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Variations in Intensity, Fundamental Frequency, and Voicing for Teachers in Occupational Versus Non-Occupational Settings

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Abstract

Purpose—This study creates a more concise picture of the vocal demands placed on teachers by comparing *occupational voice use* with *non-occupational voice use*.

Methods—The National Center for Voice and Speech voice dosimetry databank was used to calculate voicing percentage per hour, as well as average dB SPL and F_0. Occupational voice use (9am-3 PM, weekdays) and non-occupational voice use (4 PM-10 PM, weekends) were compared (57 teachers, two weeks each).

Results—Five key findings were uncovered: [1] similar to previous studies, occupational voicing percentage per hour is more than twice that of non-occupational; [2] teachers experienced a wide range of occupational voicing percentages per hour (30±11%/hr); [3] average occupational voice was about 1 dB SPL louder than the non-occupational voice and remained constant throughout the day; [4] occupational voice exhibited an increased pitch and trended upward throughout the day; [5] some apparent gender differences were shown.

Conclusions—Data regarding voicing percentages, F_0 and dB SPL provide critical insight into teachers' vocal health. Further, because non-occupational voice use is added to an already overloaded voice, it may add key insights into recovery patterns, and should be the focus of future studies.

Keywords

vocal fatigue; occupational voice use; non-occupational voice use; phonation; vocal vibration dose; intensity; fundamental frequency; vocal load

INTRODUCTION

Nearly one quarter of the U.S. workforce, or approximately 37 million individuals, are *occupational voice users*. These individuals are dependent on a high level of vocal endurance and/or voice quality to perform their primary job responsibility (e.g., emergency dispatchers, air traffic controllers, performers, telephone customer service representatives) (Titze et al, 1997). Because of this dependence, individuals in such professions are affected by the extent of *vocal loading*, a term used to quantify the demands placed on the voice mechanism by the way a voice is used and how much it is used (Vilkman, 2004). Acute laryngeal injuries due to high vocal loading (e.g., submucosal hemorrhages) or to non-neoplastic changes (e.g., nodules) can lead to missed work days or performances, lost revenue, significant rehabilitation periods, and change of profession or early retirement. The question of how vocal loads during occupational voice use relate to vocal injury is increasingly being approached as an occupational safety and health issue (Sala et al, 2002; Titze et al, 1997; Vilkman, 2004).

Although teachers represent only 16% of all occupational voice users, and a small minority of the total workforce (4.2%), the significance of their vocal health problems is documented (e.g., Hamdan et al, 2007; Jonsdottir et al, 2003; Kooijman et al, 2005; Kovess-Masfety et al, 2006; Laukkanen et al, 2006; Mattiske et al, 1998; Pekkarinen et al, 1992; Russell et al, 1998; Simberg et al, 2005; Sliwinska-Kowalska et al, 2006; Verdolini and Ramig, 2001). For example, in a survey of 237 teachers across the U.S. to assess the prevalence and impact of vocal loading, Sapir et al. (1993) found that over 50% of the teachers reported that their voice was a chronic source of stress or frustration and that it adversely impacted their ability to teach effectively. In another study, Smith et al. (1998) compared elementary and secondary teachers (N=554) with individuals working in other professions (N=220) and found that teachers were more likely to define themselves as having a voice problem (32% vs. 1%, $p < .05$).

Many *vocologists* (i.e., practitioners and researchers in voice) have studied this occupational health concern in an effort to understand how teachers use their voices in the classroom. Voice accumulation and voice dosimetry devices have been developed for unobtrusive monitoring of occupational vocal use (Airo et al, 2000; Buekers et al, 1995; Cheyne et al, 2003; Granqvist, 2003; Ohlsson et al, 1989a; Popolo et al, 2005; Svec et al, 2003; Szabo et al, 2001). One example is the National Center for Voice and Speech (NCVS) voice dosimeter (e.g., Popolo et al, 2005; Svec et al, 2003), from which has come a database of teacher's occupational voice use (Titze et al, 2007). The voice dosimeter captures raw skin acceleration data at a sampling frequency of 11,025 Hz in a rotating 30 ms buffer. From this buffered acceleration data the dosimeter makes a voicing decision (1 for voice, 0 for no voice) and then calculates vocal intensity (dB SPL, Svec et al, 2005) and fundamental frequency (F_0, Popolo et al., 2005). The result is a stored set of three variables every 30 ms: voicing (on/off), dB SPL, and F_0. The dosimeter also records accelerometer spectral information.

Devices such as this have given us the tools to begin to systematically examine voice use in a variety of occupations and situations (Airo et al, 2000; Cheyne et al, 2003; Ohlsson et al, 1989b; Popolo et al, 2005; Szabo et al, 2003). For example, Sala et al. (2002) found that the average speaking time of daycare center teachers was 40% of the time at work, compared to 28% for nurses. Rantala et al. (1994) found the average speaking percentage for teachers to be 35-55%, and 25-40% for average voicing percentages. Further, Titze et al. (2007) reported the voicing percentage of teachers during occupational voice use to be 23%; and Masuda et al. (1993) measured a voicing percentage of 21% for teachers in an 8-hour workday compared to 7% for office workers.

While these previous studies provide valuable insight into occupational vocal loads, only one study was found which provided a picture of the extent of voice use outside of work, or *non-occupational voice use*. In this study, a small group of teachers wearing the NCVS dosimeter were found to have a non-occupational voicing percentage of 13% (Titze et al, 2007). While this voicing percentage is smaller than their occupational voice use, it nevertheless represents a significant portion of a teacher's total daily voicing percentage. Vilkman (2004) suggests that a potentially substantial amount of non-occupational voice use may result from female teachers' frequent role as the primary caregivers for children in their home (Vilkman, 2004). Other after-school community and volunteer activities would also have an impact, such as coaching a Little League team, membership in a church choir, or leading a Girl Scout troop.

A teacher's non-occupational voice use has been traditionally left out of studies because it is likely no different from that of a non-teacher's. However, it is possible that its impact is significant, not because of the quantity of non-occupational vocal loading, but because it would be added to an already elevated vocal load. Thus, the impact on vocal disorder etiologies and recovery times of non-occupational vocal loading should not be ignored.

