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The Effect of Classroom Capacity on Vocal Fatigue as Quantified by the Vocal Fatigue Index

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Abstract

Objective: Previous research has concluded that teachers are at a higher-than-normal risk for voice issues that can cause occupational limitations. While some risk factors have been identified, there are still many unknowns.

Patients and Methods: A survey was distributed electronically with 505 female teacher respondents. The survey included questions to quantify three aspects of vocal fatigue as captured by the Vocal Fatigue Index: general tiredness of voice (performance), physical discomfort associated with voicing (pain), and improvement of symptoms with rest (recovery). The effect of classroom capacity on U.S. teachers' self-reported experience of vocal fatigue was analyzed.

Results: Results indicated that a classroom's capacity significantly affected teachers' reported amounts of vocal fatigue, while a teachers age also appeared to significantly affect the reported amount of vocal fatigue. A quadratic rather than linear effect was seen with the largest age effect occurring at around 40–45 years in all three factors of the VFI.

Conclusion: Further factors which may affect vocal fatigue must be explored in future research. By understanding what increases the risk for vocal fatigue, educators and school administrators can take precautions to mitigate the occupational risk of short- and long-term vocal health issues in school teachers.

Keywords

Vocal fatigue; VFI; Vocal Fatigue Index; teachers; occupational risk

1.0 INTRODUCTION

Over the last three decades, there has been a heightened interest in examining voice problems associated with people who use their voice as a tool of the trade, such as school teachers. Research has indicated that school teachers are at high risk for experiencing short- and long-term problems with their voice [1, 2]. For example, in a survey of over 2,500 teachers and non-teachers in the United States, it was reported that 57.7% of school teachers had experienced voice problems during their lifetimes. In comparison, only 28.8% of non-

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teachers had experienced voice problems [3] during their lives. According to the study, 11% of the school teacher population surveyed also reported having current voice issues (almost double that of non-teachers). Additionally, female occupational voice users have been reported to have a higher instance of voice problems than males [4]. In these cases, not only is the teacher's health and quality of life impacted, but the students are less likely to learn the information taught in class [5, 6].

A common vocal complaint of teachers is vocal fatigue. Vocal fatigue has been described clinically as an adverse reaction of voice users to extended periods of vocal load [7]. Titze et al. [8] has suggested that symptoms of vocal fatigue may be reduced by adding small short-term periods of vocal silence throughout the day. Additionally, other research has indicated that hours or even days may be needed in order to fully recover from multiple hours of prolonged voice use [9]. Nevertheless, vocal fatigue has been difficult to quantify which has made it difficult to directly link potential risk factors to voice problems.

Recently a Vocal Fatigue Index (VFI) [10] was validated which may aid in providing a more standard quantifying of vocal fatigue. The VFI is a 19 question scale used to quantify the amount of vocal fatigue experienced by a given individual in the following three scored categories: general tiredness of voice (performance), physical discomfort associated with voicing (pain), and improvement of symptoms with rest (recovery). The VFI may be a useful tool in identifying factors that affect the amount vocal fatigue reported by occupational voice users.

Many different factors have been implicated as possible contributors to the increased vocal risk factors in occupational voice users. One such factor is classroom acoustics. Poor classroom acoustics have been shown to be a factor that may increase the likelihood that school teachers experience voice problems. Bottalico et al. [11] indicated that in classrooms with longer reverberation times (generally associated with larger volumes) teachers adopt vocal behaviors that are increasing the likelihood of acquiring voice problems. Kob et al. [12] reported that differences in the room acoustical conditions in classrooms seemed to affect teachers with voice problems more than healthy teachers. Therefore, vocal health issues could likely be improved by improving classroom acoustics. This could be associated with the fact that more time speaking in larger and more reverberant classrooms increases reports of vocal effort.

Brunskog et al. [13] objectively investigated vocal adjustments and subjective judgments of talkers due to changes in physical attributes of a room (e.g., sizes, reverberation times). An increase in a talker's vocal power was found to be correlated with room size and the amplification by the room of the talker's voice at her/his ears (termed "room gain").

