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Research article

How does noise pollution exposure affect vocal behavior? A systematic review

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Abstract: Background: Various types of pollution, like atmospheric, water, soil, noise, have been reported as voice risk factors and exposure can result in vocal problems. Particularly, environmental noise causes the Lombard effect, forcing individuals to raise their voice volume. Exposure to noisy environments could provoke vocal folds lesions such as nodules, oedema, cysts, polyps as well as according to WHO (2018) annoyance, sleep disturbance, cognitive impairment in children, and adverse impacts on the cardiovascular and the metabolic system. **Objective:** The purpose of the current study was to systematically review the current literature for the impact of environmental noise on vocal behavior. **Methods:** Quires in Scholar Google and PubMed databases for peer-reviewed articles that reported environmental noise pollution exposure outcomes at voice behavior were conducted during the last 20 years. Primary Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) together with the Assessment for Multiple Systematic Reviews (AMSTAR) were employed for this study. **Results:** 32 articles were included for the final analysis according to the inclusion criteria. Environmental noise conditions in work and leisure settings were examined. Main findings indicated vocal annoyance, while when comparing patients with vocal lesions to control group, it was pinpointed that (i) they work in higher noise environments, with the consequence to raise voice levels and therefore causing hoarseness, vocal trauma and lesions on vocal cords (ii) average voice level and fundamental frequency were also significantly higher during work (iii) no significant differences in average noise, voice level and fundamental frequency were noted during leisure conditions.

Conclusions: This systematic review indicated that noise pollution exposure especially at work conditions affects vocal behavior and therefore human health. It reveals the need of further in-depth future research regarding vocally demanding professions and environmental noise along with procedures that contribute towards vocal health and prevent occupational voice disorders.

Keywords: noise pollution; voice; vocal behavior; voice disorders; Lombart effect

1. Introduction

Over the last decades, urbanization growth, industrial development and modern lifestyle have brought environmental pollution to our attention [1–4]. Air pollution and noise pollution are known to be the two major environmental causes of health problems affecting respiratory and vocal functions abusing vocal apparatus mainly in high-populated cities [1,5–11]. Since voice quality has been exacerbated by pollution, resultant pathologies occur such as decreased voice quality, mucosa dryness, irritation, nose and throat itching, sore throat, dysphonia and phonasthenia [1,3,10]. Along the same lines, the World Health Organization [12] reports that noise seems to have a larger impact on indicators associated to quality of life and mental health. In fact, continual exposure to noise may cause health problems not just with voice and hearing, but also with sleep, blood pressure, psychology and cognition.

In particular, acoustic comfort is a multidimensional factor for healthy environments and depends on noise level [8,13]. Excessive sound levels in outdoor or indoor environments (e.g. factory, airport, traffic, restaurants, school grounds) is an inhibitor to accomplish efficient communication [4,5,9]. Hearing annoyance and discomfort are shown due to differentiations in intensity and frequency levels of sound. Not to mention the fact that exposure to high noise levels may gradually do harm to hearing ability. Furthermore, lacking acoustic quality may have a negative impact on health and performance leading to learning disabilities and voice problems [2,4,8,10,12,14]. Increased noise levels (intensity > 80 db, frequency > 3000 Hz) become dangerous and lead to communication performance in high vocal sound levels, which in turn provokes pathologic voice issues [2,5,10].

Human voice characteristics (pitch, intensity, quality) depend on air flow and vocal tract anatomy, which differentiates according to gender, age, skills and cognition [15]. Any alterations of vocal folds affect fundamental frequency, pitch and quality of voice [16]. Voice disorder is the heterogeneous change of quality, pitch and intensity of voice with respect to gender, age, cultural background and geographical location of the individual [10,17,18]. It is estimated that 3–9% of U.S.A. population suffer from a voice disorder [17,19], while only 1% seeks cure [7,20]. Prevalence has shown to be influenced by gender, age, and profession with adult women, boys in childhood, elders, and professional voice users to excel [9,10,19–22]. Voice disorders are divided into organic and functional [2,6,17,23]. Organic voice disorders, which result from changes in the respiratory and phonatory systems, may be structural (e.g. vocal nodules, cysts, and polyps) or neurogenic (voice tremor, spasmodic dysphonia, vocal fold paralysis). Functional voice disorders are caused by inappropriate or ineffective use of vocal mechanism (e.g., dysphonia, aphonia, vocal fatigue). Moreover, voice disorders due to psychosocial stressors (psychogenic mutism, psychogenic dysphonia, spastic dysphonia, anxiety vocalization, hysterical vocalization) are known as psychogenic voice disorders [24]. Also, laryngeal nerve injury deteriorates the voice quality [25,26]. As reported [9,10],

most common causes of dysphonia in children are vocal nodules, vocal cysts and acute laryngitis, while adults suffer from functional dysphonia (younger) and presbyphonia (elder).

Work environments play an important role in vocal behavior. Certain occupations, such as teachers, clergy, salesmen, singers and actors, require extensive voice use making it very hard to avoid voice disorders [2,4,6,7]. Likewise, active home environments consisting of many members create difficult conditions to communicate due to excessive ambient noise, and thus the higher ambient noise levels are, the higher individuals are forced to speak (Lombard effect) abusing or misusing their voice [5]. Vocal abuse concerns a habitual use of an extremely loud voice (intensive talking, shouting, screaming, cheering, coughing, smoking, constant clearing of the throat). Vocal misuse consists of behaviors characterized by excessive laryngeal strain or inappropriate pitch level. Both are noxious to voice behavior leading to structural and physiological changes in the larynx tissue [vocal nodules, polyps, polypoid degeneration (oedema) and contact ulcers] [27,28]. The effects of voice misuse during voicing interactions in noisy environments conclude inevitably to pathologic sequelae such as functional dysphonia [6]. Being a professional voice user or not, phonation plays the major role to communicate. Phonation is the sound production through periodical vibrations made by true vocal folds [10,15,16,29] and it is found in several grades (aphonia, whisper, modal voice, breathy voice, creaky voice, harsh voice, falsetto) [16,30–32]. The presence of noise contributes to most voice disorders due to insufficient phonation. Speech quality alterations resulting in voice abnormalities, constitute a voice disorder. The latter becomes a significant obstacle to effective communication [33].

