Can teaching simulations in a virtual classroom help trainee teachers to develop oral communication skills and self-efficacy? A randomized controlled trial.

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Abstract

Effective oral communication skills are essential to ensure optimal teaching while preserving the teacher's vocal health. Training these skills in representative settings is expected to promote their generalization. Since the implementation of such training in actual school situations is challenging, virtual reality (VR) may represent a solution. This study evaluated the effects of VR simulations on trainee teachers' oral communication skills. Based on our Theoretical Framework for Teachers' Vocal Behavior, we developed and empirically assessed a voice-related prevention program including noisy communicative situations in a virtual classroom.

In a randomized controlled trial, the participants were assigned to one of two conditions: (1) individual voice training including simulations in the virtual classroom and a group information session (experimental group, n=21); and (2) a group information session only (control group, n=20). The purpose was to determine whether the experimental group would exhibit greater changes in communication skills and self-efficacy than the control group. Acoustic measures during speech production in noise (speech rate; spectral slope; phonetographic surface) and self-rated measures (vocal effort; communication self-efficacy in noise) were conducted pre- and post-intervention.

Results indicated a positive effect of the intervention on phonetographic surface, vocal effort, and self-efficacy in both groups. The self-efficacy of the experimental group improved more than for the control group, illustrating the benefit of training sessions including simulations of communicative situations in noise and immersions in a virtual classroom. These findings suggest that practicing oral communication skills in situations as close as possible to their professional reality – by using VR – can improve (trainee) teachers' belief in their ability to implement these skills in real-life situations.

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1. Introduction

1.1.Background

Oral communication is the process of verbally transmitting information and ideas from sender to receiver. According to the Oracy Skills Framework (Mercer et al., 2017), the skill dimensions involved in the effective use of spoken language fall under four areas (physical; linguistic; cognitive; social and emotional). Our research focuses on the physical category, which includes voice and body language.

At school, oral communication is predominant and the voice is its physical support. Teachers' voices are tools that enable them to (1) attract pupils' attention in order to convey pedagogical content to them, and (2) manage school situations in terms of organization and discipline. Teachers work in a profession that has a higher incidence and increased risk of voice disorders than others (Cantor Cutiva et al., 2013; Epstein et al., 2011; Martins et al., 2014; Phyland & Miles, 2019). More than half of all teachers experience a voice disorder at some point in their lifetime (Cantor Cutiva et al., 2013). Voice problems may develop from excessive or inappropriate vocal patterns (Martins et al., 2014), which may lead to phonotraumatic vocal hyperfunction (e.g., nodules or polyps) or nonphonotraumatic vocal hyperfunction (e.g., muscle tension dysphonia) (Hillman et al., 2020). Several work-related and individual factors increase the risk of teachers' voice disorders, such as high levels of noise in classrooms (Cantor Cutiva et al., 2013), being a woman, teaching at the kindergarten and elementary levels, and engaging in additional nonoccupational voice activities (Remacle & Lefèvre, 2021).

The consequences of voice disorders for teachers range from deterioration of the voice quality to a complete inability to speak, accompanied by pain, fatigue or effort during phonation. The inability to teach, the need to replace absent teachers, and the expenses related to treatment result in a considerable psychosocial and economic burden (Phyland & Miles, 2019). For

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teachers, voice problems represent a real disability: they affect their quality of life, well-being and work performance (Martins et al., 2014). Alarmingly, a meta-analysis indicates that children have more trouble perceiving speech, processing verbal messages, and recalling verbal information when listening to a dysphonic teacher, especially in noisy environments (Schiller et al., 2022). This may impede pupils' motivation and academic performance at school.

To sum up, optimal oral communication skills are essential to ensure effective teaching while preserving the teacher's vocal health. According to Mercer et al. (2017), skills involved in the effective use of spoken language should be explicitly taught in an educational context. Training of vocal behaviors in representative settings is essential for their generalization in everyday communication situations. However, in Belgium, as in many other countries, the initial training of schoolteachers essentially targets knowledge and practical and organizational expectations (Parlement de la Communauté française, 2019) but does not specifically address oral communication skills required in the profession. This represents a serious gap in teachers' education. Training these skills in actual school situations is particularly challenging for ethical and logistical reasons (i.e., need to practice in front of pupils with various behaviors in noisy classrooms). One training solution could involve the use of virtual reality (VR) to simulate environmental and communicative situations that are representative of actual teaching conditions. This study explores the effect of teaching simulations in a virtual classroom on trainee teachers' oral communication skills, and particularly vocal behaviors. The approach was to first devise an overarching framework for the design of a voice-related prevention program for teachers (see section 1.2.) and then test the program's effects. A randomized controlled trial including trainee teachers compared a control group (see section 2.6.1.) to an experimental group who received the program and immersion in a virtual classroom (see section 2.6.2.).

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1.2.Theoretical Framework for Teachers' Vocal Behavior

As a reference point to guide oral communication- and particularly voice-related interventions, we developed a Theoretical Framework for Teachers' Vocal Behavior (see Figure 1). This framework draws on principles of vocology (i.e., vocal behavior, vocal health), acoustics (i.e., background noise), pedagogy (i.e., teachers and students' behavior), and psychology (i.e., self-efficacy). An innovative feature of the framework is its reliance on ecological models of health behaviors, which focus on the nature of individuals' interactions with their physical (e.g., a noisy classroom) and sociocultural environments (e.g., distracted and restless pupils) (Sallis & Owen, 2015). In Figure 1, the arrows depict the interactions between the teacher's vocal behavior (in the central box) and four different areas (in the peripheral gray boxes). In this ecological approach, background noise level and students' behavior pertain to the physical and sociocultural environment, while teachers' vocal health is related to individual physical features. The framework also includes a specific individual psychological feature: teachers' oral communication self-efficacy. Self-efficacy, defined as one's belief in one's ability to organize and execute a specific behavior successfully (Bandura, 1997), has been applied in different fields, including teaching (Barni et al., 2019) and voice (Dacakis et al., in press). Self-efficacy has long been identified as a key predictor of the adoption of health-related behaviors and engagement in healthy habits in general (Bandura, 1997; Leman et al., 2021) and among professionals in allied health sectors (Love et al., 2017; Mäkinen et al., 2022).

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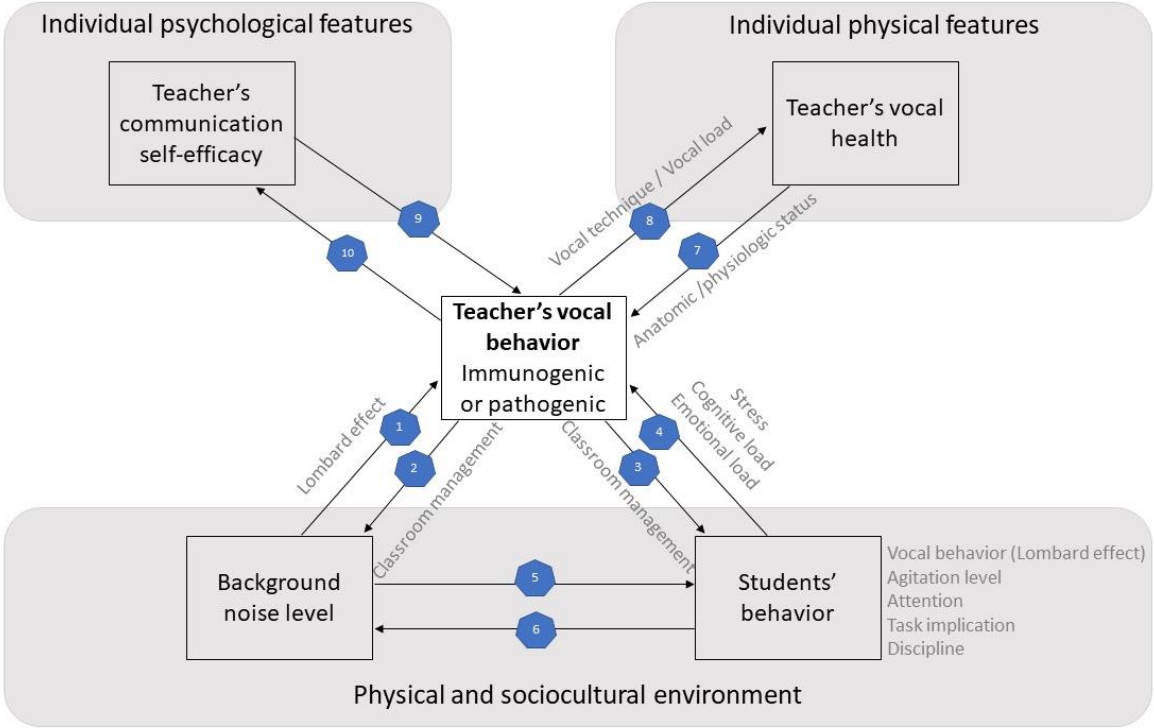
Figure 1

