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A case-study investigation of respiration in operatic singing: An implementation of research design and applications

Katty Kochman, Michiel Demey, Dirk Moelants, and Marc Leman

IPEM (Institute for Psychoacoustics and Electronic Music), Ghent University

Background in Music Performance. Previous research proposes a relationship between respiration and the communicative processes of dramatic expression in operatic singing. Controlled respiration is an essential component in operatic singing, providing the singer with support for a proper production of tone and an important factor in the structuring of melodic phrases. Respiratory regulation relates directly to the effective execution of expressive components of singing performance, including timbral variations, paralinguistic features, and expressive markings such as dynamic variations and messa di voce. While respiration is an automatic process controlled by the respiratory center of the nervous system, the rate, depth and rhythm of breathing can be modified unconsciously by mental emotions or consciously by different breathing patterns. Both processes are nonlinguistic methods with which a singer is able to communicate the expressive musical intention of a vocal composition. As such, they may be used as devices to reveal emotional subtexts and the expressive intentionality of the vocal performance.

Background in Embodied Cognition in Mediation. The theoretical paradigm of embodied music cognition assists systematic musicology research in the understanding of its role in singing. Embodied involvement in music allows performers to interpret and communicate effectively the expressive intentions of a composition to the audience. Furthermore, this theoretical paradigm may provide a better understanding of the subjective experiences and cognitive processes that enrich musical performance.

Aims. The aim was to develop an ecologically valid methodology relating to both conscious and unconscious respiration that could be used to examine the role of embodied cognition in dramatic and expressive vocal performance.

Main Contribution. This paper presents a methodology and the preliminary implementation of an experimental framework through which the effects of respiration on dramatic expressivity may be examined. The underlying theme was to examine the role of embodied music cognition in vocal performance. Since respiration in vocal performance involves both conscious and unconscious processes, the unconscious and conscious thoughts and decisions in vocal performance were considered as factors affecting the dramatic expressivity of a vocal performance. Within this context, ecological research methods were developed and utilized to monitor vocal performance for relevant data and vocal performance analysis. Timing intervals between rehearsal and performance were reliably consistent for the three vocal compositions used in the study. Lung volumes varied significantly for 2 of the 3 vocal pieces performed, and larger variations were observed during the musical climaxes of the compositions. Intensity was higher, while lung expansion was lower for performers in concert settings. Systematic differences were found between respiration patterns in the rehearsal and concert performances.

Implications. Respiration is a communicative tool between a singer and audience members. The findings of the case study showed (1) that singers had strong control over the timing of their inhalations and (2) that there were systematic differences in breath volume between the rehearsal and public performance. The findings should assist in developing a better understanding of the respiratory system when it is used for singing, with implications for vocal pedagogy and performance. Additionally, the research may support previous studies that delineated between innate and learned behaviors during singing performance. As demonstrated by Collyer (2009), different stages of our kinematic strategies may not be subject to direct conscious manipulation. Consequently, behaviors that are not directly manipulated by the singer, or that are perceived to be different from actual kinematic patterns, may lend insight into an individual's recurrent and automatic behavioral patterns within a musical performance.

Keywords: Embodied Music Cognition, Music Performance, Music Communication, Vocal Performance, Audience Interaction, Respiratory Analysis, Operatic Singing

•*Correspondence:* Katty Kochman, IPEM, Universiteit Gent, Blandijnberg 2, Gent, Belgium 9000; tel: +32 (0)9 264 4141 fax: +32 (0)9 264 4143 e-mail: katty.kochman@ugent.be;

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1. Introduction

Respiration is an essential physical function in classical singing. Sound is produced by repetitive compression and decompression of inhaled air above the glottis and through resonance and filtering in the vocal tract. The expressive elements that make classical singing performance interesting (e.g. dynamic changes, timbre variations, paralinguistic features, etc.) are closely linked with the respiratory mechanism (Pettersen and Bjørkøy, 2009; Sundberg, 1994). Recent research has demonstrated that emotional stimulus and expressive markings have an impact on respiratory patterns during singing (Pettersen and Bjørkøy, 2009, Foulds-Elliot, 2000).

The goal of this research was to develop a better understanding of the role of embodied communication in singing performance and to demonstrate methods for the measurement of singing performance, applying theories of corporeal intentionality and performer interaction with audience members in an ecologically valid and tangible context. A case study was used to explore differentiated lung volumes, and to relate these to both the type of piece and audience-performer interaction.

Vocal performance provides a unique context for the application of concepts related to embodied music cognition, as the body functions as both primary initiator and expressive mediator of performance. The singer's respiration can be used as a variable with which to measure and examine embodied expression and the communication of emotional and musical intentions. Respiration can be seen as a measure of corporeal intention and can potentially be used to quantify mutually adaptive behavioral resonances between musicians and audiences, as articulated through the expressive intentions of the singer. This is defined as nonlinguistic, bodily communication that creates shared intention, and which is responsible for the feeling of being unified with other people (Leman, 2008, p. 21).

