Clinical techniques and technology

The use and role of the Ambulatory Phonation Monitor (APM) in voice assessment

Ruolo e utilizzo clinico dell'Ambulatory Phonation Monitor (APM) nella gestione della voce

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SUMMARY

Vocal load plays a significant role in the aetiology of voice disorders and influences the response to treatment. For this reason, many researchers have focused their attention on how a voice is used, especially when vocal load is increased, during working hours for instance. The majority of studies in this regard have been performed by recording vocal parameters for brief periods with the aid of microphones. The first devices produced recorded only a few parameters and for relatively short periods of time, and since microphones were used there was a problem with both privacy and background noise such as the inclusion of voices from nearby people. Recently, microprocessors that can monitor a voice for an entire day have been developed; these use miniaturised accelerometers as vocal sensors. The latest commercially-available version is the Ambulatory Phonation Monitor (APM) (KayPENTAX, Lincoln Park, NJ, USA) which can record several vocal parameters for over 18 hours and supply a series of graphic representations of the variations in these parameters during the recording period. In particular, the APM permits recording vocal load by measuring the cycle dose and distance dose, and evaluates vocal intensity (dB sound pressure level [SPL]), fundamental frequency and total phonation time. This report describes the APM, the use of an accelerometer as a vocal sensor, the importance of its calibration and the parameters it records. In particular, details are given on phonation time, variations in frequency, vocal intensity, phonation density and vocal dose. The role of the APM in voice studies is also described, in addition to its potential clinical applications as demonstrated by the few reports available in the literature. We also discuss our experience with the device in groups of euphonic and dysphonic elementary school teachers.

KEY WORDS: Ambulatory Phonation Monitor • APM • Vocal load • Vocal doses • Total phonation time • Parameters of voice

RIASSUNTO

Il carico vocale gioca un ruolo significativo nel causare disturbi della voce ed influenzare la risposta al trattamento. Per questa ragione molti ricercatori hanno focalizzato la loro attenzione su come viene utilizzata la voce soprattutto quando aumenta il carico vocale e quindi durante le ore lavorative. La maggior parte degli studi sono stati effettuati sulla base della registrazione di parametri vocali per brevi periodi utilizzando dei microfoni. I primi strumenti prodotti, registravano pochi parametri vocali solo per alcune ore e l'utilizzo di microfoni poneva problemi non soltanto di privacy ma anche problemi relativi al rumore di fondo ed alla voce di soggetti vicini. Recentemente sono stati sviluppati microprocessori capaci di monitorare la voce per l'intera giornata utilizzando come sensori vocali, accelerometri miniaturizzati. L'ultima versione prodotta e recentemente messa in commercio è l'Ambulatory Phonation Monitor (APM) (KayPENTAX, Lincoln Park, NJ), strumento capace di registrare diversi parametri vocali per oltre 18 ore e di fornire una serie di elaborazioni grafiche delle variazioni di tali parametri nel tempo di registrazione. In particolare l'APM permette di registrare il carico vocale attraverso la misurazione del "cycle dose" e del "distance dose", stima l'intensità vocale (dB sound pressure level [SPL]), la frequenza fondamentale ed il tempo fonatorio totale. In questo lavoro viene descritto l'APM, l'accelerometro utilizzato come sensore vocale, l'importanza della sua calibrazione ed i parametri da esso registrati. In particolare verranno descritti il phonation time, le variazioni di frequenza e intensità vocale, la densità di fonazione ed il vocal dose. Inoltre verrà descritto il ruolo dell'APM nello studio della voce e le sue potenziali applicazioni cliniche sulla base sia dei pochi dati esistenti in letteratura, sia sulla base della nostra esperienza su gruppi di insegnanti eufonici e disfonici.

