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Time-of-day Effects on Voice Range Profile Performance in Young, Vocally Untrained Adult Females

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Summary: Time-of-day effects on voice range profile performance were investigated in 20 vocally healthy untrained women between the ages of 18 and 35 years. Each subject produced two complete voice range profiles: one in the morning and one in the evening, about 36 hours apart. The order of morning and evening trials was counterbalanced across subjects. Dependent variables were (1) average minimum and average maximum intensity, (2) Voice range profile area and (3) *center of gravity* (median semitone pitch and median intensity). In this study, the results failed to reveal any clear evidence of time-of-day effects on voice range profile performance, for any of the dependent variables. However, a reliable interaction of time-of-day and trial order was obtained for average minimum intensity. Investigation of other subject populations, in particular trained vocalists or those with laryngeal lesions, is required for any generalization of the results. **Key Words:** Voice range profile (VRP)—Phonetogram—Voice—Time-of-day effects—Warm-up—Fatigue.

The relationship between voice intensity and fundamental frequency variations has been a topic of interest for several decades. Systematic studies of such relationships were first introduced in the 1930s by Wolfe and colleagues[1] and by Stout,[2] who described a covariance of sound pressure level (SPL) and fundamental frequency (F_0) whereby SPL generally increased with increasing in F_0. In the 1950s, Calvert and Malhiac[3] also described similar relations. Coleman[4] and Klingholz[5] provide further historical reviews. The more recent widespread use of the maximum SPL/F_0 plot in voice research can be traced to Damsté[6] who called the function a "phonetogram."[7]

In addition to phonetogram, the SPL/F_0 plot has been variously called a "voice profile,"[8] "voice field," "fundamental frequency - sound pressure level profile,"[9] "Stimmfeld"[10] "voice area," "Stimmgebiet," and "courbe vocale".[11] Most recently, the term "voice range profile" or VRP has been recommended by the International Association of Logopedics and Phoniatrics.[12] Following this recommendation, the term VRP will be used throughout this paper to refer to plots of maximum and minimum intensities across the complete frequency range.

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The VRP may be valuable for several reasons. According to Gramming, Gauffin, and Sundberg,[13] it provides a global *picture* of voice functioning. F_0 and SPL are salient aspects of voice output and reflect physiological factors in voice production.[14] The *picture* produced by the VRP may be useful in voice pedagogy, clinical practice, and voice research. For example, these plots may be used to assist in voice classification for singers.[5] VRPs can further be used to indicate changes in voice capabilities before and after treatment for voice disorders.

Several factors have been assessed for their possible impact on VRPs. Coleman[4] presented a comprehensive listing of these factors. To briefly list them, factors include vowel type, tone duration, tone production modality (discrete vs continuous production and steady vs. repeated production), learning effects, subject pitch-matching abilities, amount of prior voice use or warm-up, subject respiratory volume, mouth opening, tone quality, register, subject motivation, room acoustics, sound-level meter settings, specifically, A vs C weighting, microphone-to-mouth distance, frequency intervals tested, plotting factors (log vs. linear scales), and assistance factors (clinician vs automated).[3,4,9,11,13,15-27]

Another variable of interest that has not yet been quantified is time-of-day. Anecdotally, time-of-day complaints of reduced function in early morning performances by singers leads to a question whether time-of-day affects phonation itself. The purpose of the present study is to investigate time-of-day effects on VRP performance in a select population. If time-of-day does affect VRP performance, then it will be important to control for this variable in the generation of normative data and in applied practice.

Theoretically, it is possible to think of several reasons why VRP performance might be influenced by time of day. Although the present study is pragmatic and descriptive rather than theoretical and explanatory, it is worthwhile to at least speculate about how-and why-VRP might vary with time of day. This is the topic of the next section.

Hypotheses About Changes in VRP Performance with Time of Day

Fluid distribution factors. Theoretically, time-of-day changes in body fluid distribution could influence VRP performance. The distribution of fluids within the body is regulated by the lymphatic system. Lymphatic glands tend to be most productive during sleep.[28] Furthermore, skeletal muscle contraction regulates lymphatic fluid distribution[28] Because skeletal muscle are relatively inactive during sleep, the combination of increased fluid production and decreased fluid circulation leads to in situ fluid accumulation at night. Relative to voice, a particular issue is that fluids tend to accumulate where they are produced. Thus, thyroid gland secretions may accumulate in the head and neck and perhaps vocal folds during sleep. The net effect of all these factors points to the real possibility that the vocal folds may tend to be more fluid-laden upon awakening in the morning, as compared with later in the day. Given the inverse relation between F_0 and vocal fold mass, the result should be a decrease in both minimum and maximum frequencies in the morning upon awakening.