Based on the concepts of embodied music cognition, this study examines the relationship between respiration and dramatic expressivity in a vocal performance. The presented preliminary results impact future research implementations, which eventually will further our understanding of singing performance with important implications for singing pedagogy. Additionally, this research should serve to extend models of the 'breathing system', integrating performance and expressive functions (Collyer, 2009).

2. Background

In music performance, subjective experience is influenced by bodily mediation. Within this context respiration can provide one means of investigating the relationship between autonomous, internal processes and external, socially mediated processes (Lyon, 1999). Respiration is both under voluntary and involuntary control and can be conditioned by association with affective states. More specifically, respiration is a reflection of, and a way to control, physiological and subjective states, reflecting and influencing interactional rhythms and synchronous behavior within groups. Through embodied interaction, the performer develops an embodied awareness of their subjective state in a relational context. This bodily perception also constitutes the cyclical action-reaction cycle inherent in musical communication (Lyon, 1999; Leman, 2008).

Respiration for classical singing has been found to differ from normal respiration in several significant ways. The respiratory system and performance habits of the singer affect phonation, intensity, acoustic features, and muscular strategies used during singing. Respiration in vocal students has been found to change significantly between study semesters with both increases and decreases in rib cage and abdominal excursions during vocal training (Mendes, et al. 2006). Breathing during singing is characterized by over-pressurizing the air in the lungs. In addition, there is an increase in muscular 'support' in key areas. For example, the intercostal muscles, joining at the ribs, provide inspiratory and expiratory muscular force. The abdominal and diaphragmatic muscles also assist in subglottic pressure regulation. Effective subglottal air pressure regulation results in effective tone production, but also increased expressive capabilities for the singer (Sundberg, 1987). In addition, when singing with a 'supported' tone singers have been found to increase peak airflow and change subglottal pressure in comparison to an 'unsupported' voice (Griffin et al., 1995). Therefore, respiration may be regarded as an important mediator, affecting the performers' phonation, emotion, and interpretation. These valuable components each contribute to the training of the respiratory system, and as a result can be used to systematically monitoring the changes that occur when a singer interacts with an audience.

2.1 Variations in respiration related to expressive intention

As previously mentioned, respiration has been shown to be an important factor, impacting vocal production and performance. Foulds-Elliot (2000) measured Sound Pressure Levels (SPL) and the time taken on inhalation and exhalation when five participants were asked to sing the same pieces with two differentiated performances: technically and as if in a performance. Magnetometers were applied to measure the inclination of the chest and abdomen in combination with a spirometer for the purposes of calibration. Foulds-Elliot found consistent differences between the two conditions: participants demonstrated higher lung volume when asked to sing with an 'emotional connection' (the in-performance condition). When singing technically, participants were also requested to sing with different levels of SPL- technical high (TL), normal (T), and technical soft (TS). The in-performance condition (with emotion) resulted in higher levels of initial lung volume (ILV) than the technical conditions, with an SPL approximately equal to the T task. In some cases, this was related to the change in phrase length, but in others to increased air-flow with little change in duration.

In Collyer's (2009) study of the effect of abdominal kinematic directives on respiratory behavior in female classical singers, participants were found to respond to and maintain behavioral changes as a result of kinematic instructions. Two respiratory strategies were used: abdomen in and abdomen out. These were defined as pulling the abdominal wall inwards or steadily expanding the abdominal wall during each phrase. Five professional singers were monitored with the use of inductance plethysmography. Audio recordings were also made to record SPL during tasks.

Changes in kinematic behavior were observed at the beginning of the musical phrases, but were closer to the habitual respiratory behaviors as the phrase progressed. Rib-cage expansion and lung volume changes were not observed to change as a result of directives. Collyer argued that these findings may indicate delineation between learned and innate respiratory behaviors for classical singers. Singers were able to modify and maintain behavioral changes.

Research by Pettersen and Bjørky (2009) extended the study by Foulds-Elliot (2000) and investigated the effects of emotional stimulus on respiratory patterns involving inter-costal and abdominal muscular activation. Participants were asked to perform vocal tasks consisting of extreme tones (the highest and lowest tone of the singers' vocal range), swell tones, arpeggio, and glissando. Similar to the study by Foulds-Elliot, singers were asked to perform these exercises with emotion and neutrally. This study involved monitoring seven conservatory students with a combination of electrodes placed on the intercostal abdomen, lateral abdomen, and lower lateral abdomen, as well as strain gauge sensors placed on the abdomen, upper thorax and lower thorax. This study found that emotional stimulus resulted in an increased contribution from the lower lateral abdomen, lower thorax and abdomen, as well as less contribution from the anterior abdominal muscles during phonation.

