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Coordination between Posture and Phonation in Vocal Effort Behavior

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Key Words
Posture · Phonation · Vocal effort

Abstract
Background: Postural correlates of vocal effort are rarely described in the literature, while they are extensively dealt with in speech therapy. ***Objectives:*** This study aims at determining whether body movement is a side effect of vocal effort or an integral part of communication effort behavior. The answer to this question is mainly based on correlations between posture and phonation. ***Method:*** Twenty healthy subjects participated in this study. They had to communicate with a listener under 3 conditions requiring different levels of vocal effort. ***Results:*** The vocal parameters increased and confirmed that the subjects had made a vocal effort. The kinematic parameters (amplitude and duration of body movement) increased with vocal effort. Lastly, vocal and kinematic characteristics were significantly correlated. ***Conclusion:*** The close correlation of posture with vocal production shows that movement is not a mere consequence of vocal effort. Posture and voice are coordinated in communication behavior, and each body segment plays its specific role in the vocal effort behavior.

Introduction

Occupational voice is becoming a real tool for many professionals. When the environment makes communication difficult, subjects need to make a vocal effort. Vocal effort is known as the origin of dysfunctional dysphonias such as muscle misuse dysphonia and is also involved in the evolution of organic dysphonias [1].

Studies about vocal effort found changes in voice acoustics; specifically, the sound pressure level (SPL) and fundamental frequency were increased. Laryngeal aerodynamics show an increase in subglottal pressure and glottal airflow [2], and glottal cycles show a lower opened quotient (phase of the glottal cycle in which the glottis is opened) [3–6]. Also, cervical muscle tension has been found that might be linked to the pathological findings of muscle misuse dysphonia [7, 8]. Cervical muscles are accessory inspiratory muscles whose activity is also related to respiratory pattern modulation during vocal effort [9]. Supralaryngeal structures participate in vocal effort as well, involving spectral characteristics of the voice [10], articulatory [11] and prosodic aspects [12].

Speech therapy often uses exercises aiming at improving postural control during phonation, but little has been reported about the coordination between posture and vocal behavior. Obviously, major postural

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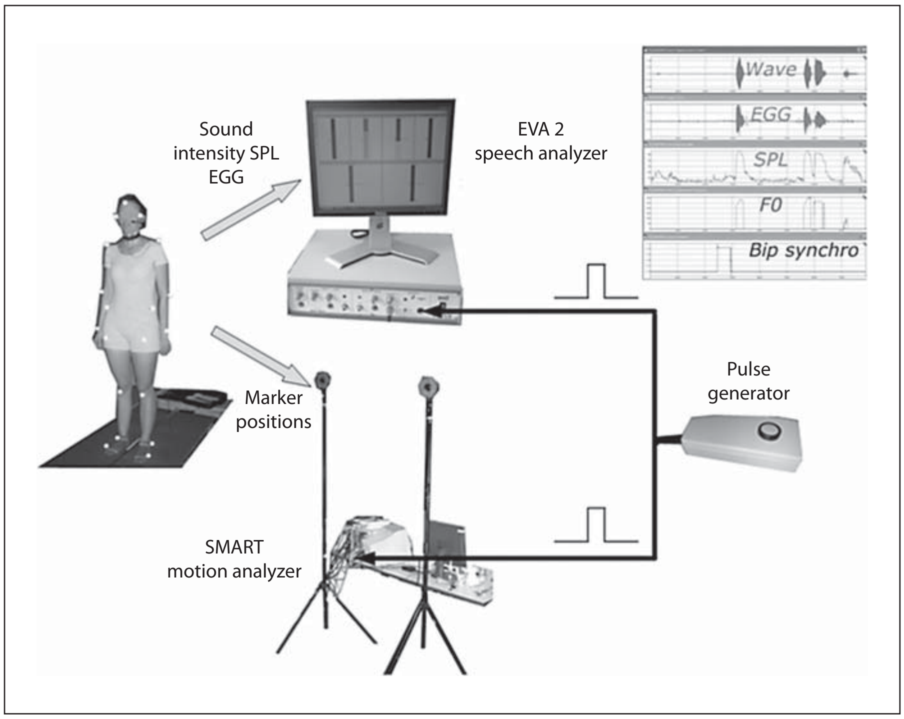

