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Vocal Demand Response to the Educational Setting Based Communication Scenarios: A Single Subject Study

Respuesta de la demanda vocal a los escenarios de comunicación basados en el entorno educativo: Un estudio de sujeto único

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The author has declared that there is no conflict of interest.

Data availability
All relevant data is in the article. For futher information, contact the corresponding author.

Abstract

Objectives. This was a single-subject study, aimed to demonstrate different vocal demand situations that are typical for primary school and teacher's vocal demand response under two acoustical conditions, with and without voice amplification, during five working days.

Methods. The long-term voice dosimetry with Vocal Holter Med (PR.O. Voice Srl) was carried out on a 49-year-old female teacher with voice disorders during daily teaching activities. A sound field amplification system (SFAS) PentaClass Runa was installed in the classroom. Voice dosimetry was provided under two different acoustical conditions: without SFAS (2 days) and with SFAS (3 days).

Results. Phonation time percentage, sound pressure level (SPL), SPL SD, fundamental frequency (F_0), F_0 SD, cycle, and distance doses were investigated in seven communication scenarios (lessons, group/individual classes, sports lessons in the gym and schoolyard, breaks, lunch breaks, and other activities). The median scores of all voice parameters differed significantly between different vocal demand contexts. The significant statistical difference in the vocal demand response was in the communication situations with and without SFAS. In addition, the number of children, reverberation time, and ambient air relative humidity impacted voice SPL and the cycle dose.

Conclusions. Lessons, sports lessons held in the gym or schoolyard, breaks, and lunch breaks were considered as high vocal demand communication situations requiring higher voice intensity and fundamental frequency, higher phonation time percentage, cycle, and distance doses. Group/individual work and other teacher activities during the day, unrelated to direct work with students, were categorized as low vocal demand communication scenarios.

Keywords

Teachers; occupational voice disorders; voice dosimetry; vocal load; vocal demand response; voice amplification; fundamental frequency; sound pressure level; vocal doses; humidity; sport lessons; background noise.

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Disclaimer
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Contribution of the author
Baiba Trinite: Conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing – original draft, writing – review & editing.

Resumen

Objetivos. Este fue un estudio de sujeto único, cuyo objetivo fue demostrar diferentes situaciones de demanda vocal típicas de la escuela primaria y la respuesta vocal de los docentes bajo dos condiciones acústicas, con y sin amplificación de voz, durante cinco días laborables.

Métodos. Se llevó a cabo dosimetría vocal a largo plazo con Vocal Holter Med (PR.O. Voice Srl) durante las actividades diarias de enseñanza en una docente de 49 años con trastornos de la voz. Se instaló un sistema de amplificación de campo sonoro (SFAS) PentaClass Runa en el aula. La dosimetría vocal se realizó bajo dos condiciones acústicas diferentes: sin SFAS (2 días) y con SFAS (3 días).

Resultados. Se investigaron el porcentaje de tiempo de fonación, el nivel de presión sonora (SPL), SPL SD, la frecuencia fundamental (F_0), F_0 SD, ciclos y dosis de distancia en siete escenarios de comunicación diferentes (clases, clases grupales/individuales, clases de educación física en el gimnasio y el patio de la escuela, recreos, almuerzos y otras actividades). Las puntuaciones medias de todos los parámetros vocales diferían significativamente entre los diferentes contextos de demanda vocal. La diferencia estadísticamente significativa en la respuesta a la demanda vocal se observó en las situaciones de comunicación con y sin SFAS. Además, el número de niños, el tiempo de reverberación y la humedad relativa del aire ambiente afectaron al SPL de la voz y la dosis de ciclo.

Conclusiones. Las lecciones, las clases de educación física en el gimnasio o el patio de la escuela, los recreos y los almuerzos se consideraron situaciones de comunicación de alta demanda vocal, que requerían una mayor intensidad y frecuencia fundamental de la voz, un mayor porcentaje de tiempo de fonación y dosis de ciclo y distancia más altas. El trabajo grupal/individual y otras actividades del profesor durante el día no relacionadas con el trabajo directo con los estudiantes se categorizaron como escenarios de comunicación de baja demanda vocal.

Palabras clave

Docentes; trastornos de la voz ocupacionales; dosimetría vocal; carga vocal; respuesta a la demanda vocal; amplificación de voz; frecuencia fundamental; nivel de presión sonora; dosis vocales; humedad; clases de educación física; ruido de fondo.

Introduction

Vocal demand is the vocal requirement for a given communication scenario that can be described by communication purpose, physical and acoustical environment, listeners age, and listeners number [1]. Vocal demand response means how an individual produces voice in an attempt to respond to a perceived vocal demand within a communication scenario. A vocal demand response would be described by physiological voice qualities and subjective qualities such as a sense of effort [1].

