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ARTICLES

Respiratory physiology during reading aloud tasks

Fisiología de la respiración en las tareas de lectura en voz alta

Fisiologia respiratória durante tarefas de leitura em voz alta

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Abstract

Objective: The purpose of this study was to determine the relation between speech utterance length and respiratory physiology. This experiment correlates respiratory kinematics, muscle activity and acoustic temporal measures of two utterance lengths read aloud tasks: phrase and sentence. **Methods:** 4 normal speakers read aloud 12 read phrases and 12 read sentences. Respiratory kinematics measures included lung volume excursion (LVE), rib cage excursion (RCE) and abdomen excursion (ABE). Respiratory muscle action included burst duration (BD) and peak amplitude (PA) of rectus abdominis (RA), pectoralis major (PM) and external oblique (EO) muscles. Acoustic temporal measures included phrase and sentence duration. For descriptive statistics means and standard deviations were used, and for inferential statistics Pearson correlation coefficient and Mann-Whitney Wilcoxon test were used. **Results:** All sentence mean values were greater than phrase and significance was achieved on duration, LVE and RCE means

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To Hixon, for his knowledge and contribution to respiration in speech and singing field.

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(*p*=.00). There was a positive correlation between duration, RCE and LVE measures (*p*=.00). There was a positive correlation between RCE and PA of PM and EO muscles (*p*=.00). **Conclusions:** To produce longer utterance tasks, RCE contributes greatly for the LVE needs. The RCE excursions are mostly supported by greater voluntary peak contractions of the PA and EO muscles rather than RA muscles.

Keywords: Phonation; Respiration; Biomechanical phenomena; Acoustic temporal measures; Electromyography.

Resumo

Objetivo: O objetivo deste estudo foi determinar a relação entre a duração da produção de fala e a fisiologia respiratória. Este estudo correlaciona a cinemática respiratória, a atividade muscular e a medida acústico-temporal de duas tarefas fonatórias de leitura-em-voz-alta de diferentes durações: oração e frase. **Métodos:** 4 normofalantes leram em voz alta 12 orações e 12 frases. Medidas cinemáticas respiratórias incluíram expansão do volume pulmonar (EVP), expansão da caixa torácica (ECT) e expansão do abdómen (EAB). A ação muscular respiratória incluiu a duração da contração (DC) e pico de amplitude da contração (AP) dos músculos reto abdominal (RA), peitoral maior (PM) e oblíquo externo (OE). Medidas acústico-temporais incluíram duração da oração e da frase. Para uma estatística descritiva foram utilizadas médias e desvios-padrão. Para a estatística inferencial foi utilizado o coeficiente de correlação de *Pearson* e o teste de *Mann-WhitneyWilcoxon*. **Resultados:** Todas as médias das medidas da frase foram maiores do que das orações, sendo que as médias de duração, EVP e ECT atingiram significância (*p*=.00). As medidas de EVP e ECT correlacionaram-se positivamente (*p*=.00). As medidas de ECT correlacionaram-se positivamente com PA dos músculos PM e OE (*p*=.00). **Conclusão:** As tarefas fonatórias mais longas apresentaram maiores amplitudes de EVP e com maiores contribuições de ECT, comparativamente com as de EAB. Por último, as amplitudes de ECT foram suportadas pelos músculos PA e OE, que apresentaram contrações significativamente mais longas e intensas, comparativamente com o RA.

Palavras-chave: Fonação; Respiração; Fenómenos biomecânicos; Medidas acústico-temporais; Eletromiografia.

