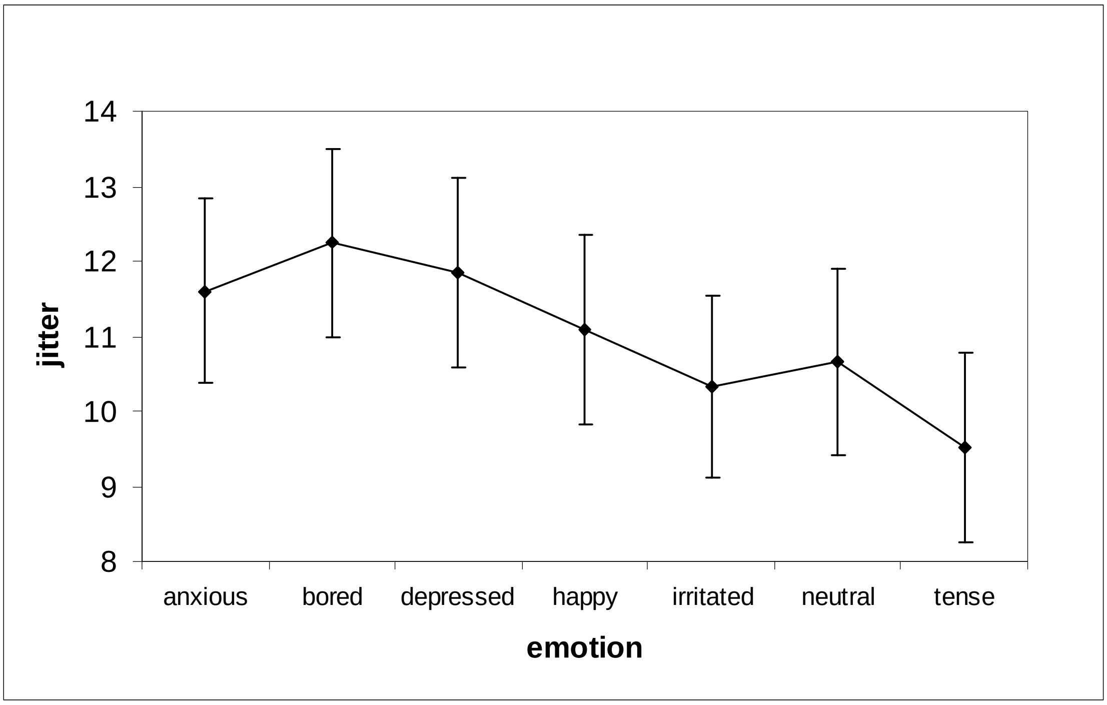


Figure 5.5. Mean values for jitter, shown as a function of emotion. Bars represent 95% within-subjects confidence intervals.

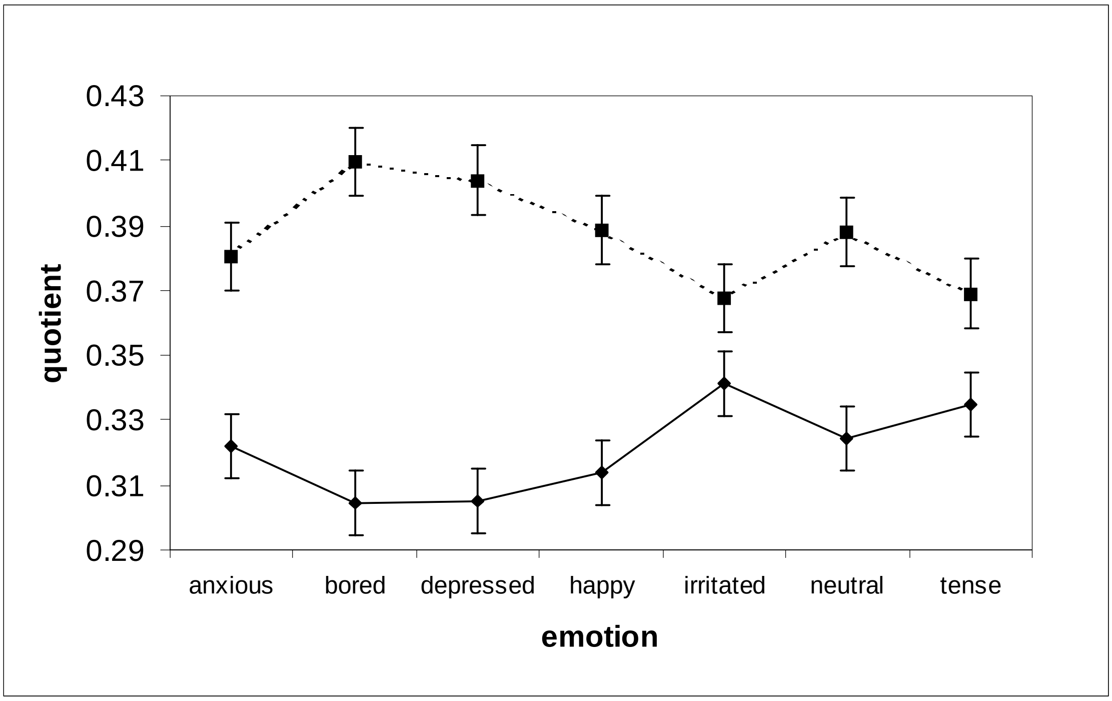


Figure 5.6. Mean values for open quotient (top) and opening quotient (bottom), shown as a function of emotion. Bars represent 95% within-subjects confidence intervals.

Opening quotient. The glottal opening quotient varied significantly as a function of emotion (F(6,78)=3.3, p=0.007), with high opening quotients for irritated and tense speech, and low opening quotients for bored and depressed speech (figure 5.6).

Open Quotient. Glottal open quotient varied significantly across emotions (F(6,78)=3.2, p=0.008), showing the inverse pattern of results from glottal opening quotient, with high values for bored and depressed speech, and low values for irritated and tense speech (figure 5.6).

Closing quotient. The glottal closing quotient did not vary significantly across expressed emotions (F(6,78)=1.2, p=0.31).

Closed Quotient. Glottal closed quotient did not vary significantly across emotions (F(6,78)<1).

Low frequency EGG power. Low frequency EGG power varied across emotions (F(6,78)=11.9, p<0.000), with high values for happy speech and low values for bored and depressed speech (figure 5.7).

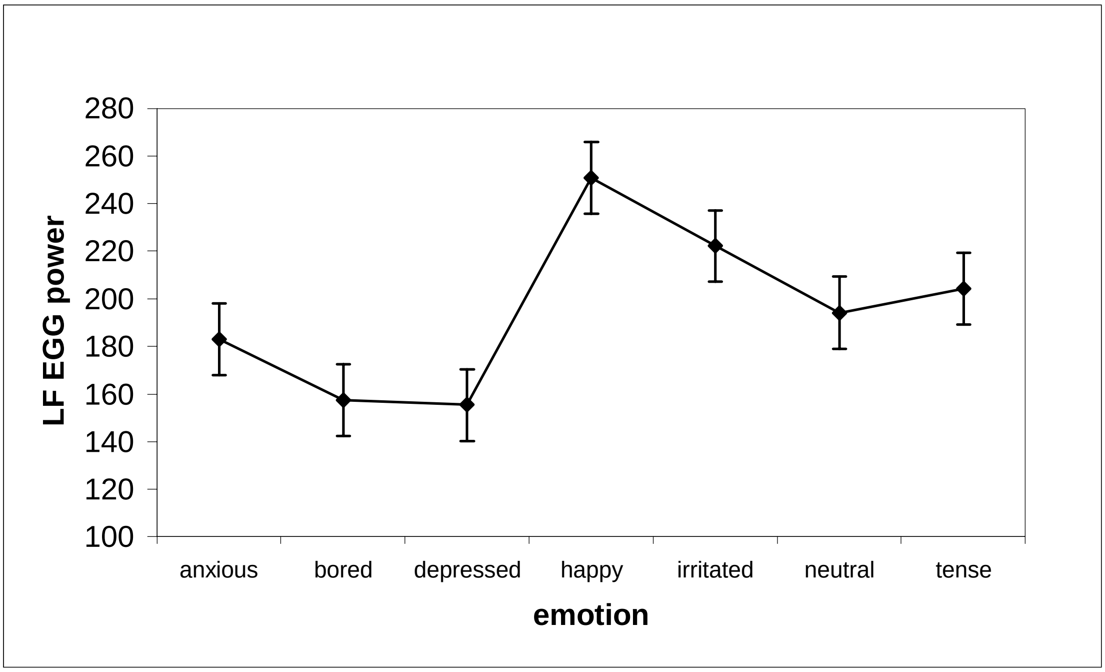


Figure 5.7. Mean values for low frequency EGG power, shown as a function of emotion. Bars represent 95% within-subjects confidence intervals.

Voiced low frequency energy. The proportion of total energy below 1000 Hertz for voiced segments of speech varied significantly according to the emotion expressed (F(6,78)=9.9, p<0.000), as did the proportion of energy under 500 Hz (F(6,78)=28.4, p<0.000). Figure 5.8 indicates that there was relatively more low frequency energy for expressed depression and boredom than for irritation and happiness.

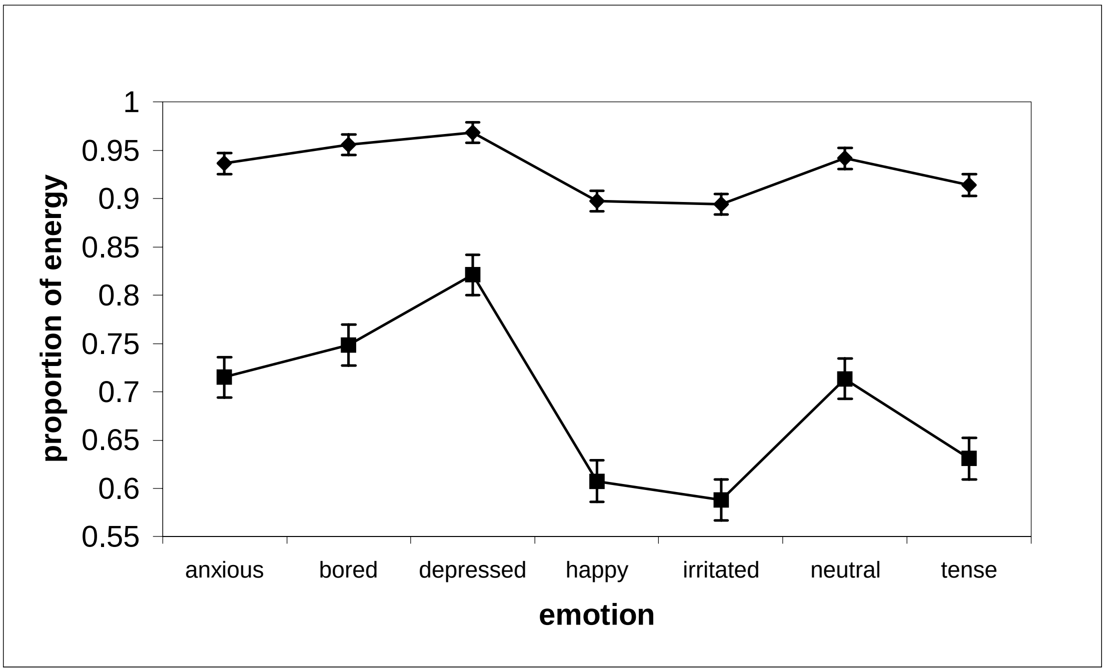


Figure 5.8. Mean values for the proportion of energy under 1000 Hz (top line) and proportion of energy under 500 Hz (bottom line), shown as a function of emotion. Bars represent 95% within-subjects confidence intervals.

Correlations between parameters. Table 5.1 provides the correlations between the different vocal parameters, after the effects of speaker, stimulus and repetition have been factored out. Many of the correlations are moderate, indicating that although the parameters might share some underlying mechanism, or to a small extent measure some common vocal feature, they capture different aspects of vocal production. Of particular note are the correlations between those glottal parameters and acoustic parameters that differed significantly across emotions.

Table 5.1. Correlations between vocal parameter residuals after effects of speaker, phrase and repetition have been factored out.

	F0 ceiling	F0 floor	Voiced	jitter	Opening	Closing	Open	Closed	LF EGG	Energy < 1	Energy <
			energy		quotient	quotient	quotient	quotient		Khz	500 Hz
F0 median	0.63	0.57	0.49	-0.15	0.24	0.10	-0.37	0.37	0.32	-0.29	-0.39
F0 ceiling		0.28	0.32	0.15	0.00	0.15	-0.11	0.17	0.30	-0.23	-0.31
F0 floor			0.47	-0.36	0.34	-0.08	-0.40	0.35	0.10	-0.28	-0.31
Voiced energy				-0.16	0.25	-0.01	-0.29	0.18	0.16	-0.18	-0.35
jitter					-0.30	0.22	0.24	-0.17	0.01	0.13	0.23
Opening quotient						-0.36	-0.90	0.37	0.04	-0.19	-0.29
Closing quotient							0.01	-0.18	0.20	0.04	0.04
Open quotient								-0.57	-0.13	0.20	0.31
Closed quotient									0.06	-0.10	-0.18
LF EGG										-0.16	-0.21
Energy < 1 KHz											0.65

Opening quotient correlated positively with F0 floor, F0 median and energy, but negatively with jitter and low frequency spectral energy. Open quotient was highly negatively correlated with opening quotient and thus showed the opposite pattern of correlations. Low frequency EGG energy correlated positively with median F0 and F0 ceiling but not with F0 floor. Low frequency spectral energy correlated negatively with the F0 measures.

Discussion

Variation of acoustic measures across emotions.

As with most prior research on acted expressions of emotional speech, F0 floor and median F0 were found to be lowest for the emotions bored and depressed, and highest for happy speech. A similar profile across emotions was found for F0 ceiling. Although these results would seem consistent with the idea that arousal causes changes to muscle tension, which in turn affects F0, the results for energy only partly support such an explanation. Energy was high for happy speech and low for depressed speech, thus corresponding to an arousal explanation for the F0 values, but bored speech did not have low energy. The correlation of 0.47 between energy and F0 floor indicates a high level of correspondence between the two measures, but given the result for bored speech, it is evident that these two parameters do not always correspond.

Low frequency spectral energy also varied across expressed emotions, indicating that there was more low frequency energy in bored and depressed speech, and less in happy and irritated speech.

Variation of EGG measures across emotions and with acoustic measures.

Of the EGG parameters, opening quotient correlated positively and open quotient negatively with F0 floor and F0 median. The pattern of these two EGG values across emotions was also similar to those of F0 floor and median F0, indicating that emotional changes to F0 level were principally mediated by changes to the time during which the glottis was open. This can be concluded because as the vocal cycle becomes shorter (i.e. as F0 rises) the open quotient falls but the opening quotient rises. Thus in absolute terms (i.e. in milliseconds rather than as a proportion of the vocal period), the open time has fallen but the opening time has remained relatively constant. An exception was the vocal expression of happiness, in which neither opening quotient nor open quotient were particularly low or high. For happiness then, it seems that an elevated F0 level was caused by relatively equal reductions in both absolute opening and open times.

F0 ceiling (but not F0 floor) was also found to correlate positively with low frequency EGG power, which was measured in this experiment as an approximate indicator of larynx movement. As has been reported previously (Iwarsson and Sundberg, 1998), movement of the larynx is one mechanism that can be used in combination with respiratory changes to vary F0 (indeed, beginner singers have to be trained in how to vary their singing pitch *without* moving their larynx). It is thus possible in this case that larynx movement was a mediator of increased F0 variation in happy speech.

The values for jitter, which correlated negatively with F0 floor and opening quotient, were highest for bored and depressed speech and lowest for tense speech. This result is in agreement with previous findings of a reduction of jitter for speakers under stress (Smith, 1977), and hints that emotional effects on jitter might be due to variation in the opening phase of the glottal cycle.

Low frequency energy correlated positively with open quotient and negatively with opening quotient, although the correlations were only moderate, indicating that spectral energy depends partly on glottal dynamics, but might also be affected by other factors including vocal tract resonance.

Conclusions

In this experiment, EGG and acoustic recordings of expressed emotional speech were analysed in an attempt to test the feasibility of using EGG techniques in studies of emotional speech. The EGG parameters open quotient, opening quotient and low frequency EGG energy were found to vary significantly across expressed emotions in ways consistent with the acoustic parameters measured as well as past results and theory of emotional speech production. Correlations between the EGG parameters and acoustic parameters indicated that EGG measurements might provide useful information on the glottal and laryngeal mechanisms responsible for emotional changes to speech. On the basis of these results it is possible to make tentative hypotheses relating laryngeal movement, as measured by low frequency EGG components, to F0 variability, and the length of glottal open phase to F0 level. Such measurements thus provide us with the potential to separate the mechanisms responsible for emotional changes to F0 level and to F0 variation. These hypotheses are tested in the final experiment of this thesis.

Although the links between spectral aspects of the speech signal and EGG parameters were not clear from this experiment, it is probable that techniques that better quantify the shape of the EGG pulses will lead to clearer results. Further refinement of the EGG analysis procedure are explained and tested in the following chapter.

[1] Although the theme of this thesis is the experimental induction of emotional speech, an imagination procedure was used here because the aim was to test the feasibility of using EGG and develop EGG analysis procedures, rather than specifically testing hypotheses of push effects on speech.

6. Experiment 3: Acoustic, electroglottographic, and physiological measurement of emotional speech

Introduction

In this experiment, physiological measurements of ANS function were combined with EGG measures of vocal fold activity and acoustic analysis of speech in an effort to better explain the mechanisms by which experimental manipulations of conduciveness and coping potential cause changes to the acoustic properties of speech. While the physiological measurements made in experiment two provide some insights into the mechanisms behind such changes, EGG was expected to provide a clearer understanding of the involvement of vocal fold vibration in producing both F0 and spectral changes to speech.

In both experiments one and two, significant changes to measures of fundamental frequency occurred in response to manipulated appraisal dimensions. In contrast with many previous studies of emotional speech, F0 floor and measures of F0 range were found to be differently affected by the manipulations. In both experiments, the level of physiological arousal, which varies with manipulations of conduciveness and coping potential, seems to play some role in both F0 floor and F0 range variation. In experiment one, F0 floor and speech energy varied in the same way as a function of goal conduciveness, which was explained in terms of a corresponding variation in sympathetic arousal. In experiment two, the behaviour of the F0 measures was less clear, with F0 range measures varying as a function of the interaction between appraisal dimensions, F0 floor varying as a function of control, and speech energy varying as a function of obstructiveness. Although there was some evidence from ANS measures that F0 range variation might have corresponded to the level of sympathetic arousal, this result was far from certain.

It was hoped that the use of EGG recording together with physiological and acoustic analysis in this experiment, would make the mechanisms underlying changes to F0 more clear. Of particular interest is the way changes to F0 as a result of experimental manipulations would be reflected in the different parts of the glottal period. As seen in the EGG pilot study in the preceding chapter, it is possible that changes to F0 range reflect changes to intonation that are not primarily mediated by changes to the vocal folds, but rather reflect vertical movement of the larynx. If this is the case, then we would expect F0 range variations across manipulations to correspond more highly with low frequency EGG energy (an indicator of larynx movement) than with glottal phase measures, such as open or closed times. Similarly, if sympathetic arousal is primarily responsible for F0 floor changes through changes to laryngeal tension, we would expect F0 floor variation across manipulations to correspond to similar variations in glottal phase measures as well as variation in ANS indicators such as skin conductance, finger temperature, and interbeat interval.

The first two experiments also directly tested a number of the predictions of Scherer (1986) of changes to spectral energy distribution due to different appraisals. Scherer predicted that constriction or opening of the vocal tract in response to appraisals of goal obstructiveness or conduciveness respectively would cause such spectral changes, by selectively increasing or decreasing amplification of high frequency harmonics. In the first two experiments of this thesis, the proportion of energy below 1000 Hertz in voiced parts of speech was found to vary with the experimental manipulations in agreement with Scherer’s predictions. Thus the proportion of energy below 1000 Hertz was lower for obstructive than for conducive situations (though only when speakers had high shooting power in experiment two). In a previous test of Scherer's predictions using acted speech, Banse and Scherer (1996) also found that the distribution of acoustic energy across a number of specific frequency bands varied across expressed emotions. A more global spectral measure of the proportion of energy below 1000 Hertz was found to vary significantly with expressed emotion. However, while expressions of anger and panic were characterised by a low proportion of low frequency energy, consistent with Scherer's predictions, expressions of the emotions sadness and shame had a high proportion of low frequency energy. Indeed, the proportion of low frequency energy seemed at least partly determined by whether the expressed emotion was high arousal (e.g. anger, panic), or low arousal (e.g. sadness, shame).

