

Vocal Impact of a Prolonged Reading Task in Dysphonic Versus Normophonic Female Teachers

*Angélique Remacle, *Dominique Morsomme, *Elise Berruë, and †,‡Camille Finck, *[†]Liège, †[‡]Mons, Belgium

Summary: Objectives. This study evaluates the effect of a 2-hour reading task between 70 and 75 dB(A) in 16 normophonic and 16 dysphonic female teachers with vocal nodules.

Methods. Objective measurements (acoustic analysis, voice range measurements, and aerodynamic measurements) and subjective self-ratings were collected before and every 30 minutes during the reading to determine the voice evolution in both groups.

Results. Fundamental frequency, lowest frequency, highest frequency (F-High), highest intensity, and intensity range increase through the reading, whereas shimmer decreases. Maximum phonation time decreases after 30 minutes. Estimated subglottal pressure (ESP) and sound pressure level increase during the first hour. Afterward, ESP decreases. Self-ratings worsen through time. When comparing the normophonic and the dysphonic teachers, self-ratings reveal more complaints in the dysphonic group. Few differences in objective measurements are found between both groups: normophonic teachers show lower ESP, higher F-High, and greater frequency range.

Conclusions. Frequency modifications from acoustic analysis and voice range measurements suggest an increased laryngeal tension during vocal load, while subjects perceive a worsening of voice. Aerodynamic parameters depict first a deterioration of voice efficiency and then an adaptation to the prolonged reading. The comparison between both groups shows a discrepancy between objective measurements and self-ratings, suggesting that both approaches are necessary to have a complete view of vocal load effects. Surprisingly, both groups behave similarly through vocal load, without more or quicker deterioration of voice in the dysphonic group.

Key Words: Vocal loading—Teachers—Dysphonic voice—Acoustic analysis—Aerodynamic measurements—Self-ratings.

INTRODUCTION

Previous studies have shown a higher prevalence of voice disorders in teachers than in the general population.^{1–5} In the United States, the prevalence of a current voice problem in 1243 teachers is 11.0%, and the prevalence of voice disorders during their lifetime is 57.7%.³ In another survey on 242 teachers, 14.6% report that they currently have a voice problem.² Among 554 elementary and high school teachers, 32% has ever had a voice problem.¹ The prevalence rate of self-reported voice problems in South Australia is 16% on the day of the survey, 20% during the current teaching year, and 19% at some time during the teaching career.⁶ In Poland, dysphonia is reported by 68.7% of 425 female teachers, at least one time in their lifetime.⁵ In a Dutch investigation, more than a half of 1878 teachers report voice problems during their career and about one-fifth have a history of absence from work because of voice problems.⁷ Even if the questions used for evaluating the prevalence of voice disorders vary from survey to survey, all these demonstrate that teaching is a high-risk profession for the development of dysphonia.

Occupational voice disorders in teachers are most frequently because of heavy vocal load and are aggravated by risk factors such as background noise, room acoustics, stress, fatigue, and poor posture.⁸ The demands placed on vocal mechanism, by the way and extent the voice is used (duration, intensity, and

frequency of phonation), define the vocal load borne by the subject.^{8,9} The higher these factors, the higher the mechanical stress on the vocal folds.¹⁰ In occupational voice users, such as teachers, repeated periods of vocal loading associated with short recovery periods may lead to vocal fold lesions as nodules.

The present study is part of a larger project that addresses occupational vocal load in teachers. In a previous study,¹¹ the impact of vocal load was evaluated in 50 normophonic females without professional voice use. Each participant underwent two sessions of oral reading with a controlled voice level of 60–65 dB(A) for the first session and 70–75 dB(A) for the second session. The aim was to evaluate the impact of the duration and the intensity level of vocal load. Results showed that both have an effect on voice, even if the intensity level affects fewer variables than duration. The present work applies the same protocol: the purpose is to evaluate the impact on voice owing to a 2-hour vocal load in 16 normophonic female teachers and in 16 dysphonic female teachers with vocal nodules. The specific questions are: (1) what are the effects of a 2-hour reading task on teachers' voice? (2) Does the vocal load affect differently the pathological teachers than the healthy teachers? Our hypotheses are that acoustic parameters, aerodynamic measurements, and self-ratings of voice (1) would worsen through the reading task for both groups, (2) would be better for the normophonic group than for the dysphonic group before and during the reading task, and (3) that the voice evolution through the loading task would be different in both groups, the nodular group showing a quicker and more important deterioration than the control group.

METHODS

Subjects

Before taking part in the experiment, all the participants underwent a videolaryngostroboscopic examination (EndoSTROB

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From the *Department of Psychology: Cognition and Behavior, University of Liège, Liège, Belgium; †ENT Department, University Hospital of Liège, Liège, Belgium; and the ‡Faculty of Psychology and Education Sciences University of Mons, Mons, Belgium.

Address correspondence and reprint requests to Angélique Remacle, Département de Psychologie: Cognition et Comportement, Unité de Logopédie de la Voix, Université de Liège, Rue de l'Aunaie, 30 (B38), 4000 Liège, Belgium. E-mail: Angélique.Remacle@ulg.ac.be

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Stroboscop; Xion gmbH, Berlin, Germany) to establish the diagnosis. Two groups of subjects were studied. One group included 16 dysphonic female teachers with vocal nodules (mean age: 33.8 years, standard deviation [SD]: 8.6, range: 21.6–51.3). The other group included 16 normophonic female teachers (mean age: 34.1 years, SD: 8, range: 22.7–51.2) who met the following criteria: no laryngeal pathologies, no complaint or history of voice disorders, and no voice therapy. Each dysphonic teacher was paired with a normophonic teacher by age. The description of the groups is presented in Table 1.

The composition of the two groups is homogenous concerning the age (Student's t test = 0.13, df = 30, P = 0.90), the average duration of employment (Student's t test = -0.67, df = 30, P = 0.51), and the average working time per week (Student's t test = -1.13, df = 30, P = 0.27).

On the 2 days before the testing, subjects were asked to avoid any vocally abusive behavior (singing, loud talking, shouting, and yelling). They received the instructions to sleep and drink normally, not to ingest caffeine, alcohol, or any medication that causes drying of the vocal folds. Participants responded to an anamnestic questionnaire before the experiment, including their drug treatments. All subjects provided informed consent but were blind to the study hypothesis. They received an oral and written explanation of the experiment procedure.

Procedure

Voice handicap index. Before the experiment, the participants responded to the French version of the voice handicap index (VHI)¹² initially developed by Jacobson et al.¹³ The VHI is a 30-items questionnaire to assess the severity of voice disorders. Each item is scored on a five-point rating scale from zero (never) to four (always). The items are equally distributed over the three subscales: functional, physical, and emotional. Low scores indicate low complaints of disability owing to the voice and high scores indicate high complaints. VHI results of the two groups are presented in Table 1.

Loading task. Teachers' voices were orally loaded by reading a novel in French (Fred Vargas, "Coule la Seine") for 2 hours.

