A Portable High-Speed Camera System for Vocal Fold Examinations

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Summary: Aim. In this article, we present a new portable low-cost system for high-speed examinations of the vocal folds. Analysis of glottal vibratory parameters from the high-speed recordings is compared with videostroboscopic recordings.

Methods and Results. The high-speed system is built around a Fastec 1 monochrome camera, which is used with newly developed software, *High-Speed Studio* (*HSS*). The *HSS* has options for video/image recording, contains a database, and has a set of analysis options. The Fastec/*HSS* system has been used clinically since 2011 in more than 2000 patient examinations and recordings. The Fastec 1 camera has sufficient time resolution (≥4000 frames/s) and light sensitivity (ISO 3200) to produce images for detailed analyses of parameters pertinent to vocal fold function. The camera can be used with both rigid and flexible endoscopes. The *HSS* software includes options for analyses of glottal vibrations, such as kymogram, phase asymmetry, glottal area variation, open and closed phase, and angle of vocal fold abduction. It can also be used for separate analysis of the left and vocal fold movements, including maximum speed during opening and closing, a parameter possibly related to vocal fold elasticity. A blinded analysis of 32 patients with various voice disorders examined with both the Fastec/*HSS* system and videostroboscopy showed that the high-speed recordings were significantly better for the analysis of glottal parameters (eg, mucosal wave and vibration asymmetry).

Conclusions. The monochrome high-speed system can be used in daily clinical work within normal clinical time limits for patient examinations. A detailed analysis can be made of voice disorders and laryngeal pathology at a relatively low cost.

Key Words: High-speed imaging–Vocal fold vibration.

INTRODUCTION

The first high-speed film of the vocal folds was produced in 1937 at Bell Telephone Laboratory and made accurate measurements of the vocal fold vibrations possible. Other high-speed recording techniques followed.[1] Because of the technical difficulties, such as illumination problems and extremely time consuming procedures for film development and analysis, the method has previously been used mainly for voice research purposes.[2] Digital high-speed cameras were primarily developed for the car industry, but since 1985 high speed has been used and further developed for the study of vocal fold vibrations in real time.[3–5] This technique allows for instant digital slow motion control and subsequent digital storage or documentation on a normal video recording system. To get a good time resolution in a high-speed recording, at least 10 images per cycle are required. Thus, 2000 images/s is the minimum camera speed for studying the vocal folds at work. For high pitches in singing voice, a minimum of 4000 images/s is needed, and even that speed is not high enough for recordings at fundamental frequencies above 400–500 Hz.[6] Commercial high-speed cameras normally deliver 4000 images/s, but by decreasing image size they can work at up to 10 000 images/s. During the last years, color high-speed cameras with a relatively high resolution and sensitivity have been made available.

For a detailed study of the mucosal wave, higher image rates than 4000 images/s are needed. Deliyski et al[6] have studied laryngeal function using cameras with a speed that high, originally made for military purposes, and reported interesting results. However, so far this type of camera has not been adapted for clinical use. An inherent problem is the high-power light that is required for such high-speed recordings, because it makes both the instruments and the mucosa of the patient overheated.

Few clinics use the high-speed cameras on a daily basis. Possible reasons are high costs and not so user-friendly software. In addition, the value of high-speed imaging compared with stroboscopy in a clinical setting is discussed. However, Patel et al[7] found that stroboscopic assessments of vibratory function for dysphonic patients with severe aperiodicity were only possible in two-thirds of the cases, whereas assessment by means of high-speed imaging was successful for all patients.

High-speed cameras are used for industrial purposes and such cameras are usually considerably cheaper than commercially available cameras constructed for laryngeal examinations. We have adopted a low-cost industrial camera system, the portable HiSpec 1, for simple handling laryngeal examination. We have also developed a software system, *High-Speed Studio* (*HSS*) (www.psytec.se) for video and sound recordings and for analyses. The system is described in the following. The only hardware needed, except for the camera, is a personal computer (PC; laptop) and a light source. The system can be used with any rigid endoscope. With good light conditions, it is also possible to adapt a flexible endoscope.

Accepted for publication April 1, 2014.
The study was supported by Karolinska Institutet, Laryngfonden, and Stockholm County Council Research Funds (Alf).
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Journal of Voice, Vol. 28, No. 6, pp. 681-687
0892-1997/$36.00

http://dx.doi.org/10.1016/j.jvoice.2014.04.002

The *HSS* software has a database for patient data and can collect information from a health care system or medical journal. Several simultaneous analyses can be performed, such as kymography,[8] edge detection, and sound synchronization. The camera and analyses system have been in our clinical use since 2011, and over 2000 patients have been examined.

Initial experiences from clinical use of the camera and the analyses systems are reported in the following.