High noise levels in the classrooms are a frequently mentioned cause of teachers' voice problems, with noise levels varying between 56.3 and 76.8 dB(A) according to the children's activities and the number of children in the classroom [14, 15]. As classroom dimensions increase to accommodate more children, noise present in those active classrooms increase as well. Though regulations differ from state to state, there are recommendations for the number of students allowed per classroom and per teacher. These recommendations

are calculated by rule and are roughly 20 square feet of the total square footage of a classroom for each student (National Association of State Fire Marshals).

In 2002, the American National Standard Institute published guidelines regarding optimal classroom acoustics (ANSI S12.60–2002). ANSI recommended that the background noise present in an unoccupied classroom remain at or below 35 dB(A). They also recommended that reverberation times remain < 0.6 seconds in smaller classrooms < 0.7 seconds in larger classrooms. Knecht *et al.* [16] found that most school classrooms surveyed (87.5%) did not meet either of these requirements.

Given the elevated vocal risk of teachers generally, and the likely tie between vocal risk and poor classroom acoustics, the current study was designed to answer the following question: How is reported vocal fatigue (as quantified by the VFI score) in an average female teacher associated to the classroom size when controlling for the age of the teacher? In addressing this question, the hypothesis was that female teachers would report higher level of vocal fatigue when (1) teaching in larger classrooms and (2) age increased. While age is not the primary question, age should be accounted for since voice does change with age [17] and a teacher's age has been found to have a negative effect on the reported amount of voice problems, especially in females. For example, several studies have found that females older than 40 consistently experience more instances of voice problems than their male counterparts [3, 18, 19].

2.0 MATERIAL AND METHODS

2.1 Human Subjects

This research was conducted in accordance with protocols outlined by Michigan State University's Human Research Protection Program (determined exempt by the Michigan State University Institutional Review Board). Participants gave their consent to participate in this study. A survey was sent via email to kindergarten to 12th grade female teachers from school districts throughout the United States, primarily focusing on Michigan, Utah, Tennessee, Alabama, Florida, Georgia, New Hampshire, and South Carolina. Responses were received from teachers in more than 30 states throughout the United States. Within the email, a link to the survey was provided. Some paper copies of the survey were completed in both Tennessee and Utah by colleagues in those areas. Finally, various listserv databases associated with teacher/education organizations were used to distribute links to this survey and obtain grade-level specific information.

Only responses from female teachers were used in the analysis because previous research has indicated a higher prevalence of voice disorders in females than males [4]. Given that most teachers are female and most of the survey respondents were female, focusing on female teachers in the analysis is a prudent focus. As such it was anticipated that results from this population would aid most in the understanding of vocal fatigue, its symptoms and development over time.

2.2 Survey

The online survey included 61 questions and was implemented by means of Qualtrics Survey software. To avoid overtaxing and high dropout rates, the length of the survey was set up to be completed in less than 15 minutes. Questions included the 19 items of the VFI and other vocal fatigue factors [20], as well as several questions inquiring about classroom capacity, class capacity (number of students) and teachers' age. Regarding the classroom capacity, the teachers were asked to describe the classroom where they primarily teach. They were asked to choose from among the following options: Small Room: (i.e., office, special needs room, 5–10 student capacity); Medium Room: (i.e., general core classroom, art room, 16–35 capacity); Large Room: (i.e., shop, music or performance room, 35+ capacity); and Very large Room: (i.e., gymnasium, cafeteria, auditorium, outdoors).

2.3 Analysis

Poisson log-linear Generalized Linear Models (GLMs) were used to test the associations between the VFI (the three components of performance, pain, recovery, and the total VFI) and the primary classroom capacity (four levels: small, medium, large, very large) and the age (considered as continuous variable).

Deviance of the Poisson log-linear GLM was tested against degrees of freedom using χ^2 distribution in order to detect and then account for potential overdispersion which is common for this type of data [21]. Statistical significance of each parameter was then assessed with likelihood ratio-based χ^2 - statistics. A post hoc multiple comparison test was used after the GLM test to capture differences between classroom capacities to identify differences between groups. The analysis was conducted using the “R Project for Statistical Computing” software (R Core Team, 2014) implemented with the “AER” package (“dispersion test” function for overdispersion detection) and the `dispmod` package (“`glm.poisson.disp`” function for Poisson log-linear GLM overdispersion correction). Nested models were compared by χ^2 - test.