Teachers were instructed to read for imaginary students, as in their classroom. Voice intensity level was constantly controlled between 70 and 75 dB(A) with a Digital Sound Level Meter (DVM805; Velleman, China) at a distance of 40 cm from the mouth. The examiner encouraged to maintain the intensity level if it differs from the target level. During the loading task, participants were seated in a quiet room (background level < 30 dB [A]) and instructed to read aloud. The relative humidity of ambient air was controlled using a hygrometer (P600; Dostmann Electronic, Wertheim-Reicholzheim, Germany) and kept constant (30% \pm 10%). Every 30 minutes, the researcher advised the participants to drink one glass of water to ensure that they remain hydrated. The experiment took place during the weekend or a day off from work to avoid overloading in teachers, especially in the dysphonic group.

Evaluation protocol. During the loading task, serial sets of evaluations were carried out every 30 minutes: (time 0 = T0) before the loading task, (time 1 = T1) after 30 minutes of reading, (time 2 = T2) after 1 hour of reading, (time 3 = T3) after 1 hour and 30 minutes of reading and (time 4 = T4) after 2 hours of reading. All measurements were repeated using an identical protocol, including the subjective self-ratings first, followed by the acoustic analysis and the aerodynamic measurements. The entire procedure (loading tasks and evaluations) took 3 hours per subject. Tests were made by the first and third authors who were a speech therapist specialized in voice and a student in speech therapy, respectively.

Subjective self-ratings. Every 30 minutes, participants were asked to answer the following questions using a 100-mm horizontal visual analog scale (VAS):

- 1) How is your voice quality (How does your voice sound)? The extremes on the VAS were 0% for the minimum voice quality and 100% for the maximum voice quality.
- 2) Do you feel any phonation effort (strain or effort to produce the voice)? The extremes on the VAS were 0% for no vocal effort and 100% for a maximum vocal effort.

TABLE1.
Description of the Normophonic and Dysphonic Groups

Description	Normophonic Group	Dysphonic Group
Number of subjects, n	16	16
Number of preschool and kindergarten teachers, n (%)	3 (18.75)	3 (18.75)
Number of elementary school teachers, n (%)	3 (18.75)	5 (31.25)
Number of high school teachers, n (%)	4 (25)	6 (37.5)
Number of junior college teachers, n (%)	6 (37.5)	2 (12.5)
Average duration of employment, y (SD)	8.2 (7.1)	10.1 (9.2)
Average working time/wk, h (SD)	21.4 (5.3)	23.1 (2.6)
Total score, VHI (SD)	6.6 (6.6)	29.6 (18.6)
Functional score, VHI (SD)	1.5 (2.2)	5.4 (5.7)
Emotional score, VHI (SD)	1.2 (3.1)	7.9 (6.8)
Physical score, VHI (SD)	3.8 (4.0)	16.4 (10.4)
Number of smokers, n (%)	3 (18.75)	3 (18.75)

Abbreviations: SD, standard deviation; VHI, voice handicap index.

- 3) Do you feel any vocal fatigue (tiredness of voice or in neck muscles)? The extremes on the VAS were 0% for no vocal fatigue and 100% for a maximum vocal fatigue.
- 4) Do you feel any laryngeal discomfort (pain or dryness in your throat)? The extremes on the VAS were 0% for no laryngeal discomfort and 100% for a maximum laryngeal discomfort.

Before the loading task, subjects were informed that they will have to complete the same questions every 30 minutes. When they scored their complaints, they did not have access to their previous ratings. We used the same VAS as in our previous study¹¹ to allow comparisons.

Acoustic analysis. Recordings were made in a $213 \times 194 \times 219$ -cm soundproof booth; the subject was sitting at the center of the booth. The voices were recorded with a head-worn microphone (AKG C420; Harman, Stamford, CT, USA), with a constant mouth-to-microphone distance of 7 cm. The microphone's frequency range (F-Range) extends from 20 to 20 000 Hz.

Serial acoustic analyses of voice were obtained by use of the Multidimensional Voice program (Kay Elemetrics, Lincoln Park, NJ): average fundamental frequency (F0), jitter percent (Jitt), shimmer percent (Shim), and noise harmonic ratio (NHR). Subjects were asked to produce three times the sustained vowel /a/ at a comfortable pitch and intensity level. The first 3 seconds of each sample were analyzed and then averaged for a final value.

The lowest frequency (F-Low), the highest frequency (F-High), the F-Range, the lowest intensity (I-Low), the highest intensity (I-High), and the intensity range (I-Range) were collected with the *Voice Range Profile* program (Kay Elemetrics, Lincoln Park, NJ) on the vowel /a/. F-Low, F-High, and F-Range were recorded during three trials, the subject gliding from a middle range note to the lowest possible note and then to the highest possible note. I-Low, I-High, and I-Range were collected at c1 pitch (262 Hz), which is in the middle of an estimated female F-Range. Subjects were instructed to sustain the target pitch with the softest and the loudest possible voice three times successively, as recommended in Sihvo et al.¹⁴ During the recording session, the investigator provided verbal encouragements and auditory examples if necessary.

Aerodynamic measurements. Aerodynamic measurements were realized using the Aerophone II, Model 6800 (Kay Elemetrics, Lincoln Park, NJ). The acoustic signal was picked up by an electret microphone (AKG CK77; Harman, Stamford, CT). For the maximum phonation time (MPT) and the mean airflow rate (MAR), participants were asked to produce three samples of the prolonged vowel /a/ at a comfortable pitch and intensity, as long as possible. The longest sample was analyzed to determine MPT and MAR. Estimated subglottal pressure (ESP) and sound pressure level (SPL) were calculated on a sequence of seven /pa:/ syllables produced at a comfortable pitch and intensity. Subglottal pressure was estimated from the intraoral pressure recorded using a silicone tube placed in the mouth, during p-occlusion. The three central syllables were

extracted and their mean was calculated for the ESP and SPL analysis.

Statistics

The following methods were used to analyze our data: (1) the Mann-Whitney *U* test to compare the VHI results for the normophonic and the dysphonic groups and (2) a repeated measures analysis of variance (ANOVA five times \times two groups) to compare data obtained at different times of the reading session for both groups. We tested the within-subjects effect (main effect of the duration of reading), the between-subjects effect (main effect of the group), and the interaction between the group and the duration. When the ANOVA showed significant differences ($P < 0.05$), a post hoc Tukey's honestly significant difference test was computed either on the main significant effects or on the interaction to compare the means. When necessary, for meeting the assumption of homogeneity of variances and normality, logarithmic transformations normalized raw data before ANOVA. For clarity, means of the raw data values are presented in figures. All calculations were conducted using the statistical software *Statistica/Win* (version 9.1; StatSoft Inc, Tulsa, Oklahoma). Subjective self-rating results are presented in Figure 1, acoustic results in Figure 2, and aerodynamic results in Figure 3.

RESULTS

Voice handicap index

Results from the Mann-Whitney *U* test reported a significant difference between the normophonic and the dysphonic groups for all scores: functional ($U = 75.0$, $P = 0.047$), emotional ($U = 43.5$, $P = 0.0009$), physical ($U = 20.0$, $P < 0.0001$), and total score ($U = 27.5$, $P < 0.0001$). Dysphonic teachers had systematically more complaints than normophonic teachers.

Subjective self-ratings

Results from repeated measures ANOVA (cf. Table 2) demonstrated significant main effects of the duration ($P < 0.0001$) and of the group ($P < 0.05$) for all the subjective self-ratings. The detailed results from the post hoc test on the main effect of the duration are presented in Table 3. No significant interaction between duration and group was found.