Theoretical Framework for Teachers' Vocal Behavior



We will now describe the interactions depicted by the arrows and based on the numbers in Figure 1. Teachers' vocal behavior forms a feedback loop with background noise level and students' behavior. (1) First, speakers modify their speech production in noisy situations: this phenomenon is called the Lombard effect (Lombard, 1911). (2) In turn, the noise level may be affected by the teacher's vocal behavior. (3) Given that the teacher's voice represents a classroom management tool, their vocal behavior can influence pupils' behavior (e.g., pupils' vocal behavior through the Lombard effect, agitation level, attention, task implication, discipline). (4) Likewise, the pupils' behavior can influence the teacher's stress level and voice since stressors and cognitive and emotional load affect the acoustic characteristics of voice (Van Puyvelde et al., 2018). There is a bidirectional relationship between background noise and students' behavior: (5) noise can affect both children's speech (i.e., Lombard effect) and their agitation. (6) Through their movements and agitation, the pupils' behavior affects the background noise level. (7) Teacher's vocal health (depending on their anatomical and physiological status) is likely to influence their vocal behavior, and (8) vocal health depends on vocal behavior, including both vocal technique and vocal load. In particular, vocal health depends on the immunogenic and pathogenic adaptations to noise described in section 1.3. Finally, (9) our framework focuses on teachers' communication self-efficacy in applying voice protection behaviors, as increased self-efficacy is a reliable predictor of actually engaging in these behaviors over time (Leman et al., 2021). (10) In turn, effective vocal behaviors are expected to enhance communication self-efficacy.

1.3. Adaptations of speech and voice in noise

In light of the Theoretical Framework for Teachers' Vocal Behavior presented in Figure 1, this section focuses on the interactions between teachers' vocal behavior and both background noise level and teachers' vocal health. For successful communication in a noisy environment, speakers can use different strategies relying on acoustic and visual cues to maintain clear speech. Depending on the impact of vocal behavior on vocal health (number 8 in Figure 1), we classify these adaptive behaviors into two categories: (1) immunogenic behaviors, which improve speech intelligibility in a way that is safe for the vocal fold tissue, and (2) pathogenic behaviors likely to increase the risk of voice disorders.

Based on the acoustic cues, Garnier and Henrich (2014) proposed three types of strategies speakers could use to improve their speech audibility and segregation in noise: (1) Boosting strategies: speakers reduce the energetic masking due to noise and enhance acoustic contrasts by raising their overall vocal sound pressure level (SPL), and more specifically the spectral energy in frequencies where the noise presents maximum energy. (2) Bypass strategies: speakers shift the spectral energy to spectral bands where the noise presents minimum energy. Acoustically, these two types of adaptive responses to noise may result in a decrease in spectral slope. (3) Modulation strategies: speakers increase temporal modulations of vocal

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fundamental frequency (f_0) and SPL, resulting in greater voice intonation. Acoustically, such modulations correspond to increased variations in f_0 and SPL, which can be measured using a speech range profile. According to Hincks (2004), varied intonation helps teachers make their speech lively and interesting to listen to.

In their experiment on speakers' acoustic adaptations when speaking in noise, Garnier and Henrich (2014) found that the primary strategy for coping with noise consisted in a general increase in vocal effort, commonly defined as an increase in vocal loudness and strain in voicing (Hunter et al., 2020). Because it increases the speaker's perceived vocal effort and represents a potential risk factor for phonotrauma, this adaptive strategy belongs to the pathogenic vocal behaviors in Figure 1. Among the secondary strategies Garnier and Henrich (2014) identified, enhancing speech modulation and spectral energy in the 2–4 kHz region are immunogenic communicative techniques that individuals can be taught in order to improve their speech audibility more safely than with the primary strategy. In noise, slowing the speech rate by lengthening speech segments or pauses and hyperarticulating speech sounds (Lu & Cooke, 2008) is also considered an immunogenic adaptive behavior. By determining the amount of time in which the listener can perceive and interpret the message, an appropriate speech rate influences children's receptive skills in classroom environments.

Some speakers also use visible cues by hyperarticulating to improve their speech intelligibility in noise (Garnier et al., 2018). The benefits of such visual strategies are that they (1) limit teachers' vocal effort and prevent vocal damage, and (2) offer an alternative channel of transmission for the pupils and enhance the quality of teacher-child communication.

Although the Lombard effect is related to an automatic mechanism, the motor cortex and high-level cognitive processes are involved, suggesting that speakers are able to control this phenomenon (Brumm & Zollinger, 2011). In this work, we posit that training designed to

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promote immunogenic behaviors and reduce pathogenic behaviors would improve teachers' communication in noise while protecting their vocal health.

1.4.Design of a voice-related prevention program including virtual reality

In voice therapy (Van Stan et al., 2015) and voice-related prevention and training (Ramos et al., in press), there are three main approaches based on what occurs during the intervention: the direct approach, the indirect approach, and the mixed approach. According to Van Stan et al.'s (2015) taxonomy of voice therapy (i.e., a classification system that integrates descriptions of therapeutic approaches from the clinical literature into a framework):

- Direct interventions include training techniques that modify vocal behavior through motor execution, somatosensory feedback, and auditory feedback.
- Indirect interventions modify vocal behavior by changing the cognitive, behavioral, psychological, and physical environments in which voicing occurs by means of pedagogy or counseling.
- A mixed approach is a combination of both direct and indirect interventions.

Van Stan et al.'s taxonomy outlines two categories of therapy tasks:

- Activities, defined as the execution of a task or action by an individual.
- Participation, characterized by involvement in a life situation. It is particularly challenging to implement this category in voice training but it is vital for the generalization of vocal skills in everyday communication situations.

As highlighted in the meta-analysis by Ramos et al. (in press), several voice-related prevention programs for teachers have been developed over the years, but none of them allow involvement in real-life situations. This is the gap that the current work aims to fill. For teachers, training tasks involving real-life situations would require voice production in realistic school situations, in the presence of pupils and facing environmental constraints.

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To that end, VR-based intervention may represent a promising method (Remacle et al., 2021). A virtual classroom constitutes a safe environment to practice communication skills by controlling task complexity. Stepwise training could begin with restless pupils, and then progressively increase their agitation level to replicate the complexity of real school situations. In practice, VR systems can promote multimodal simulations of teaching situations without requiring the teacher to be physically present in front of a real classroom. VR has significant potential for skill development and building self-efficacy and offers the possibility of including key components to promote motor learning, such as customization of the task level, adjustment of the difficulty progression, and fostering interest and motivation (Demers et al., 2021).

In a previous study (Remacle et al., 2021), we developed a virtual classroom for communication skills training for teachers (primary prevention) and rehabilitation for dysphonic individuals (treatment of speech and language pathologies). We validated the virtual classroom by conducting acoustic analyses of the speech productions of teachers who were (1) teaching in their usual classroom, (2) teaching the same lesson in the virtual classroom, and (3) speaking freely while facing the experimenter (control). The results showed that the virtual classroom elicited voice changes specific to a teaching situation, which differed from the control speaking situation. Teachers immersed in the virtual classroom experienced a strong feeling of presence and a lack of side effects such as cybersickness. This may promote the generalization and transfer of communication skills practiced in the virtual classroom to real-world situations.