It is certainly possible that the manner in which the distribution of energy in the spectrum varies with emotion depends not only on the configuration of the vocal tract, but also on vocal fold function that might be linked to arousal. Research that has shown a link between vocal fold function and spectral slope (Fant, 1993, Sundberg, 1994), suggests that increased tension in the intrinsic laryngeal musculature causes vocal folds to remain closed over a longer portion of the glottal period, only briefly opening and then very rapidly closing again. The result is proportionally more energy in upper harmonics, which might well result in speech with more high frequency energy. Thus one might expect emotions in which laryngeal muscles are more tense, to be characterised by relatively greater energy in higher harmonics, and a higher proportion of high frequency energy. The possibility that spectral changes in emotional speech might depend on phonation mechanisms rather than vocal tract mechanisms, is consistent with the results of Banse and Scherer (1996) and the first two experiments of this thesis. Unfortunately, based on those data, it is impossible to determine whether these spectral energy results were mediated by changes to resonance in the vocal tract as suggested by Scherer, or whether they might have been at least partly determined by changes to the way the vocal folds vibrated.

It was hoped that using EGG in this experiment would help determine which mechanisms are responsible for emotion-induced spectral changes to speech. If such spectral changes are mediated by changes to phonation, the effects of experimental manipulations on the shape of the glottal waveform should parallel the effects on spectral energy distribution. In addition, correlations between EGG glottal waveform parameters and spectral energy parameters should be apparent. The lack of such associations between EGG measures and spectral measures would cast doubt on a phonatory explanation, and provide further evidence that such changes are primarily related to vocal tract resonance.

Experimental design

This experiment was intended to replicate the basic experimental design of experiment two, with some modifications made to solve some of the problems with experimental control evident in the second experiment. Only one coping potential manipulation was included in this experiment, which was designed to represent a combination of both control and power as described in Scherer's appraisal theory. Thus the manipulation was deigned to manipulate the general ability of the subject to cope with the experimental situation given both the general nature of the task and the specific given circumstances. The decision to change to a general manipulation of coping was also made based on the findings of experiment two, which showed that the power manipulation had an effect on sympathetic arousal consistent with those predicted by Scherer for appraisals of control. Thus the distinction between appraisals of control and appraisals of power seems fuzzy, at least in terms of their effects on speech. It is also worth mentioning that most appraisal theorists do not make a distinction between control and power, but rather suggest a more general appraisal of coping ability (e.g. problem-focussed coping of Smith and Lazarus, 1990). The manipulation of coping potential for this experiment was also extensively piloted and the difficulty adjusted so as to avoid players disengaging from the task if it became too difficult, as might have been the case in experiment two for obstructive, low power conditions.

It was also decided in this experiment to change from adapting an existing computer game (XQuest) to using a computer task programmed from scratch. This approach had not been used in the earlier experiments of this research for practical reasons, mainly the time and effort spent programming and pretesting such a task. It was thought that using a ready made game would still allow the necessary degree of control and flexibility in manipulating events. The results in the second experiment however point to the need for increased experimental control. In addition, although a computer game was seen as a promising tool for induction of emotions, the very fact that a computer game is entertaining means that it is intrinsically emotional even before particular game manipulations are made to induce emotions. Different players play such games for different reasons and have different goals and motives, posing additional problems of experimental control (see Johnstone, van Reekum and Scherer, 2001, p. 281 for further discussion of this problem). In contrast, a computer task that is built from scratch can include manipulations that are not constrained or compromised by the structure of the game. Speech data collection can also be more easily and seamlessly integrated by constructing tasks that have natural pauses and vocal interaction. The task programmed for this experiment was a motor tracking task, in which speakers had to manipulate the position of a box on the screen in the presence of other items that would add or subtract from the participant’s score. The task was thus similar in many aspects to the XQuest game, but without the extra features in XQuest included simply to add to

XQuest's entertainment value. A more thorough description of the task used in this experiment is given in the method section.

Hypotheses

Goal conduciveness. The principal hypothesis concerning the manipulation of goal conduciveness in this experiment is the same as in experiment two. Conducive situations were expected to produce raised low frequency spectral energy relative to obstructive situations. As an independent measure of conduciveness, skin temperature was predicted to fall during obstructive situations and rise in response to conducive situations.

Coping potential. For coping potential, it was predicted that low coping situations would produce an increase in sympathetic arousal, as indicated by elevated skin conductance activity and increased heart rate. Such arousal would also be manifest in greater laryngeal muscle tension, and a corresponding increase in F0, and F0 variability. This prediction, although seemingly running counter to Scherer's predictions for low coping, is based on the idea that in this experiment, coping potential is never low enough to invoke task disengagement. Thus, given that the player is expected to remain engaged in the game, their level of sympathetic arousal should increase with perceived difficulty, and therefore be higher for the low coping condition that for the high coping condition. Such an effect was found in experiment two, and was considered even more likely in this experiment since the task had been specifically designed and pretested so as not to be so difficult as to make players give up.

Furthermore, because coping potential appraisals were predicted to cause changes to laryngeal tension, the manner in which vocal folds open and close was predicted to change as a consequence. Thus measures of the different phases of the glottal period, as measured with EGG were expected to vary with the coping potential manipulation. More specifically, low coping situations, in which laryngeal muscles were more tense, were expected to lead to relatively shorter open and opening phases and longer closed phase. Although it is possible that closing phase would also shorten during low coping situations, due to greater vocal fold compression leading to stronger elastic closing forces, no firm prediction was made for closing phase. The reason for this is that closing phase was expected to be very short for all experimental conditions, and thus a floor effect in closing phase was likely.

A consequence of the predicted changes to glottal phases in response to the coping manipulation would be corresponding changes to spectral energy distribution. The principal such change would be a shallower spectral slope, and a relatively lower proportion of energy at low frequencies, in low coping situations than in high coping situations. The follows as a consequence of the prediction of short, rapid opening and closing of vocal folds in low coping situations, which would lead to more energy in higher speech harmonics.

Interaction effects of conduciveness and coping potential. As in experiment two, the two appraisal dimensions were predicted to interact in their effect on physiology and the voice. Specifically, the predicted coping potential effects were expected to be greater in obstructive situations than in conducive situations, since appraisals of ability to cope with a situation are more pertinent when faced with obstruction.

Method

This experiment was conducted as part of an ongoing, larger research project on the effects of emotion and stress on automatic speaker verification technologies, and made up part of a larger battery of emotion induction tasks. The total duration of the experimental session was 11/2 hours, of which instructions, preparing the speaker for physiological and EGG measurements, and this experiment took approximately 45 minutes. A general introduction to the purpose of the experiment, as well as specific instructions for the task, were presented automatically by the computer program. Speakers advanced at their own pace through the program.

The task

The task used in this experiment was a tracking task, in which the speaker had to use the mouse to control the movement of a small box on the screen. The task was presented in successive stages. In each stage, in addition to the player's box, one of two symbols, representing either reward or punishment respectively, moved about the screen. The punishment symbol approached the player's box and the rewarding symbol avoided the player's box. The player's task was to avoid the punishment symbol from touching the box, and to touch the rewarding symbol with the box. In addition to punishment and reward, each type of symbol moved either quickly or slowly, thus making the task of avoiding the punishment or achieving the reward more or less difficult, corresponding to low and high coping respectively. Thus the two appraisal dimensions, goal conduciveness and coping potential were manipulated in a factorial design, as shown in table 6.1.

Table 6.1. Design of tracking task manipulations.

		Goal Coduciveness	
		Conducive	Obstructive
Coping Potential	Low	fast reward symbol	fast punishment symbol
	High	slow reward symbol	slow punishment symbol

Reward and punishment were implemented using the addition and subtraction of points respectively. The player's points were displayed in both a digital and graphical form to the left of the playing space. Points were awarded or subtracted from the player’s score on the basis of the distance of the player’s box from the reward or punishment symbol. The closer the player’s box to the reward symbol, the more points they were awarded. The closer their box to the punishment symbol, the more points they lost. All players started with 5000 points, an amount chosen such that players could not lose all their points or gain more than 10000 points during any task stage. The experiment consisted of four stages, one of each condition, presented in an order counterbalanced across subjects.

Speech material.

At four equally spaced intervals during each task stage, a small message at the bottom of the screen appeared, prompting the player to either pronounce a standard phrase (two times), or to pronounce an extended [a] vowel (two times). The order of standard phrase prompts and [a] prompts was randomised. The standard phrase was “Ceci est la tâche 4 2 5 1 0” (“This is task 4 2 5 1 0”), with a different 5-digit combination of digits used in the phrase for each task stage. The digit combinations were counterbalanced across task stages and subjects. The correct way to respond to the two prompts, including instructions on how to pronounce the extended [a] vowel, were shown with a demonstration prior to a practice stage. The four task stages then followed the practice stage.

Subjective emotion reports

Following every task stage, speakers were asked to report how they felt, using mouse-operated emotional state and intensity scales. With the scales, participants could choose any number of emotions from a given list of seven provided emotions, and indicate an intensity ranging from not felt at all to felt extremely, for each chosen emotion. The emotions were satisfied, irritated, tired, stressed, disappointed, content, bored and anxious. Alternatively, speakers could click a box indicating no felt emotion.

Measurements

Vocal measures. The acoustic speech signal and the EGG signal corresponding to the standard phrases and extended vowels were recorded to both channels of a Casio DAT recorder using a Sennheiser clip-on condenser microphone. These recordings were then transferred digitally to a PC and stored as 22kHz sampling rate stereo wave files.

Psychophysiological measures. All physiological measures were recorded continuously throughout the experimental part of the session with a Biopac MP100 physiology measurement system, at a sample rate of 250 Hz. Skin conductance was measured using 8 mm Ag-Ag/Cl electrodes placed on the tops of the index and middle finger of the non-dominant hand. The electrodes were filled with a NaCl paste (49.295 grams of unibase and 50.705 grams of isot. NaCl 0.9%). ECG was measured using pre-gelled, disposable ECG electrodes placed on the chest according to the Einthoven's triangle. Finger temperature was measured using a Biopac finger temperature probe attached to the small finger on the non-dominant hand. A respiration strain gauge was placed around the abdomen, just below the thoracic cage, to provide an approximate measurement of respiration rate and depth. The respiration signal was highpass filtered at 0.03 Hz.

A one-byte digital measurement channel channel, synchronised with the physiological data, recorded a numerical code corresponding to the different game events of interest, which was output from the parallel port of the experimental presentation PC. This channel thus marked the physiological data with the precise onset and offset of each game event, as well as the onset and offset of vocal recordings.

Speakers

Speakers were 30 male first-language French adults aged between 18 and 34 (mean age 24.5) recruited via written notices and local radio announcements. Speakers were told that the purpose of the experiment was to collect a variety of speech recordings under different situations that were designed to simulate those that might occur during everyday use of computers. Speakers were told that they would be asked to complete a series of tasks and puzzles that would be presented on a PC. They were told that they would be asked to pronounce a series of standard phrases and vowels that were selected to serve the experimental goal of improving speech recognition technologies. All speakers were paid SFr. 40 for their participation. Speakers were also told before the start of the session that if they performed well enough in the series of tasks, they could win an extra SFr. 10. This incentive served to increase motivation and involvement in the task, and thus render the manipulations more powerful. All speakers were in fact paid the extra SFr. 10 at the conclusion of the experimental session.

Procedure

On arrival, speakers were told that the purpose of the experiment was to collect a variety of speech recordings under different situations that were designed to simulate those that might occur during everyday use of computers. Speakers were informed that they would be asked to complete a series of tasks and puzzles that would be presented on a computer, and that the program would prompt them at specified times to provide spoken input, including extended vowels, isolated digits, standard phrases and spontaneous speech, which would be recorded.

The physiological sensors and EGG electrodes were then attached and regulated. Regulation consisted of checking that the signals were suitably amplified and free of noise. For all participants, the microphone was then fitted and the recording level adjusted appropriately. Participants were then asked if they were comfortable and ready to start before the experimenter left the experimental room and started the program.

The duration of the session was approximately 11/2 hours, including time to set up the EGG, acoustic and physiological apparatus. At the end of the session, speakers were debriefed and their agreement for further use of their data was obtained.

Results

Note. Although respiration was recorded with a respiration strain gauge in this experiment, technical problems with the respiration amplifier precluded the data from being analysed.

Acoustic measures

The set of acoustic measures was largely the same as that examined in experiments two and three, with some changes. Mean F0 was not analysed, since median F0 had consistently shown the same results in previous experiments and was judged to be less susceptible to the effects of outliers than the mean. F0 3rd moment, which had been included in the second experiment as an exploratory measure of the skewness of the F0 distribution, but had shown no effects of experimental manipulations, was also excluded. Only voiced spectral measures were included, since unvoiced spectral measures had not consistently shown changes with manipulations in previous experiments. Since spectral energy under 500 Hertz had been found to be less reliable and less related to manipulations in previous experiments than energy under 1000 Hertz, it was also not analysed in this experiment. A number of new measures were added to the analysis:

F0 standard deviation. The standard deviation of F0 values was calculated for each utterance, as a measure of overall F0 variability. F0 standard deviation across single phrases or utterances has been measured in other studies (see, e.g. Banse and Scherer, 1996; Scherer, 1986) and shown to increase with highly aroused emotions and decrease with emotions such as boredom. Because each F0 value has been calculated on the basis of windows of the acoustic speech signal of varying lengths (always more than two fundamental periods), it is difficult to know whether the standard deviation represents global, suprasegmental variation in F0 or period to period variation. The former corresponds to the changes in F0 associated with intonation, whether emotional or non-emotional, and is related to the F0 range (difference between F0 floor and ceiling). The latter type of variation is called jitter, and has been independently measured as an indicator of emotional stress in previous research (e.g. Smith, 1977). In this experiment, since the EGG signal made possible the accurate period to period measurement of F0, jitter, F0 standard deviation and F0 range could all be measured and compared.

Spectral slope. The power spectrum of voiced speech has a spectral slope of approximately –6 decibels (dB) per octave. The source of this spectral slope is the spectrum of the glottal excitation, which has a slope of approximately –12 dB, which is then modified by the filtering of the vocal tract and lips. Although the glottal source spectrum is not directly available for measurement, it is possible that the spectral slope of the acoustic speech signal will vary with emotion-induced changes to the glottal source spectrum (Scherer, 1986; Klasmeyer, 1998; Klasmeyer and Sendlmeier, 1997). In particular, it is predicted that greater tension in the vocal folds coupled with greater expiratory force will cause a less negative spectral slope (i.e. relatively more high frequency energy/less low frequency energy). For this reason, a regression line was fit to the voiced power spectrum and the slope of the line in dB/octave was calculated and analysed in this experiment.

Mel power spectrum. To provide further information on the change of the power spectrum with the experimental manipulations, a mean Mel power spectrum was calculated for each utterance. The Mel spectrum is a power spectrum in which the frequency axis has been warped to reflect the perceptual properties of sound. It allows for the fact that certain ranges of frequencies are perceived with greater resolution than others. A transformation is applied to the frequency axis that effectively groups together those frequencies that cannot be distinguished perceptually, while keeping separate those frequencies that can be perceptually resolved. The formula for transforming frequency in Hertz to frequency in Mel is

$$m=2595 \log_{10}(1+{}^{f}/_{700})$$

Although widely used in the domain of speech science, the Mel spectrum of emotional speech has not previously been examined. The Mel spectrum was used in this experiment because it represents a more theoretically principled way in which to reduce the 512 frequency values in a typical power spectrum than the purely statistical data reduction techniques such as factor analysis used in previous studies (e.g. Banse and Scherer, 1996).

EGG measures

The same set of EGG measures as analysed in experiment three was included in this experiment. In addition to the measurement of glottal quotients, which indicate the *proportion* of each glottal period occupied by the opening, open, closing and closed phases, the *absolute* opening, open, closing and closed times were also measured. The reason for this was to allow a better interpretation of how changes to the F0 corresponded to changes to the lengths of the four glottal phases. Quotients, in contrast, measure the shape of the glottal waveform after normalisation to the length of the glottal period, and are thus independent of the absolute F0 level.

For each utterance, an average glottal waveform was also calculated, by normalising each glottal waveform by its length and amplitude range and then calculating the mean. This waveform was intended to provide additional information on emotion-induced changes to the shape (but not the amplitude or duration) of the glottal cycle.

Statistical analysis

Acoustic, EGG and physiological measures were analysed in conduciveness by difficulty by subject mixed model ANOVA, with conduciveness and difficulty as fixed factors and subject as a random factor. Two separate analyses were performed for the EGG and acoustic data corresponding to the standard phrase and the extended vowel respectively. The acoustic measures analysed were the same for both analyses, except that duration and proportion voiced were not analysed for the extended [a] vowel, since both these fluency-related measures are only relevant for spoken phrases.

Acoustic measures for the extended [a] vowel

An interaction of conduciveness with difficulty for median and ceiling F0 was due to higher median F0 (F(1,27)=5.8, p=0.023) and F0 ceiling (F(1,28)=8.7, p=0.006) for difficult obstructive situations than for difficult conducive situations. The variation of median and ceiling F0 across conditions corresponded to that of EGG open time, for which there was an effect of conduciveness (F(1,28)=7.9, p=0.009), indicating that the vocal folds were open shorter during each vocal cycle in difficult obstructive than in difficult conducive situations, as shown in figure 6.1.

An interaction of conduciveness with difficulty was measured for EGG closed quotient (F(1,28)=6.3, p=0.018) and open quotient (F(1,28)=6.9, p=0.014), due to greater EGG closed quotient and lower EGG open quotient for difficult obstructive than difficult conducive situations. These effects, shown in figure 6.2, imply longer vocal fold contact, *as a proportion of vocal period*, during difficult, obstructive situations than during difficult, conducive situations.

