Effect of Psychological Stress on Female Vocal Quality

A Multiparameter Approach

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Key Words

Vocal quality • Stress • Dysphonia severity index

Abstract

Psychological stress can influence vocal quality. The purpose of the present study was to determine the effect of stress on female vocal quality. In this experimental study 54 female voices were studied in a stress-inducing and a relaxed condition. In the stress-inducing condition the subjects were asked to read a passage while instructions were used to evoke stress. In the relaxed condition the same reading task but without specific instructions was used. Identical subjective and objective assessment techniques were used to determine vocal quality in the stressed and the relaxed conditions. In stress-inducing and challenging conditions the female voice is more breathy, strained and of a lower objective vocal quality characterized by lower fundamental frequency, lower frequency, intensity and aerodynamic capacity. This study indicates that stress-inducing and challenging conditions change vocal quality and vocal performance. Understanding of the effect of stress on voice production is relevant for clinical diagnostic situations, particularly in patients who present with a functional (nonorganic) voice disorder, as well as those patients who have some organic pathology but who also report exacerbation of symptoms during periods of increased life stress.

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Introduction

Stress is recognized as a factor in illness and disease and is probably involved in almost every human problem. It is estimated that 50–70% of all physicians' visits involve stress-related complaints and it is known that stress can influence vocal quality [1, 2]. In line with Scherer [3, 4] stress can be thought of as the result of an internal or external stimulation of the organism, 'which upsets its inner balance requiring an adaptive coping response to restore it' [3]. Stress is characterized by physiological changes that affect 'respiration, phonation, and articulation in such a way as to produce emotion-specific patterns of acoustic parameters' [4]. Adaptive coping responses taking place in relation to stress are not only determined by the objective nature of the stress-inducing stimuli or stressors, but also by psychological factors like cognitive representations (e.g. on the controllability of an event), personality characteristics, and the nature of the emotions experienced in the stressing condition (e.g. anxiety versus excitement under stress). The effects of extreme levels of stress (just before aircraft crashes or contingent on terror) on voice characteristics were reported in some studies [5–7]. These studies indicate that several fundamental frequency (F_0)-related parameters have been identified as good correlates of stress level. Lively et al. [8] examined the effects of cognitive workload in the speech production of 5 males. Cognitive workload is the infor-

mation processing load placed on the human operator while performing a particular task [9]. In the workload condition, some talkers had increased amplitude and amplitude variability and decreased F_0 variability. The results of the study by Mendoza and Carballo [10] also suggest that in conditions of experimentally induced stress there is an increase in F_0 and an increase in jitter and shimmer. A summary of recent studies examining the effect of stress-inducing stimuli (table 1) shows conflicting results.

Whereas Fuller et al. [11] and Lively et al. [8] reported the absence of a consistent effect of workload tasks on F_0 , several researchers [12, 14] found a significant increase in F_0 in all workload conditions. Lively et al. [8] observed a reduction in F_0 variability and an increase in amplitude variability in the workload condition while Mendoza and Carballo [12] mentioned no significant changes in F_0 range or frequency tremor response instability (FTRI) and a significant decrease in amplitude tremor response instability (ATRI) in one workload condition. Moreover, a weakness in current studies is that they often fail to differentiate between the effect of a stressing condition on vocal quality and the influence of subjectively experienced emotions on voice characteristics. The authors think this distinction is necessary, since the psychological literature indicates that stressing conditions do not have a univocal effect on people [15, 16].

The main purpose of the present study was to determine the effect of stress on the female voice. The authors did not operationalize stress by inducing contrasting levels of threat or difficulty, but by focussing on public performance: participants were asked to execute a task in a performance condition and in a relaxed condition. Understanding of the effect of stress on voice production is relevant for clinical diagnostic situations, particularly of patients who present with a functional (nonorganic) voice disorder, as well as for those patients who have some organic pathology but who also report exacerbation of symptoms during periods of increased life stress. Vocal quality was measured using objective and subjective assessment techniques. Hypothetically a stress-inducing condition can create a significant change in acoustic and aerodynamic parameters. Moreover, a significant decrease in vocal performance and a decreased overall vocal quality as measured by the dysphonia severity index (DSI) are expected. Also, a change of the perceptual voice characteristics in the stress-inducing condition is hypothesized. Additionally the effect of the subjective experience of emotion was evaluated in this study. In line with previous literature [17–20] we assumed that a stress-in-

ducing condition can produce state anxiety, and that the amount of state anxiety might further affect voice characteristics. Studies evaluating the effect of stress on vocal quality using an objective multiparameter voice approach in combination with a perceptual evaluation of vocal characteristics and with an evaluation of state anxiety have – to the best of our knowledge – not been reported yet.