To the best of our knowledge, our study is the first to use VR simulations with the aim of training teachers in oral communication skills and promoting healthy and effective voice use.

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1.5.Purpose and research question

The main purpose of this study was to evaluate the effects of a voice-related prevention program based on oral communication skills training in environmental and communicative situations that are close to the reality of teaching. This program, named VirtuVox, was described in detail in Remacle et al. (2022). Among other things, it involves immersing trainee teachers in VR. Considering the elements of an evaluation of an intervention – population, intervention, comparison, and outcome ("PICO") – our research question is as follows: Do trainee teachers (P) who receive a mixed intervention including an information session and training on communication in noisy environments and immersion in a virtual classroom (I) exhibit greater changes in communication skills in noise and in self-efficacy (O) than trainee teachers who receive only an information session (C)?

The secondary purpose was to document the extent to which the virtual classroom creates a feeling of presence and does not generate unwanted negative side effects (commonly referred to as cybersickness).

2. Material and methods

2.1.Ethical statement

The Randomized Controlled Trial was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège (file number: 1819-59) and was conducted following the ethical standards described in the Declaration of Helsinki (1964).

2.2.Design

This study was a two-arm interventional randomized controlled trial using parallel assignment to two groups: (1) experimental group (indirect intervention and direct intervention with VR; see sections 2.6.1. and 2.6.2.); and (2) control group (indirect intervention; see section 2.6.1.).

To avoid performance and verification bias, double masking was applied. The trainer was blinded to the outcome measures. The outcome assessor was blinded to the group allocation, the study's progress, and the intervention program's content. The protocol was recorded beforehand on ClinicalTrials.gov (NCT number: NCT04096352).

2.3.Participants and recruitment

Participants were recruited at a postsecondary institution in the province of Liège, in French-speaking Belgium. They were trainee elementary teachers in the second or third year of a three-year training program. The educational program for Belgian elementary school teachers is three years long; each year provides a total of 60 ECTS (European Credit Transfer and Accumulation System; for more information, see European Commission, n.d.), divided among courses and internships. The time allotted to internships increases from year to year: 2 weeks in the first year, 4 weeks in the second year, and 10 weeks in the third year.

A convenience sampling method was used. After the school's management agreed to allow recruitment of trainee teachers, a group information session lasting 45 minutes was held on the day they returned to school after the summer holidays. Each of the 156 trainee teachers who attended the session received an informative letter explaining the study's purpose and methodology. The 71 trainee teachers (45.5%) who wished to take part in the study completed (1) an informed consent form, (2) a sociodemographic questionnaire, and (3) the French version of the Voice Handicap Index (VHI), which measures the biopsychosocial impact of voice problems (Woisard et al., 2004). This questionnaire comprises 30 self-rated items scored on a 5-point Likert scale (0 = never; 4 = always). The total score ranges from 0 (no complaints) to 120 (many complaints).

Eligible participants were then selected based on the following inclusion and exclusion criteria. Inclusion criteria: be between 18 and 40 years of age; be a trainee teacher who had

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completed at least one student teaching session (in order to have had at least one teaching experience in a real classroom); speak French fluently. Exclusion criterion: have a voice or hearing impairment at the time of the study.

Of the 71 participants who were screened against the eligibility criteria, 69 were enrolled (97.2%) and 41 (57.7%) completed the study (see Figure 2).

The sample size and power, established *a priori* based on the results of a previous study (Remacle et al., 2018), recommended a sample of 80 participants. Given the dropout rate in studies of prevention of voice problems in trainee teachers (Bovo et al., 2007; Chan & Yiu, 2011; Duffy & Hazlett, 2004; Grillo, 2017; Nanjundeswaran et al., 2012; Richter et al., 2016; Timmermans et al., 2011), it would have been appropriate to enroll 100 participants in order to ensure a final sample of 80. Although all trainee teachers at the school were included in the recruitment process, we could not achieve a sample size of 80 participants who completed the study.

2.4.Randomization

The participants were assigned randomly to one of the two conditions: (1) individual voice training sessions including immersion in VR and a group information session on voice functioning and vocal hygiene (experimental group, n=34); and (2) a group information session on voice functioning and vocal hygiene (control group, n=35). Table 1 shows the demographic characteristics of the participants who completed the study (experimental group, n=21; control group, n=20). There were no significant differences between the two groups.

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Figure 2. *Consort participants flow diagram*

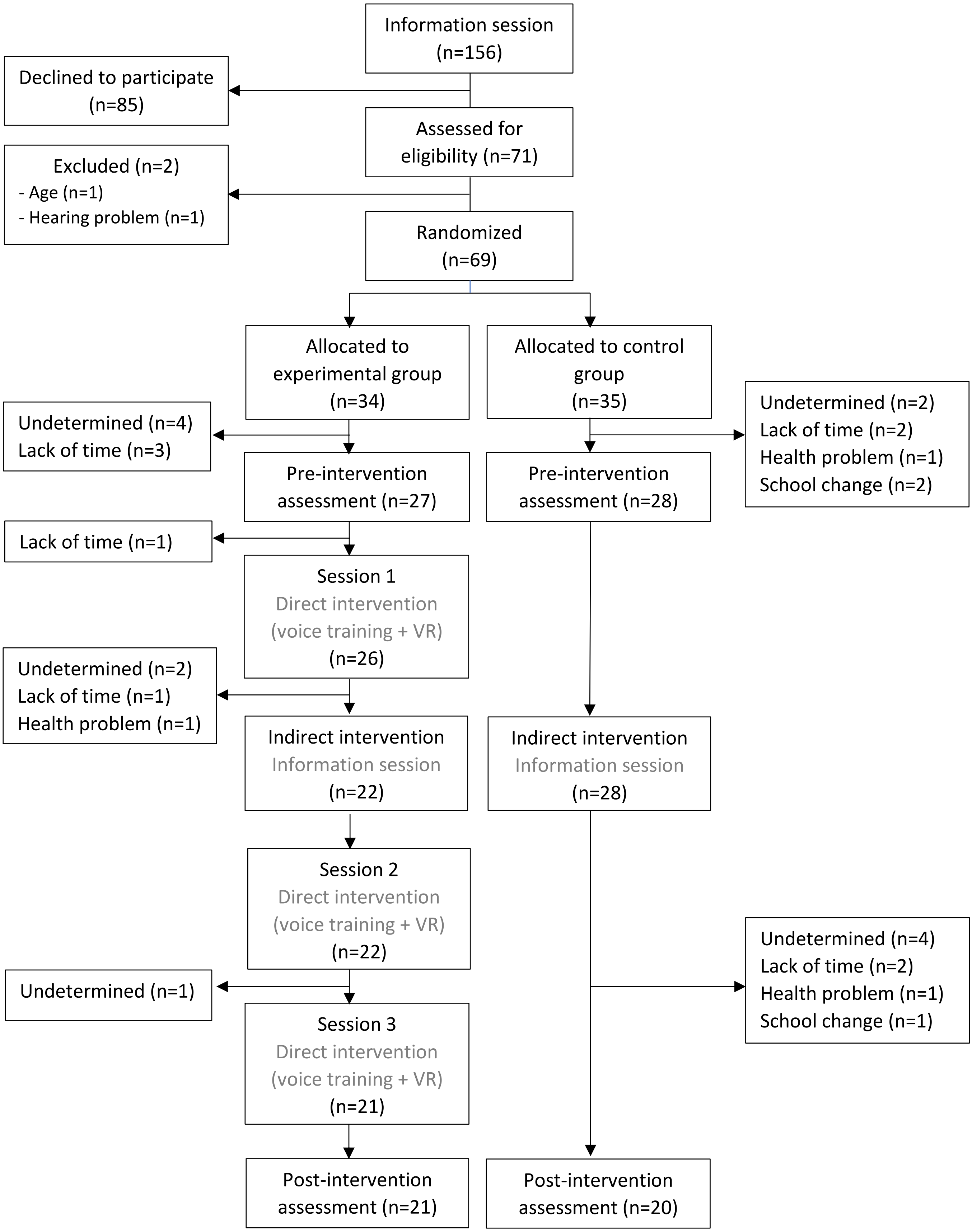

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Table 1.