Also absent from most previous studies is an examination of F_0 and dB SPL during occupational voice use. For example, we know that higher F_0 values imply a higher number of vocal fold collisions per second. Thus, because the average F_0 of males is 120 Hz and of females 200 Hz, a female teacher's vocal folds would experience 40% more collisions than a male teacher's. If a female teacher is assumed to spend 17% of her workday voicing (approximately six hours of teaching), the female vocal fold would thus experience almost 750,000 collisions per day. Roy et al. (2004) have hypothesized that this is one of several differences that may explain why women are 10% more likely than men to have prolonged voice problems (Gotaas and Starr, 1993; Morton and Watson, 1998; Russell et al, 1998; Sapir et al, 1993; Smith et al, 1997; Vilkman, 2004; Yiu, 2002). Similarly, an increased dB SPL would imply a larger vocal fold sheer stress. However, measuring the dB SPL of a person's voice throughout a day with a microphone is complicated by the difficulty of distinguishing the voice of interest from background noise and reverberation, particularly when a variety of acoustic situations are possible. This difficulty can be resolved by using an accelerometer as the transducer to calculate estimated dB SPL (as in the NCVS dosimeter), allowing vocal intensity to be tracked in different speaking situations regardless of the acoustic environment.

Finally, no study is yet available which constantly traces how a teacher's voice changes throughout the day. One study took a snapshot of teachers' voices at the beginning and the end of the teaching day and found that teachers' voices were higher during the last lesson (Jonsdottir et al, 2002). Although this study provides valuable insight, we must have a more complete picture of how teachers use their voices *during* the teaching day, which would come from continuous tracking over the course of several days. With such tracking, we may discover variations in voicing percentage, dB SPL, and F_0 that might not only provide clues to the progression of vocal fatigue during the work day, but also provide insights into how a teacher might use her/his voice differently to compensate.

This study addresses variation in teachers' *voice use* (defined in the current study as voicing percentages, estimated dB SPL, and F_0) in occupational versus non-occupational settings. Two questions are asked in the current study: [1] How does a teacher's occupational voice use compare to non-occupational voice use? and [2] How does a teacher's voice use change over a typical teaching day?

METHODS

The National Center for Voice and Speech (NCVS) teacher dosimetry databank is the primary resource for the current study. It contains voice use data which have been captured with the NCVS Voice Dosimeter (Figure 1a) as described previously (e.g., Popolo et al, 2005; Svec et al, 2004). The device has been previously used to measure voice use in teachers (Titze et al, 2007), professional vocal performers (Carroll et al, 2006), and children (Hunter, 2009).

Before beginning the study, teacher-specific dosimeter parameters were collected for use throughout the study. Using these parameters, a dosimeter could be calibrated to each teacher's voice in order to estimate dB SPL from the accelerometer (Svec et al, 2004; Svec et al, 2005). This procedure also set various internal parameters to match each device to the teacher's voice range. It then found a calibration curve relating skin acceleration level at the neck to dB SPL at 30 cm. The device then remembered the teacher-specific calibration and internal parameters throughout the study. No daily calibration was necessary.

During this session, each teacher was also taught how to attach and use the dosimeter. A laboratory technician was on call at all hours to provide technical support or to answer general questions. Each day during the study, the teacher attached the dosimeter's transducer (an accelerometer) to his/her neck at the sternal notch (as shown in Figure 1b) using a special medical adhesive (Mastisol®, Ferndale Laboratories).

Each teacher was issued two dosimeters to minimize the potential loss of data collection time during two time periods. First, internal diagnostics alerted the teachers if there was a problem with the device, notifying them to call the laboratory technician and use the second device. Second, the lab technician could download data during the week from the device not being worn without interrupting the teacher. During the first week, this downloading usually occurred every day so the technician could leave feedback for the teacher if needed. During the second week, the technician only visited the school to collect data one or two times because the dosimeter could store about five days worth of voice data.

All recorded data (every 30 msec) was time stamped according to the device's internal clock, which was synchronized to a single PC. Thus, the data could be searched by date and time for analysis. As each device was individually setup for each teacher, data files were also categorized by the device using a unique subject number.

The dosimeter battery was capable of continuously recording 18-28 hours of real-time processed data before being recharged, more than enough time for a normal day of speaking (longer times were possible if the teacher swapped the external battery pack, which could be done without affecting continuous data collection). For each teacher who completed the two-week dosimetry study, a complete data set could ideally contain approximately 108,000 data records per hour, 2 million records per day, or 28 million records per 14-day period.

Several times a day, the teachers were asked to perform the following vocal tasks (less that 1 minute): [1] sustained soft phonation; [2] soft upward pitch glide; [3] five syllables/*hi*/ repeated softly and at a high pitch; [4] portion of the "Happy Birthday" song sung softly and at a high pitch; and [5] count of "one, two, three" said in a normal voice. Figure 1b shows an example of a dosimeter recording of one of these short tasks, wherein silence is followed by the utterance. The upper line is the skin acceleration level before it is calibrated to dB SPL. The middle line depicts the F_0. The lowest line is a unit step function for voicing periods (value $k_v = 1.0$) and silence periods (value $k_v = 0$), used to calculate vocalization time.

These tasks were recorded on the device. After completing these tasks, the teachers were guided by the device through a procedure to rate their current perceived vocal performance (Carroll et al., 2006; Hunter, 2008; Hunter and Titze, 2009). This rating was time stamped, which could then be related directly to the voice data. While not part of the current report, the eventual intent of recording this perceptual rating would be to find a relation between overall voice use with a person's perceived current vocal functionality. Additionally, these tasks were used automatically by the device for internal diagnostics several times a day.

In addition to the ratings, teachers were asked for their teaching schedules. They were also given daily log sheets on which they recorded generic items such as wake time, sleep time, general daily events (usually one or two word descriptions like "dinner with friends", "in car", "in class"). Teachers were also asked to record general health events (e.g., allergies, sickness). It is important to note that, while our more recent log sheets request more specific information, this general information has been collected over the course of this multi-year study. For this report, these log sheets were used in the analysis only minimally to better understand voice dosimeter monitoring.

Subjects

At the time of this report, 57 teachers had completed the two-week study. Each teacher consented to participate under the approval of the local Institutional Review Board. Whenever possible, a teacher's participation began on a Saturday morning and ended two weeks later on Friday evening. The teachers (all K-12 teachers from more than a dozen schools in the Denver metropolitan area) consisted of 45 females and 12 males with an average age of 44 years (s.d., 10; median, 55). Consistent with the 2006 U.S. Census which reported that about 70% of teachers are women, our subject pool is skewed toward female teachers (79% of our pool). Of these teachers, 23% reported having some type of voice or speech training. A subset of the teachers were asked additional questions at the beginning of the study, such as their years of teaching and reported number of hours of teaching in a day, with responses listed in Table 1.

The subject breakdown by teaching grade was K-4th grade, 59%; 5-8th grade, 16%; and 9-12th grade, 25%. Teacher breakdown by topic was general classroom instruction, 71%; music/theater instruction, 16%; physical education instruction, 9%; and other (e.g., library instruction, special education), 4%. The results from this moderate-size corpus were statistically significant to draw preliminary conclusions about vocalization of teachers in general, but no specific comparisons between the specific teachers' teaching topics were conducted.