Nowadays voice disorders are at the forefront of occupational diseases. Environmental noise pollution has placed an additional burden on individuals who suffer from voice disorders. It is reported that voice quality is interdependent with environmental factors [3,6]. Apart from prevention programs for vocal training appearing in some regions, [6] such as mobile applications which offer the freedom of communication to individuals with voice problems [32], limited research has been done on how noise pollution affects voice behavior.

The aim of this study was to report on the impact of environmental noise on vocal behavior through a systematic review.

2. Materials and methods

2.1. Research questions

The research questions posed in this systematic review concern:

Q1: Which activity sectors in the current literature are involved in noise pollution exposure in association with voice problems?
Q2: How does noise pollution influence vocal behavior?
Q3: Which populations are reported with voice problems due to noise pollution?
Q4: What are the suggestions to prevent voice disorders due to noise pollution?

To answer these above questions, the following procedure/methodology was followed in the research.

2.2. Search strategy, inclusion criteria, and study selection

This systematic review followed the "Assessment of Multiple Systematic Reviews" (AMSTAR) [34] and has been performed according to the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) [35]. For final inclusion, publications had to fulfil the following criteria:

1. published during the last 2 decades (2001–2020)
2. published after peer review in academic journals
3. published in English language
4. should be a research article
5. should NOT be a review or meta-analysis article
6. all articles should address noise pollution exposure in association with vocal behavior (perception or measurements).

A systematic search of the literature was carried out using the Google Scholar and PubMed databases. The following search string was used for Google Scholar ["ENVIRONMENTAL NOISE" POLLUTION VOCAL BEHAVIOR LOAD MEASURE EXPOSURE "VOICE DISORDER" OR "VOICE PROBLEM" "ACOUSTIC ANALYSIS"] and it was also adjusted for PubMed.

As illustrated in Figure 1, PRISMA Flow Diagram, initially 95 articles were identified in Google Scholar and Pubmed and 14 more articles were identified through other sources. After duplicates removal by one author (KP), there were 91 articles. Titles and abstracts of all articles were then screened by the four authors in pairs (PF & KP, KV & NK) and authors (EIT & PP) reviewed any conflicts and made the final decision for 32 articles to be excluded. Following, 59 full text articles were retrieved by authors (PF & KP, KV & NK), and after consultation with EIT and PP, it was found that 27 were not fulfilling the inclusion criteria and therefore that were considered irrelevant. Finally, 32 articles were included in this study. All publications that met the inclusion criteria, were used for data extraction and methodological quality assessment.

2.3. Data extraction

To answer the research questions relevant data, need to be extracted from the established 32 articles/publications based on: (i) activity sectors, (ii) the aim, (iii) the methods used, (iv) the sample, and (v) the results.