Approximately one-third of the total labor force are working in professions where voice is an essential part of their work [2]. The concepts of "vocal demand" and "vocal demand response" are relevant to every occupational voice user in the context of voice ergonomics. Occupations that require a high voice demand, that are satisfied by excessive voice use, could cause occupational voice disorders. Scientific literature is replete with data about the prevalence of voice disorders in professions with varying different vocal demands, such as soccer coaches [3], priests [4], kindergarten teachers, hospital nurses [5], and choir conductors [6]. The teaching' profession plays a leading role in occupational voice disorders research [7-9]. The studies showed that the prevalence of voice disorders in teachers ranged from 11 to 69% [10-12]. In Latvia, 69% of Latvian school teachers reported voice problems [12].

Teachers are occupational voice users who experience high vocal demand [13]. The increased vocal loads, number of teaching hours per week, poor classroom acoustics, high activity noise in classrooms, loud speaking, and number of pupils in the classrooms were the main risk factors of teacher voice disorders [12-14]. However, the analysis of published studies showed no clear, confirmed causality between voice disorders and risk factors and, therefore, studies where individuals would be observed for a more extended period would help fill the existing gap [8].

The vocal demand response is the amount of work accomplished by the laryngeal mechanism of the speaker while phonating [15]. Phonation time, sound pressure level, and fundamental frequency characterize vocal folds work during phonation and can be measured by voice dosimeters. A voice dosimeter is a device used to measure and monitor an individual's vocal activity over a specific period of time, allowing one to obtain information about long-term vocal behavior. Moreover, the extracted parameters from voice dosimetry can be used to calculate vocal doses, quantifying the amount of work done by vocal folds. Time, cycle, and distance vocal doses assess the degree of exposure of vocal folds tissue to vibrations [16]. The relationships between vocal demands and vocal demand responses using the voice dosimetry method were investigated in field studies [17-20] and experimental settings [21,22]. These studies showed that teacher vocal loads were analyzed within the framework of a work week, day, or teacher classroom activity. However, a teacher's workday consists of different activities, and each will have a communication scenario requiring appropriate voice reactions.

This single-subject study aimed to demonstrate different vocal demand situations that are typical for primary school and teacher's vocal demand response to those under two acoustical conditions: with and without voice amplification during five working days.

Methods

Description of the participant

A 49-year-old, non-smoking, female teacher agreed to participate in a one-week vocal dosimetry study. The study was conducted in September at the beginning of the school year. The participant in the study has worked as a primary school teacher for 26 years. Before the study, the subject went to the ENT doctor because of hoarseness, voice changes, difficulties speaking, and voice fatigue at the end of her workday. The teacher underwent a laryngeal examination through transnasal flexible fiberoptic laryngoscopy (mod. 11101RP2; Karl Storz SE & Co. KG, Tuttlingen, Germany). The laryngoscopy results revealed thick vocal folds with mild edema, a typical clinical presentation of nonspecific laryngitis resulting from vocal abuse. The teacher noted that her voice symptoms were regular and recurrent. The voice symptoms were most prominent at the beginning of September and the end of May (the academic school year).

A perceptual voice assessment showed strained and pressed voice quality and, at the same time, the voice was breathy with a slight degree of turbulent noise (G1R0B1A0S1). The voice signal for estimating the Acoustic Voice Quality Index, AVQI (Phonanium, v. 02.03; Lokeren, Belgium) was obtained by a calibrated condenser microphone C544L (AKG Acoustics Ltd, Vienna, Austria), placed at 5 cm from the speaker's mouth and an audio interface Scarlett Solo (Focusrite Plc, High Wycombe, United Kingdom) in a silent room with background noise less than 35 dB. The respondent was requested to phonate the sustained vowel /a/ and read a phonetically balanced text. The middle three seconds of the vowel and 18 syllables of a connected speech sample were analyzed by the PRAAT software for speech analysis (Boersma, Weenink, v.6.1.05; Amsterdam: Institute of Phonetic Sciences, University of Amsterdam, The Netherlands). The AVQI was 3.76 (smoothed cepstral peak prominence 14.24, harmonic-to-noise ratio 19.88 dB, shimmer local 5.68%, shimmer local dB 0.62 dB, the slope of LTAS -30.17 dB, Tilt of trendline through LTAS -11.01 dB).

The teacher complained that everyday her voice becomes lower or hoarse. In addition, her voice often becomes strained, tired or breaks during the week. The teacher indicated that her voice problems have been recurring, and her voice worsens towards the end of May when the academic year ends, and in September when the teacher returns from summer vacation. Her Voice Handicap Index-30 total score was 32 points (functional scale score 13 points, physical scale score 14 points, emotional scale score 5 points).

Description of the classroom

The classroom where the teacher primarily worked during the week was located on the second floor of the school building. It had plastered and painted walls, a linoleum floor, and concrete panels on the ceiling. The windows were on two opposite walls and faced the schoolyard and a sports field, with the total area of windows being 18.8 square meters. The classroom size was 177 cubic meters, and the ceiling height was 2.89 meters. There were closed cabinets at the back of the classroom and a whiteboard in front of the classroom.

