Voice Changes in Real Speaking Situations During a Day, With and Without Vocal Loading: Assessing Call Center Operators

*,†,‡Boaz M. Ben-David and §Michal Icht, *Herzliya and §Ariel, Israel, †‡Toronto, Ontario, Canada

Summary: Objectives. Occupational-related vocal load is an increasing global problem with adverse personal and economic implications. We examined voice changes in real speaking situations during a single day, with and without vocal loading, aiming to identify an objective acoustic index for vocal load over a day.

Methods. Call center operators (CCOs, n = 27) and age- and gender-matched students (n = 25) were recorded at the beginning and at the end of a day, with (CCOs) and without (students) vocal load. Speaking and reading voice samples were analyzed for fundamental frequency (F_0), sound pressure level (SPL), and their variance (F_0 coefficient of variation [F_0 CV], SPL CV). The impact of lifestyle habits on voice changes was also estimated.

Results and conclusions. The main findings revealed an interaction, with F_0 rise at the end of the day for the students but not for the CCOs. We suggest that F_0 rise is a typical phenomenon of a day of normal vocal use, whereas vocal loading interferes with this mechanism. In addition, different lifestyle profiles of CCOs and controls were observed, as the CCOs reported higher incidence of dehydrating behaviors (eg, smoking, caffeine). Yet, this profile was not linked with voice changes. In sum, we suggest that F_0 rise over a day can potentially serve as an index for typical voice use. Its lack thereof can hint on consequent voice symptoms and complaints.

Key Words: Occupational voice–Voice loading–Call center operators–Hebrew.

INTRODUCTION

Employment in the modern world is characterized by an increasing number of employees working in professions that require continuous vocal usage.[1] The loss of vocal abilities has a major impact on the livelihood of many vocally demanding professions (in which voice is a main professional tool),[2] such as teachers, receptionists, sales personnel, physicians, clergy, singers, and actors. Not surprisingly, professional voice users are at risk of occupational voice disorders and represent a major portion of patients in voice clinics.[3,4] The risks associated with voice professions are mainly related to vocal loading defined as prolonged and intense use of voice.[5,6] The longer and louder a person uses his or her voice (talks, sings), the greater the strain on the voice mechanism,[7] and the greater the risk for vocal symptoms (and pathologies).

Occupational demands have a clear impact on vocal loading, as certain jobs require long duration of connected speech with relatively high intensity.[8] Long hours of work, irregular sleep, and fatigue are also related to voice changes, mainly with regard to voice roughness and brilliance.[9] Stress was found to have an impact on voice as well, as stress-related increase in the heart rate[10] increased the F_0 of the speaking voice.[11,12] Likewise, environmental factors can affect voice. For example, the presence of loud background noise, insufficient acoustic conditions, and large speaking distances[13,14] force the speaker to produce louder voice. Other environmental factors, such as poor air quality (dryness, dust), may have a detrimental impact on the vocal mechanism as well.[15]

The lifestyle and habits of speakers (vocal hygiene) is the focus of many voice-related clinical interventions.[16] Standard recommendations to patients with voice problems include sufficient hydration of the vocal folds (by increased environmental humidity, steam inhalation, and increased water intake) and avoiding dehydrating conditions and agents (smoke, alcohol, diuretics, antihistamines, and caffeine).[17–20] However, evidence in the literature on the direct impact of such habits on voice and its quality is not clear.[21] (For an example related to caffeine intake, refer the study by Akhtar et al.[17])

The present study directly tests the possible link between vocal load and lifestyle on voice parameters over a day. We focused on a specific high-risk profession, call center operators (CCOs), and evaluated the impact of a single day of work (voice loading) on voice characteristics, compared with matched controls.

Call center operators voice load and related problems

CCOs provide customer teleservice over shifts, usually from a workstation, located in a large-shared open workspace. To date, the global call center industry is growing at an annual rate of over 20% per year, and the number of CCOs is continually increasing.[22] CCOs are a unique subgroup of employees because their ability to work depends solely on their voice, in the absence of body- (gestures or facial expressions) or written-language.[13]

CCOs are a high-risk population for vocal disorders, because of occupational vocal load, as they continuously attend to calls with few breaks, coupled with excessive work-related stress.[1,23] CCOs were found to be at risk for developing health-related problems, including musculoskeletal disorders and

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From the *Communication, Aging, and Neuropsychology Lab (CANlab), Baruch Ivcher School of Psychology, Interdisciplinary Center (IDC), Herzliya, Israel; †Department of Speech-Language Pathology, and the Rehabilitation Sciences Institute, University of Toronto, Toronto, Ontario, Canada; ‡Toronto Rehabilitation Institute, Toronto, Ontario, Canada; and the §Department of Communication Disorders, Ariel University, Ariel, Israel.
Address correspondence and reprints requests to Communication, Aging, and Neuropsychology Lab (CANlab), Baruch Ivcher School of Psychology, Interdisciplinary Center, P.O. Box 167, Herzliya 4610101, Israel. E-mail: boaz.ben.david@idc.ac.il
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psychological distress.[24-26] Organic voice problems are also frequent in this population,[13,19] with symptoms of hoarseness, vocal fatigue (negative vocal adaptation that occurs as a consequence of prolonged voice use[27]), odynophonia, and generalized fullness in the neck.[19,28–30] The aforementioned symptoms can be related to vocal attrition—disorders or changes in laryngeal tissues caused by excessive or inappropriate use of the vocal mechanism (overuse or misuse[29]). Indeed, Jones et al[19] found that CCOs (telemarketers) were twice as likely to report one or more symptoms of vocal attrition (68%) compared with controls (for comparable results, refer the study by Devadas and Rajashekhar[22]; Liechavicius, 2000, in the study by Oliveira et al[23]).

