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# Speech breathing and prosody during statement and question productions in seven-year-old children

by

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ABSTRACT

The purpose of this study was to examine the effect of prosodic contrasts in differing contextual scenarios (e.g., questions, statements) on acoustic measures and speech breathing parameters in children. Twelve English-speaking 7-year-old children participated. Structured and unstructured speaking tasks were used to elicit productions of questions and statements. Speech breathing measures included: lung volume initiations, terminations, and excursions, and number of syllables per breath group. Acoustic measures included: $f_0$ average, $f_0$ slope, dB average, and syllable duration. Significant differences were observed for acoustic measures associated with questions and statements in both structured and unstructured tasks and only $f_0$ slope was found significant different in both tasks. Also, one breathing measure in the unstructured task had significance difference for questions and statements. Results of the study demonstrated that 7-year old children appeared to use mainly laryngeal adjustments to mark prosodic contrasts in structured conditions eliciting question and statement productions.

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# Introduction

Spoken language is a means of communicating by the use of words upon which speakers impose a variety of features of speech like pitch and loudness. Two subsystems, the laryngeal and respiratory subsystems, are vital in controlling the prosodic features of pitch and loudness. These systems contribute to spoken language across adults (Hird & Kirsner, 2002); however, while the majority of our knowledge about the control of the speech system for prosody is based on studies of adults, little is known about these systems in children's spoken output. This study is set to explore the laryngeal and the breathing system during speech in children.

Speech contains not only sound units that come together to form words, but also prosodic features like stress and intonation that are known to be essential in communicating meaning. In many languages, these features can be used to introduce new information, to distinguish questions from statements, and to convey meaning. Prosodic features are those refined features that allow listeners to perceive a phrase or a sentence as a statement, a question or an exclamation. For example, in English, rising intonation at the end of a phrase of a sentence signals a question, whereas falling intonation at the end of a phrase signals a statement. In addition, prosodic features can convey emotions such as excitement, anger, and sadness. These variations in intonation can be quantified using several acoustic parameters, including fundamental frequency, dB SPL and duration (Cruttenden, 1986).

## Developmental Aspects of Prosody

Prosody is an essential feature relative to conveying a spoken message and appears to emerge naturally. Speakers use high and low pitch at the syllable level in an effort to stress the importance of their message. This is assumed to be particularly useful when mothers are encouraging speech and language learning by their infants. For example, caregivers use different pitch levels when talking to their infants and young children, which is known as *motherese* and is thought to enhance the message as well as its emotional content. In a study on *motherese* (Fernald & Mazzie, 1991), mothers' use of fundamental frequency slope was examined during spontaneous conversation with their infants while describing pictures in a picture book, and then compared to that observed during conversation with adults. These investigators measured the highest and lowest fundamental frequency ($f_0$) peaks in the utterance and the $f_0$ range (maximum minus minimum). The results showed that rising and falling $f_0$ occurred at the syllable, word and sentence level of production. However, mothers used higher fundamental frequency and greater fundamental frequency range when conversing with their infants compared to when conversing with adults. In addition, mothers used exaggerated pitch at the end of utterances to accentuate targeted words to their infants. Furthermore, mothers used declarative sentences almost exclusively when talking to adults, whereas they used declaratives, imperatives and interrogatives in their sentences when talking to children in the same context scenario.

The use of *motherese* appears to be an important learning mechanism for children, priming them for the use of suprasegmentals in their own speech productions. For example, children at a young age start to use falling and rising $f_0$ to indicate a question or statement. Patel and Grigos (2006) characterized the acoustic correlates of $f_0$ change when 4-, 7- and 11-year-old children produced questions or statements. The results indicated that targeted CVC words in questions and statements were related to rising and falling $f_0$, respectively. More specifically, 4-year-old children exhibited a greater decrease in $f_0$ for the final word in statement sentences than 7 and 11-year-old children. In question sentences, 7- and 11-year-old children had a sharp rise in fundamental frequency on the final word, as did 4 year-old children. Grigos and Patel (2006) also measured dB SPL and syllable duration. All three age groups increased dB SPL on the final syllable when producing question sentences. It should be noted that for 7 year-old children the difference in dB SPL between statement versus question sentences was greater than that in 4 and 11 year-old children. Duration analysis showed that all three age groups elongated the final word in questions in relation to statement sentences. In summary, the oldest group relied more on changes in $f_0$ and less on syllable duration and dB SPL. The 4-year old children relied more on duration to mark questions and 7-year old children used all three acoustic features. In conclusion, this study shows that 7 and 11 year old children begin to use adult-like prosody when eliciting questions and statements. In contrast, it appeared that 4-year old children have a limited range in $f_0$ and have not yet mastered the use of this acoustic feature in combination with dB SPL, to mark questions versus statements. It may be that young children have immature speech motor control along with developing linguistic and cognitive systems that appear to be going through a period of refinement.

In another study, Patel and Brayton (2009) asked naïve listeners to identify specific prosodic features from speech produced by children. Listeners were asked to identify questions and statements and also to identify contrastive stress within an utterance produced by 4-, 7- and 11-year old children. The prosodic features that were identified were $f_0$, dB SPL and syllable duration. Listeners were less accurate at identifying the productions of 4 year-olds in the given tasks, whereas accuracy was significantly higher for the productions of 7 and 11 year-olds. These findings appear to correspond with Grigos and Patel's acoustic study (2006) and suggest that $f_0$ is an important marker for perception of suprasegmental contrasts related to questions.

Whereas some studies have examined the production (Patel & Grigos, 2006) and identification of prosody (Patel & Brayton, 2009) in children, others have examined the identification of prosody in adults. For example, Srinivasan and Massaro (2003) examined prosodic features that correlated with the identification of questions or statements produced by adult speakers. Twenty-two undergraduate students aged 18 to 22 identified pre-recorded sentences as either a statement or a question. Correctly identified statement sentences were characterized by gradual decline in terminal $f_0$ slope, shorter final syllable duration and a sharp drop in dB SPL on the final syllable. On average, the $f_0$ variability started at 97 Hz and declined to 64 Hz, syllable duration was 200ms, the overall utterance was 1192 ms, and dB SPL on the final syllable fell about 80%. In contrast, correctly identified question sentences were characterized by a high overall rise and slight terminal fall in $f_0$, longer final syllable duration, and a smaller drop in dB SPL. The average $f_0$ slope started at 86 Hz and increased to 170 Hz, the terminal fall in $f_0$ was from 170 Hz to 148 Hz, the duration was 280 ms, the overall utterance duration was 1289 ms, and dB SPL fell to 40%. These data showed that listeners perceived changes in $f_0$, syllable duration and dB SPL that distinguished question productions from statements.