Demographic information on the participants randomly assigned to the experimental group (indirect intervention and direct intervention with virtual reality) or to the control group (indirect intervention only)

	Experimental group (n=21)	Control group (n=20)	Statistical difference
Gender (M/F)	6/15	4/16	χ^2=.408, p=.523
Year of academic program (2/3)	11/10	13/7	χ^2=.672, p=.412
Previous hearing disorder[a] (YES/NO)	6/15	5/15	χ^2=.066, p=.796
Previous voice training[b] (YES/NO)	1/20	1/19	χ^2=.001, p=.972
Motion sickness (YES/NO)	6/15	8/12	χ^2=.595, p=.440
Mean VHI score (min-max, SD)	22.3 (0–48, 11.1)	21.2 (7–43, 11.7)	T=-.305, p=.762
Mean age (min-max, SD)	23.6 (19–38, 4.7)	23.9 (19–35, 5.5)	U=205, p=.905

SD, standard deviation. [a]Previous hearing disorders included insertion of ear tubes, inner ear problem, tinnitus, blocked ears, otitis, or mild hearing loss. [b]Previous voice training included acting classes and music theory classes.

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2.5. Timing of the study

Study participation lasted 5 to 9 weeks. The sequence of activities was as follows: information session for recruitment, pre-intervention assessment, intervention period, and post-intervention assessment. Figure 3 shows the timeline of the study for both groups.

Before the program was administered to the study participants, the protocol was pretested on four participants who were not included in the study. During these tests, the trainer was supervised by the first author. This pilot phase allowed us to adjust the content of the direct intervention protocol and verify the trainer's adherence to it.

2.6. Intervention

As illustrated in Figure 3, the intervention consisted in an indirect group session including information on voice and individual direct sessions including voice training and VR immersions. The detailed intervention protocol and the training scenarios for the VR immersion sessions have been published previously (Remacle et al., 2022). In the Supplementary material, the intervention for the experimental and control groups is described using the Template for Intervention Description and Replication (TIDieR) (Hoffmann et al., 2014). All of the sessions took place in the participants' school, during schooldays.

2.6.1. Indirect intervention

A one-hour group information session on voice functioning and vocal hygiene was provided to all participants (see the Supplementary material for an extensive description). To ensure that both groups received the indirect intervention at the same time, this session took place between direct sessions 1 and 2 for participants in the experimental group, for practical reasons.

Figure3. *Timeline and measures for the experimental and the control groups*

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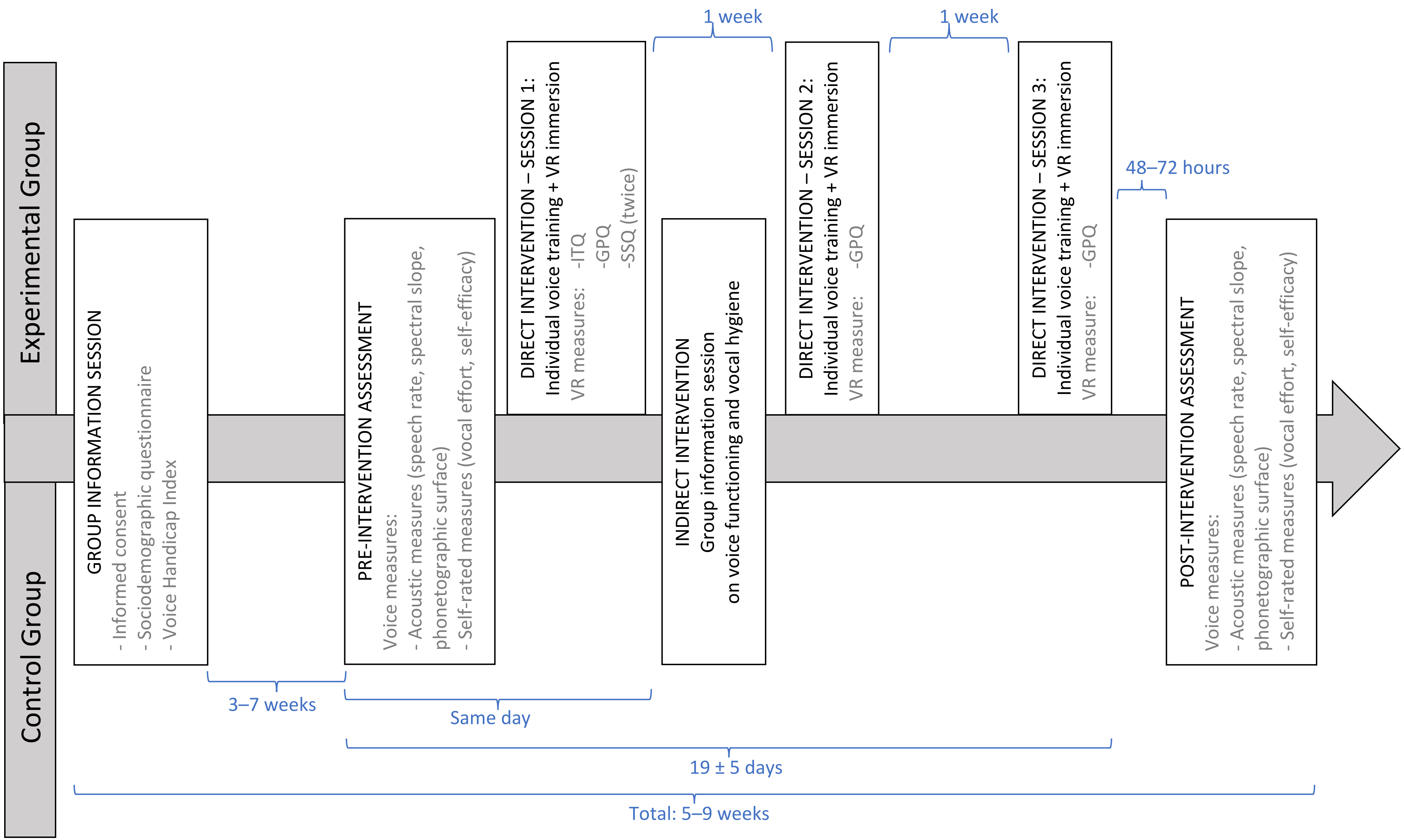

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2.6.2. Direct intervention

Participants in the experimental group were given three one-hour individual voice training sessions. Each session included immersion in a virtual classroom and simulation of communicative situations in noise, in order to train and automatize healthy vocal motor behavior. A systematic review and meta-analysis on programs for the prevention of voice disorders in teachers showed substantial variability regarding the frequency and number of sessions (Ramos et al., in press). In the present study, the sessions were spaced one week apart (the three sessions took place over 19 ± 5 days). The number of three sessions was chosen because the program was intended to be a preventive intervention for a non-pathological population. The original features of the program were (1) training oral communication skills in environmental and communicative situations that were close to the reality of teaching, and (2) including participation tasks, as defined in the taxonomy of voice therapy (Van Stan et al., 2015). In order to promote immunogenic behaviors and reduce pathogenic ones in situations involving communication in noise, the content of the sessions was based on direct methods from vocology and speech therapy.