Equivalent A-weighted continuous sound pressure level (L_{Aeq}) of background noise and reverberation time ($T_{30\_0.5\text{-}1kHz}$) were measured in an unoccupied classroom and gym according to the EN ISO 3382-1 standard [23]. The handheld acoustic analyzer XL2 (NTi Audio AG, Schaan, Liechtenstein) and microphone M4261 (Class 2/Type 2, sensitivity) measured the reverberation time at 15.2 mV/Pa. Background noise L_{Aeq} was measured in an unoccupied classroom at a distance of 1.1 meters from the floor, a distance of 1 meter from the walls, and 0.5 meters from the furniture at three measurement points. The unoccupied classrooms reverberation time was 0.94 s, and the L_{Aeq} was 39 dB. The Sabine formula was applied to calculate the reverberation time in occupied conditions ($T30_{es\_oc}$), where the number of pupils in the classroom in different communication scenarios were considered [24].

The Voice Ergonomics Assessment in Work Environment checklist [13] was completed to investigate the classroom work conditions. The checklist included four sections: noise, indoor air quality, working postures, and working practice. The assessment was based on the teacher's responses obtained during the structured interview and observations made by the investigator. The checklist was completed before the voice dosimetry. The primary indoor noise sources were the heating system, computer, and data projector. Outdoor noises from traffic, schoolyard, and adjacent rooms were overheard in the classroom. There were school decoration materials collecting dust in the classroom. However, noticeable dust on surfaces was not observable. There were no noticeable odors or signs of moisture damage in the classroom. The teacher did not have any complaints regarding room temperature or dry air in the classroom when it was heated during the wintertime. The teacher noted that her shoulders were tense during her workday. The teacher's self-assessment of her work practices showed that a loud voice was used during lessons despite the short distance between the teacher and her pupils. The technical equipment in the classroom was rarely used and frontal instructions were the primary teaching style. The teacher was most often in front of the class during the lessons. The teacher's self-assessment was that her voice use was excessive without any alternatives to decrease her voice use. She pointed out that it was impossible to rest the voice during breaks because children were always in the classroom.

Description of the procedure

The voice dosimetry was provided with calibrated vocal dosimeter Vocal Holter Med, VHM (PR.O.Voice Srl). The device consisted of Data Acquisition and Processing Unit (DAP), which has an embedded audio microphone and a contact microphone connected to the DAP. A contact microphone was placed on the neck of the teacher, and the DAP was attached to the teacher's belt during the measurements. The contact microphone registered the percentage of time spent on voicing (D_t), fundamental frequency (F_0), and Sound Pressure Level ($SPL_{0.2m}$). The contact microphone was calibrated according to manufacturer instructions each morning before lessons. The amount of voice production measured each time for every communication scenario was expressed as time, cycle, and distance dose. Vocal doses were estimated using algorithms developed by Švec et al. [16].

Other environmental measurements (activity noise, room temperature, relative humidity), were carried out by the VHM. The calibrated external audio microphone detected activity noise L_{A90}. L_{A90} was A-weighted, with the sound level just exceeding 90% of the measurement period and was calculated by statistical analysis. The teacher completed a voice diary where she noted the exact time of the beginning and end of each activity. These activities included her lessons, breaks, individual work, work in small groups, lessons conducted outside of the experimental classroom, lunch breaks, and the number of children she interacted with.

The voice dosimetry was carried out in two different acoustical environments: 2 days without voice amplification and 3 days with voice amplification. An omnidirectional sound field amplification system (SFAS) PentaClass Runa (Certes SIA, Riga, Latvia), was installed at the back of the classroom at 2.3 meters from the floor, and 1 meter from the furniture. A small microphone was linked to the amplification system using a remote control. The microphone was placed on a lanyard at a distance of 10 centimeters from the microphone to the speaker's mouth.

This study was approved by the Ethical Committee of Clinical Research of the P. Stradins Clinical University Hospital (Riga, Latvia).

Statistics

Statistical analysis was done using SPSS software (v. 28; SPSS Inc., New York, NY). The Kruskal-Wallis test was used to determine differences in vocal demand response between different communication scenarios. A post-hoc test using Dunn's (1964) procedure with Bonferroni adjustment was run to carry out pairwise comparisons. The associations between voice parameters expressing vocal demand response and vocal demand factors were investigated using the Pearson product-moment correlation (for normally distributed data) and Spearman's rank-order correlation (for non-normally distributed data).

Results

The voice dosimetry was carried out for five working days from Monday to Friday, and the total dosimetry time was 33 hours. For the first two days, the teacher worked without voice amplification (total dosimetry time was 14 hours); on the other three days, the teacher used voice amplification when she worked in the classroom; she did not use voice amplification for activities that were outside of the classroom. These three days are called the "SFAS period," with a total dosimetry time of 19 hours.

The entire working week of the teacher was grouped into seven activities, each of them representing her communication scenario: lessons, group and individual work, breaks, lunch breaks, a sports lesson in the gym, a sports lesson in the schoolyard, and other activities (meetings, preparation of materials, speaking by phone etc.). The description of the seven communication scenarios related to educational settings is presented in Table 1.