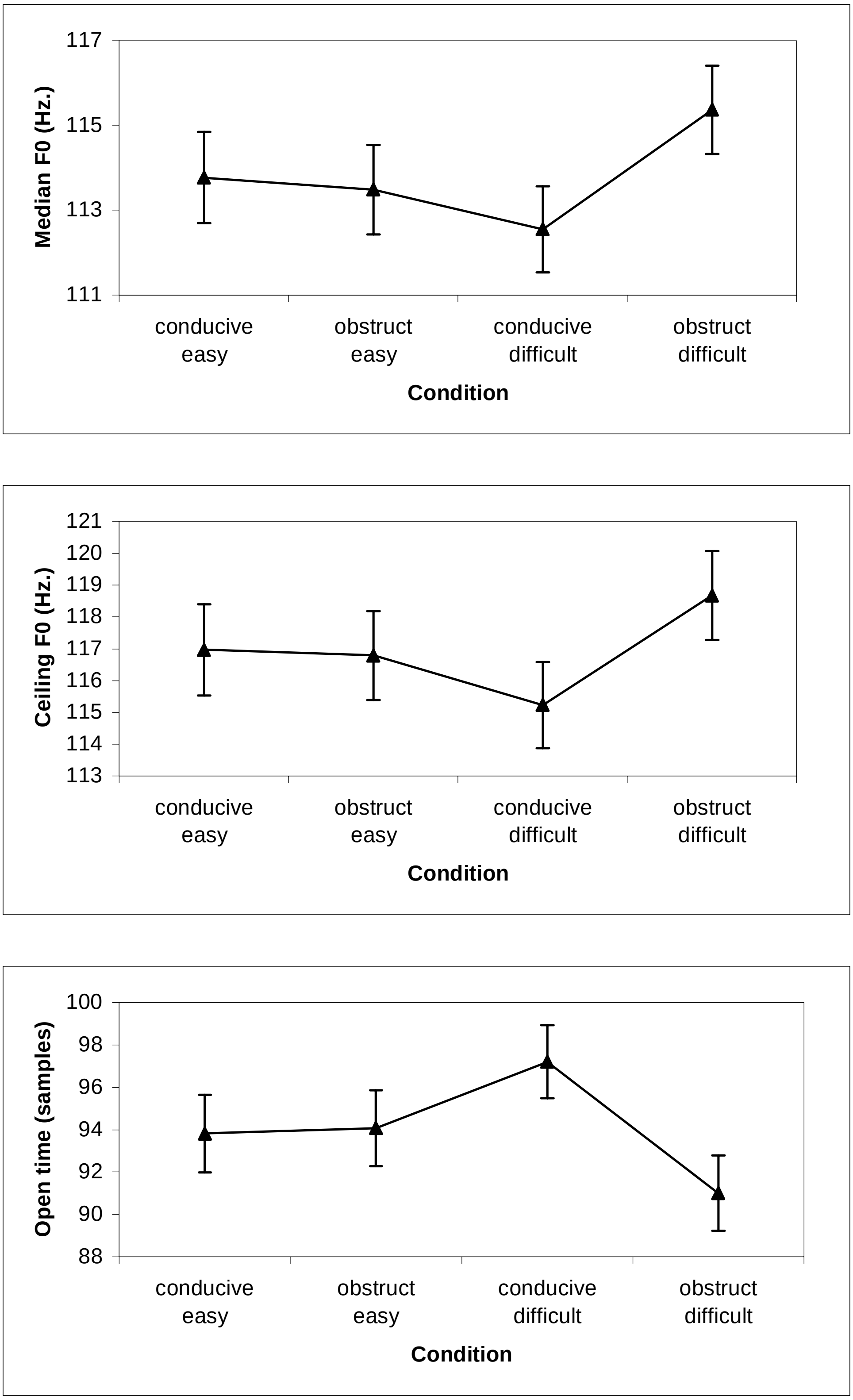
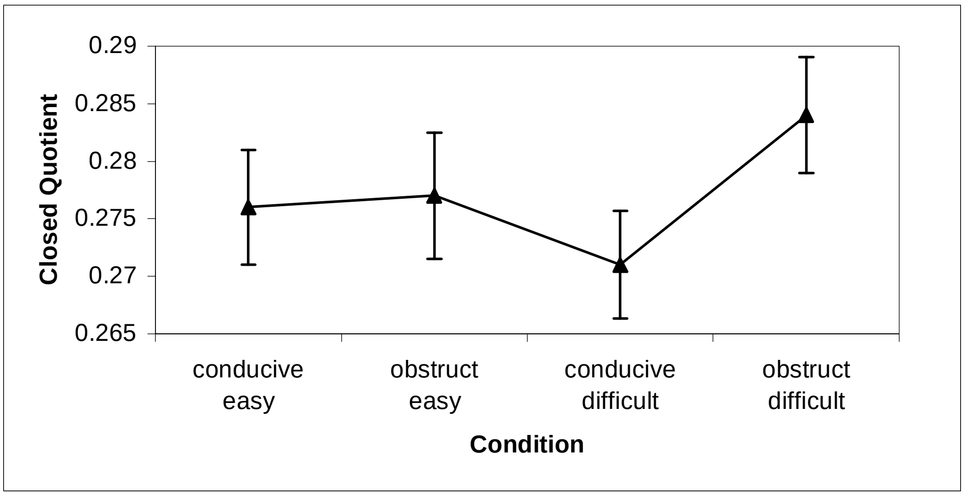


Figure 6.1. Median F0 (top), ceiling F0 (bottom) and EGG open time for extended [a] vowel as a function of conduciveness and difficulty. Bars represent 95% within-subject confidence intervals.

Figure 6.3 shows the mean normalised EGG glottal cycles for difficult conducive and difficult obstructive situations. In this figure, the longer closed quotient for difficult obstructive situations is apparent in the longer time for the EGG signal to fall from its maximum amplitude (although because figure 6.3 represents an average across all speakers, the effect appears small).



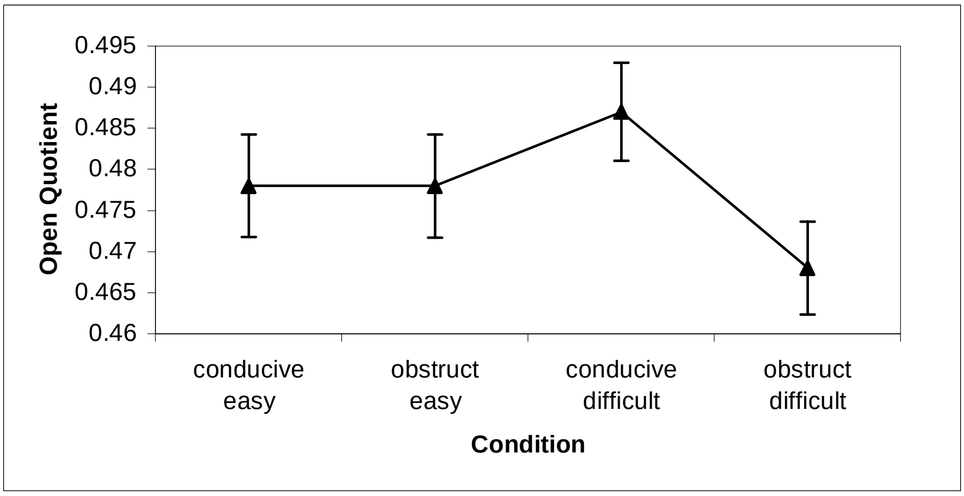


Figure 6.2. EGG closed quotient (top),and open quotient (bottom) for extended [a] vowel as a function of conduciveness and difficulty. Bars represent 95% within-subject confidence intervals.

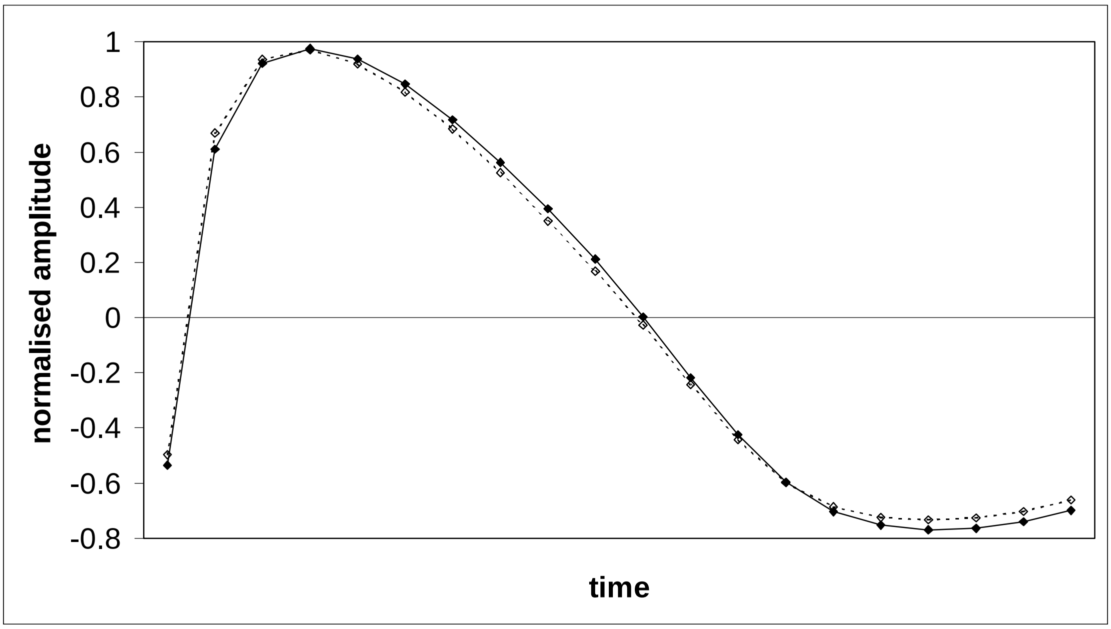


Figure 6.3. Mean EGG glottal cycles for extended [a] vowel for the difficult conducive (broken line) and difficult obstructive (solid line) conditions.

There was a nonsignificant trend for the proportion of energy under 1000 Hertz to be greater for conducive than for obstructive situations (F(,28)=3.0, p=0.093, which was mostly due to a lower proportion of low frequency energy for difficult obstructive situations than the other conditions (see figure 6.4). This effect is not immediately apparent when looking at the Mel spectrum (figure 6.5), which shows some low (under 1000 Hertz) frequencies for which there is *greater* energy for difficult obstructive situations than for the other conditions. This discrepancy might be explained by the fact that over the larger range of high frequencies, obstructive situations show greater energy than conducive situations. Therefore, as a *proportion* of total energy, averaged over the whole spectrum, the low frequency energy is lower for obstructive situations than conducive situations. However, close examination of the Mel spectrum reveals that only considering such global measures as proportion of energy under 1000 Hertz might not give a clear picture of what is actually happening in the acoustic signal. In this case, there is clearly an interesting effect of conduciveness and difficulty on a specific range of frequencies from 300 to 700 Hertz. Furthermore, in the case of an [a] vowel this range of frequencies corresponds to a part of the spectrum between two formants, implying that a standard formant analysis could not have identified the effect either.

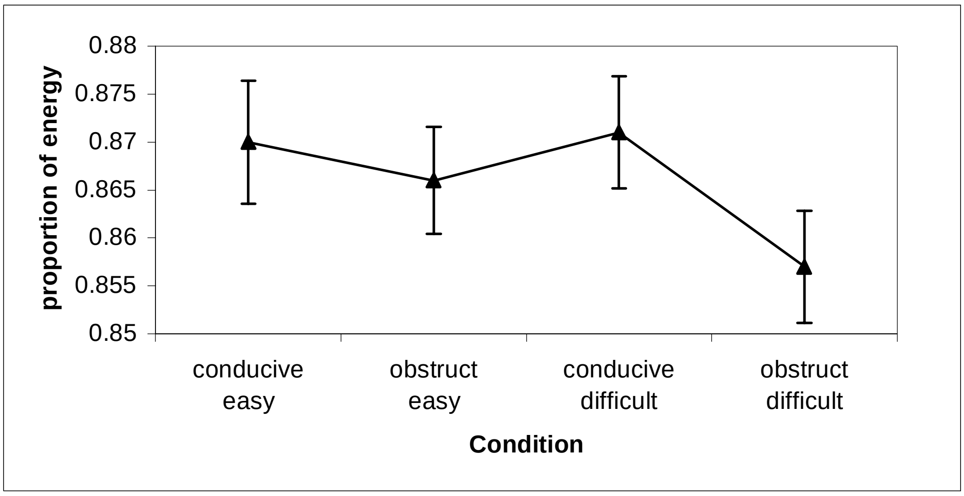


Figure 6.4. Proportion of energy below 1000 Hertz for extended [a] vowel as a function of conduciveness and difficulty. Bars represent 95% within-subject confidence intervals.

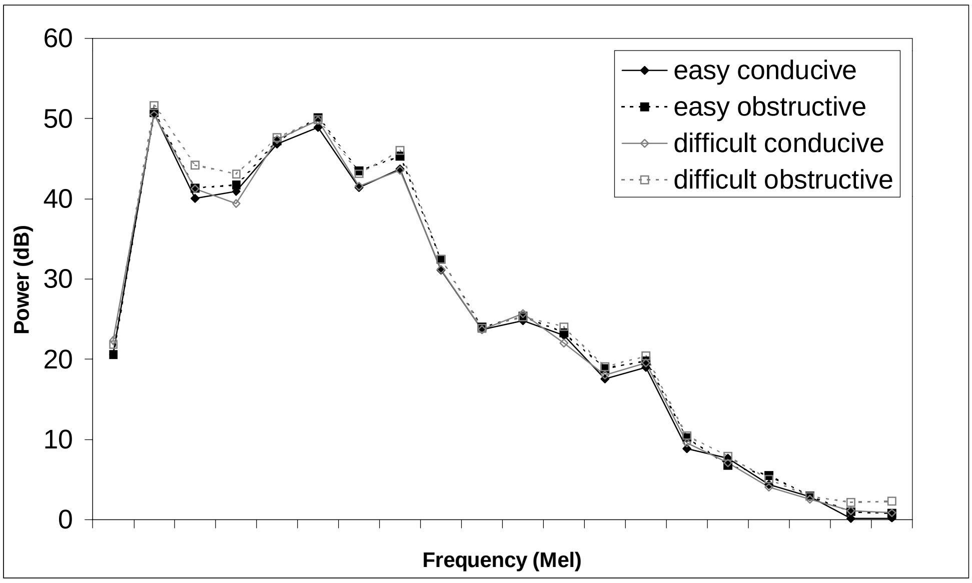


Figure 6.5. Mel power spectrum for extended [a] vowel.

Acoustic measures for standard phrase

A main effect of difficulty on median F0 (F(1,28)=4.2, p=0.049) was due to higher median F0 in difficult than in easy situations (see figure 6.6). An interaction of difficulty and conduciveness on F0 floor (F(1,27)=4.9, p=0.035) was due to higher F0 floor for easy conducive than easy obstructive situations, but higher F0 floor for difficult obstructive than difficult conducive situations. A similar difficulty by conduciveness interaction effect was found for F0 ceiling (F(1,27)=9.3, p=0.005). An interaction effect of difficulty by conduciveness on open time (F(Figure 1,27)=4.3, p=0.047) was due to shorter opening time for the difficult obstructive condition that the other conditions. Figure 6.7 shows F0 ceiling, F0 floor and glottal open time for the standard phrases as a function of experimental condition.

An interaction of difficulty and conduciveness on low frequency EGG energy (F(1,27)=4.4, p=0.046) was due to greater low frequency EGG energy for easy conducive situations than for easy difficult situations, but greater low frequency EGG energy for difficult obstructive situations than for difficult conducive situations (see figure 6.8).

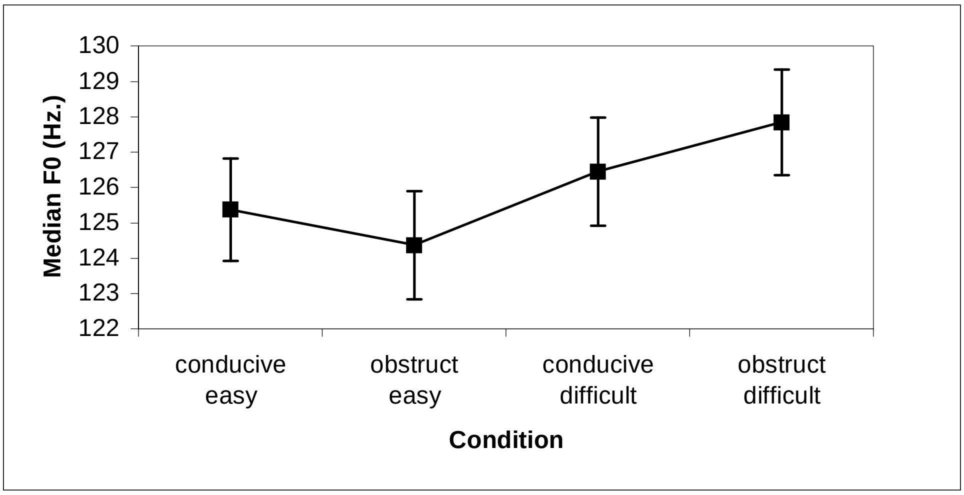


Figure 6.6. Median F0 for standard phrase as a function of conduciveness and difficulty. Bars represent 95% within-subject confidence intervals.

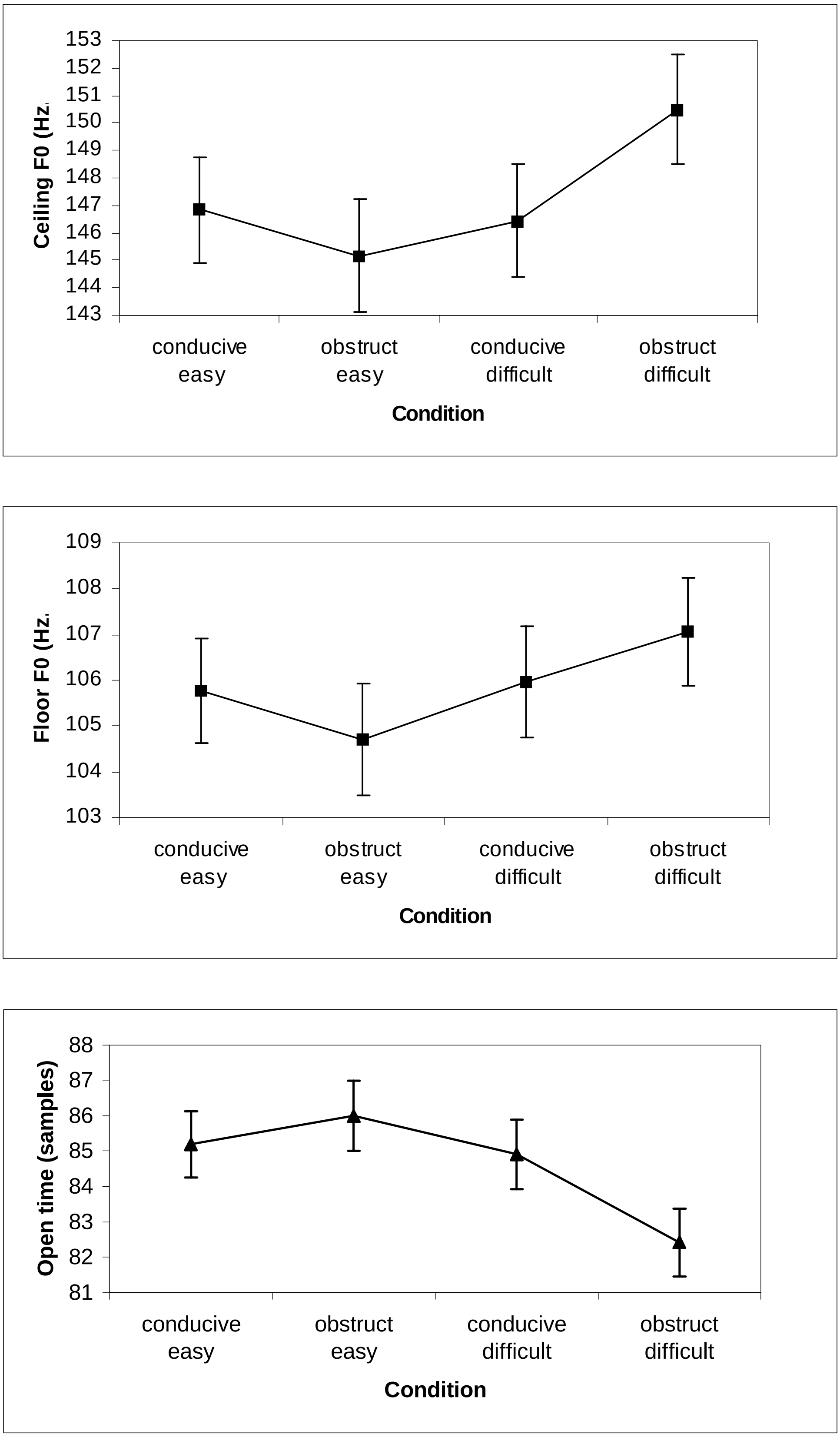


Figure 6.7. Ceiling F0 (top), F0 floor (centre) and glottal open time (bottom) for standard phrase as a function of conduciveness and difficulty. Bars represent 95% within-subject confidence intervals.

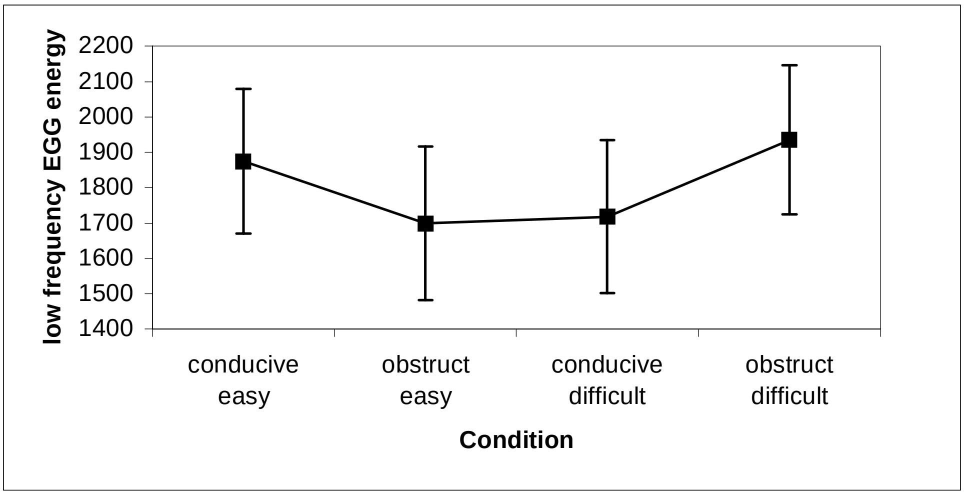


Figure 6.8. Low frequency EGG energy for standard phrase as a function of conduciveness and difficulty. Bars represent 95% within-subject confidence intervals.

