

Acoustic and Respiratory Measures as a Function of Age in the Male Voice

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Received date: Nov 18, 2015; Accepted date: Dec 03, 2015; Published date: Dec 16, 2015

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Abstract

The purpose of this study was to extend understanding of the effects of aging on the male voice by obtaining and analyzing both acoustic and respiratory measures across the aging continuum. Aerodynamic measurements such as vital capacity (VC), maximum phonation time (MPT) and the acoustic measurement Speaking Fundamental Frequency (SFF) are used commonly in Speech-language Pathology to aid in the assessment and treatment outcomes of vocal dysfunction. However, current research lacks analysis of the interaction across these parameters within males. This study examined the changes of these parameters and interactions in males across various age groups. Acoustic measures of SFF, MPT, and VC were obtained in age groups of 20-29, 30-39, 40-49, 50-59, and 60-69, N=35. Age and SFF were found to be statistically significant. No other statistically significant interactions were observed.

Introduction

In the gerontological literature, the term 'aging' is often associated with individual who are 65 and over. Furthermore, aging is defined not only in chronological changes, but in terms of changes in societal roles and capabilities [1]. One of the major hallmarks of aging is its changes in capabilities as evidenced in physical characteristics. Physical changes are the most predominant measures of aging. One outstanding physical characteristic manifested in aging is in the area of the voice.

The most dramatic vocal changes are seen during the transition from childhood to adolescence. After decades of relative vocal stability, noticeable changes in the voice occur as a function of the aging process. For example, as the body ages, there is loss in muscle mass, thinning of mucosal membranes, as well as in coordination. These changes not surprisingly, are reflected in laryngeal function that leads to changes in the perceptual and acoustical characteristics of the voice.

Common age attributed characteristics of the elderly voice are hoarseness, breathiness, roughness, instability, reduced acoustic volume, changes in pitch and vocal tremor [2-4]. The quality of voice resulting from air loss, laryngeal tension, tremor, and additionally, there are different structural and physiological changes in the speech mechanism in men and women [13]. But structural changes alone in the speech mechanism may not clearly produce functional changes in speech production. It has been suggested that men and women may differentially adjust their speech to accommodate these changes [14]. The nature and extent of these anatomical, physical, and acoustic changes are still unclear, most notably in parameters such as maximum phonation time, vital capacity, and speaking fundamental frequency.

Maximum Phonation Time (MPT)

MPT is an accepted standard clinical task in speech-language pathology for the assessment of respiratory and phonatory function. [15,16]. MPT is defined as the longest period during which an individual can sustain phonation of a vowel sound, typically /a/. MPT

is used as a quick, noninvasive, low-cost diagnostic tool to assess vocal function. It measures laryngeal function in different pathological circumstances such as dysphonia and Parkinson's disease and is also useful in measuring improvement after voice therapy [17,18].

Several researchers have reported norms for MPT, however, there have been inconsistencies among these findings [17]. Kent et al., [15] found that MPTs appear to be longer in males than females presumably due to an average larger vital capacity. They also reported that MPTs were longer for individuals over 65 than previously reported but were shorter among younger individuals. Still, it is not clear to what extent MPT is influenced by age. Kent et al., [15] sought to gain data concerning several common clinical tests, one of which was maximum phonation time. Kent et al., [15] noted that a reduced MPT may be attributable to an inadequate volume of air used during phonation or to excessive wasting of air during phonation as a result of poor laryngeal valving and thus concluded that MPT alone is not a useful determinate of respiratory inefficiency. Solomon Garlitz, Milbraith [16] combined measurements of lung volume with standard maximum phonation time measures. They did not find a systematic relationship between MPT and vital capacity (VC) but found that there was a difference in terms of laryngeal airway resistance task between the men and women tested. For men the laryngeal airway resistance increased linearly as lung volume decreased but not for women.

