Which teachers are most at risk for voice disorders?

Individual factors predicting vocal acoustic parameters monitored in situ during a workweek.

Short title: Factors predicting teachers' vocal acoustic parameters

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Abstract

Purpose: To identify the factors affecting teachers’ vocal acoustic parameters, with the aim of detecting individuals at risk of phonotrauma.

Method: The voicing time, voice sound pressure level [SPL] and fundamental frequency [f_o] of 87 teachers were measured during one workweek using a voice dosimeter. We retrospectively investigated the impact of 10 factors (gender, age, teaching experience, teaching level, tobacco, gastro-esophageal problems, nonoccupational voice activity, voice education, past voice problems, and biopsychosocial impact of voice problems measured using the Voice Handicap Index [VHI]) on each voice parameter.

Results: None of the above factors affected voicing time or SPL. f_o depended significantly on gender, teaching level, nonoccupational voice activity and VHI score. Specifically, f_o was higher in women (Δ = 69 Hz), in individuals without nonoccupational voice activities (Δ = 11 Hz), and in individuals with a lower VHI score (increase of 0.7 Hz for each additional point). For females, post hoc comparisons revealed a substantial impact of teaching level on f_o: university instructors had deeper voices than kindergarten (Δ = 66 Hz), elementary (Δ = 52 Hz), or secondary teachers (Δ = 41 Hz).

Conclusions: Since higher f_o increases the mechanical stress related to vocal fold vibration, the screening and prevention of phonotrauma should focus primarily on women, particularly those who teach at lower levels, and teachers with more self-rated voice problems. The lower f_o of teachers who engage in nonprofessional voice activities may suggest acute inflammation or muscle fatigue due to voice overload.

Keywords: Teachers, Occupational voice, Vocal demand response, Risk factors, Voice disorders, Voice monitoring.

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1. Introduction

1.1. Teachers as voice users

Teachers are occupational voice users: they work in a profession that has a higher incidence and increased risk of voice disorders (Epstein et al. 2011). They are at two to three times greater risk of voice disorders than the general population (Martins et al. 2014; Roy et al. 2004). More than half of all teachers experience a voice disorder at some point during their career (Van Houtte et al. 2011). Such problems can be devastating for their personal and professional lives, and have negative consequences for society (Van Houtte et al. 2011). Teachers' voice disorders are associated with more physical and emotional stress (Martins et al. 2014; Vertanen-Greis et al. 2018). They can lead to a decrease in teaching activities, an increase in absenteeism (Van Houtte et al. 2011), and a reassignment to administrative tasks (Martins et al. 2014; Roy et al. 2004). In addition, teachers' degraded speech signals affect schoolchildren by impairing their spoken language processing and concentration (Chui and Ma, 2019; Lyberg-Åhlander et al. 2015; Schiller et al. 2020). Thus, society must handle the consequences of these voice problems for logistics, health care and financial costs: absent teachers must be replaced, health care is expensive, and the efficiency of the school system is negatively impacted (Epstein et al. 2011; Martins et al. 2014; Van Houtte et al. 2011).

1.2. Framework for studying teachers' voice in situ

Much research has focused on teachers' voice health and their occupational voice use. Such studies commonly investigate the concepts of *vocal effort*, *vocal load*, *vocal loading*, and *vocal fatigue*. Recently, a group of experts proposed a consensus description of these terms (Hunter et al. 2020). Following an extensive literature search, these experts stated that the aforementioned concepts are often confused and distinctions are blurred. To address the ambiguity of the terms *vocal load* and *vocal loading*, they proposed to use the terms *vocal demand* and *vocal demand response*. Vocal demand is the vocal requirement for a given communication scenario (e.g., teaching in a classroom), and vocal demand response is the way voice is produced by a vocalist (e.g., a teacher) in response to the perception of the communication scenario (Hunter et al. 2020).

Acoustically, vocal demand response can be quantified in terms of vocal metrics, such as

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- The voicing time, also called the time dose, which is the total time during which the vocal folds vibrate in a period. It can be expressed as a percentage ((duration of vocal fold vibration/duration of monitoring)*100);
- The voice sound pressure level (SPL, in dB), which is the amount of energy of the voice sound wave;
- The fundamental frequency (f_o, in Hz), determined by the number of vocal fold cycle per second.

These three vocal acoustic parameters can be estimated over an entire day in an ecological context using voice dosimeters. On that basis, numerous studies have quantified teachers' vocal demand response over prolonged periods of time in situ (Astolfi et al. 2015; Bottalico and Astolfi 2012; Bottalico et al. 2017; Calosso et al. 2017; Cantor Cutiva et al. 2017; Hunter and Titze 2010; Masuda et al. 1993; Morrow and Connor 2011; Nusseck et al. 2018; Pirilä et al. 2017; Puglisi et al. 2017; Rantala and Vilkman 1999; Remacle et al. 2014; Sala et al. 2002; Schiller et al. 2018; Smith et al. 2017; Titze and Hunter 2015). More information on voice dosimetry and monitoring, with an emphasis on professional voice, can be found in the review by Manfredi and Dejonckere (2016).

1.3. Conceptualization of voice injury

To guide research on the genesis of voice disorders, it is interesting to refer to the theory developed by Haddon (1980), a leader in the field of injury epidemiology and prevention (Runyan 2003). To understand how injuries occur, the Haddon Matrix (1980) conceptualizes health problems as resulting from interactions between the *host*, *agent*, and *environment* (Runyan 2003). Transferred to our research area, the *host* is the vocalist at risk of vocal injury, the *agent* is the physical energy transferred to the host's vocal folds, and the *environment* relates to the physical and social components that contribute to injury development. Timewise, the Haddon Matrix addresses these components at three different phases of influence: before, during, and after the injury occurs.

Among teachers as *hosts*, high vocal demand has repeatedly been identified as a major risk factor for voice disorders such as fatigue, dysphonia, and laryngeal injury (Epstein et al. 2011; Hunter et al. 2020; Manfredi and Dejonckere 2016; Martins et al. 2014; Roy et al. 2004; Van Houtte et al. 2010; Vilkman 2004). The *agent* of injury is mechanical: phonation triggers mechanical stress on the vocal folds, including oscillation, collision, friction, contraction, deformation, elongation, and acceleration (Titze 2000). The longer the voicing time, the greater the stress applied on the tissue. The voice SPL is related to the amplitude of vocal fold vibration and f_o is associated with

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their vibration rate. f_o is regulated by the combined action of laryngeal muscles and subglottal pressure. The adjustment of laryngeal muscles influences the vocal folds' length, stiffness (muscle or tissue), and vibrating mass, and therefore their vibration frequency (Titze 2000). Subglottal pressure influences both the vibration amplitude of the vocal folds, affecting voice SPL, and their tension, affecting vibration frequency. It is commonly accepted that excessive mechanical loads lead to tissue damage, that is, phonotrauma. Many authors have emphasized the link between excessive vibration patterns and voice disorders (Epstein et al. 2011; Manfredi and Dejonckere 2016; Martins et al. 2014; Roy et al. 2004; Van Houtte et al. 2010; Vilkman 2004). In teachers, phonotraumatic lesions, which develop from excessive or inappropriate vocal patterns, are most commonly observed through videolaryngoscopic examinations (Martins et al. 2014).

With regard to the *environment*, the school context plays a critical role. Teachers have been found to speak longer and louder than other workers (Masuda et al. 1993; Sala et al. 2002). Their voicing time at work is twice as long as in non-working situations (Hunter and Titze 2010; Remacle et al. 2014). In addition, they speak louder and at a higher pitch at school (Hunter and Titze 2010; Titze and Hunter 2015). On average, their vocal folds can run a five-kilometer race and collide up to 2 million times in a teaching day (Titze and Hunter 2015). Several environmental factors increase the likelihood of vocal injury, such as dust, vapor, variations in temperature, dryness, and/or excessive humidity (de Jong 2010; Vilkman 2004). Voice dosimetry research has shown that environments with poor acoustics, inadequate reverberation time (Astolfi et al. 2015; Calosso et al. 2017), and high background noise (Calosso et al. 2017; Pirilä et al. 2017; Puglisi et al. 2017; Schiller et al. 2018) increase teachers' vocal load. A greater distance between speaker and listener also leads to extra phonatory effort by the speaker (Vilkman 2004).