The purpose of this article was to report our experiences of the new portable high-speed camera with the *HSS* software for clinical use and to compare judgments of glottal vibratory parameters from high-speed recordings to videostroboscopic recordings obtained for the same patients.

METHODS

High-speed camera

The system is built around the HiSpec 1 camera (Figure 1) from Fastec Imaging (San Diego), which also contains the memory. The camera weight is 280 g, and it has a resolution of about 500×250 pixels at 4000 images/s. With decreased image size, it can be used up to 6000 images/s. There are two camera models: one is monochrome and the other is color. We have chosen the monochrome because of its considerably higher light sensitivity (3200 ISO vs 1600 ISO). The Fastec camera can be connected to a standard rigid laryngeal endoscope or to a fiberoptic endoscope via a zoom objective adapter. Normally, we use a 70° Karl Storz endoscope. A foot pedal is used for trigging the camera. The camera is connected to the PC with the Ethernet. Sound is recorded with a microphone and an external sound card. The computer can be of any fast type; currently a Sony Vaio (Z11Z9) laptop model. Light source is a 300 W xenon from Wolf (model 4447). The price of the Fastec 1 camera is at present (2014) around $19 000.

Database and software

The software program is a new version of the High Speed Toolbox,[9] which is adopted for the Fastec camera. It is called *HSS*. For recording, we use the standard program provided from Fastec imaging, which provides features for setting image size, recording speed, trigger mode etc. The camera is set into post-trigger mode and continuous recording. When the foot pedal is pressed, the recording is stopped.

The sound recording is controlled by means of the *HSS*. The sound is recorded continuously, and when the foot pedal is pressed, the last 8 seconds of a recording is stored in a wave file. This action results in a time mark in the sound file, which allows for synchronizing the audio and image signals.

The *HSS* has a database with options to store patient name, id, diagnosis, recording date, file name, and comments. After the recording, the most interesting image frames can be selected and saved. By a macro, the *HSS* controls all settings for the camera software to store the image files in the database. Several search options for the database are available. In addition, the system can provide a list of patients after diagnosis, age, and sex. A recording quality index can also be selected.

HSS analysis

The analysis is started with a mouse click on the patient recording. The sequence can be played continuously or stepwise forward or backward. A button is pressed for the sound file. Several analyzes tools are provided.

Kymography can be made by marking a line in the image, Figure 2. From the kymogram, open and closed phase coefficients can be calculated.

Tracing of the glottal edges during vibration can be made by selecting an area of interest through a snake algorithm. By slight adjustments of the light and contrasts levels automatically, identification of the vocal fold edges is possible, and the glottal area is calculated in pixels (Figure 3). The area can then be presented as a graph and compared with the sound signal. Since the glottal edges are identified, it is also possible to display a graph over any selected edge point for each vocal fold separately during vibration. The midline has to be set manually (Figure 4).

Relative distances, object size, and vocal fold abduction angle can be calculated with the use of a measure stick (Figure 4). From a known distance (eg, by means of a measure stick or from a laser projected to the vocal fold surface), absolute values can be calculated.

Applications. High-speed camera systems are especially useful in studies of irregular vocal fold vibrations due to mass differences between the vocal folds (such as edemas, polyps, and cysts) or differences in vocal fold tension or elasticity (eg, vocal fold paresis and vocal fold scarring). In such phonations, high-speed motion pictures provide more detailed information than does stroboscopy.[10] In addition, the high-speed system allows for analysis of voice onset and very short phonations, for example, vocal fold tremor, which cannot be analyzed with videostroboscopy.

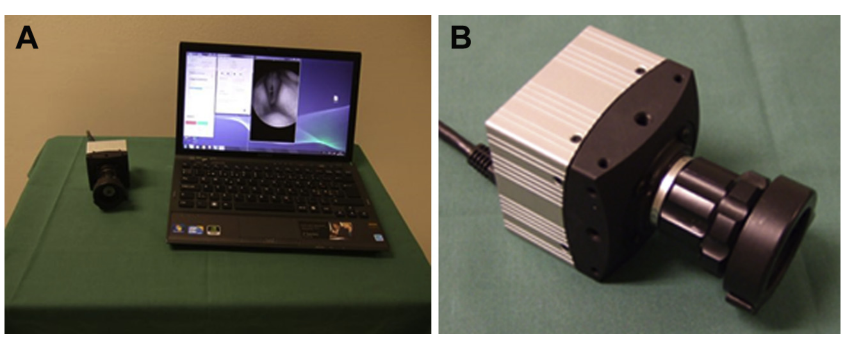

FIGURE 1. **A.** and **B.** The Fastec 1 high-speed camera, which can be connected to a laptop for recording and analysis.