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Kulning: A study of the physiological basis for long-distance sound propagation in Swedish cattle calls

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Abstract

The Swedish cattle call song, kulning, is an example of very marked and far-reaching sound propagation of vocal communication. While earlier studies have investigated the acoustic characteristics of kulning, the present study focuses on its physiological basis from the point of view of vocal fold function and supralaryngeal posture by applying electroglottography and stroboscopy to two types singing: falsetto (head voice) and kulning. It is shown that kulning, as compared to falsetto, exhibits a better contact of the vocal folds and a longer glottal closure in the phonation cycle. Nasofiberendoscopy also showed medial and anteroposterior narrowing of the laryngeal inlet and approximation of the false vocal folds in kulning.

Introduction

The Swedish cattle call, *kulning*, serves the purpose of carrying far in the habitat where it is employed.

Given that extreme long-distance sound propagation is at the core of this type of singing it is not surprising that kulning is almost exclusively sung on vowels, high in sound energy, compared to consonants.

Kulning is also characterized by a high fundamental frequency and is normally free of vibrato.

Long-distance sound propagation in various environments (e.g. forests) has been well studied during the past decades from a number of different perspectives and for a wide variety of different sounds, including animal vocalizations and human song (Embleton, 1963; Embleton, Piercy & Olson, 1976; Marten & Marler, 1977; Waser & Waser, 1977; Marten, Quine & Marler, 1977; Cosens & Falls, 1984; Embleton, 1996; Brudzynski, 2010).

It has also been shown that sound transmission in a forest habitat is subject to different attenuation forces, including absorption (shear viscosity, heat conduction, molecular vibrational relaxation), reflection and refraction (wind, air temperature and humidity) and several other factors (Embleton, 1996) – all of which dependent on factors such as foliage, air turbulence and ground effects (Waser & Waser, 1977), or as Forrest (1994:644) points out: “[t]he distance over which an acoustic signal is effective depends on the power output of the source, ambient noise, [and] distortion during propagation”. In addition, it has also been shown that there is considerable excess attenuation upwind, as compared to downwind from the sound source (Wiener & Keast, 1959). In order to combat environmental attenuation, Richards and Wiley (1980:391) list three strategies that can be employed:

selecting times and locations in which the degradation of the signal is minimal, coding the signal so that it stands out from the environmental noise, and making the signal redundant. Moreover, certain frequencies can carry further in given environments, in so-called "sound windows" (Forrest, 1994:649).

Long-distance sound propagation is not only the goal of animal vocalizations but also of some human types of sound production, including whistled speech (Meyer, 2008) and yodeling (Echternact & Richter, 2010). However, while both these types are characterized by being heard over long distances they differ from kulning in the environment where they occur: both whistled languages and yodeling most often occur in mountainous terrain, and are often used to carry far over valleys, up to 10 km (Meyer, 2004:408).

Interestingly, it has been shown that reverberation is far less pronounced in a frequency band between 1–3 (or 4) kHz (Padgham, 2005; Meyer, 2008:71), i.e. in a frequency band in which much of the sound energy of kulning is located.

While a few studies of the physiological characteristics of yodeling have been presented (Echternacht & Richter, 2010; Schlömicher-Thier et al., 2009), the physiology of kulning has been far less studied.

In a free field, with spherical expansion, the amplitude of a sound signal drops off by 6 dB SPL per doubling of distance (Piercy, Embleton & Sutherland, 1977:1403; Forrest, 1994: 645), but Eklund and McAllister (2015) showed that kulning, as compared to falsetto sustained its dB SPL remarkably well as a function of distance. Recordings of falsetto and kulning voice at 1 and 11 meters from the source (the singer) in an ecologically valid habitat showed that while falsetto voice decreased 25.2 dB at a distance of 11 m, as compared to 1 m, SPL values in kulning dropped only 9.4 dB (Eklund and McAllister, 2015). Furthermore, perceived loudness has been found to be much higher for kulning than for female falsetto at the same fundamental frequency (F0) and SPL (Rosenberg & Sundberg, 2008). The reason for this has to be related to the spectral structure of kulning (Eklund & McAllister, 2015; Johnsson, 1986). Earlier studies on the physiology of kulning have reported a strong rise of the vertical position of the larynx and a narrowed pharynx (Johnson, 1984, 1986). Given the observed difference in sound propagation for kulning voice, as compared to falsetto, the present study focuses on the physiological basis for this, very marked, difference, by studying glottal closure and supra-laryngeal setting in these two types of singing. In order to study this, we have used electroglottography (EGG) and nasoendoscopy.

Method: Subject and recordings

The singer (FP), the same singer as in Eklund and McAllister (2015), is educated in kulning at Musikkonservatoriet in Falun and Malungs Folkhögskola, and by Agneta Stolpe and Ann-Sofi Nilsson. Data consisted of FP singing a cattle call from Äppelbo in a traditional arrangement by Agneta Stolpe, (Vallslinga från Äppelbo), i.e. the same cattle call that was used in Eklund and McAllister (2015). It was recorded in two different types of singing: kulning voice and falsetto (head register) voice. The recordings took place in an examination room at the Helsinki University Hospital, in the Clinic of Otolaryngology and Phoniatrics.

The supralaryngeal structures and vocal fold vibrations were studied by performing nasoendostroboscopy (ORL Vision RS1, CCD supplied by Rehder

& Partners). Glottal contact area was simultaneously studied by recording the EGG signal. A dual-channel EG (Glottal Enterprises) was used.

The acoustic signal was also recorded with a head-mounted microphone (AKG C5441) at 6 cm from the lips, a BabyFace soundcard and Audacity software. A frequency rate of 44.1 kHz and 16 bit amplitude quantization were used.