Vital capacity is the greatest volume of air that can be expelled from the lungs after taking the deepest breath possible. It is related to the quantity of air available for phonation. Age related reduction in the vital capacity directly reduces the amount of air available to be expelled for phonation. This reduction in air available for phonation contributes to various age-related changes in speech production [11]. Total Lung Capacity (TLC) is the total volume of air in the lungs after a maximal inhalation. Tidal Volume (TV) is the amount of air that is inspired and expired from the lungs during a cycle of quiet respiration. Inspiratory reserve volume (IRV) is the volume that can be inhaled after a tidal inspiration, while, Expiratory Reserve Volume (ERV) is the amount of

air that can be expired following a tidal expiration. Even after a maximal exhalation there is air left within the lungs, this volume is referred to as Residual Volume (RV). Vital Capacity (VC) is defined as the maximal amount of air that can be taken into the lungs after a maximal exhalation or $VC = IRV$ (inspiratory reserve volume) + ERV (expiratory reserve volume) + TV (tidal volume) [19].

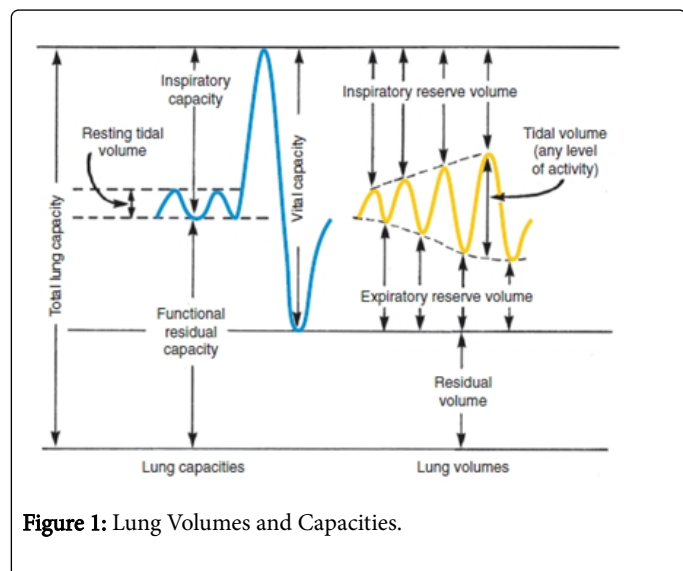


Figure 1: Lung Volumes and Capacities.

Total lung capacity (TLC) remains relatively the same across the adult lifespan, while vital capacity (VC), inspiratory capacity (IC), and expiratory reserve volume (ERV) diminish with age [20]. Rochet [21] reported that changes in pulmonary function due to aging become measurable around the age of 40. While there are declines in the respiratory system of both men and women, these changes are greater in women than men [2].

VC is known to be influenced by an individual's age, sex, and height [15]. There are numerous studies which provide normative data for both men and women [15,22,23]. One recent study utilizing the Phonatory Aerodynamic System (PAS) found that the mean expiratory volume for males was 4.14 for ages 18-38; 4.19 for ages 40-59, and 3.09 for ages 60-89 [23].

Another aerodynamic measure that provides valid basic information regarding vocal fold efficiency is fundamental frequency (F0). F0 is the acoustic correlate of pitch. It is determined by the rate at which the vocal folds open and close per second. The rate of vocal fold opening and closing does not remain constant while speaking; therefore, acoustic frequency does not remain the same throughout speech. F0 is the lowest frequency in a sound sample [24]. F0 can be derived from isolated vowels, reading or connected speech. When fundamental frequency is derived from connected speech it is often referred to as speaking fundamental frequency and describes the average frequency across an utterance [25-27]. A measurement of speaking fundamental frequency can be obtained from any speech sample. In a clinical or research setting there are multiple ways to elicit a speech sample to determine the SFF. Zraick, Skaggs and Montague [28] examined four different elicitation tasks for SFF: automatic speech, elicited speech, spontaneous, and reading aloud. They reported no significant differences in SFF between different elicitation tasks. Siupsinskiene & Lycke [29] investigated average speaking fundamental frequency for adult males and females. They reported that the range of SFF for men was 89.0-175.0 Hz with a mean of 112.4 Hz, while the

range for females was 164.5-260.0 Hz with a mean of 212.4 Hz. F0 is a commonly assessed measure by speech-language pathologists when evaluating voice disorders [30].

