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RESEARCH ARTICLE

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Affect-induced changes in speech production

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Abstract To determine how sad affect (or brief sad mood) interacts with paralinguistic aspects of speech, we investigated the effect of a happy or sad mood induction on speech production in 49 healthy volunteers. Several speech parameters measuring speech rate, loudness and pitch were examined before and after a standardized mood-induction procedure that involved viewing facial expressions. Speech samples were collected during the self-initiated reading of emotionally "neutral" sentences; there was no explicit demand to produce mood-congruent speech. Results indicated that, after the mood induction, the speech of participants in the sad group was slower, quieter and more monotonous than the speech of participants in the happy group. This speech paradigm provides a model for studying how changes in mood states interact with the motor control of speech.

Keywords Affect · Speech production · Mood induction

Introduction

In recent years, much research has focused on the brain mechanisms underlying major depression. The most robust finding, obtained from brain imaging studies of depressed patients scanned in a resting state, has been that of hypoperfusion and hypometabolism in the prefrontal cortex and the anterior cingulate cortex (Baxter et al. 1985; Bench et al. 1992; Drevets 2001; Mayberg et al. 1997). Knowledge of this apparent "hypofrontality" in depression led to the development of repetitive transcranial magnetic stimulation (rTMS) as a treatment option for drug-resistant depressed patients. Repetitive TMS is a relatively non-invasive and painless method of stimulating the cortex. To treat depression, rTMS is typically applied over the prefrontal cortex (for 2–12 sessions) and mood change is monitored by the use of a subjective rating scale (see George et al. 1997; Grunhaus et al. 2000). In this study, we hoped to facilitate future investigations of rTMS-induced mood change by developing an *objective* measure to quantify the influence of affect (i.e., brief mood states) on a particular motor behavior, namely, paralinguistic aspects of speech. Whereas much research has examined the acoustical properties of emotional speech and the discrimination of emotion through speech perception (for a review of this research area see Pittam and Scherer 1993), less is known about how changes in affect influence speech production.

Cues about affective state are often revealed through paralinguistic aspects of speech production such as pitch, loudness and speech rate (Pittam and Scherer 1993; Scherer 1989). Many researchers have taken advantage of this phenomenon to study both normal affect as well as depression. Using quantitative analyses, it is commonly observed that the speech of depressed patients is slow, quiet and monotonous (Flint et al. 1993; Garcia-Toro et al. 2000; Godfrey and Knight 1984; Nilsonne 1988; Stassen et al. 1991; Talavera et al. 1994). The relationship between non-depressed sad affect and changes in speech quality is less known.

The speech parameters that have been most often studied during sad affect as well as depression are speech rate, loudness and pitch. Fundamental frequency (F_0), the dominating frequency of the sound produced by the vibration of the vocal folds, is a major contributor to perceived vocal pitch. It is a complicated physiological mechanism involving intrinsic and extrinsic laryngeal muscles, muscles involved in respiration (e.g., muscles of the chest cavity and abdomen), as well as feedback mechanisms involving sensory receptors (Larson 1998). F_0 variation across a speech sample reflects the amount of intonation in speech. An acoustical correlate of loudness, modulated primarily through the control of respiratory muscles, is root-mean-square amplitude (RMS-amplitude). Measuring the range of amplitude provides information about the variability of loudness throughout an

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utterance. Finally, speech rate is typically measured by the speed at which utterances are produced or the length of pauses between utterances and syllables.

A number of studies have investigated the relationship between affect and paralinguistic aspects of speech, observing that speech during sad affect is often slower (i.e., lower speech rate) and/or quieter (i.e., lower RMS-amplitude) and/or more monotonous (i.e., lower range of F_0), than speech during happy affect (Banse and Scherer 1996; McKenna and Lewis 1994; Scherer 1989; Scherer et al. 1991; Sobin and Alpert 1999). Inferences about the interaction between affect and speech based on this research are limited, however, by a number of important methodological issues. Firstly, most studies examining the relationship between affect and speech have studied speech samples of actors portraying sadness and happiness (for a recent example see Banse and Scherer 1996). While this method is informative as to why we perceive speech as being sad, happy or fearful, or how people may produce such speech, it does not allow for an understanding of how the actual experience of sad affect influences speech production. Secondly, a few studies have collected speech samples from affectively-laden utterances used to induce specific affect (for a recent example see Sobin and Alpert 1999). This strategy could make the demand for mood-congruent speech explicit or capture changes in speech production that are simply related to the presence of affective stimuli.

