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Research Article

# Classroom Noise and Teachers' Voice Production

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**Purpose:** The aim of this study was to research the associations between noise (ambient and activity noise) and objective metrics of teachers' voices in real working environments (i.e., classrooms).
**Method:** Thirty-two female and 8 male teachers from 14 elementary schools were randomly selected for the study. Ambient noise was measured during breaks in unoccupied classrooms and, likewise, the noise caused by pupils' activity during lessons. Voice samples were recorded before and after a working day. Voice variables measured were sound pressure level (voice SPL), fundamental frequency, jitter, shimmer, and the tilt of the sound spectrum slope (alpha ratio).
**Results:** The ambient noise correlated most often with the fundamental frequency of men and voice SPL, whereas activity noise correlated with the alpha ratio and perturbation values. Teachers working in louder ambient noise spoke more loudly before work than those working in lower noise levels. Voice variables generally changed less during work among teachers working in loud activity noise than among those working in lower noise levels.
**Conclusions:** Ambient and activity noises affect teachers' voice use. Under loud ambient noise teachers seem to speak habitually loudly, and under loud activity noise teachers' ability to react to loading deteriorates.

Research has shown that during a working day teachers' voice production changes: sound pressure level of voice (voice SPL; Laukkanen, Ilomäki, Leppänen, & Vilkman, 2008; Laukkanen & Kankare, 2006) and fundamental frequency ($F_0$) rise (Laukkanen et al., 2008; Rantala, Hakala, Holmqvist, & Sala, 2013; Rantala, Vilkman, & Bloigu, 2002), spectral slope flattens (Laukkanen et al., 2008; Rantala, Paavola, Körkkö, & Vilkman, 1998), and perturbation (jitter and shimmer) values decrease (Laukkanen et al., 2008). These results have been interpreted to reflect voice loading changes (Rantala et al., 2002), such as increased muscle activity (Laukkanen et al., 2008). Only a few field studies on teachers' voices, however, have focused in greater detail on the reasons for voice changes. This study is part of a voice ergonomics project investigating the risk factors for teachers' voice disorders in real workplaces (classrooms). So far we have identified connections between voice production and indoor air quality, teaching postures, and teaching practices (Rantala, Hakala, Holmqvist, & Sala, 2012; Rantala et al., 2013). In this part of the project, we researched the association between noise and voice.

Noise regulates voice. This happens partly automatically, the phenomenon known as the *Lombard effect* (Lane, Tranel, & Sisson, 1970), but also partly intentionally because speakers aim at successful and fluent communication (Cooke & Lu, 2010; Garnier, Henrich, & Dubois, 2010; Junqua, 1996). In noise, speakers' voice SPL (Aronsson, Bohman, Ternström, & Södersten, 2007; Garnier et al., 2010; Kristiansen et al., 2014; Patel & Schell, 2008; Sato & Bradley, 2008; Södersten, Ternström, & Bohman, 2005) and $F_0$ (Aronsson et al., 2007; Garnier et al., 2010; Patel & Schell, 2008; Södersten et al., 2005; Vogel, Fletcher, Snyder, Fredrickson, & Maruff, 2011) increase. Furthermore, the energy in the voice spectrum shifts from lower frequency bands to higher ones (Cooke & Lu, 2010; Garnier et al., 2010), and the parameters expressing perturbation in voice signal, jitter and shimmer, change when speaking in a noisy environment (Niebudek-Bogusz, Kotyło, & Śliwińska-Kowalska, 2007; Perry, Ingrisano, Palmer, & McDonald, 2000).

Schools are especially noisy workplaces (Pekkarinen & Viljanen, 1991; Shield & Dockrell, 2004). High noise levels in classrooms have been found to load the voice (Kristiansen et al., 2014) and to be among the main work-related risk factors for voice disorders in teachers (Cutiva, Vogel, & Burdorf, 2013; van Houtte, Claeys, Wuyts, & Van Lierde, 2012). Excessive noise levels are considered to be an even more disturbing problem than poor room acoustics

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(Sato & Bradley, 2008). Teachers with voice problems tend to be more disturbed by noise than their peers without these problems (Lyberg Åhlander, Rydell, & Löfqvist, 2011).

Two kinds of noise occur in a classroom: ambient noise and noise caused by human activity. Ambient noise comes from equipment used in teaching and appliances used in the building such as ventilation, air conditioning, heating, water pipes, elevators, and lamps. Noise also carries from adjacent spaces and outside the building. For instance, in big cities such as London, 86% of the schools were exposed to noise levels of 57 dBA Leq from road traffic (Shield & Dockrell, 2004).

The recommended level for ambient noise in unoccupied learning spaces has been set at 35 dBA (ANSI/ASA S12.60-2010). However, this level has been shown to be exceeded in most classrooms (Kristiansen et al., 2014; Sato & Bradley, 2008). Ambient noise typically involves low frequencies, and thus, people may find it more annoying and louder than might be expected from the noise level measured by an A frequency–weighted meter alone (Berglund, Hassmén, & Job, 1996).