Materials and Methods

Participants

Sixty-two female university students in logopedics enrolled in a course in speech training agreed to participate in the study. All subjects were naïve about the purpose of this study. Four subjects were excluded because of a common cold or nasal congestion on the day of testing and 4 students were absent on the day of testing. The selected group of subjects included 54 healthy women ranging in age from 17.1 to 21.9 years (mean age, 19.3 years). All subjects were nonsmokers, were using only monophasic oral contraceptive pills and were familiar with vocal hygiene behavior (all subjects followed a vocal hygiene program during the course in speech training). Each subject was assessed by an otorhinolaryngologist performing a complete ear, nose and throat examination to exclude voice disorders, nasal and ear diseases 1 week before the experiment in the stressful condition. The voice handicap index questionnaire confirmed the absence of a voice disorder, as perceived by the patient (mean total score of 4.5 of 120). None of the subjects followed stress-management programs. This experiment was approved by the human subjects committee of the University of Ghent.

Procedure

Stress-Inducing Condition

In the stress-inducing condition different instructions were used to evoke stress. The subjects were asked to prepare a reading passage of 20 min and to read it before an audience of 70 students in speech and language science. For all the subjects it was their first performance in public speaking. The subjects were asked to read a passage in a specific deliberate manner with a perfect overall speech intelligibility and with respect for the following seven speech performance techniques: (1) good general posture and especially good head posture; (2) abdominal breath support; (3) good focus on vocal quality with appropriate loudness and habitual pitch level and with the use of an appropriate easy vocal onset; (4) use of a balanced resonance; (5) perfect articulation of all vowels, diphthongs and consonants of the Dutch language; (6) normal speaking rate, and (7) appropriate prosody.

Each speech performance technique was practiced in the speech training course. The subjects were aware that each technique would be evaluated by the audience, and that it would count for the final grade of the speech training course. Just before the reading task the subjective and objective voice assessment techniques were performed as described in 'Voice Measurements', and participants then filled out the state anxiety questionnaire.

Table 1. Summary of recent studies examining the effect of cognitive workload tasks on the human voice

Authors	Subjects	Workload task	Control task	Speech sample	Analysis	Results
Fuller et al. [11]	88 women	comprehensive examination	1 week after examination	two vowels /a/ /i/	<i>acoustic analysis</i> F ₀ jitter	lack of validity increased in stressed condition
Lively et al. [8]	5 males	compensatory visual tracking task while speaking test sentences	speaking sentences	word: /h/ + vowel + /d/	<i>acoustic analysis (LPC)</i> amplitude amplitude variability F ₀ F ₀ variability duration formant frequencies	greater amplitude in workload condition (60%, 3/5) increases in variability in workload condition (60%) absence of a consistent effect of workload on F ₀ reduction in workload condition (60%) shorter phrase durations under workload (80%, 4/5) no change in frequencies or bandwidths of the first three formants in the vowels (100%, 5/5)
Mendoza and Carballo [10]	82 (18–22)	reading a tongue twister with and without DAF spelling of the Spanish alphabet in inverse order	spelling of the Spanish alphabet	vowel /a/	<i>acoustic analysis of /a/ with MDVP</i> F ₀ F ₀ range SD of F ₀ PPQ (jitter) APQ (shimmer) NHR SPI VTI	significant increase in all workload conditions no significant changes no significant changes significantly reduced in all workload conditions significantly reduced in tongue twister conditions no significant changes significantly reduced in tongue twister + DAF significantly reduced in all workload conditions
Mendoza and Carballo [12]	82 (18–22)	as above	as above	vowel /a/	<i>acoustic analysis of /a/ with MDVP</i> ATRI FTRI	significant decrease in tongue twister + DAF no significant difference
Schneider et al. [13]	32	field examination (1 h teaching)	before and after teaching	speech	perceptual evaluation of F ₀ by comparison with the keyboard	no significant change of F ₀
Johnstone et al. [14]	30	tracking task		standard phrase + vowel /a/	estimation of F ₀ from successive glottal closure instants in the electroglottal signal	F ₀ higher for difficult than for easy conditions