An interaction of difficulty and conduciveness on spectral slope (F(1,27)=11.7, p=0.002) was measured, with flatter spectral slope for easy conducive situations than for easy difficult situations, but flatter spectral slope for difficult obstructive situations than for difficult conducive situations (see figure 6.9). Figure 6.10 shows the Mel power spectrum for easy and difficult conditions. For the easy condition, the flatter spectral slope for conducive than for obstructive situations is due to greater energy in the lower half of the spectrum for obstructive than for conducive situations, but little or no difference in the upper part of the spectrum. For the difficult condition, the flatter spectral slope for obstructive than for conducive situations is due to greater energy in the upper part of the spectrum for obstructive situations than for conducive situations, but little or no difference in the lower part of the spectrum. It is worth noting that the proportion of energy below 1000 Hertz showed no significant effects for the experimental manipulations. Thus spectral slope seems to capture separate, possibly more global, aspects of spectral change than the proportion of energy below 1000 Hertz measure, which is more likely influenced by changes to local parts of the spectrum.

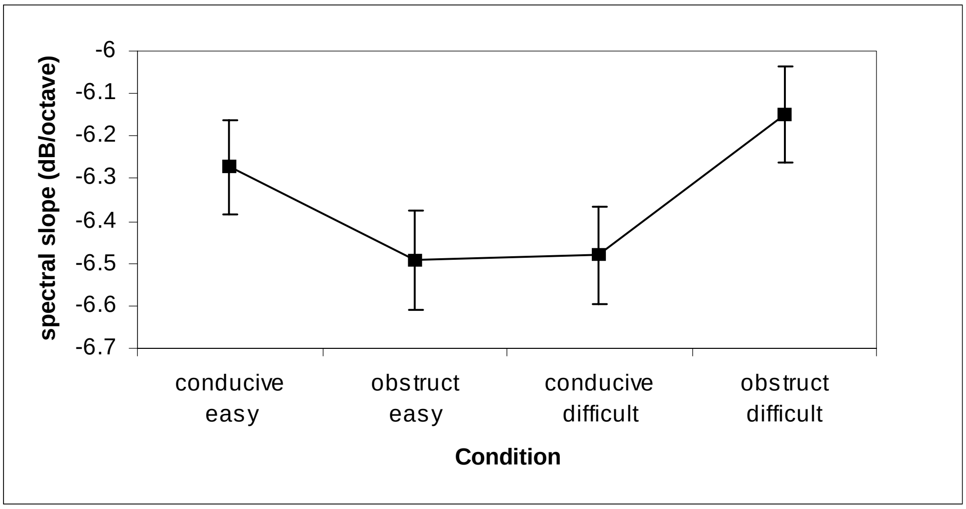


Figure 6.9. Spectral slope for standard phrase as a function of conduciveness and difficulty. Bars represent 95% within-subject confidence intervals.

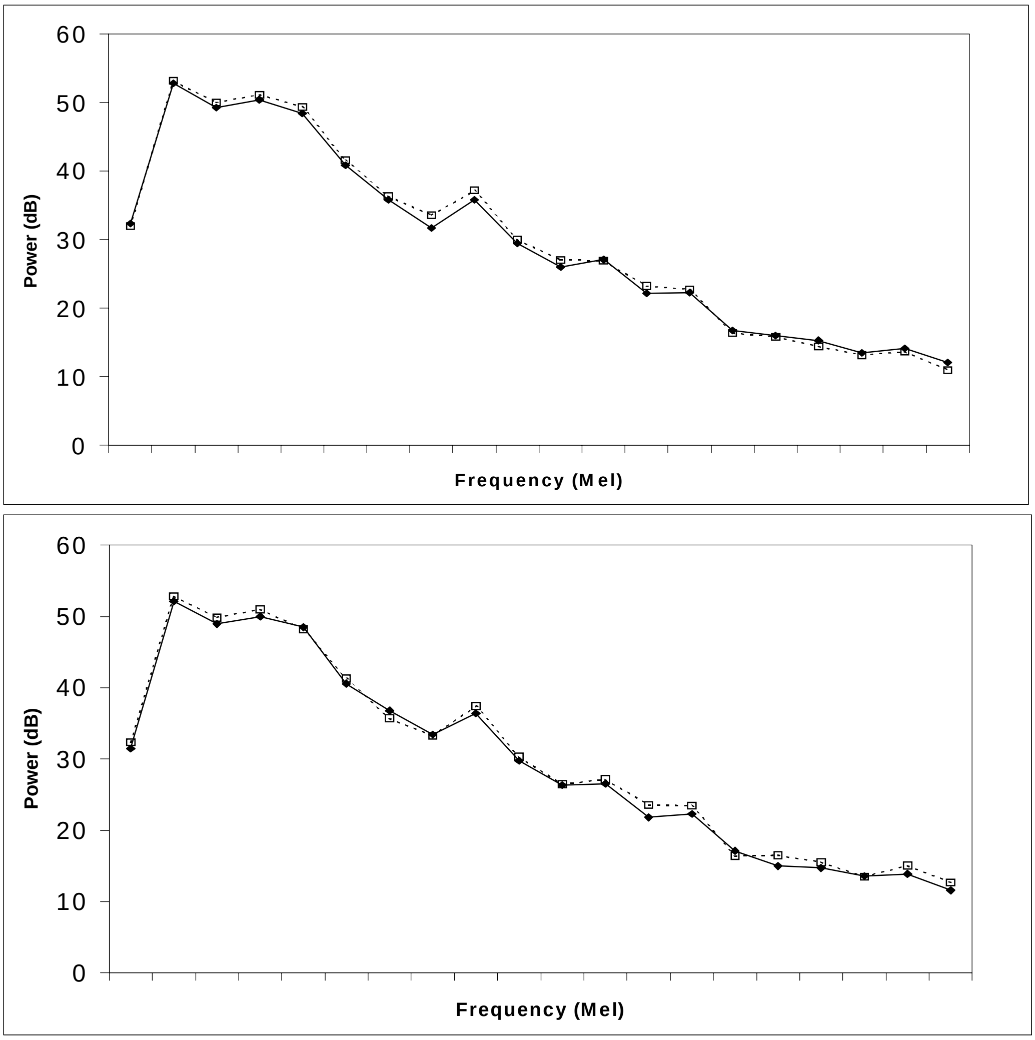
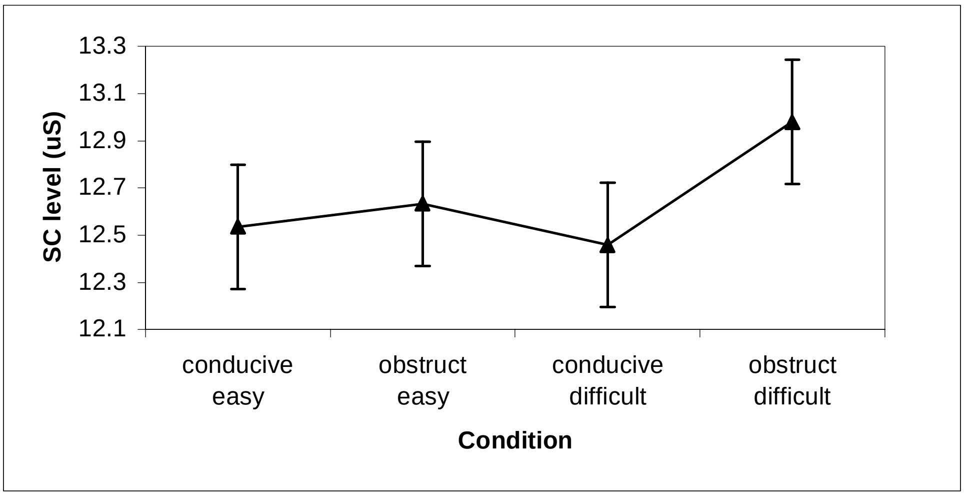


Figure 6.10. Mel power spectrum for easy situations (top) and difficult situations (bottom) for the standard phrase. Solid lines represent conducive condition, broken lines represent the obstructive condition.

Physiological measures

Skin conductance level was higher for obstructive than conducive situations (F(1,25)=6.3, p=0.019), as were skin conductance response amplitudes (F(1,24)=4.8, p=0.038; see figure 6.11). However, whereas skin conductance response amplitudes varied equally with conduciveness in both easy and difficult conditions, the effect of conduciveness on skin conductance level was larger in difficult than in easy situations, as shown in figure 6.11.



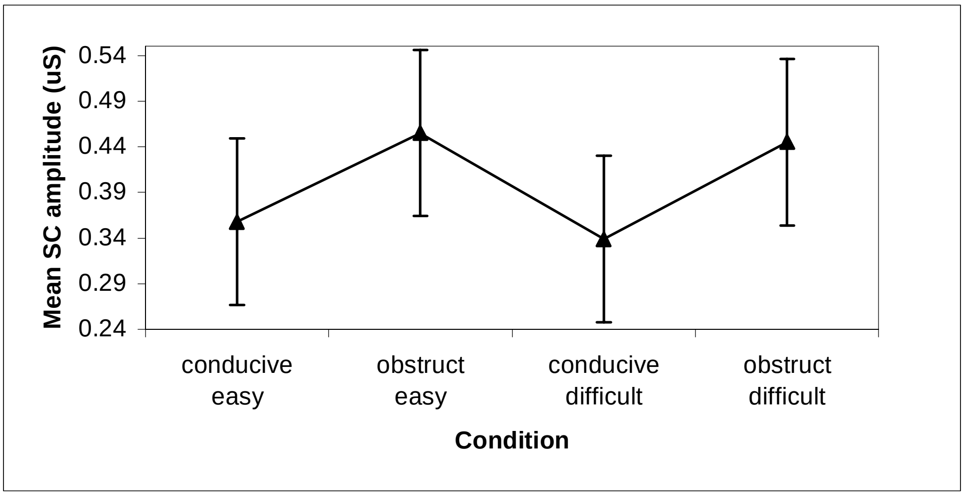


Figure 6.11. Tonic skin conductance level (top) and mean skin conductance response amplitude (bottom) as a function of difficulty and conduciveness. Bars represent 95% within-subject confidence intervals.

An interaction trend of difficulty by conduciveness on the number of skin conductance responses (F(1,23)=4.0, p=0.056) was due to more skin conductance responses in difficult obstructive situations than the other conditions (see figure 6.12).

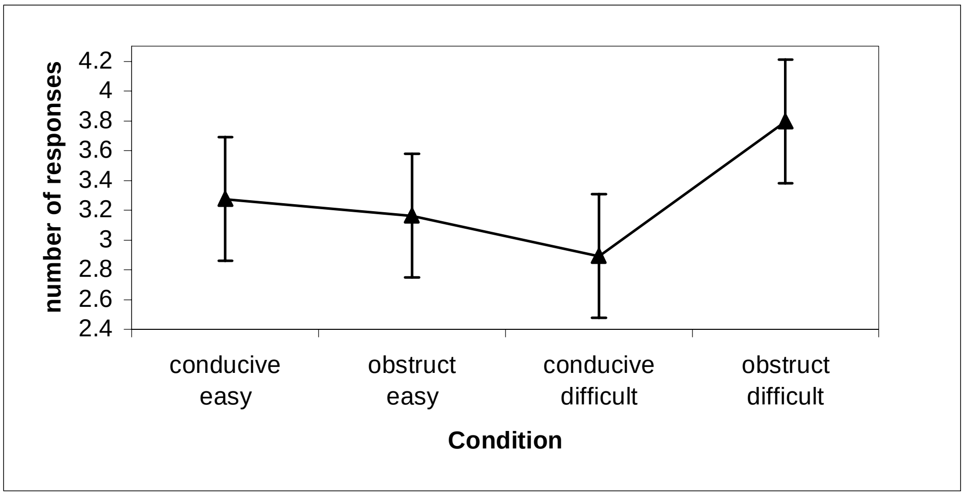


Figure 6.12. Number of skin conductance responses as a function of difficulty and conduciveness. Bars represent 95% within-subject confidence intervals.

There was a trend for heart rate variability to be lower for difficult (mean = 40.7) than for easy conditions (mean = 45.5; F(1,25)=3.4, p=0.078). An interaction of difficulty and conduciveness on finger temperature (F(1,24)=6.6, p=0.017) was due to higher finger temperature in difficult conducive than in difficult obstructive conditions, but no such conduciveness effect in easy conditions (see figure 6.13). Although finger temperature slope showed the same pattern of means as finger temperature, the effect was not significant.

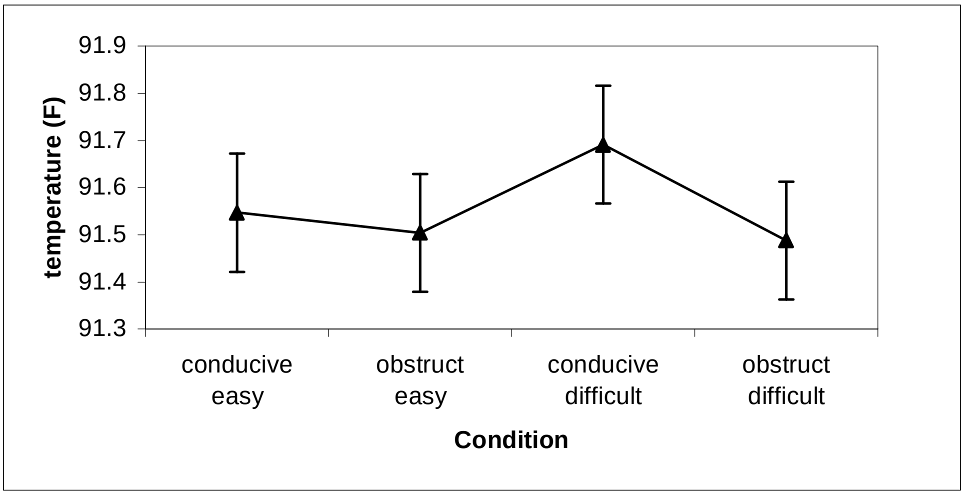


Figure 6.13. Finger temperature as a function of conduciveness and difficulty. Bars represent 95% within-subject confidence intervals.

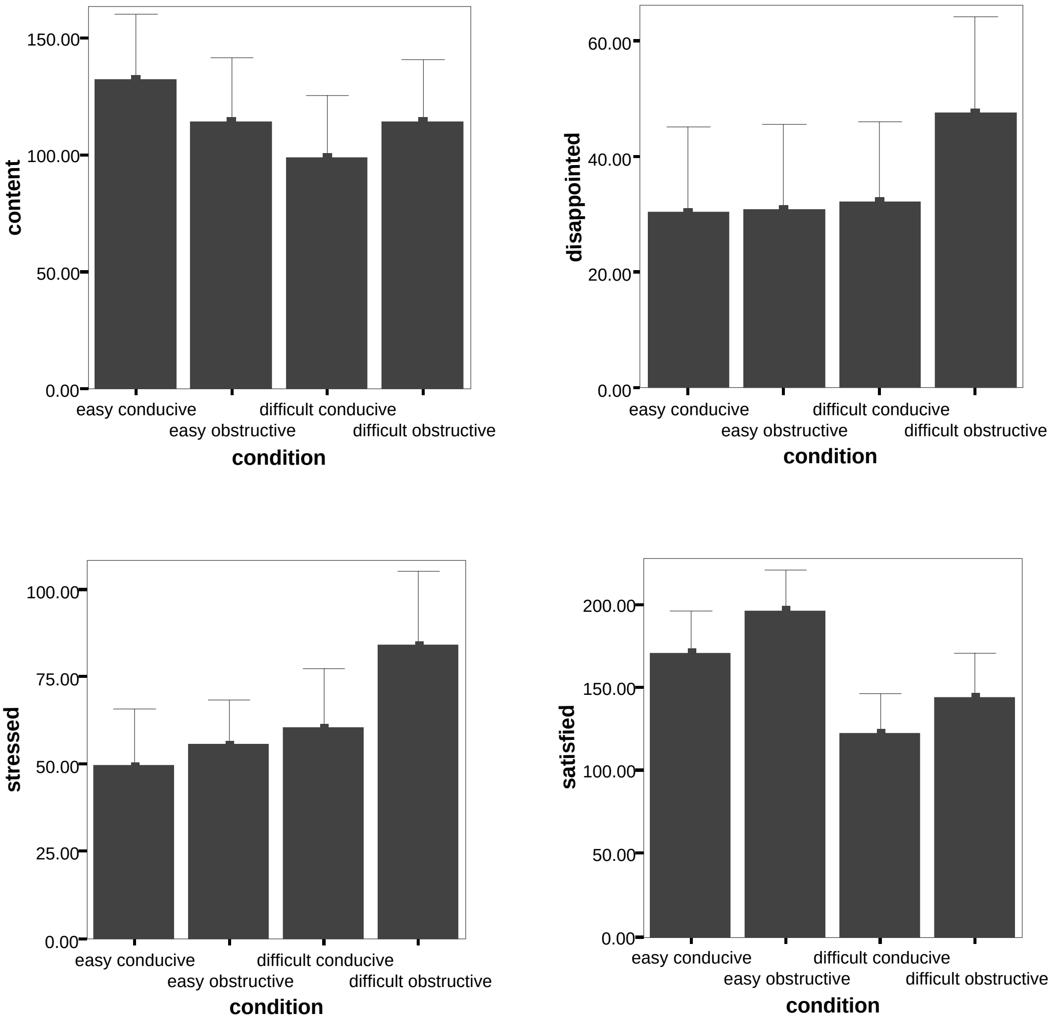


Figure 6.14. Subjective ratings of felt contentment, disappointment, stress and satisfaction for the four experimental conditions.

Emotion reports

Figure 6.14 shows the mean reported intensity of contentment, disappointment, stress and satisfaction for each condition. The other emotions are not discussed here, since they were reported by fewer than five subjects. The four rated emotions were analysed with conduciveness by difficulty mixed model ANOVA. Only rated intensity of stress and satisfaction differed as a function of difficulty and conduciveness. Stress was higher for difficult than for easy conditions (F(1,28)=4.7, p=0.038). Satisfaction was higher for easy than for difficult conditions (F(1,28)=10.9, p=0.003).

Emotion reports, vocal and physiological measures

To examine how vocal and physiological measures varied with reported emotion, emotion rating data from the four emotions presented in the preceding section was collapsed into a categorical emotion variable representing the emotion that was predominantly felt at that time. For each emotion report, the value of the emotion variable was set to the emotion that had the highest rated emotion intensity. The last category was “none” which was the case when subjects reported no felt emotion.

The means and 95% confidence intervals were then plotted for each vocal measure and physiological measure across the categories of the emotion variable. Those measures that differed across emotion (using the 95% confidence interval as a criterion) are reported below.[1] Vocal measures for the [a] vowel and the standard phrase have been collapsed together, since the vocal variables showed the same pattern across reported emotions for the two types of speech content for all variables discussed below.