Acoustic analysis

For F0 (Figure 2A), repeated measures ANOVA demonstrated a significant main effect of the duration ($F(4,120) = 16.72$, $P < 0.0001$). Post hoc comparisons showed an increase in F0 between T0 and T1, T2, T3, T4, as well as between T1 and T3. There was no significant main effect of the group ($F(1,30) = 0.38$, $P = 0.54$) and no interaction between duration and group ($F(4,120) = 0.62$, $P = 0.65$).

For Jitt (Figure 2B), there was no significant main effect of the duration ($F(4,120) = 2.41$, $P = 0.053$), no significant main effect of the group ($F(1,30) = 3.43$, $P = 0.074$), and no interaction between duration and group ($F(4,120) = 0.90$, $P = 0.47$).

A significant main effect of the duration ($F(4,120) = 2.48$, $P = 0.047$) was shown for Shim (Figure 2C). The post hoc

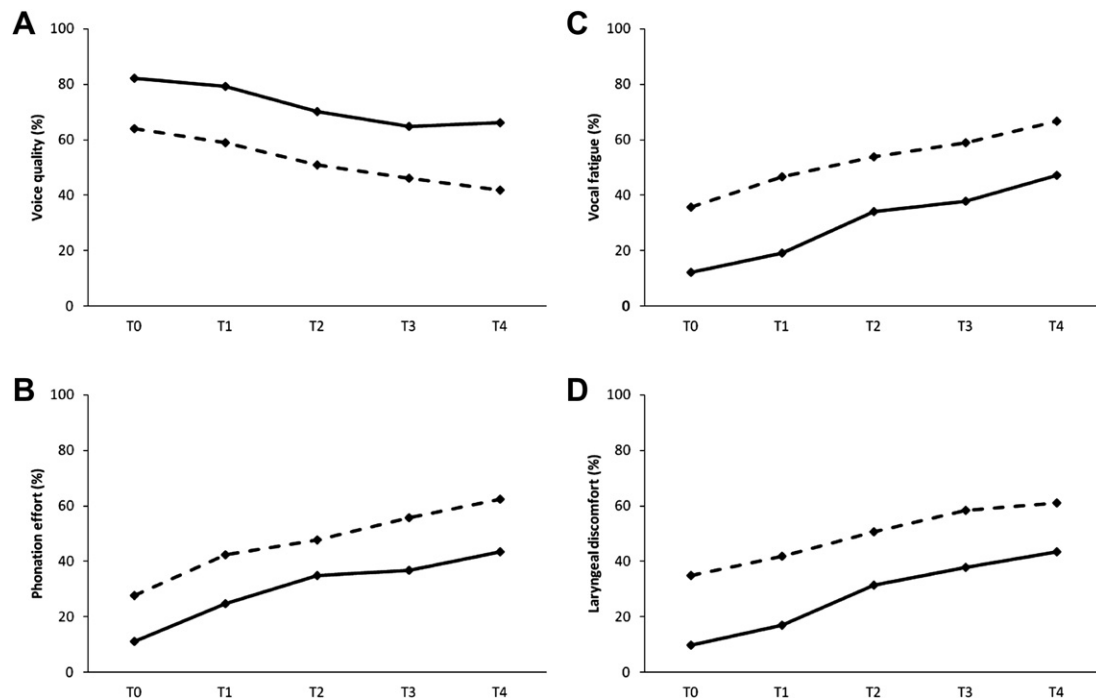


FIGURE 1. A–D. Results from the subjective self-ratings at each time (T0 = before the loading task, T1 = after 30 minutes, T2 = after 1 hour, T3 = after 1 hour 30 minutes, and T4 = after 2 hours) for the normophonic teachers (solid line) and the dysphonic teachers (dotted line).

test revealed lower values for T2 and T4 than for T0. No significant main effect of the group ($F(1,30) = 2.05$, $P = 0.16$) and no interaction between duration and group was found ($F(4,120) = 0.92$, $P = 0.45$).

Regarding NHR (Figure 2D), there was no significant main effect of the duration ($F(4,120) = 0.72$, $P = 0.58$) and no significant main effect of the group ($F(1,30) = 1.91$, $P = 0.18$). No interaction between duration and group was found ($F(4,120) = 0.74$, $P = 0.57$).

Results for F-Low (Figure 2E) demonstrated a significant main effect of the duration ($F(4,120) = 5.51$, $P = 0.0004$). The post hoc test revealed higher values for T3 and T4 than for T0 and T2 in all teachers. No main effect of the group was demonstrated ($F(4,120) = 0.94$, $P = 0.34$), but there was an interaction between duration and group ($F(1,30) = 3.01$, $P = 0.02$). The increasing curves depict a similar evolution of both groups from T0 to T1. Then F-Low continues to increase for the pathological group, whereas the control group shows a nonlinear evolution. The post hoc test shows higher values for T3 than for T0 and T2 in the control group.

For F-High (Figure 2F), there was a significant main effect of the duration ($F(4,120) = 4.23$, $P = 0.003$). Post hoc comparisons showed an increase in F-High between T0 and T3, as well as between T0 and T4. At each time, F-High was higher for the normophonic teachers than for the dysphonic teachers as a main effect of the group ($F(1,30) = 15.54$, $P = 0.0004$). No interaction between duration and intensity ($F(4,120) = 0.68$, $P = 0.61$) was demonstrated.

For F-Range (Figure 2G), there was no significant main effect of the duration ($F(4,120) = 1.17$, $P = 0.33$). At each time, F-Range was larger for the normophonic than for the dysphonic teachers as a main effect of the group ($F(1,30) = 12.20$,

$P = 0.0015$). No interaction between duration and intensity was found ($F(4,120) = 1.81$, $P = 0.13$).

Concerning I-Low (Figure 2H), there was no significant main effect of the duration ($F(4,120) = 0.80$, $P = 0.53$), no significant main effect of the group ($F(1,30) = 0.06$, $P = 0.81$), and no interaction between duration and group ($F(4,120) = 1.57$, $P = 0.19$).

I-High (Figure 2I) rose significantly through time as a main effect of the duration ($F(4,120) = 12.87$, $P < 0.0001$). Post hoc comparisons showed an increased I-High in T2, T3, and T4 compared with T0, as well as in T4 compared with T1, T2, and T3. There was neither a significant main effect of the group ($F(1,30) = 0.77$, $P = 0.39$) nor an interaction between duration and group ($F(4,120) = 0.89$, $P = 0.47$).

A significant main effect of the duration was found for I-Range ($F(4,120) = 3.65$, $P = 0.008$; Figure 2J). The post hoc test showed a greater I-Range in T4 compared with T0. There was neither a significant main effect of the group ($F(1,30) = 0.85$, $P = 0.36$) nor an interaction between duration and group ($F(4,120) = 0.84$, $P = 0.50$).

Aerodynamic measurements

For MPT (Figure 3A), results from the repeated measures ANOVA revealed a significant main effect of the duration ($F(4,120) = 3.07$, $P = 0.019$). Post hoc comparisons showed a decrease in MPT between T0 and T1. There was no significant main effect of the group ($F(1,30) = 2.76$, $P = 0.11$) and no interaction between duration and group ($F(4,120) = 0.39$, $P = 0.82$).