Children at an early age start using prosody as part of their linguistic competence (Cutler & Swinney, 1986). After the age of 4 years, children focus their attention on processing parts of utterances in the same way as adults. Cutler and Swinney (1986), concluded that children between 4 and 6 years start exploiting prosodic information for comprehension. Thus, comprehension of prosodic characteristics develops earlier than production (Cutler & Swinney, 1986).

Furrow (1984) examined the relationship between prosodic perceptual variables and aspects of social behaviour in 12 children at the age of 2 years-old. The perceptual features that were examined included pitch, loudness and pitch range and were rated as being low, medium low, medium, medium high, high. The results showed that children at the age of 2-years-old produce louder and higher-pitched utterances when they maintain eye contact with a person than when there is no interpersonal behaviour. This behaviour continues into later childhood. According to Patel and Grigos (2006), children between the ages of 7 and 11 years old begin to use adult-like patterns of prosody in the production of question-statement sentences.

Taken together, data from these studies indicate that both children and adults enhance the meaning and emotion of spoken language effectively by using elements of prosody. Moreover, listeners take advantage of the prosodic aspects of speech in order to understand a spoken message more comprehensively. These previous studies indicate however, that the emergence and refinement of prosody starts early in development and is refined throughout childhood.

**Development of the Speech Mechanism to Support Prosody**

Listeners can perceive the difference between speech produced by children and that by adults. These differences are likely related to the developmental trajectory associated with both anatomical and physiological features of the speech mechanism. Acoustic measurements of voice and speech (e.g., $f_0$, SPL, vowel duration) have been used historically as an indirect assessment of the physical and aeromechanical elements of the developing speech system. For the present study, fundamental frequency was measured in relation to prosody. Thus, a basic review of the mechanism behind changes in pitch will be presented.

**Motor control of the vocal folds.** Fundamental frequency during speech varies as a function of communicative intent (i.e., questioning, stating, emphasizing). People use rising or falling $f_0$ to convey meaning (Leonard, 1973). To produce a rising $f_0$, muscular control applied at the level of the larynx serves to lengthen and tense the vocal folds, increasing vibratory speed. In contrast, to produce a falling $f_0$, muscular control is needed to shorten and thicken the vocal folds, resulting in a slower vibratory speed. The perceptual characteristics of fundamental variability, high pitch, and low pitch are correlated with rising and falling pitch, respectively. The perception of higher or lower pitch is related to changes in vocal fold length, vibratory characteristics, tension and mass. In general, when the vocal folds have been lengthened from their natural resting state, and thus are thinner, they vibrate at a higher rate producing high frequencies, whereas when they have been shortened from their natural resting state, and thus are thicker, they vibrate at a lower rate producing low frequencies.

**Vibratory characteristics of the vocal folds.** Vibration of the vocal folds is characterized by a vertical phase difference where lower points of the vocal folds are displaced earlier than points above them in a wave-like movement (Hirano, 1974). One vibratory cycle of the vocal folds includes closed, opening, open, and closing phases. Movement through these phases is known as one vibratory cycle. Actions of the lateral cricoarytenoid muscles are responsible for medial compression of the vocal folds, a phenomenon that occurs when the vocal folds are adducted. Furthermore, medial compression of the vocal folds plays an important role in the changes of dB SPL at prevailing tracheal pressures and airflow rates. For example, when tracheal pressure is raised and medial compression is increased, providing increased resistance to airflow, dB SPL will also increase.

**Muscular tension of the vocal folds.** Tension in the vocal folds can be changed during sustained voice production by contraction of the cricothyroid muscle, which stretches the vocal folds. Tension is further increased when the posterior cricoarytenoid contracts in opposition to the cricothyroid. This results in reducing the thickness and cross section of the vocal folds and in increasing the tension, both of which are associated with a faster vibratory rate and subsequent increases in fundamental frequency. When using a modal register (speaking voice) tension doesn't play as important a role in changing the $f_0$ as it does in a falsetto register.

**Effective mass of the vocal folds.** Fundamental frequency can be altered via changes in the effective vibrating mass of the vocal folds. An increase in the length of the vocal folds results in a decrease in the vibrating mass and subsequent increases in $f_0$. In contrast, when there is a decrease in the length of the vocal folds there is a resulting increase in vibrating mass and subsequent decrease in $f_{0.}$

**Vocal fold changes across the lifespan**. The structures and histology of the vocal folds undergo changes from birth to adulthood. Infants, newborns and babies have, in general, high $f_0$ (400 to 500 Hz), which usually decreases, as children get older. At the age of 10 years, $f_0$ is about 200 to 300 Hz. Prior to puberty the average $f_0$ of males and females is similar. However, during and after puberty, $f_0$ decreases in males with an eventual difference between the sexes of approximately 130 Hz. Fundamental frequency of women aged 20-70 years is between 200 and 220 Hz, with older women (80 years and older) experiencing a slight rise in $f_0$ and gradual decrease after the age of 90 years. Men between the ages of about 30-70 years have a $f_0$ of between 110 and 140

Hz. However, as men reach old age, their $f_0$ values increase. A recent study refers to such changes of $f_0$ across the lifespan. According to Stathopoulos and colleagues (2011), $f_0$ decreases steadily in women from 4 years to 60 years of age and then begins to rise slightly but not until 80 years of age. In men, $f_0$ declines gradually from 4 to 50 years of age and then begins to slightly rise. These findings may be explained by the changes found in the histology of the vocal folds.