The general organization of the intervention was intended to help participants to (1) detect situations involving communication in noise by analyzing the environmental noise in which communicative situations take place (e.g., type of noise, noise level); identifying communicative situations that lead to inappropriate vocal behavior (e.g., vocal effort, imbalanced laryngeal muscle activity); and identifying the feelings associated with inappropriate vocal behavior (e.g., pain, discomfort); (2) practice immunogenic communication strategies in noise with the aim of retaining them; different scenarios were presented, such as talking while noise was played through speakers and talking to pupils in the virtual classroom; (3) gradually increase the difficulty of the exercises by increasing the noise level; increasing the agitation level of pupils in the virtual classroom; and increasing the

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complexity of the linguistic content produced by the participant (e.g., semi-spontaneous speech such as automatized series, spontaneous speech such as giving a lesson); and (4) transfer the skills learned: at the end of each session, the trainer asked the participant to analyze their own oral communication behavior in daily life until the next session.

In practice, each session targeted three specific skills by having the participant (1) identify a communication situation in noise they had experienced, potential adaptations they had made, and what they felt in that situation; (2) verify their theoretical understanding of the targeted skills; and (3) train these skills with specific exercises and feedback from the trainer, without and then with noise. The trainer was instructed to opt for feedback composed of specific comments about the participant's performance and suggestions about how to improve it, rather than a score or a general assessment. The feedback was also intended to improve the participant's self-efficacy. Finally, (4) the participant practiced and automatized the target competence during immersion in VR.

2.7. Material and procedures

2.7.1. VR environment and equipment

The VR environment consisted of an immersive classroom developed and validated in Remacle et al. (2021). The environment features an elementary school classroom with 16 pupils aged 9 to 12 years old animated with typical childlike actions (Figure 4). The auditory stimuli corresponding to background noise without understandable semantic content were spatialized and played through the speakers of a head-mounted display. The trainer can adjust the level of three noise sources (playground, corridor, and classroom) and the children's agitation (Figure 5), which allows for clinical flexibility.

For the VR immersion at all three direct sessions, the noise level (playground, corridor, and classroom) was consistently set at 0.2, which corresponded to a mean level of 70 dBA played

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in the helmet. The noise level was previously calibrated using an HSU III artificial head microphone. The pupils' agitation level was gradually increased to make it more difficult for the trainee teacher: it was set at 30% in session 1, 50% in session 2, and 70% in session 3.

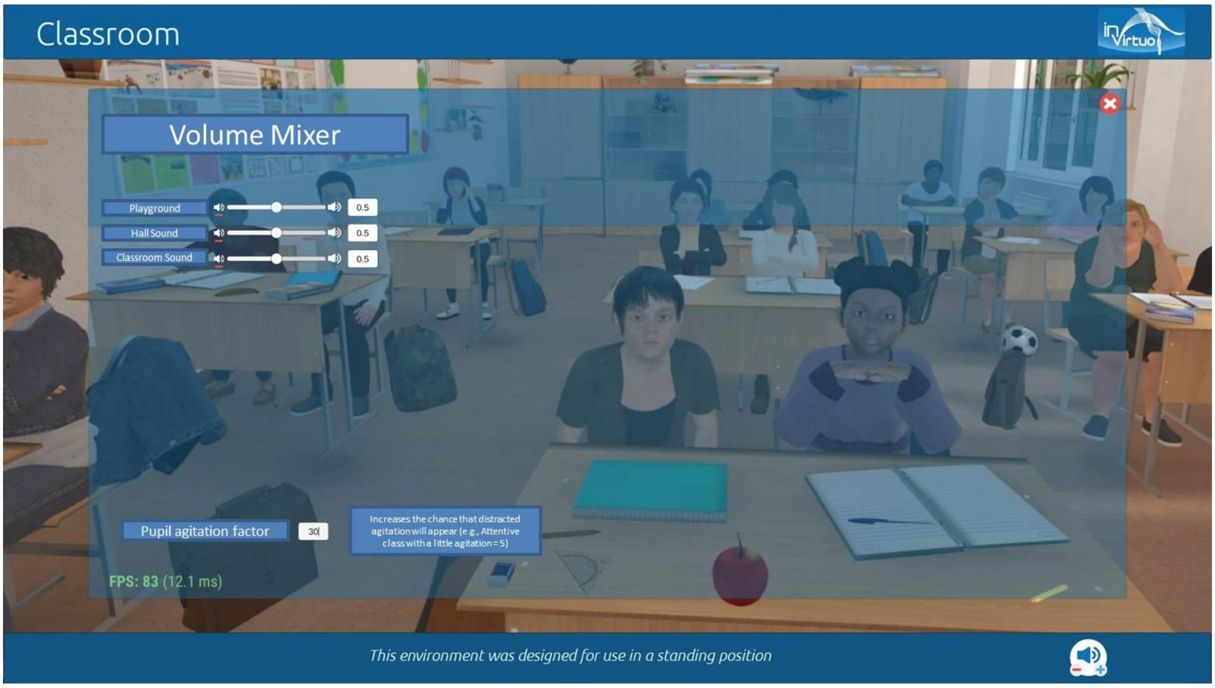
The virtual classroom was displayed using a PC running on Windows 10 Pro (Notebook Computer, Model P751M1, Intel® Core™ i7-8700 CPU@ 3.20 GHz, 3.19 GHz, 16 GB of RAM). The participants wore an Oculus Rift™ head-mounted display.

Figure 4.

Screenshot of the virtual environment displayed with the VR headset during the direct intervention

Figure 5.

Screenshot of the control panel of parameters of the virtual classroom. Above: individual adjustment of three noise sources: (1) noise from the playground, (2) noise from the corridor, and (3) noise from inside the classroom. Below: adjustment of the pupils' agitation level from 0 (very attentive and not very restless) to 100 (very distracted and restless). For the three direct sessions, the noise level was set at 70 dBA. The pupils' agitation level was gradually increased: 30% for session 1, 50% for session 2, and 70% for session 3.



2.7.2. Voice measures

To determine whether the intervention made it possible to reinforce immunogenic adaptive behaviors and reduce the pathogenic adaptive behaviors of Lombard speech, assessments of vocal behavior in noise were conducted. As shown in Figure 3, the pre-intervention assessment took place immediately before session 1, on the same day. The post-intervention assessment was done between 48 hours and 72 hours after session 3 for the experimental group and at the same time for the control group.

Voice recordings and assessments complied with the recommendations of Barsties and de Bodt (2015). The assessments took place in a quiet room measuring 4 X 2.7 X 2.8 m. The participant stood facing the experimenter, who was sitting 2.75 m away. Each assessment session lasted approximately 20 minutes and included the questionnaire about communication self-efficacy in noisy environments, two oral production tasks consisting of reading and word dictation in noise, and a self-assessment of vocal effort.

The production tasks consisted of connected speech similar to what teachers might produce during their usual teaching activities. For the reading task, we used lists 1 and 2 of Combescure's phonetically balanced sentences (Fournier, 1951). Before the task, the experimenter gave each participant the following instructions: "I'm going to ask you to read these sentences in the same way as you would in your class with your pupils. I'm going to sit on the chair facing you, as if I were your pupil, and you're going to read these sentences, as if you were telling me a story."

The dictation task was an interactive communicative situation. It was based on 13 words from Fournier's (1951) lists of common French disyllabic words. Of the 13 words, we analyzed 5 words from the middle of the dictation that included most of the vowels in the French phonemic repertoire. The words were *bouchon, brigand, grumeau, coffret,* and *gamin*. Before the task, the experimenter gave the following instructions: "I'm going to ask you to dictate this list of words as if you were in your classroom with your pupils. I'm going to sit facing you and write down the words you dictate as if I were a pupil. At the end, I'll ask you to correct them. Please say each word only once."

The tasks were carried out in the presence of non-semantic noise, which was recorded in a real classroom. It had the spectral characteristics of classroom noise and it varied in terms of f_0 and SPL. The noise and the real-time auditory feedback of the participant's voice were played in an AKG K271MKII helmet connected to an external sound card (iTrackSolo, Focusrite Audio Engineering Ltd., China). Playing the noise inside the helmet (rather than in the entire room) allows the recording of high-quality vocal signals. The long-term average level of noise played through the headphones was measured using an HSU III artificial head microphone. It was played through the helmet at a mean level of 54.5 dBA LAeq, corresponding to what has been measured in elementary classrooms during a normal lesson (Remacle et al., 2021).