Employment-related voice symptoms impair the productivity and job performance, as well as the psychological well-being, of this growing cohort of CCOs.[1] Recently, Devadas and Rajashekhar[22] found that around half of examined CCOs complained that vocal symptoms affected their job performance, 16% reported that the symptoms affected their social interactions, and 10% mentioned them as a major source of frustration. Voice problems among voice-demanding professions lead to large amount of lost time from work.[31] For example, more than one-third of teachers (a noticeable group of professional voice users) are absent from work as a result of voice problems.[32] A decade ago, related costs (lost workdays, use of sick benefits, replacement costs for substitute teachers, and treatment expenses) were estimated at $2.5 billion annually in the United States alone.[33] Consequently, the identification of a specific acoustic measure that may serve as an early indicator for later voice disorder has both personal-clinical and general-economic importance. From the clinician perspective, it is important to identify an objective (acoustic) index that correlates with voice symptoms and complaints. From an economic perspective, early identification can lead to preventative steps that can reduce the high costs.

Vocal function changes during a working day

One possible marker for voice changes over a day of vocal load is F_0. The evidence available in the present literature generally shows an increase in F_0 after a day's work for voice professionals, both in laboratory settings[34,35] (but refer the study by De Bodt[36]) and in field conditions.[37–39] For example, the F_0 of school teachers was found to be higher in the afternoon lecture than in the morning lecture.[40] It is not clear whether this phenomenon is related to voice load, as some studies reported an increase in F_0 after a single day without vocal load,[37,41] whereas others found it to be inconsistent (an effect only for men but not for women[42]; a reversed pattern[43]).

Another acoustic parameter that has been evaluated in vocal loading studies (but less commonly than F_0) is sound pressure level (SPL). Similarly to F_0, the evidence for the impact of voice load on SPL is inconsistent, with some studies suggesting that loading raises SPL values,[35] whereas others report a decrease.[36] The evidence on F_0 and SPL calls for further investigation as performed in the present study.

The present study

We investigated occupational vocal loading in Hebrew speakers CCOs in the course of a single working day, comparing changes over a day in their voice samples to a control group (healthy student, age- and gender-matched), without any voice load. The Israeli market demonstrates well the vocal challenges facing CCOs, with a rising number of call centers. In 2008, there were about 120 call centers in Israel, with around 8500 CCOs. Over the span of 4 years, the number of call centers quadrupled reaching 500 in 2012 (with 200 large-scale centers[44]) and is only expected to inflate, as a governmental plan supports the establishment of such centers.[45] The job strain on Israeli CCOs is intense, because of a recent update to the Consumer Protection Regulations limiting phone-service waiting-times to 3 minutes.[46]

We were interested in the impact of vocal loading on specific features of voice, analyzing how such acoustic parameters reflect the possible changes in the vocal function during a working day. Following Rantala et al,[39] four parameters were chosen: F_0, SPL, and their estimates of variance (F_0 coefficient of variation [F_0 CV] and SPL CV). We also tested the impact of voice load on a blind subjective measurement of voice quality (G factor of the GRBAS). Background information and behavioral factors (eg, lifestyle) were evaluated by questionnaires concerning occupational and living habits, general health, and vocal complaints.[47] We tested the link between these lifestyle factors and acoustic changes over a day.

METHODS

Participants

The CCO group was recruited during a 1-day visit at a call center of a large Israeli communication company located at the center of Israel. During recruitment, the experimenter presented the study and its goals to all CCOs present at the call center. The CCO group was made of 27 (20 women, 7 men) CCO employees who responded to the appeal and volunteered to participate, with a mean age of 27.2 years (range 18–36 years). Inclusion criteria were (1) A tenure of at least 6 months at the center; (2) A minimum average of six working hours per shift; and (3) Consecutive work at the center for the past month (ie, not returning from a vacation or a sick leave). The control group was made of 25 undergraduate students (19 women, six men), with a mean age of 22.2 years (range 20–29 years), who received course credit for their participation. None of the participants were involved in high voice-demand activities (eg, singing), and they reported no vocal disorders. At the time of the study, each participant's voice (in both groups) represented his or her typical voice, and all reported good functional health (generally and as related to voice). Only one of the participants (CCO group) received previous voice training, but this was not found to have a significant impact on the data. A similar percentage of participants in the control (5 of 25) and the CCO group (5 of 27) reported laryngeal signs and symptoms (ie, allergy, laryngeal irritation). We also note that a portion of three CCOs' afternoon recordings was corrupted, and only partial data were analyzed for these participants. The study was approved by the local Ethics Committee, and all participants provided informed consent.

Call center work setting

The call center was designed as a single-floored, open work environment. About half of the floor was arranged with traditional straight runs of call center workstations, and the remaining half, with modular cluster workstations (pods). To reduce environmental noise, the call center has sound-absorbing ceiling tiles, carpeting, and wall coverings. Also, copiers and other noisy equipment were isolated. Finally, all CCOs used headsets throughout the work shift.

Materials

Questionnaire. During the morning session, after providing informed consent, participants were asked to complete a brief questionnaire to collect general information. The questionnaire was adapted from several occupational voice studies[8, 13, 23, 39] and translated to Hebrew. It included 15 questions as follows: (1) Background information—age, gender, and level of education (open-ended questions); (2) Lifestyle habits—smoking, alcohol use, caffeine beverages and water consumption, involvement in any activities requiring intense voice use (yes/no questions, with a follow-up fill-in blank indicating the amount/type); (3) General health—frequent colds, allergies, and reflux (yes/no); (4) CCO occupational experience—duration of employment, number of working days per week, and average shift duration (multiple choice); (5) Student occupation experience—current job, description of vocal use (open ended); and (6) Laryngeal and vocal symptoms—dry throat, hoarseness, shortness of breath (yes/no).

Tasks. All participants (in both groups) were recorded before (at about 7:30 AM) and after (at about 4 PM) a typical day—vocally loading working day for the CCOs and no vocal load for controls. The recording took place in a relatively silent room, with the noise level <40 dBA, as measured by a sound level meter (TES Electrical Electronic Corp.; TES-1350A). For the CCO group, the room was located at the call center, and for the control group, the room was located at the University.