**Histology of vocal folds during childhood.** Histology of the vocal folds changes throughout age causing changes in vibratory characteristics. The vocal folds are made up of 3 different layers: a) the body (muscle fibers and deep layer of lamina propria), b) intermediate and superficial layers of lamina propria and c) the epithelium. The vocal folds during childhood change in their overall length. A newborn's vocal folds are very small in length and they tend to increase over childhood. Before the age of 4, the intermediate and deep layers are undifferentiated. Between the ages of 4 and 16 years, the collagenous and elastic fibers in the intermediate and deep layers increase in density. Also, the membranous and cartilaginous portions of the vocal folds change in length during development Therefore, an adult-like lamina propria is apparent by the age of 16. Maturation of the intermediate and deep layers affects the temporo-spatial properties of the movements of the vocal folds. These factors may have an impact on the quality of the voice during adolescence by contributing to hoarseness, breathiness or roughness (Hirano, 1974).

## The Development of the Breathing System

The breathing system plays an important role in the control of speech as it provides the air source (driving force) for sound production during speech. Thus, the key role in speech production is to maintain constant and sufficient tracheal pressure throughout the duration of the breath group. Assessment of speech breathing function can be done through kinematic measurements taken from the chest wall. A variable inductance plethysmograph can detect movement from the rib cage and abdomen simultaneously. The resulting waveforms can be used to estimate lung volume and timing events associated with speech breathing. This method allows the speaker to remain unencumbered during speaking activities. Investigators have used such systems to measure breathing patterns across the life span and, of interest to the present study, in children seven years of age. Hoit and colleagues (1990) found that speech breathing was different across age groups of children and adolescents. Significant differences were found in relation to lung volume expenditures per syllable and syllables per breath group during extemporaneous speaking. They found that 7-year-old children initiated and terminated breath groups at larger lung volumes, produced fewer syllables per breath group and expended greater volumes of air per breath group and per syllable in comparison to 10-year-old children. The data from that study also showed that 10 year-old- children exhibited adult-like speech breathing patterns, whereas breathing was still developing at the age of 7 years.

**Breathing during speech**

Control of fundamental frequency and intensity is not only influenced by the adjustments of the vocal folds, but also by adjustments made by the breathing apparatus. The breathing apparatus during speech performs actions that help control dB SPL, $f_0$, $f_0$ slope and segmentation of speech into syllables, words and phrases. Production of an extended steady utterance, for example a sustained vowel, starts after a deep inspiration and continues until air supply is depleted or exceeds depletion using muscular pressure at the level of the larynx, rib cage and abdomen. It is important to note the length of a phrase or sentence during conversation is driven by linguistic features, tracheal pressure, airflow and volume of air inhaled. During conversational speech breathing the amount of tracheal pressure used ranges from 5 to 8 cm $H_2O$ and the amount of volume per breath group covers 20% of the vital capacity. During conversational speech, 10-year old children and adults speak in the midrange of their vital capacity. Conversational speaking requires lung volumes that are one to two times resting tidal volumes. When speaking, adults usually produce about 16.55 syllables per breath group. However, children younger than 10 years old use fewer syllables per breath group than adults. Children use larger lung volume expenditures per syllable and larger lung volume excursions per breath group. In general, children at age 7 years use larger lung volumes, rib cage volumes and abdominal volume initiations and terminations for breath groups (Hoit et al., 1990).

The most consistent adjustment in the breathing apparatus that affects loudness (SPL) and frequency ($f_0$) is tracheal pressure. For conversational speech, constant tracheal pressure of about 5-7 cm $H_2O$ is needed for an average of 5 seconds. When people want to produce louder utterances, different adjustments are made at the respiratory level for increasing tracheal pressure, which can be done by increasing lung volume, increasing medial compression at the laryngeal level (lateral cricoarytenoid and interarytenoid muscles), or both. Increases in SPL can also be achieved by increasing mouth opening.

**Breathing and dB SPL**

Studies have shown that the breathing apparatus affects changes in lung volumes to impact dB SPL. In particular, Dromey and Ramig (1998) examined the impact of lung volume initiations, terminations, and excursions on dB SPL. The results indicated that lung volume initiations and terminations increased with increasing vocal SPL. Also as the time decreased between maximum lung volume and start of phonation, SPL increased.

**Breathing and $f_0$**

In addition to affecting dB SPL, changes in lung volume also have the potential to affect fundamental frequency. According to Collier (1975), a decrease in tracheal air pressure is accompanied with a decrease in $f_0$ as well as a final drop in pressure that is associated with the end of an utterance. Decreases in $f_0$ occur on the final syllable of an utterance. It is important to note that even though increases in $f_0$ may be related to increases in tracheal air pressure, increases in tracheal air pressure may not necessarily produce increases in $f_0$. Muscular control of the larynx also plays an important role in the increase of the $f_0$ as an adjustment of the breathing apparatus alone cannot make changes in the $f_0$. For example, adjustment of the breathing apparatus in coordination with the laryngeal adjustment can affect the $f_0$ when producing loft voice register (falsetto), where increases in tracheal air pressure can result in small increases in fundamental frequency.

Furthermore, literature has shown that while lung volume affects SPL and $f_0$, SPL can have an impact on $f_0$ with adjustment at the laryngeal level. For example, in Dromey and Ramig's study (1998), the results indicated that male and female speakers had an increase in $f_0$ in relation to dB SPL. The increases in $f_0$ that often accompany increases in dB SPL can be accounted for by greater tension of the vocal folds. This happens as people use louder speech, which means they increase their tracheal pressure, and at the same time at the level of the larynx this pressure affects the vocal folds and other laryngeal structures, which result in affecting the fundamental frequency.