In sum, teachers' voice-related injuries are undoubtedly the result of interactions between the three components (*host*, *agent*, and *environment*) identified in the Haddon Matrix (1980). The remainder of this introduction and the study itself focus on factors related to the host and his/her personal characteristics that represent potential agents of injury.

1.4. Factors influencing vocal demand response

According to Hunter et al. (2020), vocal demand response depends on individual attributes, which may partially explain the disparate vocal injuries in vocalists facing a similar vocal demand. Given the scenario of a workday, Remacle et al. (2018) evaluated the inter- and intra-subject variability of teachers' responses to vocal demand in terms of vocal acoustic parameters measured at the beginning and at the end of 66 teaching days. They

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established a typology including three different types of response. The first was characterized by a substantial f_o increase from morning to evening, interpreted as a common, appropriate adaptation to increased vocal requirement. The second response pattern showed increases in f_o and harmonics-to-noise ratio, and decreases in jitter and shimmer, interpreted as a shift to hyperfunctional voice production. The third response type comprised decreases in f_o and harmonics-to-noise ratio and increases in jitter and shimmer, suggesting acute tissue inflammation or muscle fatigue following the workday.

These different response patterns may rely on (1) individual factors known to interfere with vocal health such as gender, age, and voice education; (2) other potential agents of injury referred to as inflammatory influences; and (3) individual tissue's ability to withstand biomechanical energy transfer during voicing. The influencing factors considered in this study and their potential impact on teachers' vocal acoustic parameters measured in situ are presented in the following paragraphs.

Gender. For an equal amount of voicing, women's higher fundamental frequency results in more vocal fold oscillations and collisions than men's. Voice dosimetry in teachers has shown higher voice f_o, slightly higher voicing percentage and louder voice in females than in males (Hunter and Titze 2010). This has been claimed to partially explain the increased risk of voice disorders in female versus male teachers (Hunter et al. 2011; Roy et al. 2004).

Age and teaching experience. Speaking fundamental frequency becomes lower with age, particularly in women (Nishio and Niimi 2008). Age and teaching experience also affect teachers' vocal behavior (Roy et al. 2004). Monitoring of elementary teachers' voices has shown that the more teaching experience an individual has, the higher the voicing percentage is (Puglisi et al. 2017). Additionally, ambulatory monitoring of primary school teachers has indicated a decrease in their voice f_o and SPL with age (Bottalico and Astolfi 2012). These authors attribute the decrease in voice intensity to a reduction in respiratory ability with age, while the lowering of f_o is due to a progressive thickening of the vocal fold epithelium.

Teaching level. So far, studies have produced varying results regarding the impact of teaching level: some indicate a greater prevalence of voice disorders at lower levels (Munier and Kinsella, 2008; Preciado et al. 1998), while others show no connection between voice disorders and teaching level (Kooijman et al. 2006, 2007). Using voice monitoring over one workweek, Remacle et al. (2014) compared vocal parameters and vocal doses of 12 kindergarten and 20 elementary school teachers, all female. They found higher cycle doses (approximation of the total glottal cycles over time, based on voicing time and f_o) and distance doses (approximation of the distance

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traveled by the vocal folds, based on voicing time, f_o and amplitude) for kindergarten teachers. Nusseck et al. (2018) monitored voice SPL, f_o, and voicing time in 118 student teachers at elementary, junior high, secondary and special schools. During a typical classroom lesson, these parameters did not differ between teaching levels. However, the lower the level, the louder the background noise in classrooms.

Inflammatory influences. Smoking influences the microstructure of the vocal folds (Kelleher et al. 2014) and therefore voice acoustics and self-rated voice complaints (Ayoub et al. 2019). Compared to nonsmokers, cigarette smokers' f_o is lower and they experience more voice complaints (Ayoub et al. 2019). Teachers in general are less likely to use tobacco products than the general population, yet they still report more voice disorders (Roy et al. 2004).

Gastro-esophageal problems are additional risk factors for occupational voice disorders (Manfredi and Dejonckere 2016). In teachers, rush-related eating habits may favor gastrointestinal disorders, especially reflux, identified as a cause of acid laryngitis (Martins et al. 2014). Such chronic inflammation of the larynx might result in a lower voice f_o. According to the systematic review by Lechien et al. (2017), the consequences of laryngopharyngeal reflux encompass modifications of voice quality (mostly hoarseness) and modifications of acoustic parameters (i.e., impaired indicators of vibration stability and decreased signal-to-noise ratio, but no f_o or SPL change).

Voice-related factors. Voice education, in the form of training of the speaking or singing voice, might represent a protective factor against voice disorders as it is supposed to strengthen vocal technique. Although voice training is recognized as a direct method of primary prevention in professional voice users, few teachers are given such training (Hazlett et al. 2011). In their review of 10 studies investigating the impact of voice training in professional voice users, Hazlett et al. (2011) found no conclusive evidence of effects on acoustic parameters such as f_o or SPL. However, training improves voice awareness and knowledge, which may then protect against vocally abusive behaviors.

Additionally, several studies that monitored teachers' voices examined the differences between occupational and nonoccupational settings (Hunter and Titze, 2010; Remacle et al. 2014; Schiller et al. 2018). Although vocal load is clearly heavier at work, Hunter and Titze (2010) stress that nonoccupational voice use not only leaves little time for vocal rest but also adds more vocal load to an already overloaded voice. Nonoccupational voice use includes after-school communication, at home or during leisure, social, or community activities. The nonoccupational voice activities referred to hereafter include weekly vocally demanding hobbies such as singing, theater, leading a youth club, coaching sports, and leading meetings.

Finally, researchers have tracked the vocal demand response of healthy and pathological speakers using dosimetry to better understand the patterns that promote voice disorders. For instance, Van Stan et al. (2015) compared the voice use profiles of 35 women with nodules or polyps and of matched controls. Similarly, Szabo Portela et al. (2018) compared female patients with voice-intensive occupations (10 with phonasthenia and 10 with nodules) and vocally healthy colleagues. In both studies, average vocal acoustic measures did not differ between the patients and their matched controls.

1.5. Study objectives

Previous research has established that teachers' high vocal demand, quantifiable through vocal acoustic metrics, is associated with an increased likelihood of voice disorders. Mediators can intervene and the impact of several influencing factors has been considered in isolation. The objective of this study was to determine whether a large set of factors considered together can (1) predict vocal demand response through vocal acoustic parameters measured in situ during one workweek, and (2) help to identify teachers who are most at risk of phonotrauma. To our knowledge, no study has analyzed such a vast database of teachers' voice use to investigate the impact of several factors together, namely gender, age, teaching experience, teaching level, tobacco consumption, gastro-esophageal problems, nonoccupational voice activity, voice education, past voice problems, and biopsychosocial impact of voice problems. We hypothesized that each factor would influence teachers' voice use through at least one vocal parameter monitored over the workweek.

2. Method

2.1. Participants

This retrospective study relies on a database resulting from the first author's research work. From 2010 to 2017, data were collected from 90 teachers in the French community in Belgium. The data collection took place in five kindergartens, seven elementary schools, nine secondary schools, and one university. For each participant, the database includes voice ambulatory measures over one workweek, individual information collected with questionnaires, and daily self-evaluations of voice.

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Recruitment procedure. After obtaining approval from the local research ethics committee and authorizations from the schools' principals, teachers were informed orally and by letter of the study. An individual meeting with each teacher who volunteered enabled us to explain the study's objectives and procedures. Each participant signed a consent form before being enrolled in the study. All procedures were in accordance with the 1964 Helsinki Declaration. No information was collected on the response rate.

