The effect of body position on the relative contribution of the rib cage to speech breathing and voice quality

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Abstract

This study investigates how body position affects the relative contribution of the rib cage to speech breathing and voice quality. The frequently used upright and supine body positions are expanded with the addition of an inverted position as a condition. Five participants performed two speech production tasks across the three body positional conditions. The estimation of the relative contribution of the rib cage to speech breathing was obtained through respiratory inductance plethysmography (RIP). Phonation type was estimated through the usage of the α-ratio, obtained with a neck-surface accelerometer. The results between the participants suggest a pattern regarding levels of the relative contribution of the rib cage in relation to phonation type, which offers opportunities for further investigation in future research.

Keywords

Speech breathing, body position, voice quality, respiratory inductance plethysmography, accelerometer

Effekten av kroppsposition på det relativa bidraget av bröstkorgen för talandning och röstkvalité

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Sammanfattning

Den här studien undersöker hur kroppsposition påverkar det relativa bidraget av bröstkorgen för talandning och röstkvalité. Den frekventa användningen av upprät och supin kroppsposition utvidgas med en inverterad position som villkor. Fem forskningspersoner genomförde två tal-produktionsuppgifter genom de tre kroppspositionsvillkoren. Uppskattningen av det relativa bidraget av bröstkorgen för talandning var erhållen genom respiratory inductance plethysmography (RIP). Fonationstyp var uppskattad genom användningen av α-ratio, erhållen med en ytligt hals-placerad accelerometer. Resultaten mellan deltagarna föreslår ett mönster för nivåer av det relativa bidraget av bröstkorgen relaterat till fonationstyp, som ger möjligheter för vidare undersökning i framtida forskning.

Nyckelord

Talandning, kroppsposition, röstkvalité, respiratory inductance plethysmography, accelerometer

Contents

1 Introduction

Body position is a useful parameter in voice research for providing insights about physiological behaviours that affect phonation. Observed compensatory behaviour in an upright and supine position have for instance contributed to further knowledge about subglottal pressure regulation (Sundberg et al., 1991) and vocal tract configuration (Traser et al., 2013). The body positional impact on breathing have illustrated important aspects for clinical treatment of voice disorders (Hoit, 1995) and respiratory kinematics (Traser et al., 2021). However, the studied phonation and breathing have often been based on singing tasks performed by classically trained singers, which poses the question of how body position impacts speech breathing.

Of special interest is the previous findings with respect to the relative contributions of the rib cage and the abdomen towards the respiratory cycle. The description of the breathing apparatus as a two-part kinematic system, as proposed by Konno and Mead (1967), was used by Hixon et al. (1973) to investigate the effect of body position on the relative contributions of the rib cage and the abdomen during speech breathing. The varied results of the speech production tasks suggested that the relative contribution of the abdomen became more present in the supine position.

In this thesis, the body positional conditions are expanded with an inverted position, which was previously used by De Troyer (1983) in quiet breathing research. Through the additional usage of the inverted position, further awareness can be gained as to whether and how the relative contributions of the rib cage and the abdomen affects speech breathing and phonation.

2 Background

2.1 Introductory overview

The phonatory qualities of speech depend on the interaction between the subglottal pressure produced within the breathing apparatus and the vibrations of the vocal folds. Subglottal pressure is caused by the build-up of air between the lungs and a closed glottal passage, also referred to as the glottis, within the vocal tract. The vocal folds act as regulators of the air stream that flows through the glottis, which causes the subglottal pressure to rise when the folds are closed and to be released once the folds open. The interaction of the airflow through the glottis and how much the vocal folds press together, referred to as adduction, cause voice source phonation (Sundberg, 1992 p. 61). The degree of adduction influence voice quality, meaning phonation types ranging along a continuum between a breathy and a pressed voice (Gordon & Ladefoged, 2001, p. 383).

Different aspects of the breathing apparatus influence how the lungs provide subglottal pressure for speech. Structurally, the breathing apparatus consists of the pulmonary system containing the lungs and airways together with the rib cage, abdomen and diaphragm that constitutes the chest wall system (Hoit, 1995, p. 341-342). Furthermore, it has been shown that it is possible to consider the breathing apparatus as a two-part kinematic system consisting of the rib cage and abdomen. Several studies (Hixon et al., 1973; De Troyer, 1983; Sharp et al., 1975) have made use of the method presented by Konno and Mead (1967) to measure the volume distributed between the rib cage and abdomen according to movement (Sharp et al., 1975). The changes in anteroposterior diameter of the rib cage and abdomen together directly correspond to the total air volume within the breathing apparatus at a given point in the respiratory cycle (Hixon et al., 1973, p. 16). It is therefore possible to study how much the rib cage and the abdomen respectively contributes to speech breathing. This in turn can influence subglottal pressure and voice quality.

2.2 The breathing apparatus

The rib cage and the abdomen-diaphragm have one degree of freedom respectively. Together, as the two-part kinematic system, the degrees of freedom depend on if the system is closed or open. When the airways are open to the surrounding atmosphere, breathing is accomplished through a cycle of inhaling air during an inspiratory phase and exhaling during an expiratory phase. With increased air volume the chest wall system expands and with decreased air volume the system contracts. Both the rib cage and abdomen can then be used to exchange air volume. This can be described as the linear relationship between movement and air volume change within the breathing apparatus. (Hixon et al., 1973, p. 16). Additionally, muscle activity, elastic recoil and gravity affect the breathing apparatus and in turn the subglottal pressure necessary for phonation.

2.2.1 Muscle activity

Muscle activity affects and control the breathing mechanism. The rib cage accommodates inspiratory as well as expiratory muscles while the abdomen can only carry out an expiratory force and the diaphragm is simply an inspiratory muscle (Hoit, 1995, p. 341-342). Speech breathing in a typical upright body position makes use of different muscles whether one is inspiring or expiring. In this position the diaphragm is the main active muscle during inspiration while the rib cage and abdomen muscles control pressures necessary for speech during the expiratory phase (Hoit, 1995, p. 343).

2.2.2 Elastic recoil

The rib cage and lungs are able to expand and contract through an entirely passive elastic force. At rest there are no elastic forces in action. This occurs at the resting expiratory level (REL) when the breathing apparatus have a functional residual capacity (FRC). When one inhales air into the lungs the rib cage expands and deviates from REL, causing an elastic force where the rib cage recoils back to rest when exhaling. In this instance the elasticity is an expiratory force. This also works the other way around when the rib cage and lungs instead passively expand after a forced exhalation. In this case the elasticity is an inspiratory force (Sundberg, 1992, p. 52; Cleveland, 1998a, p. 47).

The inspiratory and expiratory forces are completely at equilibrium with each other at the FRC. The power of the recoil force is determined by lung volume. At a higher lung volume, the recoil forces increase (Sundberg, 1992, p. 51-52).

2.2.3 Gravity

The breathing apparatus is influenced by gravitational force. Since gravity always pulls downwards no matter which body position a speaker is in, it can cause the apparatus to alter its structure (Cleveland, 1998a, p. 47).

The implications of the gravitational force on respiration can be illustrated by examining differences between the respiratory muscles assumed in an upright position compared to a supine position. Since the abdominal contents moves downwards in an upright position, the abdomen and diaphragm gains space for inspiration whereas the rib cage is under an expiratory force because of the gravitational pull. To counter the expiratory force upon the rib cage, the abdominal muscles are activated and pushes the abdominal contents inwards. When lying down face up in a supine position gravitation exerts an expiratory force upon the entire breathing apparatus by pulling the abdominal contents headward (Hoit, 1995, p. 342-343). This causes the diaphragm to move further into the rib cage which consequently decrease the FRC (Kera et al., 2005, p. 263; Sundberg et al., 1991, p. 283).

2.3 Breathing

2.3.1 Capacity

Normal resting inspiration and expiration, referred to as tidal breathing, as well as inspiratory capacity (IC), begins from REL. IC is a maximum inspiration where one breathes in as much air as possible, expanding the lungs and rib cage (Cleveland, 1998b, p. 47). If the expiration is forced and squeezes as much air out as possible it means that one reaches a volume below REL called the residual volume (RV). The residual volume is the amount that always lingers in the lungs and can never be removed, which means that there is a set amount that can be expired within the range of REL to RV. This amount is called the expiratory reserve volume (ERV) (Cleveland, 1998b, p. 47). The combined volume of ERV and RV is the functional residual capacity (FRC), which is an important referential marker in breathing research (Hoit, 1995, p. 342). The complete volume that the lungs can contain at the point of a maximum inhalation is the total lung capacity (TLC) and differs to vital capacity (VC), which includes the inspiratory capacity and the expiratory reserve volume but not the residual volume since it always remains intact.