Analysis and Statistics

To answer the current study's research questions, custom MATLAB scripts were written that could search all of the teacher dosimeter data by date and time. Using these scripts, the data were compiled first by weekday and weekend groupings, and then by hour. This compilation also tracked the number of teachers contributing to a specific hour of data separated by weekdays or weekends (e.g., 7:00-8:00 AM weekdays). From this compilation, average voice use data (and other common statistical descriptors) across teachers for an average day, hour by hour, were first obtained. Then average voice use data during *occupational hours* versus *non-occupational hours* (defined below) were calculated across teachers. The dB SPL distribution for each teacher was obtained for a particular one-hour time slot (e.g., 7:00-8:00 AM, Teacher 57). Further, a global distribution from all contributing teachers for the same time slot was also obtained (e.g., 7:00-8:00 AM, All Teachers). For the two work weeks, a teacher could contribute up to 10 hours of data for that weekday time slot (7:00-8:00 AM, ten workdays). For the two weekends, a teacher could contribute up to four hours of observational voice data for that weekend time slot (7:00-8:00 AM for two Saturdays and 2 Sundays). Thus, even if part of one day's one-hour time slot did not contain useful data for some reason, there were still data that could be analyzed from the other days' time slot. For example, if the teacher woke up late and did not put on the dosimeter until 7:30 am on a weekday, there would still be 9.5 one-hour time slots from which statistics could be calculated (including the 1/2 hour). The data was normalized to the amount of time useable data was collected, thus keeping both the time of day and the number of data points from a particular teacher comparable to other teachers.

Using the grouped data from these time slots, histograms (distributions) of the data were calculated. Also, Type II tests were used for male-female comparisons because of the disparate gender pools (47 females, 12 males). Type I *t-test* (two-tailed) were used for all other grouped data sets..

Collection Statistics

As explained above, each teacher was asked to wear the voice dosimeter during all waking hours for 14 consecutive days, preferably beginning upon waking on a Saturday morning. For the 57 teachers, data were collected from 769 days of 798 possible days, and usable voice data for 8451 hours (weekdays: 6106 hrs; weekends: 2345 hrs). There was an average of 60 hours of possible voice dosimetry data collection per teacher for the *occupational hours* (defined as weekdays, 9:00AM-3:00PM, 6 hours for each of 10 days). From this potential 60 hours per teacher, data useful for analysis was collected 72±8% of the time (females: 71±8%, males: 76±6%), for a total of 2363 data hours (females: 1811 hrs, males: 552 hrs). During the total possible weekday non-occupational hours (defined as weekdays, 4:00-10:00PM, 6 hours for 10 days), data useful for analysis was collected 69±15% of the time (females: 66±15%, males: 79±7%), for a total of 2261 data hours (females: 1682 hrs, males: 579 hrs). The usual source of unusable data was the teacher not wearing the device or temporary equipment malfunction (e.g., short in accelerometer cable).

RESULTS

Collected data were analyzed and compared using two general divisions: [1] average daily voice use (weekday and weekend); and [2] weekday occupational versus non-occupational voice use. No comparisons between subjects taught and pupil age could be made given wide variations such as teacher characteristics, class size, and grades taught.

Average daily voice use

Weekday use data for all teachers were synchronized in time and combined to represent voice use over the average weekday. Likewise, weekend data were similarly grouped and combined. Across all teachers (male and female), a calculated intensity (dB SPL) distribution was created from all 30 ms voicing instances. As can be seen in Figure 2, the weekday normalized distribution (solid dot) had fewer quiet voicing instances and slightly more loud voicing instances than the weekend (open dot), resulting in a distribution slightly skewed to the right in comparison. The mode intensity (most frequent number of 30 ms voicing instances) also was different between the two distributions, with the weekday mode being about 1 dB louder than the weekend mode. These distributions were normalized by the number of total instances contributing to the distribution; thus, the y-axis can be thought of as a percentage within an intensity bin (e.g., 11% of the voicing instances occurred at 62 dB SPL). The figure caption contains the number of recording hours contributing to the distribution as well as the number of voicing instances found in that recording time. If the distributions were not normalized, the weekday absolute distribution curve would be about three times as high as the weekend curve.

The dissimilarity between weekday and weekend voice use was illustrated by plotting the difference between the two normalized distributions. In Fig. 2, the dotted line near the bottom indicates those times when the normalized weekend distribution was greater than weekday distribution, while the dashed line indicates those times when the weekday distribution was greater than weekend distribution. Note that weekday voice (which would contain all of the occupational voice use) had more voicing instances above 62 dB SPL and fewer soft voicing instances below 62 dB SPL. The peak weekday difference between weekday and weekend voicing occurred at 71 dB SPL.

Figure 3 shows the hour-by-hour average voice use for an average weekday (left) and weekend day (right). These curves were calculated by obtaining the average of the data across all teachers and all weekdays (or weekend days) within a specific one-hour window as described above; these hour-long windows stepped through the time of the day in 20-

minute increments. Weekend data had fewer contributing data points and a much more varied teacher schedule (e.g., some teachers did not put on the device until 10:00 or 11:00 AM on the weekend). The top graph in Figure 3 illustrates these dB SPL averages and the bottom graph shows the voicing percentages (voicing time per hour). Also presented are the standard deviations of the means.

There are a few noticeable trends featured in these graphs. First, the calculated vocal intensity during the weekdays (upper-left) between about 8:00 AM and 3:30 PM (likely occupational hours, label A) was elevated over the non-occupational hours (about 3:30 PM to late evening). Average peak voicing percentage during occupational hours within an hour window was 33%, with a standard deviation of ±11%. Second, the voicing percentage during the weekdays (Figure 3, lower-left) had two prominent peaks before and after 12:00 PM (label B). It is important to note the large standard deviation curve during the very early morning (before 7:00 am) on the weekdays, likely in part because there was a smaller number of teachers who wore the dosimeter at this time. Third, weekend voicing percentages after about 5:00 PM were similar to weekday percentages at the same time. The weekend morning, on the other hand, contained a peak before 10:00 am. As with the weekday data, the time of the peak had fewer teachers contributing to the average than at most other graphed times.

Using the analysis protocol described for Figure 3, the average F_0 was found for all weekday and weekend data and the changing voice use throughout the day was plotted (Fig. 4) for an average weekday (left) and weekend day (right). Generally speaking, there is a slight upward increase in F_0 in all situations (male and female, weekday and weekend) as the day progresses. The females had a slight elevation in mean F_0 during the weekday hours between 9:00 AM and 3:00 PM, seeming to decline after the end of the school day but then increasing again to the end of the day (Fig. 4, label A). Also interesting to note is the greater F_0 fluctuation (both males and females) during weekend hours. Although it is possible that the male teachers' fluctuations may stem from low sample size, the female teachers seem to also have several elevated periods of F_0 during the weekend (Fig. 4, label B). These periods appear to parallel the periods of increased dB SPL (Fig. 3).