Recordings were made using a portable digital recorder (Olympus Europa SE & CO. KG; VN-8500PC) and a microphone headset (TEAC America, Inc.; HPX 8 brand). The microphone was placed at a distance of about 6 cm from the participant's mouth. SPL was calibrated with a reference signal consisting of a 300-Hz sine wave with an intensity of 80 dB SPL (A) that was generated and recorded on a sample digital audio file. The level of the reference signal was monitored using the same sound level meter.

Participants were asked to perform two vocal tasks: (1) text reading of Hebrew prose and (2) spontaneous speech, both of 50 seconds duration at habitual conversational loudness. We used these two separate vocal tasks, as the CCOs' working demands usually include both spontaneous speech and reading of preprepared scripts (especially among the "telesales" subgroup[45]). Because of the short mouth-to-microphone distance, the average signal-to-noise ratio across the recordings was 24.3 dB. For acoustic analysis, we selected the second produced sentence of the text reading and of the speech samples. The mean duration of the sentences was 9 seconds.

Subjective voice evaluation. The G (grade) component (rating the overall voice quality) of the GRBAS scale[48] was used for perceptual analysis. We used a four-point scale to quantify the G parameter: 0 = no deviance, 1 = slight, 2 = moderate, and 3 = severe deviance. Two trained Speech and Language Pathology (SLP) students rated, separately, all recorded voice samples of the reading and speech tasks (for both the morning and the afternoon samples and both groups), counterbalancing for the order of the recorded tasks and participants. Final scores were assigned by a consensus of the two listeners. In case such consensus was not achieved (six cases, all CCOs), the final score was determined by an experienced SLP (the second author [M.I.]).

As indicated earlier, our participants reported no vocal symptoms. Indeed, only <5% of the tested samples were rated G = 2 (and none were rated 3). It is not surprising that the data on this subjective measure were not revealing, and no significant effects were found (using Wilcoxon signed rank tests). As a result, this measure will not be further discussed.

Objective voice evaluation. The text reading and the spontaneous speech samples were analyzed for mean and variance of F_0 and SPL. The analyses were performed using *Computerized Speech Lab (CSL)* software (Kay Elemetrics Corporation, Lincoln Park, NJ).

Statistical analysis

Statistical analyses were carried out using *SPSS-19* software (SPSS Inc., Chicago, IL). The primary analyses of objective acoustic measures were made of omnibus repeated-measures ANOVAs with two within-participant factors—time of measurement (pre and post) and task type (read or speak), and two between-participants factors—group (CCO and control) and gender (male and female). The tested dependent variables, F_0, F_0 CV, SPL, and SPL CV, are specified in each test. These were followed by post hoc ANOVAs separately for the CCO and control groups or for the two tasks separately, using a Bonferroni correction.[49,50]

In our sample, given the possible differences in F_0 average between the two tasks, the two testing times, and the two groups, we opted to use the CV.

$$CV = \frac{\text{standard deviation}}{\text{average}}$$

This estimate for variance is a division of the standard deviation by the mean. Note that CV is resilient to changes in the mean and can be taken as a measure of relative spread in the sample[51] (for similar analyses, refer the studies[50,52,53]). The CV is especially useful to generate meaningful comparisons of variance for two samples with different averages (eg, CCO and controls) or different measures, as it adjusts the scale of variables.

TABLE 1.
Mean Values of Acoustic Variables Measured in the Morning and Afternoon Recordings of the CCOs and Controls (Men and Women), for Both Tasks (Reading and Spontaneous Speech)

Measures		CCOs				Controls			
		Reading		Speech		Reading		Speech	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
F_0 (Hz)					**Males**				
	M	144.86	142.90	139.48	139.56	130.65	138.22	127.05	133.67
	SD	19.78	22.79	14.61	22.02	9.69	11.73	8.84	12.39
					Females				
	M	187.38	180.97	181.66	182.23	189.57	205.29	179.43	189.13
	SD	12.08	24.73	15.50	18.26	11.87	27.39	11.86	14.07
					Both genders				
F_0 CV (%)	M	23.83	22.76	25.24	23.2	24.24	23.73	28.21	25.92
	SD	6.79	5.86	7.34	5.97	9.65	6.56	7.72	6.56
SPL (dB)	M	68.45	69.05	68.68	69.24	66.06	66.78	66.21	66.88
	SD	1.65	1.66	2.11	1.82	1.46	1.75	2.51	1.90
SPL CV (%)	M	10.4	9.83	10.13	9.62	12.88	11.46	12.03	10.91
	SD	0.89	1.62	0.98	1.51	0.93	1.08	0.91	1.27

Abbreviations: M, mean; SD, standard deviations of the individual means.
CV, coefficient of variance, a relative measure of intraparticipant variance.

RESULTS

Table 1 lists the mean values of average F_0, F_0 CV, average SPL, and SPL CV, for the four voice samples of the first and last recordings of CCOs and controls, for both men and women. Separate data for men and women are reported for average F_0, as gender had a significant impact on its values (note, the data are analyzed for both groups). Figure 1 presents the data visually, plotting the percent change from morning session to afternoon session, for the different acoustic variables Appendix A and B provide the individual data for CCOs and controls.

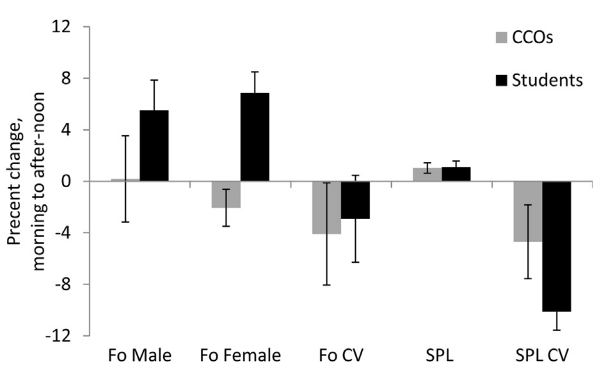

FIGURE 1. Percent change from morning session to afternoon session, for the different acoustic variables, averaged across tasks (reading and spontaneous speech). Percent change is calculated as follows: (Morning) − (Afternoon)/(Morning). Thus, positive values indicate a relative increase in the variable (eg, F_0 and SPL for students), and negative values indicate a relative decrease (eg, SPL CV and F_0 CV). Error *bars* represent one standard error around the mean difference.