2.3.2 Breathing patterns in speech and quiet tidal breathing

There are different kinds of patterns to the flow of the respiration cycle, depending on the intent of the speaker. Comparing speech breathing to quiet tidal breathing, one can see a more periodical flow in tidal breathing whereas speech breathing is characterized by a sharper intake of initial breath followed by a longer expiratory phase (McFarland, 2001, p. 132).

The differences between spontaneous speech and reading was researched by Winkworth et al. (1994; 1995) using respiratory inductance plethysmography (RIP), which is a method that consists of two respiratory bands that are placed around the rib cage and abdomen to estimate movement corresponding to air volume within the breathing apparatus. Their results consisted of findings regarding sound pressure level (SPL), which corresponds to vocal loudness, as well as lung volume and breath occurrence. Breath intake occurrence was determined to a larger extent by syntactic structure when reading out load compared to spontaneous speech. In spontaneous speech a potential aspect of neural planning combined with lung volume could possibly be determined by the duration of the incoming speech period. Increased lung volume was not associated with increased vocal loudness for spontaneous speech, however, when it comes to reading there were several participants in the study where it was correlated.

A similar result was found in a later study by Winkworth & Davis (1997) where vocal loudness in spontaneous speech was induced by surrounding noise, eliciting the Lombard effect. Contrary to previous research by Hixon et al. (1973), where high lung volume was associated with vocal loudness, Winkworth & Davis (1997) found again no significant correlation between high lung volume and vocal loudness. Instead, vocal loudness could have been dependent on other factors in order to achieve a raised voice, such as glottal configurations to increase subglottal pressure.

2.4 Phonation

2.4.1 Subglottal pressure

Muscle activity, elastic recoil and gravity always influence respiration and by extension it has an impact on phonatory qualities of speech and subglottal pressure. The main contribution the breathing apparatus provide for speech is subglottal pressure necessary for phonation. The air pressure in the lungs rises because of muscular and elastic forces, which causes a build-up of subglottal pressure against a closed glottis. The subglottal pressure increases when the vocal folds are closed and is released once they open (Sundberg, 1992 p. 61). The subglottal pressure levels strongly influence vocal loudness (Sundberg, 1992, p. 53).

2.4.2 Adduction and abduction

The gradient of how much the vocal folds press together is called adduction. Voice source phonation is produced by a combination of adduction and the airflow in the glottis (Sundberg, 1992, p. 61). With excessive adduction the voice quality becomes pressed. Abduction is the reverse relationship where the vocal folds are more open, which is associated with a breathy voice and decreased subglottal pressure. An additional factor on abduction is the elastic connection between the vocal tract and the lungs, which pulls the larynx downwards when upright because of gravitational force. This is called tracheal pull (Iwarsson et al., 1998, p. 425). The force of the tracheal pull is affected by lung volume (Sundberg, 1992, p. 49).

2.4.3 Sound Pressure Level (SPL)

The sound pressure level (SPL) of a voice relates to the radiated sound power from a speaker's mouth and is a fundamental factor in estimating perceived vocal loudness. Sound pressure is conveyed in the unit Pascal (Pa) and SPL is conveyed in decibel (dB). The sound pressure in the air (referenced as p_0, which equals to 20 μ Pa) corresponds to 0 dB SPL and a sound pressure of 1 Pa corresponds to 94 dB SPL (Švec & Granqvist, 2018, p. 442). As described by Švec and Granqvist (2018), the logarithmic relationship between SPL (L_p) and sound pressure (p) is defined:

$$L_p = 20 \cdot \log_{10} \frac{p}{p_0}$$

When collecting data from a recorded speaker to estimate vocal loudness it is important to consider both the distance between the speaker's mouth and the microphone, as well as the usage of equipment dedicated to sound calibration (Švec & Granqvist, 2018, p. 459).

2.5 Voice quality

2.5.1 Voice source estimation

It is possible to think of voice quality as a continuum between phonation types, moving from voiceless (whisper), breathy voice, modal regulated voice (neutral), creaky voice and pressed voice (Gordon & Ladefoged, 2001, p. 383). Detailed study of voice quality requires an estimate of the actual voice source, which is the glottal acoustic output located within the vocal tract. A common method to study the voice source is through inverse filtering. Based on a microphone recorded voice, filters are applied to act as negators to the resonances created in the mouth cavity. One can then get an estimate of the voice source (Sundberg, 2001, p. 90).

Another method of estimating the voice source is through the usage of neck-surface accelerometers. As described by Stevens et al. (1975), accelerometers is a non-invasive way of obtaining the glottal acoustic output. This is obtained through skin vibrations produced by the fluctuations of the air pressure within the vocal tract caused by vocal fold vibrations. The proficiency of the accelerometer has been emphasized through research by Mehta et al. (2019) where it was established that the characteristics produced by the voice source resembled the accelerometer signal when measuring the first and second harmonic and by Włodarczak et al. (2022) where it was shown that an accelerometer and inverse filtering have similar capability in voice source approximation. In contrast to the inverse filtering of a microphone recording, the accelerometer is able to record voice source information without additional filters as well as not being impacted by surrounding noise (Włodarczak et al., 2022).

2.5.2 Spectral tilt and the α-ratio

A reliable acoustic parameter to distinguish between phonation types is spectral tilt. A spectrum is a way to view the distribution of acoustic energy across frequencies. It shows amplitude of intensity along the vertical axis and increasing frequency along the horizontal axis. The spectral tilt shows how the intensity of the waveform drops off along the increasing frequencies and is correlated to phonation type. Breathy voice is associated with a steeper spectral tilt than pressed voice (Gordon & Ladefoged, 2001, p. 397-398).

A way to view voice quality over a longer duration is through Long Term Average Spectrum (LTAS), which shows average spectral characteristics. The measure used in previous studies to investigate differences between phonation types (Kitzing, 1986; Sundberg & Nordenberg, 2006) is called the α-ratio (alpha-ratio), as first proposed by Frøkjaer-Jensen and Prytz (1975). It is conveyed in decibel (dB) and measures the spectral balance between the sound energy in frequencies higher than 1000 Hz and sound energy lower than 1000 Hz, which is defined as:

$$\alpha = I_{HF} / I_{LF}$$

More energy in the higher frequencies increases the α-ratio (dB), corresponding to a decrease in spectral tilt (less incline), which correlates to a more pressed voice quality. When there is more energy in the lower frequencies the α-ratio decreases, corresponding to an increase in spectral tilt (more incline), which correlates to a breathy voice quality (Sundberg & Nordenberg, 2006, p. 453). The α-ratio has been shown to be strongly influenced by vocal loudness in a study by Sundberg and Nordenberg (2006), where the α-ratio increased 0.44 dB in women and 0.33 in men per dB of the equivalent SPL.

2.6 The effect of body position on breathing kinematics

2.6.1 Gravitation as a parameter in previous research

Gravitation is an experimental parameter that can be used to investigate the breathing apparatus and consequently phonatory functions of speech. Previous studies have shown gravitational effects on the management of subglottal pressure in singing performed by classically trained opera singers (Sundberg et al., 1991), and as a parameter for magnetic resonance imaging (MRI) studies of vocal tract configuration and respiratory kinematics in classical singing (Traser et al., 2013; Traser et al., 2021), as well as tongue behaviour in speech (Stone et al., 2007).

Depending on the body position a speaker is in while speaking a variety of breathing behaviour may be obtained for research. In order to understand the respiratory functions of the breathing apparatus during phonation it is helpful to take advantage of the apparatus' alteration depending on body position.

However, breathing is a complicated interplay of muscle activity and air volume change between the rib cage and abdomen, which involves different inspiratory and expiratory functions. With the usage of two magnetometer pairs, which were placed on either side of the rib cage and abdomen respectively in a linear anteroposterior direction, Hixon et al. (1973) could estimate the relative contributions of the rib cage and the abdomen separately while examining participants in an upright and a supine position. The changes in anteroposterior diameter of the chest wall system directly correspond to the expansion of respiratory volume between the magnetometers and is therefore an indicator of the total volume of air in the breathing apparatus at a given point in the respiratory cycle. Inspiration causes an expansion of the apparatus and expiration contracts the apparatus (Hixon et al., 1973, p. 83-84). By testing six participants that performed various speech production and respiratory tasks Hixon et al. (1973) showed that abdominal movement was more present in the supine position compared to the upright position. The results among the participants in general was varied depending on the task, where some had an inherent inclination towards more rib cage movements or more abdominal movements.

2.6.2 Abdominal muscle activity

The findings of increased abdominal movement in the supine body positions during speech production does have support with electromyographic (EMG) studies completed by De Troyer (1983), Sundberg et al. (1991), Kera et al. (2005) and Montes et al. (2017).