To address these issues, we developed a speech task that was administered in conjunction with a standardized happy or sad mood induction, or with a control (i.e., "neutral") procedure. In order to prevent possible carry-over effects across the three experimental conditions, we used a between-subjects design with the following groups: happy, sad and control. The speech task was performed before, in the middle of, and after the inductions or control procedure, and required simple, self-initiated reading of emotionally "neutral" sentences. To avoid explicit demands for affect-congruent speech, the goal of the speech task was de-emphasized using a cover story.

We anticipated that, both in the middle of and following the mood induction, measures of speech rate, loudness and pitch would reveal that the speech of participants in the sad group was slower, quieter and more monotonous than the speech of participants in the happy group, and possibly, than the speech of participants in the control group.

Materials and methods

Overview

Participants read sets of sentences, out loud and at their own pace, before, in the middle of, and after undergoing either a happy or sad mood induction or a control procedure. To deter participants from changing the quality of their speech to conform to the demands of the mood procedure, the study was described as an investigation of galvanic skin response (GSR) and mood. Participants were told that the speech task was a control measure (i.e., providing a "neutral state" for GSR collection), and that the speech task was to be considered a "break" from the mood procedure. Measures of speech rate (speech initiation and speech duration), loudness (RMS-amplitude), variation in loudness (range of amplitude), pitch (mean F_0) and variation in pitch (range and standard deviation of F_0) were obtained from the sentences.

Participants

Sixty-three undergraduate students at McGill University participated in the study (56 women, 7 men). Ages ranged from 17 to 31 years, with a mean age of 19.48 (SD =1.68). Seventy-percent of participants reported English as their first language and all were fluent English speakers. Participants were recruited through a website organized by the Department of Psychology. For their participation, students received extra-credit in their psychology courses. The procedures of this experiment were approved by the Research Ethic Committee of the Montreal Neurological Institute and Hospital.

Affect questionnaire

Participants completed an affect questionnaire before and after the mood induction. The questionnaire was designed to assess levels of comfort, fatigue, irritation, mood, anxiety and emotional arousal. Ratings were made on a seven-point Likert scale, with –3 indicating the highest negative level and 3 indicating the highest positive level for each affective state. For example, the mood rating ranged from *I feel very sad* (–3) to *I feel very happy* (3) and the fatigue rating ranged from *I feel very fatigued* (–3) to *I feel very rested* (3). The questionnaire was used as a general indicator of how the participant was feeling upon arrival at the laboratory and to assess affect after the mood induction and control procedure.

Mood induction

Each participant underwent either a happy or sad mood induction or a control procedure. The mood induction was adapted from the face stimuli and procedure standardized by Schneider et al. (1994). This procedure has been shown to elicit temporary states of sadness and happiness in people not suffering from affective disturbance. Participants viewed 40 monochrome front-view photographs of actor's faces presented on a computer screen and were asked to use the faces to become happy or sad. Face presentation was controlled by SuperLab Pro, v. 2.0 (2000; Cedrus, San Pedro, Calif., USA) on a desktop computer. Stimuli (20×20 cm) were presented on a 45 cm color monitor (1024×768 pixels, 85 Hz), approximately 90 cm away from where the participant was seated (stimulus size 12°×12°). The computer keyboard was positioned to allow the easy pressing of the space bar. All happy faces were viewed in the happy induction and all sad faces were viewed in the sad induction. To help participants achieve the desired mood, they were instructed to imagine what would make the person in the picture express that emotion, or to think of a personal event or memory that made them feel like the person in the picture. Each face was viewed for as much time as necessary to feel the desired emotion. When they were finished viewing the face, participants pressed the space bar to begin viewing the next picture until all 40 faces had been viewed. In the control procedure, participants passively viewed 40 neutral facial expressions for a fixed duration (12 s/face).

Speech task

The speech task, where participants read 12 sentences out loud, was administered immediately before the mood induction, after viewing 20 faces during the mood induction and, immediately after the mood induction. The task began with the presentation of a blank