F_0 average

For F_0 average, the omnibus ANOVA shows a main effect for the time of testing, with an overall higher F_0 at the end of the day, across groups, gender and tasks [$F(1,45) = 4.36$; $P < 0.05$; $\eta^2 = 0.09$], and a significant interaction of the time of testing and group membership [$F(1,45) = 8.44$; $P < 0.01$; $\eta^2 = 0.16$], with the increase in F_0 evident mainly for the control group. This interaction was further supported by post hoc analyses. For the control group, the time of the day effect was significant across tasks [$F(1,23) = 11.36$; $P = 0.003$; $\eta^2 = 0.33$; 156.7 vs 166.6 Hz] with additive effects for the task and the time of day (interaction of the two was nonsignificant, $F < 1$), whereas for the CCO group, the time of day did not yield significant effects ($F < 1$).

The omnibus ANOVA for F_0 average also revealed a significant effect for the type of task [$F(1,45) = 11.23$; $P < 0.01$; $\eta^2 = 0.2$] with higher F_0 for the reading task (164.7 vs 158.9 Hz) and a significant effect for gender [$F(1,45) = 108.87$; $P < 0.001$; $\eta^2 = 0.71$] with the naturally expected higher F_0 for women (187.1 vs 136.4 Hz). However, these two main effects did not interact with any of the other effects, nor did they have any impact on the effects related to the research question—the time of day and the interaction of time of day and group. As a result, the analyses reported previously describe reliable main effects across gender.

F_0 coefficient of variation

The omnibus ANOVA indicated a main effect for the time of day [$F(1,45) = 13.4$; $P = 0.001$; $\eta^2 = 0.23$] with a decrease in F_0 CV by the end of the day across groups (28.5 vs

25.7%), a marginally significant main effect for group [$F(1,45) = 3.6$; $P = 0.06$; $\eta^2 = 0.08$], with larger F_0 CV for controls (28.6 vs 25.5%), but failed to find an interaction of two effects [$F(1,45) = 1.55$; $P > 0.1$]. (We also note a small yet significant triple interaction of the time of testing, group, and gender [$F(1,45) = 4.6$; $P < 0.05$, $\eta^2 = 0.09$]. To follow it, we conducted two separate ANOVAs for men and women, but the interaction of group and time of testing was not significant in either ANOVAs. This indicates that the role of gender on the tested interaction was only marginal, and it will not be further discussed.)

SPL average

The omnibus ANOVA of average SPL revealed a main effect for the time of testing [$F(1,45) = 6.83$; $P = 0.01$; $\eta^2 = 0.13$], with higher intensity at the end of the day (68.1 vs 67.5 dB), a main effect for group [$F(1,45) = 14.4$; $P < 0.001$; $\eta^2 = 0.24$], with overall higher intensity for the CCO group (68.8 vs 66.9 dB). However, the two effects did not interact, nor were there any other main effects or interactions ($F < 1$ for all tests).

SPL CV

The omnibus ANOVA for SPL CV again failed to find an interaction of time of testing and group membership. Main effects were found for the time of testing [$F(1,45) = 19.94$; $P < 0.001$; $\eta^2 = 0.31$], with the SPL CV percentage decreasing by the end of the day (11.5 vs 10.6%), a large main effect for group [$F(1,45) = 47.5$; $P < 0.001$; $\eta^2 = 0.51$], with overall higher SPL CV values for the control group (12.0 vs 10.1%), but the two effects were additive ($F < 1$ for the interaction). We note an effect for the type of task [$F(1,45) = 11.1$; $P = 0.002$; $\eta^2 = 0.2$], with lower SPL CV for the speech task (10.8 vs 11.3%), yet this effect did not interact with any of the effects related to the research question—the time of day, group membership, and the interaction of the two. Indeed, in follow-up separate analyses for the two tasks, similar main effects for the time of testing and group were found, without an interaction of the two.

F_0 and SPL relation

In a regression analysis, we found a significant effect for group membership (CCO or student) on changes in F_0 over a day (afternoon session minus morning session), even after controlling for changes in SPL over a day [$\beta = .215$; $t(46) = 4.22$; $P < 0.001$]. In other words, group differences in F_0 changes cannot be explained by changes in SPL over a day.

To further investigate the possibility of a F_0-SPL link, we tested the correlation of changes in F_0 and in SPL over a day, for students and CCOs separately. For students, we found a significant correlation of 0.409 ($P < 0.05$ for both genders; $r_p = 0.509$, $P < 0.05$, when testing only women); however, no significant correlation was found for the CCOs ($P > 0.5$). In sum, the increase in F_0 for the students group was found to be related with an increase in intensity.

Vocal load

An analysis of participants' responses on the general information questionnaire clearly shows that the two groups differed substantially on vocal load. First, CCOs reported working on average 21.34 hours a week in the call center (2.79 days per week, in shifts of 7.65 hours), whereas the students were not employed in vocally demanding jobs. Second, 8 of the 27 CCOs reported recreation activities that may involve vocal overuse (eg, singing, taking soccer and tennis practice), whereas none of the students reported any such activities. Consequently, we consider the CCOs in our sample as "professional voice users."[1,8,19]

Lifestyle

In a preliminary analysis, several differences in the lifestyle of CCO and control participants were indicated (for detailed lifestyle information, see Table 2). Participants in the CCO group consumed a significantly larger amount of caffeinated beverages [$t(50) = 4.1$; $P < 0.001$], 4.2 versus 3.0 cups per day (calculated as the number of cups of coffee and coke drinks), and a significantly lower amount of water cups per day [$t(50) = 2.1$; $P < 0.05$; 2.9 vs 3.5 cups]. Participants in the CCO group also report more hours of sleep per day [$t(50) = 2.6$; $P = 0.01$; 7.3 vs 6.4 hours]. Finally, whereas only one participant in the control group reported smoking cigarettes (1–5 per day), almost half of the participants in the CCO group (48%) reported smoking, with 15% 1–5 cigarettes, 22% 6–10, and 11% >10 cigarettes per day (a significant difference, Mann-Whitney $U = 193$; $P = 0.001$).

