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Associations between objectively-measured acoustic parameters and occupational voice use among primary school teachers

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Abstract

Previous studies on voice disorders among teachers have reported that this multidimensional phenomenon is associated with individual factors, external factors related with the audience and with the type of task and the occupation. This work deals with the long-term monitoring (1 to 4 days) of 31 primary school teachers and with the determination of the relationship between conversational and occupational voice parameters. Statistical analysis was performed to investigate the relationships between voice parameters and room acoustics-related factors.

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Keywords: voice monitoring; acoustic measurements; vocal effort; classrom acoustics.

1. Introduction

Poor classroom acoustics is a major problem in educational environments because of its negative effects on teaching and learning activities. Italian national standards aim at providing indications on the optimal ranges for those parameters that guarantee appropriate acoustical quality for learning purposes (e.g. reverberation time, clarity, speech transmission index) [1-3], although many school buildings date back to early XX century and therefore would need to be renovated in order to comply regulations.

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This paper focuses on teaching-related issues by investigating the relationships between measured classroom acoustics parameters and professional voice use among primary school teachers. Although studies conducted so far have identified a dependence between speech production and noise level (the Lombard effect [4]), as well as the general association between acoustic conditions and the occurrence of voice disorders [5], there is little evidence on the association between acoustic parameters inside the classrooms and the long-term measures of sound pressure level (intensity of voice), fundamental frequency (pitch of voice), and phonation time percentage. Hunter and Titze [6] found that average occupational voice for teachers was about 1 dB SPL louder than the non-occupational voice and exhibited an increased pitch.

In four schools of three different cities in the north of Italy a follow-up study was conducted among 31 primary school teachers. The vocal behavior of teachers was characterized during their working activity by means of the Voice-Care device [7], which is able to sense the vocal folds vibration through a contact microphone placed at the jugular notch of the monitored person. Since this device does not interfere with the teaching activity and a small evidence of long-term vocal behaviour exists in literature, teachers were monitored for 1 to 4 days, from Monday to Thursday or Friday, to characterize the occupational voice use and to estimate possible vocal fatigue across several days. Two types of voice samples were acquired for each teacher and hereby presented, namely a conversational sample recorded at the beginning of the working day and the entire monitoring of the teaching activities, 4 hours long. The conversational sample was used to obtain a standard level of voice parameters per each teacher and per each day of monitoring. Changes between the voice parameters of the conversational sample and those obtained during the entire monitoring were then observed. Descriptive statistics was used to characterize the study population, and the Generalized Estimating Equations (GEEs) [8] were used to determine the relationship between conversational voice parameters and occupational voice parameters. In a separate model, GEEs were also used to investigate associations between the long-term measured voice parameters during the occupational voice use with the acoustic parameters inside the classrooms.

2. Methods

2.1. Design and participants

The vocal activity of 31 primary school teachers (30 female, 1 male) was monitored for 1 to 4 working days in four schools located in the Provinces of Torino and Bolzano (Italy). Their age ranged between 31 and 60 years (mean = 46.4 years) and the average number of performed monitoring was 3.3 per each teacher. None of the teachers who voluntarily took part in the monitoring campaign reported severe voice problems; although some of them reported that they have consulted a speech therapist to learn how to use their voice properly.

The four school buildings dated back to different periods of construction; therefore, the acoustic characteristics of the classrooms were very different. The main differences regarded the parameters reverberation time ($T30_{0.125\text{-}2kHz}$), room gain ($G_{RG,0.5\text{-}2kHz}$) and voice support ($ST_{V,0.5\text{-}2kHz}$) [9], which have been compared to the occupational voice use parameters to assess associations. For some classrooms, room gain and voice support have been predicted according to the method reported in [9]. Table 1 summarizes the averages of the measured parameters divided on the base of the inter-quartile-ranges (IQR) at 25% and 75%, which were used to dichotomize values as adequate or non-adequate, whose clustering is in agreement with regulations or literature [9-11] and whose significance was investigated through normality tests.

2.2. Data collection procedures

The vocal parameters sound pressure level (SPL), fundamental frequency (F_0) and phonation time percentage ($D_{t\%}$) were acquired using the Voice-Care device [7], a portable vocal analyser that has recently been developed at Politecnico di Torino. Before every voice monitoring, each teacher was required to talk for 5 minutes at a comfortable and conversational pitch, with loudness as naturally as possible, and not in a singing voice, one meter far from a seated listener. This conversational task was performed in a room with similar reverberation to the one related to the entire voice monitoring. After this conversational sample, voice production of the participants was monitored during actual teaching activities, 4 hours per day.

Table 1. Measured parameters for the acoustic characterization of classrooms. Values refer to unoccupied (unocc.) or simulated occupied (occ.) conditions. Standard deviations (SD) of the mean values are reported for frequency averaging and/or repeated measurements. The inter-quartile-ranges (IQR) at 25% and 75% were used to dichotomize values as acceptable or non-acceptable, whose significance was investigated through normality tests.