**Relationship between Breathing and Prosody**

Studies have shown that there is a relationship between the acoustic characteristics mentioned, breathing, and prosody. Specifically, one study has linked breathing and prosody (Hird & Kirsner, 2002). In this study, researchers examined categories of breath groups in relation to fundamental frequency, intensity and rising/falling fundamental frequency slope during spontaneous speech. Breath groups were assigned four different categories in an effort to determine place of inspiration during spontaneous speech and to compare them with the acoustic characteristics. The categories assigned were: inspiration that occurred at the beginning of the sentence (BS), inspiration that occurred at a junction clause (BC), inspiration that occurred at neither of these places (B), and inspiration between sentences (S). The results showed that inspiration occurred mostly at the beginning of a sentence during the first 600 ms while inspiration at the other places (BC, B, C) did not occur as often within the first 600 ms. This means that breath groups were taken at the beginning of each sentence. Data revealed that dB SPL was higher in the beginning of sentences than in the other three categories mentioned above. However, $f_0$ demonstrated no significant effects between the four categories. In summary, this study shows that there is a relationship between the acoustic characteristics, breath groups and prosodic features of loudness adjustment.

**Prosody and Breathing in Children**

Little is known about the relationship between prosody and breathing, and much less about this in children during speech production. According to some researchers, breathing can affect acoustic measures ($f_0$ and SPL) that relate to prosody characteristics. Only one study was found that specifically compared places of inspiration that constitute breath groups with $f_0$, slope and dB SPL during speech in adults (Hird & Kirsner, 2002). This study found that breathing affects acoustic characteristics in adults. However, this study may not apply necessarily to 7-year-old children, because at this age children are only starting to use adult-like patterns of prosody and breathing is still developing. Our understanding of breathing correlates for control of prosody in these young children is extremely limited.

**Purpose of this Study**

The purpose of this study was to examine whether there is a relationship between breathing and prosody during speech production in typical 7-year-old children. The literature has shown that some prosodic features are established at the age of 7 years, whereas speech breathing control is still developing and doesn't become adult-like until the age of 10. Thus, it is not apparent how breathing parameters at seven years of age may affect the acoustic measures that relate to prosody. Therefore, the research question in the current study was:

What is the effect of prosodic contrasts in differing contextual scenarios (e.g., questions, and statements) and tasks (e.g., structured tasks, unstructured tasks) on acoustic measures (e.g., $f_0$, $f_0$ slope, dB SPL, syllable duration) and speech breathing parameters (e.g., lung volume initiation, lung volume termination, lung volume excursion and number of syllables per breath group)?

Table 1: Hypotheses:

| **Dependent V.** | **Hypotheses** | |
|---|---|---|
| | **Structured task** | **Unstructured task** |
| $f_0$ average | $f_0$ will be higher across the sentence during questions and lower during statements | $f_0$ will be higher in questions and will be lower in statements. |

| | | |
|---|---|---|
| dB SPL | dB SPL will be greater in questions than in statements | dB SPL will be greater in questions and will be lower in statements. |
| $f_0$ slope | $f_0$ slope will rise on the final syllable during questions and will drop on the final syllable during statements | $f_0$ will rise on the final syllable in questions and will drop in statements |
| Syllable duration | Duration will be longer in the final syllable during questions and be shorter during statements. | Duration in the final syllable in will be longer in questions and shorter in statements. |
| Lung volume (initiation) | Initiations for questions will occur at levels greater than one tidal depth while initiations for statements will occur within one tidal depth | Increase in the number of initiations above one tidal volume depth relative to the other two tasks |
| Lung volume (termination) | Terminations will occur at levels near End-Expiratory Level (EEL) for both questions and statements. | Increase in the number of terminations below End-Expiratory Level (EEL) relative to the other two tasks |
| Lung volume (excursion in %VC) | Lung volume excursions will be greater for questions than statements | Lung volume excursions will be more variable for narratives than either questions or statements |
| Number of syllables per breath group | Number of syllables per breath group will be the same in questions and statements | Syllables per breath group will be more variable than those observed in the other two tasks |

**Design**

A within-subject repeated measures experimental design was used to assess four conditions (structured-questions, structured-statements, unstructured-questions, unstructured-statements) across 8 dependent variables ($f_0$, dB SPL, $f_0$ slope, duration of final syllable, lung volume initiation, lung volume termination, lung volume excursion and number of syllables per breath groups).

**Statistical Analysis**

Two repeated measures MANOVAs were used to assess the outcomes of this study. One was used to evaluate outcomes (i.e., questions and statements) from a structured task across 8 dependent variables: $f_0$, SPL, $f_0$ slope and duration for acoustic measures and also Lung Volume Initiation, Lung Volume Termination, Lung Volume Excursion and number of syllables per breath group for breathing measures. Another repeated measure MANOVA was used to evaluate outcomes (i.e., questions and statements) from unstructured task gathered via the Edmonton Narrative Norms Instrument (ENNI) across these 8 dependent variables mentioned above

## Method

### Participants

Twelve English-speaking 7-year-old children participated in this study. All children passed a pure-tone hearing screening (1000Hz, 2000Hz, 4000Hz) at 20 dB HL and also a formal perceptual evaluation of voice with the Buffalo III Voice Profile (Wilson, 1987) to rule out any potential voice issues. The participants had no history of speech, language, and/or developmental or neurological impairments. Table 2 shows the participants' characteristics age, sex, weight and height.

**Table 2**. Participants' characteristics (age, sex, weight and height)

| Age (yrs & months) | Sex | Weight (kg) | Height (cm) |
|---|---|---|---|
| 7.4 | Male | 64 | 132 |
| 7.0 | Male | 28 | 127 |
| 7.4 | Male | 23 | 129 |
| 7.6 | Female | 24 | 127 |
| 7.7 | Male | 24 | 122 |
| 7.1 | Female | 25 | 125 |
| 8.3 | Female | 29 | 126 |
| 7.6 | Male | 28 | 126 |
| 7.0 | Male | 64 | 126 |
| 6.11 | Male | 56 | 127 |
| 7.1 | Female | 36 | 127 |
| 7.2 | Male | 28 | 125 |

## Materials

## Experimental Protocol

Breathing measures were transduced using a respiratory inductance plethysmograph, (Respitrace-Ambulatory Monitoring, Inc., Ardsley, NY) to measure chest wall kinematics. This system transduced the circumferences of rib cage and abdomen using "respibands". The bands were placed on bare skin over the rib cage just below the axillae and below the nipples and over the abdomen below the costal margin and slightly above the iliac crests.