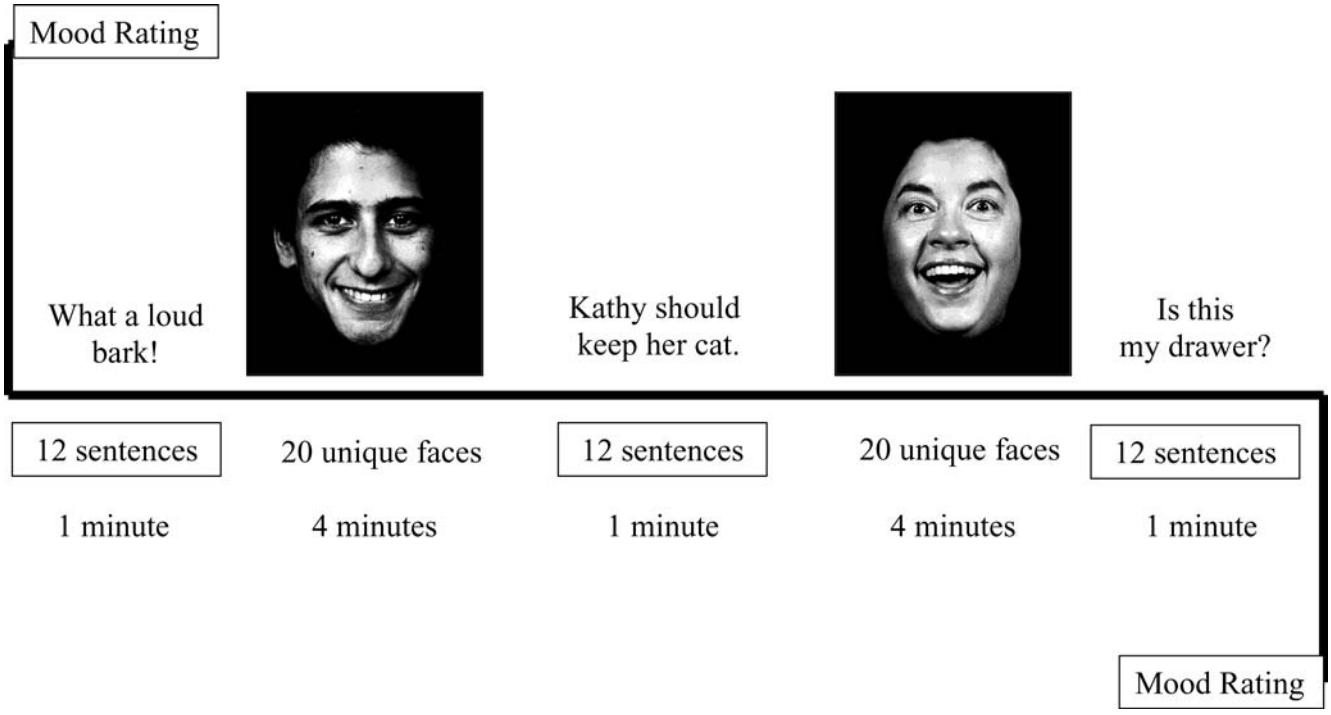

Fig. 1 The experimental procedure (with an example of two face stimuli from the happy mood induction)

screen. When participants pressed the space-bar, one sentence appeared in the center of the computer screen, accompanied by a computer-generated bell (100 ms in duration). The bell indicated the appearance of the sentence during the speech recording. When the sentence appeared, participants read the sentence out loud and pressed the space-bar to end the trial; this space-bar press was used to ensure that participants had enough time to read the sentence. A blank screen appeared again and the procedure was repeated until all 12 sentences had been read. Sentences were presented in white (Times New Roman, 67-point font) on a black screen.

Speech recording and analysis

Speech was recorded into a Dell Inspiron 2500 laptop computer through a microphone placed on the computer monitor. Subject distance from the microphone was controlled by the use of floor and desk markings that kept foot and hand position at a constant point throughout the study. Speech signals were collected and stored by CoolEdit 2000 (Syntrillium Software 2000) at a sampling rate of 22.5 kHz and 16-bit resolution (mono-channel). A Matlab (1999, The Mathworks Inc., Natick, Mass., USA) platform was adapted to extract the following parameters from the sentences: range of amplitude, RMS-amplitude, mean F_0, standard deviation of F_0 and range of F_0. Prior to the calculation of the speech parameters, the speech signal was scanned for voiced and unvoiced speech (using a script written by Crouse et al. 2001) and the unvoiced speech was discarded. The sample window for extracting the speech parameters from the voiced signal was 20 ms duration. The range of amplitude and RMS-amplitude were determined by using the general commands available within Matlab. The mean F_0, range of F_0, standard deviation of F_0 were determined by incorporating parts of the Matlab toolbox, Speech Processing and Synthesis (Childers 2000).

Galvanic skin response (GSR)

GSR collection was intended to divert the participants from the importance of the speech task and analysis of the GSR activity was beyond the focus of this study. Disposable silver-chloride electrodes were placed on the dominant hand of each participant. GSR was amplified, collected and stored by a computerized physiological recording system (F1000 Biofeedback System; Focused Technology, Ridgecrest, Calif., USA).