Inclusion criteria for this study. Out of the 90 participants in our database, only teachers without a known voice pathology at the time of data collection were included. Voice status was based on questionnaires completed by the participants and perceptual evaluations carried out by the first author assisted by a final-year graduating student in speech therapy. Based on connected speech, the purpose of the perceptual evaluation was to state whether the voice quality was normal or abnormal. No laryngeal examination was performed when setting up the database. Based on their responses to questionnaires, three participants from the database were excluded from this study because they reported voice pathologies diagnosed before their recruitment: two females with vocal fold nodules and one female with superior laryngeal nerve injury. None of the participants included had a history of vocal fold lesions or surgery on the vocal folds. One teacher had had speech therapy in the past to improve her voice use. She was included in the sample because she reported being cured of this pathology at the time of the study. The final sample comprises 87 teachers (66 women and 21 men). The mean age of the sample is 40 years (min = 23; max = 63). The mean age is 39 years for females (min = 23; max = 63) and 40 years for males (min = 24; max = 56).

2.2. Material and data collection

2.2.1. Evaluation of influencing factors

Individual data were collected using questionnaires that the participants completed before their week of voice monitoring. A summary of each teacher's individual characteristics is supplied in the supplemental material and an overview of the influencing factors according to gender is presented in Table 1. The sample can be described as follows according to the factors examined.

The mean teaching experience is 15 years (min = 1; max = 36). Regarding teaching level, the sample includes 21 kindergarten teachers (teaching children from 2.5 years old), 20 elementary schoolteachers (teaching children from 6 years old), 35 secondary schoolteachers (teaching students from 12 years old), and 11 university instructors (teaching students from 18 years old).

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Ten participants consumed tobacco daily. Their consumption ranged from 1 to 30 cigarettes per day. Fifteen participants had experienced gastro-esophageal problems, such as gastro-esophageal reflux, esophagitis, gastric ulcer, irritable bowel syndrome or hiatus hernia.

Twenty participants engaged in a nonoccupational voice activity at least once a week. Among them, 7 females and 4 males sang, 2 females were involved in theater, 1 male led a youth club, 4 females and 1 male were sports coaches or instructors outside school hours (e.g., aerobics, swimming, volleyball or track coaching), and one male led extra-professional meetings.

For the purposes of this study, voice education is considered to mean having received weekly speaking (elocution, theater, or dramatic arts) and/or singing voice training for at least one year. According to this definition, 22 participants had received voice education. Five females and 3 males had received speaking voice education, 9 females and 2 males had had singing voice education, and 2 females and 1 male had had both speaking and singing voice education.

Regarding self-rated voice problems, 29 teachers reported having experienced a voice disorder in the past. In most cases, this had involved episodes of aphonia. Finally, the biopsychosocial impact of voice problems at the time of the study was measured with the French version of the Voice Handicap Index (VHI) (Woisard et al. 2004). This questionnaire is made up of 30 items. Each item is scored on a 5-point scale from 0 (never) to 4 (always). The total score ranges from 0 to 120. Low scores indicate few complaints and high scores indicate many complaints. The mean VHI score for the sample was 11.6 (min = 0; max = 40).

<Table 1 about here>

2.2.2. Monitoring of vocal acoustic parameters

Phonatory behavior was quantified using the Ambulatory Phonation Monitor (APM), model 3200 (KayPENTAX, Montvale, NJ). Each participant wore the device over five full days of normal activities in a typical workweek (Monday to Friday).

The APM is a portable voice dosimeter that incorporates an accelerometer, that is, a throat sensor mounted on a silicon pad attached to the participant's neck with medical glue. Gluing the accelerometer prevents any movement between the sensor and the skin. The accelerometer is connected to a microprocessor carried in a waist pack. Every 50 ms, the accelerometer estimates vocal SPL and f_o from skin acceleration level due to the vocal fold vibration. According the APM specifications, the f_o is estimated using an autocorrelation algorithm, with

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measurement errors not greater than ± 1 Hz. The bandwidth ranges from 2 Hz to 3000 Hz, with a flatness of ± 1.5 dB in the frequency range 50–1000 Hz. Regarding the uncertainty of the estimated parameters, the APM tends to overestimate the calculation of both mean SPL (mean error = 1.15 ± 1.01 dB) and mean f_o (mean error = 2.9 ± 2.45 Hz) (Bottalico et al. 2018).

The voicing decision and subsequently the voicing time calculation were based on a 50–500 Hz frequency range and a 30–130 dB SPL range: occurrences within these ranges were considered as voicing while other occurrences were considered not to be voicing. Similar frequency and SPL ranges have been used previously (Remacle et al. 2014) and are the default ranges of the APM software. At the onset of each workday, the dosimeter was installed and calibrated according to the APM instruction manual (KayPENTAX, 2009), in a quiet room within each participant's school. The throat sensor calibration was intended to relate the amplitudes of the throat sensor accelerometer signal and the voice SPL signal measured at 15 cm from the mouth using a reference microphone. The participant was instructed to take a deep breath and sustain the vowel /a/ from the softest to the loudest voice for about 10 seconds. When gliding from soft to loud was not possible, the participant was instructed to produce several shorter instances of /a/ in a soft, medium, and loud voice with a breath after each production. As the participant phonates, the software displays the calibration data points and a straight line representing the linear correlation between the SPL of the microphone signal and the amplitude of the throat sensor signal. The calibration screen shows a line after at least seven data points have appeared. If the line has a low coefficient of determination, the calibration is not valid (Bottalico et al. 2018). In this study, we stopped the calibration after 10 seconds of voice production. Whenever the software had not collected adequate phonation data and instructed us to recalibrate, we did so.

After each monitoring period, data were downloaded onto a computer using the APM software. For each day, raw data were exported as a .csv file. In total, five days of monitoring were extracted for each of the 87 teachers, resulting in 435 days. Since four files proved to be unusable, the final analysis covers 431 days. To allow for further analyses using SPSS, these 431 days were compiled in a single .sav file. To enable us to use this file, we reduced its size by keeping one out of every four data points (i.e., we kept one data point every 200 ms and simply removed the other three data points). Based on five days of monitoring of the first participant, we checked whether the f_o, SPL, and voicing time measures varied between the complete file (data points every 50 ms) and the reduced file (data points every 200 ms), by calculating the relative error (RE) of the means and SDs using the following formula:

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$$RE = \frac{|\text{value for data points every 50 ms} - \text{value for data points every 200 ms}|}{\text{value for data points every 50 ms}}$$

The very small RE obtained for the means (f_o = .0002; SPL = .0002; voicing time = $1.8*10^{-5}$) and SDs (f_o = .001; SPL = .002; voicing time = $9.6*10^{-6}$) reassured us regarding our decision to use one data point every 200 ms.

Overall, the statistical analyses cover 4,479 hours of voice monitoring with one data point every 200 ms, corresponding to 18,000 data points per hour.

Supplemental material shows the total duration of monitoring, mean voicing percentage, voice f_o and SPL for each participant during the workweek.

2.3. Statistical analysis

Statistical processing was performed with SPSS Statistics for Windows (Version 25.0. Armonk, NY: IBM Corp.). All the calculations were performed considering a confidence interval (CI) of 95%. The significance level was set at .05.

To investigate the potential relationships between the influencing factors that will later be used in the statistical models, we first tested the existence of pairwise associations (see Table 2). Pearson chi-square tests examined the link between the categorical variables two by two. One-way ANOVAs were used to test the link between one continuous variable and one categorical variable. Pearson correlations were applied to test the relationship between two continuous variables. In addition, the links between the vocal acoustic parameters measured every 200 ms were tested using Pearson correlations (see supplemental material).