Resumen

Objetivo: Se buscó determinar la relación entre la duración de producción del habla y la fisiología respiratoria. Este estudio correlaciona la cinemática de la respiración, la actividad muscular y la medida acústico temporal de dos tareas de fonación de lectura en voz alta: oración y frase. **Métodos:** Cuatro hablantes normales leyeron doce frases y doce oraciones. Las medidas cinemáticas respiratorias incluían: expansión de volumen pulmonar (EVP), expansión de caja torácica (ECT) y expansión de abdomen (EAB). La acción de los músculos respiratorios incluyó la duración de la contracción (DC) y el pico de amplitud de la contracción (AP) de los músculos del recto abdominal (RA), los pectorales mayores (PM) y el oblicuo externo (OE). Las medidas acústico temporales incluyeron la duración de la oración y de la frase. Para la estadística descriptiva se utilizó desviaciones media y estándar, y para la inferencial se usó el coeficiente de correlación de Pearson y la prueba de Mann-Whitney Wilcoxon. **Resultados:** Todos los valores medios de las frases fueron mayores que los de las oraciones; las medias de duración EVP y ECT alcanzaron significancia (p = .00). Las medidas de ECT se correlacionaron positivamente con el AP de los músculos PM y OE (p = .00). **Conclusión:** Las tareas de fonación más largas presentaron mayores amplitudes EVP y mayores contribuciones de ECT, comparado a la EAB. Finalmente, las amplitudes de ECT fueron soportadas por los músculos de AP y OE, que presentaron contracciones significativamente más largas e intensas, comparados con los músculos del RA.

Palabras clave: Fonación; Respiración; Fenómenos biomecánicos; Medidas acústico temporales; Electromiografía.

Introduction

Breathing is essential for speech production. Chest wall and abdomen muscles contribute to changes of lung volume and consequently in lung/subglottal air pressure[1]. Subglottal pressure control plays an important role in the variation of intensity/loudness, frequency/pitch, segment duration, intonation and stress syllables in speech[2,3,4,5].

Respiratory kinematics is used to study chest and abdomen wall motions[6,7,8,9,10,11]. Lung volume variation is achieved through combined movements of chest wall and abdomen as the displacements of the rib cage and abdomen are linearly related to lung volume displacement. It is possible to provide an estimation of the rib cage and abdominal volumes from measurements of the displacements of their respective surfaces. When the upper airway or larynx is closed, any change in the volume of one part of the chest wall is equal and opposite of the other part. Closed airway permits a constant volume to be displaced between the rib cage and abdomen[6,8,12].

Electromyography (EMG) studies have been useful in understanding the relationship between the acoustic signal, respiratory muscle activity, subglottal air pressure and lung volume changes during speech[13]. Three respiratory muscle groups were studied: pectoralis major (PM), rectus abdominis (RA) and external oblique (EO). These muscles were chosen due to their anatomic position and their easy access to electrode placement. PM is an inspiratory muscle that increases thoracic volume. RA is an expiratory muscle. It significantly increases abdominal pressure and increases thoracic pressure, which forces air out. EO muscles are expiratory muscles. The abdominal influence for breathing comes considerably from these muscles, along with internal obliques[4,5]. The measures burst duration and peak amplitude of burst, represent the contraction duration and the maximum voluntary contraction effort, respectively.

Few authors have tried to address the relation between acoustic temporal measures and respiratory physiology. Hoit, Solomon and Hixon (1993) have demonstrated that Voice Onset Time (VOT) was influenced by respiratory physiology, being longer at high lung volume excursions (LVE) and shorter at low LVE. Concerning acoustic temporal measure duration, there was a significant positive relationship between utterance length and respiratory behavior[15,16,17,18,19,20,21]. Inspiratory and expiratory muscular forces were higher for longer sentences than for shorter ones. As the demanding levels and lengths of the phonatory tasks increase, LVE, rib cage excursion (RCE) and abdomen excursion (ABE) increased, too[15,16,17,20,21]. On the other hand, during sentence production the correlation between ABE and duration was less evident[15]. In addition, Rosenthal, Lowell and Colton (2014) demonstrated that maximal effort tasks presented higher airflows compared with comfortable effort tasks. It appears that respiratory physiology adapts to effort task, leading to an increase of subglottal pressure and, consequently, of airflow for longer productions. This may indicate that, for read sentence, there is a greater need of respiratory muscle forces than for read phrase.