Fig. 1. Experimental setup. On the left, the subject is wearing a headset microphone, an electroglottograph (EGG), and the 19 markers of the SMART system on the following anatomical landmarks: middle forehead (marker 1), temples (2 and 3), acromial processes (4 and 5), iliac spinal crests (6 and 7), lateral epicondyles (8 and 9), radial styloid processes (10 and 11), great trochanters (12 and 13), lateral condyles (14 and 15), lateral malleoli (16 and 17) and the heads of the fifth metatarsal (18 and 19). Objective vocal characteristics were collected using the EVA workstation (top). Kinematic data were collected using the SMART automatic motion analyzer (bottom). A pulse generator (on the right) produced the common data points during the analysis, allowing the study of the coordination between voice and movements.

modifications (lying vs. standing positions) have consequences on respiratory control and, as a consequence of this, on phonation [13, 14]. Previous studies of postural aspects of vocal effort in healthy subjects described an instability in the anteroposterior plane on force platforms [15]. The anteroposterior sway was shown to decrease after efficient speech therapy in dysphonic subjects [16]. A segmental approach to postural changes during vocal effort was applied by Giovanni et al. [17], who found trunk forward bending and head backward rotation, but could not relate these observations to vocal characteristics because of incomplete experimental equipment.

The aim of our study was to determine whether posture is an undesired consequence of vocal effort, or whether it is involved in vocal effort to improve communication efficiency, just like respiratory patterns and laryngeal functions. In order to answer this question, we propose a paradigm involving simultaneous vocal and kinematic recordings.

Methods

Subjects

Twenty female native French speakers with no history of laryngeal or postural disease and no hearing alteration participated in this experiment (mean age: 26 years; range: 20–43 years) which was approved by the local Ethical Committee. All subjects gave their informed consent prior to the study.

Protocols

The subjects were asked to communicate with a listener, aiming to be understood. To make the task simple and easy (without memory or cognitive load), the messages consisted of numbers, which are short and informative words. The listener was in front of the subject and wrote the numbers on a paperboard so that the subject could see whether he was understood or not. The subjects had to perform the task under 3 different conditions designed to force them to make increasing vocal efforts (in a pseudorandom order). Under conditions 1 [weak vocal effort condition (WVEC)] and 2 [moderate vocal effort condition (MVEC)], the room was quiet (background noise: 44–48 dB SPL) and the listener 4 and 10 m away, respectively. Condition 3 [high vocal effort condition (HVEC)] was designed to force the subject to make a very high vocal effort: the listener was 10 m away, and both the subject and the listener wore earphones with a 'cocktail party' soundtrack (reference: PHONAK Party Noise Night) at an average of 90 db SPL (combination of reduced auditory feedback and Lombard effect). The level of 90 dB was selected on the basis of previous studies about the Lombard effect [10, 15, 18]. Each subject performed 16 trials under each condition in pseudorandom order. Vocal and kinematic parameters were simultaneously recorded in order to observe temporal relations (fig. 1).

Voice Data Collection and Analysis

Objective voice measurements were collected using the EVA® workstation (SQLab-LPL, Aix-en-Provence, France) which can