The participants' speech was recorded using a head-mounted condenser microphone (C 544 L, AKG Acoustics GmbH, Austria) positioned 5 cm from the mouth, which was connected to a Lenovo laptop (IdeaPad, U430p, Lenovo, China) via an external soundcard (iTrackSolo, Focusrite Audio Engineering Ltd., China). The audio signal was recorded in .wav format, with a sampling frequency of 44.1 kHz and 16-bit resolution. In order to check the quality of the recordings, their signal-to-noise (SNR) ratio was calculated by comparing the SPLs of the voice signal and the noise source: the SNRs complied with the recommendations of Barsties and de Bodt (2015). Acoustic analyses were then carried out on the oral productions recorded during the two tasks.

2.8.Outcome measures

2.8.1. Acoustic measures

Speech rate: the number of syllables per minute was calculated on the reading task.

The following measures were extracted from the five previously concatenated dictation words, using Praat software (version 6.1.09).

Spectral slope: After running a Long-Term Average Spectrum, it was split into two parts to analyze the relative amount of energy in the low- versus high-frequency range of the spectrum. We calculated the spectral slope (absolute value, in dB) using a low band of 0–1000 Hz and a high band of 1000–4000 Hz (Bandwidth = 1).

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Phonetographic surface: A speech range profile was performed using the Vox Phonetography Praat Plug-in (version 1.2.3) from Phonanium. We extracted the phonetographic surface (in dB*semitones) representing the ambitus of voice SPL and f_0.

Table 2 describes the expected changes in each acoustic measure, in relation to the adaptations of speech and voice in noise (see section 1.3.), and to the skills targeted in the intervention.

2.8.2. Self-rated measures

Vocal effort: Following the oral production tasks in noise, participants self-assessed their vocal effort using the Adapted Borg CR-10 Scale for Vocal Effort (Baldner et al., 2015). This is an 11-point Likert scale (0 = no vocal effort at all; 10 = maximum vocal effort).

Self-efficacy: Oral communication self-efficacy in a noisy environment was measured with a 15-item self-rated questionnaire, using a 7-point Likert scale (0 = impossible to do; 3 = moderately possible to do; 6 = completely possible to do). This questionnaire, which is available in Remacle and Morsomme (2021), was developed for the purpose of the present study based on Bandura's (2006) guidelines. For each item, participants had to indicate how capable they currently felt of adopting the behavior in their academic life (courses, student teaching) and/or their extracurricular life (recreation, family). The final score consists of the total for the 15 items and ranges from 0 to 90. The higher the score, the greater the self-efficacy.

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Table 2.

Summary of the expected changes in each acoustic outcome measure in relation to speech and voice adaptations and the skill targeted by the intervention

Expected change in outcome measures	Interpretation in terms of speech and voice adaptations in noise	Skills targeted by the intervention
↘ Speech rate	- Lengthening of speech segments or pauses (= immunogenic behavior). - Hyperarticulation of speech sounds (= immunogenic behavior).	- Session 2, skill 3: adjust the speech rate to promote perception and understanding of the message by the listener/interlocutor. - Session 3, skill 2: search for more precise and higher-amplitude articulatory movements to favor auditory and visual perception of speech. -Session 3, skill 3: search for visual communication cues such as facial expressions, gaze and articulatory movements.
↘ Spectral slope	- Enhancement of spectral energy in the 1–4 kHz region of speech, corresponding to greater sensitivity of the human ear to SPL than in the 0–1 kHz region (= immunogenic behavior). -The energy boost in the 1–4 kHz region can contribute to voice projection and audibility, which recall the “singing formant” or “actor formant” (Garnier & Henrich, 2014) (= immunogenic behavior). - A flattening of the spectral slope may also be due to increased laryngeal adduction and glottal resistance, and would in this case reflect greater vocal effort (= pathogenic behavior).	- Session 2, skill 2: search for resonant voice patterns involving a configuration of the vocal tract that allows for improved supraglottic resonance; this technique aims to increase vocal level and spectral energy in the region where the human ear is most sensitive to SPL.
↗ Phonetographic surface	- Wider vocal f_0 and SPL range reflect greater speech modulations and intonation, which are supposed to enhance speech intelligibility in noise (= immunogenic behavior).	- Session 3, skill 1: search for variations in pitch and vocal intensity to favor temporal modulations in f_0 and SPL.

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2.8.3. VR measures

The following VR measures were administered to the participants in the experimental group. They provide useful information on users' experience for clinical applications of VR.

Immersive tendency. The Immersive Tendencies Questionnaire (ITQ) was completed at the beginning of the first direct session. It measures individuals' tendencies to experience presence in common activities (Witmer & Singer, 1998). The ITQ contains 18 self-rated items on a 7-point Likert scale (0 = never; 6 = often), which provide a *Total* score and four subscale scores: *Focus* (ability to concentrate on current activities and ignore distractions); (2) *Involvement* (feeling of being caught up by stories and movies); *Emotions* (intensity of the emotions evoked by stimuli such as movies); and *Games* (frequency of playing video games) (Robillard et al., 2003).

Presence. The Gatineau Presence Questionnaire (GPQ) was administered after the VR immersion at each direct session. It measures the feeling of presence experienced by the users while immersed in a virtual environment (Laforest et al., 2016). The GPQ includes four items rated on a 0–100 scale assessing (1) the impression of being there, (2) appraising the experience as being real, (3) awareness of the virtual environment as being artificial, and (4) the feeling of being in the physical office instead of the virtual environment. The last two items are scored in reverse and a mean percentage score is computed.

Unwanted negative side effects of immersions in VR (cybersickness). The Simulator Sickness Questionnaire (SSQ) (Bouchard et al., 2009; Kennedy et al., 1993) was completed at the beginning and at the end of the first direct intervention session. The SSQ rates 16 symptoms of unwanted negative side effects on a four-point Likert scale, providing a *Total* score and two subscale scores: *Nausea*, and *Oculo-motor problems*. The scoring is based on raw scores, as recommended by Bouchard et al. (2021).

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2.9. Statistical analysis

2.9.1. Acoustic and self-rated measures

Repeated measures ANOVAs were conducted with the pre- and post-intervention assessments as a within-subjects factor, and the control and experimental groups as a between-subjects factor. For the acoustic measures, a family-wise Bonferroni correction was applied considering the three measures ($\alpha = 0.05/3$) and the significance level was set at .017. For the self-rated measures, a family-wise Bonferroni correction was applied considering the two self-report measures and the significance level was set at .025. When the ANOVA showed a significant difference, a post hoc Tukey's honestly significant difference test was computed either on the main significant effect or on the interaction to compare the means. Effect sizes are reported using partial η^2. The normality was checked in advance using the Shapiro-Wilk test. All the variables followed a normal distribution except vocal effort post-intervention and self-efficacy pre-intervention. For vocal effort and self-efficacy, both parametric and non-parametric tests led to the same conclusions. For the sake of clarity, only parametric analyses are presented. All analyses were performed using Jamovi, version 2.2.5 (Jamovi project, 2021).

2.9.2. VR measures

For immersive tendency, the ITQ scores were compared to scores proposed by Robillard et al. (2002). The feeling of presence through the three direct sessions was compared using a repeated measures ANOVA. To determine whether the immersion in the virtual classroom induces cybersickness, SSQ scores pre- and post-immersion were compared using paired t-tests.