This investigation intends to complement the above studies, by bringing evidence to a better understand of the relation between utterance duration (phrase vs. sentence) and breathing behavior. Correlation between respiratory physiology and acoustic temporal measure duration was analyzed, specifically between respiratory kinematics and EMG measures, during read aloud phrase and sentence. The purpose was to identify the muscles and respiratory kinematics movements that most influence the length of each task. The secondary objective was to analyze the relation between respiratory kinematics and EMG measures for production of two read aloud tasks. This will help voice care professionals to assess treatment, since management of the muscles and respiratory kinematics changes are essential to a better duration adequation of phrase vs sentence, for optimum vocal performance, in both healthy and disordered speakers.

The research questions were:

- How does the respiratory system behave during the production of two different duration speaking tasks, specifically read aloud phrase and sentence?
- Is there a correlation between respiratory physiology and acoustic temporal duration measures of the two read aloud tasks?
- Is there a correlation between respiratory kinematics and EMG measures during the two read aloud tasks?

Method

Subjects

Four subjects participated in this study, with ages between 18 and 20 years. They were recruited from an undergraduate voice students population enrolled in Western Voice Studio classes at the University of Florida's Music Department. Inclusion criteria for subject selection were: 1) ages between 17 and 25 years; 2) native American-English speakers with normal articulation, voice, resonance, language and hearing abilities as judged by a certified and licensed speech-language pathologist; 3) no history of respiratory or voice disorders; and 4) symptom-free of allergies or colds on the days of recording. Exclusion criteria were: 1) smokers; and 2) professional singing experience.

Procedures

All subjects read three times a modified version of the "Rainbow Passage"[22]. Respiratory physiological and acoustic measures were extracted from the phrase ("God shed his grace on thee") and one sentence ("People look but no one ever finds it unless God shed his grace on thee"). Subjects were instructed to use a comfortable loudness, pitch, speaking rate and respiration pattern during speech tasks. At the end there were 24 productions, 12 from read phrase task and 12 from read sentence task.

Samples were recorded in a quiet environment at the Laryngeal Function Laboratory of the Institute for the Advanced Study of the Communication Processes (IASCP) at the University of Florida (noise level <50 dB). Each participant performed the tasks in a standing position. Acoustic, respiratory kinematic and EMG measurements were obtained simultaneously.

Acoustic analysis

Acoustic analysis included temporal measures duration of phrase and sentence, extracted in seconds. Acoustic waveforms were displayed using Computerized Speech Lab (CSL) Model 4300B (CSL, Kay Elemetrics Corp.), CSL's Multi-Dimensional Voice profile (MDVP) software. Samples were digitized at a rate of 25.0 kHz. An anti-aliasing rectangular filter with a cutoff frequency of 5 kHz was used before digitization[23,24]. Spectral measurements were obtained using a CSL Model 4300B coupled to a Pentium 166 MHz computer.

For calibration of SPL, a 500 Hz tone of 80 dB SPL with a 2 cm distance from sound source to microphone was recorded onto each audiotape. Prior to measuring each subject's productions, calibration tone was digitized and served as a reference tone calculated by CSL Model 4300B.

Respiratory kinematic analysis

Respiratory kinematics measures extracted included: LVE in liters (l); RCE in centimeters (cm) and ABE in centimeters (cm). Respiratory function was sensed with linearized magnetometers (GMG Scientific, Inc., Burlington, MA) following the procedures developed by Konno and Mead (1967), Hixon, Goldman and Mead (1973, 1976) and Hixon (1973). Two pairs of magnetometers were used, each pair consisting of a generator and a sensor. One pair was placed mid-sternum to sense anteroposterior diameter changes of the rib cage. The other pair was placed 1 cm above the umbilicus for sensing anteroposterior diameter changes of the abdominal wall. All signals from the magnetometers were monitored on a storage oscilloscope (Texttronix 5111A). Signals were recorded to digital VHS tapes using a Sony SLV-750 HF data recorder coupled to a Vetter Digital model 3000A or using a Sony SLV-390 data recorder coupled to an eight-channel CRC (Instruteck, model VR 100b)[10].