As a second step, we tested whether one (or more) of these lifestyle factors can moderate the effect of group membership on the change in voice parameters over a day. To focus our analyses, we used the average difference in F_0 over a day as our main research measure (note, this was the only change found to differentiate between the two groups). This measure, average F_0 change, was averaged across gender and task as neither of these variables interacted with the time of day effect. We used a moderating model, using the Process Moderation Macro for *SPSS* by Hayes (www.afhayes.com), with the group as an independent factor, lifestyle factors as possible moderators, and

TABLE 2.
Lifestyle Information of the CCOs and Controls

Lifestyle Habits	CCOs	Students	P Values
Caffeine consumption*	4.2	3.0	<0.001
Water consumption†	2.9	3.5	<0.05
Hours of sleep per day	7.3	6.4	0.01
Number of cigarettes per day			0.001
1–5	4	1	
6–10	6	0	
>10	3	0	

* Calculated by the number of cups of coffee and coke drinks per day.
† Calculated by the number of water cups per day. *P* values represent the significance of the difference between the two groups.

average F_0 change as the dependent variable. Results show that none of the lifestyle factors could act as a moderator. That is, group differences in changes in F_0 over a day were not affected by group differences in lifestyle. It is notable that reported hours of sleep were found to significantly correlate with average F_0 change ($r_p = -0.4$; $P < 0.005$), where longer reported hours of sleep were linked with smaller average F_0 changes over a day. No other lifestyle factor was found to correlate significantly with average F_0 change.

DISCUSSION

The goal of this study was to gain a broader understanding of voice changes during loading in real speaking situations over 1 day. We focused on employees at a call center as it represents an occupation with high vocal demands, and accordingly, a high prevalence of voice complaints.[54] We examined the effects of voice loading with 27 call center operators (CCOs) during one working day and compared this unique group to 25 matched controls (students), without vocal loading. We used both reading and (free) speaking tasks. Our main findings point to an interaction of the effect of group membership (CCO or control) and time of testing (morning or afternoon) on average F_0. Namely, whereas for the control group, we found a significant increase in F_0 average by the end of the day, no such changes were found for the CCO group. This effect hints that an increase in F_0 over a day reflects ordinary changes in voice, whereas its absence might be related to voice load, and consequently, voice problems.

We also note that the CCO group was characterized with lower F_0 CV, higher intensity (SPL), and lower SPL CV than the control group. These group differences did not interact with the impact of time of testing. In other words, the passing of a day had a similar impact on both CCOs and controls for these factors. The two groups presented different lifestyle profiles, but these differences did not appear to moderate our main findings. Finally, we note that the task (spontaneous speech and text reading) and the gender of the speaker did not have a significant impact on the main tested variables and will not be further discussed. The next sections describe the results on each of these parameters in detail.

F_0 average

The most revealing result in our study is the increase in F_0 average for controls during a single day, which was not paralleled by a similar increase for the CCO group. Our data suggest that an F_0 increase may be related to typical activity of the vocal mechanism over a day, characterized with vocal warm-up while talking.[35,55] This typical process was evident in our control group of no voice load. However, the stressful and vocally demanding conditions in a call center might have counteracted this normal vocal warm-up and lead to vocal fatigue.

Vocal warm-up that occurs during speech production over the day has been found to raise F_0 in soft phonation in previous studies. For example, Jonsdottir et al[37] found larger increase in F_0 for female teachers who were using sound amplification during lectures. This suggests that reducing voice load (as the amplifications enable one to produce natural F_0 and intensity) can inflate the increase in F_0 after a day of speaking. Similarly, Rantala et al[39] found a larger increase in F_0 over a day for the participants who reported fewer vocal complaints. The authors concluded that "a change in physiological functions may illustrate healthy and normal adaptation to a situation, whereas a lack of change may imply that some disorder has prevented the vocal organ from working in a normal way" (p. 351).

Following the findings by Rantala et al,[39] we reexamined changes in F_0 over a day for our students' speech samples and found a replication of the pattern. Namely, for the five students who reported laryngeal signs and symptoms, time of day had no impact on F_0 average [difference < 2.5 Hz; $t(4) = 0.78$ ns]. But, for the remaining 20 students who did not report any such problems, we found a significant F_0 average increase over a day [difference > 10 Hz; $t(19) = 4.7$; $P < 0.001$]. In fact, it appears that the main reason for the increase in F_0 over a day for the control group is generated by the latter subgroup [interaction of time-of-day and reported laryngeal problems, $F(1,23) = 2.9$, $P = 0.05$, single-tailed]. (A similar analysis was conducted on CCO's samples. Reported laryngeal problems did not have a similar effect on the time-of-day difference in F_0 [an insignificant interaction $F < 0.1$]. Indeed, time of day had no impact on F_0 average for neither the five CCOs who reported laryngeal signs or symptoms nor for the remaining 20 [$t < 1.4$; $P > 0.19$, for all tests].)

Our data are unique as (to the best of our knowledge) it presents the first direct comparison of voice professionals and matched controls for changes in average F_0 over a day of speaking. The vast majority of the literature has focused on voice professionals, such as teachers and CCOs.[34,35,37,38] Thus, it was not clear whether the F_0 rise commonly found is related to voice load and possibly voice problems or if it is merely related to voice changes over a day. By pitting voice professionals and controls against one another, our study can support the latter hypothesis.

F_0 changes in semitones

From a clinical-practical point of view, it is interesting to examine the impact of the time-of-day on F_0 values in terms of semitones (sts), to assess whether a trained clinician will be able to detect these differences subjectively (without using instrumental assessment). In CCOs, F_0 differences between the morning and afternoon recordings were minor, 0.23 sts (averaged across genders and tasks). However, in the student group, this difference was substantially larger, with an average of 1.05 sts. We note that normal discrimination abilities in adults are at the order of 0.5 sts.[56] Clearly, the 1-semitone pitch change observed for the students can be perceived by the experienced SLP, whereas the 0.2 sts for the CCOs is well below the JND. Thus, the time of day change in F_0 may be used as a clinical indicator.