Weekday occupational versus weekday non-occupational voice use

The weekday data were divided into two portions of 6 hours each. The first portion contained all voicing data which occurred between the hours of 9:00 AM and 3:00 PM, representing the most likely period during which most of the teachers were at work. The second portion contained weekday data between 4:00 PM and 10:00 PM, representing the most likely times that the teachers were not at work. This generalized delineation of at-work and not-at-work times might miss some data for some teachers. However, using these set time periods was the most consistent method of representing the average teacher's occupational and non-occupational vocal environment, given variations in: [1] definition of at-work by the teachers (e.g., several teachers listed that their occupational voice time extended from around 7:00 AM to 7:00 PM, which included preparation time, grading, monitoring quite reading times, faculty meetings, coaching, etc); [2] length of teaching day; and [3] oral instruction schedules (e.g., an elementary school teacher's pattern of teaching is likely different from a secondary education teacher; further, each teacher's pattern would likely vary depending on the day) .

When examining all voicing instances (defined as a 30 ms interval where voicing was on) over the weekday occupational and non-occupational hours, it was found that the teachers vocalized an average of 29.9% of the time from 9:00AM-3:00PM (30.7% females and 27.4% for males), compared to 14.4% of the time during 4:00-10:00PM (14.7% and 13.7% for females and males respectively). The distribution of these voicing instances sorted in terms of estimated intensity (dB SPL) for occupational voice and non-occupational voice can be seen in Fig. 5. The dotted line at the bottom represents those times when the normalized non-occupational distribution is greater than the normalized occupational distribution, while the dashed line represents those times when the occupational distribution is greater than non-occupational distribution. The difference between the two distributions peaks at 73 dB SPL, illustrating that the primary difference between occupational voice and non-occupational voice is the addition of loud voicing instances around 73 dB SPL.

Next, weekday occupational voice use and non-occupational voice use were compared, separated by gender so that F_0 differences could be seen. Figure 6 shows occupational and non-occupational voicing distributions in terms of both F_0 (left, in semitones) and intensity (right, dB SPL at 30 cm). In each figure a distribution difference line was plotted, with the dotted line representing a greater non-occupational distribution and the dashed line representing a greater occupational distribution. Here it can be seen that, while male teachers do appear to increase their occupational F_0, female teachers show a greater difference in F_0 distribution when comparing occupational to non-occupational voice use.

DISCUSSION

The current study confirms an occupational voicing percentage (29.9%) reported in previous studies (e.g., Masuda, *et al.*, 1993; Rantala, *et al.*, 1994; Titze, *et al.*, 2007). As new data, the current study highlighted the extent of non-occupational voicing percentages in teachers (14.4%). This finding suggests the non-occupational voicing percentages may be significant in computing overall vocal load. Results for teachers are comparable to those from Watanabe et al. (1987) who found the voicing percentage of 20 adults outside the teaching profession to be 11%. However, teachers' non-occupational percentage was greater than what was previously found for two other professions, nurses and speech-language pathologists, which was only about 7% (Ohlsson, *et al.*, 1989a).

The current study also revealed a considerable range of voicing percentages among teachers with the average occupational voicing percentage per hour as high as 33%. The standard deviation of voicing percentage was about half of the mean. This implies that while some teachers talk little, others vocalize nearly 45% of the time (within any one-hour slot). By comparing a teacher's speaking time (Sala *et al.*, 2002) to voicing time (Masuda *et al.*, 1993), it appears that voicing time may be as much as half of speaking time. If this percentage bears out, then teachers who vocalized nearly 45% of the time within an hour might have a speaking time as high as 90%, a percentage that may not be surprising in a lecture-format class or in a class with general instruction followed by small group or individual instruction time (i.e., roaming and answering questions).

Also interesting is the change of vocalization percentages during the day, particularly the occurrence of regular peaks (Fig. 3). During the teaching day, there appear to be two voicing percentage peaks (33%, label B) one before and one after the noon hour. The teachers experience a small reprieve over a lunch break (label C). For weekend non-occupational voice use, voicing percentages are relatively constant, but a peak was observed between 8:00-9:00AM. Unfortunately, only 55% of all teachers were wearing the device during that time. The morning weekend peak could simply be a result of poor sampling, i.e., a large standard deviation of average voicing during those early hours. Teachers were asked to put the dosimeter on after waking each morning, but while the teachers' work schedule made a relatively consistent time during the weekdays, many did not put it on until after 10:00 AM on weekends. Further, the log sheets suggest that this peak was influenced by a few very vocally active Saturday and Sunday morning events which some teachers reported. For example, a review of the 12 male teacher voice logs showed that of the 48 weekend days recorded, there were 23 potentially high vocalization events specifically noted by teachers between 9:00 AM and 12:00 PM, many more than reported on weekend afternoon and evening times. Of these events, thirteen were related to singing during religious services, and four were sports related.

As we examine a teacher's high occupational voicing percentage, we can begin to understand the potential injuries to the vocal folds by the significant number of vocal fold collisions. Almost 1.6 million collisions occurred on average for female teachers and about 1 million for men during *occupational hours* (8:00 AM to 3:30 PM, or approximately 7 1/2 hours of teaching). Both female and male teachers double their voicing percentage in the occupational setting (i.e., females: 30.7% versus 14.7%; males: 27.4% versus 13.7%). Interestingly, while female teachers' voicing percentages are larger both in occupational and non-occupational settings, they appear to increase their voicing percentage slightly less than males between the two environments.

Another significant finding is the extra vocal load placed on the vocal folds by the non-occupational voice use after school and on the weekends. Although teachers do reduce their voicing percentages during non-occupational hours, their voicing percentages nevertheless remain high (males, 13.7%; females, 14.7%). Particularly important are the periods on Saturday and Sunday morning of elevated voicing percentages, as well as the F_0 and dB SLP peaks throughout the day. The significance of the cumulative effect of non-occupational voice use was illustrated by Hunter and Titze (2009), who compared vocal fatigue from the daily use of the voice to that of a *chronic dermal wound*, which necessitates healing and repair mechanisms to be in a state of constant repair. In summary, with the teachers' significant non-occupational vocal load after school and on the weekends, it is possible that there may not be adequate time for the daily repair cycle and the weekend recovery necessary to prevent a significant vocal health issue.

The current study also provides important details about the previously reported increase in average intensity that teachers use in an occupational setting (e.g., Jonsdottir, *et al.*, 2002; Sodersten et al, 2002). On average, teachers' most frequently occurring intensity (distribution mode) was 60 dB SPL when using non-occupational voice (Figure 5). This mode shifted up about 2.5 dB when the teachers were using occupational voice. This difference may be caused in large part to the demand and pressures of the teaching environment; for example, Brenner et al. (1994) showed in a controlled environment that increased workload demands resulted in elevated vocal intensity of 1.5 to 2.25 dB over baseline.