LPC = Linear predictive coding; DAF = delayed auditory feedback; SD = standard deviation; MDVP = Multidimensional Voice Program from Kay Elemetrics; PPQ = pitch period perturbation quotient; APQ = amplitude perturbation quotient; NHR = noise-to-harmonic ratio; SPI = soft phonation index; VTI = voice turbulence index.

Relaxed Condition

The same reading task but without specific instructions concerning speech performance techniques, without a large audience, and without the context of obtaining grades was given during the summer holidays. Just before the reading task the subjective and objective voice assessment techniques were performed, and again participants then filled out the state anxiety questionnaire. There was a time interval of 2 months between the stress-inducing and the relaxed conditions.

Voice Measurements

Identical subjective (perceptual evaluation) and objective (aerodynamic, voice range, acoustic measurements, DSI) assessment techniques were used to determine vocal quality in the stress-inducing and the relaxed conditions. The voice assessments were taken within 10 min prior to the execution of the reading task. Voice sampling took place in a sound-treated room in the university clinic and was audio recorded (Sony DAT 55ES, Tokyo, Japan, and Maxell DAT DM 120 cassette, Tokyo, Japan) for further analyses. Perceptual voice assessment included a perceptual rating of the voice during spontaneous speech by 3 experienced voice therapists (E.D., S.D.L., M.B.) using the GRBAS scale [21]. This scale uses a four-point grading scale (0 = normal, 1 = slight, 2 = moderate, 3 = severe) for five different parameters that pertain to voice quality (G = overall grade of hoarseness, R = rough, B = breathy, A = asthenic, S = strained). Vocal quality in this population is modeled by means of the DSI [22], which is designed to establish an objective and quantitative correlate of the perceived vocal quality. The DSI is based on the weighted combination of the following set of voice measurements: maximum phonation time (MPT), highest frequency (F-high), lowest intensity (I-low) and jitter (%), variability in the acoustic signal for frequency, auditorily perceived as hoarseness). The DSI is calculated as $0.13 \text{ MPT (s)} + 0.0053 \text{ F-high (Hz)} - 0.26 \text{ I-low (dB)} - 1.18 \text{ jitter (\%)} + 12.4$.

The DSI equals +5 (DSI% = 100%) for perceptually normal voices and -5 (DSI% = 0%) for severely dysphonic voices. The more negative the patient's index, the poorer his or her vocal quality [22]. The MPT is the greatest length of time over which phonation can be sustained for a vowel sound, immediately after having taken a maximal inspiration. The frequency (the highest and the lowest frequency) and the intensity (the highest and the lowest intensity) were measured with the Voice Range Profile from CSL. The procedure described by Heylen et al. [23] was used. The acoustic parameters F_0 , jitter (%), shimmer (%), ATRI and FTRI were obtained using the Multi-Dimensional Voice Program, model 4300 from Kay Elemetrics. Jitter percent gives an evaluation of the variability of the pitch period and shimmer percent an evaluation of the variability of the peak-to-peak amplitude within the analyzed voice sample.

Anxiety Measures

State-anxiety was measured with the Dutch version of the Spielberger State-Trait Anxiety Inventory [24]. This self-report questionnaire assesses state anxiety (20 items) and trait anxiety (which represents a chronic anxious disposition, 20 items).