As the three sections of the survey were analyzed using a single summed vector method of analysis [10], if all of the questions of the VFI were not answered, the given subject was not included in the analysis.

3.0 RESULTS

Of the 570 female teacher respondents, 506 surveys were fully completed with an average completion time of 12.5 minutes. Among the completed responses, 50 teachers reported that they were teaching in small classrooms, 357 in medium ones, 88 in large ones and 11 in very large ones. The average reported VFI score for the individual scored factors (performance, pain, recovery) averaging 16.7, 5.9, and 2.4 respectively. The average age of the respondents in this study was 42.9 years.

Using VFI values suggested by Nanjundeswaran *et al.* [10], it was found that over 60% of teachers who responded indicated that they were currently experiencing vocal fatigue. This persistence of vocal fatigue are consistent with those of Roy *et al.* [3], which stated that 58%

of teachers reported having issues with proper voice use or sound at the time they were surveyed.

The following subsections 3.1, 3.2, and 3.3 provide statistical results for each of the 3 factors categorized by the VFI. The distributions of the VFI scores associated with the three factors were most consistent with the Poisson distribution, according to the log-likelihood and plots of the fit of various possible distributions. Hence, generalized linear model (GLM) was fit with the Poisson family of distributions and the log link function.

3.1 VFI Performance (Factor 1)

An overdispersion-corrected Poisson log-linear generalized linear model was fit with the response variable of VFI Factor 1 (performance) and the covariates (1) classroom capacity and (2) age of teachers. The reference level for classroom capacity was small. The output of this model is reported in Table I. The goodness of fit model was evaluated with the Hosmer-Lemeshow test, which assesses if the difference between the observed data and predicted data is statistically significant ($\chi^2 = -1.11$, $df = 8$, $p = 1$).

As indicated in the table and shown in Figure 1, the VFI Factor 1 increased when the classroom capacity was bigger. The mean value scored by the teachers was 12.38 (standard error, se 0.93) in small classrooms, 17.02 (se 0.42) in medium classrooms, 19.39 (se 0.93) in large classrooms, 22.55 (se 2.25) in very large classrooms. As indicated by Tukey's post-hoc multiple comparisons, responses to questions in Factor 1 was higher in larger classrooms and all the differences were statistically significant with the exception of the pairs very large – medium and very large – large classrooms, due to the low number of respondents teaching in very large classrooms (medium - small: estimate = 0.32, $z = 4.55$, $p < 0.001$; large - small: estimate = 0.46, $z = 5.47$, $p < 0.001$; very large - small: estimate = 0.58, $z = 3.88$, $p < 0.01$; large - medium: estimate = 0.14, $z = 2.57$, $p = 0.04$; very large - medium: estimate = 0.26, $z = 1.94$, $p = 0.18$; very large - large: estimate = 0.13, $z = 0.88$, $p = 0.79$).

Regarding the effect of the age on Factor 1, the preferred model was the one with second grade polynomial age terms. This means that the relation between Factor 1 is not monotonic but there is an inflection point that is changing the direction of the relation between Factor 1 and age. Figure 2 shows the aforementioned relationship, with the inflection point located between 40 and 45 years.

3.2 VFI Factor 2, Pain

An overdispersion-corrected Poisson log-linear generalized linear models was fit with the response variable from VFI Factor 2 (pain) and the covariates (1) classroom capacity and (2) age. The reference level for classroom capacity was small. The output of the model is reported in Table III. The goodness of fit model was evaluated with the Hosmer-Lemeshow test ($\chi^2 = -4.39$, $df = 8$, $p = 1$).

As indicated in the table and shown in Figure 3, the VFI Factor 2 score increased when the classroom capacity was bigger. The mean value scored by the teachers was 4.5 (standard error, se 0.51) in small classrooms, 6.09 (se 0.22) in medium classrooms, 7.06 (se 0.47) in large classrooms, 9.60 (se 1.71) in very large classrooms. As indicated by Tukey's post-hoc

multiple comparisons, VFI Factor 2 was higher in larger classrooms and all the differences were statistically significant with the exception of the pairs large – medium, very large – medium and very large – large classrooms (medium - small: estimate = 0.30, $z = 2.82$, $p = 0.02$; large - small: estimate = 0.47, $z = 3.82$, $p < 0.001$; very large - small: estimate = 0.72, $z = 3.24$, $p = 0.05$; large - medium: estimate = 0.16, $z = 2.13$, $p = 0.13$; very large - medium: estimate = 0.41, $z = 2.08$, $p = 0.14$; very large - large: estimate = 0.25, $z = 1.19$, $p = 0.60$).