Magnetometers converted displacements associated with anteroposterior movements of the chest wall into a voltage output. For calibration of the voltage change produced by the magnetometers into a distance change, a calibration routine was completed after each experimental session. Each pair of magnetometers was attached with double--sided tape to plastic plates. Transmitter's plate was placed into a slotted rule at 0 cm position and kept stationary throughout the calibration procedure. Sensor magnetometer's plate was placed away from the transmitter and then was moved up and down the rule at 2 cm increments. Voltage signal produced by the magnetometers was recorded, digitized and used as a reference[25]. Linearity of the calibration was computed using an automated software algorithm program within CSpeech 4.0[10,26].

All measures from the linearized magnetometers were normalized for each subject's body size by asking them to perform maximum capacity maneuvers for lung volume, rib cage and abdomen. Maneuvers were performed three times each by the subject. The purpose was to establish consistent and reliable calibration measurements as well as to enable inferences about muscle force generation. The maneuvers included vital capacity/maximum rib cage capacity maneuvers, resting breathing, isovolume maneuvers, maximum abdominal capacity maneuvers and relaxation maneuvers[10,12].

Vital capacity/maximum rib cage capacity maneuvers were taken. Each subject wore a nose clip and was instructed to breathe through a mouthpiece coupled to a spirometer. From resting expiratory level, each subject inspired to total lung capacity (TLC) and expired to residual volume (RV). Three trials were performed. The largest volume expired was taken as the vital capacity. The maximum and minimum excursions defined the limits of both lung (liters) and rib cage volume (displacement). Zero percent represented the minimum lung displacement in liters and rib cage excursion in centimeters. 100% represented the maximum lung (liters) and rib cage excursion (cm)[7]. Records of rest breathing were made while subjects breathed quietly for a minute after each vital capacity maneuver without equipment at the airway opening[7,10].

Isovolume maneuvers were done at resting expiratory level (REL). Each subject was instructed to alternately contract and relax abdominal muscles with the glottis closed. This displaced volume back and forth between the rib cage and abdomen at a constant lung volume[10].

Maximum abdominal capacity maneuvers were also completed at REL against a closed glottis. It included a maximum inward and outward displacement of the abdominal wall. The maximum inward displacement represents 0% of the abdominal capacity and the maximum outward displacement represents 100% of the abdominal capacity[7,10,27].

Relaxation maneuvers were performed at resting expiratory level against a closed airway. The subject was instructed to close the glottis and relax the rib cage an abdominal musculature. The resultant relaxation volume was used as a reference point, or an arbitrary zero percent point. Each initiation/termination value is positive or negative depending on whether it is higher or lower than the relaxation reference volume. For example, a positive initiation value suggests that muscular pressure was developed in an inspiratory direction[10,12].

Samples were digitized at a sampling rate of 10 kHz. Respiratory measures of lung, rib cage and abdominal volumes were made with CSpeech and a Pentium 200 MHz computer equipped with a Data Translation analog-to-digital signal processing board (DT 2839)[10].

Electromyographic analysis

EMG signals included peak amplitude of burst (PA), in volts (V), and burst duration (BD) in milliseconds (ms) of the PM, RA and EO muscles. Data was collected with bipolar surface electrodes (NDM Infant ECG Surface Electrodes Item 01-5810) attached to the skin. All EMG signals were obtained using a Regulated Power Supply Grass RPS 107. Signals were filtered at 100-3 kHz and amplification gain was set at x1000. The EMG signals were monitored on a computer screen using CSpeech 4.0. They were recorded onto digital VHS tapes using a Sony SLV-750 HF data recorder coupled to a Vetter Digital model 3000A or using a Sony SLV-390 data recorder coupled to an eight--channel CRC (Instruteck, model VR 100b)[10].

Subjects were asked to perform activation gestures in order to ensure that muscle activity was being sampled from the correct muscle group. At the end of each experimental session a 500µV signal was recorded for calibration purposes. EMG signals were analyzed with CSpeech 4.0[10].

Statistical analysis

Descriptive statistics included means and standard deviations (SD) of acoustic temporal measures, respiratory kinematics and muscle activity measures, for read phrase and read sentence tasks.

Inferential statistics included Mann-Whitney Wilcoxon test to compare read phrase and sentence tasks, in concern to duration, respiratory kinematics and EMG measures. Alpha level was .05.Pearson correlation coefficient was used to correlate acoustic, EMG and respiratory kinematic measures.