As far as MAR is concerned (Figure 3B), there was no significant main effect of the duration ($F(4,120) = 0.72$, $P = 0.58$), no significant main effect of the group ($F(1,30) = 0.032$,

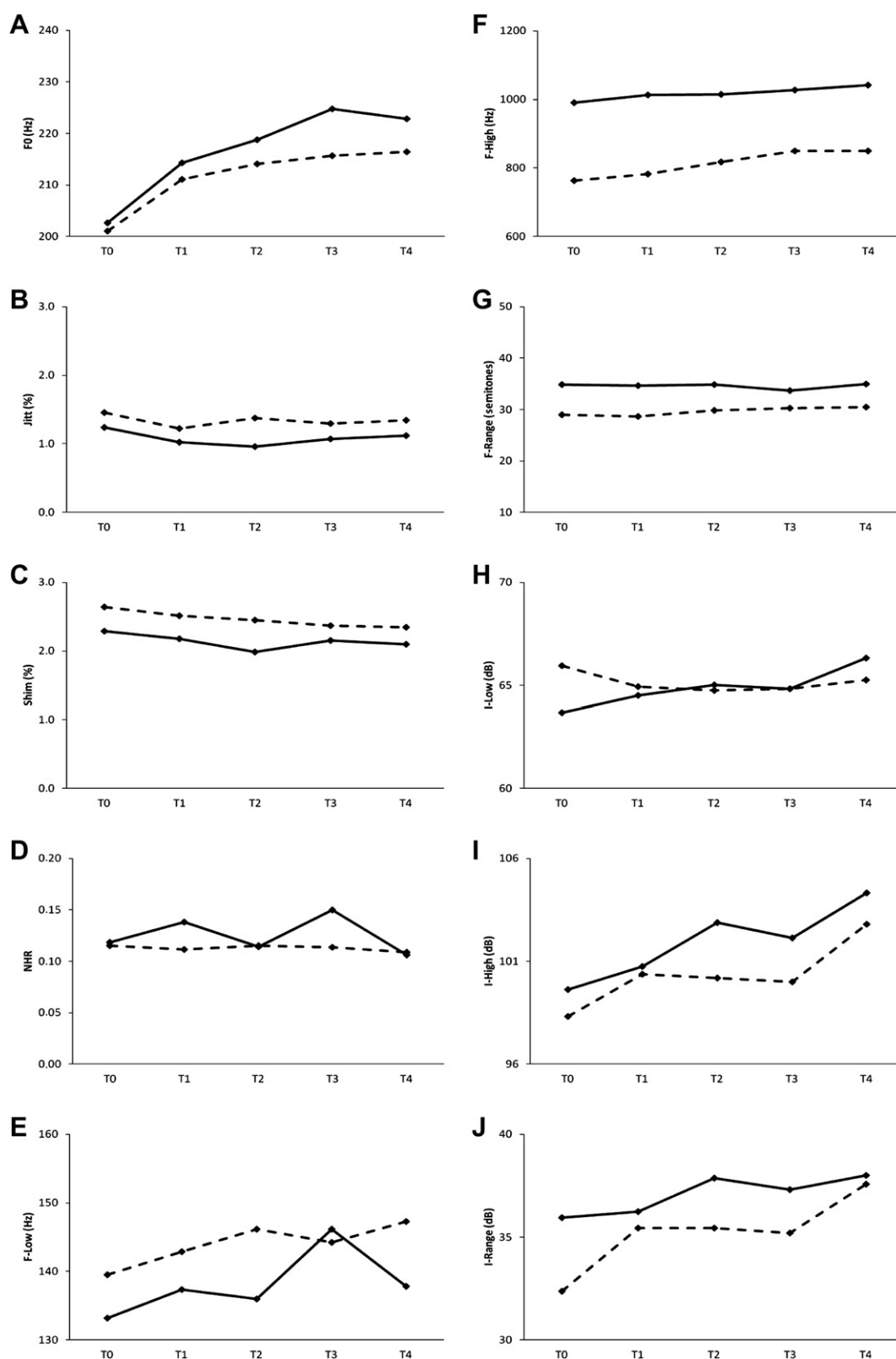


FIGURE 2. A–J. Results from the acoustic analysis at each time (T0 = before the loading task, T1 = after 30 minutes, T2 = after 1 hour, T3 = after 1 hour 30 minutes, and T4 = after 2 hours) for the normophonic teachers (*solid line*) and the dysphonic teachers (*dotted line*). F0, fundamental frequency; F-High, highest frequency; Jitt, jitter percent; F-Range, frequency range; Shim, shimmer percent; I-Low, lowest intensity; NHR, noise harmonic ratio; I-High, highest intensity; F-Low, lowest frequency; I-Range, intensity range.

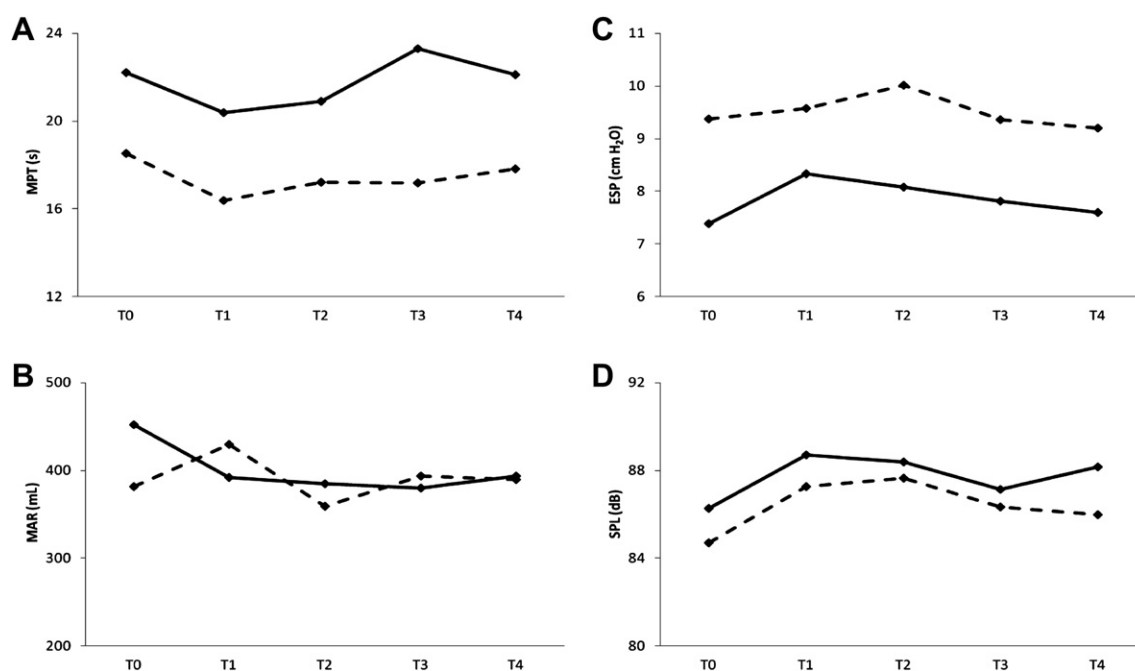


FIGURE 3. A–D. Results from the aerodynamic measurements at each time (T0 = before the loading task, T1 = after 30 minutes, T2 = after 1 hour, T3 = after 1 hour 30 minutes, and T4 = after 2 hours) for the normophonic teachers (solid line) and the dysphonic teachers (dotted line). MPT, maximum phonation time; ESP, estimated subglottal pressure; MAR, mean airflow rate; SPL, sound pressure level.