F_0 CV

To date, only a limited number of studies have investigated the impact of voice loading on the variance in F_0. In the present study, we found smaller variance in F_0 for CCOs, suggesting a better stability of phonation and control over laryngeal adjustments and vocal folds vibration for these semiprofessional speakers.[57] We also found a small yet significant decrease in F_0 CV values by the end of the day for both CCO and matched controls. These data stand somewhat in contrast to a previous study by Garrett and Healey[42] that reported an F_0 SD increase during a day (of typical voice use). We note that both our study and the 1987 one report on very small changes over a day (in the scale of 0.03–0.05 change of the baseline variance). These inconsistencies may relate to the formulae used for calculating the variance. Indeed, when recalculating the variance data presented by Rantala et al[39] (Rantala et al,[39] Table 1, p. 348) to coefficient of variance, there seems to be no change in F_0 CV over a day (23.3% for both morning and afternoon sessions). Finally, it appears that the relationship between the variance in F_0 and voice loading is not yet clear. Our data call for further investigation in future studies.

SPL and SPL CV

After a day of speaking, both CCOs and the controls used higher vocal intensity with decreased variance of SPL, compared with their baseline values. Yet, in both the morning and afternoon sessions, CCOs used higher vocal intensity with smaller variance than controls used. The overall increase in SPL over a day has been previously reported in the literature as related to vocal warm-up[39] as well as vocal loading[35] (see also a trend in some other studies[7] [58,59]). The higher SPL values for CCOs might be a long-term effect of the months of work in a call center environment (with loud background noise, poor acoustics of phone conversation etc) that creates a habit for louder voice. A similar trend was reported by Brown et al,[60] who found higher intensity levels for professional singers relative to nonsinger women. We may also consider speech-associated stress as a possible factor for the significant differences in SPL between groups. An elevation of stress levels has been shown to raise SPL levels and decrease its variation.[61,62] Likewise, CCOs who were tested at the call center experience high levels of work- and speech-related stress over a day. Finally, one cannot rule out the option that people who were chosen for a CCO position used louder voice to begin with.

F_0 and SPL relation

Our data show that the increase in F_0 over a day for our student sample was correlated with an increase in SPL (no such effect was found for CCOs). Indeed, there is a natural elevation of pitch when the speaker (especially an untrained one) is asked to increase the loudness of phonation.[63] For example, Gramming et al[64] reported that the mean fundamental frequency increased by 0.2–0.6 sts per dB equivalent sound level. Pitch changes are generally taken as the passive results of the changes of subglottal pressure applied to vary sound level of phonation.[64] As subglottic pressure increases, both amplitude and frequency increase as well.[63] We also note that the link between F_0 and SPL for students could not explain the difference in voice parameters between our two groups. That is, the group difference in F_0 changes was significant, even after controlling for changes in SPL.

Lifestyle factors

The personal questionnaires indicated differences in lifestyle habits (many of which related to vocal hygiene) between the two groups. In fact, each group had a distinctive lifestyle profile. Yet, these differences were not found to be revealing, as they did not have an impact on changes over a day in our main factor, F_0 average.

Water consumption.

Students consumed 20% more water cups per day than CCOs. Increased vocal fold hydration (both systemic and superficial hydration levels) is essential to its physiology,[65] and the lack of hydration was found to increase perceived vocal effort.[66] Yet, we found no effect for water consumption on our tested variables, possibly because both groups reported lower water consumption than the recommended daily amount (eight cups[67]).

Caffeine.

CCOs consumed 40% more caffeinated beverages (coffee and coke drinks) than matched controls. Caffeine is considered a dehydrating agent with negative effects on the quality of voice.[17] Despite the prevalence of the advice of SLP to minimize caffeine intake (as a means to preserve voice quality), to date it appears that only a limited amount of studies can support it.[18] It is thus not surprising that caffeine intake did not have an impact on the tested variable in our study.

Smoking.

Almost half of the participants in the CCO group reported smoking (most of them, 6–10 cigarettes per day), versus only one member of the control group. Although the association between tobacco use and laryngeal pathology is very strong,[68] the effect of smoking on objective voice parameters is less clear. Most studies reported lower F_0 for male smokers than for nonsmokers,[69,70] probably because of edema of the vocal folds. We note the same effect for male CCOs in our sample [129 and 153 Hz for smokers and nonsmokers, respectively—morning speech sample; $t(5) = 3.6$; $P = 0.015$]. However, smoking was not found to impact changes in F_0 over a day or explain group differences.

Sleep.

Finally, participants in the CCO group reported 14% more daily hours of sleep than controls. It is possible that the stressful and demanding work at the call center induced high levels of fatigue. Alternatively, students may have less time to sleep because of academic demands. Hours of sleep were negatively correlated with changes in F_0 average over a day. This correlation explained only a small portion of the variance (16%), and it is likely related to the difference between groups.

Vocal hygiene

The data presented previously reflect group differences in vocal hygiene habits. Vocal hygiene has a significant role in voice therapy.[71,72] Specifically, a vocal hygiene program, with information on strategies to reduce abusive vocal behaviors and to encourage optimal voice production (including hydration and vocal rest), has been found effective in treating voice problems.[16,73] For professional voice users, vocal hygiene educational program can serve as a preventive strategy,[74] helpful in facilitating vocal well-being and reducing overall risk of vocal injury. For example, Lehto et al[13] showed that a short vocal training course, which included vocal hygiene education, had a positive effect on the self-reported well-being of CCOs. However, once a professional voice user has crossed the threshold of injury, vocal hygiene training cannot serve as the sole strategy for the treatment of voice disorders.[73] Thus, vocal hygiene should be considered as a component of a broad vocal rehabilitation program for individuals with voice disorders.