Table 1. Characterization of communication scenarios encountered in the work of teacher.

Communication scenario	N of measurements*	N of children	Volume (m^3)	Reverberation time $T_{es\_oc\_0.5\text{-}1kHz}$ (s)	Activity noise, $L_{A90,}$ (dB) M (SD)	Relative humidity, (%) M (SD)
Lessons	643	24-26	177	0.74-0.76	58.7 (8.3)	45.3 (3.0)
Group/ individual work	268	1-9	177	0.86-0.93	56.5 (7.2)	44.5 (4.4)
Breaks	238	24-26	177	0.74-0.76	66.0 (9.9)	46.1 (2.7)
Lunch breaks (school canteen)	111	≈ 100	no data	no data	72.3 (10.0)	43.7 (3.0)
Sport in gym	32	24	437	1.66	68.2 (11.3)	39.3 (2.0)
Sport in the schoolyard	32	24	n/a	n/a	66.7 (8.9)	43.4 (2.4)
Other activities (different places)	230	no data	no data	no data	57.4 (12.0)	43.0 (3.6)

Note. * The length of each measurement 74 seconds.

The teacher worked with third-year students (9 years old). The mean duration of the lesson was 40 minutes, and break durations varied from 10 to 30 minutes. Table 2 demonstrates the teacher's work schedule for a week.

Table 2. Teachers' work schedule for a week.

Monday	Tuesday	Wednesday	Thursday	Friday
No SFAS		SFAS period		
group/individual work	group/individual work	group/individual work	group/individual work	other activities
break	break	break	break	break
social sciences	natural sciences	ethics	natural sciences	Latvian
break	break	break	break	break
sports (gym)	natural sciences	other activities	natural sciences	Latvian
break	break	break	break	break
math	other activities	sports (yard) *	math	Latvian
break	break	break	break	break
Latvian	other activities	Latvian	math	other activities
lunch break	lunch break	lunch break *	lunch break *	lunch break *
Latvian	math	Latvian	technologies	class lesson
break	meeting	group/individual work	break	break
group/individual work			group/individual work	
group/individual work			group/individual work	

Note. * SFAS was not used.

Phonation time percentage ($D_{t\%}$), sound pressure level (SPL), standard deviation of SPL (SD SPL), fundamental frequency (F_0), and standard deviation of F_0 (SD F_0) were parameters extracted directly from voice dosimetry. In addition, cycle and distance doses were estimated from data obtained during voice dosimetry. Voice dosimetry provides data about a teacher's vocal demand response in different vocal demand situations in natural conditions (without voice amplification), as shown in Table 3; and in conditions when sound field amplification was used in classroom activities (lessons, group/individual work, breaks, partially other activities), as it can be seen in Table 4. Table 4 also includes data about vocal parameters obtained in the SFAS period when amplification was not used (lunch breaks, sports lesson in the yard).

Table 3. Vocal Demand Parameters without Voice Amplification.

Vocal parameter	Lessons		Group/ individual work		Sport lesson (gym)		Breaks		Lunch breaks		Other activities	
	Mdn	IQR	Mdn	IQR	Mdn	IQR	Mdn	IQR	Mdn	IQR	Mdn	IQR
D_t (%)	42.0	19.0	38.0	23.0	47.0	25.0	46.0	24.0	34.0	27.0	28.0	45.0
$SPL_{@0.2m}$ (dB)	78.8	1.6	77.6	1.5	77.5	1.0	78.9	9.6	77.9	1.6	76.4	3.6
SD $SPL_{@0.2m}$ (dB)	3.3	1.7	2.8	0.9	2.4	0.7	3.5	2.2	4.1	2.9	4.0	1.1
F_0 (Hz)	240.2	29.3	218.4	26.3	266.6	30.0	234.5	26.0	250.2	29.7	204.1	32.7
SD F_0 (Hz)	81.4	7.5	74.7	14.0	83.9	7.2	79.1	9.7	85.0	10.4	79.2	29.8
D_{c_1min} (kcycle)	5.97	2.8	4.77	3.05	7.10	4.7	6.25	3.5	4.81	4.0	3.6	5.5
D_{d_1min} (m)	17.75	8.1	13.77	9.9	18.75	10.42	18.08	11.0	13.85	12.3	10.31	16.9

Note. Median values (Mdn) and interquartile range (IQR) of phonation time percentage (D_t), sound pressure level ($SPL_{@0.2m}$), standard deviation of sound pressure level (SD $SPL_{@0.2m}$), fundamental frequency (F_0), standard deviation of fundamental frequency (SD F_0), cycle dose (D_{c_1min}), and distance dose (D_{d_1min}) in different vocal demand contexts.

Table 4. Vocal Demand Parameters with Voice Amplification.