Sundberg et al. (1991) studied regulation of subglottal pressure based on two classically trained opera singers. The singers showed compensatory muscular activity depending on if they were in an upright or supine body position. While singing, EMG results showed that the abdominal wall and diaphragm had synchronized movements in an upright position, meaning that activity was both present in the diaphragm and abdomen. This seems to be necessary in order to maintain subglottal pressure while singing in an upright position. Compared with the upright position, the abdominal wall contractions were decreased in activity in the supine position and inspiration was mainly completed by the diaphragm (Sundberg et al., 1991, p. 291). The potential explanation, as discussed by Sundberg et al. (1991), is that subglottal pressure levels become elevated because of gravity in a supine position. This could mean that abdominal muscle activity is not as necessary in order to increase subglottal pressure levels for phonation in a supine position compared with an upright position. The singers were able to regulate subglottal pressure with this compensatory behaviour, which resulted in no substantial difference in subglottal pressure control between the body positions.

De Troyer et al. (1983) studied abdominal muscle activity during quiet breathing based on ten participants placed in a variety of tilted body positions upon an inversion table. The positions that were examined was upright in an 80 degree angle and a 45 degree angle along with horizontal supine (0 degrees) as well as an inverted supine position at an angle of -45 degrees. The results showed decreased muscle activity in the abdominal muscles when the participants assumed a supine position in comparison with an upright position. More muscle activity in the abdominal muscles was found in the inverted supine position compared to the horizontal supine position in four out of ten participants, similar to an upright position. The key difference between the upright and the inverted supine position was that muscle activity in the upper and lower abdomen were active in an upright position, predominantly by the lower abdomen, while only the upper abdominal muscles were activated in the inverted supine body position (De

Troyer, 1983, p. 345). Although Kera et al. (2005) and Montes et al. (2017) did not test the inverted supine position, both studies confirmed that there was less activity in the abdominal muscles in a supine position compared to an upright position while breathing.

The implications of less muscle activity in the abdominal muscles in a supine position has an effect on speech breathing research as discussed by Hoit (1995). Since the abdominal muscles are quiet in a supine position, the abdominal movements become a by-product of the inspiration completed by the diaphragm and the expiratory force upon the rib cage (Hoit, 1995, p. 345). This means that compared to an upright position where the abdominal muscles are activated to counteract the expiratory force upon the rib cage by holding in the abdominal contents, the abdominal muscles are relaxed with increased potential movability during speech breathing in a supine position.

2.6.3 Potential compensatory behaviour of an inverted body position

As described above, the breathing apparatus' sensitivity to gravity produces different compensatory strategies for speech breathing depending on if one is in an upright or a supine body position. However, further compensatory behaviour could be obtained when considering the inverted supine body position used for research by De Troyer (1983).

In an inverted body position, gravitation could exert an even more forceful pull on the breathing apparatus in a headward direction, resulting in a greater expiratory force placed upon the apparatus. In this position the abdominal contents could potentially push the diaphragm even further into the rib cage, which could potentially decrease the FRC further (Kera et al., 2005, p. 263; Sundberg et al., 1991, p. 283) compared to a horizontal supine position and cause an even more elevated subglottal pressure level. Along with the gravitationally induced loss of tracheal pull, which causes more adduction of the vocal folds (Iwarsson et al., 1998), and elevated subglottal pressure levels (Sundberg et al., 1991), the resulting voice quality could potentially move towards a more pressed voice (Gordon & Ladefoged, 2001).

The question is whether and how a speaker would counteract the gravitational pull in an inverted position in order to avoid an elevated subglottal pressure level and excessive adduction of the vocal folds, which is undesirable in order to maintain a regulated speaking voice. De Troyer (1983) had a divided result between the participants regarding muscle activity in the inverted position during quiet breathing, which presents the possibility of different potential outcomes when investigating speech breathing. As seen by previous studies (De Troyer, 1983; Kera et al., 2005; Montes et al., 2017), the abdominal muscles have little activation in a horizontal supine position, which means there is more potential movability during speech breathing (Hoit, 1995). Six out of ten participants in the study by De Troyer (1983) did not show an increase in abdominal muscle activity in the inverted position, which could potentially result in even more abdominal movability and less relative contribution of the rib cage to speech breathing, compared to a horizontal supine position. Similarly then to a horizontal supine position, the main inspiratory source is the diaphragm and because of the already elevated subglottal pressure levels caused by the gravitational pull, the abdominal muscles become relaxed.

The increased abdominal muscle activity displayed by four out of ten participants in the study by De Troyer (1983) regarding the inverted position could indicate another potential outcome. An increase in muscle activity could mean less abdominal movability and more relative contribution of the rib cage in an inverted position compared to a horizontal supine position. Considering that only the upper abdominal muscles were activated, it could mean that subglottal pressure levels remain elevated since the abdomen is not relaxed, and therefore the muscle activity shown among the four participants could be undesirable for speech. Since De Troyer (1983) studied quiet breathing, there has not been an estimation of the relative contributions of the rib cage and the abdomen to speech breathing in an inverted position and consequently the effects on phonation.

2.7 Aims and research questions

The inverted supine position employed for the study of quiet breathing by De Troyer (1983) has not been used to investigate speech breathing in combination with the relative contribution of the rib cage and the abdomen. Therefore, the present study aims to investigate how body position affects speech breathing by examining the differences in the relative contribution of the rib cage. By further analysis of phonation type, an estimation regarding voice quality across the body positional conditions will be investigated.

2.7.1 Research questions

1. Depending on body position, is there a difference in the relative contribution of the rib cage to speech breathing?
2. Depending on body position, is there a difference regarding phonation?
3. Are the patterns regarding relative contribution of the rib cage and phonation patterns related?

3 Method

3.1 Participants

Five participants took part in the experiment, including the author of this study. The participants were recruited based on availability, willing participation and were made aware of the possible dangers with the usage of an inversion table for the inverted supine body position. None of the participants to their knowledge had any of the pre-existing conditions listed as potential risks in the information given to all participants prior to the session. The listed pre-existing conditions were pregnancy, eye related diseases, cardiovascular problems, respiratory illnesses, otitis, balance problems, spinal injuries, osteoporosis, hypertension, thrombosis and circulatory disorders. All participants agreed to the conditions of the experimental procedure as well as the analysis of the data that was collected by signing a consent form (Appendix 8.2). No compensation was offered for taking part in the study.

3.2 Equipment and environment

All recordings were made within the environment of the respiratory lab in the Phonetics Laboratory (Fonetiklaboratoriet) at Stockholm University.

3.2.1 Body positional equipment

A MAXXUS Gravity pro 2.0 inversion table was used when testing the supine and inverted supine body positions.

3.2.2 Respiratory inductance plethysmography (RIP)

Hixon et al. (1973) used magnetometers to estimate volume displacement between the rib cage and abdomen, however, similar to Winkworth et al. (1994; 1995) this study used the alternative method of respiratory inductance plethysmography (RIP). Compared to magnetometers that measures linear movement, RIP estimates the cross sectional area. The RIP method consists of two bands, also referred to as respiratory bands, which are placed around the rib cage and the abdomen respectively. Similar to magnetometers the RIP-signal correspond to change in air volume within the breathing apparatus based on movement.

To calibrate the respiratory bands an isovolume manoeuvre is employed by the participant, which makes use of the two-part kinematic system when closed. When the airways are closed the system cannot exchange air with its surroundings, which means that the only way to move the air volume is within the system between the rib cage and abdomen. This means that the rib cage and abdomen are capable of paradoxical movements where the air volume can be displaced between the rib cage compartment and the abdomen compartment and that relative contribution to the respiratory cycle can be estimated (Hixon et al., 1973, p. 15-16). The sequence of the isovolume manoeuvre entails an intake of air, closing the glottis in order to keep the air within the breathing apparatus, followed by moving the air between the rib cage and abdomen through a series of forced expansions of the abdomen (Hixon et al. 1973, p. 80-81). The sensitivity of the bands can then be adjusted to produce a constant summed signal.

The respiratory movements were recorded through the ADInstruments PowerLab 16/35 data acquisition system using respiratory bands (RIP) that were connected to a Resptrack 2.4A processor, developed at the Phonetics Laboratory (Heldner et al., 2019). The respiratory bands were placed around the rib cage and the abdomen, where the navel served as a guideline to ensure that the band was placed below the rib cage.

The recording of the respiratory bands consists of three channels, each containing a specific signal. These signals are the rib cage movement, the abdomen movement and a summed signal of the rib cage and abdomen. The RespTrack processor has a potentiometer, which is a dial that is able to level the summed signal of the rib cage and abdomen in order to estimate changes regarding lung volume in real-time (Włodarczak et al., 2015, p. 109). In order to calibrate, the participant is instructed to perform an isovolume manoeuvre while the sum signal is adjusted with the dial until it is flat. This is to ensure that the sum corresponds to the total lung volume change.

Another feature of the RespTrack processor is a way to correct the curve of the signal to ensure that it begins at a zero level, which is done through an integrated button (Włodarczak et al., 2015, p. 109). This correction is useful when estimating REL.