Procedure

After participants provided informed consent they were randomly assigned to a group (happy, sad or control) and were seated at a desk where the computer monitor and keyboard were situated. Participants were told that the main purpose of the study was to understand the relationship between affect and GSR. The speech task was described as a neutral task, included to compare GSR during the mood induction with GSR during a non-affective state. Instructions were given for the mood procedure, depending on the group (happy, sad or control), and for the speech task. Next, participants read out loud the list of sentences to ensure that the sentences were adequately understood and articulated. After the instructions and practice, participants were fitted with electrodes and completed the affect questionnaire. Following this, the experimenter left the room and participants were left alone to begin the speech task and mood procedure: read 12 sentences, view 20 faces, read 12 sentences, view 20 faces, read 12 sentences (for an illustration see Fig. 1). When the last set of sentences were finished, the experimenter re-entered the room and administered the affect questionnaire. Before the debriefing, participants were asked if they thought that the study was investigating something other than GSR and mood, and if so, what they thought the study was really about. After their response, participants were told the true nature of the study and the reasons for the false description of the study. Participants were given contact information in case of further questions and were asked to refrain from divulging the details of the study to future participants.

Table 1 Mean affect scores (and SEM) at post-induction. Affect rating was on a scale –3 to 3. Numbers greater than zero indicate positive affect; numbers less than zero indicate negative affect. Pre-induction data represent ANCOVA-determined values for all groups before the mood induction or control procedure

Affect rating	Pre-induction	Group		
		Happy	Control	Sad
Discomfort-comfort	1.14	1.79[a] (0.26)	1.26 (0.28)	0.61[a] (0.28)
Anxious-calm	0.63	1.39 (0.33)	0.95 (0.32)	0.61 (0.30)
Fatigued-rested	–0.02	0.29 (0.26)	–0.14 (0.25)	–0.39 (0.23)
Sad-happy	1.14	1.80[b,c] (0.17)	0.92[b,d] (0.16)	–0.49[c,d] (0.15)
Irritated-soothed	0.90	0.94 (0.29)	0.66 (0.28)	0.29 (0.26)
Emotional pain-emotional pleasure	2.26	2.27[e] (0.21)	2.42[f] (0.21)	0.90[e,f] (0.20)

[a,b,c,d,e,f] Groups identified with the same letter are those whose comparison using Fisher's protected *t* (*df*=45) was significant (*P*<0.05)

Results

Sixty-three participants completed the study. The total time to complete the speech tasks and induction (or control) procedure was calculated for each subject and the mean time was determined for each group (happy, sad and control). Total time was defined as the time (in minutes) elapsed from the presentation of the first sentence trial to the end of the last sentence trial. Mean speech task/induction time for each group was 8.45 min (SE =0.1) for the control group, 8.53 min (SE =1.42) for the happy group, and 8.48 min (SE =1.00) for the sad group.

No one reported being aware of the actual purpose of the study or of the importance of the speech task. The data from three participants were discarded due to difficulty in sentence comprehension. Of the remaining 60 participants, the data of four participants were excluded from the analyses because of procedural problems affecting the quality of the speech signal (e.g., pressing the space bar during reading, cell phone ringing). In addition, the data of the seven men (four in control, two in happy, one in sad) were also excluded. This decision was based on the following grounds: (1) pitch, loudness and amplitude are dependent on gender, and (2) the number of men was too small for gender to be included as a between-subjects factor. The data from the remaining 49 participants was analyzed.

The data analyses are presented in two sections: affect questionnaire and speech parameters. Analysis of covariance (ANCOVA) was used to investigate all dependent measures. For each analysis, pre-induction performance was used as a covariate.