A speaker's fundamental frequency is not constant rather, there is variability of the frequencies produced. This variability of frequency is measured in one of two ways, standard deviation of F0 or in semitones called pitch sigma. The average standard deviation of fundamental frequency (F0,SD) for both men and women is 25 to 30 Hz [25]. Using pitch sigma, Siupsinskiene & Lycke [29] reported that men have a range of 7.5 to 21.0 with a mean of 14.5 while females have a range of 5.2 to 16.1 with a mean of 10.7.

Age related changes in SFF indicate that, for men, F0 drops approximately 10 Hz until around age 50 and then begins to gradually increase by up 35 Hz afterwards. On the other hand, for women, there appears to be a continuous decrease in F0 with age, or it stays constant until menopause after which time it decreases anywhere from 10 to 35 Hz [31-33].

Researchers have attributed changes in speaking fundamental frequency to differences in anatomical and physiological changes in men and women [34-37]. Men tend to exhibit an increase in F0 due to vocal fold atrophy, in contrast, females tend to exhibit a decrease in F0 post-menopause as a result of reductions in vocal fold mass. There have been several investigations into changes of fundamental frequency across age groups that show this trend [34,38-41,27]. The impact of hormonal changes prior, during and post menopause to the voice are extensive in the literature [42]. These hormonal changes during the menopause can cause additional vocal alterations [42]. While males do experience hormonal changes throughout their life, they are drastically different from the changes experienced by females [43]. The menopausal voice has been associated with a decreased vocal frequency range and decreased fundamental frequency [44].

Currently not many studies have attempted to systematically examine the acoustic changes in the male voice combining maximum phonation time, vital capacity and fundamental frequency rates. We predict that such measurements will be reflective of greater accuracy in establishing norms for changes in the male voice as a function of age.

The purpose of this investigation is to provide preliminary data that would address the following questions:

- 1) Are maximum phonation time measures and vital capacity related in males?
- 2) Does MPT decline across age groups in males?
- 3) Does SFF change across age groups in males?

Concerning the first question, it was hypothesized that MPT and VC will be related. Since MPT requires the voluntary expulsion of air, a reduction in available air from a reduced VC would naturally reduce the duration of MPT. Conversely, an increase in VC would provide more air for phonation and lengthen the duration of MPT. To the best of our knowledge, the study by Awan [34] was the only study that directly compared VC and MPT. However, this study only used female participants. Since there are established differences in vital capacities and respiratory aging patterns in females, it would be of interest to test the extent of this correlation in males.

Addressing the second question, we further hypothesized that both MPT and VC will be reduced as a function of age. VC is known to decrease with age in both males and females [45]. However, there is less agreement about the nature of changes in MPT with age. Kent et

al., [15] and Maslan et al., [17] both reported a reduction in MPT in individuals over age 65 but Maslan's data showed less of a decline in MPT in elderly individuals than previously reported in both males and females. Maslan et al. [17] investigated norms for MPT and reported that, on average, males had longer MPTs than females and presumed that this was due to the fact that, on average males, have a higher VC. However, Maslan et al. [17] did not incorporate VC into their investigation. Awan [34] established a correlational reduction of MPT and VC with age. The fact that not much is known about the nature of decline in MPT across the lifespan in males prompts the need for further investigation.

Thirdly, we hypothesized that SFF will increase with age in males. This would be consistent with previous reports [31-33,46,47].

Methodology

The investigation, materials, and procedures were approved by the Institutional Review Board (IRB) of Cleveland State University. Participants were recruited on the campus of Cleveland State University and the general public. A total of thirty five individuals participated in this study. There were no financial incentives provided for participation.

The investigators recruited, screened and collected data for all participants. All data were collected in the voice laboratory of the Speech and Hearing Clinic at Cleveland State University. All participants agreed and signed the consent form after discussing with one of the examiners.