Vocal parameter	Lessons		Group/ individual work		Sport lesson (yard)		Breaks		Lunch breaks		Other activities	
	Mdn	IQR	Mdn	IQR	Mdn	IQR	Mdn	IQR	Mdn	IQR	Mdn	IQR
D_t (%)	34.0	21.0	33.0	19.0	42.0	18.0	34.0	24.0	31.0	20.0	15.0	29.0
$SPL_{@0.2m}$ (dB)	76.9	4.4	76.0	6.1	80.4	2.6	77.6	4.7	79.9	3.5	74.7	5.5
SD $SPL_{@0.2m}$ (dB)	5.2	2.1	4.7	1.3	6.0	1.1	5.8	1.9	6.9	2.4	4.5	1.8
F_0 (Hz)	215.8	29.6	199.4	21.2	244.9	32.6	216.5	28.1	237.1	20.5	214.6	72.1
SD F_0 (Hz)	74.9	10.2	70.7	10.0	88.4	10.2	76.7	13.0	80.9	9.6	93.2	41.6
D_{c_1min} (kcycle)	4.38	2.9	4.05	2.5	6.33	2.7	4.32	3.3	4.5	2.9	1.95	3.7
D_{d_1min} (m)	12.7	8.7	11.98	8.2	20.09	8.0	12.59	10.5	14.69	8.6	5.33	10.2

Note. Median values (Mdn) and interquartile range (IQR) of phonation time percentage (D_t), sound pressure level ($SPL_{@0.2m}$), standard deviation of sound pressure level (SD $SPL_{@0.2m}$), fundamental frequency (F_0), standard deviation of fundamental frequency (SD F_0), cycle dose (D_{c_1min}), and distance dose (D_{d_1min}) in different vocal demand contexts in SFAS period.

A Kruskal-Wallis test was run to determine if there were differences in voice parameters in different communication situations. Median scores of all voice parameters statistically significantly differed between different vocal demand contexts in days without voice amplification: phonation time percentage $\chi^2(5) = 63.002$, $p < .001$, sound pressure level $\chi^2(5) = 150.926$, $p < .001$, sound pressure level standard deviation $\chi^2(5) = 117.964$, $p < .001$, fundamental frequency $\chi^2(5) = 177.950$, $p < .001$, fundamental frequency standard deviation $\chi^2(5) = 60.830$, $p < .001$, cycle dose $\chi^2(5) = 103.726$, $p < .001$, distance dose $\chi^2(5) = 99.394$, $p < .001$; and when voice amplification system was used: phonation time percentage $\chi^2(5) = 72.665$, $p < .001$, sound pressure level $\chi^2(5) = 144.735$, $p < .001$, sound pressure level standard deviation $\chi^2(5) = 132.047$, $p < .001$, fundamental frequency $\chi^2(5) = 158.723$, $p < .001$, fundamental frequency standard deviation $\chi^2(5) = 125.964$, $p < .001$, cycle dose $\chi^2(5) = 86.176$, $p < .001$, distance dose $\chi^2(5) = 99.267$, $p < .001$.

In order to discover the relevant communication scenario where the median scores of voice parameters differed, a post hoc analysis using pairwise comparisons was performed with Bonferroni correction for multiple comparisons. Adjusted *p*-values for voice parameters in different communication scenarios for conditions, with and without SFAS, are presented in Table 5 and Table 6.

Table 5. Adjusted *p*-values for voice parameters in different communication scenarios without SFAS.

Communication scenario	Vocal parameter	Lessons	Group/ individual work	Sport lesson (gym)	Breaks	Lunch breaks
Group/individual work	D_t (%)	.722				
	$SPL_{@0.2m}$	< .001				
	SD $SPL_{@0.2m}$	< .001				
	F_0	< .001				
	SD F_0	< .001				
	D_{c1min}	.001				
	D_{d1min}	.001				
Sport lesson	D_t (%)	.738	.048			
	$SPL_{@0.2m}$	< .001	1.000			
	SD $SPL_{@0.2m}$	< .001	.017			
	F_0	< .001	< .001			
	SD F_0	.700	< .001			
	D_{c1min}	.074	< .001			
	D_{d1min}	1.000	.001			

Communication scenario	Vocal parameter	Lessons	Group/ individual work	Sport lesson (gym)	Breaks	Lunch breaks
Breaks	D_t (%)	1.000	0.075	1.000		
	$SPL_{@0.2m}$	1.000	< .001	< .001		
	SD $SPL_{@0.2m}$	0.225	< .001	< .001		
	F_0	1.000	< .001	< .001		
	SD F_0	.998	.039	.054		
	D_{c1min}	1.000	.001	.542		
	D_{d1min}	1.000	< .001	1.000		
Lunch breaks	D_t (%)	.706	1.000	.042	.100	
	$SPL_{@0.2m}$	.078	.783	.313	.050	
	SD $SPL_{@0.2m}$	.004	< .001	< .001	1.000	
	F_0	.099	< .001	.854	.017	
	SD F_0	.025	< .001	1.000	.001	
	D_{c1min}	1.000	1.000	.009	.616	
	D_{d1min}	.718	1.000	.066	.143	
Other activities	D_t (%)	< .001	.003	< .001	< .001	.381
	$SPL_{@0.2m}$	< .001	.055	1.000	< .001	.001
	SD $SPL_{@0.2m}$	.075	< .001	< .001	1.000	1.000
	F_0	< .001	1.000	< .001	< .001	< .001
	SD F_0	1.000	< .001	.764	1.000	.045
	D_{c1min}	< .001	.004	< .001	< .001	.002
	D_{d1min}	< .001	.004	< .001	< .001	.008

Table 6. Adjusted p-values for voice parameters in different communication scenarios in the SFAS period.