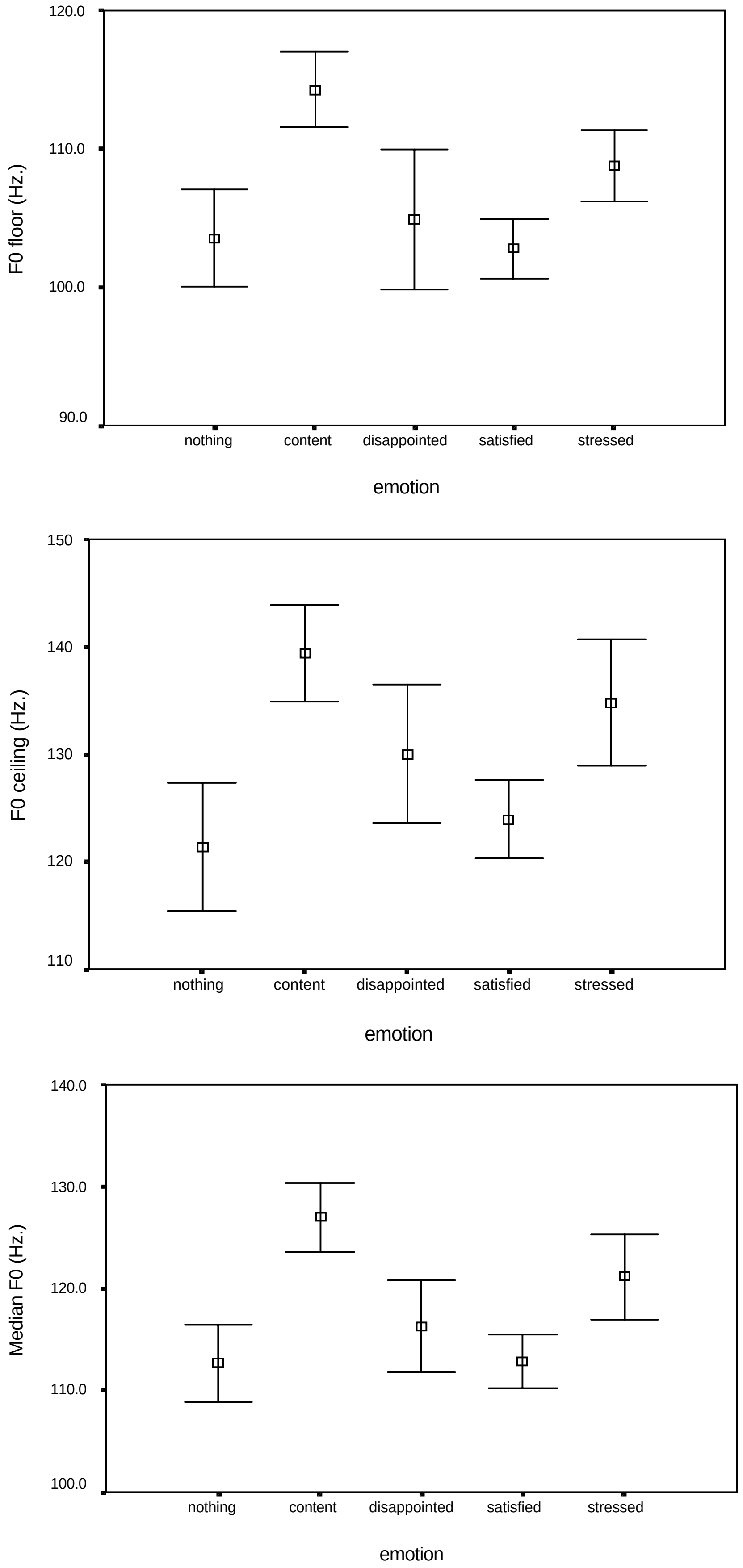


Figure 6.15. F0 floor, F0 ceiling and median F0 corresponding to different reported emotions. Bars indicate 95% within-subjects confidence intervals.

F0 floor, F0 ceiling and median F0 all varied with reported emotion, as shown in figure 6.15. Fundamental frequency level and range was relatively high when subjects reported stress or contentment and relatively low when subjects reported disappointment, satisfaction or no emotion. Values for glottal open time (figure 6.16) corresponded to this pattern in F0, with low values when stress and contentment were reported and high values when disappointment and satisfaction were reported. Figure 6.17 shows that spectral slope was relatively flatter when subjects reported disappointment than when they reported contentment or stress. Speech corresponding to reported satisfaction or no emotion had the steepest spectral slope.

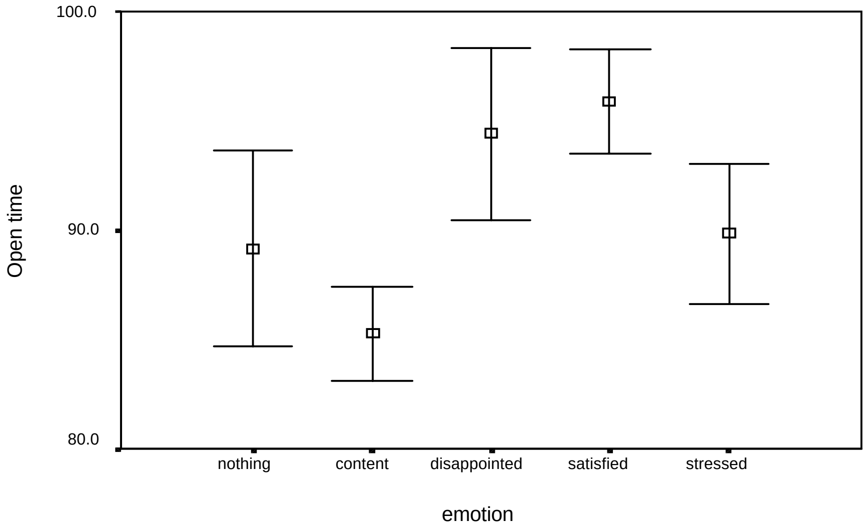


Figure 6.16. Glottal open time corresponding to different reported emotions. Bars indicate 95% within-subjects confidence intervals.

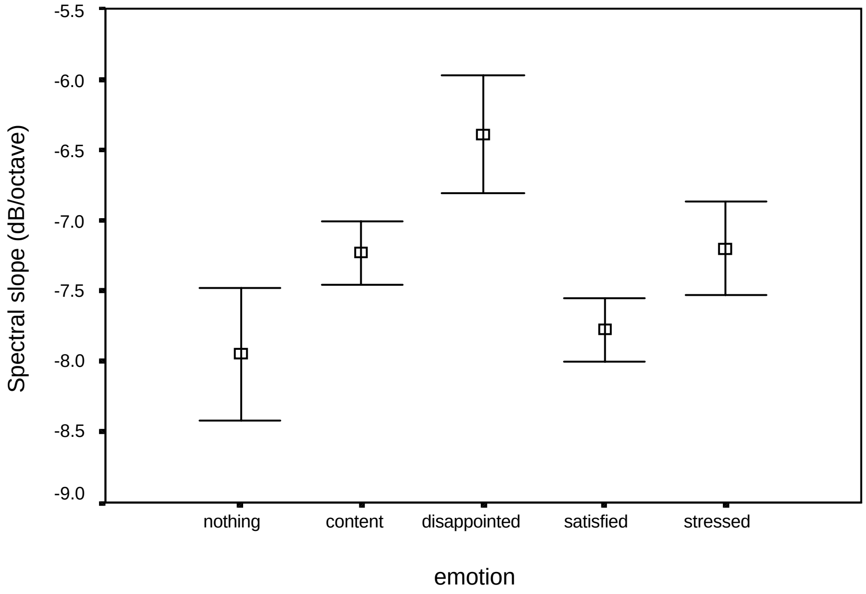


Figure 6.17. Spectral slope corresponding to different reported emotions. Bars indicate 95% within-subjects confidence intervals.

Correlations between dependent measures

Table 6.2 shows the correlations between those physiological and vocal (i.e. acoustic and EGG) measures which showed differences across experimental conditions. As can be seen, similar to experiment two there are very few significant correlations. Mean skin conductance response amplitude correlated positively with low frequency spectral energy. Apart from this correlation, however, the only significant correlations are found between physiological measures and EGG measures. This result confirms that EGG measurement allows one to look more directly than acoustic measures at the physiological mechanisms that are assumed to underlie emotional changes to speech. The correlations are nevertheless small in magnitude. Negative correlations between the measures of skin conductance activity and vocal fold open time and open quotient indicate that as sympathetic arousal increased, glottal open phase decreased, both in absolute terms, and as a proportion of glottal period. Corresponding to the lower open quotient, glottal closed quotient correlated positively with skin conductance activity, hinting that with increased sympathetic arousal, the vocal folds might have been held together more firmly and thus stayed closed longer, possibly due to increased vocal fold tension. These correlations were only present for the standard phrase and not for the extended [a] vowel, which is puzzling given the significant differences measured in glottal measures across experimental manipulations. For the extended [a] vowel, finger temperature did correlate positively with glottal open time and open period, and negatively (although not significantly) with closed quotient. Since finger temperature is an indicator of parasympathetically-mediated peripheral vasodilation, these correlations indicate that the vocal folds were held closed longer when parasympathetic activity was low than when parasympathetic activity was high. A similar pattern of correlations was observed between finger temperature and closed phase, open phase and open time for the standard phrase, although the magnitude of the correlations was smaller and they were not significant. Low frequency EGG energy showed a small correlation with skin conductance level, although there were no corresponding correlations of low frequency EGG energy with the other skin conductance measures.

Table 6.3. shows the correlations between vocal measures for both the extended [a] vowel (top) and the standard phrase (bottom). It can be seen that the overall pattern of observations is very similar for the standard phrase and the [a] vowel, except that a number of correlations are weaker or non-existent for the standard phrase. Median F0, F0 floor and F0 ceiling were all highly correlated. For the extended vowel these correlations approached unity, reflecting the limited intonation of such vowel pronunciation. For the standard phrase, F0 floor was only weakly correlated with F0 ceiling, confirming that for utterances, the two parameters describe separate aspects (level and range) of the F0 contour. Moderate positive correlations of the F0 measures with energy show that as overall speech energy increases, so does F0.

Table 6.2. Correlations between vocal and physiological measures for both the extended [a] vowel and the standard phrase. Figures in bold indicate correlations significant at p<0.01.

	IBI variability		finger temperature		SC level		# SCRs		mean SCR amplitude	
	[a]	[phrase]	[a]	[phrase]	[a]	[phrase]	[a]	[phrase]	[a]	[phrase]
median F0	0.03	0.05	-0.15	0.03	-0.11	0.02	-0.02	0.12	0.09	0.07
F0 ceiling	0.05	0.02	-0.09	-0.05	-0.06	0.09	0.01	0.13	0.12	0.04
F0 floor	0.02	0.07	-0.13	-0.09	-0.10	0.14	-0.07	0.09	0.14	0.13
energy	0.08	-0.15	-0.05	0.08	-0.02	0.04	0.07	0.13	-0.15	-0.10
energy < 1 kHz	-0.14	0.06	0.00	-0.08	0.17	0.11	-0.18	-0.17	**0.25**	**0.25**
spectral slope	0.07	0.04	0.07	0.02	0.19	-0.01	0.10	0.05	0.01	0.07
low freq. EGG	-0.08	-0.04	-0.07	0.08	**0.20**	0.07	0.05	0.12	0.00	0.03
closed quotient	-0.03	-0.02	-0.18	-0.17	0.08	***0.29***	0.10	0.13	0.08	**0.31**
open time	-0.05	0.00	**0.31**	0.17	-0.02	-0.19	-0.06	***-0.28***	-0.07	**-0.30**
open quotient	-0.05	0.03	**0.35**	0.17	-0.15	**-0.21**	-0.09	***-0.28***	-0.03	**-0.24**

Table 6.3. Correlations between vocal measures for both the extended [a] vowel and the standard phrase. Figures in bold indicate correlations significant at p<0.05.

	median F0	F0 ceiling	F0 floor	energy	energy < 1 kHz	spectral slope	low freq. EGG	closed quotient	open time	open quotient
extended [a] vowel										
median F0	1.00	**0.87**	**0.93**	**0.44**	**-0.24**	**0.19**	-0.09	**0.45**	**-0.65**	**-0.23**
F0 ceiling	**0.87**	1.00	**0.76**	**0.37**	**-0.34**	0.15	0.00	**0.37**	**-0.55**	-0.16
F0 floor	**0.93**	**0.76**	1.00	**0.44**	-0.17	**0.20**	**-0.20**	**0.43**	**-0.62**	**-0.22**
energy	**0.44**	**0.37**	**0.44**	1.00	**-0.36**	**0.42**	-0.05	**0.28**	**-0.33**	-0.17
energy < 1 kHz	**-0.24**	**-0.34**	-0.17	**-0.36**	1.00	**-0.25**	-0.11	-0.18	**0.23**	0.12
spectral slope	**0.19**	0.15	**0.20**	**0.42**	**-0.25**	1.00	-0.04	0.11	-0.13	-0.07
low freq. EGG	-0.09	0.00	**-0.20**	-0.05	-0.11	-0.04	1.00	-0.01	0.06	-0.04
closed quotient	**0.45**	**0.37**	**0.43**	**0.28**	-0.18	0.11	-0.01	1.00	**-0.85**	**-0.78**
open time	**-0.65**	**-0.55**	**-0.62**	**-0.33**	**0.23**	-0.13	0.06	**-0.85**	1.00	**0.86**
open quotient	**-0.23**	-0.16	**-0.22**	-0.17	0.12	-0.07	-0.04	**-0.78**	**0.86**	1.00
standard phrase										
median F0	1.00	**0.62**	**0.55**	**0.34**	**-0.24**	-0.05	0.02	0.17	**-0.56**	-0.06
F0 ceiling	**0.62**	1.00	**0.32**	**0.21**	-0.09	-0.09	0.03	0.14	**-0.39**	0.00
F0 floor	**0.55**	**0.32**	1.00	**0.21**	-0.17	0.07	0.11	0.06	**-0.33**	0.11
energy	**0.34**	**0.21**	**0.21**	**1.00**	**-0.50**	0.00	**0.27**	0.18	-0.18	0.02
energy < 1 kHz	**-0.24**	-0.09	-0.17	**-0.50**	1.00	0.08	-0.16	-0.01	0.07	-0.12
spectral slope	-0.05	-0.09	0.07	0.00	0.08	1.00	0.18	0.10	-0.13	-0.14
low freq. EGG	0.02	0.03	0.11	**0.27**	-0.16	0.18	1.00	0.15	-0.06	-0.04
closed quotient	0.17	0.14	0.06	0.18	-0.01	0.10	0.15	1.00	**-0.71**	**-0.75**
open time	**-0.56**	**-0.39**	**-0.33**	-0.18	0.07	-0.13	-0.06	**-0.71**	1.00	**0.80**
open quotient	-0.06	0.00	0.11	0.02	-0.12	-0.14	-0.04	**-0.75**	**0.80**	1.00

Moderate negative correlations of the F0 measures with the proportion of energy under 1000 Hertz indicate that high F0 corresponded to a reduced proportion of low frequency energy. Weak positive correlations of spectral slope with F0 measures for the extended vowel were also consistent with a decrease in low frequency energy with high F0, though the correlations were not evident for the standard phrase. In addition, a negative correlation of overall energy with low frequency energy indicates that as overall energy increased, the proportion of energy at low frequencies decreased. For the [a] vowel, but not for the standard phrase, a positive correlation of overall energy with spectral slope was measured.

Glottal closed quotient was highly negatively correlated with glottal open time and open quotient, indicating that as the vocal folds remained closed for a longer proportion of the glottal period, the vocal open period shortened, both in absolute terms and as a proportion of total vocal period. F0 median, ceiling and floor all correlated negatively with open time, indicating that the main change to F0 was brought about by a change to the length of the glottal open period. The F0 measures also correlated negatively with open quotient, and positively with closed quotient, for the extended [a] vowel, but not for the standard phrase. Overall speech energy correlated positively with closed quotient and negatively with open time. Of particular relevance to the aims of this experiment was the lack of correlation between low frequency spectral energy and spectral slope, and the EGG parameters.

Table 6.4. Correlations between physiological measures. Figures in bold represent correlations significant at $p < 0.05$.

	IBI variability	FT	SC level	# SC responses	mean SCR amplitude
IBI variability	1.00	-0.13	0.06	0.07	-0.03
FT	-0.13	1.00	**-0.35**	0.04	-0.14
SCL	0.06	**-0.35**	1.00	**0.32**	**0.51**
# SCRs	0.07	0.04	**0.32**	1.00	-0.03
mean SCR amp.	-0.03	-0.14	**0.51**	-0.03	1.00

Table 6.4. gives the correlations between the physiological measures that were found to vary significantly with the experimental manipulations. As can be seen, apart from correlations between skin conductance measures, the only significant correlation was a negative correlation between finger temperature and skin conductance level. This indicates that tonic sympathetic arousal as indicated by skin conductance level is associated with peripheral vasoconstriction. Notably, heart rate variability was not correlated with skin conductance measures. Insofar as heart rate variability might indicate parasympathetic activity, no reciprocal sympathetic-parasympathetic activity is evident here. It is also of note that no correlation was measured between the number of skin conductance responses and the mean response amplitude, suggesting that both parameters measure a different aspect of skin conductance activity.

Discussion

Efficacy of the manipulations

Based on the results of experiment two, in which players disengaged from the obstructive, low power condition, an effort was made in this experiment to ensure that players did not disengage from the difficult obstructive condition, while still effectively manipulating goal conduciveness and coping dimensions. Confirmation of the efficacy of the experimental manipulations comes from both subjective reports and physiological data. Players reported feeling more stressed in difficult than in easy conditions, and more satisfaction in easy than in difficult conditions. Coupled with these subjective reports were the skin conductance data, which suggest that players were more sympathetically aroused in difficult (particularly difficult obstructive) conditions that in easy conditions. Measurements of finger temperature indicated a greater degree of vasoconstriction for difficult obstructive situations than for difficult conducive situations, further confirming that experimental manipulations were effective in eliciting a variety of subjective and physiological emotional responses.

Effects of the manipulations on the extended [a] vowel

For the extended [a] vowel, F0 median and ceiling showed little or no difference between easy conducive and easy obstructive conditions, but were higher for difficult obstructive conditions than for difficult conducive conditions. This interaction effect was matched by a similar interaction effect of difficulty and conduciveness on glottal open time. The implication is that under difficult conditions, obstructive events cause a decrease in glottal open time and hence an increase in F0 compared to conducive events. A corresponding interaction effect was also found for open and closed quotients, indicating that under difficult obstructive conditions, the vocal folds remain closed for a greater proportion of the glottal cycle, at the “expense” of the period during which the folds are open. This pattern of results corresponds to the description of the effects of increased laryngeal muscle tension given by Sundberg (1994) according to which the vocal folds are held in a closed position with greater force. A higher subglottal pressure is therefore required to build up so as to force open the vocal folds. When the vocal folds do eventually open, the rush of air through the glottis causes a sudden drop in pressure due to the Bernoulli effect. The vocal folds are thus rapidly drawn back together again, both under the influence of elastic forces of the increased muscle tension, and the pressure drop between them. The result, termed “tense voice”, is a more skewed glottal pulse, with longer closed phase and shorter open phase. Such was the case with the [a] vowel under difficult obstructive situations compared to difficult conducive situations in this experiment, as shown in figure 6.2. The pattern of correlations between glottal open phase, glottal closed phase and F0 (shown in table 6.3) further supports such an explanation.

Physiological evidence consistent with the F0 and glottal data comes from the skin conductance data, which show the same difficulty by conduciveness interaction. The higher skin conductance level and number of responses for the difficult obstructive condition than for the difficult conducive situation indicates that in difficult situations, sympathetic arousal was higher in obstructive than in conducive conditions. Finger temperature indicated a greater degree of peripheral vasoconstriction, consistent with an increase in sympathetic arousal, in difficult obstructive than in difficult conducive events. Such high sympathetic arousal is possibly accompanied by increased muscular tension, including the laryngeal muscles.

The range of changes to F0, glottal phase measures and sympathetic arousal indicators is in partial agreement with the hypotheses of this experiment. An increase in sympathetic arousal and laryngeal tension, leading to higher F0, shorter glottal open phase and longer glottal closed phase, was predicted for difficult condition compared to the easy condition. It is apparent, however, that as in experiment two, such effects were depended primarily on an interaction of difficulty with the conduciveness manipulation. An interaction effect was predicted, although the prediction was that the effects of the difficulty manipulation would depend upon the obstructiveness manipulation, with difficulty effects being amplified in obstructive events compared to conducive events.

The results of this experiment, however, indicate that the effects of the conduciveness manipulation often depended upon the difficulty manipulation. Unfortunately, the theory of Scherer (1986), while not excluding such interaction effects, does not discuss them either. More will be said about the interaction of appraisal dimensions and the need to address how such interactions affect the voice in the concluding chapter.

The proportion of energy under 1000 Hertz was also lower for obstructive than for conducive conditions, particularly in the difficult condition. Such a result could be the result of a more skewed glottal cycle, as described above, which produces sound with more energy in higher harmonics. The positive correlation between energy under 1000 Hz and open time and the weak negative correlation between energy under 1000 Hertz and closed quotient are consistent with such a relation between glottal cycle and spectral energy. Similar correlations were found in experiment 3a. The correlations measured in this experiment were very small, however, making it unlikely that manipulation-dependent changes to the form of the glottal cycle were the sole cause of spectral energy distribution changes.