These studies present evidence for the existence of different respiration patterns as a result of variations in expressive intention. However, audience members were not present in the conditions involving expressivity. In addition, the methodologies might be enriched by analyzing pieces in their entirety rather than just phrases or key exercises.

2.2 Embodied music cognition

In order to examine the role of embodied music cognition in vocal performance, it is necessary not only to monitor individual perception, but also the mutual perception of the performer and audience (Baldwin, 1995). Within the context of the current research study, the singer's respiration is one factor hypothesized to be affected by an interaction with audience members during the singer's performance.

This idea can be further illustrated by Leman's (2008) model of musical communication between performer and listeners. According to the theory of embodied music cognition, musicians encode sound through gesture and the body. The listener then decodes this information, which may be processed through corporeal imitation providing feedback for the performer. This cycle of perception contributes to the structure, emotion and cultural significance of the performance.

> The starting point is the performer, who has in mind a musical goal or idea (possibly provided by a composer). This goal is realized as sound energy, using the human body and mediation technology. More specifically, the musical goal is realized through corporeal articulations, whose biomechanical energy is transferred to the music mediation technology (the music instrument). This device in turn translates part of the biomechanical energy of the performer into sound energy, while another part of the biomechanical energy is bounced back as haptic energy (energy related to the sense of touch) (Leman, 2008, p. 160).

Within the context of vocal performance, the singer's musical goal is translated through the corporeal articulations and imitations, and transmitted to other participants through sonic and visual feedback, which then creates behavioral resonances in the audience and feedback for the performer. A performer's intentions can also be filtered through a mediator, such as an instrument, which can also provide feedback to the performer. In the case of vocal performance, the instrumental mediator is the body itself. This concept has the potential to provide unique insights into the processes that underlie action-perception coupling in music performance. In addition, the concept also presents measurement and research design challenges, because delineating between technical and ancillary, and expressive gestures or articulations is difficult.

The objective of the present study was to develop a new method with which to study the communication of emotional content in operatic vocal performance. In developing this method, the study applied basic concepts of embodied music cognition to examine how respiration is related to performance intentionality. Based on a case study, the study focused on how respiration in singing can be utilized by the artist to enhance the emotional intensity of the music and communicate dramatic intention to an audience. The measured data were used to develop a method for studying the relationship between expressivity, respiration, and embodiment in terms of the artistic communication between singer and audience.

3. Method

3.1 Participant

The participants was a professional 34-year-old female singer, who had had over ten years of performance experience and training, and who regularly performed in choirs and as a soloist.

3.2 Procedure

Two experimental conditions were utilized for this case study: a rehearsal without audience and a performance with audience. The participant performed three operatic arias, *Deh vieni non tardar* from *Le Nozze di Figaro* by W.A. Mozart, *O mio babbino caro* from *Gianni Schicci* by G. Puccini, and *Quando m'en vo* from *La Boheme* by G. Puccini, in both the rehearsal and performance settings. It was important to control for confounding variables at an early stage in the research project. Consequently, the accompaniment was prerecorded to hold this variable constant. During the rehearsal condition the researchers exited the performance space and were not visible to the performer. During the performance condition 9 audience members were present. Both rehearsal and performance took place at the lab of the Institute for Psychoacoustics and Electronic Music (IPEM) in Gent, Belgium. The performance space is sufficiently large and resonant (approximately 10x16 meters with 7x7 meters) to successfully monitor small ensemble performances, such as a concert of operatic arias.

3.3 Materials and Equipment

The breathing of the singer was monitored using the commercial MPX5050 sensor from the company Plux. The sensor consists of a band to which an air container is attached of approximately 40 cm length and 2 cm width. The air container is under constant pressure and connected to a membrane with a piezo resistive transducer and monolithic silicon pressure sensor attached. There is a 2.5% maximum error over 0° to 85°C. The band encircles the rib cage and is placed directly below the axila. The placement of the bands was checked between conditions to ensure consistency of procedure.

During breathing, the rib cage expands against the air container resulting in increased/decreased pressure in the sensor corresponding to inhalation and exhalation, respectively. This sensor is digitized by a Wi-Microdig (Infusion Systems). The data are transmitted wirelessly via Bluetooth to a computer running a Max/MSP patch. This patch not only records the data from the sensor to a .txt file, but also records the audio from the singer and the accompaniment. For this purpose an AKG HL577L microphone was used with an AKG DPT700 wireless sender and AKG DSR700 Digital Stationary Receiver connected to an RME Fireface 800 audio card attached to the computer running the Max/MSP patch. This enabled a synchronized readout of both audio and sensor values, which corresponded to the playback of the accompaniment. Finally, the experiment was monitored with a Canon Legra HD video camera. During this case study, monitoring occurred only for intercostal inhalation and exhalation. It is expected that monitoring the abdominal activation will provide additional data in future studies.