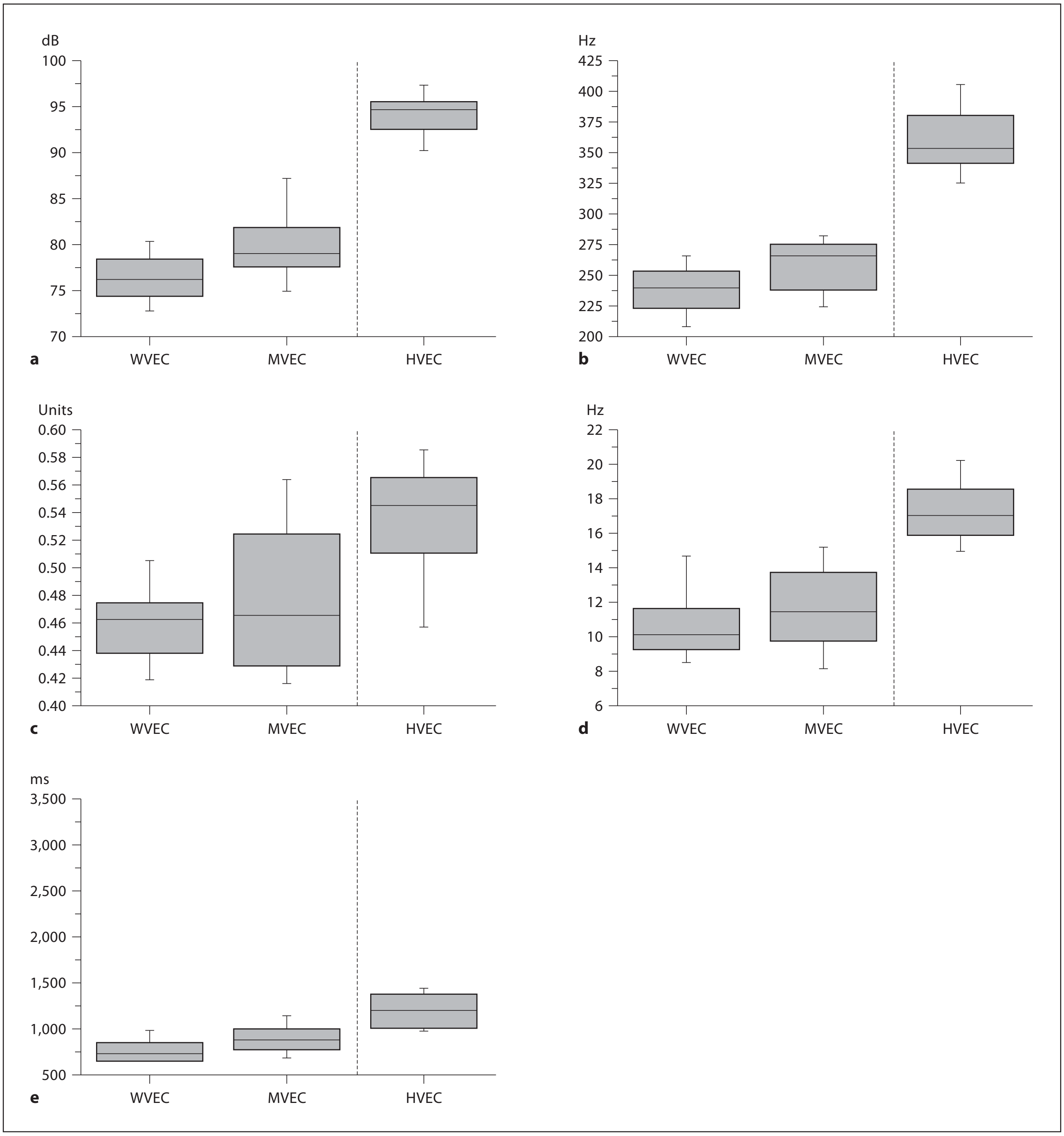

Fig. 2. Medians and quartiles (1st and 3rd) of vocal parameters under the 3 experimental conditions (WVEC, MVEC and HVEC). **a** SPL. **b** Mean fundamental frequency (F_0). **c** Closed quotient, i.e., ratio of the closed phase of the glottal cycle reported to the whole cycle duration. **d** Coefficient of variation of F_0. **e** Duration of the words.

simultaneously record several acoustic, aerodynamic and/or electrophysiological signals [19]. Speech was recorded with a headset microphone (AKG C 420), placed 6 cm away from the lip corner. We used the sonometer provided by the EVA system to measure the true SPL (dB SPL) of the speech wave in order to compare the root mean square intensity between utterances. Electroglottographic signals were recorded with a Laryngograph®, a portable device connected to the EVA workstation. We used Sesane® software (SQLab) to acquire, display and analyze acoustic and electroglottographic signals.