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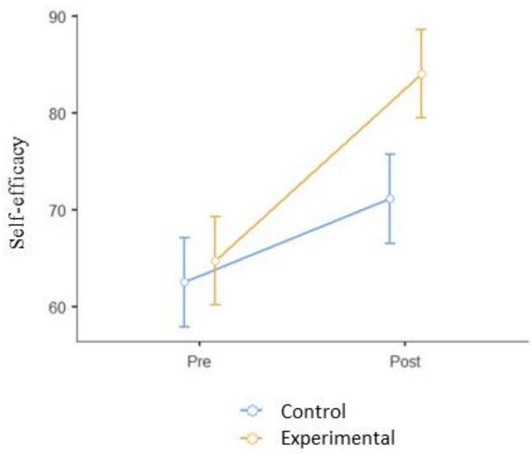
3. Results

3.1. Acoustic and self-rated measures

Table 3 presents the mean values and standard deviations, as well as the results of the ANOVAs for the acoustic and self-rated measures. When comparing both pre- and post-intervention assessments, the ANOVAs revealed a significant effect of Time with a large effect size for phonetographic surface, vocal effort, and self-efficacy, suggesting a positive effect of both indirect and mixed interventions. No statistically significant Time effect was found for speech rate or spectral slope. For self-efficacy, there was a significant effect of Group and a significant Time by Group interaction, with large effect sizes (see Figure 6). The post hoc comparisons showed a significant improvement in self-efficacy from pre- to post-intervention for the control group (T = –3.069, p = .020) and the experimental group (T = –7.053, p < .001). There was no difference between the two groups pre-intervention (T = –0.682, p = .903). Post-intervention, self-efficacy was significantly higher for the experimental group than the control group (T = –3.972, p = < .001), showing a better evolution for participants who received the direct intervention with VR immersions.

Figure 6.

Illustration of the interaction for self-efficacy for the experimental group that received the indirect intervention and the direct intervention with VR, and the control group that received the indirect intervention.



Marginal means are reported in the plots, while error bars represent 95% confidence intervals.

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Table 3.

Repeated measures ANOVAs comparing acoustic measures during an in vivo speech task in the presence of non-semantic noise and self-rated measures of participants who received indirect intervention and direct intervention with VR (experimental group), and participants who received indirect intervention only (control group).

Variable	Group	Pre M	Pre SD	Post M	Post SD	Time (d = 1,39) F	p	η²p	Group (d = 1,39) F	p	η²p	Interaction (d = 1,39) F	p	η²p
Acoustic measures														
Speech rate	Ctrl	275	38.7	263	36.7	4.706	0.036	0.108	0.007	0.935	0.000	0.172	0.681	0.004
	Expe	274	36.5	266	32.3									
Spectral slope	Ctrl	15.4	2.11	15.7	1.54	0.250	0.620	0.006	1.51	0.226	0.037	2.364	0.132	0.057
	Expe	16.4	1.81	15.9	1.86									
Phonetographic surface	Ctrl	97.8	18.9	105.6	16.7	9.240	0.004*	0.192	0.190	0.666	0.005	0.098	0.755	0.003
	Expe	95.0	15.4	105.5	20.5									
Self-rated measures														
Vocal effort	Ctrl	2.69	1.30	1.98	1.46	12.191	0.001*	0.238	3.53	0.068	0.083	0.148	0.702	0.004
	Expe	2.14	1.48	1.24	1.04									
Self-efficacy	Ctrl	62.5	9.22	71.1	9.83	50.74	<.001*	0.565	8.51	0.006*	0.179	7.45	0.009*	0.160
	Expe	64.7	11.4	84.0	11.0									

M, mean; SD, standard deviation; Ctrl, control group, N = 20; Expe, experimental group, N = 21. *Statistically significant, considering Bonferroni correction (for the acoustic measures, the significance level was set at .017; for the self-rated measures, the significance level was set at .025). Results for the post hoc comparisons are reported in the text.

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3.2.VR measures

Table 4 reports on the immersive tendency, feeling of presence and unwanted side effects.

Regarding immersive tendency, the participants' ITQ results were significantly higher than the reference scores (Robillard et al., 2002) for the *Total* score ($\mu = 64.1 \pm 13.1$, $z = 2.67$, $p = .003$), the *Involvement* subscale ($\mu = 15.3 \pm 8.7$, $z = 2.27$, $p = .02$), and the *Emotions* subscale ($\mu = 14.2 \pm 6.7$, $z = 2.32$, $p = .01$). There was no significant difference for the *Focus* subscale ($\mu = 24.8 \pm 7.5$, $z = 1.50$, $p = .07$) or the *Games* subscale ($\mu = 6.6 \pm 4.9$, $z = 1.7$, $p = .06$).

The repeated measures ANOVA showed no significant difference for the total GPQ scores between the three direct sessions ($F(2, 40) = .58$, $p = .566$, $\eta^2 = .006$). A descriptive analysis of the GPQ results reported in Table 4 indicates that the participants experienced a good sense of being there (item 1) and appraised the experience as being real (item 2). Lower scores were observed for awareness of the virtual environment as being artificial (item 3), while moderate scores were obtained for the feeling of being in the physical office instead of the virtual environment (item 4).

Paired t-tests showed no significant differences for the SSQ *Total* score ($t =1.33$, $p = .199$), the *Nausea* subscale ($t = .417$, $p = .681$), and the *Oculu-motor* subscale ($t = -1.4$, $p = .177$) before and after the immersion in session 1, indicating that unwanted negative side effects were not induced.

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Table 4.

Descriptive results for VR-related questionnaires administered to participants in the experimental group who were immersed in the virtual classroom

Questionnaire	**Mean score (SD)**
Immersive tendencies questionnaire (ITQ)[a]	
Total	71.8 (9.9)
Focus	22.3 (2.8)
Involvement	19.6 (6.4)
Emotions	17.7 (4.5)
Games	8.4 (4.4)
Gatineau Presence Questionnaire (GPQ)[b]	
Total score – S1	54.9 (14.6)
Total score – S2	57.6 (18.6)
Total score – S3	57.7 (20.1)
Impression of being there – S1	73.3 (20,6)
Impression of being there – S2	74.5 (22)
Impression of being there – S3	79.8 (15)
Appraising the experience as being real – S1	64.7 (20.4)
Appraising the experience as being real – S2	71.1 (24.3)
Appraising the experience as being real – S3	67.4 (22.5)
Awareness of the virtual environment as being artificial – S1	26 (22.1)
Awareness of the virtual environment as being artificial – S2	29.4 (26.6)
Awareness of the virtual environment as being artificial – S3	31.9 (31)
Feeling of being in the physical office instead of the virtual environment – S1	55.6 (29.8)
Feeling of being in the physical office instead of the virtual environment – S2	55.5 (31,4)
Feeling of being in the physical office instead of the virtual environment – S3	51.9 (34.1)
Simulator Sickness Questionnaire (SSQ)[c]	
Total pre-immersion	7.3 (5.5)
Total post-immersion	5.5 (2.6)
Nausea pre-immersion	2.9 (3.6)
Nausea post-immersion	2.5 (1.6)
Oculo-motor pre-immersion	4.4 (2.6)
Oculo-motor post-immersion	3 (1.7)

S1, session 1; S2, session 2; S3, session 3. [a]Administered at the beginning of session 1, [b]Administered after the VR immersion in each session, [c] Administered before and after immersion in session 1.

4. Discussion

This article reports on two contributions. The first one is a Theoretical Framework for Teachers' Vocal Behavior, which can guide the development of oral communication-related interventions. Based on interactions between concepts from vocology, acoustics, pedagogy, and psychology, this framework relies on ecological models of health behavior, as defined by Sallis and Owen (2015). Building on this framework, we have developed a voice-related prevention program including VR-based intervention for teachers, the VirtuVox program. This program represents a mixed approach combining (1) an indirect intervention including a group information session on voice functioning and vocal hygiene, and (2) a direct intervention consisting of three individual vocal training sessions with simulations of communicative situations in noise and immersion in a virtual classroom. While the indirect intervention focuses on knowledge, the direct intervention is meant to develop oral communication skills. Training these skills in the presence of noise is intended to allow participants to acquire and retain healthy vocal motor behavior, improve their self-efficacy, and ultimately prevent voice disorders. The innovative and original aspect of this intervention is that it includes opportunities in VR simulations to practice new skills in an ecological context for training teachers. This ecological approach focuses on individuals' interactions with their physical (i.e., a noisy classroom) and sociocultural (i.e., distracted and restless pupils) environments (Sallis & Owen, 2015). As recommended by Ludemann et al. (2017), complete information on the intervention is provided by Remacle et al. (2022) to enable the program to be replicated by clinicians, trainers or researchers.