Both male and female teachers raised their most frequently occurring F_0 about 10 Hz or 1-1.5 semitones in occupational versus non-occupational voicing (Fig. 6). The female teachers' most frequently occurring voicing instance in F_0 was about 43 semitones (or 194 Hz with a median of 226 Hz) when using their non-occupational voice and 42 semitones (or 183 Hz with a median of 215 Hz) when using their occupational voice. Men's occupational versus non-occupational voice had a nearly identical F_0 distribution mode voicing instances. However, their occupational distribution itself (Figure 6) was skewed higher (i.e., a higher mean at work), illustrating that there were more frequent higher F_0 instances occurring in their occupational voice (34 s.t. or 118 Hz with a median of 129 Hz) than their non-occupational voice (33 s.t. or 108 Hz with a median of 129 Hz).

Looking at just the differences between the F_0 distributions in Figure 6, the male teachers' peak difference (occupational vs. non-occupational) was at approximately 38 semitones. This illustrates that the largest difference between the male occupational and non-occupational voice is more frequent higher pitches that are 4 semitones above the most frequently occurring non-occupational F_0. It should be noted that the mean F_0 in the male teachers' non-occupational voice was about 144 Hz while the mode was 108 Hz, illustrating the potential for a skewed F_0 distribution (Hunter, 2009). The female distribution difference peak occurred at 47 semitones, nearly 5 semitones higher than the mode non-occupational fundamental frequency. The female habitual non-occupational mode was 42 semitones or 183 Hz, with an average of 241 Hz, also a skewed distribution.

This difference in occupational and non-occupational F_0 may be explained by previous studies, which suggest that increased intensity may affect vocal pitch. For example, Gramming et al. (1988) found that in 38 persons of various vocal training and a variety of vocal health status there was a mean F_0 increase of approximately 1/2-semitone per dB. This equation predicts the current study's raised occupational F_0 from the nearly 2.5 dB increase in occupational voice use.

Further, teacher F_0 values appeared to trend upwards throughout the day. On average, male teachers' F_0 slightly increased as the day progressed on both weekdays and weekend days. Interestingly, female teachers had several cycles during a weekday: a slight elevation during occupational hours; a decline after the end of the school day; and then an increase again at the end of the day. It is also important to note that both male and female teachers appeared to have greater F_0 fluctuations during the weekend non-occupational hours. A trend in increased F_0 during the teaching day has been reported before in many places (e.g., Stemple et al, 1995; Vilkman et al, 1999; Jonsdottir, *et al.*, 2002). It is possible that this increase is due to a change in the material properties of the vocal folds because of fatigue (McCabe and Titze, 2002). Thus, the fluctuations during non-occupational hours may provide important insight into an occupational voice user's vocal healing trajectory.

Finally, although there were only 12 males in the study, some gender differences may be inferred. The average female teachers raised their mode intensity much more than the males. This difference may be related to average differences in the characteristics of the classroom or students for the male versus female teachers (e.g., it is likely that, as younger grades have more female teachers than males, they were required to speak louder in those class environments). Another possible explanation may stem from the intelligibility of teachers' voices. Drullman and Bronkhorst (2004) found that the intelligibility of a voice increased as the difference in the speaker's F_0 and the background babble F_0 increased; further, increased intensity also increased intelligibility. Thus, because the F_0 of female teachers would be closer to prepubescent students than the male teachers', it is possible that the female teachers would need to raise their intensity more to increase intelligibility.

The data from this study suggest that female teachers also speak slightly more than male teachers (occupational: 30.7% versus 27.4%; non-occupational: 14.7% versus 13.7%). This finding corresponds with a study of college students (Mehl et al, 2007), which found that women tended to use about 7% more words in a day than men. However, it is also possible that the gender differences seen in the present study may relate to the grade or topic taught, or other classroom/student characteristics. Further, it is also possible that this finding may be the result of the subject pool of 12 males not being representative of *all* male teachers as a whole.

CONCLUSIONS

This study used the National Center of Voice and Speech voice dosimetry databank (57 teachers, two weeks each, 8400+ hours) to compare teachers' non-occupational voice use to their occupational voice use. It also addressed the combined measures voicing percentage,

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intensity and fundamental frequency. When possible, this study implied gender-specific distinctions.

Three findings relate specifically to the study's research questions. First, teachers' occupational voice use peaks twice daily (for about two hours total), reaching 33% voicing on average. Teachers' non-occupational voicing percentage is also not inconsequential at about 14%. This non-occupational voice use is particularly noteworthy as it potentially would not only leave little time for significant vocal rest, but also would add additional vocal load to an already vocally overloaded voice. Occupational voice intensity is only slightly greater than the non-occupational voice intensity (2.5 dB). With regard to fundamental frequency, it is somewhat elevated during occupational voice (1-1.5 s.t.), with females raising theirs above non-occupational voice mode more substantially than males.

Additional findings not directly related to the research questions also provide valuable insights. First, while there were only 12 males and they may not be an adequate representation of male teachers generally, trends in the current study show that when comparing the genders, female teachers' occupational voicing is 10% more than that of males, and their non-occupational vocalization was 7% more. Further, female teachers appeared to speak louder when using their occupational voice than male teachers. As we continue to collect data from teachers, more male teachers will be added to the dataset and we will be able to investigate these trends in more detail to determine if they point to true gender-related differences or if both/either are related to other issues, such as classroom, teaching topic or pupil characteristics. It also would be critical to examine how much of an effect the reported gender differences in voice use may contribute to females' higher number of complaints of voice problems (Roy, *et al.*, 2004). On a final note, because the current study presents some interesting preliminary data about gender-based differences in speaking amounts and styles, it is possible that a tool such as the vocal dosimeter would present an ideal method of comprehensively collecting voice use data between the genders, allowing social gender-based studies of communication strategies, management styles, etc.

While the sheer volume of consecutive hours tracked and data records collected in this study provides valuable insights, the database is not yet large enough to distinguish with confidence how teachers' occupational voice use may be affected by the topic taught or the age of pupils, nor can it account yet for after-hours occupational voice use (e.g., choir concerts, coaching, etc.). It is also possible that some weaknesses may have been introduced by comparing our data of occupational voice users to traditional studies of non-occupational voice users (our study is distinct as it collects long-term consecutive data hours with 100,000 data records per hour, 1.4 million records per day, or 20 million records per 14-day). Finally, this study cannot account for time (whether at work or outside of work) when the dosimeter was not worn. For example, it is possible that the voice use statistics might have been affected if teachers took off the dosimeter to prepare for bed but remained awake for a period of time (which would have then had a mean lower voicing percentage if the individual read or watched TV in bed; or a higher mean, softer volume, or lower fundamental frequency if, for example, they engaged in soft late evening conversation after removing the dosimeter).