Results

Descriptive statistics means and SD of all acoustic temporal measures and respiratory physiological measures of read phrase and read sentence tasks are summarized in tables 1 and 2.

Inferential statistics data are contained in tables 3 and 4.

Table 1. Acoustic duration measures and respiratory physiological measures (respiratory kinematics and electromyiography): subjects data for read phrases

Phrases	Acoustics	Respiratory Kinematics			Eletromyography					
					PA (V)			BD (ms)		
	Duration (s)	RCE (cm)	ABE (cm)	LVE (l)	PM	RA	EO	PM	RA	EO
1	1.38	0.09	0.05	0.21	0.26	0.23	0.27	87.1	120.3	115.9
2	1.60	0.22	0.82	0.21	0.43	0.91	0.42	49.3	111.9	62.7
3	1.60	0.14	0.17	0.37	0.47	--	0.62	90.5	--	110.7
4	1.39	0.13	0.03	0.1	0.57	0.22	0.35	178.3	84.7	159.5
5	1.36	0.2	0.07	0.15	0.60	1.56	0.8	95.1	70.5	109.5
6	1.30	0.29	0.28	0.19	0.49	--	0.25	93.3	--	56.1
7	1.36	0.33	0.05	0.37	0.26	0.14	0.2	71.3	71.9	254.7
8	1.34	0.57	0.04	0.29	0.69	0.41	1.6	87.7	87.7	64.1
9	1.43	0.24	0.03	0.17	0.27	0.27	0.73	104.3	102.9	69.1
10	1.47	0.06	0.09	0.1	0.17	0.68	0.32	282.7	316.6	124.3
11	1.59	0.12	0.06	0.08	0.36	0.4	0.47	91.5	63.5	63.5
12	1.39	0.11	0.10	0.18	0.36	0.70	--	1121.9	575.1	--
Mean	1.43	0.21	0.15	0.20	0.41	0.55	0.55	196.08	160.51	108.19
SD	0.11	0.14	0.22	0.1	0.16	0.43	0.40	298.02	163.29	58.89

-- No data available. RCE – ribcage excursion; ABE – abdominal excursion; LVE – lung volume excursion; PA – peak amplitude; BD – burst duration; PM- pectoralis major; RA – rectus abdominis; EO – external oblique.

Table 2. Acoustic duration measures and respiratory physiological measures, respiratory kinematics and electromyiography: subjects data for read sentences

Sentences	Acoustics (s)	Respiratory Kinematics (cm)			Eletromyography					
					PA (V)			BD (ms)		
	Duration	RCE (cm)	ABE (cm)	LVE (l)	PM	RA	EO	PM	RA	EO
1	3.75	0.3	0.23	0.79	0.26	0.24	0.26	135.1	103.9	455.1
2	3.54	0.44	2.17	0.42	0.46	0.91	0.43	73.5	192.7	84.7
3	3.57	0.3	0.47	0.91	0.47	--	0.59	81.9	--	97.1
4	3.31	0.95	0.04	0.63	0.57	0.23	0.37	178.3	84.7	75.1
5	3.34	0.59	0.19	0.45	0.6	1.60	0.80	101.5	70.5	125.1
6	3.57	0.59	0.6	0.4	0.57	--	0.34	66.9	--	171.9
7	3.12	0.52	0.07	0.57	0.28	0.15	0.24	71.1	88.7	265.1
8	3.10	1.19	0.02	0.56	1.71	1.05	4.23	129.9	77.9	77.9
9	3.56	06	0.06	0.42	0.29	0.4	0.74	396.7	122.3	91.9
10	3.72	0.43	0.14	0.37	0.35	0.68	0.31	75.9	309.7	265.1
11	3.73	0.68	0.01	0.31	0.36	0.41	0.51	70.7	110.7	70.7
12	3.73	0.4	0.09	0.44	0.35	0.82	--	2169.1	540.7	--
Mean	3.50	0.58	0.34	0.52	0.52	0.65	0.80	295.88	170.18	161.79
SD	0.23	0.26	0.61	0.18	0.39	0.46	1.15	597.07	149.03	121.12

-- No data available. RCE – ribcage excursion; ABE – abdominal excursion; LVE – lung volume excursion; PA – peak amplitude; BD – burst duration; PM- pectoralis major; RA – rectus abdominis; EO – external oblique.