	Vocal parameter	Lessons	Group/ individual work	Sport lesson (gym)	Breaks	Lunch breaks
Group/individual work	D_t (%)	1.000				
	$SPL_{@0.2m}$	< .001				
	SD $SPL_{@0.2m}$	.047				
	F_0	< .001				
	SD F_0	.001				
	D_{c1min}	1.000				
	D_{d1min}	.972				
Sport lesson	D_t (%)	.001	.003			
	$SPL_{@0.2m}$	< .001	< .001			
	SD $SPL_{@0.2m}$	.027	< .001			
	F_0	< .001	< .001			
	SD F_0	< .001	< .001			
	D_{c1min}	< .001	< .001			
	D_{d1min}	< .001	< .001			
Breaks	D_t (%)	1.000	1.000	.003		
	$SPL_{@0.2m}$	1.000	< .001	< .001		
	SD $SPL_{@0.2m}$	.009	< .001	1.000		
	F_0	1.000	< .001	< .001		
	SD F_0	.682	< .001	< .001		
	D_{c1min}	1.000	1.000	< .001		
	D_{d1min}	1.000	.877	< .001		

	Vocal parameter	Lessons	Group/ individual work	Sport lesson (gym)	Breaks	Lunch breaks
Lunch breaks	D_t (%)	1.000	1.000	< .001	1.000	
	$SPL_{@0.2m}$	< .001	< .001	1.000	.001	
	SD $SPL_{@0.2m}$	< .001	< .001	.160	< .001	
	F_0	< .001	< .001	1.000	< .001	
	SD F_0	< .001	< .001	.350	.047	
	D_{c1min}	1.000	1.000	< .001	1.000	
	D_{d1min}	1.000	.923	< .001	1.000	
Other activities	D_t (%)	< .001	< .001	< .001	< .001	.003
	$SPL_{@0.2m}$	< .001	.159	< .001	< .001	< .001
	SD $SPL_{@0.2m}$	< .001	1.000	< .001	< .001	< .001
	F_0	1.000	< .001	.001	1.000	.001
	SD F_0	< .001	< .001	1.000	.001	1.000
	D_{c1min}	< .001	< .001	< .001	< .001	< .001
	D_{d1min}	< .001	< .001	< .001	< .001	< .001

The teacher's voice intensity was analyzed in relation to background noise (LAF90). The median background noise level significantly differs in different communication situations, regardless of whether the teacher used or did not use voice amplification: no SFAS period (Monday and Tuesday) $\chi^2(5) = 124.400$, $p < .001$, SFAS period (Wednesday, Thursday, Friday) $\chi^2(5) = 196.622$, $p < .001$. The median activity noise was in the range of 54.1 dB (other activities) to 75.7 dB (lunch breaks), during the SFAS period from 52.7 dB to 77.2 dB (Table 7). There were significant positive correlations between activity noise and a teacher's voice sound pressure level in lessons, breaks, lunch breaks, and other activities. During the SFAS period, significant statistical associations between LAF90 and a teacher's voice intensity were found in lessons, group and individual work, breaks, lunch breaks, and other activities (Table 7).

The number of children varied in different communication situations, from engaging in individual consultations to having 26 students in one lesson. There were significant statistical correlations between the number of children and phonation time percentage ($r_s = .124$, $p = .018$), SPL ($r_s = .224$, $p < .001$), SPL SD ($r_s = .146$, $p = .006$), and cycle dose ($r_s = .131$, $p = .012$).

Table 7. Associations between background noise (LAF90) and teacher's voice sound pressure level (SPL) in the different acoustic conditions.

Acoustic condition	Communication scenario	L_{A90} (dB)		$SPL_{@0.2m}$ (dB)		r	p
		Mdn	IQR	Mdn	IQR		
No SFAS	Lessons	59.2	11.2	78.8	1.6	.133	.038[a]
	Group/individual work	57.7	13.3	77.6	1.5	.124	.188[b]
	Sport lesson	69.4	12.5	77.5	1.0	.236	.193[b]
	Breaks	67.0	12.1	78.9	9.6	.457	<.001[b]
	Lunch breaks	75.7	8.9	77.9	1.6	.429	.003[a]
	Other activities	54.1	15.5	76.4	3.6	.720	<.001[b]
SFAS	Lessons	54.0	9.4	76.9	4.4	.379	<.001[a]
	Group/individual work	56.4	6.8	76.0	6.1	.595	<.001[b]
	Sport lesson	66.0	10.1	80.4	2.6	-.290	.096[b]
	Breaks	65.6	16.1	77.6	4.7	.336	<.001[a]
	Lunch breaks	77.2	7.2	79.9	3.5	.429	.003[b]
	Other activities	52.7	9.5	74.7	5.5	.377	.001[b]

Note. [a] Pearson product-moment correlation; [b] Spearman's rank-order correlation.

