Gravity and anti-gravity behaviour in speech production

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Abstract

Even though most speech is produced while standing up or sitting down, we are perfectly capable of speaking while lying down or hanging head-down. The ease with which we accomplish this task obscures the complexity of mechanisms necessary to adapt to the changing effects of gravity in each of these conditions. In the planned future project *The effects of gravity on speech production,* we aim to investigate adjustments to breathing, phonation and articulation when speech is produced across three body positions using a mixture of established instrumental techniques. In this paper, we motivate the project proposal.

Introduction

Humans are capable of producing speech in a wide range of physical conditions—at rest and while jogging, in sound-treated echo-free rooms, reverberant cathedrals, and in noisy nightclubs. We can also speak when standing up, lying down, and, even though as adults we have regrettably few excuses to do so, when hanging upside-down. While speaking in different orientations feels almost effortless, from the point of view of motor control the varying effects of gravity on Earth present a complex problem which involves adjustments to all three major components of speech production, i.e. breathing, phonation and articulation, mediated via proprioceptive feedback.

Effects of gravitation on breathing and phonation

One of the primary functions of the breathing apparatus in speech is generating an egressive air-stream, which is in turn used for the build-up of the pressure below the larynx (i.e. subglottal pressure, P_s) for setting the vocal folds in motion. It has been shown (Konno & Mead, 1967) that the breathing apparatus can be adequately modelled using two degrees of freedom – one for expansion of the rib cage and one for the abdomen. Despite the simplicity of this model, previous research (Hixon, 1973) reported a great interspeaker variation in terms of the relative contributions of the two components, which additionally depend on both lung volume and speech task (McFarland & Smith, 1992).

Gravitational effects on speech breathing are primarily due to the displacement of the abdominal content (Hoit, 1995), which in the upright position is pulled caudally (footward) and exerts an inhalatory force. To prevent the abdominal wall from becoming distended by the resulting hydrostatic pressures, the abdominal muscles are often activated. Additionally, the lungs pull the larynx downwards, particularly when the diaphragm is contracted. This tends to result in lowering of the larynx combined with a reduction of glottal adduction (and thus breathier voice quality) at high lung volumes (Iwarsson & Sundberg, 1998; Iwarsson et al., 1998).

By contrast, in the supine position (lying face upwards) gravity displaces the abdominal content cranially (headward), exerting an exhalatory force and reducing the functional residual capacity of the lungs (Ibañez & Raurich, 1982). This extra load, which is likely to result in undesirably high P_s, is countered by a two-fold compensatory strategy. First, there is a reduced or ceased contraction of the abdominal muscles (De Troyer, 1983). Second, the range of motion of the diaphragm is increased, pushing against the abdominal content and enlarging the chest cavity (Takazakura et al., 2004). Combined, this strategy leads to a predominant contribution of the abdomen to the total lung volume change (Hixon et al., 1976; Sundberg et al., 1991), in contrast to a mixed contribution of the abdomen and the rib cage when standing up.

Since in the supine position the caudal pull on the larynx is reduced or absent, the vertical larynx position is increased (Traser et al., 2014). However, the effect of body position on phonation is not well understood. In a small study of two professional singers performing a series of vocal tasks, Sundberg et al. (1991) found that the participants were able to maintain largely unchanged levels of P_s in the upright and the supine positions. However, it is not known to what extent P_s levels and voice source characteristics are sensitive to changes in body position in untrained participants. Indeed, Traser et al. (2021) demonstrated that professional singers can maintain a mixed strategy involving the diaphragm and the rib cage in both the supine and upright positions, suggesting that they might evolve more complex compensatory strategies.

Little is known about breathing kinematics in the reclined position. De Troyer (1983) collected muscle activity data in participants breathing quietly while tilted head-down at a 45° angle. His results showed increased activity of the abdominal muscles compared to the supine position. A possible explanation is that similar to the upright position, abdominal muscles are activated to counteract the hydrostatic pressure exerted by the abdominal content being pulled caudally (in the upright position) or cranially (in the reclined position).

Effects of gravitation on articulation

As we know from snoring, gravitation pulls articulatory structures backward in the supine position, which results in a narrowing of the throat (Engström, 2023; Stone et al., 2007; Vorperian et al., 2015). With no compensation, we would therefore expect a more retracted tongue position and reduced lip protrusion in the supine position. In contrast to this prediction, previous studies report mixed, and sometimes contradictory results. For example, Tiede et al. (2000) report x-ray microbeam measurements for two participants, comparing upright and supine positions, noting slightly anterior tongue position in one speaker when supine, while the opposite was found for the other speaker, who had a somewhat more posterior tongue position when supine. Similarly, Kitamura et al. (2005) present MRI data from three speakers of Japanese, which show overall retraction of the tongue root in the supine position, but the magnitude of the difference appeared to vary considerably between participants. One speaker showed virtually no difference between upright and supine positions, one showed consistent tongue root retraction when supine, and one showed retraction in some vowel contexts, and no difference in others.

Stone et al. (2007) propose that such mixed articulatory results may be due to individual differences in the degree of compensation for gravitational forces in different positions, where the primary goal of the compensation is to keep the airway open. In their ultrasound study of 13 speakers, Stone et al. (2007) identify three broad strategies in response to being in a supine position: 1) no compensation, which produces differences consistent with gravitational effects, e.g. retracted tongue root; 2) sufficient compensation, such that little difference is observed between upright and supine position; 3) overcompensation, which produces ‘anti-gravity postures’, such as relative tongue anteriority in supine position. In general, sufficient compensation appeared to be the most common strategy, consistent with Vorperian et al. (2015). This, however, varied depending on the segment, as also seen in Kitamura et al. (2005).