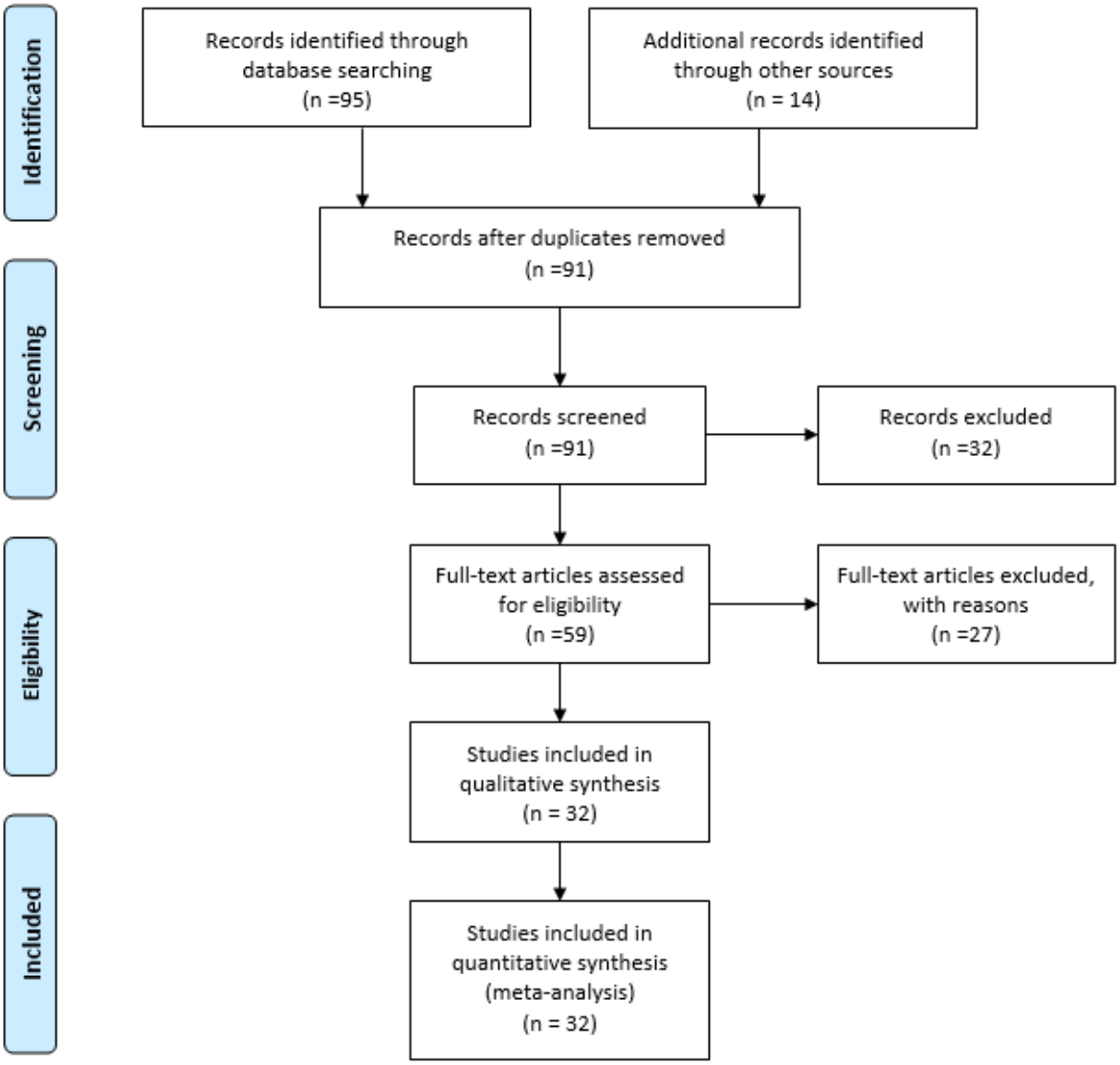

Figure 1. PRISMA Flow Diagram [35].

3. Results

There were 32 articles included in this systematic review. The first area of interest is to identify the activity sectors referred in the articles, which according to the results of this study fall under the educational sector (77.13%), and then less on the clinical sector (9.37%), the entertainment sector (6.25%) and other sectors (6.25%). As described in Table 1, Articles' sample categorization.

Table 1. Articles' sample categorization.

Categories	Articles	N: 32
Educational sector	[36–60]	25
Clinical sector	[10,61,62]	3
Entertainment sector	[63,64]	2
Other occupational sectors	[65,66]	2

The second area of interest regarded the aims of each article. According to the results of this study it was found that the main aims are described in Table 2 and concerned: (i) noise perception, (ii) noise measurements, (iii) individuals' perceptions on vocal habits and voice, and (iv) vocal measurements.

Table 2. Research aims.

Reference article	Noise Perception	Noise Measurements	Individuals' perceptions on vocal habits and voice	Vocal measurements
[10]	✔		✔	
[36]		✔	✔	✔
[37]	✔	✔		✔
[38]	✔	✔		✔
[39]	✔		✔	
[40]	✔		✔	
[41]		✔	✔	✔
[42]		✔	✔	✔
[43]		✔	✔	✔
[44]	✔		✔	✔
[45]	✔	✔	✔	
[46]	✔	✔	✔	
[47]		✔	✔	✔
[48]	✔	✔	✔	
[49]	✔	✔	✔	
[50]	✔	✔	✔	
[51]	✔		✔	
[52]	✔	✔	✔	✔
[53]	✔	✔		✔
[54]		✔	✔	✔
[55]	✔		✔	✔
[56]	✔		✔	
[57]	✔		✔	✔

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Reference article	Noise Perception	Noise Measurements	Individuals' perceptions on vocal habits and voice	Vocal measurements
[58]	✔		✔	✔
[59]	✔		✔	
[60]		✔		✔
[61]	✔		✔	✔
[62]	✔	✔	✔	✔
[63]	✔	✔		✔
[64]	✔		✔	✔
[65]		✔	✔	✔
[66]		✔	✔	✔

An important issue to outline in this systematic review was the research methods used in the included articles. Table 3 summarizes the data collection tools used in each study and described in materials and methods section. Precisely, 25 of them used questionnaires, 6 took interviews, 6 involved clinical examination. Finally, voice recordings were included in 17 articles, lab simulation of noise recordings were used in 2 articles, and environmental noise level measurements were taken in 19 articles.

Table 3. Data collection tools used in current literature.

Data collection tool	Articles	N
Questionnaires	[10,36,39–49,49–52,55–58,61,62,64–66]	25
Interview	[43,45,52,58,61,62]	6
Clinical examination	[41,43,45,61,62,64]	6
Voice recording	[36–38,41–44,52,53,55,57,58,60–64]	17
Lab simulation of noise recordings	[36,62]	2
Environmental noise level measurement	[37,38,41–43,45–50,52–54,60,62,63,65,66]	19

Finally, a total report of this systematic review, presenting quantitative and qualitative elements of each article. Exactly, data referring on sample, aim, method and results according to authors is shown in Table 4.

Table 4. Each study's sample, aim, method and results.

Study	Sample	Aim	Method	Results
[10]	205 patients with exudative lesions of Reinke's space.	The aim was to compare socio-demographic characteristics of vocal fold nodules, polyps and oedema	Self-administered questionnaire	Nodules and oedema were more frequent in women than men in comparison with polyps Patients with nodules and polyps were younger than those with oedema. Patients with nodules were more frequently lecturers, singers and actors compared with polyp patients had occupational voice demands more frequently than patients with oedema and were less frequently smokers than patients with polyps and those with oedema Patients with oedema were more frequently current smokers than patients with nodules and those with polyps. Hoarseness as the main symptom was more frequent among patients with nodules than among patients with polyps and those with oedema. Voice problems in the family was more frequently reported by oedema patients than by patients with polyps.
[36]	23 healthy teachers & university students [M:11 (1 preschool teacher; 5 university teachers; 5 university students), F:12 (10 preschool teachers; 2 university teachers)]	To investigate loud and very loud voice production in healthy adults. To elicit loud voices, the subjects were asked to make themselves heard over a realistic background noise.	Subjects read a text in 5 conditions: quiet, soft continuous noise (75 dBA to 70 dBA), day-care babble (74 dBA), disco (87 dBA), and loud continuous noise (78 dBA to 85 dBA). The noise was presented over loudspeakers and then removed from the recordings in an off-line processing operation. The voice signals were analyzed acoustically with an automatic phonetograph and perceptually by four expert listeners. Subjective data were collected after each vocal loading task.	The perceptual parameters press, instability, and roughness increased significantly as an effect of speaking loudly over noise, whereas vocal fry decreased. Having to make oneself heard over noise resulted in higher SPL and F0, as expected, and in higher phonation time. The total reading time was slightly longer in continuous noise than in intermittent noise. The women had 4 dB lower voice SPL overall and increased their phonation time more in noise than did the men. Subjectively, women reported less success making themselves heard and higher effort. The results support the contention that female voices are more vulnerable to vocal loading in background noise.
[37]	66 teachers (F:66) (Age: 40–64) [35: occupational voice pathologies 31: functional dysphonia]	To assess the results of acoustic analysis	acoustic analysis via IRIS software before and after 30-minute vocal loading test	There was statistical significant differences at F0, shimmer & NHR. IRIS is useful at vocal examinations, especially in occupational dysphonia.
[38]	62 teachers and 464 pupils	To evaluate the acoustical quality of classrooms in Brazilian public schools	The tools used were (i) sound analyzer BK 2260, (ii) sound amplifier 2271, (iii) sound source, (iv) building acoustic software BZ 7204, (v) building acoustic software Qualifier 7830, and (vi) sound level meter Mediator BK 2238. All measurements were carried out under ideal meteorological conditions: no wind and no rain	Results have shown that teachers and pupils consider the noise generated and the voice of the teacher in neighboring classrooms as the main sources of annoyance inside the classroom. Acoustic simulations resulted in the suggestion of placement of perforated plywood on the ceiling, for reduction in reverberation time and increase in the acoustic comfort of the classrooms.