Next, to determine the effect of influencing factors on the vocal acoustic parameters, general linear mixed models (GLMMs) were used. The term "mixed" refers to the use of both fixed and random effects in the same model. Compared to traditional approaches such as ANOVAs, the advantage of mixed models is that they take into account all the data points of the vocal parameters (i.e., repeated measures every 200 ms for 5 days), instead of the means. A statistical model was constructed for each vocal acoustic parameter. Voicing time, SPL and f_o (dependent variables, continuous) are predicted by 10 influencing factors (independent variables) in their respective models. Independent variables include gender (0 = female, 1 = male), age (in years), teaching experience (in years), teaching level (1 = kindergarten, 2 = elementary, 3 = secondary, 4 = university), tobacco use (yes or no), gastro-esophageal problems (yes or no), nonoccupational voice activity (yes or no), voice education (yes or no), past voice problems (yes or no), and biopsychosocial impact of voice problems (VHI score). For each significant effect ($p < .05$) of an

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independent variable on a vocal parameter, the associated F-test value and p-value are reported. Table 3 shows the associated t-test value and p-value, degrees of freedom (df), estimates (E), standard errors and 95% CIs. The estimates indicate the direction of the relationship between two variables. The 95% CIs indicate the magnitude of the effect in addition to the statistical significance provided through the p-value (Lee 2016). For post hoc comparisons of teaching levels, pairwise comparisons of means were performed using Holm's sequential Bonferroni procedure. The applicability of the analyses was checked in advance. Residual analysis for the models reported shows that the validity conditions were respected, and particularly homoscedasticity and normality.

3. Results

3.1. Relationships between the influencing factors

Table 2 presents statistics concerning the relations between the factors.

In this data set, there is a significant association between gender and teaching level. Table 1 shows the breakdown of participants according to gender for each teaching level.

The strong positive correlation between age and teaching experience (see Table 2) indicates that the older teachers are, the more teaching experience they have.

There is a negative correlation between self-rated voice complaints and age (see Table 2): the older teachers are, the lower their VHI score is.

There is a negative correlation between self-rated voice complaints and teaching experience (see Table 2): the more experience teachers have, the lower their VHI score is.

The one-way ANOVA shows that teachers who report past voice problems have higher VHI scores than those who report never having had a voice problem (VHI scores: mean = 16.1, SD = 10.4, and mean = 9.3, SD = 9.3 respectively).

<Table 2 about here>

3.2. Relationships between the vocal acoustic parameters

For each participant, the correlations between the f_o, SPL, and voicing time measured every 200 ms are presented in the supplemental material. All the participants show a positive correlation between f_o and SPL. The summary across participants indicates weak to strong positive correlation between voice f_o and SPL (r median = .496; min = .164; max = .638). Correlations between voicing time and f_o are weak to null, with variability across participants (r median = –.010; min = –.224; max = .219). Similarly, weak to null correlations are observed between voicing time and SPL, with variability across participants (r median = –.090; min = –.273; max = .284).

3.3. Factors predicting vocal acoustic parameters

According to the voicing time and SPL models, none of the examined factors influences the amount of voicing or voice SPL (see Table 3). However, the f_o model shows that several factors have a significant impact on teachers' fundamental frequency.

More specifically, gender has a significant impact on f_o ($F(1, 74) = 132.1$ $p < .001$). The estimate (E = 69; 95% CI 56.7– 80.4) expresses the contrast between the female participants and the male participants: women's mean f_o is 69 Hz higher than men's. Table 4 shows means for f_o according to gender.

VHI score has a significant effect on f_o ($F(1, 74) = 8.95$, $p = .004$): for each additional point, f_o increases by 0.7 Hz (95% CI 0.2–1.2) (see Table 3).

Engagement in a vocally demanding nonoccupational activity has a significant effect on f_o ($F(1, 74) = 4.34$, $p = .041$): teachers who use their voices nonoccupationally have an f_o that is 11 Hz lower (95% CI 0.5–21.3) (see Table 3). Table 4 presents the means for f_o according to nonoccupational voice activity for males and females.

Teaching level has a significant effect on f_o ($F(3, 74) = 12.49$, $p < .001$). To compare f_o for each pair of teaching levels, a post hoc pairwise comparison of means was done, with a sequential Bonferroni correction (see Table 5). These results suggest that f_o decreases as teaching level increases in the overall sample. However, gender was found to influence teaching level (see Table 2): the lower the level, the higher the proportion of females. Table 1 shows that our sample is made up exclusively of females at the kindergarten and elementary school levels. Because gender is a confounding factor, we subsequently created two separate models investigating f_o: one for males and one for females.

<Tables 3, 4 and 5 about here>

When the analysis covers only men, teaching level has no effect on f_o ($F(1, 11) = 0.336$, $p = .574$). When the analysis covers only women, teaching level has a significant impact on f_o ($F(3, 54) = 14.02$, $p < .001$). Post hoc pairwise comparisons of means with a sequential Bonferroni correction (see Table 5) show that female kindergarten teachers have a mean f_o 13 Hz higher than elementary school teachers (95% CI -5.2–31.7), 25 Hz higher than secondary teachers (95% CI 6.4–43.4) and 66 Hz higher than university instructors (95% CI 36.7–94.6). Elementary

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teachers have a mean f_o 12 Hz higher than secondary teachers (95% CI -6.6–30) and 52 Hz higher than university instructors (95% CI 24.2–80.6). Finally, secondary school teachers have a mean f_o 41 Hz higher than university instructors (95% CI 12.6–68.8). Table 4 shows the means for f_o according to teaching level.

4. Discussion

4.1. Relationships between the influencing factors

The main purpose of this study was to identify the factors that influence teachers' voice use in real-life situations during one workweek. When one studies the effect of influencing factors on vocal acoustic parameters, it is important to strictly control the links among those factors. In our sample of teachers from kindergarten, elementary school, secondary school and university, we found a significant correlation between gender and teaching level: the lower the teaching level, the more female-dominated the profession is, which is representative of the teaching population in general. To take this into consideration, further analyses examined the effect of teaching level with separate statistical models for women and men.

As expected, there is a significant association between age and teaching experience: an older teacher is likely to have more experience than a young teacher. There is a negative correlation between the biopsychosocial impact of voice problems and both age and teaching experience: the higher the VHI score, the more likely teachers are to be young and inexperienced. To explain these data, two hypotheses can be formulated. First of all, experience may have a protective effect: the better VHI in older, more experienced teachers may be due to learning of compensatory habits or techniques to minimize voice problems (Thibeault 2004). Secondly, the "healthy worker effect" may apply: teachers who have voice disorders may leave the profession earlier (Thibeault 2004) to take early retirement or change professions, which would leave a sample made up exclusively of teachers without voice disorders.

Finally, there is a significant association between a history of past voice problems and the biopsychosocial impact of voice problems at the time of the study. Worse VHI scores in individuals who have previously had voice complaints suggest that teachers' voice problems may become chronic.

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4.2. Relationships between the vocal acoustic parameters

The positive correlation between the ambulatory measures of f_o and SPL confirms previous long-term monitoring findings (Hunter and Titze 2010). From the physiological point of view, the link between voice frequency and intensity is well known: the voice gets louder with increased lung pressure and with higher pitch (Titze, 2000).

The absence of a clear link between voicing time, on one hand, and voice f_o and SPL, on the other, might be due to the variability of the teachers' response to vocal demand. The changes in the voice acoustic parameters following a workday are teacher-specific (Remacle et al. 2018).

4.3. Factors predicting vocal acoustic parameters

Using GLMMs, the voicing time, vocal SPL and fundamental frequency of 87 teachers monitored for one workweek were studied in light of 10 factors (gender, age, teaching experience, teaching level, tobacco consumption, gastro-esophageal problems, nonoccupational voice activity, voice education, past voice problems, and biopsychosocial impact of voice problems at the time of the study).

Based on the results of the voicing time and SPL statistical models, none of these factors predicts teachers' amount of voicing and vocal SPL. However, the f_o model showed that gender, teaching level, VHI score and nonoccupational voice activities can predict teachers' fundamental frequency.

As established in the literature, we found a significant effect of gender on f_o. Throughout their daily activities, female teachers' mean speaking f_o (= 224.5 Hz) is 69 Hz higher than that of their male colleagues (= 155.9 Hz). Similar differences have been found in other studies that monitored teachers' voices over long durations (Bottalico and Astolfi 2012; Hunter and Titze 2010). Gender-specific anatomo-physiological differences explain women's higher f_o, which makes them more vulnerable to phonotrauma due to the increased vocal fold oscillations and collisions for a similar amount of voicing (Hunter et al. 2011).