PAROLE CHIAVE: *Sistema portatile ambulatoriale per il monitoraggio della voce • APM • Carico vocale • Dosi vocali • Tempo totale fonatorio • Parametri della voce*

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Introduction

The majority of investigators maintain that vocal load plays a significant role in the cause of voice disorders and influences response to treatment. For this reason, clinicians and researchers have focused their attention on how a voice is used. Studies that have been published in the past on voice usage as a factor of risk for dysphonia have referred to briefly performed recordings and/or evaluations. As a result, there is little objective information on the real use of the voice throughout the day and, in particular, during working hours. The need for quantitative information on the use/abuse of voice has led to the development of devices that can monitor voice function over a period of several hours [1 2]. The use of the first devices was limited from a clinical point of view. It was possible to record only a limited number of vocal parameters, which were not reliable, and the instruments were invasive and/or were not easy to carry around for an entire day. In particular, the use of microphones caused problems to privacy concerns as the devices were sensitive to surrounding noise and the voices of nearby people. The recent development of microprocessors devised for ambulatory monitoring of the voice, and the introduction of miniaturised accelerometers for detecting vocal parameters has helped to overcome many of the aforesaid limitations. When the accelerometer sensor is placed at the jugular level, it captures the vibrations of the skin, and therefore the acceleration, indirectly supplying a true estimate of vocal parameters such as duration of phonation, fundamental frequency and vocal intensity. The latter is considered as sound pressure level and 'vocal dosing' [3-5]. Recently, a new device has been commercialized, namely the Ambulatory Phonation Monitor (APM - KayPENTAX, Lincoln Park, NY, USA). With the APM it is possible to study, identify and improve – by means of biofeedback – habitual voice patterns (pitch, loudness, amount of voice use). The aim of this study is to describe this new device, the importance of its calibration, the parameters that it records and its potential applications, both on the basis of the limited existing data and our brief experience with the device in groups of euphonic and dysphonic elementary school teachers.

Clinical techniques and technology: Ambulatory Phonation Monitor (APM)

The APM is a portable device that allows to objectively document voice during an entire day. Specifically, the APM measures the amount of time a subject has phonated, when the phonation occurred and estimates the subject's vocal intensity (dB SPL) and fundamental frequency (F0) during all phonation activity. The data essentially provide a 'profile' of a subject's 'typical' phonatory behaviour during the period of monitoring. The APM can also be used to provide immediate, real-time vibrotactile feedback to the patient during daily activities based on settings entered by the clinician prior to usage. The rationale for this feedback is to assist the patient in establishing and to get used to new phonatory behaviours outside a clinical environment. This possibility of having a pre-set vibrotactile feedback helps the patient to follow the indications recommended by the speech therapist and automates control of frequency and intensity, factors that might play an important role in the cause of voice disorder.

The APM uses a miniaturised accelerometer as a voice sensor, mounted on a silicone pad, attached to the neck at the jugular level using surgical adhesive. Švec et al. (2005) demonstrated that the accelerometer can indicate the mean SPL of soft, comfortable or loud voices with an accuracy of over ±2.8 dB in 95% of cases if these were previously and individually calibrated [5]. Later, Hillman et al. (2006) demonstrated that in the case of fundamental frequency, vocal intensity (SPL) and phonation time, the accelerometer can supply data that were essentially superimposable with those captured through a traditional microphone, both in normophonic subjects and in dysphonic individuals with mild and severe dysphonia [6].

In order to obtain a reliable evaluation of vocal intensity, each patient must calibrate the sensor; the signal detected by the accelerometer will be able to supply true data concerning the sound pressure level only if calibration is performed. The subject is placed in front of the calibration microphone at a distance of 15 cm. Participants should be instructed to take a deep breath and sustain the /a/ vowel, starting with a soft voice and steadily increasing volume until the loudest voice he/she can produce is reached. Patients who cannot sustain a long enough phonation to cover the soft to loud range in one breath, should be instructed to produce the /a/ vowel for 1 or 2 seconds with a soft, medium and loud voice, inhaling between each production. Published data report an average speaking SPL range of 35 dB during calibration [7]. However, the exact range varies from one subject to another. As soon as the subject starts to phonate, calibration data points will show up on the display, along with a straight red line which represents the best linear correlation between the sound pressure levels recorded by the microphone and the amplitude of the signal captured by the accelerometer on the neck of the patient. The software will trace a straight red line after at least 7 data points have appeared; this does not mean that the calibration has been performed well. The software provides an error message if the best-fit red line drawn on the available points is not statistically valid, but not on the basis of the range reached by the patient. Therefore, the examiner must invite the patient to continue with the phonation until his/her full amplitude range is reached.

The APM can record many parameters, which are described below.