The current study provides a more complete picture of the true nature of teachers' voice use by detailing their vocalization patterns from the two weeks and presenting average daily use. Future studies should differentiate how occupational voice use is affected by classroom characteristics (e.g., room dimensions, humidity, temperature), course topic (e.g., band, choir, physical education, general education), and pupil traits (e.g., age, gender, number). Future studies should also examine the variations in fundamental frequency during non-occupational hours to determine if these trends provide insight into vocal healing. Further, it would be valuable to examine how the reported characteristics of teachers' occupational voice use (e.g., higher fundamental frequency) may vary with different occupational voice users. Other studies could examine how teachers use variability in pitch and intensity in the classroom to maintain interest, and how such variations might affect vocal fatigue. Finally, future work could look at the distribution of voicing and silence durations (Titze, *et al.*, 2007) within those high voicing times to see if specific size voice breaks and frequency of such breaks could make a difference in vocal health.

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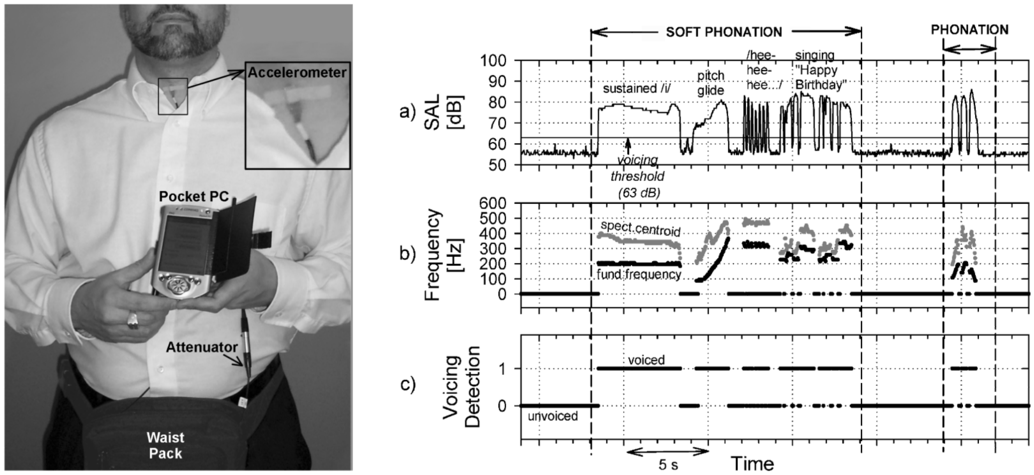

Figure 1.

The NCVS voice dosimeter worn by a male adult (left) and (right) sample output of [a] dB SPL, [b] frequency (spectral centroid and F_0), and [c] voicing detection in 30 msec intervals.

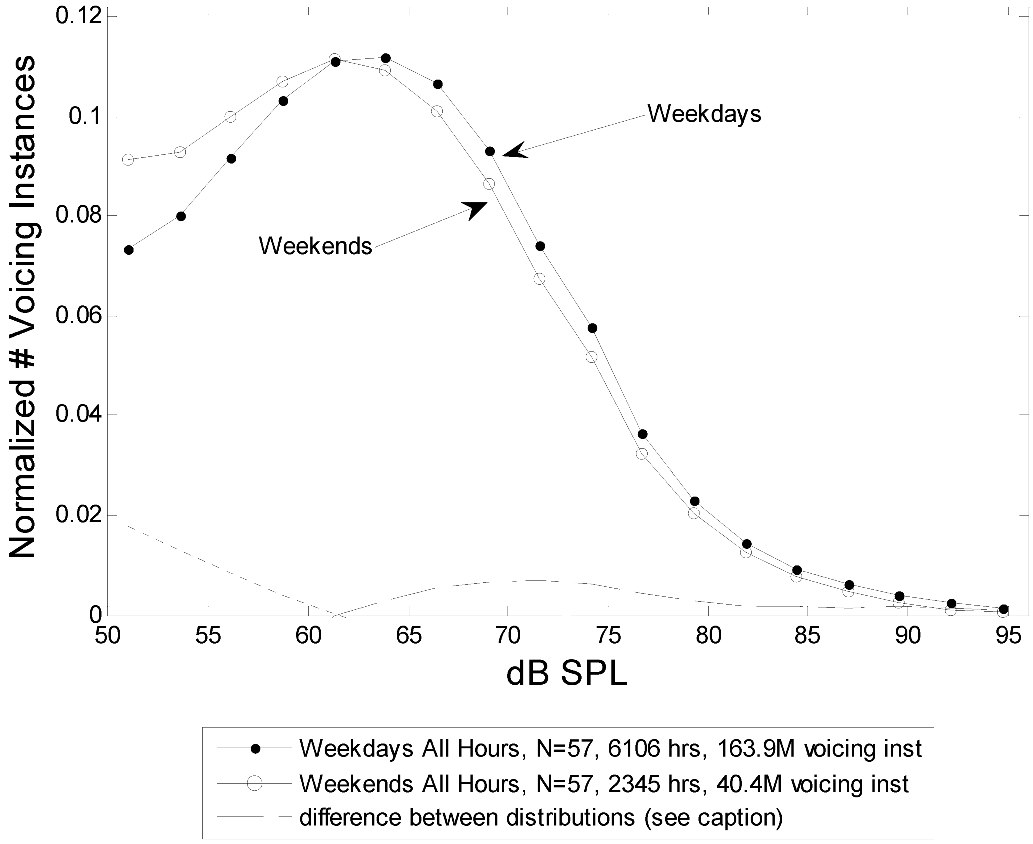

Figure 2.
dB SPL normalized distribution of voicing time as measured within 30 ms windows. The difference between the normalized distributions is shown: *Dotted line* - weekend distribution greater than weekday distribution; *Dashed line* - weekday distribution greater than weekend distribution. Note that the normalized distributions hide the fact that there were more than twice the numbers of occupational instances than non-occupational instances.