Output signals from the transduction bands were used as estimates of the volume displacements of the rib cage and the abdomen (Figure 1), and their sum was used to estimate the volume displacement of lungs. Outputs for the rib cage and abdomen were recorded on separate channels on an FM data recorder and were displayed on an oscilloscope.

Each participant was seated upright on a chair in front of a table so that they didn't put pressure on the Respitrace bands. Output from the transducers was low-pass filtered using analog filters with a cut-off of 30 Hz and acquired through the use of an FM digital instrumentation recorder for subsequent analysis. Speech audio signals were obtained using a microphone worn by the child and were recorded on a separate digital channel of the same instrumentation recorder as well as on a separate digital-audio recorder. The microphone was placed on the child's forehead and calibrated using a tone generator and a SPL meter. Audio recordings were sampled at 44 kHz and stored for later analyses. All stimuli were placed in front of the child. The experimenter was seated across from the child. Simultaneous kinematic and audio recordings were acquired for all experimental conditions.

Figure 1.

| | | | | | | DATA RECORDER | | COMPUTER |
|---|---|---|---|---|---|---|---|---|
| Child wears respitrace bands | → | Oscillator 1 | → | DC Amplifier | → | Rib cage signal | → | Rib cage signal |
| | → | Oscillator 2 | → | DC Amplifier | → | Abdomen signal | → | Abdomen signal |
| For Calibration wears face mask pneumotachometer | → Pressure Transducer | → Carrier Amplifier | → Integrator → | DC Amplifier | → | Volume signal | → | Volume signal |
| 2 Microphones | → | | → | | → | Audio signal | → | Audio signal |
| Video camera | → | | → | | → | Video signal | → | Video signal through video monitor |

Before collection of speech-breathing data, a series of calibration maneuvers were completed to obtain individual baselines for each child (Boliek, et al., 2009). For calibration there were several procedures used to elicit breath holding and attendant isovolume adjustments of the chest wall. Children were asked to hold their breath and, while doing so, they were asked to pull their "tummy" inward and then allow it to relax outward. Isovolume maneuvers that were selected for calibration of the chest wall were free of extraneous movement or postural adjustment.

Calibration of chest wall and lung volumes was completed for each participant from the isovolume and breathing signals collected during the data acquisition procedures. Calibration of the chest wall required that rib cage and abdomen signals were gain-adjusted to be equal during isovolume maneuvers. In order to calibrate volume, inspiratory and expiratory volumes were measured at the airway opening and time-locked to kinematic signals from the chest wall. Volume collected at the airway opening was used to convert the kinematic signals to volume equivalence. The combination of isovolume adjustments and volume measured at the airway opening served to derive estimates from kinematic data for volume displacements of the rib cage, abdomen, and lung.

**Elicitation of Speech Samples**

A barrier game was introduced to the participant where spontaneous production of questions and statements was elicited. The task was presented as a game where both the participant and the clinician took part. In the activity intended to elicit sentences, the clinician put magnets on her scene in different places on the board. The clinician introduced 5 magnets and 4 different scene boards. The magnets had been specifically chosen so that CVC words were elicited. The magnets selected were: bird, fish, dog, duck, cake. The scene boards selected were: picnic, camping, castle and pirate. The barrier games came from Super Duper Publications and the kits that were chosen for this research were:  the Adventure kit, the Around the World kit and the Fantasy Adventures kit. The participant was not able to see where each magnet was placed, therefore requiring the participants to ask the clinician where she had placed the magnets. Before starting each game, the clinician provided specific names to be used for each magnet and the 5 potential locations for placement on each scene board.  This helped ensure that the vocabulary was similar across participants. The participant produced at least 15 different questions during this activity. For example, a child could ask questions like: “Is the dog in the castle?” or “Is the fish in the cave?”

In the activity intended to elicit statements, the participant prepared his or her own scene by putting the same 5 magnets in different places on the same 4 scene boards. The participant then instructed the clinician about where to place each magnet on her board. The goal of this activity was for the clinician to make the same scene as the participant. In this task the participant needed to produce at least 15 different statements. For example, the participant might give the following instructions: “Put the dog in the cave”, “Put the cake in the castle”.

The vocabulary used in both question and statement tasks was very similar in terms of targeted vocabulary. This helped to standardize the acoustic features and breathing parameters associated with the speaking tasks. Furthermore, all tasks were designed to elicit relatively spontaneous speech with minimal cueing. Each sentence was recorded so that acoustic features ($f_0$, $f_0$ slope, dB SPL and syllable duration) and breathing parameters (lung volume initiation, lung volume termination, lung volume excursion and number of syllables per breath group) could be analyzed at a later time.

One story from the Edmonton Narrative Norms Instrument (ENNI) was administered to each participant to assess the use of prosody in children during spontaneous discourse. The ENNI was selected because it is a Canadian tool that has been designed to elicit narratives in a standardized manner in children aged 4-9 years old. This test presents evidence of validity and reliability, with local normative information collected from 377 typically developing children in Edmonton, Alberta.

The clinician followed the procedures on how to administer the test but did not score the responses in the standardized manner. Since the data were not analyzed for narration but for speech, the clinician asked questions about the story to elicit more speech from the participants when necessary.

## Procedure

The clinician introduced herself to the participant and explained what the participant would do the day of the assessment. The participant was introduced to the Respitrace equipment where the clinician took the appropriate measurements for calibration. During that time, the clinician explained to the child what they needed to do during calibration measurements. This was done in a playful way so that the participant would be engaged in the activity. Later on, warm-up activities followed where the participant was engaged in producing questions and statements. These activities differed from those used in the formal experiment. Therefore another barrier game and another story from the ENNI were selected for practice purposes. The clinician explained to the participant the instructions for each activity. After the practice and warm up activities were completed, the barrier game and narrative tasks were presented.

## Data Analysis

**Acoustic analysis.** Questions and statements were analyzed through the *Praat* speech analysis software package (http://www.fon.hum.uva.nl/praat/) using a customized script that generates labels for demarking the beginning and end of each syllable. This software program was used to analyze: $f_0$, $f_0$ slope, dB SPL and syllable duration.