Effects of vocal fold fluid accumulation upon intensity are less straightforward to predict. Speculatively, accumulated fluid might cause an increase in the vocal fold cross- section participating in phonatory oscillation. Thus, closure might improve, leading to increased maximum flow declination rate, a fuller harmonic spectrum, and thus an increase in maximum intensity. Similarly, well-closing-but not pressed vocal folds require the least amount of subglottic pressure for oscillation. Thus, minimum intensity also might reduce as a function of increased fluid. Finally, if vocal fold viscosity decreases due to added fluid, a further reduction might be expected in minimum intensities.[14,29,30] The sum result of the combined factors would be a decrease in F_0 range, but an *increase* or improvement in dynamic range due to fluid- filled folds.

Voice use factors. Relative to voice use, both warm-up and fatigue effects could affect VRP performance, in opposite directions. Warm-ups lead to increased blood perfusion. to the muscles, and consequently an increase in nutrient deposition to the muscles used.[31] As a result, exercised muscles have increased muscular activation potential, increased muscle contractile abilities, and possibly improved fine motor control. Warm-up of thyroarytenoid and cricothyroid muscles occurring in this way should lead to an increase in F_0 range. Warm-up of the laryngeal complex together with warm-up of respiratory musculature should translate to an increase in maximum and possibly minimum intensity, and thus an increase in intensity range.

Opposite effects should be seen with vocal fatigue. A fatigue-induced decrease in laryngeal and respiratory maximum contractile ability and control[32,33] should lead to reductions in both F_0 and dynamic ranges. Additionally, a fatigue-induced loss of the vocal folds' elastic properties also could add to an F_0 range reduction.

Summary and Experimental Questions

In summary, at least two general factors, body fluid distribution and voice use, might cause changes in VRP performance as a function of time of day. The purpose of the present study is to address possible time-of-day effects on VRP performance. Although the findings could have theoretical interest, this study's focus is pragmatic. Specifically, we are motivated first and foremost by the practical question of whether time of day needs to be considered in the generation of normative VRP data, for healthy subjects. The findings also could provide a baseline for investigations in other subject groups, as well as investigations of the specific physiological mechanisms underlying any changes noted.

The general experimental question is: Does VRP performance vary with morning versus /evening trials? This question is operationalized. in the next section.

METHODS

Subjects

Subjects were 20 women recruited from the Department of Speech Pathology and Audiology and other academic departments at The University of Iowa. The subjects ranged in age from 18-35 years (average = 23.3 years). All subjects denied any history of a voice disorder or known laryngeal pathology, smoking, or voice training beyond minimal training in high-school choir. Subjects' speaking voices were normal on the days of the experiment, according to the experimenter's auditory-perceptual judgments. Each subject was paid $10 for her participation. All were uninformed about the experimental hypotheses.

Procedures

At the outset of the experiment and before their participation, subjects were randomly assigned to one of two experimental groups, with 10 subjects in each group. In one group, subjects produced a first VRP in the morning about 7:00 AM, and a second one about 33-36 hours later (between 4:00-7:00 PM the following day). In the other group, the first VRP in the early evening (between 4:00-7:00 PM) and the second was produced 36-39 hours later, about 7:00 AM.

For morning VRPs, intensity/frequency plots were produced within 1 hour of waking. Subjects were instructed to abstain from voice use and from eating and drinking before to their participation. All indicated compliance with these instructions. Before to the evening VRP procedure, subjects rated their voice use during the day on a scale from 1 to 10 (1 = no voice use; 10 = heavy voice use.) All subjects rated between 4-8 (X = 5.3, SD = .8)

For the experimental procedures, subjects first read and signed consent forms. Then, the experimenter read standardized instructions to the subject about how to operate the computed VRP program that would be used to collect the experimental measures. In brief, the subject was seated in front of the computer and with the screen showing a graph with a y-axis labeled as intensity (dB SLP) and an x-axis labeled as frequency (Hz). The frequency axis was further divided into discrete pitch "bins" with two to three semitones in each bin.

When the subject produced a sound, an "x" appeared on the computer screen displaying the intensity/frequency coordinate of the sound produced. The "x" changed into a line across one pitch bin when the sound was held steady for 2 seconds. The subject was instructed to produce lines in as many pitch bins as possible, ranging from lowest and highest notes. The instruction was to first produce a set of bars across the full pitch range as quietly as possible. Then a second set of lines was to be produced, again across the entire pitch range, as loudly as possible without incurring discomfort.

For all training and experimental trials, a microphone was mounted on the subject's head. The microphone was positioned at a 45-degree angle from the subject's lips, and the microphone-to-mouth distance was 8 cm from the center of the mouth to the center of the microphone.[27] Subjects were instructed not to displace the microphone from the established position throughout data collection.