4. Analysis and Results

The signal from the respiration sensor was digitized with a Bluetooth Wi-Microdig and sensor values were sent wirelessly to the computer. The digitization returns the raw sensor signal with values between 0 and 1023 (10 bit analog-to-digital convertor – ADC) at a sampling rate of 200Hz, which are analyzed offline. To reduce the sensor artifacts on the raw signal, the data were filtered using a Savitzky-Golay filter with order 3 and a frame size of 51 samples. This polynomial filter has the advantage that it preserves sharp peaks well, without introducing any time delay. The resulting signal is displayed as the top curve in Figure 1. Lower values correspond to lower pressure during exhalation, while higher values correspond to a high pressure due to the expansion of the ribcage against the sensor. Peaks represent points of inhalation, while the exhalation phase during singing is represented by a slow gradual decrease in the signal. In Figure 1 the audio signal of the voice is also displayed as the bottom curve where the amplitude is shifted to a mean value of 300 and scaled to a maximum amplitude of 100 for displaying purposes. The points of inhalation correspond clearly to an absence of audio. The synchronization of both signals is indicated by the vertical dotted lines.

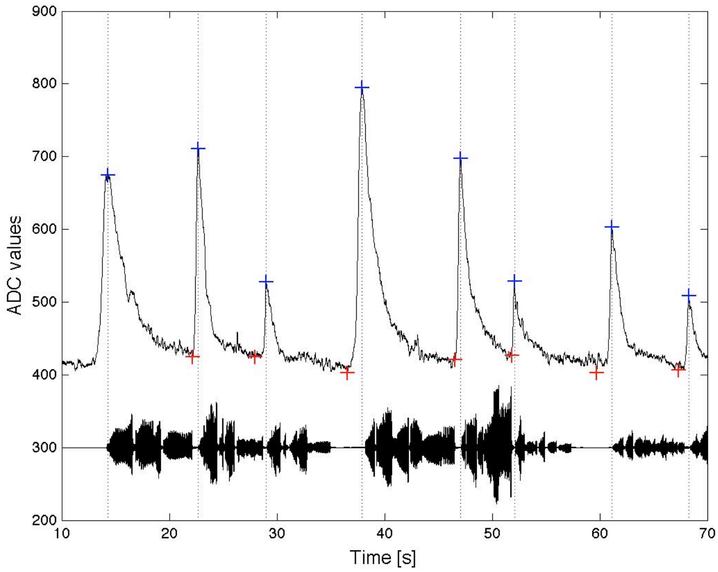

Figure 1. Excerpt of the respiration signal after filtering (top curve), displayed together with the audio of the voice (bottom curve). Markers indicate the maxima and minima for each breath.

A first step in the quantification of the respiratory data from the sensor signal was the determination of the points of maximum inhalation. These were located by applying a peak detection function *findpeaks* in the Matlab software package. The peaks found are indicated with markers in Figure 1. In only one of the three pieces did a difference in the number of peaks occur. As this extra breath occurred during a musical pause, it could confidently be excluded from further analysis as an outlier.

The timing of the remaining peaks was analyzed by calculating the difference in absolute time between the corresponding peaks in the two recordings for the three arias. The results are displayed in Figure 2. This timing was calculated with absolute time, which was facilitated by the fixed accompaniment for both conditions. In only 3 out of 55 breaths was there a timing difference greater than 1 second. These breaths occurred at an interlude, where there was no accompaniment (aria 1, peak 13), or at the beginning of the piece where the timing was not fixed by the accompaniment (aria 3, peak 1). The average absolute difference in timing was 0.226 seconds with a standard deviation of 0.336 for all inhalations, while it was only 0.175 seconds with a standard deviation of 0.207 when the two largest values were excluded.