The other noise source in classrooms is pupils' and teachers' activities and results from normal daily school routines such as talking, walking, moving furniture, and handling papers and other materials. Activity noise usually varies in pitch and loudness, especially if it consists of the hum of many voices (also called *babble* in the literature). This kind of vocal hum as a strong speech masker impairs sound identification whenever the number of speakers rises (Lu & Cooke, 2008; Simpson & Cooke, 2005).

On average, pupils' activities increase activity noise level by 5 dBA, and at maximum by 10 dBA (Sato & Bradley, 2008). The highest activity noise levels found in many schools (77–87 dBA Leq; Kristiansen et al., 2014; Pekkarinen & Viljanen, 1991; Shield & Dockrell, 2004; Wålinder, Gunnarsson, Runeson, & Smedje, 2007) indicate that teachers have to increase their vocal effort to increase their voice SPL if they want to be heard (van Heusden, Plomp, & Pols, 1979). Poor acoustics in a classroom exacerbates the harmful effect of the noise by making it more continuous and restricting its attenuation (Pekkarinen &Viljanen, 1991; Sala et al., 2002; Sala, Viljanen, & Honka, 1995). Noise levels naturally depend on the number and the ages of pupils and the work they are engaged in, and likewise for the measurement method used in the studies and the period of observation.

Although effects of noise have been studied quite a lot, little is known about the effects of the two kinds of noises—ambient and activity, with their differing characteristics—on voice production in real working environments. Laboratory studies have revealed that when ambient noise exceeds 40 dBA, a speaker's voice SPL (e.g., Lane & Tranel, 1971), $F_0$, tilt of spectrum slope (e.g., Garnier et al., 2010), and perturbation values (Niebudek-Bogusz et al., 2007) change. Activity noise may similarly affect teachers' voice production because the levels of activity noise are known to be high in classrooms (e.g., Kristiansen et al., 2014). On the basis of these findings, we hypothesized that teachers' exposure to classroom noise causes changes in voice production that can be detected by measuring acoustic features of the voice. Consequently the main aim of this study was to research the associations between noise and voice parameters.

## Method

### *Teachers and Schools*

Forty teachers and their classes from 14 elementary schools were randomly selected for the study. The schools were located in five municipalities, and the mean number of pupils was 20 per classroom. Thirty-two teachers were women (mean age = 45 years, range = 27–57 years) and eight were men (mean age = 39 years, range = 31–45 years). Sixteen participants had worked as teachers for fewer than 10 years. Four participants smoked. Fourteen participants (36%) reported a hoarse voice and 21 (54%) a tired voice at least weekly. The mean score on the Voice Handicap Index (VHI; Jacobson et al., 1997; Finnish version by Alaluusua & Johansson, 2003) for the participants was 18 ($SD$ = 13.5, range = 1–58); two participants had mild and two had moderate voice disorders according to the VHI.

The participants were analyzed as a whole group ($N$ = 40) and as two subgroups. The division into subgroups was based on the ambient and activity noise levels measured in the classrooms. One subgroup was formed from those subjected to lower noise levels (the low-noise group) and the other from those teachers working in higher noise levels (the high-noise group). Because five different noise variables were analyzed in the study (see next section, Noise Data, for the noise variables), the subgroups were formed separately for each noise variable—hence, the low-noise group and the high-noise group had five different groups each. The number of participants in the five low-noise groups varied between 15 and 21 (mean age = 41–44 years) and in the five high-noise groups between 19 and 25 (mean age = 43–45 years). Seven participants in the low-noise group and eight in the high-noise group had worked as teachers for fewer than 10 years. The mean score on the VHI varied between 15 and 17 for the low-noise group and between 19 and 20 for the high-noise group.

### *Noise Data: Ambient and Activity Noise*

Noise data consisted of one ambient noise variable and four activity noise variables. Ambient noise caused by heating, plumbing, air conditioning, and other appliances installed in the building was measured in unoccupied classrooms during breaks between lessons with a precision sound level meter (Symphonie and Harmonie, 01db-Stell, Limonest, France) at the center of the classroom. The measurement period was 1 min. The sound level was measured as an equivalent sound level with A-weighting (A $Leq_{1\ min}$), that is, a continuous sound level, which has the same energy as a variable sound level during a specific time period.

Activity noise levels were measured during lessons. Noise during breaks was excluded. The number of lessons was four for 29 teachers, three for six teachers, and two for five (mean number was four lessons). The sound level meter was fixed to a tripod and placed on the floor in the right back corner of the classroom 2 m away from the walls and at a height of 1.5 m from the floor. During the measurement the researcher supervised the procedure. The meter was the same as that used to evaluate ambient noise. The parameters measured were (a) equivalent continuous sound level, A Leq, that is, a continuous sound level with the same energy of a sound level during the specified period of time, and the statistical sound levels of (b) $L_{10}$, (c) $L_{50}$, and (5) $L_{90}$. The three last-mentioned levels occurred or exceeded the limits 10%, 50%, or 90% of the time measured, respectively.

## *Voice Data: Voice Samples and Variables*

Voice samples were recorded on the same day as the noise data were collected. The voice samples were spontaneous speech, text reading, and sustained phonation of vowel [a]. The voice samples were recorded 30–60 min before work (the morning sample) and 5–15 minutes after it (the afternoon sample) in a quiet, unoccupied meeting room at each school. One female participant did not provide the afternoon spontaneous speech and reading samples.