After training and before data collection, the experimenter reviewed the instructions and procedures with the subject. The subject was reminded to produce the greatest VRP area possible, without incurring discomfort. Once the training phase was completed, subjects performed all further VRP trials without the experimenter's assistance or presence. All subjects completed the initial training plus data collection for the first set of trials in 30 minutes or less. Then, subjects returned about 36 hours later to produce a second VRP, as already noted.

Equipment and Software

Equipment and software are described in detail elsewhere.[27] Briefly, VRPs were produced in an OSHA and ANSI certified Industrial Acoustics Corporation recording booth. Acoustic signals were collected with an AKG C410 microphone powered by a Symetrix SX 202 preamplifier. The signals were then routed to a MacII FX computer for analogue-to-digital signal conversion using a TMS320C30-based digital signal processor. LabView was used to extract F_0 and intensity information in real time.

Intensity and F_0 were displayed on the computer screen. As the subject produced the vowel /a/, an "x" appeared in the graph on the computer screen at the intensity and frequency coordinate. This "x" or data point was compared with the data points from the proceeding 1.5 seconds. This "x" converted to a line and was permanently saved if the tone was stable. Stability criteria were set up within the parameters of the computer program.[27] This line indicated the averaged intensity/frequency coordinate. If additional trials were attempted within the same pitch bin, a new line replaced the previous one if the additional trial involved a lower intensity for minimum intensity trials, or a greater intensity for maximum intensity trials.

Experimental Design and Statistical Analyses

The experimental design was a cross-over trial design, with time of day (morning vs evening) as a within-subjects factor and order (AM first vs PM first) as a between-subjects factor. VRP performance was evaluated statistically using three sets of parameters: (1) average maximum minimum and average intensity (2) VRP area and (3) VRP *center of gravity*.

Averaging the dB levels across all bins for the bottom curve (minimum intensity) and the top curve (maximum intensity) obtained both the average minimum and the average maximum intensity curves. In light of the known dependence of phonation threshold pressures on a series of factors including hydration,[29,30] and the further effect of subglottal pressure on intensity.[14] minimum intensity was of particular interest.

VRP area was obtained for each condition by initially calculating the area within each pitch bin. This area was calculated as the product of the pitch-bin size (arbitrarily set as "1" for each pitch bin) times the dynamic range, in dB. The total VRP area was then obtained by summing the areas for all pitch bins.

The VRP center of gravity was the coordinate of the median semitone note and the median intensity. It was considered that together, the VRP area and center of gravity would provide an indication of performance *variability* (area) as well as *central tendency* (center of gravity).

For each set of parameters, a two-factor analyses of variance (ANOVA) with repeated measures was conducted to assess the main effects of time of day (morning vs evening), order (AM vs PM trials first), and the interaction of time of day and order.

RESULTS

Minimum and Maximum Intensity Curve Analyses

Minimum Curve Analyses

Average minimum intensity data are shown in the Figures 1-4. Visual inspection of these curves indicates a small but systematic change in minimum intensity curve with time of day. Figure 1, which shows average minimum curves for the morning versus evening trials, shows little indication of any clear differences in minimum curves as a function of time-of-day. Figure 2, which show average minimum curves for the first versus second trials, also shows little indication of any clear differences in minimum curves as a function of trial number. Figures 3 and 4 display average morning versus average evening perfor-