$P = 0.86$), and no interaction between duration and group ($F(4,120) = 0.93$, $P = 0.45$).

Results for ESP (Figure 3C) demonstrated a significant main effect of the duration ($F(4,120) = 2.58$, $P = 0.04$). The post hoc test revealed an increase between T0 and T2, and then a decrease between T1 and T4 as well as between T2 and T4. ESP was systematically higher for the dysphonic than for the normophonic teachers as a main effect of the group ($F(1,30) = 5.81$, $P = 0.02$). No interaction between duration and group was found ($F(4,120) = 0.61$, $P = 0.66$).

Finally, results showed a significant main effect of the duration for SPL ($F(4,120) = 3.0$, $P = 0.02$), (Figure 3D). Post hoc revealed that T1 and T2 are higher than T0. There was no main effect of the group ($F(1,30) = 0.3$, $P = 0.57$) and no interaction between duration and group ($F(4,120) = 0.3$, $P = 0.89$).

DISCUSSION

Methodological aspects

This study observes the effects of vocal load during a prolonged reading task on acoustic, aerodynamic, and self-evaluations of voice in normophonic and dysphonic teachers. Many studies have been built to evaluate the effects of a loading task on voice, but only a few compare dysphonic and normophonic subjects. In a study by Buekers,¹⁵ electroglottography, acoustic analysis, and self-ratings were performed through a 30-minutes voice endurance test in 20 females with a history of vocal fatigue compared with 12 healthy females. In another study, Akerlund¹⁶ recorded phonetograms before and after a 15-minute loud reading task through 80-dB SPL masking noise of 10 females and 10 males with nonorganic dysphonia, and of

10 female and 10 male normal-speaking controls. In a study by Jilek et al,¹⁷ electrographic perturbation values were collected from 32 patients with functional dysphonia and 31 normophonics before and after a 20-minute loading task comprising repeated vowel sequences at 80 dB SPL. More recently, Aronson et al¹⁸ observed voice SPL, F0, speaking phonetogram area, subglottal pressure, and subjective self-ratings in 10 females with bilateral vocal fold nodules and 23 control females reading a 90 seconds text in four different noise conditions. As far as we know, Niebudek-Bogusz et al¹⁹ are the only authors who reported the effects of a reading task in dysphonic teachers. Acoustic parameters and videostroboscopic examination are realized before and after a 30-minute loud reading under exposure to 80 dB SPL white noise in 51 female teachers with voice disorders. However, no comparison was made with a normophonic group. To the best of our knowledge, the present study is the first one comparing the effects of a prolonged reading task on normophonic and dysphonic teachers' voice.

This investigation addresses female teachers for two reasons. The first one is because, compared with male population, female teachers are twice as likely to report voice problems⁶ and to seek phoniatic care.²⁰ This disparity between genders is explained by differences in laryngeal structure,²¹ molecular composition of vocal fold tissues,²² hormonal factors, and a higher F0 implying a greater load for vocal folds in females.²³ The second reason comes from the fact that most Belgian teachers are women. Statistics by the *Ministère de la Communauté Française* report that the proportion of females in the *Fédération Wallonie-Bruxelles* is 97% for the kindergarten teachers, 80% for the elementary school teachers, and 61% for the high school teachers.²⁴

TABLE 2.
Results From the Repeated Measures ANOVA for Subjective Self-Ratings

Variables	Duration Effect		Group Effect		Interaction Effect (Duration × Group)	
	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
Voice quality	13.83	<0.0001*	8.37	0.007*	0.30	0.88
Phonation effort	24.95	<0.0001*	4.45	0.040*	0.25	0.91
Vocal fatigue	30.75	<0.0001*	8.22	0.007*	0.50	0.73
Laryngeal discomfort	26.13	<0.0001*	7.63	0.009*	0.49	0.75

Notes: Degrees of freedom for the duration effect = (4,120); degrees of freedom for the group effect = (1,30); degrees of freedom for the interaction between duration and group = (4,120); *F* = *F* value from the ANOVA; *P* = *P* value from the repeated measures ANOVA where *P* < 0.05 indicates statistical significance, shown by an asterisk.

Abbreviation: ANOVA, analysis of variance.

The reason for choosing nodular pathology for the dysphonic group is because it is the most common organic pathology in teachers.²⁰ Nodules are benign swellings, generally bilateral, reducing the glottic closure and the vocal folds' mucosal wave, and impacting on voice quality and efficiency. They are localized in the center of the membranous vocal fold, where the maximum impact takes place. Nodules form because of high vocal load, leading to excessive localized mechanical stress and to repetitive acceleration and deceleration, which may traumatize the vocal fold tissues.^{21,23,25} Note that in the present study, the nodular group is heterogeneous in terms of mass size and degree of associated stiffness of the vocal folds, implying some physiopathological differences.

Concerning the loading task, 2 hours of reading is chosen to allow comparisons with other works using the same duration.^{11,26–28} The duration that we have chosen is longer than in the studies previously published comparing the effects of vocal load on dysphonic and normophonic subjects.^{15–18} In terms of intensity levels, the noise SPL ranges from 64 to 72 dB(A) in day care center environments, and the preschool teachers voice ranges from 71 to 79 dB(A).²⁹ Elementary classroom teachers use a vocal intensity of 77.2 dB SPL (SD = 4.02).³⁰ These voice levels were collected using an accelerometer attached to the teachers' neck. In the present study, the intensity level of reading was constantly controlled between 70 and 75 dB(A) at 40 cm from the mouth to replicate the protocol used in the second session of our precedent study.¹¹ Because subjects with vocal nodules generally speak louder than normophonic subjects, the intensity level of the reading task had to be loud enough to allow the dysphonic teachers to maintain the target level. The loading task took place in controlled laboratory conditions. Studying vocal load through a prolonged reading without interlocutors or audience may not reflect the reality of teachers' daily voice use. The fact that these experimental conditions differ from the real-life vocal use is discussed in Remacle et al.¹¹ Also note that prolonged reading task may induce a general fatigue and may be a burden that we cannot control.

Duration (time dose or voicing time^{31,32}), SPL, and F0 of phonation are different factors influencing the mechanical stress applied on the vocal folds. In the present study, the duration and

the intensity level of the loading task are controlled, but not the F0. Indeed, we had to reach a compromise between the level of control of the experimental task and the voice production in natural conditions. Nevertheless, it would be interesting to monitor simultaneously the duration, the intensity, and the frequency of the loading task, using devices such as voice dosimeters. We believe that highly controlled laboratory tests as well as studies on field over longer periods of time, with devices such as voice accumulators, are needed to have a complete view of occupational vocal load in teachers.