Screening

Based on self-report, prospective participants were screened for laryngeal pathologies and other health conditions that could affect the voice. Exclusionary conditions self-reported by participants were asthma, sinus problems, acid reflux, use of antihistamines, vocal fold pathology, emphysema or neuromotor impairment that may impact the voice. Prospective participants were also asked to self-report if they currently had a respiratory infection. Current users of tobacco and any within the past five years were excluded from the study. See screening questionnaire in Appendix A

Two instruments were used to record the acoustic and respiratory measures. The Visi-Pitch IV (Model 3950)/Sona-Speech II (Model 3650) with a Shure hand-held microphone were used to record and analyze all speech samples at a sampling rate of 50 kHz. Acoustic data were collected and analyzed using the Real-Time Pitch module, a component of Visi-Pitch, which allows the user to capture a speech signal and perform a variety of acoustic analyses. The Real-Time Pitch module was also used to determine MPT. The spirometer used to measure vital capacity was a Buhl type hand-held spirometer produced by Baseline. Each participant received a disposable plastic mouthpiece which was discarded after use. Each data elicitation task was preceded by the investigator reading an explanatory script explaining what the participant needed to do in order to perform a task.

To obtain vital capacity measures participants were asked to breathe in as deeply as possible and exhale maximally into the handheld spirometer in order to measure vital capacity. The investigator offered an example of a maximal inhalation and exhalation. The higher of two trials was taken as a measure of vital capacity

Participants were asked to take the largest breath possible and sustain the vowel /a/ for the longest possible time. The experimenter

provided a verbal description of the maximum phonation time task then offered a demonstration. (See Appendix B). The longer of two trials was used. This measure was calculated using the Visi-Pitch-IV Maximum Phonation Time protocol. For the average Fundamental Frequency measures, participants spoke into a hand-held microphone placed four to six inches away from their mouths. Participants were asked to read an excerpt from the "Rainbow Passage" at a comfortable volume (see Appendix C). The Visi-Pitch Real-Time Pitch module was used to calculate the average speaking fundamental frequency across the reading sample. Average Fundamental Frequency in Hz was defined as the average value of all extracted period-to-period fundamental frequency values, excluding voice break areas (Kay Elemetrics Corp., 2004). This measure was calculated using the Visi-Pitch-IV Speaking Fundamental Frequency protocol.

Results

Participant Data

Descriptive statistics for the participants and all measures were calculated. The number of participants in each age group, mean age within group, and standard deviation are presented in Table I.

| Age Group | Number of Participants | Mean Age within Group | SD of Age |
|--------------|------------------------|-----------------------|-----------|
| 20-29 | 10 | 22.7 | 2.541 |
| 30-39 | 5 | 34.6 | 3.050 |
| 40-49 | 6 | 42.5 | 2.074 |
| 50-59 | 9 | 55.11 | 2.619 |
| 60-69 | 5 | 62.6 | 1.817 |
| Total | 35 | 41.82 | 15.2 |

SD = Standard Deviation

Table I: Participant demographic data.

Group means and standard deviations for SFF, VC, and MPT are presented in Table IV of SFF, VC, and MPT. The highest SFF was within the 30-39 year old group. The highest mean MPT and VC were in the 40-49 year old group.

| Age Group | Mean SFF | SD of SFF | Mean MPT | SD of MPT | Mean VC | SD of VC |
|--------------|----------|-----------|----------|-----------|---------|----------|
| 20-29 | 121.547 | 14.867 | 19.534 | 7.341 | 4.08 | 0.986 |
| 30-39 | 128.376 | 12.073 | 17.38 | 5.784 | 3.17 | 0.844 |
| 40-49 | 117.16 | 6.034 | 26.89 | 1.732 | 4.60 | 1.025 |
| 50-59 | 114.2467 | 14.631 | 15.93 | 7.561 | 3.33 | 0.871 |
| 60-69 | 112.946 | 6.284 | 16.84 | 4.890 | 3.36 | 0.698 |
| Total | 118.665 | 12.757 | 19.176 | 7.035 | 3.74 | 1.004 |

SFF=Speaking Fundamental Frequency; MPT=Maximum Phonation Time; VC=Vital Capacity; SD=Standard Deviation.