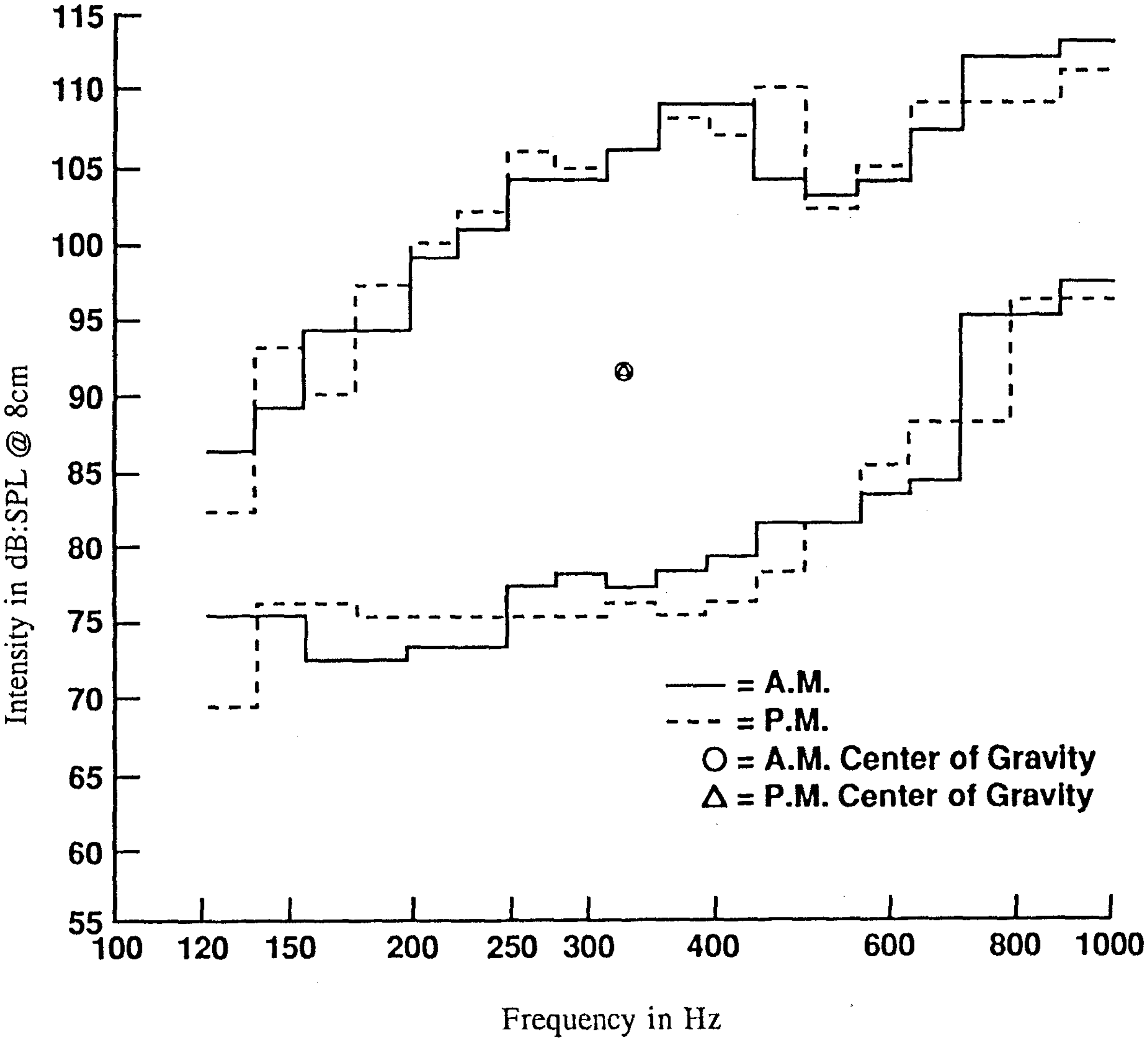

FIG. 1. Average am VRP compared with the average pm VRP. Solid lines designate am VRP, dashed lines pm VRPs. Average minimum intensity curve was 79 dB for am trials and 80 dB for pm trials. Average maximum intensity was 104.7 dB for am trials and 103.7 dB for pm trials. VRP area was 398.5 total dB units for am trials and 363.1 total dB units for pm trials. Center of gravity is the circle (coordinate 339 Hz, 91.2dB) for am trials and the triangle (coordinate 337.4 Hz, 91.4 dB) for pm trials.

mance for subjects who executed the morning VRP trials first (Figure 3) and for those who executed the evening VRP trials first (Figure 4). Note the similar findings for minimum curves for subjects who executed the morning VRP trials first (Figure 3). However, for those who executed the evening VRP trials first (Figure 4) minimum curves appeared consistently lower in the morning than in the evening.

The average intensity in the morning was about 1 dB lower than the average intensity in the evening. Further, the average intensity for the second trial was about 2 dB lower than for the first trial. The mixed-model ANOVA for *minimum* intensities did show this effect: minimum intensities were reliably lowest in the morning, when morning trials were performed second. This effect was shown by a reliable interaction of time-of-day and trial order ($F(1{,}654) = 5.13$, $p = .032$). However, main effects of time-of-day and trial order were unreliable ($F(1{,}654) = 1.30$, $p = .201$, and $F(1{,}654) = 0.68$, $p =$