Each syllable with a question and statement was analyzed to estimate $f_0$ values.. The analysis was done manually where a cursor was placed at the beginning of the syllable and at the end. Through this software, upper and lower limits of $f_0$ were calculated and an average was calculated. To calculate a grand mean for each task, the averages of each syllable were summed and divided using Excel calculations.

In order to calculate $f_0$ slope, each syllable within a sentence was analyzed so that changes in $f_0$ could be examined and compared, particularly in the final syllables between questions and statements. Slope was calculated by taking measures of the maximum $f_0$ and the minimum $f_0$ of each syllable. The formula used for monosyllable words was: $f_0$ slope= ($f_0$ maximum-$f_0$ minimum)/(maximum time-minimum time). The maximum $f_0$ (MAX $f_0$) and the minimum $f_0$ (MIN $f_0$) along with their associated times, were identified in multisyllabic words and used to calculate the slope for two- and three-syllable words with the above formula. The same formula for $f_0$ slope calculations on monosyllables was used on multisyllable tokens. A negative slope indicated a falling $f_0$ as in the case of statements and a positive slope indicated a raising $f_0$ as in the case of questions.

The loudness of each syllable was measured by calculating average dB SPL for each syllable by marking the upper and lower limits of the syllable. An average dB SPL for each sentence was calculated using the syllable-level dB SPL comprising that sentence. The average of durations of each final syllable in the last word of each sentence was calculated.

**Reliability Analysis.** Ten percent of the data was randomly selected, using random numbers for each file. The researcher re-analyzed ten percent of the data in order to calculate intra-rater reliability and an independent rater analyzed the same ten percent of the data in order to calculate inter-rater reliability. A Pearson product moment correlation for inter-reliability was calculated with $r= .98$ and for intra-reliability was calculated with $r= .99$.

**Speech breathing kinematic analysis.** The rib cage and abdomen kinematic signals were digitized and displayed in two formats: motion-time (y –t) and motion-

motion (y-x). The kinematic and integrated flow signals were filtered at 30Hz and were digitized at a rate of 250Hz. An audio signal, digitized at 10000 Hz, was used to indicate speech events as they related to the breathing signals.

A semi-automated custom-developed program (Labview 7.0) was used for kinematic analysis. After calibration, volume displacements of the rib cage, abdomen, and lung were analyzed and referenced to the tidal end-expiratory level (EEL). This level was referred to as zero displacement for rib cage, abdomen, and lung volumes. Thus, larger volumes or smaller volumes than EEL were expressed as positive or negative values, respectively. Calibrated rib cage volume initiations, terminations, and excursions, together with abdomen volume initiations, terminations, and excursions, were used to derive lung volume initiations (LVIs), lung volume terminations (LVTs), and lung volume excursions (LVEs), and percent rib cage contribution to LVE.

Analyses of each breath group yielded 18 measures. Those used in the present study were: (a) LVI (in ml); (b) LVT (in ml); (c) LVE (in ml and %VC) and (d) syllables per breath group (in syllables/breath group).

**Results**

For this study, two separate within-subjects repeated MANOVAs (structured and unstructured tasks) were run with 2 CONDITIONS (Questions, Statements) x 8 dependent measures (lung volume initiation, lung volume termination, lung volume excursion, number of syllables per breath group, $f_0$ average, $f_0$ slope, dB average, syllable duration). Descriptive analyses revealed one participant outlier who was subsequently removed from the final analysis (N=11).

**Structured Task**

Table 3 presents the descriptive statistical results for the dependent variables in questions and statements on the structured task.

Table 3. Means and standard deviations of the dependent variables: lung volume initiation, lung volume termination, lung volume excursion, number of syllables per breath group, $f_0$ average, $f_0$ slope, dB SPL average and syllable duration in statements and questions on the structured task.

| **Dependent Variables** | **Questions** | | **Statements** | |
|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation |
| Lung volume initiation | 760.13 ml | 325.05 ml | 871.91 ml | 562.64 ml |
| Lung volume termination | -15.64 ml | 116.81 ml | 43.33 ml | 250.04 ml |
| Lung volume excursion | 775.77 %VC | 329.69 %VC | 828.58 %VC | 527.55 %VC |
| Number of syllables/breath group | 6.59 syllables | .13 syllables | 6.52 syllables | .13 syllables |
| $f_0$ average | 240.28 Hz | 12.99 Hz | 238.29 Hz | 18.20 Hz |
| $f_0$ slope | 726.60 Hz/sec | 327.09 Hz/sec | -668.55Hz/sec | 386.25 Hz/sec |
| dB SPL average | 59.38 dB | 5.28 dB | 58.12 dB | 5.30 dB |
| syllable duration | .49 sec | .10 sec | .51 sec | .13 sec |

For the structured task, significant differences were found between questions and statements in the number of syllables per breath group $F(1,10)= 5.284$, $p < .05$, partial $\eta^2 = .346$; $f_0$ slope $F(1,10)= 65.004$, $p < .05$, partial $\eta^2 = .867$; and dB SPL average $F(1,10)= 5.092$, $p < .05$, partial $\eta^2 = .337$. As can be seen in Table 3, the number of syllables per breath group was slightly greater on questions than on statements (x= 6.59s vs 6.52s, respectively). The $f_0$ slope for questions (x = 726.60 Hz/sec) was higher than for statements (x = -668.55 Hz/sec) (Table 3). Average dB SPL for questions (x= 59.38 dB SPL) was higher than that found for statements (x = 58.12 dB SPL).

**Unstructured Task**

Descriptive statistical results for the dependent variables in questions and statements on the unstructured task are presented in Table 4.