Examination of the mean Mel power spectrum also reveals that the most prominent differences between obstructive and conducive conditions correspond to fairly limited frequency regions. Such differences, localised in frequency, are more likely a result of differences to the resonance characteristics of the vocal tract than changes to glottal function, which would lead to a more global spectral slope change. Indeed, no significant effects of conduciveness or difficulty on spectral slope were measured for the extended vowel, implying that the changes in the proportion of low frequency energy were more localised in frequency, and at last partly due to resonance changes. Such an interpretation is consistent with the results from experiment two and the predictions of Scherer (1986), based on changes to resonance caused by a more constricted vocal tract in obstructive or negative conditions.

Effects of the manipulations on the standard phrase.

For the standard phrase, results were similar to those for the extended vowel, although median F0 showed a main effect of difficulty, with median F0 higher for difficult than for conducive conditions. For F0 ceiling and F0 floor, an interaction between difficulty and conduciveness was measured, with higher F0 ceiling and F0 floor in difficult obstructive conditions than in difficult conducive situations, but an opposite or no difference between easy obstructive and easy conducive situations. Glottal open time varied in the same manner, suggesting that changes to the F0 floor, median and ceiling were due to changes in the length of the glottal open phase.

In contrast with the results for the extended vowel, no significant effects were found for glottal closed quotient nor glottal open quotient. It is probable that such parameters are of limited use in describing glottal function when averaged across multiple different vowels, and across sentences where intonation causes large shifts to F0. The lower correlations between the glottal and acoustic parameters for the standard phrase compared to the extended vowel indicate that this is the case.

It is also probable that the mechanisms responsible for changing F0 in a fluent sentence differ from those at play during steady-state vowel production. A large influence on F0 in sentences is intonation, which is non-existent in extended vowel production. Although emotional changes to laryngeal tension might still have an effect on the opening and closing function of the vocal folds, it is possible that such an effect is swamped by the influence of emotion on large intonational F0 changes.

Relative to this point, an interesting correspondence between the effects of difficulty and conduciveness manipulations on F0 ceiling and EGG low frequency energy was measured. EGG low frequency energy had been measured in an exploratory manner as a possible indicator of larynx movement that could be associated with sentence intonation. The similarity in results between EGG low frequency energy and F0 ceiling indicates that larynx movement might well be a significant contributor to emotional changes to F0 range.

An interaction effect of difficulty and conduciveness on spectral slope was also measured. Spectral slope was flatter for difficult obstructive than for difficult conducive conditions, but flatter for easy conducive than for easy obstructive conditions. This result raises the question of whether the changes observed to spectral slope were due to changes in vocal fold function. The lack of correlation between spectral slope and any of the F0 or EGG parameters would seem to suggest that no direct link exists. However, the Mel spectra in figure 6.10 indicate that the differences between obstructive and conducive conditions, for both easy and difficult cases, are quite global, stretching over an extended range of frequencies. One might expect that changes to spectral characteristics due to vocal tract resonance changes would be concentrated around parts of the spectrum that correspond to formants, or perhaps anti-formants. This does not seem to be the case here.

Unfortunately it is also the case that the spectra measured here were averaged over multiple phonemes, and thus it is impossible to make inferences about individual formant changes. A more detailed phoneme-by-phoneme formant analysis might be required to understand the nature of emotion-induced spectral changes to fluent speech. Apart from being very time consuming however, current techniques of formant analysis are fraught with inaccuracies. The precise measurement of formant locations, amplitudes and bandwidths requires very high quality, linear, recordings of speech without phase distortions (as recorded in an anechoic chamber for example).

Conclusion

The results of this experiment indicate that faced with an obstructive situation with limited coping potential, the body mobilises its resources to actively cope. This it does by elevating activity in the sympathetic branch of the autonomic nervous system, as indicated by skin conductance level and skin conductance responses. This elevated sympathetic activity corresponds to a probable increase in laryngeal tension, which leads to a corresponding change in the opening and closing of the vocal folds. In addition to a general speeding up of the vocal cycle, the folds close with more force and remain closed for a longer proportion of each vocal cycle. The result is a higher fundamental frequency, as well as a possible increase in the strength of high harmonics and thus in the proportion of acoustic speech energy at higher frequencies.

For pronunciation of a phrase, as opposed to an extended vowel, some F0 variation is due to the larynx movement involved in intonation, as indexed by the low frequency EGG signal. Further investigation of larynx movement, possibly using more accurate measurement techniques such as dual EGG recording from two vertically separated locations on the neck, is needed to understand how such a mechanism is affected by different types of emotional response.

Obstructive, challenging conditions also produce more local changes to spectral distribution, possibly as a result of constriction of the walls of the vocal tract, as predicted by Scherer (1986). The use of EGG measurements in this experiment has provided valuable insights into the changes that occur in vocal fold function due to emotional physiological responses, but has not provided clear results with respect to spectral changes. An understanding of the causes of emotional spectral changes to speech will require further use of such EGG techniques in combination with accurate formant analysis.

[1] Multivariate techniques of analysis, such as ANOVA, were not used in this instance since they make implicit assumptions about the dependent and independent variables, which we do not wish to make here (subjective ratings are as much a dependent variable as vocal and physiological measures). In addition, given the unbalanced nature of the repeated measures design, with eight unequally represented categories of emotion, violations of the sphericity assumption in a repeated measures ANOVA would be severe.

7. General Discussion

This thesis has focussed on the changes to the voice produced by emotion, with an emphasis on physiological push effects as described by Scherer (1986). The principal aim of the research was to test competing models of emotional changes to voice production. Scherer's predictions of a multi-dimensional pattern of changes based on emotion antecedent appraisal outcomes were tested against the competing theory of one underlying physiological arousal mechanism being responsible for changes to emotional speech. In a series of three experiments, computer games and tasks were manipulated in such a way as to provoke emotion appraisals along a small number of appraisal dimensions. Acoustic and electroglottographic recordings of standard phrases and vowels were made in conjunction with physiological measurements in an effort to elucidate some of the mechanisms responsible for the resulting emotional changes to speech.

In experiment one, the paradigm of using computer games as a means of inducing and studying emotional responses was tested. Two appraisal dimensions, intrinsic pleasantness and goal conduciveness, were manipulated in the computer game. At set moments immediately following game manipulations, players were prompted to provide a verbal report of the game situation, which was recorded for subsequent analysis. The results from the first experiment indicated that the two appraisal dimensions affected speech acoustics in two distinct ways. Manipulations of the intrinsic pleasantness of game situations produced changes to the spectral characteristics of speech, with unpleasant situations leading to a greater proportion of high frequency energy than pleasant situations. This result was consistent with Scherer's prediction (1986) based upon the hypothesis that unpleasant situations lead to a response that includes the constriction of the vocal tract, a configuration that causes relatively greater resonance at high frequencies than the unconstricted vocal tract corresponding to pleasant situations. Manipulations of goal conduciveness lead to changes primarily to energy and F0 parameters. Goal obstructive game events were followed by speech with higher F0 floor and energy than were goal conducive situations. This result was not consistent with Scherer's original (i.e. Scherer, 1986) predictions for goal conduciveness appraisals. A possibility was that the game manipulation of goal conduciveness also inadvertently led to other appraisals such as that of discrepancy. Appraisals of goal discrepancy should, according to Scherer, lead to an increase in sympathetic arousal and muscle tension that would cause a higher F0. Players' emotion reports lent credence to such an explanation, with more surprise being reported after obstructive than after conducive game events.[1] Aside from addressing the specific predictions made by Scherer, data from experiment one also indicated that emotional changes to speech occurred along at least two, and possibly more, dimensions. It was concluded that such a result is inconsistent with the hypothesis that emotional changes to speech reflect the effects of a single dimension of physiological arousal.

Experiment two was designed to address the major problem with experiment one, namely the possibility that the goal conduciveness manipulation had also provoked other, unintended appraisals. A new manipulation of goal conduciveness was designed in which the game situation was identical in both conducive and obstructive conditions, except for the manipulation of conduciveness by awarding or penalising the player points. In addition, the appraisal dimension of coping potential was studied by manipulating the players' control of their space ship and the power they had to defeat enemies. All the manipulations in experiment two were also designed to last a number of seconds, so that effects on the voice and physiology could be measured without pausing the game. A number of physiological measurements were made in an effort to more directly measure the physiological changes due to appraisal that might in turn affect vocal production.

Experiment two provided additional evidence that a simple arousal model of emotional response could not be used to explain all the observed emotional changes to vocal production. Manipulations of conduciveness produced changes to overall energy of the speech signal, whereas control manipulations produced main effects in F0 range and F0 floor. Median F0, and the proportion of energy below 1KHz changed according to the interaction of conduciveness and power manipulations. The fact that the different acoustic parameters showed such distinct effects of different experimental manipulations implies that multiple mechanisms, rather than a single arousal mechanism, are responsible for such vocal changes. Further support for such a conclusion was drawn from the lack of unidimensional covariance of the physiological measurements. Thus the very notion of "physiological arousal" as a quantifiable and scientifically useful construct was brought into doubt.

The results of experiment also highlighted some areas in which Scherer's predictions of the effects of multiple appraisal outcomes on the voice need to be made more specific. For example, instead of appraisal outcomes producing a cumulative, additive effect on voice production, there was an interaction between appraisals in determining vocal changes. In particular, manipulations of power interacted with manipulations of conduciveness to produce effects on physiology and voice. The theory of Scherer does not exclude that the outcome of one appraisal might depend on the output of other appraisals, and thus lead to interaction effects on the voice. However, the lack of an explicit description of exactly how multiple appraisals combine in their effects on the voice makes it difficult to test the predictions empirically.

The finding in experiment two of greater low frequency energy for conducive than for obstructive events under high power conditions was consistent with Scherer's hypothesis of constriction of the vocal tract for obstructive events leading to greater resonance of higher frequencies. No such conduciveness effect was found for low power conditions however. In addition, consistent with results from experiment one was the finding of greater F0 values for obstructive events than for conducive events in high power situations, although no such difference in low power conditions was measured. Since experiment two had specifically been designed to other, uncontrolled factors as the cause of such F0 changes (as there might have been for experiment one), the effect of higher F0 values for obstructive than conducive situations seems to indicate greater arousal during these conditions.

Such an explanation was supported by the data for heart rate variability, which was consistent with lower parasympathetic activity for high power, obstructive than high power conducive conditions. The data for skin conductance response amplitude indicated a higher level of sympathetic arousal for obstructive situations than for conducive situations regardless of power however, a result matched by greater overall speech energy for obstructive than for conducive situations. These results would seem to indicate that although sympathetic arousal plays a role in modulating certain vocal characteristics, the mapping is not one-to-one. Unfortunately, the complexity of the experimental design (a three factor factorial design), in experiment two, together with the lack of more direct measures of vocal physiology, made it impossible to ascertain with more precision the relationship between physiological changes and vocal changes.

Experiment three was designed to address these questions. In addition to physiological measures, EGG was used to provide a more direct measure of changes to vocal fold opening and closing as a function of experimental manipulations, and in relation to concurrent acoustic changes to speech. Further refinements were made to the experimental design, including concentrating on only two manipulated appraisal dimensions, conduciveness and coping potential, in order to reduce complexity and make the results more easily interpretable. In addition, the coping potential manipulation was designed and pretested specifically so as not to lead to disengagement under the most difficult condition, as might have happened in experiment two.

Results indicated that as with experiment two, changes to vocal measures depended not only on individual manipulated appraisal dimensions, but also interactions between them. The increased experimental control and more simple design of experiment three led to results for vocal and physiological measures that were more consistent than those of experiment two. In addition, EGG measures were found to be particularly useful in interpreting F0 changes, and in linking them to changes to physiology.

Specifically, it was found that difficult, obstructive conditions led to generally higher F0 (range and level) than difficult conducive conditions. For extended [a] vowels, these changes in F0 were mirrored closely by a conduciveness by coping interaction for skin conductance data and for finger temperature, indicating that sympathetic arousal was higher in difficult obstructive than in difficult conducive conditions. Examining the EGG measures revealed that the F0 changes could be explained in terms of shorter glottal open times for obstructive situations. In addition, longer relative closed phases and shorter relative open phases were consistent with raised laryngeal tension in difficult obstructive conditions. Correlations between acoustic, EGG and physiological data, though still small, supported these interpretations.

The picture for standard phrases was similar, although there was less correspondence between physiological data and F0 measures. Measurement of low frequency EGG signal energy indicated that larynx movement is likely an important determinant of F0 variation in emotional speech. In pronunciation of full phrases or sentences, such movement of the larynx, associated with speech intonation, is likely to dominate more subtle changes in vocal fold function due to changes in laryngeal tension. This experiment revealed that both low frequency EGG signal and F0 ceiling were higher in easy conducive and difficult obstructive conditions than in easy obstructive or difficult conducive situations, though the mechanisms behind such an interaction effect are were unclear.

For both extended [a] vowels and standard phrases, there was evidence for a lower proportion of energy at low frequencies for difficult obstructive than for difficult conducive conditions. This result was partly consistent with Scherer's predictions that obstructive situations would lead to constriction of the vocal tract and thus more resonance of higher frequencies. There were also indicators that changes to spectral slope were brought about partly by changes to vocal fold function, with tense voice having more high frequency energy and a less steep spectral slope, as described by Sundberg (1994).

Can emotional vocal changes be explained with an arousal model?

The primary aim of this research was to test unidimensional arousal theories of emotional speech against multidimensional models. The results from the three experiments clearly mitigate against a simple arousal model. In all three experiments, patterns of change across different vocal – and physiological – measures did not covary with experimental manipulations as one would predict under an arousal hypothesis. Instead, while some measures were influenced primarily by manipulations of conduciveness or pleasantness, others were influenced by manipulations of coping while still others were changed by interactions between appraisal dimensions.

The most compelling evidence against a single arousal dimension came, however, from the physiological measurements. Skin conductance response amplitude and finger temperature were found to vary as a function of conduciveness, whereas the number of skin conductance responses and skin conductance level were determined by interactions between conduciveness and coping. Heart rate variability, which reflects both sympathetic and parasympathetic influences, was found to vary primarily as a function of coping.

Given what is now known about the organisation of the peripheral nervous system, this should come as no surprise. The sympathetic and parasympathetic branches can both be activated largely independently of one another (Bernston, Cacciopo, Quigley, and Fabro, 1994). Different combinations of parasympathetic and sympathetic activity provide the body with more possible responses to the variety of emotional situations encountered, as well as subserving more basic homeostatic functions. Thus reciprocal activation of sympathetic and parasympathetic branches (i.e. the activation of one and the deactivation of the other) leads to a relatively stable response with a high dynamic range (Bernston et al., p. 45). Such a response might be suitable for unambiguous situations in which a clear, and extreme response is required, such as confrontation with a clearly threatening stimulus. Coactivation of both branches leads to an inherently unstable system (Bernston et al., 1994), in which small changes to activation in one of the branches can lead to a sudden change in organ end state. Such a mode of activation might be appropriate in highly relevant, but ambiguous situations.

Although it is unclear how such different modes of autonomic functioning correspond to, or affect voice production, it is clear that the concept of one arousal dimension producing concomitant changes to vocal measures is no longer tenable. The results of this series of experiments have largely confirmed this.

Can emotional vocal changes be explained with an appraisal model?

The alternative model tested in this thesis has been the appraisal theory of Scherer (1986), which proposes that situations are appraised by people along a number of pertinent dimensions, with each appraisal outcome producing an adaptive pattern of physiological responses, with predictable consequences on voice production. It should again be noted, however, that appraisal theory was used in this research as a principled way in which to examine emotional changes to voice production. One of the core aspects of appraisal theory – that appraisals themselves are subjective evaluations, and do not map one-to-one onto situations - was deliberately avoided in this research by designing experimental manipulations that were as unambiguous as possible. The link between appraisal outcomes and changes to speech and physiology is already highly complicated, with many unknown parameters. To ensure that the results of the experiments in this thesis could be meaningfully used to test or falsify competing hypotheses, it was deemed necessary to eliminate any possible additional variation due to the link between situation and appraisal outcome.

The most consistent agreement of the data with Scherer's predictions was that unpleasant or obstructive conditions led to speech with a lower proportion of low frequency energy than conducive conditions, albeit only for difficult situations in experiment three. Although mechanisms underlying such a change remain unclear, it seems likely that changes to vocal tract resonance, as suggested by Scherer, are at least partly involved. Scherer also suggested a link between appraised coping potential (specifically control) and sympathetic arousal, that should be associated with changes to laryngeal muscle tension and thus changes to F0. Such changes were found (for example, the higher value of F0 for high control versus low control in experiment two), although in most cases, coping potential (as manipulated with control and power in experiment two, and difficulty in experiment three) interacted with conduciveness in producing vocal and physiological effects.

The fact that in the last two experiments, the majority of effects found involved interactions between coping potential and conduciveness manipulations represents the greatest problem in comparing these results with Scherer's predictions. According to Scherer, the outcome of each appraisal dimension can be expected to produce changes to physiology, and therefore the voice, relatively independently of the other appraisal dimensions. The result of a combination of appraisal outcomes will thus be the cumulative effect of individual appraisal effects. To the extent that two appraisal dimensions produce effects on different physiological organs, one might thus expect their measured effects on resulting speech to be independently measurable. For example, Scherer makes the prediction that appraisals of goal conduciveness will cause changes to the configuration of the vocal tract, whereas appraisals of coping potential (specifically power) will cause changes to the tension of laryngeal muscles. Since vocal tract configuration has relatively little or no effect on F0, one would predict that manipulations of coping potential would produce changes to F0 regardless of any concurrent manipulations of conduciveness. This was clearly not the case in this research. Consistent interaction effects of conduciveness and coping potential on vocal measures were found.

One possibility is that the subjective appraisal of the manipulated events on one dimension depended upon the appraisal on the other dimensions. Hence, rather than coping being appraised as low in conducive, difficult situations, the appraisal of coping might simply not have happened, or at least might have been accorded less importance, following an appraisal of the situation as conducive. Scherer indeed allows for this type of process in his sequential appraisal theory, with the outcome of one appraisal feeding into and influencing the outcome of succeeding appraisals. The interactions observed in this experiment might be explained by such a mechanism, although given that we have no knowledge of exactly how each situation was subjectively appraised by the speakers, we cannot be sure either way. Clearly it would be preferable in future studies to collect data on how all manipulated situations are appraised. One suspects, however, that overt verbal reports of appraisal of obviously easy or difficult situations will reflect the obviously intended appraisal, rather than the possibly automatic or unconscious appraisal that actually occurred.

How does appraisal affect the voice and physiology?

Another possible explanation for the interaction effects of appraisal dimensions on vocal changes observed in this research is that appraisal outcomes are combined in some way before an emotional response is generated. The idea that physiological and expressive emotional responses might be organised at the level of specific combinations of appraisal outcomes, rather than at the level of individual appraisals, is not contrary to the basic tenets of appraisal theory. Appraisal theorists are in broad agreement on the role of cognitive evaluations in eliciting emotions, and the core set of evaluative dimensions involved. There is, however, a lack of agreement over how appraisals organise emotional responses, including subjective feeling, physiology, and facial and vocal expression. Smith and Lazarus (1990) make the distinction between a *molecular* level of organisation, in which responses are organised at the level of single appraisals, and a *molar* level of organisation, in which responses are organised around patterns of several appraisals or even more holistic "core relational themes" (see Lazarus, 2001; Lazarus, 1991; Smith and Lazarus, 1990).

Most appraisal researchers who have made specific predictions of the effects of appraisal results on response patterning have done so at a molecular level, i.e., suggesting specific effects of appraisal results separately for each evaluation dimension (e.g. Scherer, 1986; Smith, 1989; Schmidt, 1998; Wehrle, Kaiser, Schmidt and Scherer, 2000). In making predictions for full-blown emotional responses, the individual appraisal effects are usually combined additively.