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Study	Sample	Aim	Method	Results
[39]	282 teachers (M:82, F:200); Kindergarten:120	To analyze the links between teachers' voice disorders and other collateral problems which are frequently associated	Participants answered questionnaires assessing (a) voice disorders prevalence and characteristics—Occupational Voice Profile; (b) psychosocial dimensions of employment—Copenhagen Psychosocial Questionnaire; and (c) voice-related quality of life—Voice Activity and Participation Profile	1. 26.4% of the teachers reported noise levels as low, 51.4% as moderate, and 22.2% as high 2. 62.7% teachers were currently experiencing voice disorders, whereas 37.3% subjects did not refer either vocal effort or voice complaints Voice problems resulted more prevalent among female subjects and kindergarten. Noise levels were related to teachers' voice disorders independently of gender and age. Regarding the possible consequences of vocal problems, 3 categories of collateral factors were found associated to teachers' voice disorders: - physiological, socioeconomic, and psychosocial conditions of work. This study's data indicated the importance of facing teachers' voice problems from interdisciplinary and multidimensional perspectives. Preventive and assistive measures should include vocal hygiene information and vocal technique training, together with stress coping strategies and improvement of environmental factors such as acoustics. As far as health is considered a multidimensional system resulting from physical, mental and social facets of life, it should be advocated that the multifactor variety of risk factors involved in teachers' work are included in the treatment and prevention of teachers' occupational voice disorders. It is also necessary to improve teachers' preventive culture and their self-consciousness about vocal problems so that they start considering their vocal health a preventive objective, instead of assuming voice disorders as inevitable consequences of their job or eventual diseases to be treated. Teachers should learn to manage both stress and vocal technique at an efficient level to avoid overactivation, exhaustion or phonasthenia.
[40]	467 teachers (M:131, F:336)	(1) Teachers' perceptions on workplace factors that affect vocal behavior (2) The prevalence of voice problems among Swedish teachers	Cross-sectional cohort study. Self-report questionnaires about teachers' perceptions on working environments' factors that affect vocal behavior.	13% of teachers declared that they had voice problem emerged often, sometimes or always. Teachers with vocal issues considered room acoustics as an important factor, more than non-vocal problems group. It is necessary for teachers to receive vocal training.
[41]	40 teachers (M:8, F:32)	To study the association between ergonomic factors in classrooms with teachers' voice parameters	The authors used the Voice Ergonomic Assessment in Work Environment—Handbook and Checklist before and after the working day. F0, SPL, Alpha ratio, were analyzed.	The higher the number of the risk factors in the classrooms, the higher SPL the teachers used and the more strained the males' voices (increased alpha ratio) were. The SPL was already higher before the working day in the teachers with higher risk than in those with lower risk.

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Study	Sample	Aim	Method	Results
[42]	28 teachers from three preschool institutions, São Paulo	To analyze the association between noise levels present in preschool institutions and vocal disorders among educators.	Sound pressure levels were measured according to Brazilian Technical Standards Association, with the use of a sound level meter. The educators underwent voice evaluation: self-assessment with visual analogue scale, auditory perceptual evaluation using the GRBAS scale, and acoustic analysis utilizing the Praat program.	The noise average was 72.7 dB, considered as damage 2. The professionals' vocal self-assessment ranked an average of 5.1 on the scale, being considered as moderate alteration. In the auditory-perceptual assessment, 74% presented vocal alteration, especially hoarseness; of these, 52% were considered mild alterations. In the acoustic assessment the majority presented fundamental frequency below the expected level. Averages for jitter, shimmer and harmonic-noise ratio showed alterations. An association between the presence of noise between the harmonics and vocal disorders was observed.
[43]	11 female university students Age: 21–25	This investigation compared voice performance of student teachers across an academic semester in order to examine the effect of increasing demands on their voice	A repeated measures design was applied to the data analysis: all participants were tested three separate times throughout the semester. The equipment used was Ambulatory Phonation Monitor (APM), the Computerized Speech Lab (CSL), and the Phonatory Aerodynamic System (PAS), Additionally, participants completed surveys related to voice usage.	most voice parameters of student teachers measured in a natural setting and in a controlled environment indicated changes that revealed progressive instability and noise in the course of an academic semester. Additional comparisons demonstrated differences between voice usage in the school environment and voice produced in the voice lab. Self-reported information demonstrated overall reduced awareness regarding preventive methods for voice disorders.
[44]	14 Teachers with self-estimated voice problems (VP) (M:2, F:12) age & gender matched to 14 voice healthy (VH) teachers	The aim was to examine if teachers with voice problems and without voice problems use their voice differently, regarding F0, sound pressure level (SPL), and in relation to the background noise	The fundamental frequency, SPL, and phonation time were recorded with an Ambulatory Phonation Monitor during one representative workday. The teachers reported their activities in a structured diary. The SPL (including teachers' and students' activity and ambient noise) was recorded with a sound level meter; the room temperature and air quality were measured simultaneously. The acoustic properties of the empty classrooms were measured	Teachers with VP behaved vocally different from their VH peers, in particular during teaching sessions. The phonation time was significantly higher in the group with VP, and the number of vibratory cycles differed between the female teachers. The F0 pattern, related to the vocal SPL and room acoustics, differed between the groups.
[45]	35 teachers during actual classroom teaching	The aims were to investigate if noise posed a risk of impairment of hearing and to study the association between classroom acoustical conditions, noise exposure, vocal symptoms, and cognitive fatigue.	Background noise levels, vocal load and speaking time were measured. The classrooms were characterized acoustically by measurements of reverberation time. Before and after the workday, the teachers answered a questionnaire on fatigue symptoms and carried out two cognitive test tasks sensitive to mental fatigue.	The average noise level during the lessons was 72 dB(A), but during indoor sports activities the average noise level increased 6.6 dB(A). Room reverberation time (range 0.39–0.83 s) had no significant effect on the noise level. The teachers were talking with a raised voice in 61 % of the time, and the vocal load increased 0.65 dB(A) per dB(A) increase in the average lesson noise level. An increase in voice symptoms during the workday correlated significantly with individual average noise exposure, and a decrease in performance in the two-back test correlated significantly with individual average vocal load.