Lessons, group and individual work, breaks, and other activities took place in the classroom but sports lessons were organized in the gym. The classroom and gym had different reverberation times. A significant statistical correlation was found between reverberation time and SPL (r_s = .296, p < .001), SPL SD (r_s = -.562, p < .001), F_0 (r_s = .516, p < .001), F_0 SD (r_s = .335, p < .001), D_c (r_s = .198, p < .001), and D_d (r_s = .216, p < .001).

An increase in relative humidity in the school premises was associated with a decrease in phonation time percentage (r_s = -.107, p = .041), SPL (r_s = -.189, p < .001), F_0 (r_s = -.368, p < .001), F_0 SD (r_s = -.164, p = .002), D_c (r_s = -.169, p = .001), and D_d (r_s = -.168, p < .001).

Discussion

Seven communication scenarios (vocal demands), requesting different phonatory challenges (vocal demand response), were investigated in one teacher with voice problems during a working week. Activities carried out by the teacher during the week varied according to the number of children (lessons *vs.* group and individual work), room size and reverberation time (classroom *vs.* gym), and background noise (lunch break in the school cafeteria versus other activities not related to direct pedagogical work). Each activity involved a specific use of voice. For example, during lessons, teachers mainly provide frontal instructions standing in front of the class, during group and individual consultations, the teacher uses her voice for explaining and advising at a closer distance to children during lessons. During lunch and other breaks, the teacher used her voice for organizing and disciplining purposes; it was observed that during breaks the teacher used a conversational voice.

The distance dose offers a quantitative metric for vocal loading or vocal demand response. D_d estimation is based on fundamental frequency, sound pressure level, voicing duration, and the vocal duty ratio. It is more comprehensive than other single parameter-based metrics [25]. The study showed that the highest vocal distance dose was observed in sports lessons with and without voice amplification. However, significant statistical differences in vocal load expressed in D_d were not found between sports lesson in the gym, other lessons, breaks, and lunch breaks when the teacher did not use SFAS. Also, statistically significant variations in phonation time percentage and cycle dose were not found between sports lessons, other lessons, and breaks. The obtained vocal doses indicate that within the working day, the teacher experienced high-demand communication contexts (sports lesson, lessons, breaks, lunch breaks), and low-demand communication scenarios (individual/group work, other activities including meetings, preparation of materials, small conversations, etc.). Significant differences in vocal demand response emerged when SFAS was applied. Distance, cycle, and time doses obtained during sports lesson in the schoolyard (the teacher did not amplify the voice) significantly differed from all other activities, even from lunch breaks where the teacher also did not use SFAS. This finding agrees with previous studies reporting decreased vocal fold oscillations and the total distance traveled by vocal fold tissue in teachers with voice disorders when voice amplification was used [26,27].

The highest fundamental frequency was observed during sports lessons. It is well known that fundamental frequency is affected by room acoustics, particularly reverberation time [23]. The reverberation time in the gym was longer than in the classroom. Consequently, the teacher's F_0 during the sports lesson was higher than in other vocal demand situations. The second sports lesson was held in the schoolyard and higher teacher's voice SPL explained high fundamental frequency during this communication context [28]. Similarly, and consistent with our results, higher F_0 in outdoor activities than indoor activities were found in the Sodersten et al. study investigating preschool teacher vocal behavior [29]. An increase in the fundamental frequency is closely related to an increase in background noise level [18]. The results showed that the teacher's F_0 obtained during low background noise activities, such as group/individual work and other activities, were significantly lower than the F_0 obtained in lessons, sports lessons, lunch, and other breaks.

Furthermore, the results demonstrated that F_0 decreased when relative humidity increased. The higher relative humidity of ambient air improves the vocal fold's viscoelastic properties, decreasing vocal effort, sound pressure level, and fundamental frequency [30]. Our study confirmed these findings not only with F_0, but also applicable regarding SPL, SD SPL, SD F_0, D_c, and D_d decreasing in communication situations where relative humidity was higher.

The outdoor sports lesson was only one communication scenario that required the teacher to use a raised voice. According to the ISO standard 9921 [31], the sound pressure level for a normal loudness voice is 60-65 dB(A), and for the raised voice, 66-71 dB(A) measured at a 1 meter distance (74-79 dB(A), and 80-85 dB(A) at a 0.2 meter distance). In all other situations, regardless of the level of different background noise, the teacher used a normal intensity voice. Interestingly, the Lombard effect was not observed during the sports lesson, where the median background noise was 69.4 dB, and during group and individual work, where the activity noise was 57.7 dB.