Interestingly, some systematic group-level differences emerge when comparing two studies by Traser et al. (2013) and Traser et al. (2014). Both were MRI studies of articulatory differences in singing phonation, but Traser et al. (2013) studied classically trained singers, while Traser et al. (2014) studied untrained participants. The professional singers showed minimal-to-no-differences between upright and supine positions, as far as supralaryngeal articulators are concerned, suggesting the presence of compensation. In contrast, the untrained singers showed some differences in tongue position consistent with variable or insufficient compensation. As far as the specific nature of articulatory compensation is concerned, both Traser et al. (2013) and Traser et al. (2014) found that the jaw position may be adjusted to counter the gravitational pull on the tongue in the supine position. More specifically, the jaw was more protruded in the supine position. The combination of this effect with stable supralaryngeal articulation in Traser et al. (2013) is consistent with a pattern of jaw-tongue coordination, in which jaw manipulation is used to adjust the position of the tongue (Johnson et al., 1993).

Overall, previous articulatory research suggests that speakers tend to compensate for the effects of gravity on speech. Similarly, recent results on astronauts returning from space missions indicate that the gravitational pull on articulatory structures is compensated by anti-gravity behaviour on Earth (Shamei et al., 2023). However, we also know that speakers achieve compensation in a variety of ways, and the nature of this variation is only partially understood. The picture is even less complete when it comes to speech produced in the reclined position (see Figure 1), which to our knowledge, has not been systematically studied using articulatory methods.

Purpose and aims

The first purpose of the present project is thus to investigate the strategies speakers employ under these conditions to produce comprehensible speech.

The observation that we can speak when our speech organs are perturbed in some way, for instance when holding an object between our teeth, is not new. Indeed, studies exploring adaptations of speech production to mechanical constraints have been instrumental in understanding some of the basic principles of speech motor control. However, so far, they have been predominantly restricted to articulatory phenomena. This limitation obscures the synergistic nature of speech production, which involves precise coordination of many anatomical structures. Since gravity is known to perturb breathing, phonation, and articulation, the second purpose of the project is to help overcome the fragmentation of the research field by contributing to a more holistic account of speech production, encompassing all its major components.

In short, we propose to draw on the known effects of gravity on speech production and investigate adaptive patterns across the whole speech production pipeline as body position is changed from upright to supine to reclined. Specifically, the project aims to address the following research questions:

1. What respiratory, phonatory and articulatory strategies are employed by speakers to compensate for the effects of gravity in the upright, supine, and reclined positions?
2. To what extent do these strategies vary across participants?
3. Does manipulating body position result in changes to speech output, such as vowel and voice quality differences?
4. Does vocal training (e.g. in classically trained singers) result in more consistent compensatory patterns?

Method

Human participants will be recorded using established methods for studying speech production: audio recordings, miniature accelerometers attached to speakers' necks, intraoral pressure sensors, electroglottography, ultrasound tongue imaging and respiratory inductance plethysmography.

The speech recorded in the project will consist of isolated syllables, read text and small samples of casual spontaneous speech and will contain no sensitive information. Should data of such character be inadvertently collected, they will be removed from the database in line with the recommendations of The Swedish Ethical Review Authority. None of the tasks involves an increased risk of vocal fatigue. Video recordings will be collected for the purpose of lip and jaw tracking and will only capture a small fragment of the participants' faces containing the lips and the jaw in profile.

The research plan involves collecting speech samples from participants placed in the supine and reclined positions using an inversion table (see Figure 1). Inversion tables are used in spinal traction, a home-based decompression therapy to relieve back pain, muscle spasms, compressed spinal disks and sciatica pain. Due to increased blood pressure in the inverted position, the method is not recommended for individuals with:

- Diseases of the eyes, (glaucoma, conjunctivitis, high myopia of -6 diopters or more)
- Cardiovascular problems
- Respiratory illness
- Otitis
- Balance problems
- Spinal injuries
- Osteoporosis
- Hypertension
- Thrombosis
- Circulatory disorders
- Pregnancy

In the project, we will only record healthy individuals and we will screen for any of the above exclusion criteria. We will also screen for gastroesophageal reflux disease, which while not an exclusion criterion in itself, might be exacerbated in the reclined position. The inversion table will only be operated by trained research personnel. The gradient and the duration of the speaking tasks will be adjusted in order to avoid participant fatigue in the reclined position. Participants will also be allowed to take breaks (as well as to terminate the experiment) at any point. Due to the physical intervention involved, as well as the processing of health data in the screening process, we will apply for a permit from The Swedish Ethical Review Authority before the research starts. The remaining data collection methods carry no significant risks for the participants. Similarly, the research is not associated with any long-term risks.

Overall, with proper screening, we assess the risks for participants to be low and to be fully justified by the research goals. Gravity offers a unique opportunity to study compensatory strategies which affect the whole speech production mechanism, a holistic perspective which is routinely overlooked in existing literature.

Figure 1. First author in reclined position on an inversion table.

Discussion

By providing a more comprehensive account of physiological constraints in speech, the project will contribute to overcoming the fragmentation of the research field, which overwhelmingly focuses on individual components of speech production and loses track of its coordinative nature. In addition to its theoretical contributions, the project will develop protocols for collecting speech data encompassing breathing, phonation and articulation. It will also inform vocal pedagogy, for instance with respect to optimal strategies when vocal performances involve body position other than upright. The project will be carried out over three years by an international group of researchers with expertise in the different aspects of speech production and instrumental techniques.

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