Phonation time

Phonation time is the total duration of phonation expressed as the total time (hours, minutes and seconds) and as the percentage of time (%) spent phonating for the recording period. Hence, calculation of the phonation time excludes pauses for breathing and all moments when the patient is not phonating. Using the vocal dosimeters, it is possible to evaluate the percentage of phonating time during working hours and compare these percentages with those referring to non-working time and during weekends. The APM also gives a graphic view of the phonation time, the socalled Phonation Time Profile Graph (Fig. 1a), which is a time-history display of the entire recording period: time is displayed on the horizontal axis and the percentage of time phonating is shown in green; the percent phonation scale (% values) is displayed on the vertical axis on the left edge of screen, and average amplitude (dB) is represented by a black line with the associated dB SPL units displayed vertically on the right edge of the screen. The Phonation Time Profile uses a moving average to display the data. Five minutes is the default time interval over which data is averaged for display. The user can select subintervals of time to be viewed on the Phonation Time Profile graph (Fig. 1b).

Phonation Density Graph

The Phonation Density Graph is a three-dimension graph that shows the amount of phonation (total duration) with reference to the SPL (x-axis) and the F0 (y-axis). The colourimetric scale on the right of the graph indicates the density of the phonation at a given fundamental frequency (F0) and amplitude (z-axis). More often than not, a couple of SPL and F0 are used and in this case, the colour (see the z-axis) at the intersection of these intensity and frequency values will be deeper. The more the area is circumscribed the higher the colourimetric value will be, especially if the patient has used limited frequency and intensity values (coupled), keeping the manner of voice usage constant (Fig. 2a). If there are widespread areas of high density, it means that the subject has used extremely variable fundamental frequency and intensity values during the recording period (Fig. 2b). Euphonic subjects can generally keep F0 and SPL constant when they use their voice in different circumstances (during work, during intervals from work, after work and during weekends). In contrast, dysphonic patients cannot keep the F0 and SPL values constant and their relative graph will show widespread areas of high density.

Sound pressure level and fundamental frequency histogram

These graphs show the distribution of the SPL and F0 levels, respectively, compared with the percentage of total voicing. The highest SPL or F0 column in the graph corresponds to the values of the vocal intensity and the F0 that have been used most during the recording period. If there are many columns of similar height in the graph, this

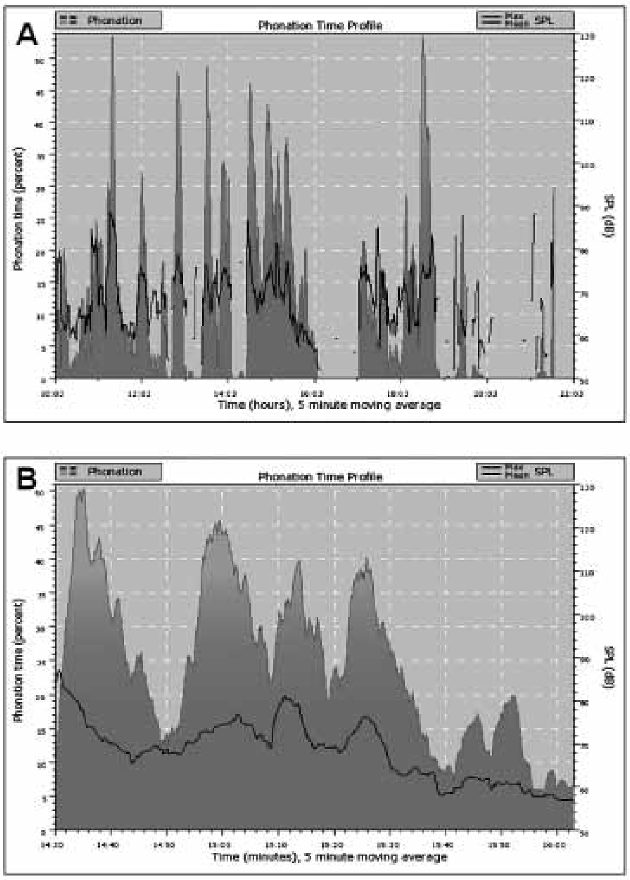

Fig. 1. Phonation Time Profile Graph. Phonation time profile of an entire recording period (10:03 a.m. - 10:03 p.m.) (A) and of selected subintervals of time (2:30-4:00 p.m.) during the same exam (B).