SPL was measured with two sound level meters used in parallel: an Extech 407732 and a Brüel & Kjaer 2238 Mediator. For both sound level meters, A-weighting and a slow response time (1 second) were used.

Analyses

Nasoendoscopic images were studied qualitatively by an experienced phoniatrician. Special attention was paid to the width of the hypopharynx and the laryngeal inlet (space surrounded by the epiglottis in the front, the aryepiglottic folds on both sides, the arytenoids and pharyngeal backwall).

The EGG signal was studied by calculating contact quotient, CQ, i.e. the time of vocal fold contact divided by the period time; see Figure 1.

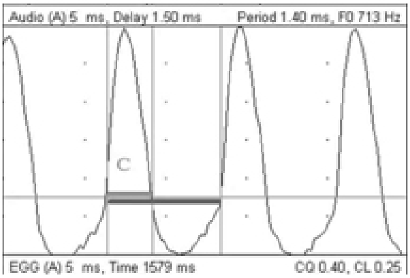

Figure 1. EGG signal (increasing vocal fold contact Upwards). Contact quotient (CQ) has been calculated as the contact time (light grey line; C) divided by the period time (dark grey line).

CQ characterizes the type of phonation e.g. along the axis from breathy to pressed (e.g. Verdolini et al., 1998; Kankare et al., 2012). CQ analyses were carried out using VoceVista software. The baseline for distinguishing the contact time from the non-contact time during one vocal fold period was set to 25% of the peak-to-peak signal amplitude, since calculations using this threshold have previously been shown to have a good correspondence with high-speed findings (Henrich et al., 2004).

Results

Nasoendoscopy findings

Plate 1 and Plate 2 illustrate the hypopharyngeal and laryngeal structures in kulning and falsetto, respectively. The low pharynx and the laryngeal inlet are narrowed in kulning compared to falsetto. In kulning the base of the epiglottis is pulled backwards together with an approximation of the ventricular folds and the anterior posterior laryngeal distance, which obstructs visualization of anterior part of the vocal folds.

Plate 1: Shape of the laryngeal inlet during kulning.

Plate 2: Shape of the laryngeal inlet during falsetto.

EGG findings

Figure 2 shows an example of EGG waveform in falsetto and kulning.

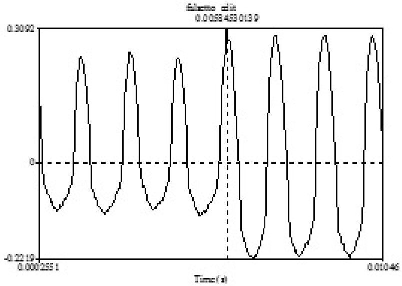

Figure 2. An example of the EGG waveform in falsetto to the left and kulning to the right. Note the higher amplitude in kulning.

The amplitude of the EGG signal was higher in kulning compared to falsetto, suggesting a better contact of the vocal folds in kulning. Mean CQ was 47% (SD 0.03%) in kulning and 41 % SD 0.06 %) in falsetto. Mean F0 was also somewhat higher in kulning (759 Hz, i.e. circa F#5) compared to falsetto (694 Hz, i.e. E5 or F5). Mean F0 in kulning was 759 Hz (circa F#5), SD 41.9 Hz. Mean CQ was 47% (SD 0.03%). Comparable values for falsetto were lower except for SD.

Discussion

The nasoendoscopic findings are in line with those reported by Johnson (1984, 1986). The hypopharyngeal walls are constricted and the epilaryngeal inlet is so narrow that it covers about half of the glottal length.

The constricted laryngeal inlet seems to be an important aspect in establishing a highly projecting sound. Kmucha et al. (1990) demonstrated narrowing of the epilaryngeal sphincter in loud singing of classically trained singers. Through mathematical modeling, Titze and Story (1997) have shown that narrowing of the epilarynx (in relation to hypopharynx) increases the vocal tract input impedance on a large frequency range. It leads to increased SPL, diminishes the spectral tilt, may result in a formant cluster, typical in classical singing at 2–3 kHz range, and thus increases loudness (Titze & Story, 1997; Sundberg. 1974).

The EGG signal in kulning showed a clear contact between the vocal folds, i.e. the signal amplitude was relatively strong. Unlike in soft phonation the waveform was not rounded but the increasing contact during glottal closing phase seemed to be relatively rapid (i.e. pulse skewing was observable). The mean CQ was 47% which also Herbst et al. (2010) found in a female soprano, singing with low adduction at G5 (783 Hz). With high adduction CQ was 48%. Herbst et al. (2010) used the same 25% baseline in CQ calculation. In high pitched singing CQ does not differentiate phonation type as well as in speech. However, our result seems to suggest that the phonation was not pressed in kulning, which is also in line with the subjective sensation of the singer. Therefore it may be speculated that the epilaryngeal narrowing assists in establishing extremely loud sound without excessive vocal fold collision during phonation.

Experiments on excised larynges and modeling have given evidence that the impact stress related to vocal fold vibration can be significantly reduced by increased vocal tract impedance, e.g. Montequin et al. (2000), Titze (2006) and Titze and Laukkanen (2007).

Conclusions

The results of the present study show that kulning is characterized by a narrowed hypopharynx and larynx and clear glottal closure during phonation. These physiological alterations probably contribute to the acoustic properties and preserved long-distance sound levels observed in kulning.

Further studies are needed to compare kulning with other types of well-projecting types of singing, like western classical singing. High-speed recordings would shed light on characteristics of vocal fold vibration. Magnetic-resonance imaging (MRI) and finite element modeling could allow for calculations of vocal tract impedance.

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