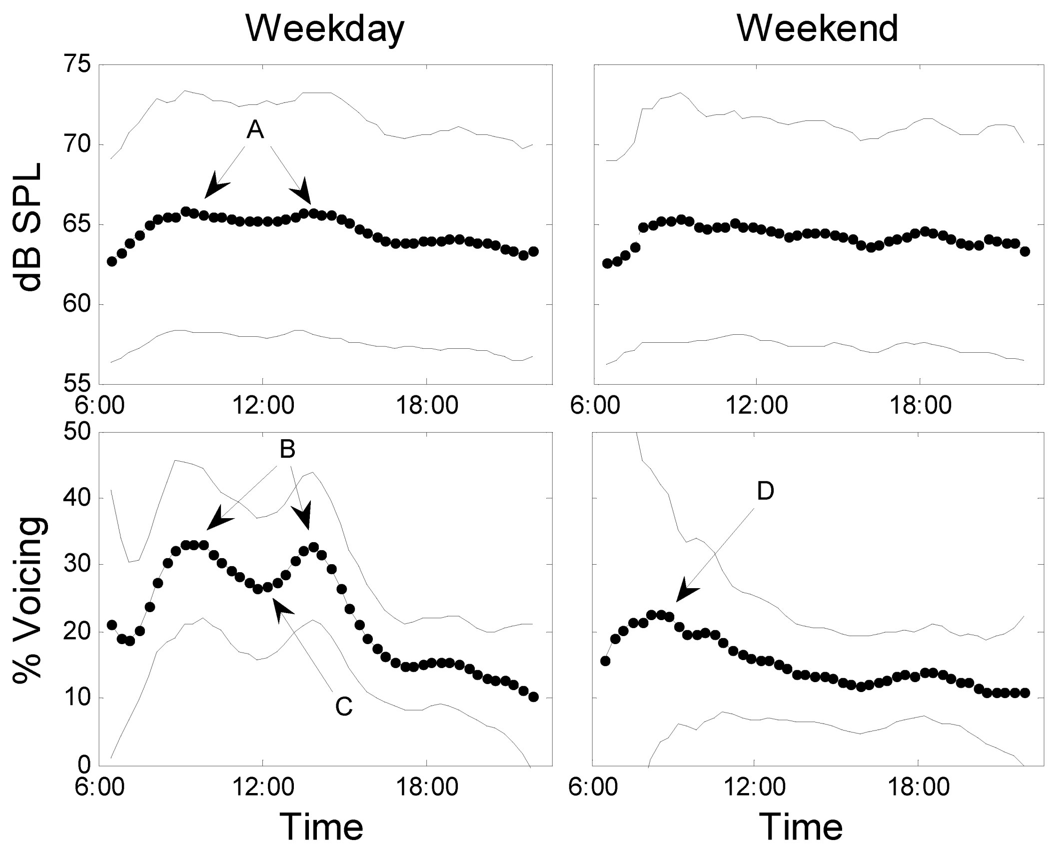

Figure 3.

Mean voice use over a day, averaged in 1-hour windows and presented in 20-minute steps. Thick line with dots shows the mean over the window with the outer thin lines showing the standard deviation: *Upper* - dB SPL at 30 cm; *Lower* - percent voicing; *Left* - Weekdays; *Right* - weekends.

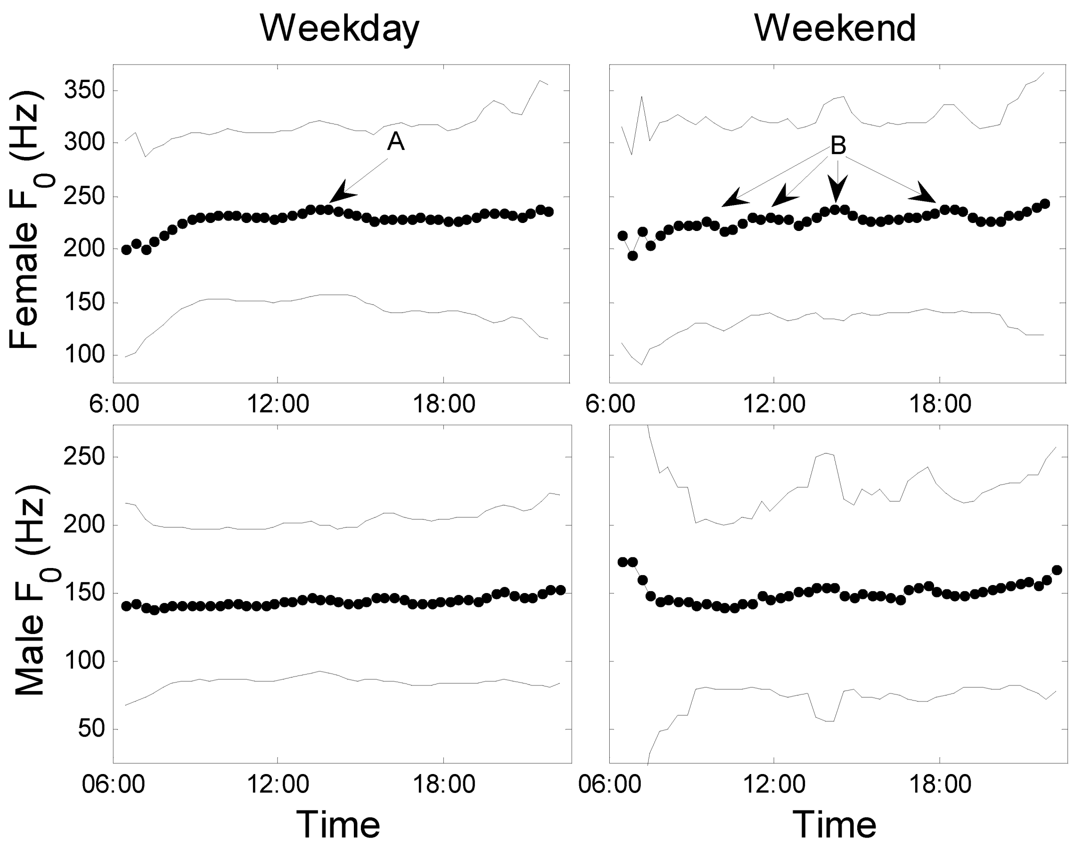

Figure 4.
Mean F_0 shown over an average day in 20-minute steps with 1-hour averaging windows. Thick line with dots shows the mean over the window with the outer thin lines showing the standard deviation: *Upper* - Females; *Lower* - Males; *Left* - Weekdays; *Right* - Weekends.