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Study	Sample	Aim	Method	Results
[46]	Initially 1449 teachers, and 143 non-teachers. Finally included 621 teachers (M:177, F:444) And 61 non-teachers (M:27, F:34) from 12 public schools Bogotá, Colombia	A need for observational studies that investigate associations of objective measurements of physical conditions in the classroom with the presence of voice symptoms among teachers.	The questionnaire was designed to collected information on individual characteristics, voice functioning, lifestyle habits, work-related conditions, and health conditions possibly related to voice disorders. In addition, short-term objective measurements of physical conditions at the workplace were conducted.	The univariate analyses of potential risk factors for voice symptoms showed that objectively measured noise outside the school and self-reported high noise levels and poor acoustics in the workplaces were strongly associated with the presence of voice symptoms. The multivariate analysis showed that only objectively measured high noise levels in the surroundings of school and self-reported poor acoustics remained associated with voice symptoms. In the current study, it was not possible to disentangle completely the relative importance of acoustics and noise in schools since both factors were interrelated. However, the multivariate analysis suggests that voice symptoms were stronger associated with poor acoustics than with noise.
[47]	40 teachers	Research associations between classroom acoustic parameters and teachers' voice use and vocal health	Voice samples, sound pressure level (SPL), fundamental frequency (F0), and the tilt of spectrum slope were analyzed. Information on voice symptoms was collected by means of questionnaires. Room acoustic variables were reverberation times (T60, EDT), sound attenuation (DL2) and parameters measuring how well speech is perceived (C50, D50, STI). The associations between the variables were studied for the whole group and separately for quiet and noisy classrooms.	The results showed that all the room acoustic variables measured correlated with a teacher's voice variables. Voice SPL was influential especially in the noisy classrooms and F0 in the quiet classes. A teacher's vocal health was poorer if the room acoustic variables indicated better listening conditions. The findings suggest that good listening conditions do not necessarily imply good speaking conditions in classrooms.
[48]	682 school workers (621 teachers, 61 nonteachers)	To determine the natural course of voice complaints among school workers and established the risk factors associated with incidence and chronic voice complaints	Questionnaire on individual and work-related conditions and the nature and severity of voice complaints. If still working in the school →11-month follow-up. Short-term environmental measurements of physical work-related factors were performed. Logistic regression analysis determined associations between work-related factors and voice complaints.	This longitudinal study among school workers presented some indications that self-reported high noise levels may contribute to the incidence of voice complaints, whereas self-reported poor acoustic conditions may be an important associated factor of chronic voice complaints.
[49]	102 teachers in 2 schools (A and B)	To investigate whether acoustical refurbishment of classrooms for elementary and lower secondary grade pupils affected teachers' perceived noise exposure during teaching and noise-related health symptoms.	Control measurements of RT and activity sound levels were measured before and after refurbishment. Data on perceived noise exposure, disturbance attributed to different noise sources, voice symptoms, and fatigue after work were collected over a year in a total of six consecutive questionnaires.	Refurbished classrooms were associated with lower perceived noise exposure and lower ratings of disturbance attributed to noise from equipment in the class compared with unrefurbished classrooms. Before acoustical refurbishment, the mean classroom reverberation time was 0.68 (school A) and 0.57 (school B) and 0.55 s in sham refurbished classrooms. After refurbishment, the RT was approximately 0.4 s in both schools. Activity sound level measurements confirmed that the intervention had reduced the equivalent sound levels during lessons with circa 2 dB(A) in both schools.