It seems likely, however, that at least some emotional response patterns reflect highly learned combinations of appraisal outcomes occurring simultaneously. One argument for the existence of such combined appraisals is that by combining appraisal outcomes a more coherent understanding of the appraised situation will result. Such an understanding should enable more appropriate response preparation to be undertaken. For example, confronted by an overly inquisitive flying insect that is possible, though difficult to escape (moderate coping potential), knowing whether or not the insect can bite (goal conduciveness) would be highly useful in determining whether to prepare the body for escape, and therefore whether to increase sympathetic arousal. The extreme form of a combined-appraisal view, holds that it is the total appraised meaning of the situation that leads to a coordinated, adaptive response (Smith and Lazarus, 1990, p. 624) or action tendency (Frijda, 1986). Such coordinated responses are not contrary to the principles of appraisal theory, nor are they equivalent to the idea of completely "hard-wired" emotion circuits. The subjective appraisal of a situation is still at the core of such a mechanism.

The level of organisation, single or combined, with which emotional responses are organised, has a direct bearing on the study of changes to speech due to appraisal. Given a single-appraisal level of organisation, one might be able to find specific acoustic vocal parameters which serve as markers of single appraisals. For example, eyebrow frown and heart rate changes have been linked to appraisals of goal obstruction and anticipated effort (Smith, 1989). In this thesis there is some evidence that changes to spectral energy distribution are primarily related to appraisals of pleasantness or conduciveness. However, at least in the case of the vocal measures examined herein, it seems that the effect of a given appraisal dimension on vocal characteristics often depends on other appraisal outcomes. Thus sympathetic arousal and F0 changes depend on the combined meaning of conduciveness and coping potential appraisals, as indicated in particular by the results of experiment three.

This does not imply that vocal measures cannot be used as indicators of single appraisal dimensions. One must simply be careful to keep other appraisal dimensions constant, and be aware of their influence on the measures of interest should they change. Thus both F0 and high frequency spectral energy could be used as consistent measures of coping potential only when studying goal obstructive situations. It is equally possible that research on other response modalities, such as autonomic physiology or facial expression, would benefit by considering the interaction between different appraisal dimensions. Research on the cardiovascular indicators of coping (e.g. Smith, Ellsworth and Pope, 1990; Pecchinenda and Smith, 1996) for example, might benefit from explicitly examining the effects of goal conduciveness (e.g. by using reward or punishment) on manipulations of coping.

How do emotional changes to physiology affect the voice?

This research has differed from most previous research on emotional speech in two aspects. The emotional speech examined was not acted, but rather elicited using manipulations of games and tasks. Furthermore, in an effort to understand the mechanisms underlying emotional changes to speech, physiological measures were also taken. In the last two experiments of this research, the correspondence between vocal measures and physiological measures was examined, both in terms of how each measure was affected by the experimental manipulations, as well as directly through correlational analysis.

Direct correlations between vocal and physiological measures were very low in both experiments, indicating a low degree of correspondence in their general (i.e. non-manipulation specific) variation. The lack of higher correlations is probably due to two factors. First, despite efforts to control for other sources of physiological and vocal variation, the largest amount of variation to both types of measures is due to non-experimental factors. Such non-controlled variation will mask any manipulation-specific correlations. Second, the physiological measurements made were necessarily very indirect measures of vocal physiology. Although it is possible to directly measure laryngeal muscle tension, lung volume, subglottal pressure and the position and tension of vocal tract muscles, such measurements are extremely invasive and would thus interfere with the emotion induction procedure. Nevertheless, in experiment three, EGG recordings were successfully used to “bridge the gap” between acoustic and physiological measures. Correlations between EGG measures, acoustic measures and physiological measures showed a covariation of glottal measures such open time and closed phase, with autonomic measures such as skin conductance activity and finger temperature, and acoustic measures such as F0. Thus sympathetic arousal was seen to correspond to shorter glottal open time, and thus higher F0, confirming the role that sympathetic arousal plays in emotional effects on F0.

The patterns of physiological and vocal changes across experimental conditions showed that fluency changes (in the second experiment), as well as spectral changes and changes to F0 range, could not be fully explained by sympathetic arousal. However, interactions of conduciveness and coping potential consistently produced changes in sympathetic arousal, as indexed by skin conductance activity and finger temperature, as well as corresponding changes to glottal open time, glottal open phase, glottal closed phase, and F0 measures. Such changes indicate that at least for some vocal measures, changes due to emotion are mediated by changing autonomic activity. These results are consistent with the research of Jürgens (1979, 1988, 1994), who has suggested that the functional evolution of vocalisation is reflected in three hierarchically organised neural systems, the second of which, consisting of the mid-brain periaqueductal gray, parts of the limbic system including the hypothalamus, midline thalamus, amygdala and septum, and the anterior cingulate cortex, is also central to the generation and regulation of emotion. Consistent with the ideas of Jürgens, the Polyvagal Theory of Emotion of Porges (1997) posits a special role of the Ventral Vagal Complex, which includes both somatic and visceral efferent neural fibres of the cranial nerves, in both the rapid regulation of metabolism to meet environmental challenges, and the production of emotional expressions, including vocalisations. Organised neural structures have also been identified in the midbrain periaqueductal grey (PAG) that are involved in differentiated emotional responses and are also fundamental to the control of respiratory and laryngeal functioning during vocal production (Davis, Zhang, Winkworth & Bandler, 1996; Bandler & Shipley, 1994). Interestingly, these studies indicate that control of the vocal tract and articulators is mediated by separate mechanisms, which might explain why emotion-invoked changes to speech fluency and spectral energy distribution did not covary consistently with skin conductance measures.

Integrating these results, a picture develops of an emotional expression system that makes up part of a more general emotional response system, in which specific brainstem nuclei, activated via pathways from the limbic system, co-ordinate the activation of groups of laryngeal and respiratory muscles leading to specific vocal patterns. It remains to be seen if such neural mechanisms are organised around appraisals, as suggested by

Scherer (1986) and other appraisal theorists (see Smith and Scott, 1997). It also remains unclear to which extent such mechanisms are the exclusive result of automatic processing or might, particularly in humans, also be engaged in a controlled manner. If the latter is the case, then one would expect the characteristics of voluntary emotional speech to largely correspond to those of speech perturbed by involuntary emotional responses, as had been suggested by Scherer (1986).

Conclusions and directions for future research

This research represents a first attempt to systematically study the changes to speech that are produced by emotion. In attempting to integrate current theories of emotion, psychophysiology and speech production, modest progress has been made in understanding what mechanisms underlie changes to speech under emotional conditions. The idea that the effects of emotion on speech are limited to the effects of general physiological arousal has been refuted. Although some changes to emotional speech, such as those involving the vocal folds, were shown to depend largely on sympathetic arousal, other speech characteristics, such as speech fluency and spectral energy did not. An alternative view, that changes to speech reflect changes to the underlying speech physiology resulting from appraisals of the environment along a number of appraisal dimensions, has received some support. Changes to a number of speech variables were measured in response to manipulations of pleasantness, goal conduciveness and coping potential. In finding that vocal changes often result from the interaction of appraisal dimensions, this research has also identified an area where appraisal theories of emotional speech need to be made more explicit. In particular, the mechanisms by which interactions of goal conduciveness and coping potential consistently produce effects on vocal and physiological measures need to be specified.

A number of additional questions remain as to the mechanisms responsible for emotional changes to speech characteristics. In particular, consistent changes to the spectral distribution of energy across different emotional conditions defy simple explanation in terms of vocal fold function or resonance changes. F0 variation, while partly affected by the changes to vocal fold function that correspond to sympathetic activation of the ANS, also seems to change as a function of larynx movement. The latter does not show a connection to sympathetic arousal, and given its role in speech intonation, might reflect the effects of emotion on cognitive planning. Given current interest in the topic of cognition and emotion, and how cognitive and emotional factors interact in phobias, anxiety disorders and depression (as indexed by a number of recent books on these topics, e.g. Dalgleish and Power, 1999; Eich, Kihlstrom, Bower, Forgas, and Niedenthal, 2000), research on the possible cognitive mediators of emotional changes to speech intonation and fluency could prove fruitful.

It should also be noted that the participants in these experiments were predominantly young males, and in the case of the first experiment, were all adolescents. There are reasons to believe that the results from these experiments can be generalised to a large degree to females and older populations. There is no empirical evidence to suggest that the way that speech physiology is influenced by emotion, differs fundamentally with sex or age. The mechanisms of vocal fold vibration, and resonance of the glottal sound wave through the vocal tract, are basically the same in males and females of different ages. Indeed, in these experiments, the results from adolescent speakers in experiment one were consistent with the results of subsequent experiments with young adults. This fits with previous studies that have shown that for a range of acoustic parameters, including f0 measures and formant frequencies, there is no interaction between speaker or age and phonetic context (e.g. Whiteside & Hodgson, 2000). Nonetheless, although the basic mechanisms are likely to be the same across age and sex of the speaker, some important age- and gender-specific differences can be expected. The most obvious difference is that children and pre-pubescent adolescents have a significantly less massive and differently positioned vocal apparatus than adults, particularly for males for whom the larynx starts to descend as early as age 7 or 8 years (Woisard, Percodani, Serrano, Pessey, 1996). The result is not simply a scaling of fundamental frequency and formants. Vocal fold vibration modes in particular are likely to be different in children than in adults, due to their different length and mass, and might be differently affected by emotional physiological changes. A similar argument applies to female speakers, for whom the vocal folds do not change following puberty to same extent as for males. Further differences might result from the interaction between F0 and formant frequencies that can take place with children's and female's voices (due to the much higher F0 than adult male speakers). For example, studies have found that formant frequencies and amplitudes depend upon a combination of vocal intensity and speaker age and sex (Huber, Stathopoulos, Curione, Ash & Johnson, 1999). Unfortunately, it is impossible even to speculate on the nature of emotion-dependent acoustic differences in females and children, given the paucity of research on the topic. As mentioned earlier in this thesis, female and child voices are intrinsically more difficult to analyse precisely because of such F0-formant interactions; such difficulties would need to be overcome in future research on emotional speech in these populations.

There are a number of obvious avenues for the continuation of this research. As has been discussed, much can be done to improve and expand upon the acoustic and physiological measures examined. Accurate formant analysis, using linear, non-phase distortion recording equipment, could be used in combination with more accurate laryngeal measurements, to better understand the causes of emotional changes to spectral energy distribution. The formant analysis would need to include not only measurement of formant frequency, but also bandwidth and amplitude. Laryngeal measurements could include photoglottography, which would yield a precise measurement of the form of vocal fold closure. With non-phase distorted recordings, accurate inverse filtering techniques could also be used to arrive at an estimate of glottal airflow under different emotional conditions (see Klasmeyer, 1998 for an example of such an approach).

An extension of the current research to other appraisal dimensions is warranted. In particular, an examination of those appraisal dimensions concerning social situations would seem particularly relevant to vocal expression, although it is unclear whether the distinction between push and pull factors could be maintained in such a study. In addition, further measurement of the same appraisal dimensions as those studied in this thesis, but with different instantiations or in different contexts are needed. In order to examine more intense forms of emotion, it might be necessary to resort to non-experimental, or quasi-experimental designs. Portable voice recording and physiological recording systems are now available that make it feasible to monitor and record speech and physiology online in real emotion-inducing situations outside the laboratory. Although activities involving physical movement are excluded due to the artefacts they would produce in physiological measurements, it might be possible to successfully record speech and physiology in situations such as interviews or public presentations.

The study of the expression of emotion in the voice, in particular the involuntary effects of emotion on speech, has for a long time received much less attention than the perception of emotional speech. The reasons are numerous, but primary among them no doubt is the time-consuming nature and difficulty of eliciting emotions in the laboratory, recording and analysing speech, and recording and analysing physiology. As has been evident in this research, the results of such a long-winded undertaking are often inconsistent and contradictory. However, such a continued effort is required if we are to develop more than the rudimentary understanding of emotional speech that we currently possess.

[1] Although Scherer (1986) originally made a distinction between goal conduciveness appraisals and discrepancy appraisals, in the most recent version of Scherer's theory (Scherer, 2001; Scherer, personal communication), goal conduciveness and discrepancy are treated as the same appraisal dimension. Thus, obstructive/discrepant appraisal outcomes are predicted to produce changes to the voice corresponding to the predictions for obstructive appraisals and discrepant appraisals previously published.

References

Alpert, M., Kurtzberg, R. L. & Friedhoff, A. J. (1963). Transient voice changes associated with emotional stimuli. Archives of General Psychiatry, 8, 362-365

Anderson, C. A., & Ford, C. M. (1986). Affect of the game player: Short-term effects of highly and mildly aggressive video games. Personality and Social Psychology Bulletin, 12, 390-402.

Arnold, M. B. (1960). Emotion and personality. (Vol.1). Psychological aspects. New York: Columbia University Press.

Bachorowski, J. A., & Owren, M. J. (1995). Vocal expression of emotion is associated with formant characteristics. Paper presented at the 130th meeting of the Acoustical Society of America, St. Louis, MO.

Bachorowski, J. A., & Owren, M. J. (1998). Laughter: Some preliminary observations and findings. In A. H. Fischer (Ed.), Proceedings of the Xth conference of the International Society for Research on Emotions. (pp. 126-129).Wuerzburg: International Society for Research on Emotions.

Baddeley, A. (1986). Working memory. Oxford: Clarendon Press.

Bandler, R. & Shipley, M. T. (1994). Columnar organization in the mid-brain periaqueductal gray: modules for emotional expression? Trends in Neuroscience, 17, 379-389.

Banse R. & Scherer, K. (1996). Acoustic profiles in vocal emotion expression. Journal of Personality and Social Psychology, 70(3), 614-636

Banse, R., Etter, A., Van Reekum, C. & Scherer, K. R. (1996). Psychophysiological responses to emotion-antecedent appraisal of critical events in a computer game. Poster presented at the 36th Annual Meeting of the Society for Psychophysiological Research, Vancouver, Canada, 16-20 October 1996.

Baum, S. R., Pell, M. D. (1999). The neural bases of prosody: Insights from lesion studies and neuroimaging. Aphasiology, 13, 581-608.

Berntson, G. G., Cacioppo, J. T., Quigley, K. S., & Fabro, V. T. (1994). Autonomic space and psychophysiological response. Psychophysiology, 31, 44-61.

Berry, D. C. (1987). The problem of implicit knowledge. Expert Systems, 4, 144-151.

Boiten, F. (1996). Autonomic response patterns during voluntary facial action. Psychophysiology, 33, 123-131.

Boiten, F. (1993). Emotional breathing patterns. Doctoral dissertation, University of Amsterdam.

Boiten, F. A. (1998). The effects of emotional behaviour on components of the respiratory cycle. Biological Psychology, 49, 29-51.

Boiten, F. A., Frijda, N. H., & Wientjes, C. J. E. (1994). Emotions and respiratory patterns: Review and critical analysis. International Journal of Psychophysiology, 17, 103-128.

Borden, G.J., & Harris, K. S. (1994). Speech science primer. Physiology, acoustics and perception of speech, 3rd Ed. London: Williams & Wilkins.

Bradley, M. M. & Lang, P. J. (2000). Measuring emotion: Behavior, feeling, and physiology. In R.D. Lane, L. Nadel, G. L. Ahern, J. J. B. Allen, A. W. Kaszniak, S. Z. Rapcsak, & G. E. Schwartz (Eds.), Cognitive neuroscience of emotion (pp. 242-276). New York: Oxford University Press.

Bunn, J.C. & Mead, J. (1971). Control of ventilation during speech. Journal of Applied Physiology, 31, 870-872.

Cacioppo, J. T., Berntson, G. G., Larsen, J. T., Poehlmann, K. M., & Ito, T. A. (2000). The psychophysiology of emotion. In R. Lewis & J. M. Haviland-Jones (Eds.), The handbook of emotion, 2nd Ed (pp. 173-191). New York: Guilford Press.

Cacioppo, J. T., Klein, D. J., Berntson, G. G., & Hatfield, E. (1993). The psychophysiology of emotion. In R. Lewis & J. M. Haviland (Eds.), The handbook of emotion (pp. 119-142). New York: Guilford Press.

Cacioppo, J. T., Tassinary, L. G., & Fridlund, A. J. (1990). The skeletomotor system. . In J. T. Cacioppo & L. G. Tassinary (Eds), Principles of psychophysiology: Physical, social, and inferential elements. (pp. 325-384). New York: Cambridge University Press.

Cannon, W. B. (1929). Bodily changes in pain, hunger, fear, and rage (2nd ed.). New York: Appleton.

Childers, D. G., & Krishnamurthy, A. K. (1985). A critical review of electro-glottography. Critical Reviews in Bioengineering, 12(2), 131-161

Cornelius, R. R. (1996). The science of emotion. Upper Saddle River NJ: Prentice Hall.

Cosmides, L. (1983). Invariances in the acoustic expression of emotion during speech. Journal of Experimental Psychology: Human Perception and Performance, 9, 864-881.

Dalgleish, T. & Power, M. J. (Eds.). (1999). Handbook of cognition and emotion. Chichester, England: John Wiley and Sons.

Daniloff, R., Schuckers, G., & Feth, L. (1980). The physiology of speech and hearing. Englewood Cliffs, NJ: Prentice-Hall.

Darwin, C. (1872). The expression of emotions in man and animals. London: John Murray (3rd. edition, P. Ekman (Ed.). London: HarperCollins, 1998).

Davidson, R. J., Gray, J. A., LeDoux, J. E., Levenson, R. W., Panksepp, J., & Ekman, P. (1994). Is there emotion-specific physiology? In P. Ekman, & R. J. Davidson. (Eds.), The nature of emotion: Fundamental questions. (pp. 235-262). New York: Oxford University Press.

Davis, P. J., Zhang, S.P., Winkworth, A., & Bandler, R. (1996). Neural control of vocalization: Respiratory and emotional influences. Journal of Voice, 10, 23-38.

Dawson, M. E., Schell, A. M., & Filion, D. L. (1990). The electrodermal system. In J. T. Cacioppo & L. G. Tassinary (Eds.), Principles of psychophysiology: Physical, social, and inferential elements (pp. 295-324). New York: Cambridge University Press.

Deller, J. R., Proakis, J. G., & Hansen, J. H. L. (1993). Discrete time processing of speech signals. New York: Macmillan.

Duncan, G., Laver, J. & Jack, M. A. (1983). A psycho-acoustic interpretation of variations in divers' voice fundamental frequency in a pressured helium-oxygen environment (Work in Progress Report Ser.No.16 (S.9-16) University of Edinburgh, Department of Linguistics)

Edwards, P. (1998) Etude empirique de déterminants de la différenciation des émotions et de leur intensité. Unpublished Ph.D. Thesis, University of Geneva.

Eich, E., Kihlstrom, J. F., Bower, G. H., Forgas, J. P., & Niedenthal, P. M. (Eds.). (2000). Cognition and Emotion. New York: Oxford University Press.

Ekman, P. (1972). Universals and cultural differences in facial expressions of emotions. In J. Cole (Ed.) Nebraska symposium on motivation, 1971 (pp. 207-283). Lincoln, NE: University of Nebraska Press.

Ekman, P. (1973a). Cross-cultural studies of facial expression. In P. Ekman (Ed.), Darwin and facial expression: A century of research in review. (pp. 169-222). New York: Academic Press.

Ekman, P. (1973b). Darwin and facial expression: A century of research in review. New York: Academic Press.

Ekman, P. (1979). About brows: Emotional and conversational signals. In M. V. Cranach, K. Foppa, W. Lepenies, & D. Ploog (Eds.), Human ethology (pp. 169-202). Cambridge: Cambridge University Press.

Ekman, P. (1982a). Emotions in the human face (2nd ed.).New York: Cambridge.

Ekman, P. (1982b). Methods of measuring facial action. In K. R. Scherer, & P. Ekman (Eds.), Handbook of methods in nonverbal behavior research (pp. 45-90). Cambridge: Cambridge University Press.

Ekman, P. (1984). Expression and the nature of emotion. In K. R. Scherer & P. Ekman (Eds.), Approaches to emotion (pp. 319-343). Hillsdale, NJ: Erlbaum.

Ekman, P. (1992). An argument for basic emotions. Cognition and Emotion, 6(3-4), 169-200.

Ekman, P., & Friesen, W. V. (1978). The Facial Action Coding System: A technique for the measurement of facial movement. Palo Alto, CA, Consulting Psychologists Press.

Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. Science, 221, 1208-1210.

Ellgring, H. & Scherer, K. R. (1996). Vocal indicators of mood change in depression. Journal of Nonverbal Behavior, 20, 83-110.

Ellsworth, P. C., & Smith, C. A. (1988a). From appraisal to emotion: Differences among unpleasant feelings. Motivation and Emotion, 12, 271-302.