Affect questionnaire

To determine whether the mood manipulation was successful, each affect rating (comfort, fatigue, irritation, mood, anxiety and emotional arousal) was analyzed using a one-way ANCOVA examining the effect of group (happy, sad and control) on the post-induction rating. Adjusted affect means and standard deviations are reported in Table 1. Results of the ANCOVA revealed a main effect of group for comfort ($F_{2,45}$=4.02, P<0.05), mood ($F_{2,45}$=51.73, P<0.001), and emotional arousal ($F_{2,45}$=16.03, P<0.001). Group differences in comfort, mood and emotional arousal were evaluated using Fisher's protected *t* (*df*=45). For the comfort rating, which assessed affect on a *discomfort-comfort* dimension, the scores for the sad group were significantly lower than the scores for the happy group (P<0.001). For the mood rating, which assessed affect on a *sad-happy* dimension, the scores for control group were significantly higher than the scores for the sad group and significantly lower than the scores for the happy group. The scores for the sad group were also significantly lower than the scores for the happy group (all P-values <0.001). Finally, for the emotional arousal rating, assessing affect on an *emotional pain-emotional pleasure* dimension, the scores for the sad group were significantly lower than the scores for the control and happy groups (all P-values <0.001). Based on these findings, it appeared that the happy and sad mood inductions were successful in eliciting the desired affect and that the control procedure did not invoke a change in affect.

Speech parameters

For each speech parameter (sentence duration, sentence initiation, mean F_0, standard deviation of F_0, range of F_0, range of amplitude, RMS-amplitude) mean values were calculated for the 12 sentences at each speech collection point by subject and group.

Speech initiation and duration

Two measures of speech rate were obtained from the raw sentence files: sentence initiation time and sentence duration. Sentence initiation was measured by determining the time in seconds between the start of the bell and the start of reading. Sentence duration was measured by determining the period from the start of sentence reading

Table 2 Mean speech initiation and speech duration measures (and SEM) at post-induction. Pre-induction data represent ANCOVA-determined values for all groups before the mood induction or control procedure

Measure	Pre-Induction	Group		
		Happy	Control	Sad
Sentence initiation (s)	1.57	0.81 (0.06)	0.82 (0.07)	0.83 (0.07)
Sentence duration (s)	1.63	1.52[a] (0.03)	1.59 (0.03)	1.62[a] (0.03)

[a] Groups identified with the same letter are those whose comparison using Fisher's protected *t* (*df*=45) was significant ($P<0.05$)

Table 3 Mean fundamental frequency and amplitude measures (and SEM) at post-induction. Pre-induction data represent ANCOVA-determined values for all groups before the mood induction or control procedure

Measure	Pre-Induction	Group		
		Happy	Control	Sad
Fundamental frequency (Hz)				
Mean	225.50	227.88 (4.25)	221.50 (3.46)	225.42 (3.83)
Standard deviation	67.34	71.78 (1.72)	71.19 (1.66)	68.19 (1.56)
Range	237.06	246.18[a] (6.85)	246.93[b] (6.65)	226.39[a,b] (6.30)
Amplitude (absolute value)				
Range	209.30	252.31[c,d] (14.46)	204.52[c] (13.93)	178.34[d] (12.54)
Root-mean-square	14.05	15.62[e] (0.86)	13.36 (0.82)	12.23[e] (0.76)

[a,b,c,d,e] Groups identified with the same letter are those whose comparison using Fisher's protected *t* (*df*=45) was significant ($P<0.05$)

to the end of sentence reading. Adjusted means for sentence initiation and sentence duration at post-induction are reported in Table 2. For mean sentence initiation, a one-way ANCOVA examining the effect of group (happy, sad and control) on mid- and post-induction performance revealed no main effects. For mean sentence duration, a one-way ANCOVA examining the effect of group (happy, sad and control) on mid- and post-induction performance revealed a main effect of group at post-induction only ($F_{2,45}$=3.46, $P<0.05$). Group differences in sentence duration at post-induction were examined using Fisher's protected *t* (*df*=45); the only significant difference was found between the sad and happy groups, where sentence durations in the sad group were significantly ($P<0.01$) longer than sentence durations in the happy group. Thus, after the mood induction, subjects in the sad group read significantly more slowly than subjects in the happy group.

Fundamental frequency

To examine affect-related changes in pitch, mean F_0, standard deviation of F_0 and range of F_0 were extracted from the speech data. For all measures, adjusted means for post-induction performance are provided in Table 3. For both mean F_0 and mean standard deviation of F_0, a one-way ANCOVA examining the effect of group (happy, sad and control) on mid- and post-induction performance revealed no significant main effects. For the mean range of F_0, a one-way ANCOVA examining the effect of group (happy, sad and control) on mid- and post-induction performance indicated a main effect of group at post-induction only ($F_{2,45}$=3.22, $P<0.05$). To examine group differences in performance, multiple comparisons using Fisher's protected *t* (*df*=45) were conducted on mean range of F_0 at post-induction; results revealed that the mean range of F_0 for the sad group was significantly ($P<0.05$) lower than that of the happy and control groups, indicating that the post-induction speech of the subjects in the sad group was more monotonous than the post-induction speech in the other two groups.