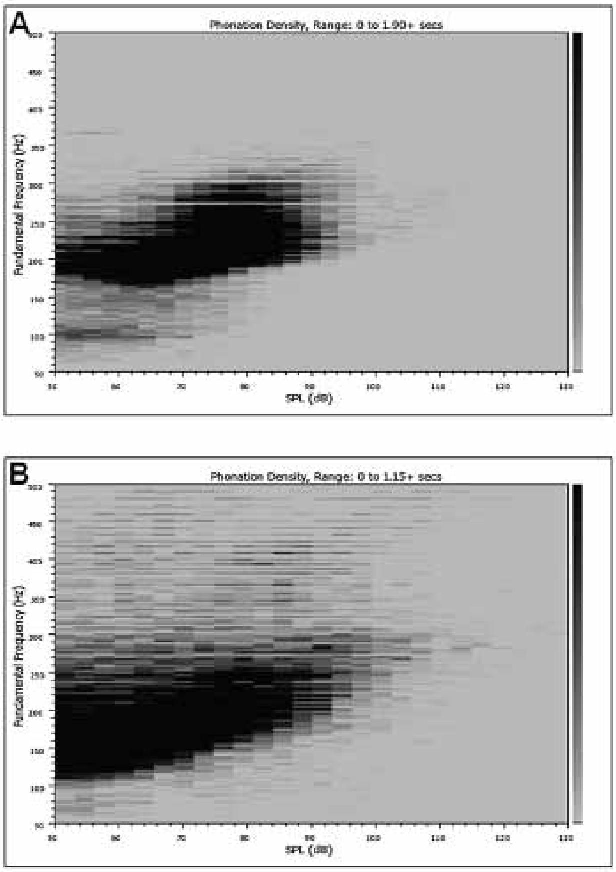

Fig. 2. Phonation Density Graph. Normophonic subject: the area is circumscribed (limited F0 and SPL values (coupled), keeping the manner of voice usage constant) (A). Patient with dysfunctional dysphonia: there are widespread areas of high density (the subject has used extremely variable F0 and SPL values during the recording period) (B).

indicates that the subject has used different vocal intensities and F0 in the total period shown (Fig. 3). This situation in the graph, like the phonation density, might be due to the subject's impossibility to keep constant SPL and F0 values under the different phonation conditions.

Fundamental frequency/SPL density scatter plots

These graphs show the distribution of F0 and SPL, respectively, over the time period. In other words, they show the variation in F0 and vocal intensity over time during recording (red line) (Fig. 4).

Vocal dose (vocal load)

Vocal loading is a combination of prolonged voice use and additional loading factors (background noise, acoustics, air quality) affecting the fundamental frequency, the type and loudness of phonation and the vibratory characteristics of the vocal folds [8]. Therefore, one of the most fundamental issues when studying the effects of long-term vocalization is determination of the proper way of quantifying the amount of voicing. For this purpose, 'vocal doses' as an expression of vocal load have been introduced over the past 10 years [9]. The term 'dose' in this case refers to the effect of long-term exposure of the vocal fold mucosa to vibrations.

Vocal load and the relative 'vocal doses' can be identified with three different parameters: time dose (D_t), cycle dose (D_c) and distance dose (D_d).

Time dose (D_t) is the same as voicing time and measures the total time the vocal folds have spent vibrating. This is calculated as follows:

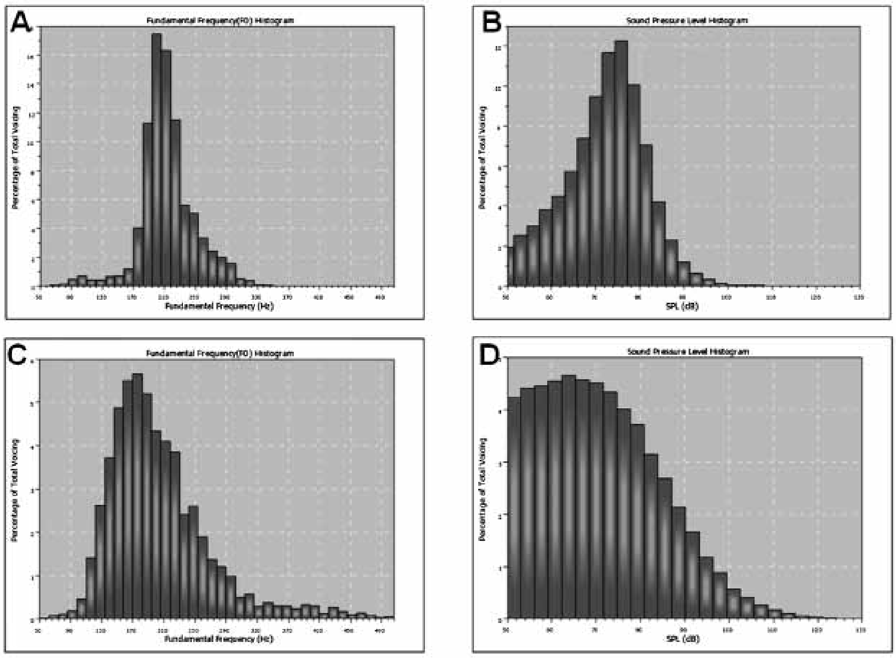

Fig. 3. Sound Pressure Level and Fundamental Frequency Histogram. The highest SPL or F0 column in the graph corresponds to values of vocal intensity and the fundamental frequency used most during the recording period. Normophonic subject: only two columns are similar in height (limited F0 and SPL values keeping the manner of voice usage constant) (A, B). Patient with dysfunctional dysphonia: several columns of similar height in the graph indicate that the subject has used different vocal intensities and fundamental frequencies in the period shown (C, D).

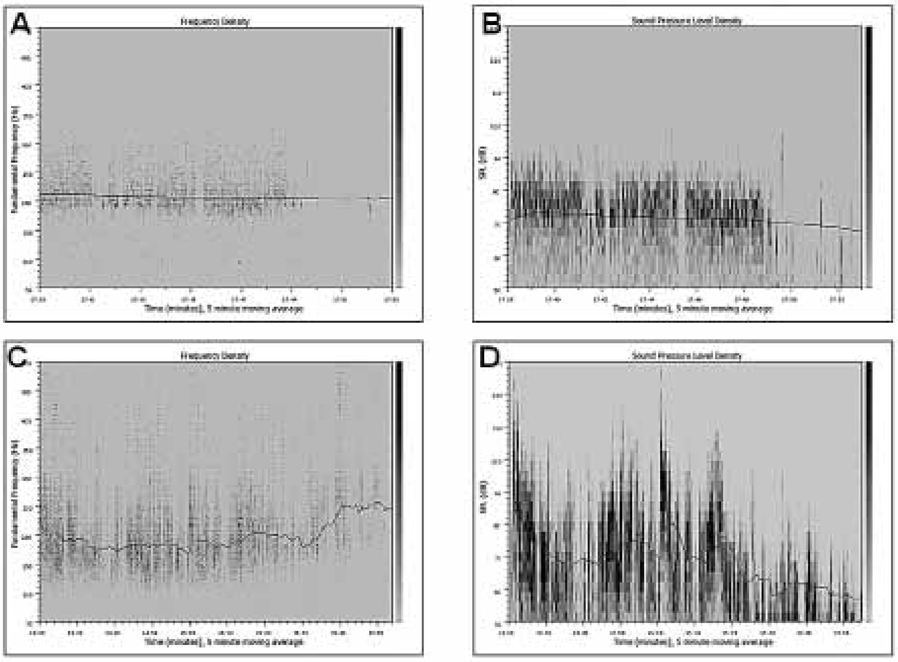

Fig. 4. Fundamental Frequency/SPL Density Scatter Plots. These graphs show the distribution of F0 and SPL, respectively, over time (line). The graphs also show the frequency density and the sound pressure level density, coloured in grey and superimposed over the mean values that can be seen in the tracing. Normophonic subject: F0 and SPL do not vary significantly over time of recording (A, B). Patient with dysfunctional dysphonia: a progressive increase in F0 and a progressive contemporary decrease in SPL (C, D) is apparent.

$$D_t = \int_0^{t_p} k_v \; dt \; seconds$$

where t_p is the total data collection time in seconds, k_v is the voicing unit step function [9 10].