Spontaneous speech samples were 1-min responses to requests: "Tell me what you did this morning" (before work) and "Tell me about your typical working day" (after work). The participants were asked to speak continuously without any long thinking pauses. The reading sample was a 102-word text that included no sibilants so as to be amenable to spectrum analysis for studying voice quality. Another fricative in Finnish, [h], does not produce a friction sound (Iivonen, 1981), nor does Finnish contain aspirated plosives.

Sustained about 10 s, [a] was produced three times at habitual pitch and comfortable loudness. The researcher helped the participants to find their habitual speaking pitch and loudness because our clinical experience has shown that people in an examined situation have a tendency to produce sustained vowels with higher $F_0$ and softer voice SPL than usual. The phonation selected for acoustic analysis was the one that was steadiest and closest to the participant's habitual voice-production type.

The voice samples were recorded with a digital H2 recorder (Zoom Corporation, Tokyo, Japan) and a headset microphone (C555 L, AKG, Vienna, Austria) at a distance of 3 cm from the lip corner of the mouth. A short distance was selected because it is essential for measuring perturbation (Titze & Winholtz, 1993); the researcher measured it in every recording session. The recordings were calibrated for the measurements of voice SPL using a sound generator (BOSS TU-120, Roland Corporation, Los Angeles, CA) and a sound level meter (Brüel & Kjær 2206).

$F_0$ and voice SPL were analyzed from the spontaneous speech. In the SPL analysis, plosives and short, natural pauses between expressions (less than 2 s) were accepted, and this is why the voice SPL of spontaneous speech is not comparable with the values given in other studies (e.g., sound level of spontaneous speech was 13 dB [*SD* = 6.2 dB] lower for the morning and 15 dB [*SD* = 5 dB] lower for afternoon samples than the SPL of sustained phonations). Nonetheless, because spontaneous speech is a more natural voice use mode than sustained phonation and text reading, it was selected for the analysis of voice SPL and $F_0$.

From the text reading, the tilt of the sound spectrum slope (alpha ratio, relationship of voice energy levels between SPL of 50–1 kHz and SPL of 1–5 kHz) was calculated. The ratio expresses voice quality on a continuum of hypo- to hyperfunctional mode of voice production. Perturbation variables, jitter and shimmer, were measured from the sustained phonation. The phonations of all the participants could be classified as *Type I signals* (Titze, 1995)—that is, they were periodic or nearly periodic in nature, which meant that the perturbation analysis of these data can be considered reliable.

In addition, the changes in the voice variables during the working day were also taken as a dependent variable (called *voice change*; the values of the morning sampleswere subtracted from those of the afternoon samples). Furthermore, the absolute value of the voice change was calculated as well, because the participants' voice complaints varied quite a lot; hence, voice quality differed among participants and their reactions to loading might therefore differ accordingly. The absolute value of the variable was worthy of attention because, according to findings, voice loading may induce different vocal reactions in speakers: acoustic parameters of voice increased, exhibited normal values, or decreased (Jilek, Marienhagen, & Hacki, 2004; Lindstrom, Waye, Södersten, McAllister, & Ternström, 2011; Niebudek-Bogusz et al., 2007; Rantala et al., 2002).

Although research has shown that men use louder voice and have less jitter (Naufel de Felippe, Grillo, & Grechi, 2006) and shimmer (Brockmann, Storck, Carding, & Drinnan, 2008; Naufel de Felippe et al., 2006) than women, only $F_0$ was analyzed separately for each gender. This decision was made because a preanalysis of the data showed that the mean values of the voice variables did not differ significantly from each other between genders. The acoustic analyses were done with Praat software for Windows (Version 5.3.79; Boersma & Weenink, 2014).

## *Statistical Analyses*

Means and standard deviations were calculated for normally distributed variables and medians and interquartile range for nonnormally distributed ones (absolute value of voice SPL change, jitter before and after work, absolute value of jitter change, all parameters of shimmer, absolute value of alpha ratio change). The differences between acoustic variables before and after a working day were analyzed with Student's *t* test (paired samples) for the entire group and for women and Wilcoxon signed-ranks test (paired samples) for men due to the small sample size.

The associations between noise and voice variables were studied with Spearman's rho for nonnormally distributed variables and for the male group (small sample size).

Pearson's correlation coefficient was applied for the other variables.

To study the differences between the low and high noise groups, Student's *t* test or the Mann-Whitney *U* test for independent samples were used according to the distribution of the variable or the size of the group (male participants). Effect size for the group differences was calculated with Cohen's *d* (Cohen, 1988). Interpretation of the values was as follows: .2 = small, .5 = medium, and .8 = large effect.

The statistical significance levels were reported up to the level of .05, although it might permit a Type I error to occur due to the many statistical calculations computed. This liberal decision was made because the study was one of the first to investigate the effects of noise in a real work environment. The analyses were carried out with PASW Statistics 18.0 software for Windows/Mac operating system (SPSS, Inc., Chicago, IL).

### *Ethical Considerations*

Participation was voluntary and participants were free to withdraw from the study at any time. No social security number or other identification data were collected and no invasive examinations were conducted. The project was granted the approval of the relevant school authorities. According to legal advice, the study setting did not require ethical approval.