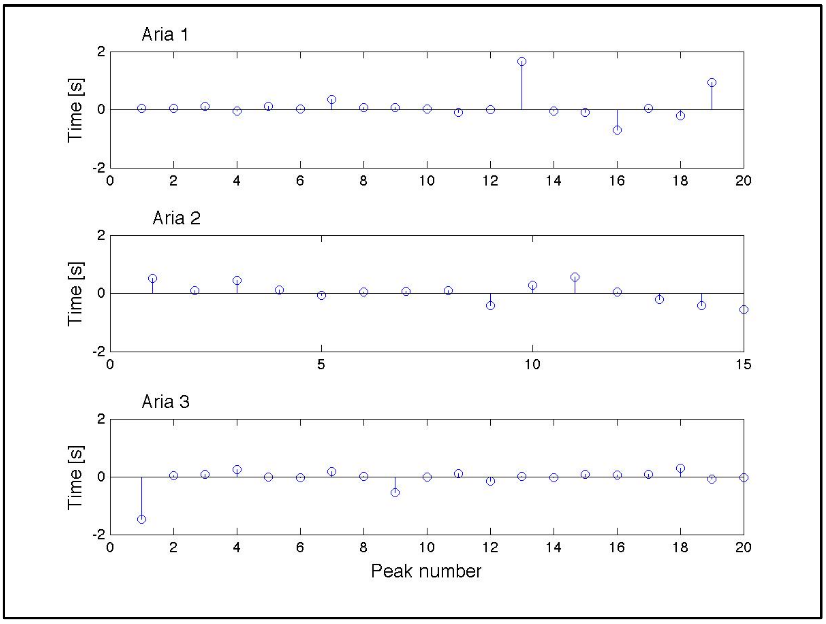

Figure 2. Timing differences of the points of inhalation between the rehearsal and concert recordings for the 3 arias.

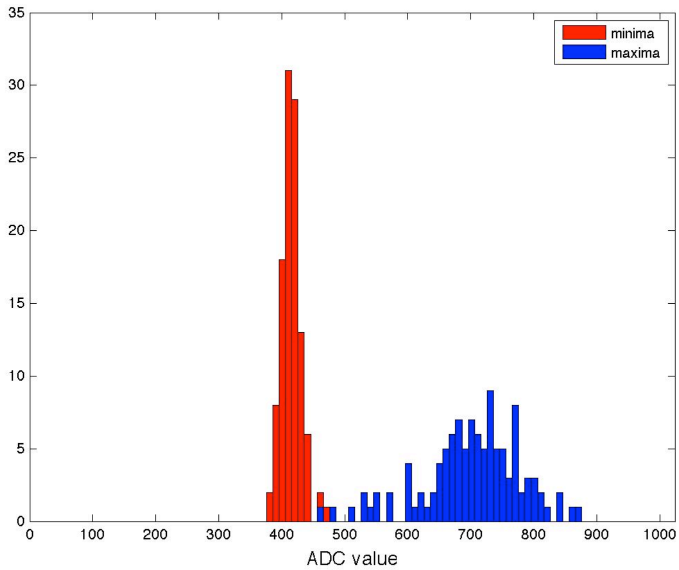

Figure 3. Distribution of ADC values for the peak values, and values of exhalation for all breaths of all 6 songs under study (n=108)

In order to quantify the size of the ribcage expansion, the baseline value was determined representing exhalation values. This baseline value is depended on sensor tension and placement around the ribcage of the subject. In the following analysis the baseline value, as indicated with a red marker in Figure 1, was determined by locating the minimum between two peaks for those data points where the mean envelope of the audio signal was below a threshold of 0.025. This threshold was chosen, so that it represents those parts where singing was absent. When comparing the minima and the maxima in a histogram the results shown in Figure 3 were obtained. From the distribution of the minima (shown in red), we can conclude that there is little variance in the baseline. Note that the bins of the minima corresponding to the highest ADC values correspond to those breaths where there was very little time to breath, and as a result maximal exhalation cannot be reached. The histogram in blue represents the peak values, which indicate a large variance.

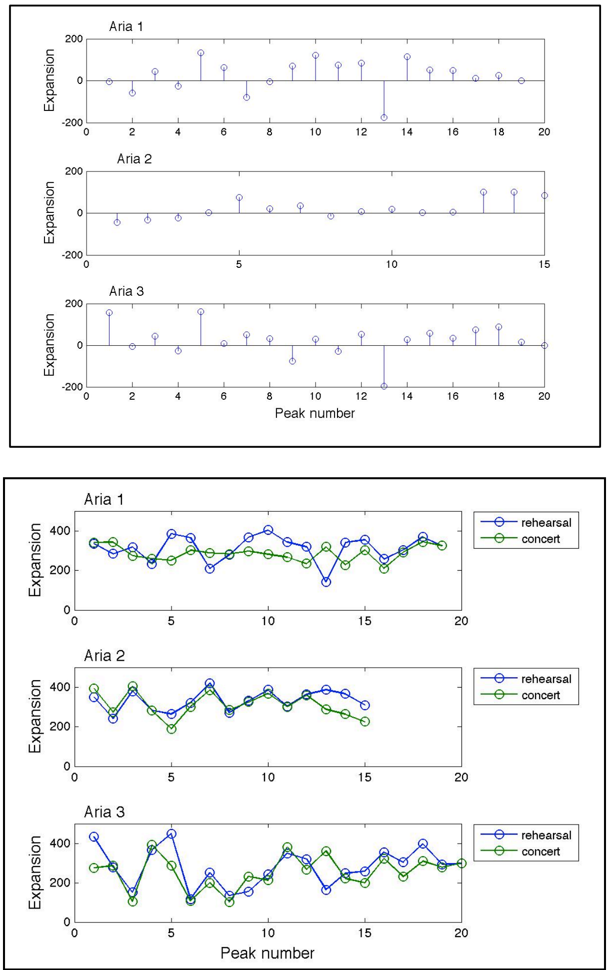

Figure 4. Differences between (top) and overlay of (bottom) measured expansion for each breath in the rehearsal and concert performances of the three arias