Table 3. Comparison between read phrase and read sentence tasks, concerning acoustic duration measures and respiratory physiological measures

		Phrase		Sentence		
		Mean	**SD**	**Mean**	**SD**	**p-value**
Duration		1.43	.11	3.5	.23	.00
Respiratory Kinematics						
RCE		.21	.14	.58	.26	.00
ABE		.15	.22	.34	.61	.48
LVE		.20	.1	.52	0.18	.00
	EMG					
PA	PM	.41	.16	.52	.39	.71
	RA	.55	.46	.65	.46	.53
	EO	.55	.40	.80	1.15	.75
BD	PM	196.08	298.02	295.88	597.07	.8
	RA	160.51	163.29	170.18	149.03	.58
	EO	108.19	58.89	161.79	121.12	.17

Mann – Whitney – Test; ($p<.05$);EMG – electromyography; RCE – ribcage excursion; ABE – abdominal excursion; LVE – lung volume excursion; PA – peak amplitude; BD – burst duration; PM- pectoralis major; RA – rectus abdominis; EO – external oblique.

Table 4. Correlation between respiratory physiological measures

Temporal		**Respiratory Kinematics**	**Correlation**	**p-value**
Duration		RCE	.61	.00
		ABE	.11	.61
		LVE	.74	.00
Temporal		**EMG**	**Correlation**	**p-value**
Duration	PA	PM	.11	.63
		RA	.06	.80
		EO	.09	.7
	BD	PM	.17	.45
		RA	.08	.74
		EO	.35	.13
Respiratory		**EMG**	**Correlation**	**p-value**
RCE	PA	PM	.66	.00
		RA	.11	.65
		EO	.62	.00
	BD	PM	-.07	.76
		RA	-.26	.28
		EO	-.11	.63
Respiratory		**EMG**	**Correlation**	**p-value**
ABE	PA	PM	-.18	.93
		RA	.25	.29
		EO	-15	.51
	BD	PM	-.14	.53
		RA	-.04	.88
		EO	-.11	.63
Respiratory		**EMG**	**Correlation**	**p-value**
LVE	PA	PM	.19	.38
		RA	-.09	.72
		EO	.15	.5
	BD	PM	-.16	.94
		RA	-.12	.61
		EO	.41	.06

Pearson correlation coefficient; ($p<.05$); EMG – electromyography; RCE – ribcage excursion; ABE – abdominal excursion; LVE – lung volume excursion; PA – peak amplitude; BD – burst duration; PM- pectoralis major; RA – rectus abdominis; EO – external oblique.

The mean duration of the read aloud sentence was more than double that the phrase, 3.5 and 1.43 sec., respectively. This difference was significant with $p = .00$.

All physiological means, i.e., kinematics and EMG measures, taken from read aloud sentence tasks were greater than the measures taken from read aloud phrase tasks.

For respiratory kinematics measures, RCE, ABE and LVE means of sentence task were more than double than phrase task. RCE and LVE means of sentence task were significantly greater than the phrase task ($p = .00$). ABE of read sentence was slightly higher than read phrase (See Table 3).

For EMG measures, BD and PA of the PM, RA and EO muscles were always greater for the read sentence than for the read phrase. The PA and BD means of PM and EO muscles presented the greater difference between the two lengthy tasks (See Table 4).

Pearson correlation coefficient between acoustic temporal measures, respiratory kinematic and electromyographic measures was performed. There was a positive correlation between acoustic duration measures and respiratory kinematic measures of RCE (r=.61, p=.00) and LVE (r=.74, p=.00). ABE was not correlated with duration. PA and BD of the three muscles were not correlated with acoustic duration measure.

Correlation between respiratory kinematics and electromyographic measures was also performed. There was a positive correlation between RCE, PA of PM (r=.66, p=.00) and PA of EO muscles (r=.62, p=.00). There was no correlation among ABE, LVE and PA of the three muscles. Respiratory kinematics was not correlated with BD of the three muscles.