## Results

### *Ambient and Activity Noise and Voice Variables*

The means for the ambient noise level and the activity noise levels in the classrooms are presented in Table 1, and the values of the voice variables for the morning and afternoon samples are in Table 2. Among the variables, jitter and shimmer values decreased significantly during the working day.

### *Correlations Between Noise and Voice Variables*

The results showed that the higher the ambient noise, the higher the participants' SPLs in the morning and afternoon samples (Table 3). The ambient noise levels also correlated with the $F_0$ of the male voices: the higher the noise level, the lower the men's $F_0$ in the morning and afternoon voice samples. These correlation coefficients were the strongest in the study.

**Table 2.** Means and medians[a] (standard deviations and interquartile ranges in parentheses) for voice variables before (morning) and after work (afternoon).

| Voice variable | Time of measurement: Morning *M* (*SD*) | Afternoon *M* (*SD*) |
|---|---|---|
| Voice SPL @ 0.03 m (dBA) | 67 (5.4) | 69 (4.3 ) |
| $F_0$ (Hz) by gender | | |
| F, *n* = 32 | 182 (15.7) | 185 (17.2) |
| M, *n* = 8 | 97 (11.6) | 102 (14.9) |
| Alpha ratio (dB) | –15.7 (1.28) | –15.2 (2.06) |
| | ***Med.* (IQR)** | ***Med.* (IQR)** |
| Jitter (%) | 0.59 (0.24) | 0.43 (0.125)[b] |
| Shimmer (dB) | 0.26 (0.075) | 0.20 (0.05)[c] |

*Note.* IQR = interquartile range; $F_0$ = fundamental frequency.
[a]Means and standard deviations are for normally distributed variables and medians and interquartile ranges for nonnormally distributed variables. [b]$p = .002$ ($z = –3.159$; effect size = .84).
[c]$p = .001$ ($z = –3.226$; effect size = .94) for differences.

The activity noise levels correlated more often with the voice variables of the afternoon samples than those of the morning samples (Table 4). Furthermore, every activity noise level was found to be associated with the voice variable analyzed from the afternoon samples, but only one noise level ($L_{90}$) was related to the voice variable of the morning samples. The associations between the variables were negative except for the shimmer of the morning sample. Of the voice variables, only the $F_0$ of the male voices correlated with a noise variable ($L_{90}$) measured in both morning and afternoon samples.

The activity noise levels were associated more often with the voice change than with the values of the voice variables measured from the morning or afternoon samples. The voice SPL and the alpha ratio had the highest number of correlations: They correlated with all the other noise levels except $L_{90}$ (Table 5).

Of the voice variables, the voice SPL and the jitter changed nonlinearly (the absolute value of the change in the variable; see Table 5). The interpretation of this result is that during higher activity noise, the participant's voice SPL changed less (negative correlation)—that is, the voice

**Table 1.** Ambient and activity noise levels (standard deviations in parentheses) in classrooms. Mean number of lessons = 4, *N* = 40.

| | Ambient noise level (dB) | Activity noise level (dB) | | | |
|---|---|---|---|---|---|
| | A Leq $_{1\ min}$ | A Leq $_{2–6\ h}$ | $L_{10\ 2–6\ h}$ | $L_{50\ 2–6\ h}$ | $L_{90\ 2–6\ h}$ |
| Mean | 34 (5.6) | 68 (5.4)[a] | 68 (4.2) | 55 (4.8) | 42 (4.1) |
| Minimum | 21 | 57 | 57 | 42 | 29 |
| Maximum | 44 | 80 | 77 | 64 | 51 |

[a]*N* = 39; one value of the parameter was 87 dB. This may be an outlier or a measurement error/artefact and was deleted from the data.

**Table 3.** Statistically significant correlation of coefficients between measured ambient noise levels voice variables from samples recorded before (morning) and after (afternoon) work ($N$ = 39–40; 8 men, 31–32 women).

| Voice variable | Morning | | Afternoon | |
|---|---|---|---|---|
| | Correlation | *p* value | Correlation | *p* value |
| Voice SPL | .31 | .027 | .36 | .012 |
| Men's $F_0$ | −.95 | .000 | −.85 | .004 |

*Note.* $F_0$ = fundamental frequency. Women's $F_0$ correlated with no noise variables.

SPL could either increase or decrease, but it increased or decreased less than in those participants who worked in quieter conditions (voice SPL increased in 22, decreased in 10, did not change in six participants). Likewise, if activity noise was louder, the participants' jitter values either increased or decreased more markedly (positive correlation).

The shimmer correlated with the same activity noise parameter—namely, with $L_{90}$—as it had in the morning voice samples (Table 5). The connections showed that the higher the noise levels in the classrooms, the higher the shimmer values in the participants' voices before work but the less the values changed during the day.

### *Differences Between the Low- and High-Noise Groups*

The means for the noise values of the low- and high-noise groups are presented in Table 6. Because there were classrooms that had the same noise levels, the low- and high-noise classrooms could not be divided exactly in half, and hence the number of classrooms varied in the analysis of different noise variables.