Measure	Optimal/typical range or value	Reference	N classrooms	Mean	SD	Median	Mode	IQR (25%-75%)	Normality test (*p-value*)
$T30_{0.125\text{-}2kHz,unocc}$ [s]	0.7	DIN 18041 [10]	16	1.0	0.3	1.0	0.4	(0.7 ÷ 1.1)	0.3
$T30_{0.125\text{-}2kHz,occ}$ [s]	0.5		16	0.8	0.3	0.8	0.4	(0.6 ÷ 0.9)	0.8
$ST_{V,0.5\text{-}2kHz,occ}$ [dB]	-14 ÷ -9	Pelegrìn-Garcìa [9,11]	14	-9.5	1.0	-9.2	-9.0	(-10.2 ÷ -8.8)	0.6
$G_{RG,0.5\text{-}2kHz,occ}$ [dB]	0.2 ÷ 0.5		14	0.5	0.1	0.5	0.5	(0.4 ÷ 0.5)	0.5

2.3. Statistical analysis

Statistical analysis was performed with SPSS software (v. 21; SPSS Inc, New York, NY). Descriptive statistics was used to characterize the study population. The Shapiro-Wilk test [12] was used to evaluate whether variables were normally distributed. The variable age was dichotomized using a cut-off value of 50 years of age because menopause-related hormonal changes that may affect the voice of both men and women start around the age of 50 years [13]. Firstly, the relation between conversational voice parameters and occupational voice parameters using Generalized Estimating Equations (GEE) [8] was assessed. Secondly, GEEs were applied to investigate associations between the long-term measured voice parameters during the occupational voice with the acoustic parameters inside the classrooms. For the acoustic parameters, those variables with a *p-value* lower than 0.20 in the univariate analysis were included in the multivariate analyses in order to avoid residual confounding [14], and were only retained if the *p-value* reached the conventional level of significance of 0.05. The associations were expressed as the beta (β) and its standard error (SE). GEE is an extension of the Generalized Linear Model (GLM) to analyse correlated data. This technique takes into account the dependency of the observations by specifying a “working correlation structure”. In this study, a dependency could have occurred since multiple monitorings were collected for each teacher. Taking into account the dependency of the observations avoid under- or over-estimation of the standard errors of the independent variables (accounting between-subject variability) [13,15].

3. Results

3.1. Participant characteristics and acoustic conditions’ parameters

In total, 27 teachers were included in this analysis, being monitored from 1 to 4 days each during their normal teaching activities. Some monitorings were considered as outliers for the subsequent analyses because of little significance in gender dimension (1 male out of 31 teachers) and because of the failure in the validation of the calibration session [16].

As shown in Table 2, in the four days of follow-up, SPL and F_0 along the occupational voice use (entire monitoring, EM) registered the tendency to have higher values compared with the conversation task (pre-monitoring, PM). On the contrary, $D_{t\%}$ was higher during the conversation task compared with the entire monitoring.

Teachers worked in 33 different classrooms that were characterized with objective measurements. Table 3 shows the correlation matrix obtained for the measured parameters reverberation time ($T30_{0.125\text{-}2kHz}$) in unoccupied and occupied conditions, voice support ($ST_{V,0.5\text{-}2kHz}$) and room gain ($G_{RG,0.5\text{-}2kHz}$) inside the occupied classrooms.

Table 2. Socio-demographic characteristics, self-reports, and objectively measured physical conditions and voice parameters of primary school female teachers during four days of monitoring in four primary schools in Torino, Italy. SD is the standard deviation of the analyzed parameters.

Variable	Day one (n=25)		Day two (n=13)		Day three (n=15)		Day four (n=26)	
Socio-demographics								
< 50 years of age (n, %)	12	48	2	15	7	47	11	42
Environmental acoustic parameters								
Long RT in non-occupied classroom (≥ 1.05 s) (n, %)	10	40	1	8	5	33	10	39
Long RT in occupied classroom (≥ 0.93 s) (n, %)	10	40	1	8	5	33	10	39
High Voice Support (≤ -8.8 dB) (n, %)	9	39	0	0	2	14	10	44
High Room Gain (≥ 0.54 dB) (n, %)	9	39	0	0	2	14	10	44
Objective parameters of voice (Entire monitoring)								
SPL equivalent (mean, SD) at 16 cm from the speakers mouth [dB]	80.8	6.3	80.8	6.7	80.9	7.2	79.3	7.0
SPL mean (mean, SD) at 16 cm from the speakers mouth [dB]	80.5	6.8	80.2	5.9	79.6	6.3	76.7	4.4
SPL mode (mean, SD) at 16 cm from the speakers mouth [dB]	81.8	7.4	80.3	6.8	80.8	5.3	76.5	5.6
Fundamental frequency mean (mean, SD) [Hz]	191.1	24.1	179.5	17.2	185.9	14.9	196.6	24.3
Fundamental frequency SD (mean, SD) [Hz]	45.5	9.4	44.0	9.3	49.0	8.5	45.3	9.4
Fundamental frequency mode (mean, SD) [Hz]	178.7	20.4	175.6	21.2	170.9	14.2	181.8	24.5
Phonation time percentage (mean, SD) [%]	43.7	10.7	39.5	11.4	48.1	11.9	42.9	11.3
Objective parameters of voice (Pre-monitoring)								
SPL equivalent (mean, SD) at 16 cm from the speakers mouth [dB]	80.1	3.0	79.2	4.9	78.0	3.8	78.9	5.8
SPL mean (mean, SD) at 16 cm from the speakers mouth [dB]	79.8	4.3	80.3	5.0	77.9	3.6	77.5	5.4
SPL mode (mean, SD) at 16 cm from the speakers mouth [dB]	80.8	4.0	79.9	5.3	78.9	3.6	77.1	6.0
Fundamental frequency mean (mean, SD) [Hz]	187.2	23.6	178.9	25.7	180.2	15.8	193.4	27.6
Fundamental frequency SD (mean, SD) [Hz]	44.8	8.9	44.4	9.2	44.3	7.6	44.2	9.2
Fundamental frequency mode (mean, SD) [Hz]	172.9	20.2	171.6	19.9	169.9	15.2	178.1	29.8
Phonation time percentage (mean, SD) [%]	44.1	11.6	40.8	13.5	46.5	7.5	44.3	13.0