Statistical Analysis

SPSS software (SPSS for Windows, version 10 advanced statistics, release 5; SPSS Inc., Chicago, Ill., USA) was used. For the

comparison of objective voice measurements between the two conditions (within-subject effect), the GLM repeated-measures analysis technique was used. Effects were tested based on the Wilks' lambda F ratio. Effect sizes were estimated by means of the partial eta-squared statistic ($p\eta^2$), which describes the proportion of total variability attributable to a factor. A value between 0.01 and 0.06 indicates a small effect, a value between 0.06 and 0.14 a medium effect, and a value higher than 0.14 a large effect. To test interaction effects, the state anxiety score was included as a between-subjects factor. For the comparison of the results on the perceptual evaluation of voice characteristics between both conditions, the Wilcoxon signed-rank test for two related samples was used. The effect of state anxiety on the perceptual ratings is tested through ordinal regression analysis in which differences in vocal quality between both conditions are predicted.

Results

The results of aerodynamics, voice range measurements, acoustic analysis and DSI values of the stress-inducing and the relaxed conditions are presented in table 2. As hypothesized a significant effect of the stress-inducing condition on vocal quality was observed for DSI [Wilks' lambda $F(1, 53) = 49.33, p < 0.01; p\eta^2 = 0.48$], F_0 [Wilks' lambda $F(1, 53) = 7.82, p < 0.01; p\eta^2 = 0.13$], MPT [Wilks' lambda $F(1, 53) = 51.15, p < 0.01; p\eta^2 = 0.49$], I-high (highest intensity) [Wilks' lambda $F(1, 53) = 8.74, p < 0.01; p\eta^2 = 0.14$], F-low [lowest frequency, Wilks' lambda $F(1, 53) = 20.55, p < 0.01; p\eta^2 = 0.28$] and F-high [highest frequency, Wilks' lambda $F(1, 53) = 18.02, p < 0.01; p\eta^2 = 0.25$]. Effect sizes were each time large, except for F_0 , where it was medium. In each case lower values were present in the stressing condition. No statistically significant differences were found for I-low [Wilks' lambda $F(1, 53) = 1.03, p = 0.31; p\eta^2 = 0.02$] and the acoustic parameters jitter [Wilks' lambda $F(1, 53) = 1.60, p = 0.21; p\eta^2 = 0.03$], shimmer [Wilks' lambda $F(1, 53) = 0.001, p = 0.98; p\eta^2 = 0.00$], FTRI [Wilks' lambda $F(1, 53) = 0.58, p = 0.58; p\eta^2 = 0.01$] and ATRI [Wilks' lambda $F(1, 53) = 2.36, p = 0.13; p\eta^2 = 0.04$]. For these parameters, effect sizes were each time small. With respect to the perceptual evaluations (concordance value, 92%) significantly higher values in the stress-inducing condition were observed for G (overall grade of vocal quality, $Z = -3.56, p < 0.01$), B (breathiness, $Z = -2.11, p = 0.04$) and S (strainedness, $Z = -2.12, p = 0.03$). The stressing condition had no significant effect on R (roughness, $Z = -0.94, p = 0.35$), A (asthenicity, $Z = -1.13, p = 0.26$), the perceptual evaluation of pitch [Wilks' lambda $F(1, 53) = 2.04, p = 0.16; p\eta^2 = 0.04$] and the perceptual evaluation of intensity [Wilks' lambda $F(1, 53) = 1.83, p = 0.18; p\eta^2 =$

Table 2. Results of aerodynamic, voice range, acoustic, and DSI measurements in the stress and the relaxed conditions