Differences between the groups were most often found in the voice variables measured from the morning samples (Table 7) and in the variables expressing the voice change during work (Table 8). If the participant had worked in a noisy classroom, his or her voice SPL was 3 dB higher before work than it was for his or her peers who taught in quiet classrooms. A difference was also found in shimmer (0.9 dB higher in the high activity noise level of $L_{90}$). The effect size of this difference was large. The only difference between the groups found in the afternoon voice samples was detected in the male participants' $F_0$ (Table 7). The male teachers whose classrooms had high ambient noise levels used a $F_0$ that was 19–26 Hz lower before work than those who worked in quieter classrooms; after work the situation had not changed: $F_0$ was still lower (15–40 Hz) in the men of the high-noise group.

Two voice variables—voice SPL and alpha ratio—changed differently in the low- and high-noise groups (Table 8). The nature of these changes also differed. Voice SPL altered less in the high-noise group than in the low-noise group. Alpha ratio, in turn, changed in different directions: increased in the low-noise group but decreased, albeit slightly, in the high-noise group. The effect size was large for the group difference in alpha ratio under $L_{50}$ noise. The finding of voice SPL confirmed the results given by the correlation analysis, whereas the test for the group differences revealed the nature of the change in the alpha ratio more precisely (see Table 5).

## Discussion

The results of this research confirmed the known connection between noise and voice production (Aronsson et al., 2007; Cooke & Lu, 2010; Garnier et al., 2010; Kristiansen et al., 2014; Patel & Schell, 2008; Sato & Bradley, 2008; Södersten et al., 2005). The results also showed that ambient noise has developed in a favorable direction: On average, the ambient noise level for all the classrooms (34 dB) was within the recommended level (35 dB; ANSI/ASA S.12.60-2010). However, there were still many classrooms where the recommended level was exceeded. Activity noise levels, in turn, have not changed for decades: They were as high as they were 10 (Shield & Dockrell, 2004) or 20 years ago (Pekkarinen & Viljanen, 1991). From these results, we can infer that teachers and pupils need to raise their voice SPL in order to be heard in a classroom (van Heusden et al., 1979).

**Table 4.** Statistically significant correlation of coefficients between activity noise levels and voice variables measured from samples recorded before (morning) and after (afternoon) work ($N$ = 39–40; 8 men, 31–32 women).

| | Noise | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Morning | | Afternoon | | | | | | | |
| | $L_{90}$ | | A Leq | | $L_{10}$ | | $L_{50}$ | | $L_{90}$ | |
| Voice | Correlation | *p* value | Correlation | *p* value | Correlation | *p* value | Correlation | *p* value | Correlation | *p* value |
| Men's $F_0$ | .62 | .05 | NS | NS | NS | NS | NS | NS | −.64 | .045 |
| Alpha ratio | NS | NS | −.28 | .044 | NS | NS | NS | NS | NS | NS |
| Jitter | | | | | −.33 | .019 | −.28 | .043 | NS | NS |
| Shimmer | .27 | .049 | NS | NS | NS | NS | NS | NS | NS | NS |

*Note.* $F_0$ = fundamental frequency; NS = not significant. Women's $F_0$ correlated with no noise variables.

**Table 5.** Statistically significant correlation of coefficients between activity noise levels and the changes in voice variables during a working day ($N$ = 39–40, measured time for noise 2–6 h).

| | Noise | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A Leq | | $L_{10}$ | | $L_{50}$ | | $L_{90}$ | |
| Voice | Correlation | $p$ value | Correlation | $p$ value | Correlation | $p$ value | Correlation | $p$ value |
| Voice SPL | –.35[a] | .016 | –.35[a] | .014 | –.37[a] | .011 | NS | NS |
| Alpha ratio | –.36 | .012 | –.32 | .024 | –.28 | .043 | NS | NS |
| Jitter | .27[a] | .043 | NS | NS | NS | NS | NS | NS |
| Shimmer | NS | NS | NS | NS | NS | NS | –.27 | .046 |

*Note.* NS = not significant.

[a]Absolute value of change.

## *Associations Between Noise and Voice Variables*

This research offered a new perspective on the study of the effects of two different noises (ambient noise and activity noise), separately, in a real working environment. Because our intention was to explore the phenomenon as completely as possible, we researched many variables regarding both noise and voice. Consequently, the image illustrating the connection between noise and voice proved fairly complex and difficult to interpret. However, the findings do indeed permit some conclusions to be drawn.

First, ambient and activity noise affected voice variables somewhat differently. Ambient noise was relatively more often connected with voice SPL and the men's $F_0$, whereas activity noise correlated more frequently with alpha ratio and perturbation values. Second, the voice production of the teachers working in higher ambient and activity noise levels differed before work: The teachers subjected to higher ambient noise levels used higher voice SPL, and the teachers working in higher activity noise levels had more uneven vocal fold vibration (higher shimmer values) than those working in lower noise levels. Third, less change in voice parameters was observed during the working day among those teachers in whose classrooms there was a higher level of activity noise than among those in whose classrooms there was less noise.

The different effects of ambient and activity noise were especially apparent in the voice SPL of the teachers: In higher ambient noise the teachers raised their voice SPL (voice samples before and after work), but in louder activity noise teachers' voice SPL changed less during a working day (absolute value of voice SPL change). The result seems to indicate that the Lombard effect influences speakers' voice SPL more consistently under ambient noise than under activity noise.