Regarding the effect of the age on VFI Factor 2, the preferred model was the one with second grade polynomial age terms. This means that the relation between this factor is not monotonic but there is an inflection point that is changing the direction of the relation between Factor 1 (performance) and age. Figure 4 shows the aforementioned relationship, with the inflection point located between 40 and 45 years.

3.3 VFI Factor 3, Recovery

An overdispersion-corrected Poisson log-linear generalized linear models was fit with the response variable of VFI Factor 3 (recovery) and the covariates (1) classroom capacity and (2) age. The reference level for classroom capacity was small. The output of the model is reported in Table IV. The goodness of fit model was evaluated with the Hosmer-Lemeshow test ($\chi^2 = -17.61$, $df = 8$, $p = 1$).

As indicated by the model output, the effect of classroom capacity on the responses to the Factor 3 questions is not statistically significant, with the exception of the difference between the classrooms small and very large. However, the Tukey's post-hoc multiple comparisons test showed that also the aforementioned difference was not statistically significant, once the correction was applied.

Regarding the effect of the age on VFI Factor 3, the preferred model was the one with second grade polynomial age terms. This means that the relation between responses about vocal recovery is not monotonic but there is an inflection point that is changing the direction of the relation between Factor 3 and age. Figure 5 shows the aforementioned relationship, with the inflection point located between 40 and 45 years.

4.0 DISCUSSION

Teachers in higher capacity (presumably larger sized) classrooms reported increased VFI scores in all three factors (performance, pain, and recovery). This is consistent with previous research [22] and may provide a link between vocal fatigue and vocal effort measures. It may be that the increased effort associated with speaking in larger classrooms is creating an increase in the amount of vocal fatigue that teachers are reporting.

Specifically, teachers' reports of vocal fatigue in the vocal performance factor of the VFI were significantly elevated when compared to the lowest capacity classroom size (5–10 students). However, the elevated scores were not in the range high enough to be considered vocally fatigued in that factor according to Nanjundeswaran et al. [10] (24 and higher is considered fatigued in this factor). In factor 2 of the VFI however, both teachers of large and very large classrooms averaged over 7 out of a possible 20 indicated vocal fatigue in this

factor (large = 7.06; very large = 9.6). This average score indicates a high amount of vocal fatigue as compared to non-occupational voice users and vocally healthy individuals. Female teachers in factor 3 reported decreased ability to recover with rest in very large capacity classrooms compared to small, medium, and large capacity classrooms (7 out of a possible 12 for this factor). These results generally indicate a significant effect of the capacity (number of students) of classrooms on teachers reported amounts of vocal fatigue, which corresponds with previous work that room acoustics may affect teachers' vocal health [23, 24].

Per the research question, it was predicted that VFI scores would have a positive correlation with primary classroom capacity and age of teachers. It was hypothesized that those teachers who teach in larger capacity classrooms would report higher amounts of vocal fatigue as there would be more noise in the classroom (with more students). Teachers would be obliged to use a louder voice to instruct in these large classrooms as their voices would need to carry throughout the entire room. Teachers instructing in more reverberant classrooms, which are also larger in capacity, experience higher amounts of vocal effort and a higher likelihood of voice problems [23, 11]. Therefore, the results of the current study may be used to raise awareness among teachers about the potential vocal risks of speaking for extended periods of time in a large classroom (especially one with poor acoustic properties).