Calculating the difference in height between these minima and maxima allowed us to assign values to the expansion of the ribcage for each breath (see Figure 4, bottom).

The differences between these expansion values for each breath in both conditions are displayed in Figure 4 (top). Lung values varied more greatly for arias 1 (*Deh vieni non tardar*) and 3 (*Quando m'en vo*), than for aria 2 (*O mio babbino*). However, for aria 2 variation in lung values were greater for the last three breaths (during the musical climax of the aria). A positive correlation was reported between expansion variation in the concert and rehearsal performances ($r = .57$, n=54, $p < .01$).

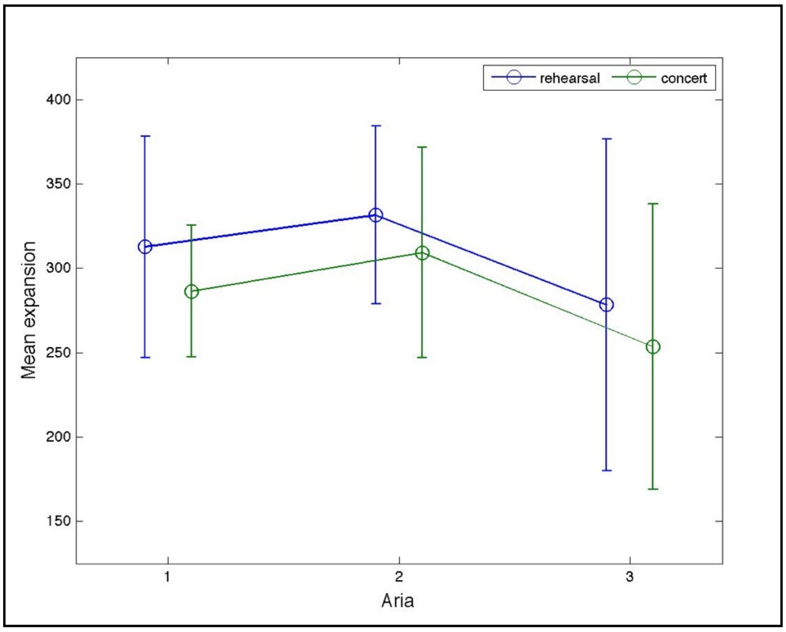

Figure 5. Mean expansion values and standard deviations for the three arias in both conditions

When the mean expansion values of the three arias in the rehearsal are compared to those in the concert condition the results in Figure 5 are obtained. Systematically larger expansion values were observed in the rehearsal compared to the concert condition in all three arias.

To quantify the dynamics of the audio, the Root Mean Square (RMS) value of the amplitude was calculated using the *mirrms* fuction from the MIRtoolbox (Lartillot and Toiviainen, 2007). This function calculates the RMS value for each frame of 50ms with half overlapping[i] of the audio signal. Using these values it was possible to obtain a mean and standard deviation for each song as presented in Figure 6. A Kolmogrov-Smirnov test was conducted and reported that the normality of the distribution could be accepted for rehearsal (*KS*, a =.05, p= 0.534) and concert (*KS*, a =.05, p= 0.823). Here a systematic difference was observed between the rehearsal and concert conditions. However, this difference is opposite of the tendency of the mean expansions shown in Figure 5 for the two conditions.

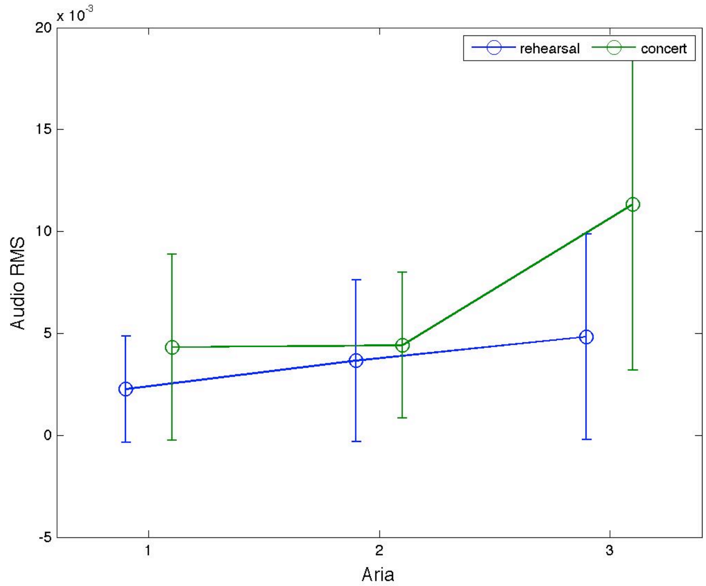

Figure 6. The mean and standard deviation values of the calculated RMS on the envelope of the audio of each song for the rehearsal and concert conditions.