Table 4. Means and standard deviations of the dependent variables: lung volume initiation, lung volume termination, lung volume excursion, number of syllables per breath group, $f_0$ average, $f_0$ slope, dB SPL average and syllable duration in statements and questions on the unstructured task.

| Dependent Variables | Questions | | Statements | |
|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation |
| Lung volume initiation | 635.68 ml | 335.03 ml | 748.08 ml | 370.81 ml |
| Lung volume termination | -92.91 ml | 213.31 ml | 52.63 ml | 204.24 ml |
| Lung volume excursion | 728.59 %VC | 332.68 %VC | 695.45 %VC | 280.78 %VC |
| Number of syllables/breath group | 6.19 syllables | 1.25 syllables | 6.87 syllables | 1.05 syllables |
| $f_0$ average | 243.40 Hz | 20.50 Hz | 228.68 Hz | 20.83 Hz |
| $f_0$ slope | 674.06 Hz/sec | 356.15 Hz/sec | -655.07 Hz/sec | 260.80 Hz/sec |
| dB SPL average | 56.54 dB | 4.92 dB | 57.54 dB | 5.55 dB |
| syllable duration | .43 sec | .10 sec | .46 sec | .12 sec |

Significant differences were found between questions and statements in the lung volume initiation $F(1,10)= 5.323$, $p < .05$, partial $\eta^2 = .347$; $f_0$ average $F(1,10)= 10.949$, $p < .05$, partial $\eta^2 = .523$; $f_0$ slope $F(1,10)= 130.432$, $p <.05$, partial $\eta^2= .929$; and dB SPL average $F(1,10)= 5.431$, $p < .05$, partial $\eta^2 = .352$.

As can be seen in Table 4, lung volume initiation was greater on statements (x = 748.08 ml) than on questions (x = 635.68 ml). The $f_0$ average was higher on questions (x = 243.40 Hz) than on statements (x = 228.68 Hz) and $f_0$ slope was higher on questions (x

= 674.06 Hz/sec) than on statements (x = -655.07 Hz/sec). Lastly, dB SPL average for statements (x = 57.54 dB SPL) was higher than dB SPL for questions (x = 56.54 dB SPL).

## Discussion

Previous research has shown that children can adjust their prosodic features of speech when producing questions and statements (Patel & Grigos, 2006). This ability emerges as early as 4 years of age (Patel & Grigos, 2006); however, children only begin to use adult-like patterns of prosody at the age of 7 years. Most of what is known about prosody has come from acoustic measurements ($f_0$ average, $f_0$ slope, dB SPL, syllable duration) associated with laryngeal adjustments. Little is known about the role of the breathing subsystem in making prosodic adjustments. The only previously published study was on adults and demonstrated that breathing parameters can affect $f_0$ average, $f_0$ slope and dB SPL (Hird & Kirsner, 2002). There is limited understanding of breathing and its relationship to the control of prosody in children whose breathing system is still developing. Thus, the purpose of this study was to examine the effects of prosodic contrasts in differing contextual scenarios and tasks on acoustic measures and speech breathing parameters. The results of this study demonstrated that the children used mainly laryngeal adjustments to mark prosodic changes.

### Laryngeal Adjustments

Significant differences in $f_0$ slope were found between questions and statements for both speaking tasks. During the structured and the unstructured tasks, $f_0$ slopes were found to be higher in questions than in statements, as expected. Consistent with the present findings, results from Patel and Grigos' study (2006) showed significant differences in $f_0$ slope in questions and statements during a structured task. Rising intonation in the final syllable signals a question, whereas a falling intonation signals a statement. These patterns are consistent with previous studies showing that children use $f_0$ slopes to signal questions and statements (Cruttenden, 1986; Patel & Grigos; 2006, Patel & Brayton, 2009).

The present study showed that significant differences were found in the $f_0$ average between questions and statements for the unstructured, but not structured, tasks. These results were not consistent with those of Patel and Grigos (2006), who found significant differences in the $f_0$ average of questions and statements during a structured task. One reason why $f_0$ average did not differ between questions and statements in the structured task within the present study might be due to the nature of the task. The $f_0$ average in questions and in statements was found to have similar mean values for the structured task, which was not expected. Moreover, the data showed that the range of $f_0$ averages among participants had about the same values in questions and statements for this condition. Relating to other studies, $f_0$ in statements is expected to be lower than in questions, and particularly in 7-year-olds who used more exaggerated differences (Patel & Grigos, 2006; Cruttenden, 1986). In the present study, during the structured task, modelling for question productions was provided more often than for statement productions, whereas no modelling was provided in the unstructured task. Modelling on question productions may have interfered with the elicitation of inherent or spontaneous productions of questions. Although not tested statistically, the $f_0$ in questions for the structured task was slightly lower than the $f_0$ in questions for the unstructured task. It seems that 7-year-old children's intonation pattern in the structured task was influenced by the model that was provided to them and produced questions and statements in a similar way resulting in an increase in the $f_0$ averages and particularly in the statements. Thus, children's voice variation on both questions and statements may have been restrained by modelling, consequently masking potential inherent differences in average $f_0$ associated with question and statement productions.

The data revealed significant differences on dB SPL between questions and statements during both tasks. In Patel and Grigos' study (2006), significant differences in dB SPL during questions and statements in structured tasks also were observed. In their study, seven-year-old children demonstrated greater differences in dB average in comparison to 4- and 11-year olds, along with greater variability in dB SPL. As expected from previous studies (Patel & Grigos, 2006), dB SPL in the present study had higher values during question production and lower values in statements during the structured task. In contrast, dB SPL in questions during the unstructured task was lower than in statements, which contradicts Patel and Grigos' findings. An explanation for this finding might be that the children seemed to be less certain when producing questions than when producing statements when the task was unstructured. They often needed to be prompted by the clinician to produce a question and some children seemed to be uncertain whether they were providing correct spontaneous questions when describing the ENNI pictures. This uncertainty could have led to the participants using a lower volume of speech.

In the present study, syllable duration in questions and statements in both tasks was found to be different from Patel and Grigos' findings (2006). Specifically, in Patel and Grigos' study (2006), means of syllable duration in questions and statements were found to be smaller than the means of syllable duration in the present study. One reason why syllable duration was larger in both questions and statements within the present study might be due to the nature of the tasks. Patel and Grigos (2006) examined vowel durations on four monosyllabic words that contained voiced and unvoiced bilabial stops in a structured task. In the present study, syllable durations were examined and a vocabulary of different words was used that consisted of stops, fricatives, sibilants and non-sibilants. It is possible that these segments of speech could affect the means in syllable duration in structured and unstructured tasks, and make them longer. Furthermore, in the present study, the nature of both tasks required children to the use their cognitive abilities to formulate speech, which might also have resulted in an overall slower rate of speech, and longer syllable durations.