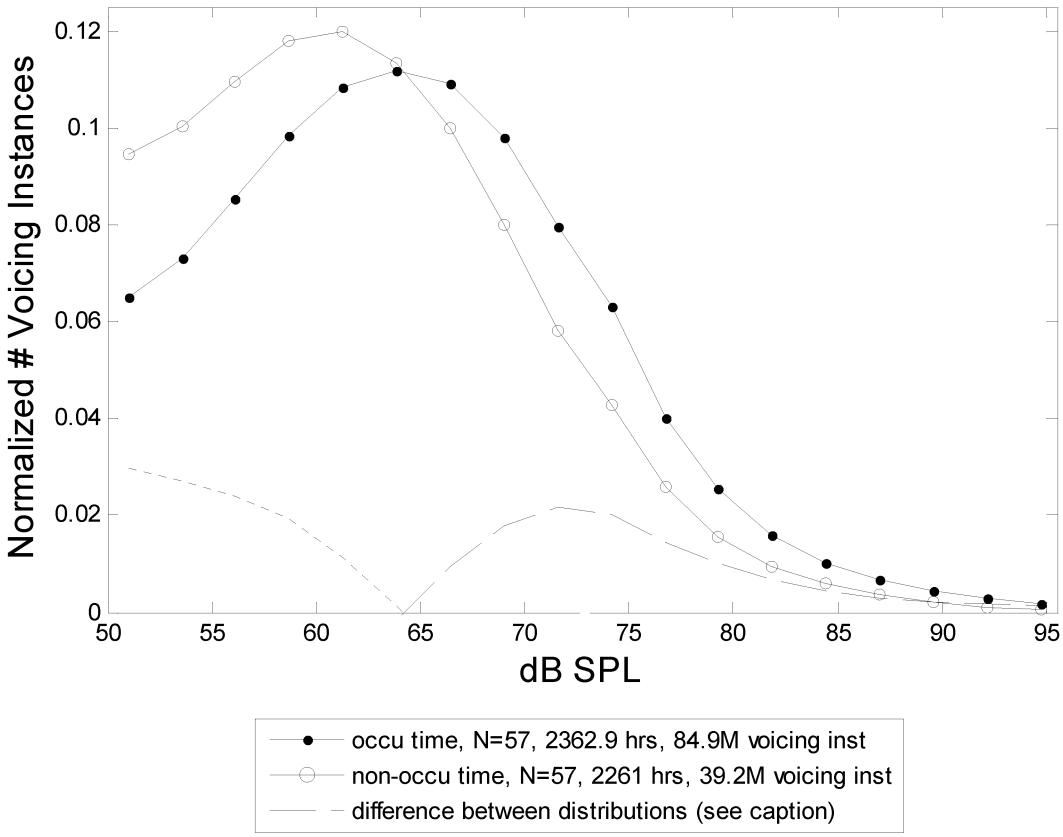

Figure 5.

dB SPL distribution of normalized voicing instances for all subjects. The difference between the normalized distributions is shown: *Dotted line* - non-occupational distribution greater than occupational distribution; *Dashed line* - occupational distribution greater than non-occupational distribution. Note that the normalized distributions hide the fact that there were more than twice the numbers of occupational instances than non-occupational instances.

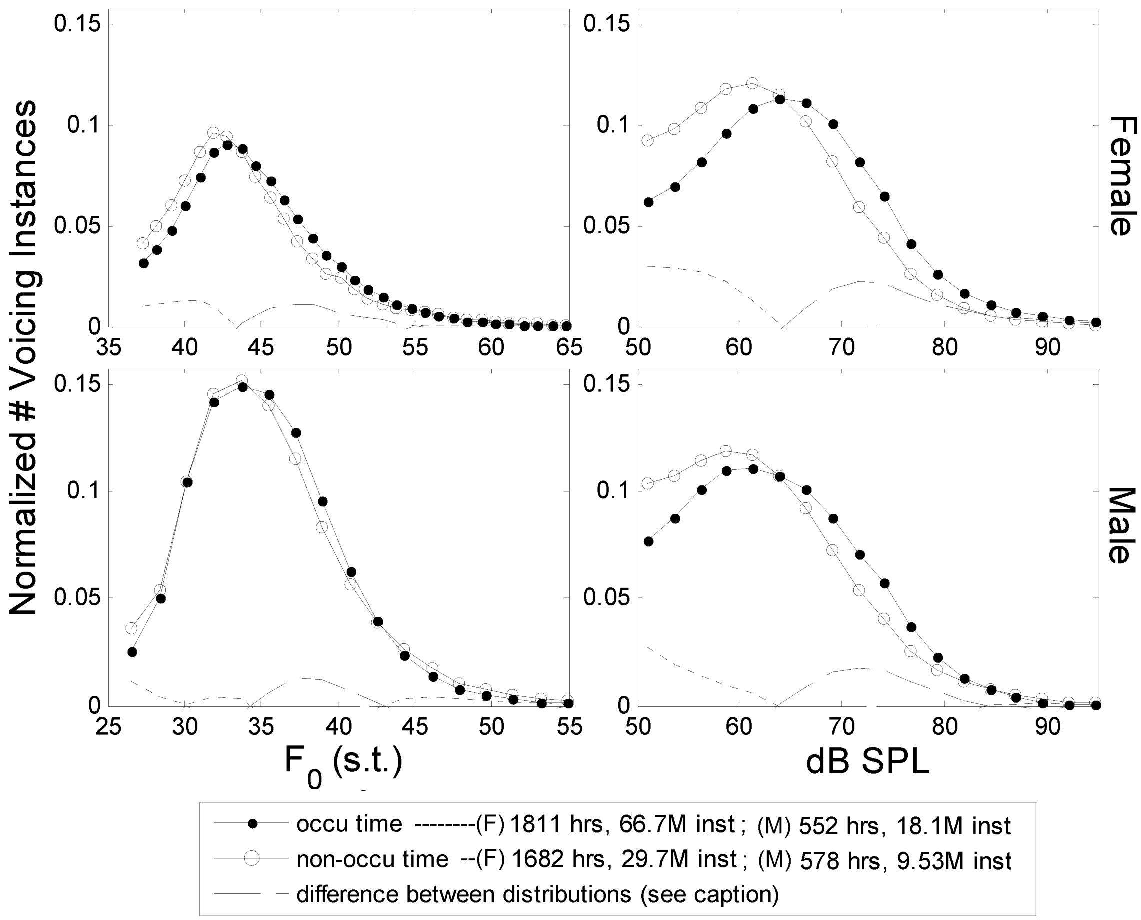

Figure 6.

Normalized distribution of voicing instances in terms of F_0 (*left*, semitones, where semitone=39.86 $\log_{10}(F_0/16.25)$) and loudness (*right*, dB SPL @ 30 cm) averaged over all subjects' occupational weekday times (9:00 am - 3:00 pm) and non-occupational times (4:00 pm - 10:00 pm). Female data (N=45) are on the top; Male data (N=12) are on the bottom. The difference between the distributions is shown: *Dotted line* - non-occupational distribution greater than occupational; *Dashed line* - occupational distribution greater than non-occupational. Note that the normalized distributions hide the fact that there were more than twice the numbers of occupational instances than non-occupational instances (Female occupational distribution includes 66.7M 30msec voicing instances in 1181 hours of data and 29.7M in 1692 hours of data; Male occupational distribution includes 9.53M 30msec voicing instances in 578 hours of data and 18.1M in 552 hours of data).

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Table 1

Questions asked of a subset of the teachers before the start of the study.

	Years of Teaching	Hours in Teaching Day	% Voicing at Work	% Voicing Not at Work	Class Size
Mean	23.3	6.6	80.7	34.5	23.9
Std. Dev.	10.7	2.2	8.8	20.5	12.0
Median	25	5	78.5	30	20
N	15	15	14	13	14