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Study	Sample	Aim	Method	Results
[50]	250 teachers (M:0, F:250)	The aim of this study was to evaluate the exposure to noise levels in classrooms using a digital sound level meter.	Questionnaires and noise level measurements.	It is crucial to reconsider the noise pollution in classrooms. Bigger classrooms and wider yards should be adopted while building new schools. Also, schools should be built in distances from noise sources.
[51]	140 teachers (M:55, F:85) from 4 schools chosen randomly in Upper Egypt	This study aimed to assess teachers' voice symptoms and noise in schools in Upper Egypt and to study possible differences between teachers in public and private schools.	They answered a questionnaire on vocal and throat symptoms and their effects on working and social activities, as well as levels and effects of experienced noise.	Of all teachers, 47.9% reported moderate or severe dysphonia within the last 6 months, and 21.4% reported daily dysphonia. All teachers reported frequent feelings of being in noise, with 82.2% feeling it sometimes or always during the working day, resulting in a need to raise their voice. Teachers in public schools experienced more noise from nearby classes.
[52]	voice monitoring of 27 teachers for four working days	Aimed to determine the changes in self-reported voice and noise condition over a follow-up of 4 days (equivalent to one working week), to define the relationship between the objective voice parameters and the self-reported voice condition, as well as to characterize the relationship between classroom acoustics and the self-reported noise condition.	The Voice-Care device, which provides information on the fundamental frequency, vocal sound pressure level, and phonation time percentage. The participants performed a pre-monitoring, which consisted of a brief conversation, before each monitoring session, and filled in a questionnaire after each monitored lesson, in which they indicated their opinions about their voice condition and the classroom noise conditions.	The teachers who, during the pre-monitoring, showed a higher standard deviation of the vocal sound pressure level and a greater phonation time percentage difference between the entire monitoring and the pre-monitoring sessions, reported fewer voice complaints. Decay time (DT40ME), a reverberation measure from the speakers' perspective, resulted to be associated with the self-reporting of the noise condition.
[53]	24 female elementary school teachers	How teachers' voices behave during the delivery of lessons in core subjects. We sought to evaluate the relationship between voice sound pressure level (SPL), vocal fundamental frequency (F0), voice symptoms, activity noise, and differences therein during the first and the last lessons in core subjects of the day	Voice symptoms were evaluated by questionnaire. The data were recorded on 2 portable voice accumulators (VoxLog) from the first and last lessons of the day. The versions of accumulators differed by frequency weighting; therefore, the analysis and the results of noise and voice SPL were treated separately: unweighted (group 1) and A-weighted (group 2)	Difference in voice SPL followed difference in activity noise. F0 increased between the first and last lessons. Correlations were found between differences in the noise and the voice symptoms of tiredness and dryness. Irritating mucus was associated with high F0 during the first lesson.
[54]	40 college students (M:18, F:22) Age: 20–25 Condition: (mean = 22; SE = 0.2) monolingual native speakers of American English	Two aims: (1) determine the occurrence of perceptually identified vocal fry, and (2) identify individual and environmental factors associated with vocal fry	Participants produced speech under 9 different room acoustic conditions (simulated). The recorded speech was perceptually evaluated by three speech-language pathologists. Multivariate logistic regression analysis was used to identify variables (individual, environmental) associated with the perceptual assessment of vocal fry.	Fry-like phonation seems to be influenced by individual and environmental factors. Therefore, clinicians may take particular note of the caffeine consumption and the background noise conditions of the room.

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Study	Sample	Aim	Method	Results
[55]	University teachers (M:0, F:27) Age: 22–50 Condition: no vocal complaints	The objective of this study was to evaluate if noise interferes with the vocal dose in women without vocal complaints.	Speech-language pathology evaluation was performed employing auditory-perceptual analysis and a vocal symptom questionnaire. The acoustics of the classroom were evaluated via both observation of the characteristics of the room and the quantification of background noise and reverberation time. Two distinctive acoustic conditions were created for evaluations: condition 1, a room without acoustic treatment and without noise reproduction, and condition 2, a room without acoustic treatment with noise reproduction.	Fundamental frequency, vocal intensity, percentage of phonation, and cycle dose significantly increased in the background noise condition.
[56]	140 teachers Age: 21–56	To identify associations between teachers' voice symptoms and their perception of noise, the location of schools, as well as the location and conditions of their classrooms.	They filled out a questionnaire including questions about the severity and frequency of their voice symptoms, noise perception, and the location and conditions of their schools and classrooms. Questionnaire responses were statistically analyzed to identify possible correlations.	There were significant correlations ($P < 0.05$) between voice symptoms, teachers' noise perception, and noise resulting from the location and conditions of schools and classrooms. Teachers experienced severe dysphonia, neck pain, and increased vocal effort with weekly or daily recurrence. Among the teachers who participated in the study, 24.2% felt they were always in a noisy environment, with 51.4% of the total participants reporting having to raise their voices. The most common sources of noise were from student activities and talking in the teachers' own classrooms (61.4%), noise from adjacent classrooms (52.9%), and road traffic (40.7%).
[57]	23 primary-school teachers	This study investigated the relationship between teachers' well-being and classroom acoustics.	Questionnaires on well-being. In each teacher's classroom, the acoustical properties were measured with the variables reverberation time, clarity of speech (C50) and ventilation system noise (VSN).	There was a significant bivariate correlation between burnout and VSN, as well as voice symptoms correlated with VSN and teaching grade. Although the results became not significant after correction for multiple tests, the findings indicate that higher degree of burnout is associated with higher levels of VSN in classrooms, and voice symptoms increase with higher VSN. Teachers working in lower grades had more voice symptoms than those working in higher grades.