Several insights can be gained when we look at potential interactions between the variables that were measured in this study. For example, during the structured task, both dB SPL and $f_0$ slope were found to differ between questions and statements. According to previous studies (Stathopoulos & Sapienza, 1993; 1997), there are two mechanisms that usually control dB SPL: tracheal pressure and laryngeal adjustment. In the present study, dB SPL appeared to be somewhat associated with $f_0$ slope. During question productions, both dB SPL and $f_0$ slope increased while during statement productions they decreased. The present findings were similar to Dromey and Ramig's study (1998). They found that $f_0$ increased with an increase in dB SPL for both males and females, whereas $f_0$ decrease was not significant with a decrease in dB SPL. In the present study, 7-year old children appeared to use primarily laryngeal adjustments to produce prosodic contrasts in highly structured tasks eliciting question and statement productions.

**Speech-Breathing Adjustments**

Besides the laryngeal adjustments observed for prosodic adjustments in structured and unstructured tasks, one speech breathing measure (lung volume initiation) was found to be significantly different between speaking contexts during unstructured tasks. Specifically, children initiated statements at higher lung volumes than initiations for questions. Statements were produced at slightly higher loudness levels (dB SPL) so perhaps going to higher lung volumes was associated with targeting slightly greater tracheal pressure. Others have previously reported speech breathing adjustments associated with changes in vocal loudness (Stathopoulos & Russell, 1988; Stathopoulos & Sapienza, 1997; Dromey & Ramig, 1998; Huber et al., 2005). Stathopoulos and Russell (1988) found that 8- and 10-year-old children increased their vital capacity to speak at louder volumes increasing at higher lung volumes for end-inspiratory levels and decreasing to lower lung volumes for end-expiratory levels. Their study concluded that 8- and 10-year old children used different respiratory adjustments from those of adults when stressing their system to speak at louder volumes. According to Stathopoulos and Sapienza (1997) 4-, 8-, and 10-year old children produced loud speech with even greater respiratory adjustments than the adults. These age groups of children terminated speech at lung volumes below the end-expiratory level and used a higher percentage of their lung capacity to achieve higher vocal intensity. In addition, the researchers found that 12- and 14-year old children used adultlike patterns when increasing dB SPL, including laryngeal adjustments and lung volume terminations near end-expiratory levels. In that study, Stathopoulos and Sapienza (1997) concluded that adults and 12- and 14-year old children made laryngeal adjustments to increase dB SPL, whereas younger age groups (4-, 6-, 8- and 10-year olds) tended to make respiratory adjustments to increase dB SPL. The present data show that 7-year old children tended to use laryngeal adjustments to increase dB SPL, which were similar to 12- and 14-year olds from Stathopoulos and Sapienza's study (1997). The significant difference found for lung volume initiations for productions during unstructured statements might be related to the fact that children were using more spontaneous speech and formulating their own sentences during picture narration. For example children might have used higher lung volumes not only to produce slightly louder utterances but also as an anticipatory gesture for the narration. Furthermore, another reason why lung volume initiation was found to be significant in the unstructured task might be because the linguistic load required in this activity was higher than that in the structured task. For example, children might have used higher lung volumes in anticipation of the linguistic demands required to formulate what they wanted to say during the spontaneous discourse.

The results from this study showed significant differences in lung volume initiations between questions and statements for the unstructured task but not the structured task. The findings are consistent those previously reported by Hoit et al. (1990) who indicated that lung volume initiation was significantly different on a spontaneous speaking task in 7-year-old children compared to adults. In that study, researchers found that during spontaneous speaking, 7-year old children initiated speech at higher lung volumes than those observed in older age groups (10- and 13-years). In the present study, it was noted that statements were initiated at larger lung volumes than questions. During the narrative task, questions were mostly prompted, were produced within one breath, and were shorter sentences. During statement production, children used more spontaneous speech associated with anticipatory behavior to narrate the story which would be more similar to the spontaneous task reported in the Hoit, et al. study (1990).

Unexpectedly, significant differences were found between questions and statements in the number of syllables per breath group in the structured task. It was expected that there would have been greater differences in the number of syllables per breath group during the unstructured task where spontaneous speech production would consist of larger number of syllables per breath group than the structured task. Hoit and colleagues (1990) found that when 7-year old children talked about a topic of their choice, they used fewer syllables per breath group than 10-, 13- and 16-year-olds. The present findings show that the number of syllables per breath group in question production was lower than in statement production only in the structured task; however, actual mean differences were so small that they do not indicate a meaningful behavioural observation.

**Limitations of the Study**

Although the findings would suggest that the breathing system played a small role in speech production in 7-year-old children, the present study had a small sample size. The power values obtained from SPSS on the structured task ranged between partial $\eta^2 = 0.09 – 1.0$, with all but one variable falling below 0.55, and on the unstructured task between partial $\eta^2 = 0.08 – 1.0$, with all but two variables falling below 0.55. Thus, a larger sample might provide more statistical power. Another limitation of the study was that only one age group was used. Assessing different age groups would give a better understanding about the relationship between breathing and prosody across childhood. It also would help us obtain normative data necessary for future treatment protocols for children with speech difficulties at different ages. Another limitation of this study was that, during the structured task, participants were often given models on how to produce questions, which could have affected their spontaneous performance on this task.

## Conclusions

This study sought to provide insights into the relationship between breathing and prosody during speech production in 7-year-old children. The results indicated that there was a relationship between breathing and prosody in the unstructured task, but not the structured task. Participants used primarily laryngeal adjustments to produce prosodic changes to mark questions and statements for both tasks, with the only exception of using lung volume initiation in the unstructured task. These findings provide data that address speech production in typical 7-year-old children. These data add to the literature that eventually will inform voice and speech treatment protocols for children with neurogenic communication disorders. Ultimately, clinicians will want to know whether they should focus on laryngeal adjustments, breathing adjustments, or both speech subsystems to improve suprasegmental aspects of speech.

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