3.2.3 Accelerometer

To investigate phonatory qualities the method of using an accelerometer to record neck-surface skin vibration was used, which made it possible to analyse spectral differences that correlates to voice quality. Compared to the usage of a microphone and inverse filtering, the recorded accelerometer signal can be analysed without additional filtering, which makes it easier and less time-consuming to use when analysing phonation types based on the voice source (Włodarczak et al., 2022).

To record neck-surface vocal fold vibration a Knowles BU-27135 accelerometer was attached with an adhesive to the participant's neck, specifically below the glottis.

3.2.4 Microphone

Sound was recorded using a head mounted Sennheiser HSP2 microphone that was positioned at a 15 centimeter distance from the participant's face. In order to estimate the sound pressure level a Brüel & Kjær type 4231 SPL calibrator was used to emit a 1 kHz tone at 94 dB for calibration of the recorded sound.

3.2.5 Data collection of the RIP-signal, accelerometer signal and microphone signal

The LabChart interface by ADInstruments was used for the respiratory recordings as well as a complimentary sound recording in order to synchronize the microphone and accelerometer signals, which was recorded with REAPER.

3.3 Experimental procedure

The author and the supervisor of this study were both present and shared workload regarding equipment and instruction throughout the sessions. The recordings were made with one participant at a time. The participant was equipped for recording, where the head mounted microphone was adjusted for suitable placement and the inversion table was regulated according to the participant's height. With the SPL calibrator, a 1 kHz tone at 94 dB was emitted into the microphone for later stage estimation of SPL.

The body positional conditions were upright, horizontal supine, and an inverted supine position with a backwards tilt at a -10 degree angle relative to the horizontal supine position, as seen in Figure 1. The upright position was performed by standing on the floor, while both the supine positions were assumed using the inversion table. The angle measurement was accomplished using an angle chart made at the Phonetics Laboratory as an additional feature design of the inversion table.

Figure 1. Participant equipped for recording placed in the inverted body position at -10 degrees. (Image included with permission.)

The speech production tasks consisted of a reading task and a syllable repetition task. The reading consisted of three texts in Swedish (Appendix 8.1), which were *Nordanvinden och solen* ('The north wind and the sun'), *Ett svårt fall* ('A difficult fall/case') and *Trapetskonstnären* ('The trapeze artist'). The participants were simply instructed to read the texts, with no further instruction considering vocal loudness, articulation or voice quality. The syllable repetition task used the syllable /pæ:/. The participants were instructed to perform a maximum inhalation followed by repeating the syllable for as long as possible until it felt as if all air had been exhaled, all within the same breath. The exhaled volume should correspond to VC. Before the session began the participants were asked to trial read the texts that were going to be recorded to prevent stumbling with the reading during the session. The reading task was performed across all body positional conditions whereas the syllable repetition task was only recorded in the upright and horizontal supine position.

In preparation for each condition calibration of the respiratory bands was completed in real-time. The isovolume manoeuvre was also recorded for usage at a later stage where the signals were further calibrated though the usage of a Praat script. IC and REL was recorded for reference. For the supine body positions the reading material was held above the participant's head by the experimental instructor and for the upright body position it was displayed using a note stand.

Due to the sensitivity of the placement of the respiratory bands, adjustments were made throughout the sessions. It was noted that depending on the clothes the participant was wearing, the respiratory bands had a higher chance of being displaced in the inverted supine body position. To prevent the bands from moving around, the participant's upper garment was taped down onto the trousers, when possible.

Typos in the text *Nordanvinden och solen* was noticed into the sessions, but not removed. IC was not estimated in the case of participant five, since VC was attempted instead.

3.4 Data processing and analysis

In order to process data, the speech analysis software Praat (Version 6.3; Boersma & Weenink, 2022) was used. All recordings were synced with each other through a recorded hand clap, which ensured that the microphone, accelerometer and RIP-recordings were completely synchronized. The recordings were cut according to the body positional conditions and a further calibration of the RIP-signals was completed through a Praat script designed to calibrate using the recorded data of the isovolume manoeuvres (obtained from and developed by Marcin Włodarczak, 2023). An example of a calibrated RIP-recording can be seen in Figure 2.

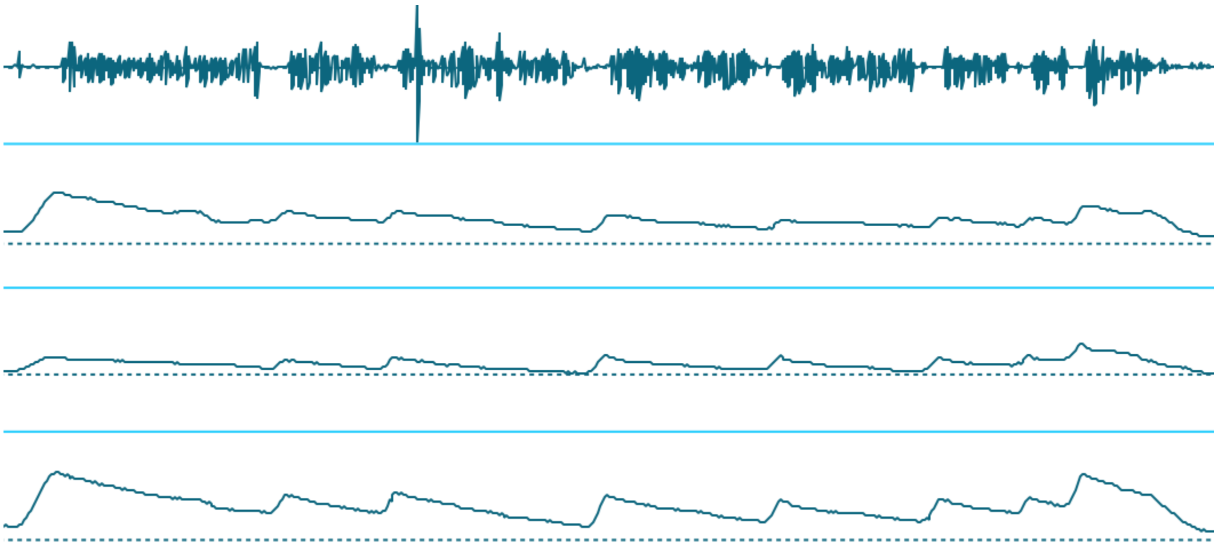

Figure 2. An image taken from a Praat window, showing a calibrated RIP-recording of a participant reading the text *Ett svårt fall* (‘A difficult fall/case') in an inverted supine body position. The signals as follows from top to bottom: Sound recording, rib cage signal, abdomen signal and sum signal. The dotted line marks 0, corresponding to REL.

The onsets of inhalations and exhalations in the speech production tasks were annotated manually, using the sum signal as the baseline.

The annotation was used to collect data points to estimate the relative contribution of the rib cage. The data points were obtained through measuring the amplitudes of the rib cage signal and the abdomen signal at the start and end of an expiratory phase. The data points were developed into a dataset where the difference between the values of the start and end amplitudes in an expiratory phase of respectively the rib cage (Δ_{RC}) and abdomen (Δ_{AB}) were calculated (where Δ is the difference between the start and end in an expiratory phase). The estimation of the relative contribution of the rib cage was calculated by estimating relative rib cage contribution in relation to the summed total of the rib cage and abdomen movements using the formula:

$$\textit{Relative contribution of the rib cage} = \Delta_{RC} / (\Delta_{RC} + \Delta_{AB})$$

The relative contribution of the abdomen is then 1 – *Relative contribution of the rib cage*. This resulted in 565 data points obtained from the reading task and an additional 30 data points obtained from the syllable task.

A calculation of duration and breaths for the reading task were collected from the annotated data in order to estimate if there were any differences in breath rate between the body positional conditions.

In order to analyse voice quality, the accelerometer recordings of the reading task were purged of superfluous noise and pauses in between the readings of the three different texts by editing the recording so that the texts flowed immediately one after the other without pauses. The α-ratio was then calculated in Praat by extracting a spectrum that ranged across the edited recording (LTAS), as well as using the built in function of calculating mean energy band difference between frequencies higher than 1000 Hz (ranging from 1000 Hz to 5000 Hz) and lower than 1000 Hz (ranging from 0 Hz to 1000 Hz). This was completed for all participants across all body positional conditions.