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Study	Sample	Aim	Method	Results
[58]	183 healthy Finnish teachers (99 kindergarten teachers [KT] and 84 primary school teachers [PST]	This study investigated the relationship between the acoustic measure smoothed cepstral peak prominence (CPPS), teacher's quality of life as measured by the voice activity and participation profile (VAPP), laryngeal signs and symptoms, voice related health problems and laryngoscopic findings.	Vowel and text samples were analyzed for CPPS. Text reading was recorded in conversational loudness by PST, and KT were recorded wearing headphones, while listening to a masking noise of children talking to simulate their classroom voice and environment. CPPS values were correlated with the VAPP, self-reported laryngeal signs and symptoms, voice related health variables, and laryngoscopic findings	There was a significant difference between the two groups for CPPS text, PST showed significantly lower CPPS values (10.44) than KT (11.52). There was a significant correlation between SPL text and CPPS text for KT ($P < 0.001$, $r = 0.43$) but not for PST ($P < 0.10$, $r = 0.16$). There was a significant correlation between SPL vowel and CPPS vowel for both PST ($P < 0.001$, $r = 0.47$) and KT ($P < 0.001$, $r = 0.45$). CPPS did not correlate with the VAPP, laryngeal signs and symptoms, health variables or laryngeal findings. Factorial analysis of variance resulted in a significant relationship between the VAPP, laryngeal signs and symptoms, and teacher type. Teacher type and symptoms had a significant effect on VAPP scores.
[59]	6,324 teachers working in Basic Education	To analyze the limitation at work because of the voice and to examine possible associations with sociodemographic characteristics, life and health habits and work conditions among Basic Education teachers in Brazil.	Data collection was carried out through the application of a questionnaire via telephone with questions regarding health and working conditions. The "limitation at work because of the voice" was considered a dependent variable, whose response options were a scale with four Likert items that varied from frequently to never. The independent variables were grouped in blocks for ordinal logistic regression analysis with hierarchical entry. The magnitude of the association was assessed by the Odds Ratio (OR) with the respective confidence intervals (95% CI).	Factors associated with an increase in the chance of higher frequency of reporting work limitations due to the voice: being female, lack of physical activity, losing sleep due to concern, using anxiolytic or antidepressant medication, school location in the North and Northeast, teaching for the elementary school stage, high noise at school and psychosocial aspects of work organization. The Brazilian educational sector needs public policies that take into account regional inequalities and the health and work conditions of teachers.
[60]	23 primary and secondary school female teachers	To measure the risk of dysphonia in teachers, as well as investigate whether perceptual-auditory and acoustic aspects of the voice of teachers in situations of silence and noise, the signal-to-noise ratio, and the noise levels in the classroom are associated with the presence of dysphonia.	To observe teachers with and without dysphonia performing the following procedures: 1. general Dysphonia Risk Screening Protocol (General-DRSP) 2. complementary to speaking voice – teacher (Specific-DRSP) 3. voice recording during class and in an individual situation in a silent room measurement of the signal-to-noise ratio and noise levels of classrooms.	The findings concerned differences between groups regarding physical activity (General-DRSP) and particularities of the profession (Specific-DRSP), as well as in all aspects of the perceptual auditory vocal analysis. Also, signs of voice wear in the group without dysphonia were found. Regarding the vocal resources in the situations of noise and silence, a difference for the production of abrupt vocal attack and the tendency of a more precise speech in the situation of noise have been identified. Both the signal-to-noise ratio and the room noise levels during class were high in both groups.

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Study	Sample	Aim	Method	Results
[61]	33 participants with Parkinson's disease (PD)	To investigate whether speakers with hypophonia, secondary to PD, would increases their vocal intensity when speaking in a noisy environment. To examine the underlying laryngeal and respiratory strategies used to increase vocal intensity	Each participant was fitted with the SpeechViveTM device that played multi-talker babble noise into one ear during speech. Using acoustic, aerodynamic and respiratory kinematic techniques, the simultaneous laryngeal and respiratory mechanisms used to regulate vocal intensity were examined.	Most speakers with PD (26/33) were successful at increasing their vocal intensity when speaking in the condition of multitalker babble noise. They were able to support their increased vocal intensity and subglottal pressure with combined strategies from both the laryngeal and respiratory mechanisms. Individual speaker analysis indicated that the particular laryngeal and respiratory interactions differed among speakers.
[62]	10 females with phonasthenia 10 females with vocal nodules 20 vocally healthy female colleagues	To assess vocal behavior in women with voice-intensive occupations to investigate differences between patients and controls and between work and leisure conditions with environmental noise level as an experimental factor.	-Laryngeal examination -Interview -Questionnaires -Voice recordings -Field recordings	High–environmental noise levels and occupational voice demands impact the vocal behavior more than individual factors. Reducing background and activity noise levels is important in workplaces. Ergonomic factors should be assessed at work environments.
[63]	18 adults (M:4, F:14)	This study describes the vocal fold structure and function of a select group of vocal performers placed in a high-risk environmental condition.	Acoustical field measurements were conducted at the theme parks using a Quest Acoustic, measures were made using the MDVP	Results of the analysis suggest that high-risk performers are a unique performance type defined by distinctive, acoustic, laryngostroboscopic, and environmental characteristics.
[64]	27 undergraduate female students participated, age range of 18−27 years	Aimed to study the effect of a vocally demanding situation (college Fest) on perceptual and objective voice features of college students.	Pre-test—post-test research design was applied. Data analysis consisted of video stroboscopic examination, acoustic analysis using the Multi-dimensional voice program (MDVP), and perceptual evaluation with the GRBAS scale.	Incomplete glottis closure, asymmetric vibration of vocal folds, and aperiodicity of vocal folds increased significantly postcollege Fest. GRBAS parameters also showed a change from pre Fest scores on grade (hoarseness) increased by 38%, breathiness in 34%, roughness in 26%, Asthenia in 15%, and strain increased in 38% participants.

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Study	Sample	Aim	Method	Results
[65]	32 customer-service advisors, who mainly use telephone during their working hours (M:8, F:24)	To investigate how different acoustic parameters, extracted both from speech pressure waveforms and glottal flows, can be used in measuring vocal loading in modern working environments and how these parameters reflect the possible changes in the vocal function during a working day. In addition, correlations between objective acoustic parameters and subjective voice symptoms were addressed.	Speech samples were recorded from continuous speech four times during a working day and voice symptom questionnaires were completed simultaneously	The result for both genders was that, among the various objective parameters, only F0 showed any statistically significant change. In the present study, F0 and SPL levels of the CSA were much lower than those reported for teachers. The main reason for this is obvious: the background noise level was low despite the fact that the working space was an open-plan office. The findings of the phoniatric examination also indicate that the vocal loading on the subjects could not cause organic changes. Background noise level in the CSA's office was lower than the working environment of teachers in kindergartens and elementary schools, who are known to be the group of employees with the most voice problems. The results of the present study showed that all three voice symptoms (vocal fatigue, hoarseness, and sum-variable) yielded a statistically significant increase during the working day in females, while hoarseness reached a statistically significant increase in males. However, the correlation between the first and last times of the working day did not show a significant result. No correlations between objective and subjective measurements were found. Noninvasive measurement of glottal activity in realistic work environments is not possible with any technique other than IF based on pressure signal. The present study achieved encouraging results in showing that a semiautomatic IF method gives reliable estimates of the glottal flow for this purpose.
[66]	Call center operators (CCOs: 27; M:7, F:20) and age- and gender-matched students (n:25); (M:6, F:19)	To examine voice changes in real speaking situations during a single day, with and without vocal loading, aiming to identify an objective acoustic index for vocal load over a day.	Participants were recorded at the beginning and at the end of a day, with (CCOs) and without (students) vocal load. Speaking and reading voice samples were analyzed for fundamental frequency (F0), sound pressure level (SPL), and their variance (F0 coefficient of variation [F0 CV], SPL CV). The impact of lifestyle habits on voice changes was also estimated.	The main findings revealed an interaction, with F0 rise at the end of the day for the students but not for the CCOs. It was suggested that F0 rise is a typical phenomenon of a day of normal vocal use, whereas vocal loading interferes with this mechanism. In addition, different lifestyle profiles of CCOs and controls were observed, as the CCOs reported higher incidence of dehydrating behaviors (eg, smoking, caffeine). Yet, this profile was not linked with voice changes. In sum, it was suggested that F0 rise over a day can potentially serve as an index for typical voice use. Its lack thereof can hint on consequent voice symptoms and complaints.