The cycle dose measures the number of oscillations of the vocal folds during the recording period; it depends both on F0 and the total phonation time, and is calculated as follows:

$$D_c = \int_0^{t_p} k_v F_0 \, dt \text{ cycles}$$

where t_p is the total data collection time in seconds, k_v is the voicing unit step function and F_0 is the F0 in Hertz [9,10].

The distance dose (D_c) is the 'total distance accumulated by the vocal folds in a cyclic path during vibration; it depends not only on the total phonation time and F0, but also on the amplitude of the vocal fold vibration and, therefore, the vocal intensity (dB SPL). It is calculated as follows:

$$D_d = 4 \int_0^{t_p} k_v A F_0 \, dt \text{ meters}$$

where A is the amplitude of the vocal folds.

The distance dose parameter (D_d) is particularly interesting because it can calculate the safe limits just as they are used in industries for assessing vibrations transmitted to the hands of operators. The safe limit for hand tissues is approximately 520 metres of accumulated distance, and therefore any exposure to vibration that exceeds this limit is considered to be a risk factor. Likewise, in the future it will be possible to establish the safe limits for vocal folds exposed to vibrations, in order to reduce the risk of voice disorders [4 8 10].

We describe below our personal experience with the APM. In our Unit, we studied 10 female elementary school teachers (mean age: 42.4 ± 7.2 yrs); the anamnesis of 5 teachers (mean age: 42.0 ± 5.2 yrs) was negative for voice disorders, and phoniatric and laryngostroboscopic examinations showed no laryngeal dysfunction nor any signs of vocal fold disorders; on the other hand, 5 teachers (mean age: 42.8 ± 8.8 yrs) had vocal fold nodules. The participants were monitored using the KayPENTAX Ambulatory Phonation Monitor, Model 3200, for one week. The APM was calibrated for each participant using the procedures described, and each participant was monitored for their entire workday.

During their five-hour working day, the five healthy teachers showed progressively increased F0 (mode and average) and intensity values, and this increase became statistically significant as they reached their fourth hour of teaching. In contrast, all the teachers with vocal nodules all showed a progressive decrease in intensity, F0 mode and F0 average, which became statistically significant in all three parameters as they reached the fifth hour. These results are summarized in Table I. The percentage of phonation time did not change significantly in the two subgroups. The distance dose value was slightly reduced in the group with vocal nodules, but without reaching statistically significant differences.

Discussion

The APM is a portable device that objectively documents voice use during an entire day of normal activity. Specifically, the APM measures the amount of time a subject has phonated, when the phonation occurred and estimates the subject's vocal intensity and fundamental frequency during all phonation activity. These data essentially provide a 'profile' of a subject's 'typical' phonatory behaviour during the period of monitoring. The potential clinical applications of the APM include study of the vocal load in singers, use of vocal dosimetry in forensic medicine, real-time biofeedback studies of voice and study of voice parameters as well as vocal load in teachers.

Carrol et al. (2006), in their evaluation of vocal load in professional and semi-professional classical singers, suggested that dosimetry appears to be an effective tool for data collection on prolonged use of the voice and for accurate evaluation of vocal load even in the case of singers [11]. In this case, since the APM is easy to wear even under stage costumes (in the case of classic mu-

Table I. Variation of F0 mode, F0 average and Sound Pressure Level (mean ± SD) during a five-hour working day in healthy teachers and in teachers with vocal nodules.

Healthy teachers					
Parameters	First hour	Second hour	Third hour	Fourth hour	Fifth hour
F0 Mode	217.1 ± 4.8	217.2 ± 4.3	218.7 ± 4.1	225.2 ± 1.9*	227.1 ± 2.1†
F0 Average	220.2 ± 1.4	220.9 ± 1.3	222.4 ± 1.9	227.0 ± 3.1*	228.8 ± 2.5†
SPL	75.4 ± 2.6	75.9 ± 1.9	76.8 ± 2,0	80.9 ± 2.0*	82.7 ± 1.6†
Teachers with vocal nodules					
F0 Mode	218.3 ± 4.7	217.6 ± 4.6	216.2 ± 5.7	214.2 ± 5.7	205.9 ± 5.4‡
F0 Average	220.9 ± 6.3	219.2 ± 4.8	217.7 ± 5.4	215.6 ± 5.2	207.3 ± 6.1‡
SPL	73.3 ± 2.6	72.1 ± 2.2	71.3 ± 2.2	69.4 ± 2.4	65.7 ± 1.2§