Discussion

The purpose of this study was to determine the relation between speech utterance length and respiratory physiology. Respiratory kinematics, muscle activity and acoustic temporal measures of two utterance length read aloud tasks: phrase and sentence were taken. The mean duration of read aloud sentence was significantly greater than the read aloud phrase, as was expected ($p = .00$). The objective was to understand the respiratory physiology that contributes mostly for the longer speech productions.

The results of the kinematics analysis revealed that RCE and LVE means were significantly greater in sentence than in phrase tasks ($p = .00$). It seems that RCE has a greater contribution than ABE for greater LVE necessary for longer speech productions. These findings were in agreement with previous research. The breathing mechanism is only significantly responsive to the complexity of the reading tasks in concerning to RCE[15,16] and LVE[17,19,20]. This means that as the demanding levels and the lengths of the phonatory tasks increase, the chest wall kinematics system is able to anticipate them and respond appropriately to support their aerodynamic demands, regarding the amount of volume necessary to produce a spoken sample[15,16,19,20]. This assisted in initiating and maintaining subglottal pressures needed for each phonatory task[1]. Thus, it seems that there is a relatively sophisticated neural planning of this system, in anticipation to the demands and lengths of the tasks. At the same time, according to the results of this study and also shown by Fuchs et al. (2008), the participation of abdominal movement (ABE) is less evident than lung and ribcage movements (LVE and RCE).

This study revealed a significant positive correlation between PA of PM and EO muscles and RCE (p=.00). This relation among PA of PM and PA of EO muscles and RCE indicates that for rib cage movement, the muscles PM and EO are more active than RA. It may support the hypothesis that PM, as an accessory inspiratory muscle, has a large contribution in lifting up and posturing the rib cage[28].It has an important role in checking action, ie., it is an inspiratory muscle that keeps contracting during phonatory expiration[12]. By doing so it maintains pulmonary/ribcage/thoracic volume and subglottal air pressure, as well as a steady air flow for speech production purposes. If so, the PM muscle helps to generate high positive subglottal air pressures that, when encountering a resistance at the glottis level or any other point of the vocal tract, create high airflow rates. These high subglottal air pressures and airflows are required for longer production tasks, such as read aloud sentences as opposed to phrases. On the other hand, the EO as an expiratory muscle, as expected, contracted during reading aloud tasks but presented greater contractions during longer utterances, i.e., sentences than phrases.

This experiment corroborates with previous investigation concerning the contribution of EMG and respiratory kinematics to acoustic temporal measure duration. The findings can be used in speech pathologists' practice, once breathing control techniques are required for the adequacy of voice, speech and swallowing functions.

Limitations of this investigation correspond to the reduced subjects and reading aloud samples. However, descriptive and inferential statistics revealed a clear and coherent pattern of greater excursions of RCE and LVE associated with greater recruitment of pectoralis major and external obliques muscles for longer phonatory utterances. Future work needs to include a larger subjects and speech samples.

Conclusion

The control and the behavior of the respiratory physiological system vary according to the length of speech production even if the duration difference is within seconds. The same breathing mechanisms were used for the production of reading aloud both phrase and sentence. Longer speech utterances presented greater excursions of the respiratory system (i.e., ribcage, abdominal and lung volume) as well as longer and more intense contractions of the studied inspiratory (pectoralis major) and expiratory muscles (external obliques and rectus abdominal).

Moreover, the longer speech utterances have larger lung volume excursions that are mostly supported by the larger ribcage excursions, rather than abdominal excursions. The ribcage excursions were mostly supported by greater contractions of pectoralis major and external obliques, rather than rectus abdominal muscles.

The respiratory system is a very efficient neurologically planned mechanism that responds very rapidly to the needs of the speech production. With this paper the understanding of respiratory physiology underlying the speech production for small utterances became clearer and it can be used in clinical practice for voice disorders, however it raised more questions that need to be answered such as for longer read aloud sentences and paragraph and for singing tasks.

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