Amplitude

Indices of speech loudness and variability in speech loudness, respectively, the RMS-amplitude and the range of amplitude, were also extracted from the speech samples. Adjusted means (absolute value) for post-induction performance are provided in Table 3. For the mean range of amplitude, a one-way ANCOVA examining the effect of group (happy, sad and control) on mid- and post-induction performance revealed a main effect of group at post-induction only ($F_{2,45}$=7.56, $P<0.01$). Group differences in post-induction mean range of amplitude investigated using Fisher's protected *t* (*df*=45) revealed that mean range of amplitude in the happy group was significantly higher than that in the sad ($P<0.001$) and control ($P<0.05$) groups. Although mean range of amplitude in the sad group (178.34, SE =12.54) was substantially lower than that in the control group (204.52, SE

=13.93) this difference was not found to be statistically significant (P=0.169). For the mean RMS-amplitude, a one-way ANCOVA examining the effect of group (happy, sad and control) on mid- and post-induction performance revealed a main effect of group at post-induction only, ($F_{2,45}$=4.27, P<0.05). Fisher's protected t (df=45) was used to investigate differences between groups in post-induction mean RMS-amplitude; the comparisons revealed that only the mean RMS-amplitude for the sad group was significantly lower (P<0.01) than that of the happy group. These findings suggest that the speech of subjects in the sad group was quieter and displayed less variation in loudness than the speech of subjects in the happy group. In addition, the speech of subjects in the happy group displayed more variation in loudness than the speech of subjects in the control group.

Discussion

Our results demonstrate that experimentally induced sad affect is associated with changes in paralinguistic aspects of speech. These changes are similar to the speech quality observed during depression, as well as the speech quality reported in studies examining speech during induced sad affect as well as during posed sad affect. Importantly, none of the participants reported being aware of the actual purpose of the speech task.

After the mood induction, participants in the sad group spoke significantly more slowly, quietly and monotonously than participants in the happy group. In addition, the post-induction speech of participants in the sad group was more monotonous than the post-induction speech of control group participants. No significant results were found at mid-induction, suggesting that the affect elicited halfway through the mood procedure was not sufficient to observe between-group differences in speech quality. Furthermore, with the exception of range of F_0, the majority of group differences in speech quality were found between the happy and sad groups only. Thus, comparing the speech produced at the opposite ends of a happy-sad affect continuum was necessary in order to observe significant differences in affect-induced changes in speech production. This may also reflect problems inherent to a neutral condition, with no specific instructions, it is very difficult to control the actual affect of the participants during and after the procedure; in fact, many reported the control procedure to be dull. It is encouraging, however, that the happy, sad and control group means were in the expected direction for all speech parameters.

Some important limitations should be addressed before further interpretation of the present findings. Firstly, as the microphone was not fixed in relationship to the subject's mouth, we cannot be sure that the observed group differences in speech amplitude are due to the affect manipulation, and not merely to subject movement during the experiment. For example, it is possible that the sad mood induction may have resulted in subjects "slumping" in their chair, which could lead to a reduction in both the range and RMS of speech amplitude. It is of note, however, that this potential confounding factor would not have influenced the other speech parameters where differences were found, i.e., range of F_0 and sentence duration. Secondly, due to the known differences between men and women in nonverbal speech quality (Fitzsimons et al. 2001), the results of this study are limited to women. It is not known whether or how gender differences in paralinguistic aspects of speech interact with affective state. Thus, we cannot be sure whether the affect-related speech differences observed in this study would be universal across gender.

This study has identified a valid model of how sad affect interacts with paralinguistic aspects of speech production. Our model provides two possibilities for future research. Firstly, we have identified a motor behavior, sensitive to change in affect, that may be used to assess mood change in an objective manner. To help assess the antidepressant affect of rTMS, we will employ our speech task as an objective measure of mood change in both non-depressed and depressed patients. Secondly, in the light of this aim, an important step will be to determine what brain regions are involved in the affect-induced changes in paralinguistic aspects of speech observed in this study: research in animals and humans strongly suggests that the control of paralinguistic aspects of speech production, especially in the context of emotion and motivation, are subserved by the mesial frontal cortex (Aitken 1981; Barris and Shuman 1953; Jürgens 1976, 1998; Jürgens and Ploog 1970; Jürgens and von Cramon 1982; MacLean and Newman 1988; Müller-Pruess 1988; Neilsen and Jacobs 1951; Sutton et al. 1974; Vogt and Barbas 1988; West and Larson 1995).

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