The analyzed variables were: the SPL (dB SPL), the duration of the utterance (ms), and 2 parameters extracted from the electroglottographic signal. The first of these parameters was the fundamental frequency, which was determined for each cycle using a peak-to-peak method expressed in Hz. For each trial, the mean fundamental frequency (i.e. the voice pitch) and the coefficient of variation of the fundamental frequency (which provides information about melodic variations) were computed. The second parameter was the closed quotient (the relative duration of the closed interval of the glottal cycle), calculated with a 35% threshold [20].

Kinematic Data Collection and Postural Analysis

Kinematic data were collected at 120 Hz with the SMART automatic motion analyzer using passive body markers. The subjects performed the tasks facing 6 SMART TV cameras and wearing 19 markers positioned symmetrically on anatomical landmarks as indicated in figure 1.

The analysis of the kinematic curves focused on the positions of the head, the trunk and the thighs in the sagittal plane (pitch) as they were the most relevant kinematic features with respect to our speech task in which the subjects had to communicate with a listener located in front of them. The duration and amplitude of the body movement were analyzed only for the MVEC and HVEC. Indeed, the phonation-related postural modulations observed during the WVEC did not differ from the postural sway when the subject was silent.

Statistical Analysis

Friedman's ANOVA was used to test the global effect of the task, followed by Wilcoxon signed rank tests for pairwise comparisons. Correlations were calculated and tested using Spearman's coefficient. The threshold of significance was $\alpha = 0.05$.

Results

Vocal Parameters

There was a significant effect of the conditions on all the vocal parameters (fig. 2): the SPL ($\chi^2 = 36.4$; $p < 0.001$), the mean fundamental frequency ($\chi^2 = 25.2$; $p < 0.001$), the coefficient of variation of the fundamental frequency ($\chi^2 = 23.3$; $p < 0.001$), the closed quotient ($\chi^2 = 19.6$; $p < 0.001$) and the utterance duration ($\chi^2 = 38.1$; $p < 0.0001$).

From WVEC to MVEC, the following parameters significantly increased: vocal intensity ($Z = -3.58$; $p < 0.001$), mean fundamental frequency ($Z = -3.07$; $p < 0.01$) and utterance duration ($Z = -3.55$; $p < 0.001$). There was no significant difference for the coefficient of variation of the fundamental frequency and the closed quotient.

From MVEC to HVEC, all the vocal parameters significantly increased: vocal intensity ($Z = -3.92$; $p < 0.001$), mean fundamental frequency ($Z = -3.41$; $p < 0.01$), utterance duration ($Z = -3.92$; $p < 0.0001$), the coefficient of variation of the fundamental frequency ($Z = -3.41$; $p < 0.001$) and the closed quotient ($Z = -3.01$; $p < 0.01$).

Kinematic Parameters

The movement amplitude significantly increased from MVEC to HVEC for the head pitch (backward movement; $Z = -3.58$; $p < 0.001$) and for the trunk movement (forward bending; $Z = -3.92$; $p < 0.0001$) (fig. 3). But the amplitude of the thigh movement was barely observable: it was <1° under both MVEC and HVEC, it could be forward or backward movement, depending on the subject.

The movement duration significantly increased from MVEC to HVEC for the head pitch ($Z = -2.99$; $p < 0.005$), for the trunk movement ($Z = -3.88$; $p < 0.0001$) and for the thigh movement ($Z = -3.70$; $p < 0.001$).