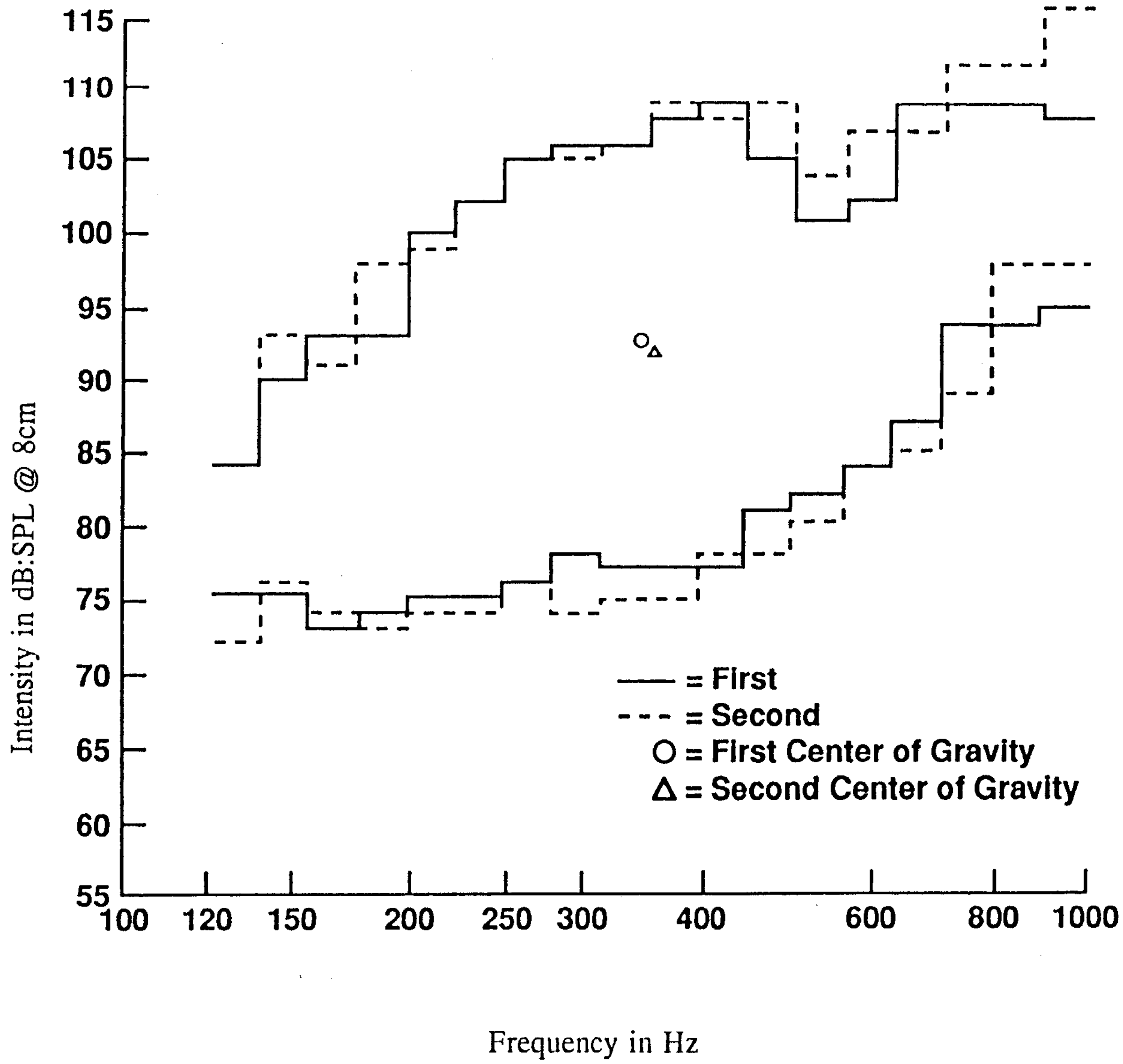

FIG. 2. Average first VRP compared with the average second VRP. Solid lines designate first VRP, dashed lines second VRPs. Average minimum intensity curve was 80.4 dB for first trials and 78.6 dB for second trials. Average maximum intensity curve was 105.3 dB for first trials and 103.1 dB for second trials. VRP area was 358.8 total dB units for first trials and 402.8 total dB units for second trials. Center of gravity is the circle (coordinate 327.8 Hz, 92.4 dB) for first trials and the triangle (coordinate 370 Hz, 90.2 dB) for second trials.

.989, respectively). For the time-of-day factor, statistical power was poor (.044).

Maximum Curve Analyses

Average maximum intensity data are shown in Figures 1-4. As for *minimum* intensities, average *maximum* intensities for the morning were also about 1 dB higher than those for the average *maximum* intensities for the evening. Furthermore, average maximum intensities on the first trial were more than 2 dB greater than for the second trial. However, a mixed-model ANOVA failed to confirm any reliable trends in these data ($F(1,654) = 0.20$, $p = .650$ for time of day; $F(1,654) = 0.75$, $p = .876$ for order; $F(1,654) = 0.14$, $p = .457$ for the interaction). For the time-of-day factor, which was of conceptual interest, the power to detect a true effect was .044 (2-tailed, alpha = .05).