The sound pressure level (SPL) was estimated by following the tutorial guidelines by Švec and Granqvist (2018) and the Praat manual (Entries: Sound Pressure Level, Sound pressure level calibration). First, the microphone recordings were edited in the same way as the accelerometer recordings were for the voice quality analysis. Then the mean energy of a stable section of the sinus wave emitted by the SPL calibrator at 94 dB was collected from each participant's recording. The level difference (ΔL) between the collected mean value (dB) and 94 dB was calculated. The edited microphone recording was then multiplied by the factor of $10^{(\Delta L / 20)}$ and used to modify the recording to show the actual SPL (at 15 centimeters distance) of each participant's voice by using the Praat built in *Multiply* option (Švec & Granqvist, 2018, p. 454). Afterwards, the built in function in Praat of estimating mean intensity across the entire edited recording was completed, resulting in the mean SPL of the reading task consisting of all three texts for each participant and body positional condition.

Statistical analysis was completed using R programming (Version 4.2.3; R core Team, 2023) by working within the RStudio environment (Version 2021.09.3; Rstudio Team, 2023). Mean, median and standard deviation was calculated, and the results were visualized as box-and-whiskers plots.

4 Results

4.1 Relative contribution of the rib cage

The results regarding the relative contribution of the rib cage across the body positions for the reading task resulted in three different patterns between the five participants. These results have been visualized as box-and-whiskers plots, that visualizes the data points through quartiles, where the vertical axis marks the relative contribution of the rib cage to the sum of the total movement of the rib cage and abdomen. The horizontal axis marks the three different body positional conditions that were tested: upright, supine and inverted. The grey box visualize the middle 50 percent that ranges from the 25 percent mark to the 75 percent mark of the total. The whiskers mark the range between 0 and 25 percent and 75 percent and 100 percent respectively. The darker line within the grey box marks the median and the small circles outside of the range of the whiskers are outliers that ranges further than 1.5 times the edges of the middle 50 percent. The line running though the diagrams shows the 50 percent mark regarding relative contribution of the rib cage to the sum. Henceforth, it will be referred to as the contribution line. Decreased values regarding relative contribution of the rib cage indicates an increase in the relative contribution of the abdomen.

The relative contribution of the rib cage reaches values above 1 and below 0 along the vertical axis of the box-and-whiskers plots, because of the included 34 data points among the total 595 data points that were paradoxical cases where the rib cage and abdomen moved in opposed directions. The majority of the paradoxical cases were instances where the abdominal movement increased instead of decreasing throughout the expiratory phase and only one instance where the rib cage movement increased throughout the expiratory phase instead of decreasing.

All participants had more relative contribution of the rib cage in the upright body position compared to the supine and inverted position. Not including outliers, a 100 percent of the data points in the upright position occurred above the contribution line for all participants.

The relative contribution of the rib cage in the inverted position was closer to the contribution line for all participants. The differences between the three cases presented below occurred mainly between the supine and the inverted body position.

4.1.1 Mean, median and standard deviation

In Table 1, the collected values regarding mean, median and standard deviation of each position across all participants can be seen for the reading and syllable repetition task.

Participant	Condition	Task	Mean	Median	SD
1	Upright	Reading	0.84	0.82	0.10
	Supine		0.37	0.38	0.06
	Inverted		0.49	0.51	0.12
2	Upright	Reading	0.92	0.92	0.12
	Supine		0.31	0.34	0.18
	Inverted		0.42	0.41	0.16
3	Upright	Reading	0.90	0.89	0.16
	Supine		0.66	0.62	0.14
	Inverted		0.43	0.43	0.17
4	Upright	Reading	1.00	1.00	0.04
	Supine		0.61	0.62	0.10
	Inverted		0.59	0.58	0.10
5	Upright	Reading	0.84	0.85	0.12
	Supine		0.67	0.67	0.11
	Inverted		0.50	0.52	0.14
1-5	Upright	Syllable repet.	0.87	0.83	0.10
	Supine		0.67	0.69	0.13

Table 1. Mean, median and standard deviation of the relative contribution of the rib cage for the reading and syllable repetition task across all participants. The numbers are rounded based on the full-length data point values.

4.1.2 Case 1

The pattern that both participant 1 and 2 displayed can be seen in Figures 3 and 4. In the upright position there was the most relative contribution of the rib cage across the three body positions. In the supine position there was a decrease in the relative contribution of the rib cage which means an increase in the relative contribution of the abdomen compared to the upright position. When in the supine position 75 percent of the datapoints were below the contribution line, including the middle 50 percent, which means that the abdomen contributed more than the rib cage towards the speech breathing process. Like the supine position, the inverted position showed a decrease in the relative contribution of the rib cage compared to the upright position. However, when comparing the supine position and the inverted position an increase of the relative contribution of the rib cage can be seen in the inverted position.

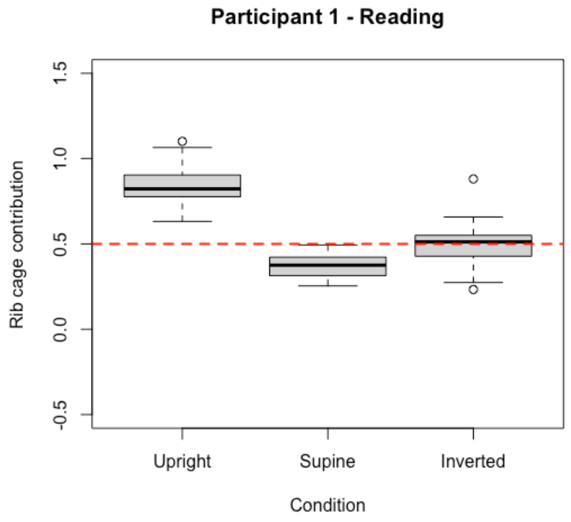

Figure 3. Relative contribution of the rib cage to the sum across all body positions for participant 1.

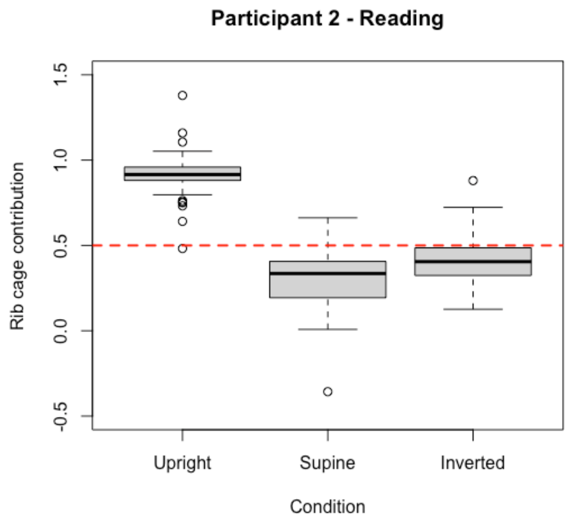

Figure 4. Relative contribution of the rib cage to the sum across all body positions for participant 2.

4.1.3 Case 2

The second case as seen in Figures 5 and 6, shows a different kind of pattern regarding participant 3 and 5. Like the first case, the upright position showed the most relative contribution of the rib cage across the three body positions. In the supine position there was also a decrease in the relative contribution of the rib cage which means an increase in the relative contribution of the abdomen compared to the upright position. More than 75 percent of the datapoints occurred above the contribution line in the supine position, including the middle 50 percent, which means that there was not as large of a decrease in the relative contribution of the rib cage compared with participants 1 and 2 in the first case. For participants 3 and 5, the inverted position showed further decrease in the relative contribution of the rib cage compared to the supine position.

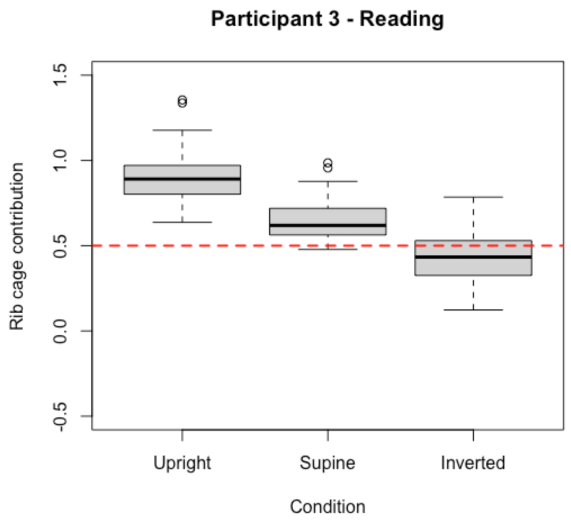

Figure 5. Relative contribution of the rib cage to the sum across all body positions for participant 3.

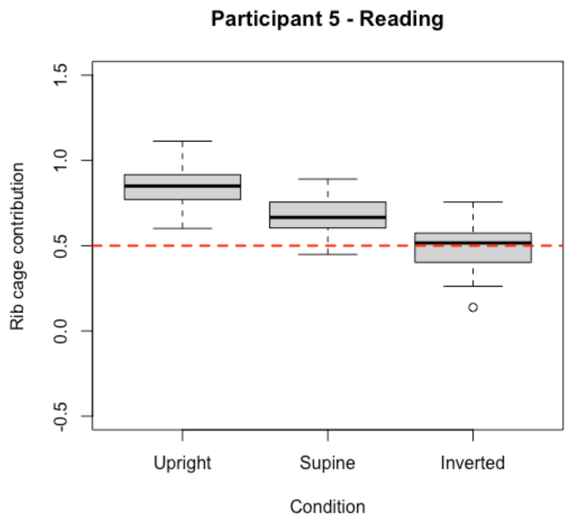

Figure 6. Relative contribution of the rib cage to the sum across all body positions for participant 5.