Correlation between Body Movement and Phonation

The chronology of the vocal and kinematic events is presented in figure 4. The beginning of the movement anticipated the onset of the phonation under MVEC (median: 313, 455 and 470 ms for head, trunk and thighs, respectively) and HVEC (median: 424, 579 and 534 ms for head, trunk and thighs, respectively). The anticipation duration significantly increased from MVEC to HVEC for the head ($Z = -3.62$; $p < 0.001$) and the trunk ($Z = -2.39$; $p < 0.05$), but not for the thighs.

The correlation between movement amplitude and SPL was significant for 17/20 subjects for the trunk, whereas it was significant for 12/20 subjects for the head.

Discussion

The present study focused on subjects' spontaneous communication behavior under obstructive conditions. The subjects were not given further instructions, in contrast with the more artificial tasks (e.g. to achieve a target SPL) used in many previous studies. The obstacle to communication was the distance to the auditor under the MVEC, and the HVEC added a decreased auditory

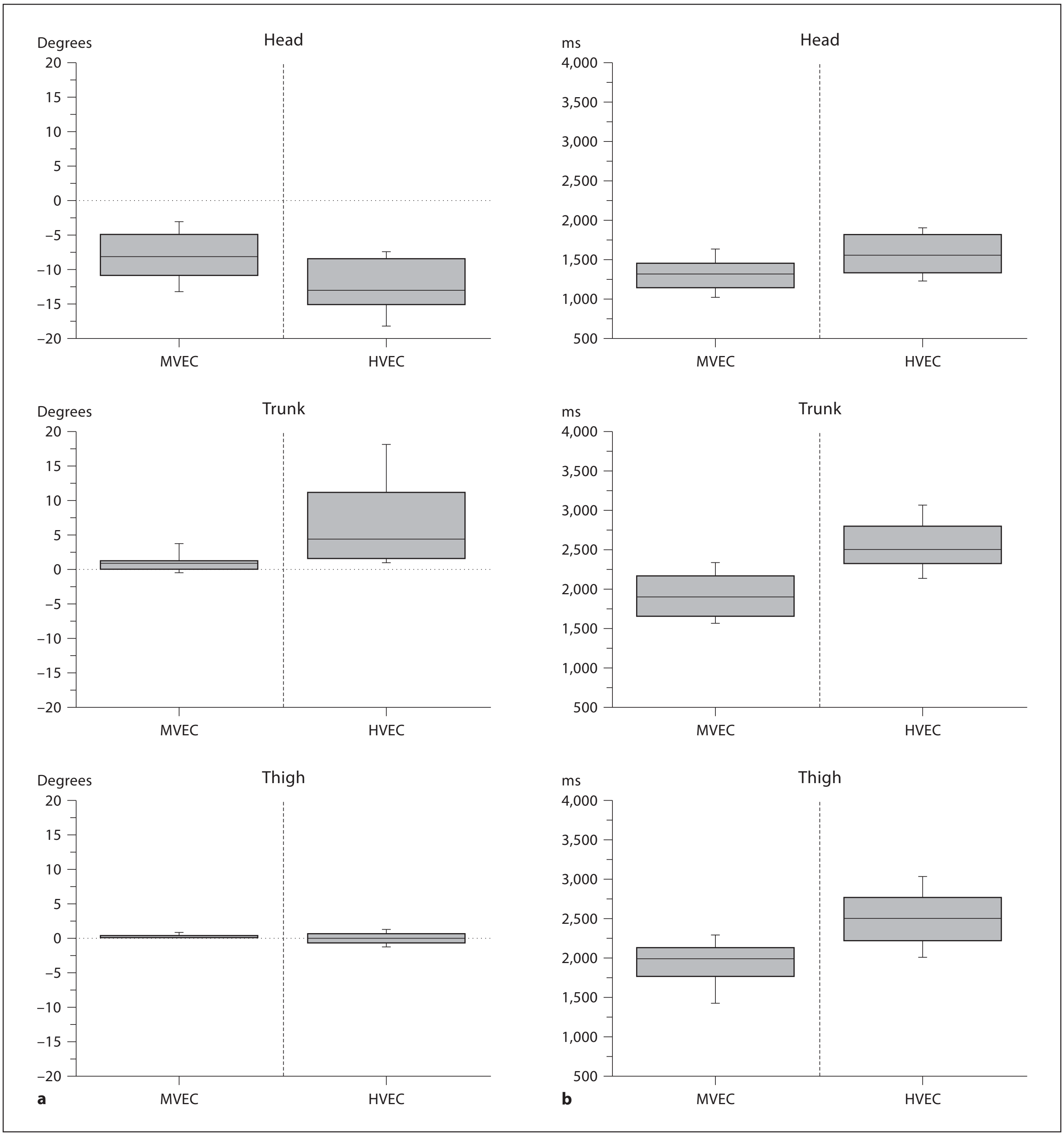

Fig. 3. Medians and quartiles (1st and 3rd) of kinematic parameters in MVEC and HVEC. **a** Movement amplitude. **b** Movement duration.

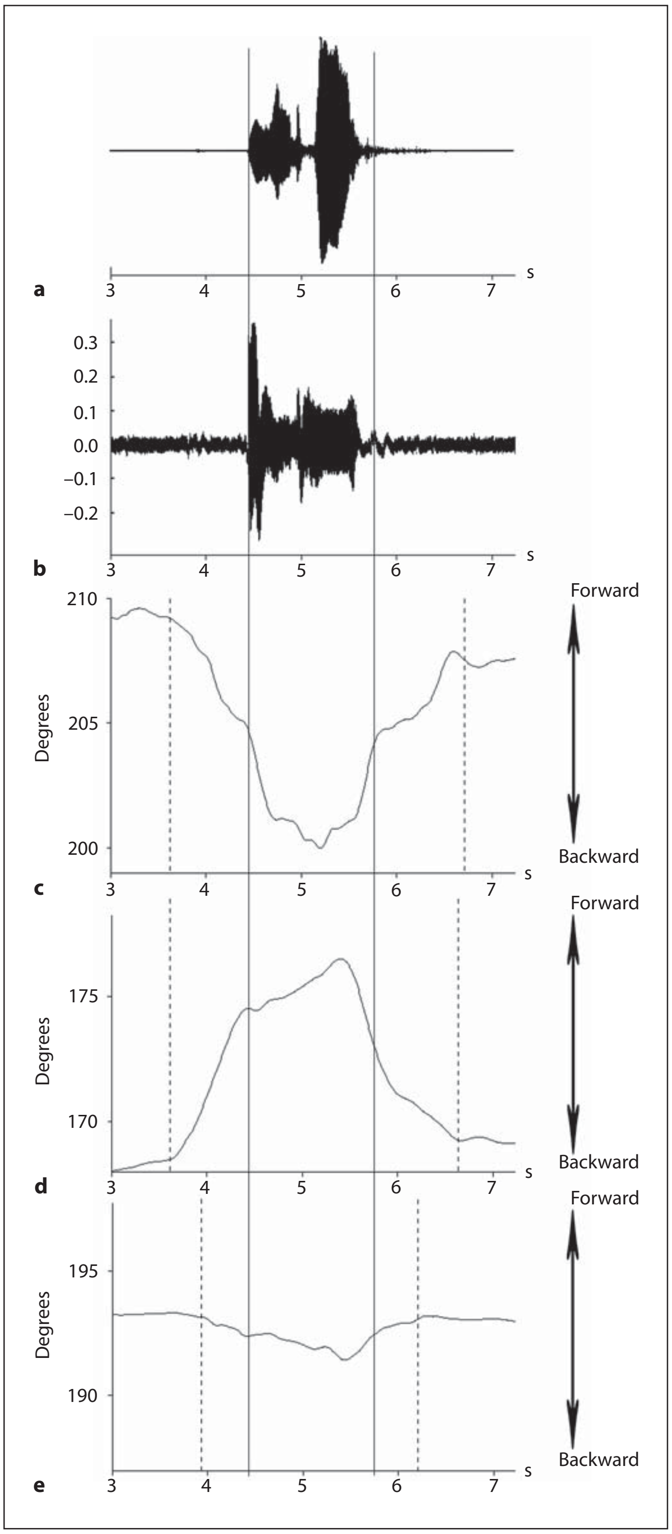

Fig. 4. Chronology of vocal and kinematic events. **a** Vocal signal. **b** Electroglottographic signal (EGG wave). **c** Head movement. **d** Trunk movement. **e** Thigh movement. The solid lines note the onset and offset of the phonation. The broken lines note the beginning and the end of the movement for each body segment.