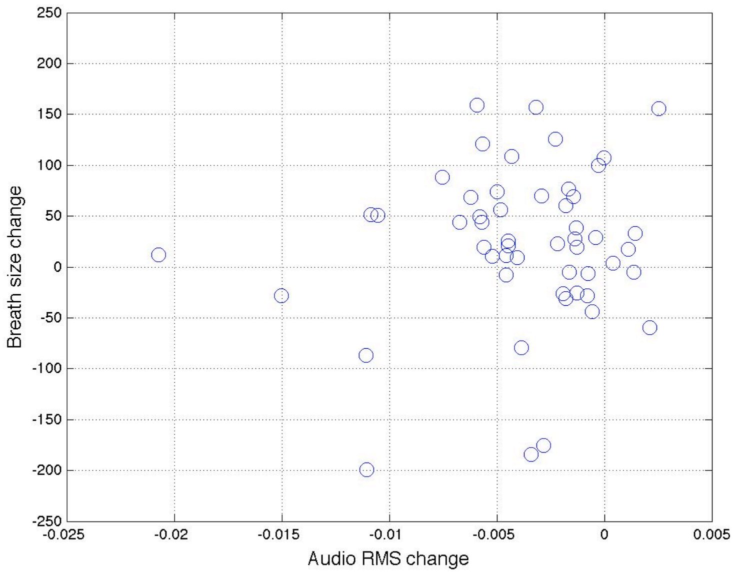

Figure 7. Comparison between audio RMS and breath size in the rehearsal and concert conditions for each breath.

In order to check if there was a correlation between the mean expansion and the RMS value of the audio both values were calculated per breath and are displayed in Figure 7. A significant correlation was not observed between these sets of data in the performances ($r = .117$, $N = 52$, $p = .408$).

5. Discussion

This case study implemented a methodology for the investigation of the role of embodied communication in singing performance, using theories of corporeal intention and performer interaction. These preliminary results will be used for further research development in this area. However, the findings already indicate that there are differences in the respiration patterns for the two experimental settings, which may support the conclusion that the expressive intention of the performer changes as a result of audience interaction. Further tests and increased subject numbers are needed in order to broaden the generalizability of results.

The theory of embodied music cognition maintains that embodied mediation and musical communication is a translation of internal cognitive processes that cannot be fully understood through linguistic description. These processes are commonly studied through performance analysis between a musician and their instrument. However, in vocal performance an additional external mediator does not impede the action reaction cycle that results from the matching of perceptual and behavioral resonances. As demonstrated, audience interaction has a concrete and measurable impact on the vocal instrument of the singer. In this particular case, lung volumes decrease while intensity increased with the presence of audience members. Greater lung volume differences were observed during the musical climaxes of the pieces. These variations are likely to increase if timing is allowed to vary more greatly by using live accompanying musicians

The results of this study demonstrated consistent differences in breathing between the rehearsal and public performance. Notably, the findings of Foulds-Elliot (2000) contrasted with our findings. The research by Foulds-Elliot (2000) would lead one to expect higher lung volumes in the performance condition compared to the rehearsal. In contrast, we found lower lung volumes during the public performance. This may signify that the kinematic strategies utilized by singers may be more varied than previously thought, meriting further investigation. For example, the singer in this particular case used more dramatic pauses and paralinguistic features, such as pausing briefly at the words *la gente sosta e mira* (people stop and stare), when performing with an audience.