The following part of the discussion concerns the questions stated previously, namely: (1) What are the effects of a 2-hour reading task on teachers' voice? and (2) Does the reading task affect differently the pathological teachers from the healthy teachers? These questions are answered in the light of self-ratings, acoustic analyses, and aerodynamic measures.

Effects of a 2-hour reading task on teacher's voice

For recall, a worsening of voice through the reading task is expected, as an effect of the duration. As hypothesized, self-ratings of both groups demonstrate progressive and negative changes during the reading task, from T0 to T4. Subjects report that their voice quality worsens significantly during the reading, whereas phonation effort, vocal fatigue, and laryngeal discomfort increase. After 2 hours of reading (T4), ratings noted by normophonic teachers on a 0–100% VAS are as follows: 66% of voice quality, 43% of vocal effort, 47% of vocal fatigue, and 43% of laryngeal discomfort. At the same time (T4), dysphonic teachers report 42% of voice quality, 62% of vocal effort, 67% of vocal fatigue, and 61% of laryngeal discomfort. Both groups do not reach extremely high values on the VAS, especially the normophonic teachers, suggesting that they probably do not feel at the end of their vocal resources. Identical patterns are observed in a previous study using the same reading task in 50 normophonic women.¹¹ These results corroborate research on vocal load conducted in laboratory. In Solomon and DiMattia,³³ the self-perceived effort for speaking increases after 1 hour of reading in four women and increases further after an additional hour. Kelchner et al.³⁴ demonstrate a worsening of the voice quality and an increased physical effort to produce the voice after 2 hours of reading in peripubescent boys. Chang and

TABLE 3.
Results From the HSD Tukey Post Hoc on the Main Effect of Duration for Subjective Self-Ratings

Variables	Time (A)	Time (B)	P	Normophonic Teachers	Dysphonic Teachers
				Mean Difference (B – A)	Mean Difference (B – A)
Voice quality	0	1	0.753	–2.8	–4.8
	0	2	0.002*	–11.9	–12.9
	0	3	0.0001*	–17.4	–17.8
	0	4	0.0001*	–15.9	–22
	1	2	0.060	–9.1	–8.1
	1	3	0.0004*	–14.6	–13
	1	4	0.0002*	–13.1	–17.2
	2	3	0.476	–5.6	–4.9
	2	4	0.249	–4	–9.1
	3	4	0.994	1.6	–4.2
Phonation effort	0	1	0.002*	13.7	14.7
	0	2	0.0001*	23.8	20
	0	3	0.0001*	25.6	28.1
	0	4	0.0001*	32.3	34.6
	1	2	0.227	10.1	5.2
	1	3	0.007*	11.9	13.4
	1	4	0.0001*	18.6	19.9
	2	3	0.652	1.8	8.1
	2	4	0.016*	8.6	14.6
	3	4	0.368	6.7	6.5
Vocal fatigue	0	1	0.062	6.9	10.9
	0	2	0.0001*	21.9	18.1
	0	3	0.0001*	25.6	23.4
	0	4	0.0001*	35.1	31
	1	2	0.009*	15	7.2
	1	3	0.0001*	18.7	12.5
	1	4	0.0001*	28.1	20.1
	2	3	0.656	3.7	5.3
	2	4	0.001*	13.1	12.9
	3	4	0.082	9.4	7.6
Laryngeal discomfort	0	1	0.257	7.2	6.9
	0	2	0.0001*	21.7	15.6
	0	3	0.0001*	28.1	23.5
	0	4	0.0001*	33.6	26.1
	1	2	0.009*	14.5	8.7
	1	3	0.0001*	20.9	16.6
	1	4	0.0001*	26.4	19.1
	2	3	0.244	6.4	7.9
	2	4	0.014*	11.9	10.4
	3	4	0.774	5.5	2.6

Notes: Time 0 = before the loading task; time 1 = after 30 minutes; time 2 = after 1 hour; time 3 = after 1 hour 30 minutes; time 4 = after 2 hours; Column P represents P values from the HSD Tukey post hoc test, where $P < 0.05$ indicates statistical significance, shown by an asterisk.

Abbreviation: HSD, honestly significant difference.

Karnell²⁶ found an increased phonatory effort in women after a 2-hour reading task. Laukkanen et al³⁵ showed more throat and voice symptoms after 45 minutes of reading in females. According to Buekers,¹⁵ both patients and controls report significantly more fatigue, pain, and discomfort in the throat after the voice interval test. Finally, most subjective symptoms are reported to increase through five 45-minute reading sessions in 40 females and 40 males.³⁶ Studies on field are also congruent with the present work observations. At the end of 1 working

day, voice quality decreases in customer advisors^{37,38} and more tiredness of throat is reported by female teachers.³⁹

Concerning the evolution of acoustic parameters, a gradual and significant increase of F0 through vocal loading is observed. This result confirms data in known literature, in both laboratory^{11,28,34,35,40} and field conditions.^{37–39,41–43} Physiologically, F0 is regulated by the combined action of laryngeal muscles and lung pressure, influencing the length of the vocal fold, the longitudinal stress in vocal fold tissue, and the tissue density.²¹

F0 is increased by either increase in muscle stiffness or cover stiffness,²⁵ directly proportional to the laryngeal muscles and vocal fold tension. On the basis of these physiological principles,^{21,25} F0 rise though vocal load could be a consequence of an increased tension in the larynx and in paralaryngeal areas.

F-Low and F-High measured with the *Voice Range Profile* program also significantly increase through time. F-Low rise is in congruence with a previous study using the same loading task,¹¹ whereas no changes are demonstrated in other articles.^{28,34} F-High increase does not corroborate precedent studies where there are no changes after the loading task.^{11,28,34} As in other studies, F-Range does not change with vocal load.^{11,28,34} F-Low and F-High increase is congruent with F0 evolution as described previously. As for F0, F-Low and F-High rise though vocal load may be the consequence of an increased laryngeal tension. Note that F-High improvement can also be the result of learning a suitable strategy to perform the task owing to its repetition every 30 minutes.

I-Low and I-High are both known to be increased with increased F0.⁴⁴ Consequently, they are expected to increase through the reading task as F0 rises. When looking at the graph of I-Low (Figure 2H), we can see a slight increase for the healthy group, albeit not statistically significant. Previous studies demonstrate an increase of I-Low after reading aloud in normophonic subjects.^{11,16,45} For the dysphonic group, I-Low decreases slightly, but nonsignificantly (Figure 2H). Akerlund¹⁶ observes that the lower phonetogram contour (I-Low) significantly rises in dysphonic patients after reading in an 80-dB SPL white noise for 15 minutes. He interprets I-Low rise as a consequence of stiffer vocal folds requiring higher subglottal pressure. Surprisingly, the present study does not demonstrate any significant I-Low evolution through time.