Table 3. Correlation matrix indicating the strength of the linear dependence between pairs of measured acoustic parameters. Values in bold have high significance (p-value < 0.05).

	$T30_{0.125\text{-}2kHz,occ}$ [s]	$ST_{V,0.5\text{-}2kHz,occ}$ [dB]	$G_{RG,0.5\text{-}2kHz,occ}$ [dB]
$T30_{0.125\text{-}2kHz,unocc}$ [s]	**0.96**	0.31	0.35
$T30_{0.125\text{-}2kHz,occ}$ [s]		0.49	**0.54**
$ST_{V,0.5\text{-}2kHz,occ}$ [dB]			**0.97**

3.2. Relationship between conversational voice parameters and occupational voice use parameters

The results of the GEE suggest that systematically higher values for SPL_{16cm} equivalent were registered during the occupational voice compared with the conversational task (regression slope= 0.66). The same tendency was found for SPL_{16cm} mean (regression slope = 0.73), SPL_{16cm} mode (regression slope = 0.50), F_0 mean (regression slope = 0.37) and phonation time percentage (regression slope = 0.13). No significant association was found on F_0 mode measured during the conversation task and the entire monitoring.

3.3. Relationship between classroom acoustics parameters and occupational voice use parameters

Table 4 shows the results of the GEEs during the occupational voice. Multivariate analysis showed that teachers who worked in classrooms with longer $T30_{0.125\text{-}2kHz,unocc}$ registered higher SPL_{16cm} mean and mode, teachers who worked in classrooms with lower room gain registered higher SPL_{16cm} mode, and teachers who worked in classrooms with higher voice support registered an increase in the standard deviation of the fundamental frequency and phonation time percentage. Furthermore, teachers older than 50 years registered lower standard deviation of fundamental frequency and higher phonation time percentage.

Table 4. Multivariate analysis between acoustic and vocal parameters obtained in the case of entire monitoring during four days of teaching.

	SPL_{16cm} mean [dB]		SPL_{16cm} mode [dB]		F_0,sd [Hz]		$D_{t\%}$ [%]	
	β	SE	β	SE	β	SE	β	SE
> 50 years of age	0.4	1.4	1.7	1.80	-8.0*	1.60	8.5*	2.80
$T30_{0.125\text{-}2kHz,unocc}$ [s]	4.7*	1.4	5.8*	2.00				
$ST_{V,0.5\text{-}2kHz,occ}$ [dB]					1.1*	0.5	2.3*	1.2
$G_{RG,0.5\text{-}2kHz,occ}$ [dB]	-12.1	6.5	-19.4*	7.2				

* $p<0.05$

4. Conclusions

The objective of this study was twofold: to assess the relationship between conversational and occupational voice parameters, and the relationship between the long-term voice parameters and the acoustic parameters inside the classrooms.

The results indicate that teachers speak at higher SPL and F_0 during the occupational activity compared with the conversational task (non-occupational setting). This finding is in agreement with previous studies showing that, compared with non-working tasks, during the working days teachers talk louder and with higher pitches [6,17-19].

Teachers who worked in classrooms with longer reverberation time and lower room gain registered higher sound pressure levels during the occupational voice use. This tendency is confirmed in past researches [11] only for the room gain effect on speech level. The positive association between sound pressure level and reverberation time can be explained assuming that higher reverberation time increases the activity noise level of students, as pointed out by Hodgson et al. [20], which would also make the teachers raise their voice power level due to the Lombard effect. Further investigations on the combined effect of background noise level and reverberation time in the classrooms and their influence on vocal parameters will be carried out.

Those teachers older than 50 years of age have highlighted a significant lowering in standard deviation of fundamental frequency, which may be related with hormonal changes and variations in the status of the vocal folds tissue [12]. Higher voice support is related to an increase in fundamental frequency standard deviation and phonation time percentage.

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