**Table 6.** Ambient noise (A Leq $_{1\ min}$) and activity noise (A Leq, $L_{10}$, $L_{50}$, $L_{90}$, measured time 2–6 h) levels in the classrooms with low and high noise levels ($N$ = 40).

| Noise variable | Low noise level (dB) | | High noise level (dB) | |
|---|---|---|---|---|
| | $n$ | $M$ ($SD$) | $n$ | $M$ ($SD$) |
| A Leq $_{1\ min}$ | 21 | 30 (3.8) | 19 | 39 (3.2) |
| A Leq | 20 | 64 (2.7) | 19 | 73 (4.0) |
| $L_{10}$ | 20 | 65 (2.9) | 20 | 71 (2.5) |
| $L_{50}$ | 17 | 51 (3.4) | 23 | 58 (2.8) |
| $L_{90}$ | 22 | 39 (3.1) | 18 | 45 (2.3) |

Some of the characteristics of ambient noise may account for speakers' reactions to it. A typical feature of such noise is that it is mostly constant and continuous. In ambient noise, speakers do not have the same avoidance opportunities they have if the noise fluctuates, as is the case with activity noise. Under fluctuating noise, people are prone to decrease speech in noisy moments but increase it in silent ones (Aubanel & Cooke, 2013). The other common feature for ambient noise is that it contains low frequencies. Consequently, people commonly find ambient noise to be louder than one could conclude on the basis of the values of a sound level meter (A-weighted) alone (Berglund et al., 1996). In addition, low-frequency noise has been found to be annoying, and this effect persists even after the apparent loudness has decreased (Broner, 2008). Annoyance, in turn, raises stress (Bakker, Pedersen, van den Berg, Stewart, Lok, & Bouma, 2012), and this affects voice production (Giddens, Barron, Byrd-Craven, Clark, & Winter, 2013).

In contrast to ambient noise, activity noise usually comprises frequencies similar to those of the human voice and so largely masks speech (Simpson & Cooke, 2005). Speakers are prone to compensate for this by increasing prosody (Garnier et al., 2010)—that is, not linearly raising the pitch and loudness but varying the levels of these vocal features. Such unsystematic variation of $F_0$ and voice SPL may explain the nonlinear effect of activity noise on the teachers' voices in this study.

Another feature of activity noise as opposed to ambient noise is that it fluctuates depending on the situation. This may be why the teachers reacted to it probably more consciously than to ambient noise. Our clinical experience supports this explanation: Teachers often report that they have developed strategies to use if pupils' classroom work turns noisy: Instead of shouting over the racket, they wait until the noise abates or they use other means to get attention, such as clapping their hands, using a whistle, or giving orders with the help of pictures. Speakers' tendency to

**Table 7.** Means (standard deviations) for voice variables in participant groups with low and high noise levels in the classrooms. Only those voice variables correlating with noise were analyzed (see Tables 4 and 5 for the variables).

| | | Morning samples | | |
|---|---|---|---|---|
| Noise variable | Voice variable | Low-noise group, $n$ = 15–23 | High-noise group, $n$ = 17–25 | Significance of difference and ES |
| Ambient noise | Voice SPL @ 0.03 m (dBA) | 66 (6.82) | 69 (2.05) | $p$ = .044, $t$ = −2.128, ES = −.59 |
| | $F_0$/males[a] (Hz) | 110–111 | 83–100 | Not calculated |
| $L_{90}$ | $F_0$/males[b] (Hz) | 91–111 | 85–111 | Not calculated |
| | Shimmer (dB) | 0.24 (0.05) | 0.33 (0.12) | $p$ = .016, $z$ = −2.39, ES = −.98 |
| | | Afternoon samples | | |
| Ambient noise | Voice SPL @ 0.03 m (dBA) | 68 (4.73) | 70 (3.67) | NS |
| | $F_0$/males[b] (Hz) | 115–124 | 83–100 | Not calculated |
| $L_{Aeq}$ | Alpha ratio (dB) | −14.9 (1.64) | −15.4 (2.37) | NS |
| $L_{10}$ | Jitter (%) | 0.51 (0.105) | 0.34 (0.075) | NS |
| $L_{50}$ | Jitter (%) | 0.44 (0.115) | 0.33 (0.095) | NS |
| $L_{90}$ | $F_0$/males[b] (Hz) | 92–124 | 83–115 | Not calculated |

*Note.* ES = effect size; NS = not significant; $F_0$ = fundamental frequency. Women's $F_0$ correlated with no noise variables.

[a]Due to the small number of male teachers, range was given and difference between the groups was not calculated. For men, the low-noise group ($n$ = 3), range of age 32–48 years and range of Voice Handicap Index (VHI) scores 3–31; the high-noise group ($n$ = 5), 31–45 years and scores of 1–21, respectively. [b]For men, the low-noise group ($n$ = 4), range of age 32–44 years and range of VHI scores 3–17; the high-noise group ($n$ = 4), 31–48 years and scores of 1–31, respectively.

avoid temporal overlap with other people's speech has also been found in laboratory conditions (Aubanel & Cooke, 2013; Cooke & Lu, 2010). Individual and, hence, conscious vocal reaction patterns to noise have also been detected in kindergarten teachers (Lindstrom et al., 2011).