Female teachers' elevated reports of vocal fatigue when teaching in a larger classroom may be due in part to their increased vocal demands in this setting. In 2002, the American National Standard Institute published guidelines regarding optimal classroom acoustics (ANSI S12.60–2002) which included the recommended reverberation time and background noise present in an unoccupied classroom. However, as mentioned previously, the majority of school classrooms surveyed did not meet these requirements. For example, in an active classroom, sound levels may reach 50 – 60 dB in active classrooms [25], and if a signal-to-noise ratio of +15 dB is to be maintained [26], a teacher would be required to speak with a vocal effort of raised (66 dBA) to very loud (78 dBA), following the definition of the ISO 9921, during the majority of the instruction period. The necessity of maintaining a sufficiently high voice level is likely a major reason why school teachers experience such elevated amounts of vocal fatigue.

As expected, the scores of the VFI associated with performance (general tiredness of voice) and pain (physical discomfort associated with) were directly proportionate to the classroom capacity. However, the recovery score was not associated with the capacity of teachers' primary classrooms. The reason for this may be that while the first two components of the VFI can be affected by environmental factors such as room capacity, recovery from vocal fatigue is more related to the physiology of the vocal mechanism. This is evidenced by the effect of age on vocal recovery.

While treated primarily as a control variable, it was assumed that older teachers would experience higher amounts of vocal fatigue due to physiological changes that occur with age [3]. However, in this study, the relationship between age and the VFI in all three factors appeared to be quadratic rather than linear. The highest values on the VFI were reported by teachers between 40 and 45 years of age, indicating the lowest levels of performance, the

highest amounts of pain, and the longest recovery times. A possible explanation for this phenomenon could be that teachers younger than 40–45 produce hormones which affect external tissue hydration [27, 28] and make the vocal folds stiffer than females older than 40–45. This quadratic relationship between teachers' room capacity and their reported vocal pain, performance, and recovery may also be associated with teaching experience and the increased ability to adapt their voices to physiological and hormonal changes they experience over time. It is also conceivable that as teachers age, they are participating in fewer vocally demanding activities both during and after school. Additionally, older teachers with more tenure may be better respected and thus may be more able to manage classes as students will treat them more respectfully. Teachers older than 60–65 years may also be scaling back on the number of classes they teach in a school day and thus are demanding less of their voices. Additionally, measurements of performance, pain, and recovery in female teachers may be affected by the average number of vocal fold collisions (related to their pitch). Due to this generally increased rate of collisions in the vocal folds during speech, females younger than 40–45 may be more prone to poor vocal performance, increased pain, and increased recovery times.

Steps were taken to enhance the validity and authenticity of the survey responses. Only 12% (506/570) of participants dropped out after completing less than half of the survey (these responses were not included in the analysis), indicating that most participants who began the survey were willing to complete it. To further verify the authenticity of responses, most surveys were distributed by school administrators or to teachers' emails obtained directly from school websites and listserv databases. Finally, one question within the survey was an 'attention filter' that identified those participants not paying attention to what they were answering if they filled in an answer other than the one instructed. This occurred rarely (less than 3%). Cultural differences and native languages spoken were not accounted for in this survey and may have led to dropouts or fewer completed surveys.

5.0 CONCLUSION

Teachers in general and female teachers specifically, have a higher instance of voice problems. Female teachers responding to our survey report an elevated level of vocal fatigue, as quantified by the Vocal Fatigue Index. Additionally, per the research question, there was connection found between the vocal fatigue and the teachers' classroom size. Together, the vocal fatigue factors of vocal pain, performance, and, recovery, may have an effect on the vocal fatigue experienced by those who require the use of their voices to complete the day to day tasks of their jobs. Additionally, these factors may be affected by teachers' primary room capacity.

Additionally, this research suggests that female teachers reported amounts of vocal fatigue increases from age 20 until age 40–45. After this time, it seems that age no longer has a negative effect on vocal fatigue. This may be an indication of teacher's ability to adapt to vocal demands of their work. It may also indicate a leveling off of biological changes occurring as women age.

Generally, these findings may be able to inform vocal health professionals, school administrators, and female teachers of the risks involved with teaching conditions in larger capacity classrooms. It may also assist to build the awareness of the need for better care of the voice especially for teachers from age 20 to about 45 as this population reported higher risk for vocal fatigue.

Future work will include more detailed surveys and analysis of other risk factors, which could lead to additional insights and even modification of how and where teachers teach. Future research in this area will undoubtedly compare teachers' objective measures of voice in addition to the scores of the VFI. Perceptual ratings by trained listeners will also be used as comparison to teachers' VFI scores and objective measures collected. This may give further insight into the amount of vocal fatigue experienced by teachers as well as the notable subjective and objective differences in teachers' voices teaching in various capacities of classrooms.