** Fourth hour versus First, Second, Third hour: $p < 0.02$; † Fifth hour versus First, Second, Third hour: $p < 0.01$; ‡ Fifth hour versus First, Second, Third, Fourth hour: $p < 0.05$; § Fifth hour versus First, Second, Third, Fourth hour: $p = 0.01$.*

sic singers), it is a valid device for understanding voice usage during artistic performances. However, for a 'numeric' calculation of vocal doses through analysis of D_c and D_d in the case of singers of all types of music, it might be useful to understand what limits the vocal load must not exceed, so that they can programme periods of rest for their voices and consequently avoid organic damage to vocal cords.

APM permits monitoring voice usage during working hours. The possibility to quantify voice load by assessing the cycle dose and distance dose, and obtain parameters such as mean intensity, mean fundamental frequency, variations of F0 and SPL over time, total duration of the phonation and its density (studied on both the total recording time and during working hours) may help to solve many of the problems mentioned above, and supply data for an objective evaluation of dysphonia even in the field of forensic medicine.

The APM can provide a real-time vibrotactile feedback that is useful for rehabilitation purposes both in the rehabilitation of dysfunctional dysphonia, and in establishing adequate post-surgical rehabilitation [12]. The vibrotactile device associated with the vocal dosimeter is a small box connected to the APM and is attached to the patient's belt or to the strap of the bag that contains the APM itself. Both the APM and the vibrotactile device are very light, and even when worn together do not hinder normal activities or work during recording. The device begins to vibrate when the patient's voice exceeds the sound pressure and/or fundamental frequency levels previously set by the clinician. Moreover, the instrument can be set so that the vibration starts when vocal intensity and/or fundamental frequency drop below the pre-set values. The rationale for this biofeedback is to help the patient establish and become accustomed to new phonatory behaviours outside a clinical environment (e.g. speaking at a softer or louder amplitude). Furthermore, if one of the main causes associated with the dysphonia is excessive vocal load, then having the possibility of being warned by a vibration when the vocal intensity and fundamental frequency limits are exceeded (particularly during working hours) will allow the subject to modify the use of his voice and, consequently, reduce both overload and abuse of the laryngeal apparatus.

It is important to define the safe limits of the vibration dose and phonation time to avoid damage to the phonatory organs in certain categories at risk [8 13] (e.g. teachers), and the device has the potential to objectively measure voice parameters even while the subject is teaching. There are few publications in the literature about the use of an APM for studying voice and vocal load in teachers. Recently, using APM Morrow and Connor showed that in elementary school music teachers the use of electric voice amplification significantly reduces mean vocal intensity, phonation time, cycle dose and distance dose [14 15].

Our data are preliminary, but promising, since the APM has shown to be useful for confirming available data that show how the F0 and voice intensity values in teachers with a negative anamnesis for voice disorders, laryngeal dysfunctions or vocal fold pathologies increase as their teaching hours pass. Some authors have demonstrated that the fundamental frequency (F0) and intensity (dB SPL) in teachers gradually increases from the first hour of lessons to the fifth, whether electric amplifiers are used or not [16-18], possibly in an attempt to keep the attention of the students as the hours pass and also in the attempt to overcome voice fatigue. Some authors have reported an increase in fundamental frequency (F0) and sound pressure level (SPL) after long periods of voice usage, whether for professional use or not [19 20]. In fact, after a substantial vocal load, changes in the voice that are characteristic of hypertone in the laryngeal structures have been described (especially in females), though episodes of post-stress vocal hypotonia have also been reported [21]. Furthermore, the APM demonstrated that in the case of the teachers with cord nodules there was a progressive drop in intensity and in F0 during teaching, while vocal load and phonation time did not vary significantly. Though these data must be evaluated further on larger groups of subjects, they already show that periods of rest (or intervals of temporary interruption) should be considered in the case of teachers who have vocal fold disorders, and that electric voice amplifiers should be used during lessons. The APM data may be useful in the future for establishing vibration dose safe limits, and, consequently, for recommending phonation times to protect teachers from the risk of further damage to their voice.

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