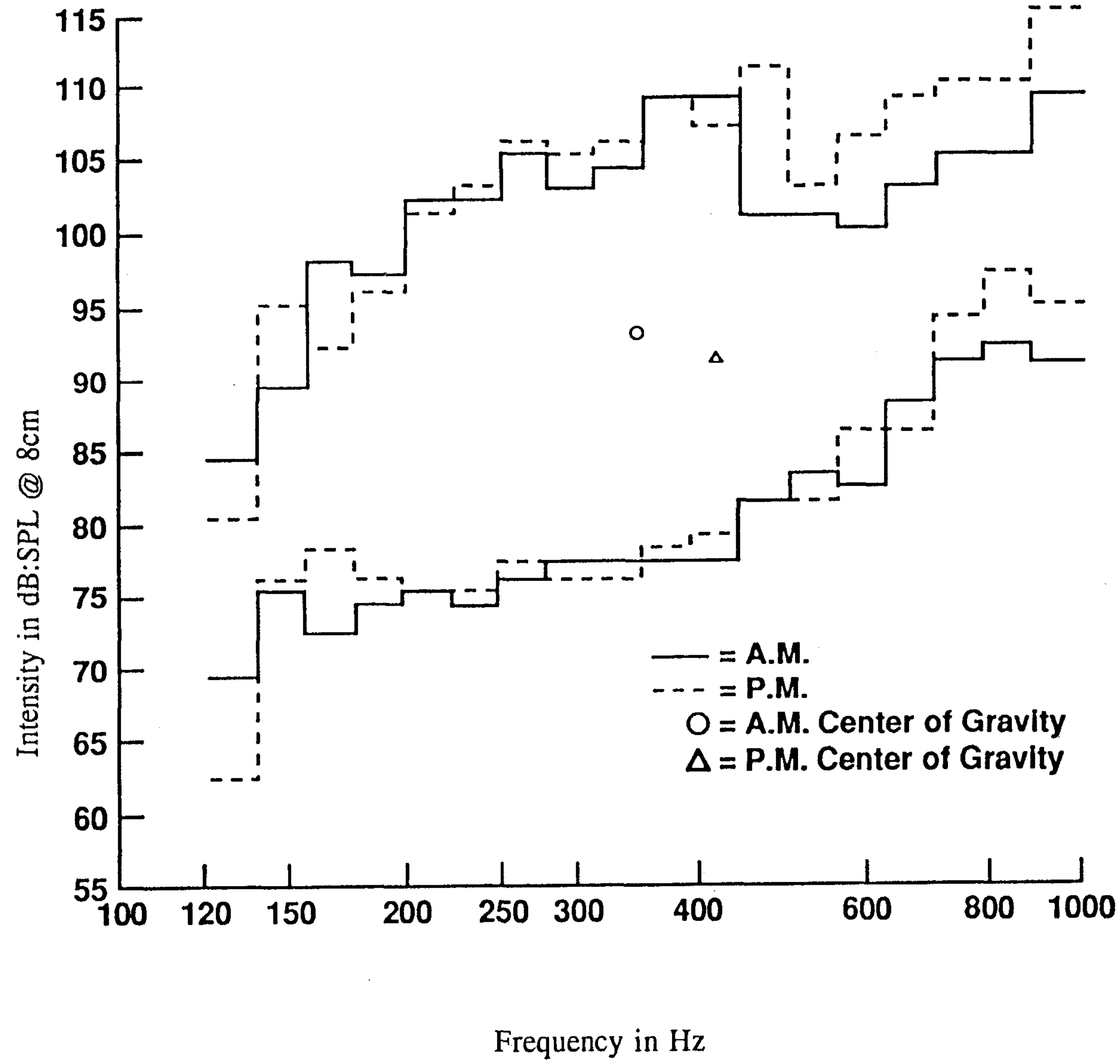

FIG. 3. Average am VRP compared with the average pm VRP for subjects who began in the morning. Solid lines designate am VRP, dashed lines pm VRPs. Average minimum intensity curve was 80.2 dB for am trials and 79.4 dB for pm trials. Average maximum intensity curve was 106.3 dB for am trials and 103.0 dB for pm trials. VRP area, was 393.5 total dB units for am trials 402.1 total dB units for pm trials. Center of gravity is the circle (coordinate 322.2 Hz, 92.9 dB) for am trials and the triangle (coordinate 341.5 Hz, 90.9 dB) for pm trials.

Area

Results for VRP area are shown in Figures 1-4. In Figure 1, mean VRP performance in the morning versus the evening, visual inspection of these areas indicates little evidence of any systematic changes in area with time of day. Similarly, in Figure 2, average area results for the first versus second trials, displays little indication of any clear differences in VRP areas as a function of trial number. In Figure 3, subjects who executed the morning VRP trials first, exibit no obvious difference in VRP area. Only in Figure 4 is there any apparent indication of a change in VRP area with time of day: for subjects in this group, the minimum intensity curve appeared consistently lower for morning as compared with evening trials, increasing the overall VRP area for this condition.