feedback from the subjects' own voice due to earphones [21] and noise (i.e. the Lombard effect [18]). Vocal data confirmed that the subjects did make a vocal effort under both MVEC and HVEC. The increase in fundamental frequency and closed quotient along with the SPL are consistent with previous studies on loud voice [3, 5, 10, 22–24]. The present study also highlights 2 features of prosodic adaptation to vocal effort: the increased utterance duration and the increased variation in the fundamental frequency that reflects the variation in melody.

The results of the kinematic analysis are consistent with previous knowledge about postural behavior in vocal effort. In adults, postural modulations during vocal effort are mainly observed in the sagittal plane (pitch), as described in previous studies using force platforms [15, 16]. Based on the kinematic analysis, the present study allowed an accurate description of the segmental posture. Forward bending of the trunk and backward rotation of the head are confirmed [17]. Moreover, the combination of the movements of the head and the trunk increased the cervicocephalic angle. This result should be linked up with the cervical muscle activation pattern in loud voice, described especially in electromyographic studies [7].

The amplitude and duration of the movement increased when the vocal effort was high. The movement was not identifiable under WVEC. The displacement of the head was quite important under MVEC, while the motion of the trunk remained barely perceptible. During HVEC, the amplitudes of the movements of both head and trunk increased. The trunk bending became substantial although it was still weaker than the pitch of the head. The correlation between trunk movement and SPL was significant for most of the subjects. These results seem to indicate that the trunk movements are more specific to vocal effort.

As was reported on many posturokinetic activities in adults and children [25], this experiment showed an articulated operation of the head-trunk unit during the speech task while standing: there is no cephalothoracic block as the head is articulated with the trunk. This is consistent with the idea that both of these body segments are controlled independently. The head position might be involved in improving vocal acoustics through changes in the laryngeal position and in the resonance cavities. Some recent studies have also introduced the notion of visual prosody: vocal intelligibility is improved when the auditor can see the head movements [26].

Two main hypotheses could explain the trunk bending, one linked to respiration and the other in the behavioral field. The respiratory patterns change during vocal effort. Previous studies suggest that phonatory breath can disturb posture when subjects perform a speech task [27, 28]. The role of respiration in trunk bending is consistent with the correlation between sound pressure and the amplitude of the trunk bending. The present study did not properly measure respiration, and this question should be explored in further studies.

The forward bending of the trunk may also be behavioral as this movement makes the subject projected toward the listener. The trunk bending may provide information about the energetic requirement of the vocal production and, therefore, about the importance of the message content. It is specific to vocal effort and might be precisely the part of the message it carries. Moreover, the subjects' equilibrium was never compromised, so the thigh movement was very light. Thus, it is an additional argument to consider forward trunk bending as having an orientating function in the context of social interaction.

Conclusion

This study highlights the coordination between posture and voice during vocal effort. The movement which is associated with vocal effort is structured and involves the whole body. The amplitude and duration of the movement increase along with increasing vocal effort, and the movement anticipates phonation. The head and the other parts of the body present specific patterns of movement. The head movement may be involved in improving vocal efficiency, and the forward trunk bending may emphasize the energetic/effortful aspect of the communication. Lastly, the perception of the vocal effort by the auditor may be a constitutive part of the message, parallel to the significance of the message. The 2 tasks (movement and phonation) are coordinated, and the postural anticipation may be meant to catch the auditor's attention and make him or her focus on the message's content.

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