As for voicing time and SPL, no gender-based difference was measured. Similarly, Bottalico and Astolfi (2012) did not see any significant effect of gender on voicing time percentage and vocal SPL in elementary schoolteachers. Nusseck et al. (2018) also found no difference based on gender in elementary and secondary teachers starting their careers. Hunter and Titze (2010) found a trend toward female teachers speaking louder and longer. To date, voice dosimetry studies have not statistically confirmed the belief that women have higher voicing percentages

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than men. Nevertheless, Nusseck et al. (2018) found greater differences between noise SPL and voice SPL for male teachers than for female teachers, suggesting that the men covered background noise more.

A crucial finding of this study is that teaching level has a significant impact on fundamental frequency for women. The absence of male participants at the kindergarten and elementary school levels may have prevented us from detecting differences based on teaching level in men. For women – who are represented at all teaching levels in our sample but in only a small number at the university level – the lower the grades they teach, the higher-pitched their speaking voice. The difference between the lowest and the highest level is 66 Hz. There are several possible explanations of this phenomenon. First, it may be due to the Lombard effect, which automatically causes speakers to increase their voice SPL and f_o in noisy environments (for a review, see Yiu and Yip 2016). Higher noise levels have been measured in teaching establishments for lower grades (Nusseck et al. 2018) and for younger groups, where noise is frequently attributed to student activities (Picard and Bradley 2001). However, our data do not show any increase in voice SPL in teachers at lower levels. Secondly, it could be the convergence effect, defined as adults' tendency to imitate some acoustic-phonetic characteristics of another speaker's speech to facilitate communication by establishing common perceptuo-motor ground between speakers (Sato et al. 2013). This automatic phenomenon would explain a tendency for teachers to imitate the acoustic characteristics of their students' voices, particularly fundamental frequency (Remacle et al. 2014). Given that children's f_o decreases with age, teachers of lower grades would adopt a higher-pitched voice in the workplace. Thirdly, the phenomenon may be due to some characteristics of child-directed speech, defined as the spontaneous way in which adults speak with infants and young children (Saint-Georges et al. 2013). The higher f_o and greater f_o variability of speech directed to children (Saint-Georges et al. 2013) may contribute to teachers at lower teaching levels adopting a higher-pitched voice. Fourthly, greater f_o values for these teachers may be related to occupational stress. Previous studies have shown that the lower the teaching level, the higher the stress (Agai-Demjaha et al. 2015; Malik et al. 1991). According to the Model for Voice and Effort (Van Puyvelde et al. 2018), increased f_o is a response to stress in the form of cognitive and/or emotional load. Finally, speaking with a lower-pitched voice could be an adaptation to assert authority in classrooms with older students. In summary, the lower the teaching level, the higher the female teachers' f_o and consequently the greater the risk of potential tissue damage due to mechanical load. In point of fact, lower grades have often been associated with more voice problems (Martins et al. 2014; Munier and Kinsella 2008; Preciado et al. 1998). Apart from fundamental

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frequency, our findings show no effect of teaching level on voicing time or vocal SPL, which matches the conclusions of other dosimetry studies (Nusseck et al. 2018; Remacle et al. 2014).

Contrary to the assumption that previous voice education might prevent abusive vocal behaviors such as speaking for long durations, with high voice SPL and f_o, teachers who had received such training did not show different vocal parameters than those who had not. The data do not reveal different ambulatory voice patterns in situ for teachers who had had speaking and/or singing voice training. However, longitudinal randomized control trials would be worthwhile to determine whether voice education has an effect on teachers' daily-life vocal acoustic parameters.

Of the 87 participants, 15 women and 5 men engaged weekly in a nonoccupational activity where they were likely to project their voice, such as singing, theater, coaching sports, and leading a youth club or meetings. This had a significant effect on their voice frequency measured over the week, since these teachers' mean f_o was 11 Hz (or 1.7 semitones) lower than that of the others. In their typology of teachers' vocal demand response, Remacle et al. (2018) identified three patterns. Regarding the frequency changes from morning to evening, the first and second patterns were both characterized by an f_o increase, interpreted respectively as an appropriate adaptation to vocal demand and as a change to a hyperfunctional voice. In contrast, the third response pattern was characterized by an f_o decrease, suggesting acute inflammation or muscle fatigue following the workday. Although this is not statistically significant, our teachers with a nonoccupational voice activity also had an average voicing time 1% higher than others (see Table 3). In addition to occupational voicing time, earlier studies have measured a nonoccupational voicing percentage in teachers ranging from 10% to 15% (Hunter and Titze, 2010; Remacle et al. 2014). As Hunter and Titze (2010) point out, this nonoccupational voice use is noteworthy, as it represents an additional burden for an already overloaded voice and may also impede vocal recovery. In light of these studies, the lower frequency in teachers who have a vocally demanding nonoccupational activity may be due to excessive mechanical stress, leading to tissue inflammation or muscle fatigue.

Logically, we could expect that teachers who reported past and present voice complaints would use their voice in a more phonotraumatic way, including speaking longer, with an increased voice SPL and f_o. Statistical analyses reveal that self-reported past and current voice problems are not associated with an increase in ambulatory measures of voicing time or voice level. However, teachers who self-report more voice complaints have higher-pitched voices: for each additional point on the VHI score, f_o rises by a mean 0.7 Hz. This phenomenon is not

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directly caused by gender since VHI score does not differ significantly between men (mean = 12.7, SD = 9.1) and women (mean = 11.2, SD = 10.5). More voice complaints associated with higher fundamental frequency may indicate increased laryngeal tension (Remacle et al. 2012), that is, a hyperfunctional adaptation to vocal demand (Remacle et al. 2018). Some previous studies have shown that higher f_o following teachers' voice use may be accompanied by an increase in self-reported vocal symptoms (Rantala and Vilkman 1999; Remacle et al. 2012), while others found no association between ambulatory measures during daily lessons and self-reported voice complaints (Cantor Cutiva et al. 2017).

Logically enough, age and teaching experience are strongly correlated. Although earlier studies have described longer durations of phonation in teachers aged over 50 years (Astolfi et al. 2015) and teachers with more than 21 years of teaching experience (Puglisi et al. 2017), we did not observe any effect of age or teaching experience on vocal acoustic parameters. Moreover, the ambulatory measures of fundamental frequency and intensity do not confirm the age-related changes described in the literature (Bottalico and Astolfi 2012; Nishio and Niimi 2008). The absence of a link between the participants' age and experience, on the one hand, and their ambulatory acoustic parameters, on the other hand, is difficult to explain. Further in situ studies are needed to unravel this point.

Regarding inflammatory influences, three men and seven women in this study consumed tobacco. Although cigarette smoking has been associated with lower VHI scores and lower speaking f_o (Ayoub et al. 2019), we did not find such effects. Indeed, there is no correlation between tobacco consumption and VHI score. In addition, tobacco consumption has no significant effect on any of the vocal parameters, including fundamental frequency. Note that we did not collect information about the number of years of tobacco consumption. Finally, gastro-esophageal problems, which five women and eight men suffered from, did not influence the examined vocal acoustic parameters.

4.4. Limitations and prospects for future research

In communication situations encountered by professional voice users, vocal demand responses are multifactorial. Based on epidemiological models such as Haddon's (1980), voice injuries are known to result from interactions between the vocalist (*host*), the physical energy transferred to his/her vocal folds (*agent*), and the *environment*. In this study, we investigated the impact of ten influencing factors on schoolteachers' vocal acoustic parameters. Additional factors pertaining to the vocalist should be studied, such as medication use, alcohol consumption, asthma, allergies, sedentarity, hormones, women's menstrual cycle, menopause, stress, and personality

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traits. Analysis of daily and weekly voice changes in relation to influencing factors may help to detect different patterns of responses. A next step would be to study the ambulatory voice parameters in light of several environmental factors together, such as background noise level, reverberation, room size, temperature, and humidity. Controlling certain environmental factors may help to mitigate the vocal risk among teachers. Future studies combining environmental and individual factors are necessary to acquire a more complete understanding of teachers' vocal behavior and better identify vulnerable individuals and risky situations.