4. Discussion

This study focused on the effects of noise pollution on vocal behavior. Through systematic search in Google Scholar and Pubmed databases, and screening procedures according to the inclusion criteria, 32 articles were included for this systematic review. Aiming at noise perception, noise measurement, vocal measurement and individuals' perception on voice, the studies involved in this review used qualitative (questionnaires, interview, readings, laryngeal examination) and quantitative (voice recordings, environmental noise measurements) parameters in their methodology. Based on the results of the study presented previously, the research questions are discussed next.

The results of this study revealed that the current literature focused mainly on the educational sector, as it has been highlighted that teaching is one of the most vocally demanding profession and has been exposed to noise pollution [36–60,65,66]. To answer Q1, regarding the activity sectors reported in noise pollution exposure in association with voice problems, emphasis has been put on the educational sector while less emphasis has been devoted to the clinical, entertainment, and other occupational sectors.

In relation to Q2, the results of the study indicated that all included studies came to the agreement that noise pollution influence vocal behavior. This is because acoustic conditions resulted in vocal alterations as average noise exposure level exceeded the allowable limits confirming the high prevalence of Lombart effect [1] in noisy working environments. Precisely [43,55,60–63], as occupational vocal users are forced to use their voice excessively in loud intensities and for long durations they are considered at risk for the development of dysphonia. Numerous symptoms can be triggered [50,54], such as vocal cord problems, hoarseness, vocal strain and vocal fry, possibly along with headache, fatigue, sleep disturbances, ear discomfort. As behavioral factors interact with voice discomfort [10,40,42,51,53,60,62,64] breathiness, roughness, asthenia, dryness, vocal pain, dysphonia, and irritating mucus may also appear. In addition to noise exposure certain lifestyle habits, such as (i) smoking, that has been stated to relate to voice problems, as smokers appeared to develop more frequently vocal polyps and oedema than other vocal cord hazards [10] and (ii) caffeine consumption, that has been remained associated with perceptually identified vocal fry [54]. Objective examinations [10,50,53] reported on clinical examinations and measurements. Clinical examinations disclosed severe voice problems, and confirmed emerging nodules, polyps, and oedema in vocal cords. In the same lines, measurements presented deviations from normal in fundamental frequency, jitter and shimmer, SPL, NHR. Besides, environmental acoustic measurements indicated that ergonomic characteristics in (neighboring) classroom settings were the main source of annoyance minimizing their acoustic quality. Summing up for Q2, noise pollution influences negatively vocal behavior pinpointing [10,61–66]: (i) noise interference in all daily activities, (ii) behavioral habits as additional factors to vocal lesions, and (iii) the need to enhance voice intensity in pathological groups due to noise loading.

Regarding Q3, specific populations reported in this study present voice problems due to noise pollution. These populations concerned mainly occupational voice users, such as teacher across all educational levels, university students, call center operators, as well as pathological groups (PD patients, educators with voice pathologies). As most of the studies involve teachers, there is sparse data on other professional voice user populations. Moreover, females and younger adult populations have been reported to develop voice pathologies. Bearing in mind the anatomical differentiations between genders, and that the majority of teachers are females, women are notably more susceptible to nodules and oedema than men, while younger people suffer from nodules and polyps more often than older ones [10,40]. It was also reported that teachers working in lower grades had more voice symptoms than those working in higher grades [57].

With reference to Q4, some evidence of suggestions was reported for preventing voice disorders due to noise pollution. The placement of perforated plywood on the ceiling was proposed, for reduction in reverberation time and increase in the acoustic comfort of the classrooms [38]. However, it was also

[1] When producing speech in noisy backgrounds talkers reflexively adapt their speaking style in ways that increase speech-in-noise intelligibility. This adaptation is known as the Lombard effect [67].

argued that acoustical refurbishment did not affect voice symptoms [49]. Further, the significance of facing teachers' voice problems from interdisciplinary and multidimensional perspectives was outlined [39]. Precisely, teachers' self-consciousness about vocal problems, vocal hygiene knowledge and vocal technique training, together with stress management and improvement of environmental factors may help to prevent occupational voice disorders.

This systematic review has also revealed opportunities for possible future research. First and foremost, the Educational sector has been mainly focused studying the Lombart effect. Consequently, there is little evidence on other non-educational professional voice users. Secondly, apart from a few existing studies, the sample size used is insufficient. Thirdly, the lack of comparison groups in most studies should be considered for future research. Future studies may focus to get more insights on large and various populations, their work-related determinants, occupational performance and consequences and prevention of the development of voice disorders in line with current trends.

5. Conclusions

A systematic review on noise pollution and voice problems has revealed an emphasis on the current literature for the educational profession. The results of this study revealed that current literature comes to the agreement that exposure to occupational noise pollution, as well as occupational voice demands lead to voice problems. The accumulative effect of vocally abusive behaviors in the presence of high ambient noise, poor vocal hygiene, and other environmental factors may contribute significantly towards reducing vocal effectiveness and affecting several systems in human health. Finally, this review reveals that noise exposure has become an important factor in determining vocal health and quality of life.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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