Ellsworth, P. C., & Smith, C. A. (1988b). Shades of joy: Patterns of appraisal differentiating pleasant emotions. Cognition and Emotion, 2, 301-331.

Fant, G. (1979a). Glottal source and excitation analysis. Speech Transmission Laboratory Quarterly Progress and Status Report, 1, 70-85.

Fant, G. (1979b). Vocal source analysis – a progress report. Speech Transmission Laboratory Quarterly Progress and Status Report, 3, 31-54.

Fant, G. (1993). Some problems in voice source analysis, Speech Communication, 13, 7-22.

Frick, R. W. (1985). Communicating emotion: The role of prosodic features. Psychological Bulletin, 97, 412-429.

Frijda, N. H. (1986). The emotions. Cambridge: Cambridge University Press.

Frijda, N. H., Kuipers, P., & ter Schure, E. (1989) Relations among emotion, appraisal, and emotional action readiness. Journal of Personality and Social Psychology, 57, 212-228.

Fuller, B. F. (1984). Reliability and validity of an interval measure of vocal stress. Psychological Medicine, 14, 59-166.

Gehm, Th., & Scherer, K. R. (1988). Factors determining the dimensions of subjective emotional space. In K. R. Scherer (Ed.), Facets of emotion: Recent research. (pp. 99-114). Hillsdale, NJ: Erlbaum.

Giles, H., Coupland, N., Coupland, J. (1991). Accommodation theory: Communication, context, and consequence. In H. Giles, J. Coupland, & N. Coupland, (Eds.). (1991). Contexts of accommodation: Developments in applied sociolinguistics. Studies in emotion and social interaction. (pp. 1-68). New York: Cambridge University Press.

Green, R. S., & Cliff, N. (1975). Multidimensional comparisons of structures of vocally and facially expressed emotion. Perception and Psychophysics, 17, 429-438.

Hixon, T. J. (1987). Respiratory Function in Speech and Song. Boston: College-Hill Press.

Hollien, H., Geison, L., & Hicks, J. (1987). Voice stress evaluators and lie detection. Journal of Forensic Sciences, 32(2), 405-418.

Huber, J. E., Stathopoulos, E. T., Curione, G. M., Ash, T.A., Johnson, K. (1999). Formants of children, women, and men: the effects of vocal intensity variation. Journal of the Acoustical Society of America, 106, 1532-42.

Iwarsson, J. & Sundberg, J. (1998). Effects of Lung Volume on Vertical Larynx Position during Phonation. Journal of Voice, 12, 159-165.

Iwarsson, J., Thomasson, M., & Sundberg, J. (1996). Long volume and phonation: A methodological study. Logopedics Phoniatrics Vocology, 21, 13-20.

Iwarsson, J., Thomasson, M., & Sundberg, J. (1998). Effects of lung volume on the glottal voice source. Journal of Voice, 12(4), 424-433.

Izard, C. E. (1972). Patterns of emotions: A new analysis of anxiety and depression. New York: Academic Press.

James, W. (1884). What is emotion? Mind, 4, 188-204.

Johnstone, T., Banse, R. and Scherer, K. R. (1995). Acoustic Profiles from Prototypical Vocal Expressions of Emotion. Proceedings of the XIIIth International Congress of Phonetic Sciences, 4, 2-5.

Johnstone, T. & Scherer, K. R. (2000). Vocal communication of emotion. In M. Lewis & J. Haviland-Jones (Eds.), Handbook of Emotions, 2nd Ed (pp. 220-235). New York: Guilford Press.

Johnstone, T., vanReekum, C. M., & Scherer, K. R. (2001).Vocal correlates of appraisal processes. In K.R. Scherer, A. Schorr, & T. Johnstone (Eds.). Appraisal processes in emotion: Theory, Methods, Research (pp. 271-284). New York: Oxford University Press.

Jürgens , U. (1979). Vocalization as an emotional indicator. A neuroethological study in the squirrel monkey. Behaviour, 69, 88-117.

Jürgens, U. (1988). Central control of monkey calls. In D. Todt, P. Goedeking, & D. Symmes (Eds.). Primate vocal communication (pp. 162-170). Berlin, Germany: Springer.

Jürgens, U. (1994). The role of the periaqueductal grey in vocal behaviour. Behavioural Brain Research, 62, 107-17

Kaiser, S., Wehrle, T. & Edwards, P. (1994). Multi- modal emotion measurement in an interactive computer-game: A pilot-study. In N. H. Frijda (Ed.), Proceedings of the VIIIth Conference of the International Society for Research on Emotions (pp. 275-279). Storrs: ISRE Publications.

Kappas, A. (1997). His master's voice: Acoustic analysis of spontaneous vocalizations in an ongoing active coping task. Thirty-Seventh Annual Meeting of the Society for Psychophysiological Research, Cape Cod.

Kappas, A. (2000). Up, up, up, left, left, right, right: Affective vocalizations in a voice-controlled video game. Presented at the XIth conference of the International Society for Research in Emotions, Québec, Québec.

Kent, R. D. (1997). The Speech Sciences. San Diego: Singular.

Klasmeyer, G. (1998) Akustische Korrelate des stimmlich emotionalen. Ausdrucks in der Lautsprache. Unpublished doctoral dissertation. Technical University of Berlin.

Klasmeyer, G. & Sendlmeier, W. F. (1997). The classification of different phonation types in emotional and neutral speech. Forensic Linguistics – The International Journal of Speech, Language and the Law, 4, 104-124.

Klatt, D. H., & Klatt, L. (1990) Analysis, synthesis, and perception of voice quality variations among female and male talkers. Journal of the Acoustical Society of America ,87, 820-856.

Ladd, D. R., Silverman, K. E. A., Tolkmitt, F., Bergmann, G., & Scherer, K. R. (1985). Evidence for the independent function of intonation contour type, voice quality, and F0 range in signaling speaker affect. Journal of the Acoustical Society of America, 78, 435-444.

Ladefoged P. (1968). Linguistic aspects of respiratory phenomena. Annals of the New York Academy of Sciences, 155,141–151.

Laver, J. (1980). The phonetic description of voice quality. Cambridge: Cambridge University Press.

Laver, J. (1991). The gift of speech. Edinburgh, UK: Edinburgh University Press.

Lazarus, R. S. (1991). Emotion and adaptation. New York: Oxford University Press.

Lazarus, R. S. (2001). Relational meaning and discrete emotions. In K. R. Scherer, A. Schorr, & T. Johnstone (Eds.). Appraisal Processes in Emotion: Theory, Methods, Research. (pp. 37-67). New York: Oxford University Press.

Lazarus, R. S., Averill, J. R., & Opton, E. M. Jr. (1970). Towards a cognitive theory of emotion. In M. B. Arnold (Ed.), Feelings and emotions: The Loyola Symposium (pp. 207-232). New York: Academic Press.

Lee, D.H. & Park, K.S. (1990). Multivariate analysis of mental and physical load components in sinus arrhythmia scores. Ergonomics, 33, 35-47.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexica access in speech production. Behavioral and Brain Sciences, 22, 1-75.

Levenson, R. W. (1992). Autonomic nervous system differences among emotions. Psychological Science, 3, 23-27.

Levenson, R. W., Ekman, P., Heider, K., & Friesen, W. V. (1992). Emotion and autonomic nervous system activity in the Minangkabau of West Sumatra. Journal of Personality and Social Psychology, 62, 972-988.

Leventhal, H. & Scherer, K. R. (1987). The relationship of emotion to cognition: A functional approach to a semantic controversy. Cognition and Emotion, 1, 3-28.

Lieberman, P. (1986). Alice in declinationland - A reply to Johan 't Hart. Journal of the Acoustical Society of America, 80, 1840-1842.

Lieberman, P. (1996). Some biological constraints on the analysis of prosody. In J. Morgan & K. Demuth (Eds.), Signal to syntax: Bootstrapping from speech to grammar in early acquisition (pp. 55-65). Mahwah: NJ: Erlbaum.

Lieberman, P., & Blumstein, S. E. (1988). Speech physiology, speech perception, and acoustic phonetics. Cambridge & New York: Cambridge University Press.

Lieberman, P., & Michaels, S. B. (1962). Some aspects of fundamental frequency and envelope amplitude as related to the emotional content of speech. Journal of the Acoustical Society of America, 34, 922-927.

Lively, S., Pisoni, D., Van Summers, W., & Bernacki, R. (1993). Effects of cognitive workload on speech production: Acoustic analyses and perceptual consequences. Journal of the Acoustical Society of America, 93(5), 2962-2973.

MacDowell, K. A., & Mandler, G. (1989). Constructions of emotion: Discrepancy, arousal, and mood. Motivation and Emotion, 13, 105-124.

MacLeod, C., & Rutherford, E. M. (1998). Automatic and strategic cognitive biases in anxiety and depression. In K. Kirsner, C. Speelman, M. Maybery, A. O'Brien-Malone, M. Anderson & C. MacLeod (Eds.), Implicit and explicit mental processes (pp 233-254). Hillsdale, NJ: Erlbaum.

Mackey, M. (1994). XQuest. Computer software. Available on the internet at http://www.ch.cam.ac.uk/MMRG/people/mdm/xquest.html

Mandler, G. (1975). Mind and emotion. New York: Wiley.

Martin, M. (1990). On the induction of mood. Clinical Psychology Review, 10, 669-697.

Marusek, K. (1997). EGG and voice quality. Electronic tutorial. http://www.ims.uni-stuttgart.de/phonetik/EGG/frmst1.htm

Mathews, A., & MacLeod, C. (1994). Cognitive approaches to emotion and emotional disorders. Annual Review of Psychology, 45, 25-50.

Morton, E. S. (1977). On the occurrence and significance of motivational-structural rules in some bird and mammal sounds. American Naturalist, 111, 855-869.

Mozziconacci, S. J. L. (1995). Pitch variations and emotions in speech. Proceedings of the XIIIth International Congress of Phonetic Sciences, 1, 178-181.

Mozziconacci, S. J. L. (1998). Speech variability and emotion: Production and perception. Ph.D. thesis, Eindhoven, the Netherlands.

Mozziconacci, S. J. L., & Hermes, D. J. (1997). A study of intonation patterns in speech expressing emotion or attitude: production and perception. IPO Annual Progress Report 32, IPO, Eindhoven, the Netherlands, 154-160.

Öhman, A. (1992). Orienting and attention: Preferred preattentive processing of potentially phobic stimuli. In B. A. Campbell, R. Richardson, & H. Haynes (Eds.). Attention and information processing in infants and adults: Perspectives from human and animal research. (pp. 263-295). Chichester, England: Wiley.

Öhman, A. (1987). The psychophysiology of emotion: An evolutionary-cognitive perspective. In P. K. Ackles, J. R. Jennings, & M. G. H. Coles (Eds.), Advances in psychophysiology, Vol. 2 (pp. 79-127). Greenwich, CT: JAI Press.

Pecchinenda, A., & Smith, C. A. (1996). The affective significance of skin conductance activity during a difficult problem-solving task. Cognition and Emotion, 10(5), 481-503

Pittam, J. & Scherer, K. R. (1993). Vocal expression and communication of emotion. In M. Lewis and J. M. Haviland (Eds.) Handbook of Emotions. New York: Guilford Press.

Porges, S. W. (1997). Emotion: An evolutionary by-product of the neural regulation of the autonomic nervous system. In C. S. Carter, I. I. Lederhendler, & B. Kirkpatrick (Eds.). The integrative neurobiology of affiliation. Annals of The New York Academy of Sciences, Vol. 807. (pp. 62-77). New York: New York Academy of Sciences.

Roberts, B. & Kirsner, K. (2000). Temporal cycles in speech production. Language and Cognitive Processes, 15, 129 – 157

Roseman, I. J. (1984). Cognitive determinants of emotion: A structural theory. In P. Shaver (Ed.), Review of personality and social psychology: Vol. 5. Emotions, relationships, and health (pp. 11-36). Beverly Hills, CA: Sage.

Rothenberg, M. (1973). A new inverse filtering technique for deriving the glottal airflow during voicing. Journal of the Acoustical Society of America, 53, 1632-1645.

Schachter, S., & Singer, J. (1962). Cognitive, social, and physiological determinants of emotional state. Psychological Review, 69, 379-399.

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

Scherer, K. R. (1986). Vocal affect expression: A review and a model for future research. Pychological Bulletin, 99(2), 143-165

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

Scherer, K. R. (1989) Vocal correlates of emotion. In H. Wagner & A. Manstead (Eds.), Handbook of psychophysiology: Emotion and social behavior (pp. 165-197). London: Wiley.

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: Wiley.

Scherer, K. R. (2001). Appraisal considered as a process of multi-level sequential checking. In K. R. Scherer, A. Schorr, & T. Johnstone (Eds.). Appraisal processes in emotion: Theory, Methods, Research (pp. 92-120). New York and Oxford: Oxford University Press.

Scherer, K. R., Banse, R., & Wallbott, H. G. (2001). Emotion inferences from vocal expression correlate across languages and cultures. Journal of Cross-Cultural Psychology, 32(1), 76-92.

Scherer, K. R., Banse, R., Wallbott, H. G., & Goldbeck, T. (1991). Vocal cues in emotion encoding and decoding. Motivation and Emotion, 15, 123-148.

Scherer, K. R., & Kappas, A. (1988). Primate vocal expression of affective states. In D. Todt, P. Goedeking, & E. Newman (Eds.). Primate vocal communication. (pp. 171-194). Heidelberg: Springer.

Scherer, K. R., Ladd, D. R., & Silverman, K. E. A. (1984). Vocal cues to speaker affect: Testing two models. Journal of the Acoustical Society of America, 76, 1346-1356.

Scherer, K. R., & Oshinsky, J. S. (1977). Cue utilization in emotion attribution from auditory stimuli. Motivation and Emotion, 1, 331-346.

Scherer, K. R., Schorr, A., & Johnstone, T. (Eds.). (2001). Appraisal Processes in Emotion: Theory, Methods, Research. New York: Oxford.

Scherer, T. M. (2000). Stimme, Emotion und Psyche. Untersuchungen zur emotionalen Qualität der menschlichen Stimme. Unpublished Ph.D. thesis, Philipps-Universität Marburg.

Scherer, U., Helfrich, H., & Scherer, K. R. (1980). Paralinguistic behaviour: Internal push or external pull? In H. Giles, P. Robinson & P. Smith (Eds.), Language: Social psychological perspectives (pp. 279-282). Oxford: Pergamon.

Schmidt, S. (1998). Les expressions faciales émotionnelles dans le cadre d'un jeu d'ordinateur: Reflet de processus d'évaluation cognitive ou d'émotions de base? Unpublished Ph. D. Thesis, University of Geneva.

Schneider, W., & Shiffrin, R. (1977). Controlled and automatic human information processing: I. Detection search and attention. Psychological Review, 84, 1-126.

Shea, S. A., Hoit, J. D., & Banzett, R. B. (1998). Competition between gas exchange and speech production in ventilated subjects. Biological Psychology, 49(1-2), 9-27.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attention and a general theory. Psychological Review, 84, 127-190.

Simonov, P. V. & Frolov, M. V. (1973). Utilization of human voice for estimation of man's emotional stress and state of attention. Aerospace Medicine 44, 256-258

Smith, C. A. (1989). Dimensions of appraisal and physiological response in emotion. Journal of Personality and Social Psychology, 56, 339-353.

Smith, C. A., Ellsworth, P. C., & Pope, L. K. (1990, Abstract). Contributions of ability and task difficulty to appraisal, emotion, and autonomic activity. Psychophysiology, 27, S64.

Smith, C. A., & Lazarus, R. S. (1990). Emotion and adaptation. In L. A. Pervin (Ed.). Handbook of personality: Theory and research (pp. 609-637). New York: Guilford.

Smith, C. A., & Scott, H. S. (1997). A componential approach to the meaning of facial expressions. In J. A. Russell & J. M. Fernández-Dols (Eds.), The psychology of facial expression: Studies in emotion and social interaction (pp. 229-254). Cambridge: Cambridge University Press.

Smith, G. A. (1977). Voice analysis for the measurement of anxiety. British Journal of Medical Psychology, 50, 367-373.

Smith, G. A. (1982). Voice analysis of the effects of benzodiazepine tranquillizers. British Journal of Clinical Psychology, 21, 141-142.

Sobin, C., & Alpert, M. (1999). Emotion in speech: The acoustic attributes of fear, anger, sadness, and joy. Journal of Psycholinguistic Research, 28, 347-365.

Sokolov, E. N. (1963). Perception and the conditioned reflex. Oxford: Pergamon.

Starkweather, J.A. (1956). Content-free speech as a source of information about the speaker. Journal of Personality and Social Psychology, 35, 345-350.

Stemmler, G. (1996). Psychophysiologie der Emotionen. Zeitschrift fur Psychosomatische Medizin and Psychoanalyse, 42, 235-260.

Strik, H. & Boves, L. (1992). Control of fundamental frequency, intensity and voice quality in speech. Journal of Phonetics, 20, 15-25.

Sundberg, J. (1994). Vocal fold vibration patterns and phonatory modes. STL-QPRS 2-3, KTH Stockholm, Sweden, 69-80.

Tartter, V. C. (1980). Happy talk: Perceptual and acoustic effects of smiling on speech. Perception and Psychophysics, 27, 24-27.

Tartter, V. C., & Braun, D. (1994). Hearing smiles and frowns in normal and whisper registers. Journal of the Acoustical Society of America, 96, 2101-2107.

Titze, I. R. (1994). Principles of voice production. Englewood Cliffs, NJ: Prentice Hall.

Tolkmitt, F. J., & Scherer, K. R. (1986). Effects of experimentally induced stress on vocal parameters. Journal of Experimental Psychology: Human Perception and Performance, 12, 302-313.

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

Tranel, D. (2000). Electrodermal activity in cognitive neuroscience: Neuroanatomical and neuropsychological correlates. In R. D. Lane & L. Nadel (Eds.). Cognitive neuroscience of emotion. Series in affective science. (pp. 192-224). New York: Oxford University Press.

Uldall, E. (1960). Attitudinal meanings conveyed by intonation contours. Language and Speech, 3, 223-234.

van Bezooijen, R. (1984). The characteristics and recognizability of vocal expression of emotions. Dordrecht, The Netherlands: Foris.

van Reekum, C. M., & Scherer, K. R. (1997). Levels of processing in emotion-antecedent appraisal. In G. Matthews (Ed.), Cognitive science perspectives on personality and emotion (pp. 259-330). Amsterdam: Elsevier

Wehrle, T., Kaiser, S., Schmidt, S. & Scherer, K. R (2000). Studying dynamic models of facial expression of emotion using synthetic animated faces. Journal of Personality and Social Psychology, 78, 105-119.

Whiteside, S. P. & Hodgson, C. (2000). Some acoustic characteristics in the voices of 6- to 10-year-old children and adults: a comparative sex and developmental perspective. Logopedics, Phoniatrics, Vocology, 25, 122-32.

Willemyns, M., Gallois, C., Callan, V. J., & Pittam, J. (1997). Accent accommodation in the job interview: Impact of interviewer accent and gender. Journal of Language and Social Psychology, 16, 3-22.

Woisard, V., Percodani, J., Serrano, E., & Pessey, J. J. (1996). La voix de l'enfant, evolution morphologique du larynx et ses consequences acoustiques. [The voice of the child, morphological evolution of the larynx and its acoustic consequences]. Revue de Laryngologie Otologie Rhinologie, 117, 313-7.

Appendix 1. Vocal correlates of appraisal processes

This chapter provides a theoretical overview and relevant empirical evidence on how appraisal processes affect the production of speech. The chapter is primarily the work of the first author. Sections of the chapter were drawn from the introduction and general discussion chapters of this thesis. Van Reekum provided advice on the effects of appraisals on physiology, as well as contributing general comments on the first draft of the chapter. Scherer was primarily responsible for the introduction paragraphs of the chapter, as well as sections on personality and clinical issues in appraisal theory and emotional speech, and contributed general comments on the first draft of the chapter.

Johnstone, T., vanReekum, C. M., & Scherer, K. R. (2001).Vocal correlates of appraisal processes. In K.R. Scherer, A. Schorr, & T. Johnstone (Eds.). Appraisal processes in emotion: Theory, Methods, Research (pp. 271-284). New York: Oxford University Press.