The second contribution of this work is the empirical assessment of the effect of this prevention program in trainee teachers. A randomized controlled trial was conducted for that purpose. During both the intervention and the evaluation, trainee teachers were placed in audio conditions as close as possible to their professional reality, particularly noisy

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environments, and the oral production tasks were similar to those encountered in teaching contexts. The standardized and content-identical intervention guided by the same trainer for all participants, the assessors who were blinded to group allocation and study progress, and the trainer who was blinded to pre- and post-intervention measures represent methodological strengths.

The **primary purpose** of this randomized controlled trial was to determine whether the participants who received the mixed intervention involving VR simulations (experimental group) would exhibit greater changes in acoustic and self-rated measures than participants who received only an indirect intervention based on one information session (control group). The most interesting effect is therefore the Time by Group interaction. It was expected that training designed to promote immunogenic behaviors and reduce pathogenic behaviors would improve teachers' communication in noise while protecting their vocal health.

For both groups, the main effect of Time indicates a significant improvement in phonetographic surface, self-rated vocal effort, and self-efficacy from the pre- to the post-intervention assessments. While speech rate exhibits a non-significant decrease, suggesting an immunogenic adaptation post-intervention, spectral slope (an indicator of spectral energy and laryngeal effort) shows no consistent pattern of change.

More specifically, the increased phonetographic surface reflects greater contrasts in SPL and f_0, which contribute to speech intelligibility. According to Garnier and Henrich (2014), the enhanced modulation of SPL and f_0 may improve speech segregation from noise and the segmentation of an utterance into lexical units. This temporal modulation in voice SPL and f_0 results in more varied intonation. It may help teachers make their speech lively and interesting to listen to (Hincks 2004), and keep students' attention. While the main effect of Time reflects an immunogenic adaptation, we did not find any significant interaction suggesting greater phonetographic surface changes in the experimental group compared to the control group.

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Regarding vocal effort, the main effect of Time suggests that speech adaptations in noise result in less effort post-intervention. Perceived vocal effort may be due to increased voice SPL and f_0 (two well-documented characteristics of Lombard speech), increased strain, and greater mechanical stress and vocal load during phonation, possibly leading to phonotrauma (Hunter et al., 2020). The reduction in perceived vocal effort may result either from the knowledge conveyed during the indirect intervention or the application of the different skills targeted in the direct intervention.

Importantly, self-efficacy regarding oral communication in noise was improved following the intervention for 34 out of the 41 participants. The significant interaction, with a large effect size, shows that self-efficacy was greater for the experimental group than the control group post-intervention. Practicing protective voice adaptations in noise, including during teaching simulations in the virtual classroom, may have improved the participants' belief in their ability to apply these behaviors in real teaching situations. These results are consistent with previous studies in which VR simulations improved self-efficacy, as illustrated by Zheng et al. (2021) in their scoping literature review, and by experimental studies on the training of allied health students (e.g., Atuel & Kintzle, 2021) and professionals (Chiang et al., 2022). Furthermore, the stronger self-efficacy due to simulation of communicative situations that are close to the reality of teaching is expected to promote the transfer of appropriate behaviors to real teaching situations, favor long-term changes in optimal health-related behaviors, and ultimately prevent voice disorders. All these ideas should be tested in further studies.

In comparison with the control group, the absence of greater changes in the acoustic measures and the self-rated vocal effort in the experimental group requires further discussion. These parameters do not support specific vocal behavior changes in trainee teachers for whom communication skills were trained in noise and by means of virtual simulations. This lack of behavioral changes might be related to the participants' vocal health and consequently the

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nature of the preventive activity. Our study focuses on a population without voice disorders and without specific needs to change their vocal behavior. According to Caplan's (1964) typology, the primary level of prevention applies, for which (1) the targeted population is individuals who have not yet shown any sign of problems, and (2) the aim is that these individuals never will develop disorders. Similarly, previous studies failed to demonstrate significant changes in objective voice measures (Chan & Yu, 2011; Duffy & Hazlett, 2004; Ramos et al., in press) and communication skills (Andersson et al., 2022) following training of teachers without pathologies.

It is likely that prevention programs would trigger more pronounced behavioral change in individuals who have just begun to manifest problems (secondary level of prevention) or who are already suffering from a disorder (tertiary level of prevention). The effect of simulations in VR with clinical populations has repeatedly been shown to be stronger and more impactful that in non-clinical populations (e.g., Diemer et al., 2014; Robillard et al., 2003; Simon et al., 2020). These populations should be targeted in future voice-related prevention studies.

Finally, note that the control group received an indirect intervention because we consider that such a time-saving group intervention can easily be implemented in all teacher training programs. We suggest that every trainee teacher should at least receive such an information session on voice functioning and vocal hygiene. It is likely that, if the control group in this study had not received any intervention, greater differences would have been observed between the two groups.

The **secondary purpose** of the study was to document the extent to which the virtual classroom elicits a feeling of presence and does not generate unwanted negative side effects. Qualitatively, the mean ITQ score was within the normal range according to Witmer and Singer (1998) and the GPQ scores were similar to those in Laforest et al. (2016), meaning that participants in the experimental group tended to experience immersion and presence

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comparable to that of the general population. Compared to the standards of Robillard et al. (2002), the ITQ *Total* score, as well as the *Involvement* and the *Emotions* subscales were significantly higher for the experimental group in this study. The feeling of presence experienced by the trainee teachers while immersed in the virtual classroom did not differ between the three direct sessions, suggesting that the content of simulated communicative situations in VR and the pupils' gradually increased agitation level had no influence. No significant difference in SSQ scores before and after the immersion in VR were found, indicating that unwanted negative side effects such as nausea or oculo-motor problems were not induced. In line with the validation study of the virtual classroom (Remacle et al., 2021), the favorable user experience is expected to promote the generalization and transfer of communication skills practiced in the virtual classroom to real-world school situations.

5. Conclusion

Effective oral communication skills are essential for teachers in school settings, given their impact on teachers' vocal health and on the quality of students' learning. Currently, the initial training of schoolteachers does not specifically include oral communication skills training and supervised practice. This study proposed to address this lack by the use of individual training sessions including simulations of noisy communicative situations in a virtual classroom, in addition to one information session on voice functioning and vocal hygiene. The results indicate that trainee teachers who received the prevention program showed a greater improvement in their oral communication–related self-efficacy in noise, compared to a control group that received only an information session.

While the results of this original study are encouraging regarding the implementation of VR simulations in voice training programs, some limitations must be acknowledged. First, the

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number of participants is limited. Second, the post-test evaluation was limited to the short-term effects of the intervention. It would be interesting to evaluate the long-term effects, in terms of maintenance of the self-efficacy results and regarding the prevalence of voice disorders experienced by teachers during their careers. Third, the results of this study of trainee teachers without pathologies may not be generalizable to other populations, such as teachers and other individuals suffering from voice disorders. The sessions involved a progressive increase in agitation in pupils in the virtual classroom to help participants progressively build their skills. Further studies should examine the role of individual characteristics that may moderate the impact of mild, moderate and high agitation levels. In practice, it may also be useful to select levels of agitation that correspond to the specific needs of each trainee (i.e., it may be better for some trainees to practice more often with mildly or highly agitated pupils). More generally, it would be worth looking at the effects of this program on the quality of teaching and student learning. Although incorporation of VR simulations in teachers' training is a promising method that is becoming affordable, instructor training in the technical aspects of VR may be required, as this technology is very new. Finally, trainers should be informed of the potential side effects of VR (i.e., cybersickness) and of how to reduce and manage their occurrence.

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