Although the Lombard effect typically affects voice pitch by raising it (e.g., Garnier et al., 2010), we found different impacts on the $F_0$ of our participants. First, voice pitches did not change in the female teachers but only in the men (under ambient and $L_{90}$ noise before and after work). As stated by Stowe and Golob (2013), the Lombard effect on $F_0$ may be not a general response to any competing sound in the environment but rather a response to the frequencies vital for speech. Thus, the fact that the energy of ambient noise is generally located in the 20- to 100-Hz band (Berglund et al., 1996) may explain why this noise only affected the male speakers' voices. Furthermore, the similar effect of the ambient and $L_{90}$ noise on voice is very likely because they originate partly from the same sources (Pekkarinen & Viljanen, 1991).

Second, the direction of the association between the noises and male teachers' $F_0$ was not consistent with the Lombard effect: the higher the noise levels, the lower the $F_0$. One reason for the lowered voice pitch may result from the male teachers' attempts to express dominance (Hodges-Simeon, Gaulin, & Puts, 2010) in order to control pupils in a noisy classroom. The lowered voice pitch may have also derived from vocal loading: Edema in the vocal fold mucosa decreases the vibration rate of the vocal folds (Stemple, Glaze, & Klaben, 2000). Because the number of male teachers was low, this particular result remains open to further research.

**Table 8.** Means (standard deviations) for sizes of voice changes in participant groups with low and high noise levels in the classrooms. Only those voice variables that correlated with noise were analyzed (see Table 6 for the variables).

| | | Size of voice change during work | | |
|---|---|---|---|---|
| Noise variable | Voice variable | Low-noise group, $n$ = 17–22 | High-noise group, $n$ = 18–23 | Significance of difference and ES |
| $L_{Aeq}$ | Voice SPL @ 0.03 m (dBA)[a] | 4.5 (5.3) | 2.9 (4.2) | NS |
| | Alpha ratio (dB) | 1.1 (1.43) | −0.12 (1.64) | $p$ = .024, $t$ = 2.35. ES = −.28 |
| | Jitter (% points)[a] | 0.21 (0.194) | 0.3 (0.3) | NS |
| $L_{10}$ | Voice SPL @ 0.03 m (dBA)[a] | 3 (5.3) | 2 (4.0) | NS |
| | Alpha ratio (dB) | 0.93 (1.58) | -0.26 (1.6) | $p$ = .025, $t$ = 2.34, ES = .75 |
| $L_{50}$ | Voice SPL @ 0.03 m (dBA)[a] | 3 (5.6) | 1.5 (3.8) | $p$ = .035, $z$ = −2.12, ES =.31 |
| | Alpha ratio (dB) | 1.14 (1.53) | −0.25 (1.56) | $p$ = .008, $t$ = 2.79, ES = .9 |
| $L_{90}$ | Shimmer (dB) | −0.06 (0.16) | −0.14 (0.11) | NS |

*Note.* ES = effect size; NS = not significant.

[a]Absolute value of change.

Among the voice variables, alpha ratio (spectrum slope) was the one that was more sensitive to activity noise than to ambient noise. It was associated with all the parameters of activity noise except $L_{90}$: the higher the activity noise levels, the lower the alpha ratios (i.e., steeper spectrum slope, more hypofunctional voice quality). This result deviates from the expectations on the basis of earlier studies, according to which voice spectrum levels out (more hyperfunctional voice quality) under noise exposure (Cooke & Lu, 2010; Garnier et al., 2010) and loading caused by teaching (Laukkanen et al., 2008). It is possible that the leveling of the spectrum (increased alpha ratio) is a normal reaction both to noise and vocal loading. However, if both burdening factors are present—loading and loud activity noise—the loading reaction may be greater and so lead to greater changes such as a lowered muscle tonus in the vocal organs. This claim is supported by another finding of ours: In the classrooms with higher activity noise level (high-noise group), the teachers' alpha ratios decreased during a working day (more hypofunctional voice quality), but in the quieter ones they increased (more hyperfunctional voice quality). This was particularly obvious in $L_{50}$ (large effect size).

There may be another explanation for the decreased alpha ratios besides weakened muscle tone. In our clinical experience, if a speaker's voice has noise elements due to air leakage through her or his vocal folds, even slightly, the alpha ratio decreases even though the speaker's phonation mode remains as hyperfunctional as before. Thus, our finding regarding activity noise and alpha ratio may not contradict the results of earlier studies (see Cooke & Lu, 2010; Garnier et al., 2010). Changes into a more pressed phonation mode in our participants with louder pupils might not have emerged because their voice qualities had possibly turned hoarse or breathy due to loading-related changes in the larynx. Naturally, a perceptual evaluation of the voice quality would be needed to verify this assumption.