4.1.4 Case 3

Compared to the other participants, participant 4 had a similar pattern regarding the upright position, as seen in Figure 7. However, 75 percent of the data points were above the contribution line, including the middle 50 percent, for both the supine and inverted position. With the exception of the median, which is just slightly lower in the inverted position compared to the supine position, there is not much difference at all between the supine and inverted position.

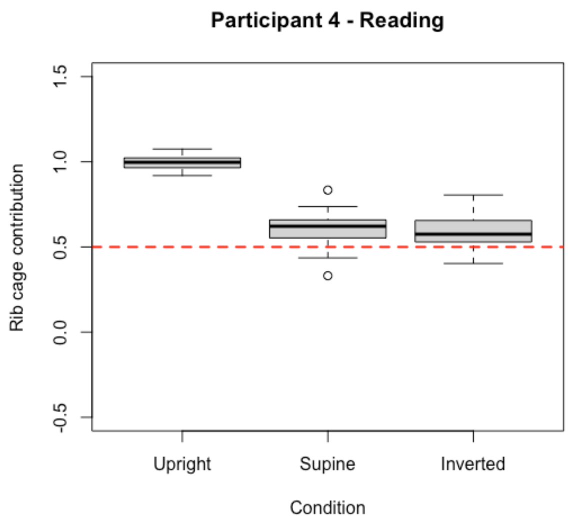

Figure 7. Relative contribution of the rib cage to the sum across all body positions for participant 4.

4.1.5 Syllable repetition

In Figure 8, the results are visualized from the syllable repetition task for all participants across the upright and supine body positional conditions. Since there was only 30 data points in total for all participants, the result is presented based on the entire participant group. There was more relative contribution of the rib cage in the upright position compared to the supine position. Almost 100 percent of the data points from the supine position were above the contribution line, including the middle 50 percent.

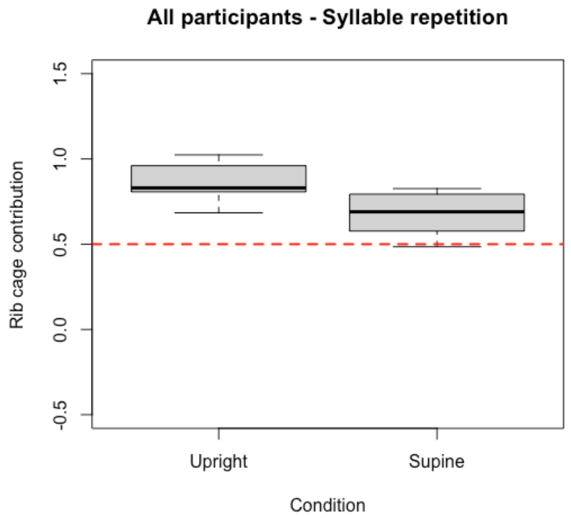

Figure 8. Relative contribution of the rib cage to the sum for all participants in the syllable repetition task across the upright and supine body position.

4.2 Breaths and duration

In order to have an estimate of the breath rate across the body positional conditions, calculations regarding duration, number of breaths and breaths per minute can be seen in Table 2. It contains the total duration of the reading task, including all three texts, as well as the total number of breaths for each body position. Participants 1, 2, 4 and 5 had a small change in duration, at most 4.98 seconds increase between the upright, supine and inverted position. In the case of participant 2 and 5 the duration increased gradually from upright to the inverted position, whereas the differences in duration for participant 1 and 4 was varied across the positions. Participant 3 showed the largest increase in duration with a total of 11.92 seconds in duration that occurred gradually from upright to the inverted position.

The number of breaths were varied across the positions. In the case of participant 1 and 4, the number of breaths were stable across the upright and supine body position with an increase in the inverted position. For participants 2, 3 and 5 the number of breaths does not seem to depend on which body position they were placed in.

Participant	Condition	Duration (s)	Breaths	Breaths per minute
1	Upright	141.8	32	13.5
	Supine	142.8	32	13.4
	Inverted	141.3	39	16.6
2	Upright	157.1	60	22.9
	Supine	158.4	52	19.7
	Inverted	161.6	54	20.0
3	Upright	131.7	37	16.9
	Supine	136.3	33	14.5
	Inverted	143.6	36	15.0
4	Upright	169.2	26	9.2
	Supine	166.5	26	9.4
	Inverted	167.3	28	10.0
5	Upright	125.8	35	16.7
	Supine	127.4	38	17.9
	Inverted	130.8	37	17.0

Table 2. The total duration and number of breaths of the reading task performed by all participants across the upright, supine and inverted body position. The numbers are rounded based on the full-length data point values.

There was not much difference regarding breaths per minute across all participants. Participant 1 had an increase in the inverted position compared to the other positions. Participants 2 and 3 had a small decrease in the supine and inverted position compared to the upright position. Participants 4 and 5 did not have much of a difference between positions.

4.3 α-ratio and SPL

In Table 3, the value of the α-ratio corresponding to spectral tilt and the equivalent SPL at 15 centimeters can be seen across all body positions for each of the participants for the reading task.

Included in the table is also the difference in decibel (dB), regarding the α-ratio, between the three body positional conditions. The α(S) - α(U) measure is the difference between the supine and the upright position, and the α(I) - α(S) measure is the difference between the inverted position and the supine position.

Participant	Condition	SPL at 15 cm distance (dB)	α-ratio (dB)	α(S) - α(U) (dB)	α(I) - α(S) (dB)
1	Upright	72.0	-26.93	0.98	0.00
	Supine	72.1	-25.95		
	Inverted	72.7	-25.95		
2	Upright	73.6	-33.17	1.12	0.62
	Supine	71.9	-32.05		
	Inverted	71.8	-31.43		
3	Upright	73.7	-26.71	-2.55	-0.40
	Supine	74.2	-29.26		
	Inverted	75.0	-29.66		
4	Upright	77.5	-29.95	2.42	0.12
	Supine	76.6	-27.53		
	Inverted	77.3	-27.41		
5	Upright	73.9	-25.82	-1.11	1.51
	Supine	73.0	-26.93		
	Inverted	74.5	-25.43		

Table 3. The results of the α-ratio for the reading task across all body positions for each participant. The numbers are rounded based on the full-length data point values. The values of the α(S) - α(U) and the α(I) - α(S) measures are based on the full-length data point values and rounded after the completed calculations.

4.3.1 α-ratio

Participant 1, 2 and 4 shared a similar pattern where the spectral tilt decreased from upright, supine to inverted position. This means that the α-ratio increased since there was more intensity at higher frequencies. It would suggest that along the voice quality continuum these participants went from a breathier voice in the upright position towards a more pressed voice in the supine. Participants 1 and 4 showed basically no difference between the supine and inverted position. Participant 2 had a further increase in the α-ratio in the inverted position, compared to the supine position, which could mean a slightly further pressed voice.

In contrast, the α-ratio of participant 3 and 5 decreased between the upright and supine position, which means that there was less intensity at higher frequencies and an increase in spectral tilt. It shows that along the voice quality continuum these participants went from a more pressed voice in the upright position towards a more breathy voice in the supine position. Regarding the inverted position, participant 3 showed a further but smaller decrease in the α-ratio, whereas participant 5 had an increase in the α-ratio.

4.3.2 α-ratio dB levels compared with SPL dB levels

Overall for the participants, the difference in SPL between the upright, supine and inverted positions have basically no effect on the dB levels of the α-ratio (where the dB levels of the α-ratio increases resulting in less spectral tilt if the SPL dB levels increase).

Participant 1 had a 0.1 dB increase in the supine position compared to the upright position and a 0.6 dB increase in the inverted position compared to the supine position. There was no change in the α-ratio between the supine and inverted position despite the increase in SPL dB.

Participant 2 had a 1.7 dB decrease in the supine position compared to the upright position and a 0.1 dB decrease in the inverted position compared to the supine position. Despite a decrease in SPL dB the α-ratio increased between the supine and inverted position, as well as compared with the upright position.

Participant 3 had a 0.5 dB increase in the supine position compared to the upright position and a 0.8 dB increase in the inverted position compared to the supine position. The α-ratio decreased between the supine and inverted position, as well as compared with the upright position, despite the increase in SPL dB.