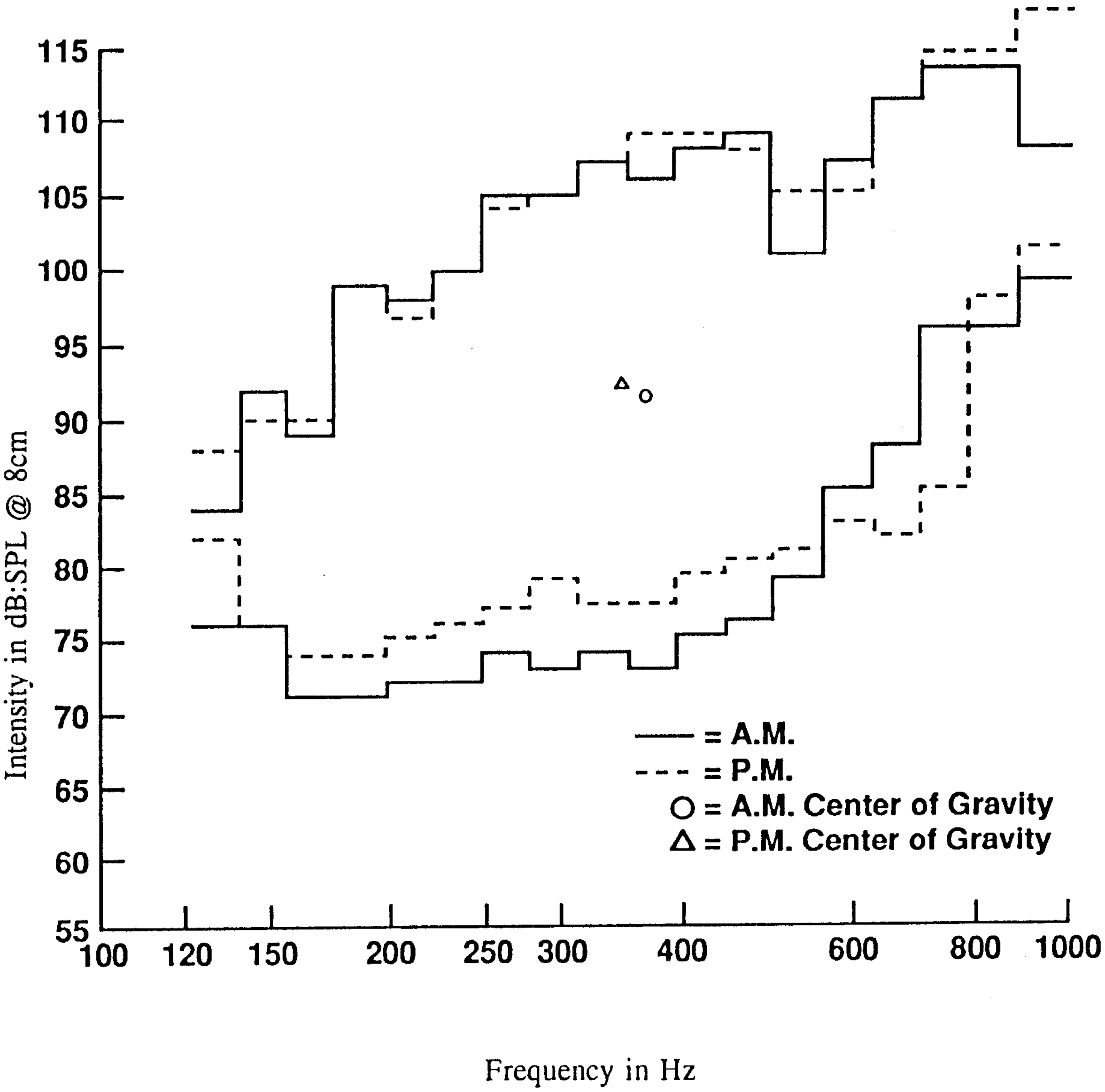

FIG. 4. Average am VRP compared with the average pm VRP for subjects who began in the evening. Solid lines designate am VRP, dashed lines pm VRPs. Average minimum intensity curve was 77.7 dB for am trials and 80.6 dB for pm trials. Average maximum intensity curve was 103.1 dB for am trials and 104.3 dB for pm trials. VRP area was 403.4 total dB units for am trial and 324 total dB units for pm trials. Center of gravity is the circle (coordinate 357.5 Hz, 89.5 dB) for am trials and the triangle (coordinate 333.5 Hz, 91.9 dB) for pm trials.