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Figure 1.
Mean values and standard errors for the VFI Factor 1, Performance scored in classrooms with different capacity.

Figure 2. Mean values and standard errors for the VFI Factor 1, Performance, scored by the teachers grouped in 5-year intervals of age. The blue curve represents the best quadratic fit and the grey band represents the 95 % confidence intervals.

Figure 3.
Mean values and standard errors for VFI Factor 2 (Pain) responses scored in classrooms with different capacity.

Figure 4. Mean values and standard errors for the VFI Factor 2 (pain) scored by the teachers grouped in 5-year intervals of age. The blue curve represents the best quadratic fit and the grey band represents the 95 % confidence intervals.

Figure 5. Mean values and standard errors for the Factor 3 (recovery) scores grouped in 5-year intervals of age. The blue curve represents the best quadratic fit and the grey band represents the 95 % confidence intervals.

Table I.

Overdispersion-corrected Poisson log-linear generalized linear model fit with the response variable VFI Performance and the covariates classroom capacity and the age. For the intercept and for each fixed factor, the estimate, the standard error, the test statistic, z and the p value are reported.

VFI Factor 1, Performance	Estimate	Std. Error	z value	p value
<i>(Intercept)</i>	2.51	0.07	36.45	<0.001 ***
<i>Classroom Medium</i>	0.32	0.07	4.39	<0.001 ***
<i>Classroom Large</i>	0.46	0.08	5.47	<0.001 ***
<i>Classroom Very Large</i>	0.59	0.15	3.88	<0.001 ***
<i>Age</i>	-0.90	0.47	-1.92	0.055 .
<i>Age²</i>	-1.15	0.47	-2.45	0.014 *

Signif. Codes:

<0.001

**
<0.01

*
<0.05 ' ' <0.1

Table II.

Overdispersion-corrected Poisson log-linear generalized linear model fitted with the response variable VFI Factor 2 (pain) and the covariates classroom capacity and the age. For the intercept and for each fixed factor, the estimate, the standard error, the test statistic, z and the p value are reported.

VFI Factor 2, Pain	<i>Estimate</i>	<i>Std. Error</i>	<i>z value</i>	<i>p value</i>
<i>(Intercept)</i>	1.49	0.10	14.80	<0.001 ***
<i>Classroom Medium</i>	0.30	0.11	2.83	<0.005 **
<i>Classroom Large</i>	0.47	0.12	3.83	<0.001 ***
<i>Classroom Very Large</i>	0.72	0.22	3.24	<0.002 **
<i>Age</i>	-1.57	0.68	-2.30	0.021 *
<i>Age²</i>	-2.38	0.69	-3.46	<0.001 ***

Signif. Codes:

<0.001

**
<0.01

*
<0.05 ; * <0.1

Table III.

Overdispersion-corrected Poisson log-linear generalized linear model fitted with the VFI Factor 3 (Recovery) and the covariates classroom capacity and the age. For the intercept and for each fixed factor, the estimate, the standard error, the test statistic, z and the p value are reported.

VFI Factor 3, Recovery	<i>Estimate</i>	<i>Std. Error</i>	<i>z value</i>	<i>p value</i>
<i>(Intercept)</i>	<i>0.56</i>	<i>0.15</i>	<i>3.63</i>	<0.001 ***
<i>Classroom Medium</i>	<i>0.05</i>	<i>0.16</i>	<i>0.32</i>	0.752
<i>Classroom Large</i>	<i>0.05</i>	<i>0.19</i>	<i>0.26</i>	0.795
<i>Classroom Very Large</i>	<i>0.57</i>	<i>0.34</i>	<i>1.68</i>	0.092 .
<i>Age</i>	<i>-1.52</i>	<i>1.10</i>	<i>-1.38</i>	0.168
<i>Age2</i>	<i>-2.18</i>	<i>1.10</i>	<i>-1.98</i>	0.048 *

Signif. Codes:

<0.001

**
<0.01

*
<0.05 ; . <0.1