Regarding the *agent* of injury, excessive mechanical load related to vibration is potentially damaging to vocal fold tissue, but its effect on laryngeal muscles is less straightforward. For instance, Titze (2017) argued that the morphology of the vocal folds appears to be optimized for communication at higher f_o and SPL and with more voiced segments than are found in actual human speech patterns. Contemporary voice use tends to produce a contracture of the laryngeal muscles and some vocal behaviors counterbalance this contracture, such as raising one's voice to call, shout, or sing (Titze 2017). Future research should unravel the exact impact of mechanical load on vocal fold tissue versus muscle, taking into account the great inter-individual variability in vocal demand response.

5. Conclusions

As is unanimously recognized in the field of occupational voice, it is crucial to identify subgroups with higher risks of voice problems. Long-term monitoring of voice behavior was made possible thanks to the use of dosimetry. The main contribution of this work was to consider a large set of influencing factors together to predict acoustic measures of 87 teachers' voices tracked for a total of 431 days.

Our results show that higher ambulatory measures of f_o are statistically predicted by being a woman, teaching a lower grade and having a higher VHI score. On the one hand, the higher-pitched voices of kindergarten and elementary female teachers may be due to the Lombard effect, the convergence effect, the characteristics of child-directed speech, or the cognitive and/or emotional load related to occupational stress. On the other hand, lowering the pitch may be a strategy secondary and university teachers use to assert their authority. In addition, lower ambulatory measures of f_o are statistically predicted by engaging in a vocally demanding nonoccupational activity, which is likely to increase mechanical load.

Considering the high prevalence of voice problems among teachers, researchers agree that primary prevention and early detection are key. Given their cost, these actions should be made available primarily to

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individuals at risk of developing vocal fold tissue damage due to mechanical load, namely females, and specifically those teaching at the kindergarten and elementary levels, who have substantially higher f_o than those teaching higher grades. In addition, self-assessment questionnaires such as the VHI could also help to detect individuals with potentially harmful f_o voice patterns.

Declarations

Conflicts of interest: There are no conflicts of interest.

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Author contributions: AR: study conceptualization and design, methodology, data acquisition and analysis, writing – original draft preparation and review. NL: statistical analysis.

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Table 1. Overview of the influencing factors according to teachers' gender

	Female (n = 66)		**Male** (n = 21)		**All** (n = 87)	
	n	**%**	**n**	**%**	**n**	**%**
Teaching level						
Kindergarten	21	24.1	0	0.0	21	24.1
Elementary	20	23.0	0	0.0	20	23.0
Secondary	20	23.0	15	17.2	35	40.2
University	5	5.7	6	6.9	11	12.6
Tobacco						
No	59	67.8	18	20.7	77	88.5
Yes	7	8.0	3	3.4	10	11.5
Gastro-esophageal problems						
No	56	64.4	16	18.4	72	82.8
Yes	10	11.5	5	5.7	15	17.2
Nonoccupational voice activity						
No	51	58.6	16	18.4	67	77.0
Yes	15	17.2	5	5.7	20	23.0
Voice education						
No	50	57.5	15	17.2	65	74.7
Yes	16	18.4	6	6.9	22	25.3
Past voice problems						
No	44	50.6	14	16.1	58	66.7
Yes	22	25.3	7	8.0	29	33.3
	mean	**SD**	**mean**	**SD**	**mean**	**SD**
Age (years)	39.0	9.3	43	9.6	40	9.5
Age per teaching level (years)						
Kindergarten	39.3	7.9	-	-	39.3	7.9
Elementary	39.2	9.1	-	-	39.2	9.1
Secondary	37.6	10.6	40.7	9.6	38.9	10.2
University	42.6	11.6	48.8	7.4	46.0	9.6
Teaching experience (years)	14.7	8.6	16.6	8.0	15.2	8.5
VHI score	11.2	10.5	12.7	9.1	11.6	10.2

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Table 2. Relationships between the influencing factors

Variables	Test	Test value	df	P-value
Tobacco*Gastro-esophageal problems	Pearson chi-square	r = .06	1	.806
Gender*Teaching level	Pearson chi-square	r = 25.29	3	<.001
Voice problems*Voice education	Pearson chi-square	r = .76	1	.383
Voice education*Nonoccupational voice activity	Pearson chi-square	r = .30	1	.581
Nonoccupational voice activity*Voice problems	Pearson chi-square	r = .51	1	.471
Past voice problems*VHI score	One-way ANOVA	F = 9.43	1	.003
Gender*VHI score	One-way ANOVA	F = 0.31	1	.579
Voice education*VHI score	One way ANOVA	F = .208	1	.649
Age*Teaching experience	Pearson correlation	r = .85	85	<.001
Age*VHI score	Pearson correlation	r = –.22	85	.038
Teaching experience*VHI score	Pearson correlation	r = –.21	85	.043

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Table 3. Results of the general linear mixed models for voicing time, SPL, and f_p

Voicing time (%)	Estimate	Standard error	df	t-value	p-value	95% confidence interval (lower bound–upper bound)
Intercept	9.05	2.1	1, 74	4.35	<.001	4.9 – 13.2
Gender = female	0.2	0.6	1, 74	.38	.706	–1.0 – 1.5
Age	0.04	0.1	1, 74	.82	.416	–0.06 – 0.1
Teaching experience	–0.02	0.1	1, 74	–.41	.682	–0.1 – 0.1
Teaching level* = 1	0.3	1.0	3, 74	.33	.739	–1.6 – 2.2
Teaching level* = 2	0.8	0.9	3, 74	.92	.361	–1.0 – 2.6
Teaching level* = 3	–0.1	0.8	3, 74	–.07	.945	–1.6 – 1.5
Tobacco = no	–0.1	0.7	1, 74	–.17	.868	–1.6 – 1.3
Gastro-esophageal problems = no	0.6	0.7	1, 74	.95	.343	–0.7 – 2.0
Nonoccupational voice activity = no	–1.0	0.6	1, 74	–1.70	.093	–2.1 – 0.2
Voice education = no	–0.8	0.5	1, 74	–1.49	.140	–1.9 – 0.3
Past voice problems = no	–0.6	0.5	1, 74	–1.16	.248	–1.6 – 0.4
VHI score	–0.03	0.02	1, 74	–1.04	.301	–0.1 – 0.02
Voice SPL (dB)	Estimate	Standard error	df	t-value	p-value	95% confidence interval
Intercept	69.3	6.3	1, 74	11.03	<.001	56.8 – 81.8
Gender = female	–0.1	1.9	1, 74	–.04	.967	–3.9 – 3.8
Age	0.1	0.1	1, 74	.37	.712	–0.2 – 0.4
Teaching experience	–0.01	0.2	1, 74	–.08	.934	–0.4 – 0.3
Teaching level* = 1	5.0	2.9	3, 74	1.72	.089	–0.8 – 10.7
Teaching level* = 2	3.9	2.7	3, 74	1.41	.163	–1.6 – 9.3
Teaching level* = 3	4.3	2.4	3, 74	1.80	.076	–0.5 – 9.0
Tobacco = no	0.6	2.2	1, 74	.28	.778	–3.8 – 5.0
Gastro-esophageal problems = no	–1.2	2.0	1, 74	–.59	.556	–5.2 – 2.8
Nonoccupational voice activity = no	0.4	1.7	1, 74	.22	.827	–3.0 – 3.7
Voice education = no	–0.3	1.6	1, 74	–.20	.845	–3.6 – 2.9
Past voice problems = no	0.8	1.6	1, 74	.50	.621	–2.4 – 3.9
VHI score	–0.02	0.1	1, 74	–.24	.806	–0.2 – 0.1
Voice f_o (Hz)	Estimate	Standard error	df	t-value	p-value	95% confidence interval
Intercept	126.6	19.4	1, 74	6.51	<.001	87.9 – 165.3
Gender = female	68.5	5.9	1, 74	11.49	<.001	56.7 – 80.4
Age	–0.5	0.5	1, 74	–.95	.343	–1.4 – 0.5
Teaching experience	0.03	0.5	1, 74	.06	.952	–1.0 – 1.1
Teaching level* = 1	52.9	8.9	3, 74	5.91	<.001	35.1 – 70.7
Teaching level* = 2	39.9	8.5	3, 74	4.69	<.001	23.0 – 56.9
Teaching level* = 3	25.4	7.4	3, 74	3.44	.001	10.7 – 40.1
Tobacco = no	11.7	6.8	1, 74	1.72	.089	–1.8 – 25.3
Gastro-esophageal problems = no	4.8	6.3	1, 74	.77	.444	–7.7 – 17.4
Nonoccupational voice activity = no	10.9	5.2	1, 74	2.08	.041	0.47 – 21.3
Voice education = no	–5.7	5.1	1, 74	–1.13	.263	–15.2 – 4.4
Past voice problems = no	–3.1	4.9	1, 74	–.63	.528	–12.8 – 6.6
VHI score	0.7	0.2	1, 74	2.99	.004	0.2 – 1.2

Note. For teaching level, 1 = kindergarten, 2 = elementary, 3 = secondary. *The reference level for comparisons is university.