Despite this last, weak trend noted graphically, statistical tests failed to reveal any clear differences in VRP areas as a function of the experimental manipulations. Neither of the main effects (time of day and order) nor their interaction produced significant results according to mixed-model ANOVAs ($F(1,36) = 0.51$, $p = .148$ for time of day; $F(1,36) = 0.79$, $p = .612$ for order; $F(1,36) = 0.47$, $p = .077$ for the interaction). Focusing on the time-of-day factor, (the variable of conceptual interest in this study), the effect magnitude and the variance present in the data, power was .059 for a 2-tailed test at an alpha criterion level of $p = .05$.

Center of Gravity

Data for VRP center of gravity are shown in Figures 1-4. In like manner, these data show little evidence of any systematic changes with time of day or trial order. ANOVAs evaluating the main effects of time of day (morning vs evening) and trial order (AM/PM versus PM/AM trials) and the interaction of main effects (time of day x trial order) failed to confirm any statistically significant effects [for *pitch*, $F(1,36) = 0.01$, $p = .866$ for time of day; $F(1,36) = 1.59$, $p = .528$ for order; $F(1,36) = 0.64$, $p = .077$; for the interaction; for *intensity*, $F(1,36) = 0.02$, $p = .892$ for time of day; $F(1,36) = 2.05$, $p = .470$ for order; $F(1,36) = 0.61$, $p = .145$ for the interaction]. Again, focusing on the time-of-day factor, statistical power was .074 for intensity and .067 for pitch for 2-tailed tests at a criterion level of $p = .05$.

DISCUSSION

In this experiment, there was little evidence of a clear time-of-day effect on VRP performance in young, vocally untrained, vocally healthy adult females. VRP areas, centers of gravity, and maximum and minimum intensities did not reliably vary with morning versus evening performance. Although a verification of these findings is required for other subject groups, the present data do not provide any strong indication that significant time-of-day effects might be expected for the group tested.

The findings do warrant further comment. First, the variability in VRP data was large in this study, in comparison with potential effect sizes. In fact, the statistical power to detect a time-of-day effect was consistently poor. Further experiments with larger subject groups might uncover reliable time-of-day effects. However, the present findings do not suggest that such effects would be large in magnitude, on average even if statistically significant.

A second point is that although the main effect of time-of-day was unreliable for all parameters evaluated, one *interaction* of time of day and trial order was shown. Subjects who performed their first VRP in the evening had reliably lower minimum intensities in the morning than subjects who performed their first VRP in the morning. This implication is consistent with the point from the previous paragraph: Although subtle time-of-day effects on VRP performance may exist, they require particular circumstances to be clearly seen and, even when they are seen, the effect sizes appear small (on the order of about 2 dB).

Third, although group measures did not reveal systematic time-of-day effects on VRP performance other than in the interaction described, it is not excluded that *individual subjects* may indeed experience real changes as a function of time of day. This question might be explored in other studies using experimental designs suited to analysis of individual data.

Fourth, hypotheses which we generated about possible time-of-day effects on VRP performance had opposing theoretical outcomes. It is not excluded that such effects do exist, but cancel each other out thus obscuring real changes that may be present.

Such considerations caution us about confidently concluding that time of day is irrelevant for VRP performance. Caution is increased by the axiom that one cannot impute significance to null results. Stated differently, without converging data from other studies, it is incorrect to conclude that VRP performance does not vary with time of day in the population tested. We can only say that we did not find evidence of it.

Caution about generalization extends in particular to other subject populations, beyond normal young adult, female, untrained voice users. For example, there are reasons to think that different results might be obtained with trained vocalists. According to Ericsson, Krampe, & TeschRömer,[34] the training of specific muscle groups as may occur with voice instruction and practice may alter muscle anatomy and physiology due to an increase in muscular capillary architecture. Increased vascularization could conceivably enhance warm-up effects—and decrease fatigue—yielding a net improvement in VRP performance in the evening. Such effects could underlie common the aforementioned anecdotal complaints among singers of inferior performance in the morning compared with the evening.

Similarly, generalization of the present results to a voice-impaired population is unwarranted. In particular persons with benign mucosal lesions affecting the membranous vocal folds may have increased cellular fluid extravasion due to poor cellular boundary integrity, resulting in extracellular fluid pooling within the vocal folds.[33] Such effects might be accentuated in the morning, producing distinct morning decrements in VRP performance. Furthermore, traumatic voice use patterns that may occur during the day in this population might produce local injuries affecting evening VRP performance. Similar studies should be undertaken to assess time-of-day effects in other special interest populations.

In conclusion, this study provided no strong indication of time-of-day effects on VRP performance. A potential finding was that minimum intensities may be lower in the morning than in the evening when subjects are already familiar with the VRP task, in the subject group tested. However, even under such conditions, the effect size appears small, on the order of about 2 dB.

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