Possible cross-cultural effects

Various cross-cultural factors (eg, stress levels, environmental noise levels, average speech intensity and rate, and personal habits) may affect vocal load of professional speakers and their lifestyle habits (for a related impact on oral Diadochokinesis (DDK) rate, see the study by Icht and Ben-David[50]). For example, class size can directly affect the amount of teachers' vocal load. Interestingly, an average class size varies significantly across countries, ranging from >32 students in Japan and Korea to $\leq$19 in Estonia and Iceland.[75] Not surprisingly, a recent review found differences between countries in the life-time prevalence of voice disorders among teachers, ranging from 51% (Italy and Belgium) to 69% (Poland; for a review, see the study by Cantor Cutiva et al[76]), with an even higher prevalence in Israel (83.5% for Hebrew speakers[77]). Specific cultural factors may be identified for CCOs as well, which invites further cross-cultural studies.

Summary and recommendations

The main goal of this study was to locate an objective acoustic index for vocal load and possible voice disorders. This has both personal-clinical and general-economic implications, as the number of people working in vocally demanding profession is rising. Our main finding was an increase in average F_0 at the end of the day for the control group, without vocal loading. However, for the CCO group, after a day of vocal loading, no change occurred. We suggest that F_0 rise during a day reflects a natural phenomenon of vocal warm-up, and vocal loading may impair this mechanism. In support of this assumption, we found that the increase in F_0 average was absent for controls with laryngeal complaints. Notably, these differences in F_0 can be perceptually detected by a trained clinician (without the need for digital analysis). We therefore recommend to further test changes in F_0 average over a day and their absence as a possible marker for vocal overuse or abuse. This is of specific importance, given the increasing number of vocally demanding professions in the global market and the cost (both to the employee and to the society) associated with voice related health problems.

We also note different lifestyle (and vocal hygiene) profiles of CCOs and controls. In general, the CCOs were characterized with behaviors that tend to "dry out" the voice, including smoking, consumption of caffeinated beverages, and insufficient water intake. Given the (admittedly scant) evidence in the literature and clinical experience, our data highlight the need to consider vocal hygiene education as a part of training programs for voice professionals, mainly as a preventive measure. We note that our study did not find these lifestyle habits to have a significant impact on voice changes over a day. This calls for further investigation of these relations with other groups of vocal professionals. Finally, future studies should also consider examining older professional voice users (60-year-old teachers, professors, tellers, singers, etc) and the dual impact of physical aging[78,79] and decades of vocal load.

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APPENDIX

TABLE 3.
CCOs Individual Data: Mean Values and Standard Deviations of Acoustic Variables Measured in the Morning and After-noon Recordings, for Both Tasks (Reading, Spontaneous Speech)

		Morning Recordings (Pre)								After-noon Recordings (Post)							
		Reading				Speech				Reading				Speech			
		F_0 (Hz)		SPL (dB)		F_0 (Hz)		SPL (dB)		F_0 (Hz)		SPL (dB)		F_0 (Hz)		SPL (dB)	
No.	Gender	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	f	178.7	38.06	68.88	7.26	159.83	35.54	70.45	6.41	174.64	40.21	69.7	7.07	157.42	31.24	69.44	6.58
2	f	194.73	40.87	69.48	7.24	199.88	38.2	67.93	7.49	178.47	55.11	67.75	7.89	174.04	52.82	67.64	7.56
3	f	193.5	41.32	68.44	6.95	186.71	37.66	68.17	6.79	179.04	41.25	68.92	7.84	189.86	46.83	69.73	6.88
4	m	133.37	53.88	65.59	8.02	122.52	53.07	66.65	6.99	115.77	31.91	63.49	8.85	110.14	32.69	66.95	7.58
5	m	139.52	40.21	68.45	7.53	141.92	47.62	67.51	6.89	135.28	22.02	68.46	7.29	125.93	24.31	66.68	7.63
6	f	190.23	33.19	66.59	6.43	185.75	35.85	67.36	6.12	189.28	40.67	67.28	6.98	191.66	35.87	67.49	6.35
7	f	158.55	41.84	67.08	8	142.96	47.19	66.98	7.17	140.93	36.4	66.47	8.18	134.32	26.18	66.92	7.42
8	f	180.55	37.88	66.21	6.78	180.38	32.23	66.6	6.68	175.39	28.49	68.81	5.06	169.69	28.51	68.61	6.18
9	m	155.72	39.41	69.09	6.98	152.58	40.78	67.97	7.97	149.9	25.97	69.55	5.75	–	–	–	–
10	f	196.1	42.1	69.39	6.32	186.93	36.89	70.82	5.35	198.6	35.4	68.81	7.46	197.32	28.01	69.36	7.09
11	f	196.46	47.49	69.33	6.99	166.54	58.75	63.46	7.17	107.06	37.16	69.03	8.5	195.16	44.81	65.6	9.05
12	f	195.9	33.98	71.14	6.41	182.11	35.7	72.81	5.85	214.99	34.55	70.27	6.46	193.33	35.9	69.86	6.14
13	f	181.51	37.51	65.21	7.13	187.83	47.53	66.07	7.18	185.04	38.61	68.63	6.59	184.3	48.48	68.85	6.88
14	f	204.07	39.14	68.15	7.5	199.81	41.16	67.09	7.44	196.03	36.22	69.66	6.53	180.94	39.72	69.88	6.96
15	f	202.63	32.06	70.4	7.86	200.05	32.24	71.44	6.92	206.92	39.11	69.89	7.26	203.91	38.79	71.12	6.57
16	f	194.57	42.47	65.42	8.27	185.94	46.91	67.12	7.59	200.65	45.94	67.97	7.25	182.02	46.67	66.39	7.51
17	f	178.23	32.27	68.97	6.81	200.28	42.76	68.63	7.26	186.43	30.8	70.86	5.39	214.46	46.55	70.67	5.2
18	f	174.15	41.54	68.41	7.1	168.89	35.85	69.34	6.75	172.48	40.31	71	5.61	170.15	38.74	71.01	6.14
19	m	138.38	55.11	67.94	6.66	134.45	53.85	67.85	7.16	137.98	49.74	69.14	6.55	134.48	52.4	70.14	6.64
20	f	173.76	34.1	69.16	6.44	173.9	31.75	70.75	7.04	–	–	–	–	–	–	–	–
21	m	116.44	47.71	66.97	7.34	119.2	46.2	67.17	7.78	120.64	33.14	69.12	6.25	136.22	43.23	70.55	5.59
22	f	188.42	43.2	70.44	7.15	173.37	40	69.95	7.13	–	–	–	–	–	–	–	–
23	m	151.43	28.43	70.48	6.84	149.48	32.47	70.85	7.01	159.28	24.9	71.32	6.22	162.78	28.27	71.86	6.05
24	f	202.41	46.48	68.78	7.01	202.26	51.05	69.4	6.73	191.1	50.17	70.04	5.89	185.77	46.27	71.16	5.05
25	f	172.76	51.17	67.7	6.71	168.4	47.02	69.93	6.86	170.11	50.87	68.87	5.78	168.9	55.33	69.16	5.85
26	f	190.53	44.53	70.37	6.71	181.54	40.95	71.86	6.65	190.34	43.69	70.07	6.32	187	40.23	71.2	6.38
27	m	212	179.17	70.2	7.59	156.23	37.55	70.32	7.16	181.45	35.34	71.11	6.29	167.81	29.51	71.46	6.12