This observation can be explained by restricted voice flexibility due to voice problems that do not allow a voice to adapt loudness to alternating background noise sound pressure levels. However, during lunch and other breaks, the median background noise was higher than during sports lessons and in these communication situations the Lombard effect was observed. The same observation applies to the case of other activities where median background noise was lower than during group or individual work. It can be explained by the different teacher vocal behavior in a sports lesson, breaks, and activities not directly related to working with children. During the sports lesson in the gym and individual consultations, the teacher required a constant voice loudness. Teachers voice SPL was appropriate to the room acoustics, number of children, and noise activity throughout the lesson. Whereas during lunch and other breaks, the teacher's phonation time is lower, and the voice is used for a different purpose: to organize and discipline pupils. During other activities, the teacher had the appropriate communication situation short-term voice reactions. Using SFAS, improved the teacher's voice ability to adapt to the background noise, and SPL increased when the background noise increased.

Breaks are an essential part of a teacher's workday schedule. Breaks between lessons can give teachers time to prepare materials, review lesson plans, make necessary adjustments, and provide opportunities for teachers to interact with colleagues and students. Also, teachers can rest their voices, hydrate, and engage in vocal warm-up exercises during breaks. This study was conducted in conditions where students did not leave the classroom during breaks and the results demonstrated that breaks were as vocally demanding as the lessons. There were no significant statistical differences in the teacher's vocal behavior (median SPL, F_0, SD F_0), and vocal doses between breaks and lessons with or without SFAS. The only parameter that changed when SFAS was used was SD SPL.

The objective data obtained during voice dosimetry were in accordance with the information received from the teacher voice ergonomic self-assessment before the study. The teacher had pointed out excessive and loud voice use during the working day despite different communication situations and difficulty resting her voice during the breaks. The voice dosimetry data confirms these statements.

Three days out of five, the teacher had time (1-2 lessons) when she did not have direct work with children (other activities). According to the teacher's records, the content of "other activities" corresponded to what we would like to expect in breaks if we understand them as a pause in work. The results showed that during other activities, the teacher used a softer voice, spoke less, had a lower cycle and distance dose, and demonstrated vocal health preserving behavior. Such vocal rest periods, regardless of their title, that could be deemed "breaks or noise free" allocated time, should be regular throughout the working day, that is, it is recommended that teachers should designate or reserve time for voice rest during the workday. Teacher and student voice ergonomics education could facilitate reviewing and modifying vocal behavior routines. Teacher educational programs should provide education in voice ergonomics, and teachers should forward this knowledge to children educating them about noise and silence in classrooms [32]. Voice ergonomics includes both speaker and listener comfort through different communication scenarios.

In this study, several limitations should be acknowledged. Firstly, it was a single-subject study, which may limit the generalizability of findings to a larger teacher population. Secondly, the fact that the teacher had voice problems due to nonspecific laryngitis was a significant factor that likely impacted the obtained results. The involvement of another subject with a healthy voice would have provided more robust insights into vocal behavior during school-based activities. Moreover, it would have allowed us to explore the causality between the vocal demands of the job and vocal difficulties. Finally, the stationary voice amplification system installed in the experimental classroom did not consistently provide voice amplification in all communication scenarios throughout the SFAS period. Including voice amplification during lunch breaks and outdoor sports lessons would have yielded valuable insights into vocal behavior when a teacher's voice is amplified.

Despite these limitations, the study contributes to a better understanding of occupational voice disorders. A detailed description of typical primary school communication scenarios and monitoring of vocal behavior during one working week provides a unique insight into the conditions teachers face in their jobs. The study's practical implications are related to improving the working conditions of primary school teachers by addressing vocal demands through enhancements in classroom acoustics and air quality, teacher training, support, and scheduling adjustments. These improvements can help reduce the risk factors for voice disorders and promote voice ergonomics.

Based on the study's findings, a series of recommendations can be proposed for teachers with voice disorders to reduce their vocal demand response. It is recommended to reduce background or activity noise during various educational activities. Implementing strategies to create a quieter learning environment can enhance teachers' vocal health. The use of sound field amplification systems is also recommended during working days. However, it is advisable that school administrations take on the responsibility of acquiring the necessary equipment and providing technical support. Additionally, teachers should undergo training on the proper utilization of voice amplifiers to ensure optimal effectiveness. Teachers should also incorporate periods of voice rest into their daily routines. It is essential to maintain ambient air relative humidity levels within the range of 25% to 60% in teachers' occupational *settings* [13].

Conclusions

Considering the study's single-subject design, it can be observed that lessons, sports lessons, lunch and other breaks tend to impose higher vocal demands requesting higher voice intensity and fundamental frequency, higher phonation time percentage, cycle, and distance doses. Lower vocal demand teacher experienced during group, individual work and other activities unrelated to working directly with students. Statistically, Vocal demand response significantly differed in communication situations with and without SFAS. The number of children, reverberation time, and ambient air relative humidity impacted voice sound pressure level and cycle dose in primary school teacher with voice problems.

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