It is a cause of clinical concern in this study that ambient noise was not only associated with the raised voice SPL of the afternoon samples but also with those samples recorded before work. Moreover, the noise-induced effect was even more obvious before work than after it (higher voice SPL before work in teachers with noisy classes). This suggests that teachers may habitually use a loud voice in loud ambient noise environments, particularly if the noise persists day after day over a period of years. In addition, teaching entirely fulfills the conditions in which speech modification is most intensive: in an interactive situation with a need for clear communication (Garnier et al., 2010). The persistence of adopting a louder voice after cessation of subjection to noise has not, as far as we are aware, been scientifically documented. What we do know is that it continues for at least some minutes (Södersten et al., 2005).

Furthermore, the observation that voice features changed less among teachers working in noisy classes may suggest that these teachers' vocal organs had already undergone changes due to vocal loading. Namely, there is a general tendency in human organs that their ability to react —that is, to change their functions—deteriorates when loading persists (Enoka, 1988). The phenomenon has also been found in voice use: The voices of teachers with severe voice symptoms changed less during a working day than did the voices of those with mild symptoms (Rantala et al., 2002).

Moreover, the long-term effects of noise can also arguably be detected in shimmer before work. Its values were elevated in the teachers working in high $L_{90}$ noise. The value also had a tendency to decrease in those whose working environment was noisy, which implies that the teachers' voice production probably changed in a more hyperfunctional direction (see Laukkanen et al., 2008).

### *Methodological Considerations*

Some effect sizes of our results were small. One reason for this was that this study was conducted in an authentic school environment, where acoustic conditions in the classrooms were quite similar, and consequently, the values of the variables could hardly differ very much. Furthermore, because our results reflected more the effects of long-term exposure to fairly low doses of noise, it is obvious that the effect sizes in this study were smaller than those found in laboratory settings, where momentary loading with high noise levels can demonstrate the connections more clearly. In addition, the consequences of long-term loading cannot be interpreted unambiguously because they are likely due to varying reasons. Some of them may manifest fatigue, some tissue damage in the vocal folds, and some compensatory reactions to the problems due to fatigue and tissue damage (see Enoka, 1988). Thus the reasons mentioned herein complicate the evaluation of the meaning of the low values of effect sizes in this study.

The absolute change in a voice variable, a new parameter used in the study, showed its potential to reveal speakers' vocal reactions in a situation where the direction of the change of a parameter is nonlinear. Without this variable we could not have found certain results; it was instrumental in the observation of the change in the voice SPL. This parameter may especially suit study settings where speakers can react individually and intentionally to the circumstance as in real working environments (see e.g., Lindstrom et al., 2011). On the other hand, individual reactions in voice use have also been detected in laboratory conditions (Niebudek-Bogusz et al., 2007).

There were some limitations in the study setting that may have affected the results. First, of the variables, jitter and shimmer were the most doubtful parameters. Acoustic analysis has been shown to be somewhat unreliable especially for dysphonic voices with severely perturbed sound signals (Carding et al., 2004; Titze, 1995), and invalid (Kreiman & Gerratt, 2005) but opposite findings have also been reported (Zhang & Jiang, 2008). On the other hand, for normal voices, perturbation analysis is more trustworthy (Carding et al., 2004). However, a cepstrum analysis used in recent voice studies (see, e.g., Awan, Roy, & Cohen, 2014) might have been a good addition in the acoustic analysis of this study.

Second, it is possible that factors other than noise also influenced the teachers' voice production. One of these extraneous elements is undoubtedly stress, with its direct and indirect effects on voice (Giddens et al., 2013; Mendoza & Carballo, 1998). Moreover, we did not separate the participants according to their sensitivity to noise, and that, too, may have had an impact on the results (Berglund et al., 1996).

Third, the voice variables were studied separately by gender, $F_0$ being the only exception. This was because the number of male participants was low and the values of the voice variables were very similar between genders (except $F_0$). Nevertheless, because voice features (Brockmann et al., 2008; Naufel de Felippe et al., 2006) as well as the vocal strategies used under noise may differ between genders, research including only one gender was called for.

Fourth, the short mouth-to-microphone distance used in this study may have skewed the results. Although the researcher monitored the position of the microphone throughout the recordings, there may have been small differences in distances that may have affected the voice SPL values. In addition, it is a disadvantage of a short distance that it also boosts lower frequencies (Švec & Granqvist, 2010). Because our protocol for the recordings did not change at any time, the bias due to the distance is linear, but the alpha ratio values of this study cannot be compared with those of other studies.

Last, a choice possibly influencing the results was risking Type I error (despite many statistical computations, $p$ level was $\leq .05$), thereby favoring sensitivity at the expense of specificity. This was done because to the best of our knowledge, the effect of noise has not been studied before with the design we used in our research. In addition, because the study was performed in real working environments, numerous extraneous variables might have inhibited the emergence of results if the statistical criteria had been too strict.

### *Conclusions and Clinical Implications*

Ambient and activity noise both affect voice features but to some extent in different ways, perhaps due to their different qualities. If the ambient noise in a classroom is loud, the teacher uses a louder voice even before work, and perturbation values are higher than among those working in quieter working environments. Male teachers use lowered voice pitches under loud ambient noise. Teachers' voice SPLs change less and spectrum slopes steepen more (reflecting more hypofunctional voice quality) while working in high activity noise levels than while working in lower activity noise levels. These findings may illustrate the loading-induced effects of noise or compensation reactions to it.

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