Some previous research has found similar patterns. In a study by Mendes et al. (2006), singing students in their 1st and 2nd semesters increased their rib cage expansion and abdominal expansion, but these values decreased in the 2nd and 3rd semester of vocal training. In Mendes's study, these lower lung volumes could not be sufficiently explained. Researchers surmised that increased efficiency during training might be the underlying cause for the unexpected behavior. However, lower lung volumes cannot be explained by more efficient production in this current study, as repeated measures would probably result in additional variations. It would not be logical to conclude that a professional classically-trained singer is consistently inefficient in rehearsal, when the same piece is rehearsed multiple times. However, different singers may utilize different kinematic strategies during performance. For example, the singer in this particular case used more dramatic pauses and paralinguistic features when performing with an audience. Comparisons between singers will allow researchers to confirm the effect of these strategies on respirations. In addition, factors relating to inner cognitive processes, paired with the ability to carefully control embodied processes through years of training and performance, may impact respiration during performance. For example, the singer in our study demonstrated more consistent respiratory patterns before emotionally-charged phrases and musical climaxes in performances with audience, and used more ‘support’ during expressive musical passages. Finally, additional devices used to measure respiration are not commonly used by singers. It may be informative to undertake studies longitudinally to assess whether comfort and familiarity with measurement devices has an impact. This singer is also of particular interest as a case study due to her particular kinematic strategies. Inspiration altered with the intention to communicate – overall, volumes lowered, while SPL actually increased in this particular case. Professional singers have a highly trained and developed respiratory mechanism and can describe in detail the technique used for effective performance. However, they maybe unaware of the specific changes that occur during performance. In this particular case, variations occurred during emotive passages; for example, the idea of happiness expressed by the work *felice* (happy). In future work, particular emotions could be combined with audience reactions to further investigate their effect on respiration.

The impact of audience interaction on performance is observed through the use of methodologies integrating the monitoring the embodied attunement of the performer (Leman, 2008). Effective quantitative methodologies to monitor the mirroring of these processes in audience members are still in development. The observations derived from this vocal performance may imply that respiration was not only used to support appropriate vocal production, but also served to align the performer and audience, in a process of embodied attunement. This process could involve additional cognitive operations between the consciously controlled aspects of vocal technique and innate respiratory actions used for the communication of intent in vocal performance. Variations in respiratory activity seemed to reflect the expressiveness of previous passages. In addition, respiration could reflect communicative planning based on the expressive intentions of the piece.

Future work will focus on implementing the same experimental methodology with larger subject populations. Additional data should result in more information regarding the kinematic strategies used in performance and show how specifically respiration changes are related to the presence of audience members. With respect to additional performers and how effectively expressive content is communicated, listener ratings and professional evaluations could be used to obtain information regarding audience perceptions.

6. Conclusion

The experimental method and results presented in this research allow researchers to investigate the role of embodied communication in singing performance, as translated through corporeal intentions and performer interaction. The study highlighted the role of performer-audience communication and its impact on the instrumental mediator of the singer. Awareness of the multiple kinematic strategies available and the impact of interpersonal communication may have implications for effective vocal pedagogy and performance. The experimental setup involved monitoring respiration values during vocal performance in rehearsal and performance conditions. The features that were extracted from signal analysis demonstrated significant differences in lung volumes in all three pieces for the 2 conditions, indicating smaller expansion values used in performance. Audio analysis of the pieces found higher RMS values with lower expansion. The findings of this study have implications in vocal pedagogy and performance training. Technically, classical singers are trained in respiratory production in order to efficiently develop their 'natural' instrument and to maintain good tone, phrasing and expression. However, a comprehensive understanding of embodied communicative functions resulting from audience and performer interaction is so far lacking.

An objective of the current research project is to further delineate the role of embodiment and respiration as an expressive tool in classical singing performance. This involves further investigating respiration as a communicative tool in vocal performance both between audience members and other musicians. In addition, strategies to assist in monitoring audiences' reactions with respect to respiration and embodied communication in singing performance are still in development. Further research has the potential to provide a better understanding of effective embodied strategies for meaning construction in musical performance, as well as their physical implications for vocal production.

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[i] overlapping refers to the process of shifting the next window after 50% of the previous window has elapsed

Biographies

Katty Kochman is a PhD student at the Institute of Psychoacoustic and Electronic Music (IPEM). Her research incorporates the development ecological models for the study of vocal performance and embodied cognition in music. She holds an M.A. in Music and is experienced in performing operatic repertoire. She has also earned an M.S. in Education, with a background in behavioral analysis and therapy.

Michiel Demey holds a PhD in physics at the University of Amsterdam. His focus is on movement sensing and capturing systems, real-time platforms related to multimodal data acquisition and the analysis of motion and biosensor signals.

Dirk Moelants holds a PhD in musicology from Ghent University, with a thesis on rhythm perception. He specializes in ethnomusicological aspects of music perception and performance, based on psychological experiments related to beat and rhythm.

Marc Leman holds a PhD in musicology from Ghent University, with a thesis on computer modeling of tonal semantics. His focus is on the methodological and epistemological foundations of (social) embodied music cognition. He is currently Director of the Institute of Psychoaccoustics and Electronic Music, Ghent University. He also serves as Head of the Department of Art, Music, and Theater Studies (Faculty of Letters and Philosophy) and is currently a Research-Professor in Systematic Musicology.