Participant 4 had a 0.9 dB decrease in the supine position compared to the upright position and a 0.7 dB increase in the inverted position compared to the supine position. The α-ratio increased despite the decrease in SPL dB in the supine position compared to the upright position.

Participant 5 had a 0.9 dB decrease in the supine position compared to the upright position and a 1.5 dB increase in the inverted position compared to the supine position. The α-ratio increased 1.51 dB, which means that it increased more than solely based on the increase of 1.5 SPL dB, since that would only increase the α-ratio at the most with 0.66 dB.

5 Discussion

5.1 Results discussion

5.1.1 1. Depending on body position, is there a difference in the relative contribution of the rib cage to speech breathing?

The results of this investigation suggest several interesting possibilities as to how body position affects speech breathing. The body positional conditions had a clear effect regarding the relative contribution of the rib cage to the sum of the total movements of the rib cage and abdomen. There was less relative contribution of the rib cage in the supine body position compared to the upright position. Similarly then to previous studies (Hixon et al., 1973), this means there was more relative contribution of the abdomen in the supine body position compared to the upright position. The results are also similar to the findings of De Troyer (1983), where the inversion caused a divide between the participants with respect to potential abdominal muscle activity.

The differences between the supine and inverted position are where the most differences occurred between the participants. As previously discussed, with increased abdominal muscle activity there is less abdominal movement when speech breathing, since the muscles are not relaxed (Hoit, 1995; Kera et al., 2005; Montes et al., 2017). For the results, this means that participant 1 and 2 (Case 1) were possibly more relaxed in the supine body position and had more muscle activity in the inverted position, which cause less abdominal movement and more relative contribution of the rib cage. This would be in line with the findings of De Troyer (1983) for quiet breathing, where abdominal muscle activity was very low in the supine body position but increased for some participants with the inverted supine position. In simpler words, it is possible that participant 1 and 2 (Case 1) contracted their abdominal muscles in the inverted position, which caused less abdominal movability.

For participants 3 and 5 (Case 2), where the least relative contribution of the rib cage occurred in the inverted position, there are two possibilities to consider. One potential conclusion could be that these participants' abdominal muscles were relaxed in both the supine and inverted position, increasing the abdominal movement even more in the inverted position compared to the supine position. Another potential conclusion is that the participants' abdominal muscles were not completely relaxed in the supine position and became more relaxed instead in the inverted position. Considering that the middle 50 percent of the collected values for the supine body position were above the contribution line, this is a possibility. Especially compared to participants 1 and 2 (Case 1) where the middle 50 percent were below the contribution line in the supine position.

The duration, the number of breaths and breaths per minute were relatively unchanged between the body positions for the reading task, which could suggest that the participants did not have a large variation between how they read the texts across the body positions. It is possible that the intent of each participant, consciously or not, was to read the text similarly to how they performed the task the first time, which was in the upright position, in respect to the duration and number of breaths. This could potentially be due to the same observed behaviour in the study by Winkworth et al. (1994), where breath intake occurrence was influenced by the syntactic structure of the reading material. This would require the participants to compensate by regulating the airflow or with deeper inhalations in the supine and inverted position. However, this was not estimated in this study. In order to actually estimate in what manner the participants read the texts across the body positions, one would have to investigate further into the breathing pattern with regard to breath intake occurrence and lung volume in comparison with the reading of the texts.

5.1.2 2. Depending on body position, is there a difference regarding phonation?

Taking the α-ratio results regarding voice quality into consideration, most of the participants (1, 2, 4) had an increasingly more pressed voice across the body positions, ranging from upright to supine to the inverted position. This could potentially be attributed to the gravitational forces that pushes the abdominal content headwards in a supine (Hoit, 1995) and inverted body position and the gravitationally induced loss of tracheal pull, which could cause more adduction of the vocal folds (Iwarsson et al., 1998). Adduction is associated with a more pressed voice (Gordon & Ladefoged, 2001). This would suggest that similarly to the supine position the inverted position has an impact on tracheal pull.

Even so, two participants had a different pattern. Participant 3 in particular had an increasingly breathy voice across the body positional conditions, ranging from upright to supine to the inverted position. Participant 5 had a similar pattern with the exception of the inverted position.

Overall, the changed voice quality in the supine and inverted position, compared to the upright position, suggest that the participants were not able to compensate completely for the change in body position. Considering the results of Sundberg et al. (1991), where there was no substantial difference in regulation of subglottal pressure in singing between an upright and supine position in classically trained singers, there is potentially more differences found in speech among speakers.

5.1.3 3. Are the patterns regarding relative contribution of the rib cage and phonation patterns related?

There is an interesting possible connection in relation to the different patterns in the relative contribution of the rib cage and phonation patterns. The increasingly breathy voice that could be seen in participant 3 and 5 could potentially be the result of the compensatory behaviour of relaxing the abdominal muscles in order to alleviate elevated subglottal pressure caused by the gravitational pull in the supine and inverted position. Considering that these participants share similar patterns in regards to phonation and patterns regarding the relative contribution of the rib cage across the body positions, it could suggest a different compensatory strategy in comparison with participants 1 and 2 (Case 1). Especially considering that participants 1 and 2 instead had an increasingly more pressed voice across the body positions. However, considering participant 4 (Case 3), it is also possible to not have much difference in regards to the relative contribution of the rib cage and voice quality between a supine and an inverted position.

Although the possible findings of a connection between voice quality and compensatory strategies with respect to the relative contribution of the rib cage are of interest, unfortunately there are several other possible factors that could influence voice quality. It would be necessary to estimate the effect of increased subglottal pressure levels and the degree of adduction independently, which was not estimated in this study. As discussed previously, an increase of subglottal pressure increases the vocal loudness and it has been shown that the spectral tilt is affected by vocal loudness (Sundberg & Nordenberg, 2006, p. 455). However, in relation to the findings of Sundberg & Nordenberg (2006), where the change per 1 dB SPL in the α-ratio was at most 0.44 dB, the equivalent SPL dB comparisons in this study does not seem to affect the α-ratio.

5.2 Method discussion

There was little consideration regarding the participants chosen for this study, since the most important requirement was to find participants that were available, with no pre-existing conditions that were in conflict with potential risks and that were comfortable with the experimental procedure. In hindsight, one could have collected more information about the participants. Age, gender, weight and height is information that was not collected, and therefore is not included within the study. Additionally, it could have been of interest to collect information about exercising habits considering muscle control and fitness. Having more participants would also have been beneficial to the results.

The syllable repetition task was slightly redundant for the present study, since the inverted position was not a body positional condition for the task. The reason that it was not tested was out of consideration for potential participants. Performing VC in the inverted position could potentially cause light-headedness, which is why it was not tested. This might have been an unnecessary precaution.

The angle of the inverted position chosen for the present study was not the same as used by De Troyer (1983), which could make a comparison in result difficult. The choice of setting the inverted position at a -10 degree angle was mainly made in consideration for the potential participants' comfort. It is possible that the angle was not different enough from the supine position to fully estimate a compensatory difference between the positions. However, it is also interesting that the result in the present study did show an effect even in an inverted position that was -10 degrees compared to an inverted position at a -45 degree angle. It is therefore possible that an interval of tilted positions ranging from -10 degrees to -45 degrees would have made the results even more precise. Although, that would have demanded more time than was available for this study.

5.3 Future research

There are several different methods that could be implemented in order to further estimate the reasons behind the results of how body position affects the relative contribution of the rib cage to speech breathing and voice quality. As discussed above, it would be helpful to measure subglottal pressure to determine if the pressure increases in a supine or inverted position in comparison to an upright position. Since increased subglottal pressure is associated with more adduction of the vocal folds it would differentiate results in voice quality even further. It would also help to further examine the differences between the participants regarding the inverted position.

Another method that could be used to further estimate voice quality across the body positional condition is electroglottography (EGG), which is useful when estimating the closed quotient. The closed quotient is how long the duration of the vocal folds are closed. A longer closed quotient is associated with adduction.

In the present study there was no estimation of flow rate with regards to lung volume. By measuring lung volume capacity with a spirometer, one could correspond the amplitudes of the breaths obtained from the RIP-recordings to actual lung volume measured in litres for each participant. One could then have a better grasp on the air volume inspired and expired while performing a speech production task.

6 Conclusion

This thesis investigated the relative contribution of the rib cage across an upright, supine and an inverted body position during speech breathing by using respiratory inductance plethysmography (RIP). Through the usage of an accelerometer voice quality was also estimated throughout the body positional conditions. The α-ratio was used to determine phonation type across the voice quality continuum. SPL was also measured.

The results show a difference in the relative contribution of the rib cage between the body positional conditions. Overall, all participants had the most relative contribution of the rib cage in the upright position, with a decrease in the supine body position. The inverted body position resulted in a divided response between the participants, where some had an increase and others had a decrease in relative contribution of the rib cage compared to the supine position. One participant did not have much difference between the supine and inverted position.