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Table 4. Estimated marginal means for f_o (Hz) according to gender

	Females		Males	
	Mean	**Standard error**	**Mean**	**Standard error**
Gender[a]	224.5	4.6	155.9	6.3
Nonoccupational voice activity[b]				
No	229.3	5.2	144.0	7.1
Yes	219.2	7.05	140.6	10.2
Teaching level[b]				
Kindergarten	250.2	7.22	–	–
Elementary	236.9	6.6	–	–
Secondary	225.3	6.4	138.1	7.4
University	184.5	9.7	146.4	12.5

Note. [a] To estimate the f_o values, the continuous variables of the overall f_o model (n = 87) were set at their mean values: age = 40, teaching experience = 15, VHI score = 11.6.
[b] To estimate the female f_o values, the continuous variables of the f_o model for females (n = 66) were set at their mean values: age = 39, teaching experience = 14, VHI score = 11.
To estimate the male f_o values, the continuous variables of the f_o model for males (n = 21) were set at their mean values: age = 43, teaching experience = 17, VHI score = 12.

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Table 5. Pairwise comparisons of teaching levels based on estimated marginal means for f_o (Hz) in the overall sample (males and females) and in females only

				95% confidence interval for difference	
Teaching levels compared	**Averaged mean difference**	**Standard error**	**p***	**Lower bound**	**Upper bound**
Males and females (n = 87)					
Kindergarten vs. Elementary	13.0	6.5	.303	–4.7	30.7
Kindergarten vs. Secondary	27.5	6.3	<.001	10.4	44.7
Kindergarten vs. University	52.9	8.9	<.001	28.7	77.2
Elementary vs. Secondary	14.5	6.4	.148	–2.6	31.7
Elementary vs. University	39.9	8.5	<.001	16.9	63.0
Secondary vs. University	25.4	7.4	.006	5.4	45.4
Females (n = 66)					
Kindergarten vs. Elementary	13.2	6.7	.330	–5.2	31.7
Kindergarten vs. Secondary	24.9	6.8	.003	6.4	43.4
Kindergarten vs. University	65.7	10.6	<.001	36.7	94.6
Elementary vs. Secondary	11.7	6.7	.515	–6.6	30.0
Elementary vs. University	52.4	10.3	<.001	24.2	80.6
Secondary vs. University	40.7	10.3	.001	12.6	68.8

Note. * The mean difference is significant at the .05 level. Adjustment for multiple comparisons: sequential Bonferroni procedure.

Supplemental material. Overview of the participants' individual characteristics and vocal acoustic parameters. Each teacher wore the Ambulatory Phonation Monitor for five full days of normal activities in a typical workweek.

Individual characteristics											**Vocal acoustic parameters**						
											Weekly measures				**Pearson correlations (r)**		
Participants	Gender	Age (years)	Teaching experience (years)	Teaching level	Tobacco use	Gastro-esophageal problems	Nonoccupational voice activity	Voice education	Past voice problems	VHI score	Mean f_o (Hz)	Mean SPL (dB)	Mean voicing time (%)	Total monitoring duration (hh:mm:ss)	f_o * SPL	Voicing time * f_o	Voicing time * SPL
1	0	39	15	2	no	yes	yes	yes	no	5	243.6	76.3	13.6	46:14:56	.492**	-.069**	-.113**
2	0	50	25	2	no	no	no	yes	yes	6	289.2	80.4	22.1	23:14:21	.585**	.093**	.052**
3	0	36	11	1	no	no	no	no	no	8	277.5	80.9	15.1	54:15:38	.514**	-.114**	-.148**
4	1	32	11	3	no	no	yes	no	no	15	159.8	69.4	18.5	54:42:37	.348**	.035**	-.044**
5	0	58	17	2	no	no	no	no	no	10	228.9	77.6	19.9	34:19:58	.467**	.012**	-.048**
6	0	46	6	2	yes	no	no	no	no	3	229.4	73.8	15.2	55:27:58	.478**	-.030**	-.113**
7	0	41	19	1	no	no	no	no	no	31	314.6	78.3	13.3	65:45:53	.638**	-.174**	-.273**
8	1	53	20	3	yes	no	no	no	no	1	123.6	73.5	12.2	46:14:56	.309**	.030**	-.079**
9	1	36	12	4	no	no	no	no	yes	27	154.9	64.4	14.3	47:43:13	.302**	.134**	.014**
10	1	31	6	3	no	no	no	no	no	14	158.8	68.5	13.5	54:52:23	.244**	.031**	-.074**
11	0	34	6	3	no	no	yes	no	yes	15	245.0	67.8	11.5	58:20:42	.518**	.215**	.003
12	1	46	20	3	no	no	yes	no	no	4	143.1	71.2	26.3	58:10:33	.189**	-.010**	-.045**
13	0	29	8	3	yes	yes	no	yes	yes	14	201.6	72.4	22.0	51:20:35	.417**	.065**	-.068**
14	0	23	1	1	no	no	no	no	no	5	263.2	92.5	10.7	51:24:21	.468**	-.034**	-.016**
15	0	25	4	2	yes	no	no	yes	no	0	253.0	76.8	18.2	42:24:37	.536**	-.077**	-.197**
16	0	37	12	3	no	no	no	no	yes	15	246.2	70.3	14.3	55:50:15	.527**	.169**	.048**
17	0	44	22	3	no	no	yes	no	no	6	237.2	77.7	15.0	58:50:34	.476**	.014**	-.037**
18	0	41	20	2	no	no	yes	yes	yes	4	244.0	74.8	20.7	34:22:54	.509**	.051**	.068**
19	1	56	25	4	no	yes	no	yes	no	14	124.9	67.7	11.4	53:39:46	.196**	.051**	-.040**
20	1	43	20	3	no	no	no	yes	no	0	155.8	69.9	19.2	39:32:15	.330**	.043**	.106**