Measurements	Stress condition			Relaxed condition		
	mean $\pm$ standard error	standard deviation	range	mean $\pm$ standard error	standard deviation	range
Aerodynamic						
MPT, s	16.6 $\pm$ 0.6	4.4	6.8–24.7	20.3 $\pm$ 0.8	5.9	7.2–33.9
Voice range						
F-high, Hz	838.5 $\pm$ 20	147.7	466–1,174	926.2 $\pm$ 21.3	156.4	466–1,318
F-low, Hz	136.9 $\pm$ 3.8	28.1	69–196	156.8 $\pm$ 3.2	22.8	78–207
I-high, dB	101 $\pm$ 0.8	6.3	83–117	104 $\pm$ 0.8	6.1	88–116
I-low, dB	56.4 $\pm$ 0.2	1.7	55–62	56.1 $\pm$ 0.2	1.2	55–60
Acoustic						
F ₀ , Hz	203 $\pm$ 1.8	15.2	172–236	209.1 $\pm$ 2.1	13.6	171–243
Jitter, %	1.2 $\pm$ 0.1	0.6	0.3–3	1.1 $\pm$ 0.1	0.6	0.12–34
Shimmer, %	3 $\pm$ 0.1	0.8	1.5–5.3	3.0 $\pm$ 0.3	2.0	0.2–16.1
FTRI	0.4 $\pm$ 0.02	0.21	0–1.4	0.6 $\pm$ 0.3	2.3	0–16.9
ATRI	3.2 $\pm$ 0.4	2.7	0–13	3.9 $\pm$ 0.3	2.3	0–8.9
Vocal quality						
DSI	3.0 $\pm$ 0.2	1.5	–0.2–(+6.6)	4.3 $\pm$ 0.2	1.6	–0.6–(+8)

0.03]. For the two latter variables, effect sizes were each time small. Vocal quality was characterized as G1 R0.5 B0.5 A0 S1 (median) in the stress-inducing condition and as G0 R0 B0 A0 S0 (median) in the relaxed position. With respect to the second research question, the participants experienced significantly ($t = -3.73$, $p < 0.01$) less state anxiety in the stressing condition (mean = 42.4, SD = 4.4) than in the relaxed condition (mean = 44.8, SD = 3.4). However, for 22% (12/54) of the participants more state anxiety was experienced in the performance condition compared to the relaxed condition. An analysis of the question whether the experience of state anxiety (more versus less state anxiety in the stress-inducing condition) interacted significantly with the effect of stress induction revealed that for the objective measures of vocal quality no significant interaction effects were observed, while all main effects remained significant (table 3).

Discussion

The purpose of this study was to analyze the effect of a stress-inducing condition on vocal quality characteristics in 54 young females. As hypothesized, the results of this study showed significant changes in the objective and subjective vocal quality between the stressing and the relaxed conditions. The F₀ was significantly lower in

the stress-inducing condition (203 Hz) in comparison with the relaxed condition (209 Hz). This finding is in contrast with the results of other researchers [12, 14], who found a significant increase in F₀, and with the findings of Lively et al. [8] and Schneider et al. [13], who found no consistent effect of workload on F₀. In our study we made use of a specific type of stress-induction: public performance combined with an evaluation of the performance, and with attendance by peers. In contrast, most other studies examining the effect of stress induction on voice performance made use of threats or pressure (e.g. different difficulty levels in performing a task) [3, 4]. This difference in stress induction might explain why F₀ is not increased but decreased in our stressing condition. Moreover, the observation that generally, and for most participants, state anxiety was lower in the stressing condition is connected to our observation of a reduced F₀. The trend in the anxiety scores indicates that our participants experienced the reading task as a challenge or excitement, and not as a threat. All participants were students in logopedics enrolled in a course in speech training. Most probably the use of their voice in a public performance condition was agreeable and challenging to them. The decrease in F₀ suggests that this is the case. Also Scherer [25] mentioned in his literature review on the vocal expression of emotion that enjoyment or a happy condition is associated with a decrease in F₀, as it is the case in this

Table 3. Impact of performance condition on objective voice characteristics and interactions with subjective experience of stress

Voice parameters	Main effect condition			Interaction effect condition $\times$ subjective experience stress		
	Wilks' lambda	F (1, 52)	p	Wilks' lambda	F (1, 52)	p
Aerodynamic						
MPT, s	0.628	30.748	<0.001	0.992	0.444	0.508
Voice range						
F-high, Hz	0.764	16.106	<0.001	0.985	0.780	0.381
F-low, Hz	0.779	14.764	<0.001	0.999	0.038	0.847
I-high, dB	0.913	4.931	0.031	0.997	0.154	0.697
I-low, dB	0.977	1.248	0.269	0.995	0.251	0.619
Acoustic						
F ₀ , Hz	0.923	4.363	0.042	0.997	0.154	0.696
Jitter, %	0.997	0.160	0.691	0.974	1.387	0.244
Shimmer, %	1.000	0.011	0.915	1.000	0.024	0.878
FTRI	0.998	0.090	0.766	0.993	0.353	0.555
ATRI	0.990	0.502	0.482	0.980	1.052	0.310
Vocal quality						
DSI	0.629	30.704	<0.001	0.996	0.210	0.648