TABLE 4.
Students' Individual Data: Mean Values and Standard Deviations of Acoustic Variables Measured in the Morning and After-noon Recordings, for Both Tasks (Reading, Spontaneous Speech)

		Morning Recordings (Pre)								After-noon Recordings (Post)							
		Reading				Speech				Reading				Speech			
		F0 (Hz)		SPL (dB)		F0 (Hz)		SPL (dB)		F0 (Hz)		SPL (dB)		F0 (Hz)		SPL (dB)	
No.	Gender	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	f	188.98	36.2	64.59	7.49	190.06	38.13	64.48	7.13	297.03	42.71	67.7	8.13	202.57	37.6	67.41	6.91
2	f	221.86	44.07	66.94	7.98	201.94	47.43	65.37	7.47	248.72	42.13	66.02	6.33	223.07	37.31	67.23	5.89
3	f	164.01	37.12	66.31	8.42	154.54	37.68	67.07	7.97	180.55	37.49	66.72	7.21	162.69	37.44	67.94	6.81
4	f	181.58	34.65	64.56	7.76	171.95	37.59	64.43	7.48	191.73	38.24	65.81	6.88	188.49	37.37	63.71	6.87
5	f	184.79	36.69	67.41	8.78	175.55	57.74	68.03	8.63	190.5	36.79	68.61	7.4	184.82	48.03	69.98	7.35
6	f	185.82	44.35	66.83	8.29	182.16	46.93	67.84	8.39	186.59	44.12	67.32	6.97	175.39	34.91	66.81	6.17
7	f	186.34	39.73	66.44	8.85	181.27	37.3	68.03	7.99	192.37	42.37	68.86	7.1	183.16	43.65	68.03	7.37
8	f	176.52	44.04	65.34	8.44	167.88	52.49	64.14	8.27	184.59	41.65	68.59	8.21	170.98	52.23	65.49	8.86
9	m	142.26	34.21	67.04	8.16	142.62	46	63.14	8.47	159.54	44.4	68.5	7.38	157.32	61.09	65.95	8.17
10	f	189.99	38.99	63.99	7.45	188.08	50.25	62.58	8.33	196.04	47.22	63.68	6.17	201.76	54.24	63.37	6.85
11	f	182.85	41.64	66.65	7.63	169.91	41.61	66.42	7.48	186.36	29.66	63.61	8	176.46	42.87	65.14	7.58
12	f	184.52	41.73	63.73	7.8	168.34	51.5	64.2	7.79	194.63	49.21	65.67	7.46	191.07	54.92	67.56	7.2
13	f	200.29	20.87	67.49	9.23	196.59	35.2	66.4	8.22	209.03	45.79	68.11	8.15	194.24	40.37	67.64	6.99
14	f	186.77	31.99	63.41	8.16	172	48.43	63.91	8.24	196.51	35.91	67.24	7.68	182.53	48.75	63.06	7.85
15	f	193.22	48.84	65.13	8.27	168.56	57.43	60.77	7.94	197.74	48.82	63.48	7.71	195	52.28	66.36	6.67
16	f	199.71	47.33	66.49	8.7	187.96	36.85	69.18	6.84	213.83	46.07	68.21	7.48	187.12	42.38	68.6	6.78
17	f	199.19	47.68	65.07	9.33	189.79	38.42	67	7.54	207.31	42.31	66.72	7.52	176.46	42.87	65.14	7.58
18	f	201.22	45.4	65.76	9.14	190.42	41.33	67.41	7.23	223.85	52.78	65.71	9.01	202.45	41.26	67.24	6.88
19	f	189.25	40.13	66.29	8.48	176.81	49.15	68.84	7.85	194.95	47.04	67.57	7.57	202.57	37.6	67.41	6.91
20	f	184.99	43.48	64.68	8.72	175.38	43.88	63.9	7.56	208.18	46.46	64.15	7.14	192.78	43.37	67.55	7.06
21	m	141.64	75.23	65.25	9.6	126.71	62.9	66.04	8.81	135.19	45.09	66.05	8.45	130.19	43.88	66.73	7.34
22	m	121.29	49.34	68.24	8.63	129.38	44.75	69.63	7.9	132.57	41.12	68.57	8.42	130.28	44.38	69.71	7.28
23	m	122.94	8.13	68.05	10.27	120.26	38.24	70.51	9.28	140.58	28.29	69.19	9.53	135.76	30.83	69.14	9.7
24	m	133.01	45.97	69.05	8.81	126.1	46.02	70.16	8.18	136.83	61.6	65.5	7.94	125.56	49.85	65.21	8.32
25	m	122.76	52.37	66.8	8.33	117.24	51.32	65.76	7.96	124.61	42.61	68.06	7.53	122.94	46.74	69.73	6.83