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21	0	31	9	1	no	no	no	no	no	5	280.6	81.1	17.8	57:44:09	.494**	-.111**	-.172**
22	1	29	5	3	no	no	yes	no	no	12	150.1	77.1	16.0	67:40:21	.218**	-.003	-.109**
23	1	50	20	4	no	no	no	no	yes	37	135.0	69.9	14.1	49:19:22	.269**	.035**	.028**
24	0	32	10	1	no	no	no	no	no	1	246.6	83.1	16.8	56:07:44	.536**	-.085**	-.138**
25	1	51	26	3	no	no	no	no	no	5	155.9	90.6	16.6	35:17:26	.309**	.031**	-.117**
26	0	49	26	1	yes	no	no	no	no	5	243.7	76.2	20.9	49:09:47	.489**	-.112**	-.129**
27	0	46	23	3	no	yes	no	no	yes	10	225.8	68.7	14.4	49:26:13	.534**	.020**	.055**
28	0	33	13	1	no	no	no	no	yes	12	269.7	85.9	11.1	54:33:24	.614**	-.050**	-.132**
29	0	38	13	4	yes	no	no	yes	no	12	216.6	60.7	16.3	57:45:41	.528**	.021**	-.018**
30	0	38	11	2	no	no	no	yes	yes	16	247.0	92.0	26.7	36:36:51	.500**	.026**	.009**
31	0	42	19	1	no	no	no	no	no	5	260.1	78.4	23.3	48:53:36	.466**	-063**	-.105**
32	0	29	7	1	no	no	no	no	no	6	239.6	73.1	13.7	72:08:18	.469**	-.035**	-.257**
33	0	32	11	3	no	no	yes	yes	yes	39	255.9	79.6	16.2	64:54:24	.611**	-.080**	-.227**
34[a]	0	35	6	3	no	no	no	yes	no	7	215.5	73.7	25.1	44:40:02	.433**	-.046**	-.061**
35	0	55	14	2	no	no	no	no	no	2	205.8	93.7	13.7	35:24:13	.478**	.034**	-.090**
36	0	54	33	3	no	no	no	no	no	8	229.6	74.8	13.2	51:06:23	.543**	-.105**	-.130**
37	0	35	11	1	no	no	no	yes	yes	6	244.9	82.3	16.0	50:02:33	.524**	-.118**	-.139**
38	1	39	10	3	no	no	yes	yes	yes	11	153.7	72.0	22.07	50:35:19	.397**	.096**	-.005*
39[a]	1	29	9	3	no	no	no	no	yes	12	170.7	76.3	20.2	63:09:12	.260**	.003	.032**
40	1	49	17	3	no	no	no	no	no	28	154.3	72.7	9.8	62:24:12	.411**	-.064**	-.188**
41	0	25	1	3	no	no	yes	no	no	13	222.6	78.7	18.6	67:38:02	.418**	-.017**	.023**
42	0	23	3	3	no	no	yes	no	no	30	234.8	85.4	18.3	44:52:44	.533**	.009**	-.030**
43	0	30	7	2	no	no	no	no	no	15	263.5	83.4	17.2	48:45:04	.556**	.012**	-.061**
44	0	31	12	2	yes	no	no	no	no	11	254.6	80.7	13.3	49:35:32	.515**	-.088**	-.116**
45	0	33	10	2	no	no	no	yes	no	3	248.9	80.2	16.9	42:56:30	.568**	-.012**	-.016**
46	0	41	17	3	no	no	no	no	yes	27	234.4	73.5	18.9	55:56:44	.427**	.027**	.124**
47	0	28	6	2	no	no	no	no	no	14	266.2	70.9	15.3	49:21:54	.413**	.023**	-.096**
48	0	38	14	2	yes	no	no	no	no	40	262.9	81.2	9.3	50:42:56	.514**	-.027**	-.170**
49	0	31	10	1	no	no	yes	yes	no	2	260.8	79.8	25.3	61:19:27	.509**	.056**	-.108**
50	1	56	24	4	no	yes	no	no	no	8	134.9	82.0	19.6	73:20:47	.565**	-.191**	-.244**
51	0	25	5	3	no	no	yes	yes	yes	37	261.8	73.8	20.1	52:02:54	.540**	.052**	.068**
52	0	35	10	1	no	yes	no	no	yes	30	275.2	80.0	12.3	36:02:12	.422**	-.120**	-.212**
53	0	45	23	1	no	no	no	no	yes	7	259.9	78.7	13.2	44:55:23	.461**	-.042**	-.021**
54	0	48	27	2	no	no	no	no	no	3	239.5	72.4	18.9	53:24:22	.518**	-.048**	-.071**
55	0	51	30	3	no	yes	no	no	yes	6	207.1	87.8	15.6	59:13:02	.337**	.040**	-.116**
56	0	39	18	1	no	no	no	no	no	2	264.9	74.6	24.2	42:21:37	.529**	-.051**	-.095**
57	0	59	36	3	no	yes	no	no	no	1	186.6	76.7	18.1	45:12:56	.460**	.002	-.087**
58	1	49	20	4	no	yes	no	yes	yes	17	140.3	67.6	14.1	62:04:08	.192**	.009**	-.193**
59	0	53	31	1	no	no	yes	no	yes	7	238.7	71.0	15.9	68:57:22	.547**	-.042**	-.183**
60	1	24	1	3	no	no	no	no	yes	16	135.4	60.2	6.9	38:57:55	.332**	.065**	.078**

61	0	36	5	4	no	no	no	no	yes	28	219.4	70.3	23.0	65:17:24	.498**	-.013**	-.075**
62[a]	0	48	6	3	no	no	no	no	yes	5	241.5	80.1	25.9	45:29:56	.590**	-.090**	-.094**
63	0	33	10	2	no	no	no	no	yes	19	261.1	72.3	18.5	51:29:50	.545**	-.074**	-.118**
64	0	41	20	1	no	no	no	no	no	0	231.9	78.4	18.4	49:50:52	.572**	-.164**	-.228**
65	1	44	21	3	yes	no	no	yes	no	14	144.5	83.4	14.8	44:53:28	.202**	.032**	.171**
66	0	47	23	1	no	yes	yes	no	no	1	238.1	73.5	20.8	54:18:05	.547**	-.086**	-.208**
67	0	41	21	2	no	yes	no	no	no	10	240.5	77.7	13.2	56:15:54	.554**	-.090**	-.071**
68	1	54	34	3	no	yes	no	yes	no	5	147.7	84.7	14.5	53:49:30	.433**	.038**	-.161**
69	1	41	17	3	no	no	no	no	no	7	160.4	80.5	16.2	43:31:56	.635**	.017**	.056**
70	0	41	15	4	no	yes	no	no	yes	5	223.9	80.1	15.0	40:05:23	.402**	.020**	-.019**
71	0	46	23	1	no	no	no	yes	no	4	268.5	74.1	13.8	59:50:55	.615**	-.178**	-.221**
72[a]	0	63	33	4	no	no	yes	no	no	5	149.8	84.0	17.2	47:02:38	.261**	.051**	-.033**
73	0	36	15	3	no	no	yes	no	yes	18	242.5	75.2	13.2	50:51:08	.617**	.219**	.284**
74	0	32	11	3	no	no	no	yes	no	7	237.9	68.7	14.1	46:43:13	.546**	-.019**	-.093**
75	0	44	20	2	no	no	no	no	yes	15	266.4	77.3	17.9	47:00:20	.516**	-.059**	-.104**
76	1	45	20	3	yes	yes	yes	no	yes	6	135.1	78.0	21.6	60:48:56	.225**	-.033**	-.120**
77	0	35	8	4	no	no	yes	no	no	1	112.8	67.3	19.2	46:47:42	.365**	.116**	-.024**
78	0	27	5	3	no	no	no	no	no	7	234.0	71.1	15.5	57:14:49	.488**	-.077**	-.133**
79	0	51	30	1	no	yes	yes	no	no	8	246.8	70.0	21.7	62:33:43	.496**	.049**	-.167**
80	0	44	23	1	no	no	no	no	no	3	229.4	78.8	15.6	65:08:29	.505**	-.022**	-.010**
81	0	43	11	1	no	no	no	no	no	9	265.6	81.3	14.5	54:57:38	.556**	-.049**	-.166**
82	0	40	17	2	no	no	no	no	no	40	238.7	79.8	17.5	47:31:35	.604**	-.224**	-.237**
83	0	47	17	3	no	no	no	no	no	7	262.7	71.9	9.8	60:14:36	.164**	.021**	-.252**
84	0	39	17	2	no	no	no	no	no	29	253.5	76.2	21.2	26:43:15	.556**	.086**	.061**
85	1	46	11	4	no	no	no	no	no	13	192.8	68.0	14.3	64:52:28	.500**	.018**	-.091**
86	0	27	4	2	no	no	no	no	no	4	263.8	81.6	14.0	38:49:07	.448**	-.039**	.005
87	0	27	4	3	no	no	no	yes	no	13	242.6	73.3	19.9	44:54:52	.566**	-.065**	-.097**

Note. For gender, 0 = female, 1 = male. For teaching level, 1 = kindergarten, 2 = elementary, 3 = secondary, 4 = university.
[a] Participants who missed one day of recording.
* $p \leq 0.05$
** $p \leq 0.001$

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