Otherwise, I-High and consequently I-Range significantly increase during the loading task in both groups. I-High evolution is similar to the results of Vinturi et al⁴⁵ in 40 women reading 45 minutes, and to the results of Sihvo and Sala⁴⁶ in 10 women reading 5 × 45 minutes. These authors explain the rise of I-High by the learning of a suitable strategy to perform the task or by an increased effort and vocal fold tension.⁴⁶ I-High elevation through vocal load could also be explained by modifications in the vocal fold tissues and of the supraglottal tract (that we did not measure), or by increased ESP that we indeed observe within the first hour in our study. In other works, no significant differences in I-High are found in dysphonic and normophonic subjects after reading for 15 minutes,¹⁶ as well as in normophonic women reading for 2 hours.¹¹

In terms of measures collected using the *Voice Range Profile* program, data evolve differently from study to study. This can be owing to: (1) differences in the intensity and duration of the loading tasks and (2) differences in the material and the task used to collect the measures. However, our results differ from those obtained in our previous study on healthy individuals¹¹ using the same loading task and the same material (*Voice Range Profile* program). More experiments would be needed to better understand the impact of a reading task on F-Low, F-High, F-Range, I-Low, I-High, and I-Range. In the present work, I-Low, I-High, and I-Range are collected on a target pitch

(262 Hz). It would be interesting to realize a complete voice range profile with measurements of I-Low, I-High, and I-Range through the entire F-Range. Additionally, voice range profile measurements evolution observed in this study could be because of a habituation effect, that is, results improvement because of the task repetition. In further studies, the potential habituation effect could be assessed by including a control group without vocal loading, with subjects recorded every 30 minutes while silently reading.

As far as the stability of voice is concerned, Jitt decreases nonsignificantly, whereas Shim decreases significantly and gradually through a 2-hour reading task. These results are in line with Laukkanen et al³⁹ who report a significant drop in Jitt and Shim after a working day in 79 female teachers. Stemple et al²⁸ also demonstrate a significant decrease in Jitt at high pitch level after a 2-hour reading task in 10 normophonic women. Several studies,^{11,28,39} including the present one, show more stability of voice after vocal load. One explanation can be an increased laryngeal tension, leading to the observed F0 rise and to more stability in vocal folds vibration. Jitt is known to decrease as F0 increases.⁴⁴ In accordance with other data,^{11,19} NHR does not show any significant change. In the light of these results, it is doubtful that NHR is a relevant parameter for studying the evolution of voice through a loading task.

For the aerodynamic measurements, we expected decreased MPT, increased MAR, and increased ESP through the reading task, suggesting a degradation of the voice efficiency. MPT shows the expected decrease within the first 30 minutes. We can hypothesize that MPT decrease is because of a decreased tidal volume or an air leak; tidal volume measurements and videostroboscopic examinations would be needed to confirm these interpretations. As in our previous study,¹¹ the lower value of MPT occurs at T1. Unexpectedly, MPT improves progressively but nonsignificantly from T1 to T4, possibly reflecting an adaptation of respiratory muscles and laryngeal apparatus to loading. Other studies describing the evolution of MPT through a loading task are few and do not corroborate our results. Stemple et al²⁸ and Kelchner et al³⁴ do not find any significant modification after a 2-hour reading task at 75–80 dB.

For MAR, statistical analysis fails to demonstrate any significant difference during the loading task. The curves on Figure 3B depict an inconsistent evolution of MAR. Similarly, Stemple et al²⁸ observed no difference of flow rate after 2 hours of reading at 75–80 dB in 10 women. However, Niels and Yairi⁴⁷ find increased mean air flow values after 45 minutes of reading in 50- and 70-dB(A) noise conditions in six women, but not in 90-dB(A) noise condition.

A significant increase of ESP during the first hour of reading (between T0 and T2) is observed. Afterward, ESP decreases (between T1 and T4, as well as between T2 and T4), possibly reflecting a progressive adaptation of the laryngeal apparatus to loading. Studies generally find an increased ESP through loading tasks, which could be the consequence of more stiffness of the vocal folds.^{40,45} Increase of ESP is greater in low-humidity conditions than in high-humidity conditions, the viscoelasticity of the vocal fold mucosa being supposed to be improved in high-humidity conditions.⁴⁵ Solomon and DiMattia³³ study

the phonation threshold pressure, which is the minimal pressure required to initiate vocal fold oscillation. The phonation threshold pressure increases after 2 hours of reading at 75–80 dB in four women. Chang and Karnell²⁶ find a relationship between the phonation threshold pressure and the perceived phonatory effort through a 2-hour reading task. Phonation threshold pressure is found to increase in response to vocal fatigue and is therefore presented as an objective index of vocal fatigue. In our study, we can see the same relationship between ESP and self-rated phonatory effort, as both of them rise during the first hour of loading. Afterward, the perceived phonatory effort keeps on rising, whereas ESP decreases. Chang and Karnell²⁶ suggest that in case of acute fatigue resulting from 2 hours of loud reading, subjects could reach the point where the respiratory muscles or laryngeal muscles get tired, leading to loss of subglottal pressure. In our study, we rather interpret the decrease in ESP since T2 as an adaptation of the vocal apparatus to vocal loading. This explanation is supported by the fact that self-ratings do not reach extremely high values on the VAS, as discussed previously.

In terms of SPL, the present results are in line with previous studies^{35,40} showing a rise in SPL after a prolonged oral reading in adult speakers. Similarly to the ESP evolution, SPL significantly rises during the first hour of reading (from T0 to T1 and from T0 to T2), and then decreases nonsignificantly. In the same way, SPL increases after 1 working day in teachers as a consequence of vocal loading.^{39,42}

To sum up, the main effects of a 2-hour reading task on acoustic parameters are an increase of F0, F-Low, F-High, I-High, I-Range, and a decrease of Shim. Given that F0, F-Low, and F-High elevation are observed through the reading task and that laryngeal muscles are primarily responsible for pitch control, increased laryngeal tension is a potential consequence of vocal loading. However, muscle activity measurements would be needed to confirm this hypothesis. When studying the evolution of aerodynamic parameters, the repetition of the measurements during the loading task seems worthwhile. In the present work, we took these measures every 30 minutes during the 2 hours (ie, five measurements: T0, T1, T2, T3, and T4). Different evolutions are observed from the start to the end of the experiment. MPT decreases after 30 minutes of reading, ESP and SPL increase within the first hour of reading, suggesting a less efficient voice use. Improvement of these measures occurring afterward depicts a possible adaptation of the voice apparatus to the prolonged loading. Previous studies proposed that prolonged period of phonation may lead to changes in the composition of fluids within the vocal folds, resulting in an elevation in the viscosity and stiffness of the folds.⁴⁸ A greater energy input to initiate and sustain vocal folds vibration would be needed,⁴⁸ as the increase of ESP that we indeed observed. Vocal folds viscosity and stiffness are not measured in the present article, but a similar study manipulates water intake (presumably hydration level) to influence the tissue viscosity during 2 hours of loud reading.³³ Results show that increased hydration appears to attenuate or delay the elevation of the phonation threshold pressure. However, modification of tissue viscosity as an explanation of our results remains

hypothetical; we did not measure it. More research is essential to explore modification of tissue viscosity as a consequence of vocal loading.

Although F0, SPL, and ESP elevation are commonly observed as a result of vocal loading, it is not without risks for vocal health. The higher the number of oscillations over time (F0), the higher the mechanical stress applied on the vocal folds.¹⁰ Mechanical stress is also positively correlated with driving pressure, which is proportional to voice intensity.²⁵ Therefore, ESP, SPL, and F0 elevation because of prolonged vocal load increase the mechanical stress of phonation and may contribute to the development of vocal fold tissues traumas. Professional voice users who frequently experience prolonged voice use, such as teachers, are consequently more exposed to vocal load-related disorders.