With regards to phonation some had an increasingly breathy voice across the body positional conditions and others had an increasingly more pressed voice across the body positional conditions. One participant showed breathier voice quality in the supine position and a pressed voice quality in the inverted position when compared to the upright position.

In conclusion, the results could suggest a pattern regarding how body position and the relative contribution of the rib cage to speech breathing affects voice quality. The further decreased relative contribution of the rib cage in the inverted position compared to the supine position in relation to an increase in breathier voice quality is interesting, since the opposite was found when the relative contribution of the rib cage increased instead. These findings could be due to untested influences and therefore provide opportunities for future investigations.

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8 Appendix

8.1 Reading task: Texts

8.1.1 *Nordanvinden och solen* (‘The north wind and the sun’)

Nordanvinden och solen tvistade en gång om vem av dem som var starkast. Just då kom en vand-rare vägen fram insvept i en varm kappa. De kom då överens om att den som först kunde få vand-raren att ta av sig kappan, han skulle anses vara starkare än den andra. Då blåste nordanvinden så hårt han nånsin kunde, men ju hårdare han blåste desto tätare svepte vandraren kappan om sig, och till slut gav nordanvinden upp försöket. Då lät solen sina strålar skina helt varmt och genast tog vandraren av sig kappan och så var nordanvinden tvungen att erkänna att solen var den starkaste av de två.

8.1.2 *Ett svårt fall* (‘A difficult fall/case’)

En pojke kom en dag inspringande på en bondgård och undrade, om han kunde få låna en spade. När bonden frågade, vad han skulle ha den till, svarade pojken att hans bror hade ramlat i ett träsk och att han måste gräva upp honom.

- Hur djupt har han ramlat i? frågade bonden.

- Upp till vristerna, blev svaret.

- Men då kan han väl gå därifrån utan din hjälp. Då behöver du väl ingen spade?

Pojken såg förtvivlad ut och sa:

- Jo, men ni förstår, han ramlade i med huvet först.

8.1.3 *Trapetskonstnären* (‘The trapeze artist’)

Cirkusen var i stan. Förtjust tittade jag på affischen med en flygande trapetskonstnär. Morfar böjde sig mot mig:

– Vill du gå på cirkus?

– Får jag det? Tack, tack, tack!

På ängen hade man rest ett enormt tält. Vi var först i kön och fick platserna längst fram. När ljuset dämpades spratt jag till av förväntan. Orkestern spelade upp och föreställningen började.

Nummer efter nummer följde: farliga tigrar, jonglörer, ormmänniskor, strutsar, magiker, svärdslukare, spjutkastare och sjölejon som skvätte vatten på publiken. Höjdpunkten kom när cirkusdirektören presenterade trapetskonstnärens nummer. Utan säkerhetslina skulle hon göra en trippelvolt högt uppe under taket. Hon tog fart och kastade sig ut. Graciöst voltade hon genom luften men när hon greppade den andra trapetsen trodde vi allihop att hon skulle tappa taget. Någon skrek:

– Hon faller!

I sista ögonblicket lyckades hon klamra sig fast. Stort jubel utbröt.

Dagen efter hade cirkusen dragit vidare och ängen var tom. Kvar fanns bara ett minne för livet.

8.2 Experimental information and consent form

Information till forskningspersoner

I det här dokumentet får du information om projektet och vad det innebär för dig att delta i experimentet.

Vad är det för projekt och varför vill ni att jag ska delta?

I studien undersöks hur kroppsposition påverkar andning när man producerar språkljud. Vi är särskilt intresserade av att se vilka skillnader som finns mellan magen och bröstkorgens aktivitet vid stående, liggande och bakåtlutad liggande kroppsposition.

Studien utförs i Fonetiklabbet på Stockholms universitet. Forskningspersonens andning kommer att registreras genom andningsband och bli ljudinspelad genom en mikrofon och en accelerometer (strupmikrofon) i stående, liggande och en bakåtlutad liggande position. För de liggande kroppspositionerna används en ryggbänk. För samtliga kroppspositioner kommer en kalibrering av andningsbanden att genomföras där forskningspersonen andas in, behåller luften och putar med magen, följt av utandning till ett avslappnat läge och maximal inandning från avslappnat läge. Vid inspelningen kommer forskningspersonen att utföra två uppgifter. Den första uppgiften är högläsning av tre korta texter och den andra uppgiften börjar med att forskningspersonen andas in så mycket som möjligt och sedan ljudar en stavelse flera gånger tills luften tar slut. Stavelsen vi tittar på är /pæ:/. Första uppgiften utförs en gång för varje text och den andra uppgiften upprepas tre gånger i stående och liggande kroppsposition. I den bakåtlutade liggande kroppspositionen utförs endast den första uppgiften.

Inspelningstillfället tar cirka 30 min.

Hur fungerar andningsband (Respiratory Inductance Plethysmography)?

Tekniken Respiratory Inductance Plethysmography (RIP) består av två andningsband som spänns över bröstkorg och mage för att analysera andning genom att spela in bröstkorgens och magens rörelse.

Hur fungerar en accelerometer (strupmikrofon)?

Accelerometern är en strupmikrofon som klistras på forskningspersonen med hjälp av en klisterlapp på halsen mellan nyckelbenen (nedanför struphuvudet). Strupmikrofonen registrerar stämbandsvibrationer när forskningspersonen talar och registrerar inga vibrationer när man är tyst.

Vad är en ryggbänk?

Ryggbänken är en vadderad tippbräda som används för den liggande och den bakåtlutade liggande kroppspositionen. Den kan ställas in efter forskningspersonens längd och har ett säkerhetsreglage vid fotleden som forskningspersonen själv kan justera för sin bekvämlighet.

Möjliga följder och risker med att delta i studien

Det kan kännas obekvämt att vara i en bakåtlutad liggande kroppsposition och om det känns för obekvämt kan inspelningen avbrytas omedelbart. Det finns förhöjda risker med användningen av en ryggbänk i en bakåtlutad liggande kroppsposition om du har några av följande tillstånd/sjukdomar:

- Graviditet
- Ögonsjukdom, såsom grön starr eller en ögoninfektion
- Öroninflammation
- Hjärt- och kärlsjukdom
- Andningsproblem
- Balansproblem
- Ryggradsskador
- Benskörhet
- Högt blodtryck
- Förhöjd risk för blodproppsbildning
- Blodcirkulationsproblem

Om du har några av dessa tillstånd/sjukdomar avråds du från att delta i studien.

Vad händer med dina uppgifter?

Projektet kommer att samla in och registrera information om dig:

1. Andningsinspelning med andningsband. Andningsbandens inspelning kommer att användas inom studien för analys.
2. Ljudupptagningar med accelerometer (strupmikrofon) och en vanlig mikrofon.

Strupmikrofonens inspelning kommer att behandlas för analys och inspelningen från den vanliga mikrofonen kommer att användas främst för att sortera relevanta delar av inspelningen och för en mätning av SPL (Sound Pressure Level) som är en ljudnivåsmätning. Analysen av ljudupptagningarna fokuserar på när forskningspersonen ljudar. Eventuella konversationer mellan forskningspersonen och studieledaren som spelas in kommer inte att användas inom studien. Ni har rätt att när som helst och utan vidare förklaringar ta del av informationen eller begära att era personuppgifter tas bort.

Hur studieresultatet kommer att redovisas

Studiens resultat kommer att redovisas skriftligt i en kandidatuppsats och i en muntlig redovisning av en student vid Stockholms universitet.

Deltagandet är frivilligt

Deltagandet är helt frivilligt och du kan när som helst välja att avbryta deltagandet. Om du väljer att inte delta eller vill avbryta ditt deltagande behöver du inte uppge varför och det kommer inte att påverka din relation med Stockholms universitet. Om du vill avbryta ditt deltagande efter inspelningen är klar, ska du kontakta studiesamordnaren.

Medgivande

Med detta formulär ger du ditt medgivande till:

1. Att din andning registreras medan du talar eller är tyst med andningsband.
2. Att du registreras när du talar eller är tyst med strupmikrofon.
3. Att du registreras när du talar eller är tyst med mikrofon.
4. Att alla inspelningar bearbetas av en student vid Stockholms universitet.

Du kan när som helst avbryta ditt deltagande i studien utan att uppge anledning. Detta har inte några konsekvenser för din nuvarande eller framtida relation med Stockholms universitet, Institutionen för lingvistik, eller dess medarbetare.

Jag har läst och förstått ovanstående information, är medveten om riskerna och har inget av tillstånden/sjukdomarna som listas under *Möjliga följder och risker med att delta i studien,* och ger härmed mitt samtycke till att delta i studien.

Underskrift ………………………………………………………………………………

Namnförtydligande ………………………………………………………………………

Ort och Datum ……………………………………………………………………………

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