study. To what extent the other types of stress induction (workload task versus public performance) and different use of speech samples (vowel /a/ vs. speech) lead to lower F₀ in the stressing condition is hard to determine from the present study. In agreement with previous findings by Scherer et al. [26] the authors conclude that F₀ carries indeed emotional information. The difference in F₀ has clinical significance. Pitch levels that are too low can be observed in many different types of laryngeal pathologies. Use of a low-pitched voice in a stress-inducing condition is a vocal misuse and can lead to the development of vocal pathology [27]. This low-pitched voice may be treated with direct pitch modification techniques. MPT, vocal range capacity and the DSI are significantly decreased in the stress-inducing condition. As the DSI is a weighted variable including aerodynamic and acoustic measures, small improvements (closer to value 5 or 100%) are indicative of vocal quality improvement [22]. The subjects in the stressed condition showed a DSI of +3.0, corresponding to a DSI% of 80%, whereas a DSI value of +4.3 in the relaxed condition corresponds to a percent scale of 93%. Analysis of the components of the DSI shows that the main responsible variables for this difference in objective vocal quality between the two conditions is MPT and the highest frequency that decreased in the stressing condition. The significant difference in DSI values between the two conditions is in agreement with the

significant difference in perceptual findings with regard to voice characteristics like overall vocal quality (G), grade of breathiness (B) and strainedness (S). This agreement is not totally unexpected, especially not for the G factor, as the DSI was transformed in such a way that for the group of voices characterized by G0 the DSI corresponds to +5, and for those patients with a G3 it corresponds to -5 [22]. The voices in the stress-inducing condition were perceptually judged as more breathy, strained and characterized by a decreased overall vocal quality in comparison with the relaxed condition. Comparison of MPT, vocal performance and DSI values of the current study with data in the literature is not possible because no multiparameter approach using the DSI has been reported.

Contrary to our hypotheses, the results of this study showed that no significant differences (except for the F₀) in acoustic frequency and amplitude parameters were found between the two conditions. This is in agreement with the study by Mendoza and Carballo [12], where no differences in FTRI were measured. However, significant differences for ATRI, jitter and shimmer were found in other studies [9, 12, 15]. It is not clear how these differences are to be explained. Variability in workload tasks, induced anticipatory psychological stress, coping styles, population or differences in speech samples and analysis technique may influence the results.

There is much controversy in the literature about the effect of stress on vocal quality. The authors addressed this issue by both examining the influence of a stressing condition and by studying interaction effects with subjectively experienced state anxiety. The present study indicates that a stress-inducing condition clearly changes female vocal quality. In a stress-inducing and challenging condition the female voice is more breathy, strained and of a lower quality with a lower F_0 , lower frequency, intensity and aerodynamic capacity. Subjectively experienced state anxiety hardly proved to interact with the effect of the stress-inducing condition. The precise way in which levels of subjectively experienced anxiety have an effect on vocal quality has not been addressed in this experiment, but merits study. The authors also suggest that fur-

ther research into this subject could focus on biological parameters of stress. One of the known biological reactions of stress is skeletal muscle tension [18]. Further research needs to be done to determine to what extent increased tension or physical effort in the system of respiration, phonation or resonance and laryngeal hypertonicity in the stressing condition may lead to a different phonation style and to what extent a stress management program can change this phonation style.