Differences between normophonic and dysphonic teachers

After observing the general evolution of teachers' voice through a 2-hour reading task, the second question of this study is to determine if normophonic and dysphonic teachers behave differently. Our hypotheses are that the acoustic parameters, aerodynamic measurements, and self-evaluations would be better for the normophonic group than for the dysphonic group before and during the reading task, and that the voice evolution through the loading task would be different in both groups. We assume a quicker and greater degradation of voice in the dysphonic group.

Concerning the subjective self-ratings, the VHI completed before the loading task shows that dysphonic teachers have more complaints than normophonic teachers. This finding is in agreement with the VAS results collected before and during the reading. Indeed, teachers with nodules systematically perceive more vocal fatigue, phonation effort, and laryngeal discomfort than normophonic teachers. They also note a lower voice quality than healthy teachers. Surprisingly, there is no interaction between duration and group. This means that subjective self-ratings depict a similar evolution of both groups, whereas we expected more degradation of voice through time in the nodular group. Contrary to the present results, Aronsson et al¹⁸ do not find any significant difference in self-rated strain between females with nodules and healthy females. The authors' explanation is that patients with vocal nodules do not feel more strain than controls because of their lower sensitivity to strain, and thus they continue to overuse their voices when controls stop.¹⁸ The different results between Aronsson study and the present one can be explained by the duration of the reading, which is 90 seconds in Aronsson versus 2 hours in the present work. In Buekers,¹⁵ feeling of pain, discomfort, and globus do not differ after a 30-minutes voice endurance test between patients with a history of vocal fatigue and controls. However, fatigue increases more in patients than in controls.

Surprisingly, acoustic analyses show no differences between the two groups before and during the loading task, except for F-High and consequently F-Range, which are greater in the normophonic group. F0 is systematically slightly lower for the dysphonic group than for the healthy group (Figure 2A), but

statistical test do not show significant differences. These results are congruent with Aronsson's results after a 90-seconds reading task.¹⁸ As already known, organically based voice disorders do not appear to have a significant influence on F0,⁴⁴ even through a loading task. Concerning the frequency measures collected using the *Voice Range Profile* program, F-High is lower in the dysphonic group than in the normophonic one. Vocal fold tissues cannot vibrate at high frequency because of the increased stiffness owing to the nodular pathology. This inability to reach high pitches results in a lower F-Range in the dysphonic group than in the normophonic one. For F-Low, there is an interaction between the group and the duration, meaning that the evolution differ in both groups. From T0 to T1, there is a similar increase of the two groups. Then F-Low continues to increase for the pathological group, whereas the control group shows a nonlinear evolution.

For Jitt and Shim, the same pattern of evolution is observed in both groups, except that dysphonic subjects' voices are less stable than healthy subjects' voices, from T0 to T4. Nevertheless, statistical tests fail to demonstrate any significant difference. As in the study by Buekers,¹⁵ there is no significant difference for NHR between the healthy and the dysphonic subjects. This absence of difference in Jitt, Shim, and NHR between the two groups is surprising because the effects of nodular pathology would be to reduce the tissue pliability and the vocal folds vibratory qualities, leading to irregular vibrations. The nodular pathology was expected to cause some mechanical differences increasing the values of Jitt, Shim, and NHR in the dysphonic group. However, statistical analyses show no group effect and no interaction between duration and group, which means that both groups evolve in the same way.

In terms of aerodynamic measurements, the only group effect is observed for ESP. According to the literature,¹⁸ subjects with nodules use a higher ESP than normophonic subjects at each time of the reading task. More pressure is required to initiate and maintain the vibration of the vocal folds because of their lack of pliability. This also explains the fact that subjects with nodules feel more phonation effort than normophonics. Even if no significant difference is found, SPL values are lower for the dysphonic than for the normophonic teachers. At the same time, ESP is significantly higher in the dysphonic group than in the normophonic one. These observations are congruent with the study of Aronsson et al¹⁸: subjects with nodules need more pressure and thus more phonatory effort to achieve a lower voice level than normophonics. Therefore, voice production is less efficient in the nodular group throughout the reading task. Note that ESP first increases in both groups. The normophonic group reaches their maximum ESP value at T1 and the dysphonic group at T2. Then both groups show a decrease in ESP, suggesting an adaptation of the vocal apparatus. It seems important to emphasize this possible adaptation of the dysphonic teachers to vocal loading.

Finally, vocal nodules are known to cause impaired vocal closure during phonation resulting in air leak, decreased MPT, and increased MAR. However, the present work finds no difference between both groups for MPT and MAR, meaning that they evolve in the same way.

To sum up, when studying the differences between normophonic and dysphonic teachers through vocal load, subjective self-evaluations and objective measurements yield different results. Most acoustic and aerodynamic measurements do not differ between both groups, except F-High, F-Range, and ESP. VHI and VAS results demonstrate more complaints in the dysphonic group. This discrepancy shows that self-assessments and objective measurements are two different and complementary approaches to evaluate the voice, which is multi-dimensional. Previous studies making correlations between self-assessments and objective measurements of voice give independent results,^{49,50} meaning that there is no evident relationship between the patient's perception and objective measures. Consequently, both approaches are necessary to have a complete view of the vocal load effects.

CONCLUSIONS

This study observes the effects of a 2-hour reading task on objective analyzes and self-evaluations of voice in 16 normophonic and 16 dysphonic female teachers. The first part of the study addresses the impact of a 2-hour reading task on teachers' voice. As expected, the teachers report that their voice quality worsens significantly during the 2 hours of reading, whereas phonation effort, vocal fatigue, and laryngeal discomfort increase. In terms of acoustic and voice range measurements, F0, F-Low, F-High, I-High, and I-Range progressively increase during the prolonged oral reading, whereas Shim decreases. Aerodynamic measurements depict first a deterioration in voice efficiency: MPT decreases after 30 minutes, whereas ESP and SPL increase within the first hour. Afterward, improvement of these aerodynamic measures suggests an adaptation of both groups to the prolonged loading.

The second part of the study observes the differences between normophonic and dysphonic teachers' voice during the loading task. As expected, subjective self-ratings reveal that dysphonic teachers feel systematically more affected than healthy teachers. However, most objective measurements do not differ between both groups: the only differences observed are lower ESP, higher F-High, and consequently greater F-Range in the normophonic group. Surprisingly, there is no interactions between the duration and the group, meaning that the voice evolution through the loading task is similar for dysphonic and normophonic teachers (except for F-Low). In other words, there is no more or quicker deterioration of voice in the dysphonic group. However, it would be interesting to prolong or repeat the loading task: it is possible that if the reading lasts longer or occurs repeatedly, more differences between both groups would appear. The recovery time after vocal loading should also be examined to determine if the dysphonic group needs more time to recover than the healthy group.

The present study addresses vocal loading using subjective self-ratings, acoustic analysis, and aerodynamic measurements. Some measurements of the muscle activity would be needed to investigate a potential increased laryngeal tension as an effect of vocal loading. In a subsequent study, the impact of vocal load will be examined using perceptual evaluations of expert

listeners. Moreover, an analysis of postural, respiratory, and articulatory adaptations would be of great interest.

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