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References

- 1 Everly GS: A Clinical Guide to the Treatment of Human Stress Response. New York, Plenum Press, 1989.
- 2 Ruben JS, Sataloff RT, Korovin GS: Diagnosis and Treatment of Voice Disorders. San Diego, Plural Publishing, 2006.
- 3 Scherer KR: Vocal indicators of stress; in Darby JL (ed): Speech Evaluation in Psychiatry. New York, Grune & Stratton, 1981, pp 171–187.
- 4 Scherer KR: Vocal communication of emotion: a review of research paradigms. *Speech Commun* 2003;40:227–256.
- 5 Protopapas A, Lieberman P: Fundamental frequency and perceived emotional stress. *J Acoust Soc Am* 1997;4:2267–2277.
- 6 Williams CE, Stevens KN: On determining the emotional state of pilots during flight: an exploratory study. *Aerospace Med* 1969;40:1369–1372.
- 7 Kurado I, Fujiwara O, Okamura N, Utsuki N: Method for determining pilot stress through analysis of voice communication. *Aviat Space Environ Med* 1976;47:528–533.
- 8 Lively SE, Pisoni DB, Van Summers W, Bernacki RH: Effects of cognitive workload on speech production: acoustic analyses and perceptual consequences. *J Acoust Soc Am* 1993;5:2962–2973.
- 9 Sheridan T, Stassen H: Definitions, models and measures of human workload; in Moray N (ed): Mental Workload. New York, Plenum, 1979, pp 219–234.
- 10 Mendoza E, Carballo G: Vocal tremor and psychological stress. *J Voice* 1997;13:105–112.
- 11 Fuller BF, Horii Y, Conner DA: Validity and reliability of nonverbal voice measures as indicators of stressor-provoked anxiety. *Res Nurs Health* 1992;15:379–389.
- 12 Mendoza E, Carballo G: Acoustic analysis of induced vocal stress by means of cognitive workload tasks. *J Voice* 1998;12:263–273.
- 13 Schneider B, Enne R, Cecon M, Diendorfer-Radner G, Wittels P, Bigenzahn W, Johannes B: Effects of vocal constitution and autonomic stress-related reactivity on vocal endurance in female student teachers. *J Voice* 2006;20:242–250.
- 14 Johnstone T, Van Reekum CM, Bänziger T, Hird K, Kirsner K, Scherer K: The effects of difficulty and gain versus loss on vocal physiology and acoustics. *Psychophysiology* 2007;44:827–837.
- 15 Mendoza E, Carballo G: Vocal tremor and psychological stress. *J Voice* 1999;13:105–112.
- 16 Delatore B: Psychoendocrinologic mechanism of life stress. *Stress Med* 1994;10:107–114.
- 17 Lazarus RS, Folkman S: Stress Appraisal and Coping. New York, Springer, 1984.
- 18 Barnes LLB, Harp D, Jung WS: Reliability generalisation of scores on the Spielberger State-Trait Anxiety Inventory. *Educ Psychol Meas* 2002;62:603–618.
- 19 Meijer J: Stress in the relation between trait and state anxiety. *Psychol Rep* 2001;88:947–964.
- 20 Boudarene M, Legros JJ, Timsit-Berthier M: Study of the stress response: role of anxiety, cortisol and DHEAs. *Encephale* 2002;28:139–146.
- 21 Hirano M: Clinical Examination of Voice. New York, Springer, 1981.
- 22 Wuyts F, De Bodt M, Molenberghs G, Remacle M, Heylen L, et al: The Dysphonia Severity Index: an objective measure of vocal quality based on a multiparameter approach. *J Speech Lang Hear Res* 2000;43:796–809.
- 23 Heylen L, Wuyts FL, Mertens F, De Bodt M, Pattyn J, Croux C, et al: Evaluation of the vocal performance of children using a voice range profile index. *J Speech Lang Hear Res* 1998;41:232–238.
- 24 Van der Ploeg H: Handleiding bij de Zelf-beoordelingsvragenlijst. Een Nederlandstalige bewerking van de Spielberger State-Trait Anxiety Inventory. Lisse, Swets, 2000.
- 25 Scherer KR: Vocal affect expression: a review and a model for future research. *Psychol Bull* 1986;2:143–165.
- 26 Scherer KR, Ladd DR, Silverman KA: Vocal cues to speaker affect: testing two models. *J Acoust Soc Am* 1984;76:1346–1356.
- 27 Stemple JC, Glaze LE, Klaben BG: Clinical Voice Pathology. San Diego, Singular, 2000.