Table 2: SFF, MPT And VC of groups and total participants.

Analysis of acoustic and respiratory measures

A series of Pearson product-moment correlations between all variables: age, MPT, VC, and SFF were calculated. Additionally, scatter plot diagrams are provided with the measures that were compared using the Pearson product-moment with the line of best fit. Sigma Plot 11.0 was used to calculate the results and scatter plot figures.

The data from all age groups were analyzed with respect to whether there was a correlation between age and MPT. A Pearson product-moment correlation was calculated to determine the relationship between age and MPT. There was no significant correlation between age and MPT ($r=-1.46$, $p>.05$). A scatterplot representing the relationship between age and MPT is presented in Figure 2.

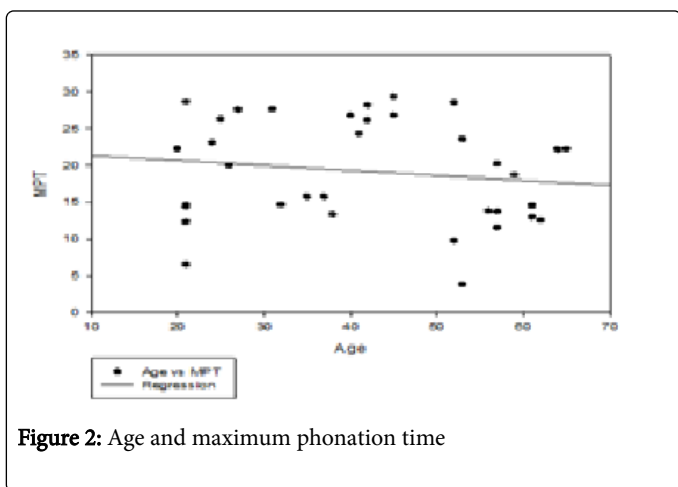


Figure 2: Age and maximum phonation time

The data from all age groups were analyzed with respect to whether there was a correlation between age and VC. A Pearson product-moment correlation was calculated to determine the relationship between age and Vital Capacity. There was no significant correlation between age and MPT ($r=-3.08$, $p>.05$). A scatterplot representing the relationship between age and Vital Capacity is presented in Figure 3.

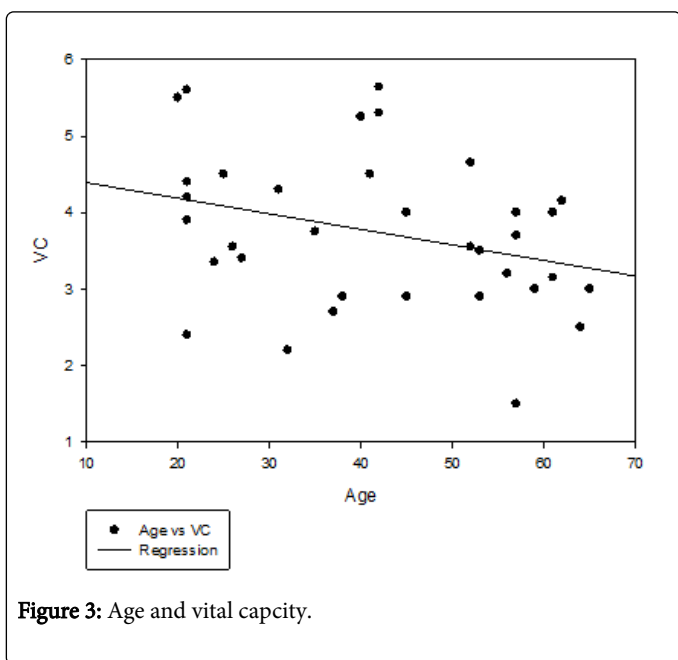


Figure 3: Age and vital capacity.

The data from all age groups were analyzed with respect to whether there was a correlation between age and SFF. A Pearson product-moment correlation was calculated to determine the relationship between age and Speaking Fundamental Frequency. There was a significant correlation between age and SFF ($r=-3.06$, $p<.05$). A scatterplot representing the relationship between age and SFF is presented in Figure 4.

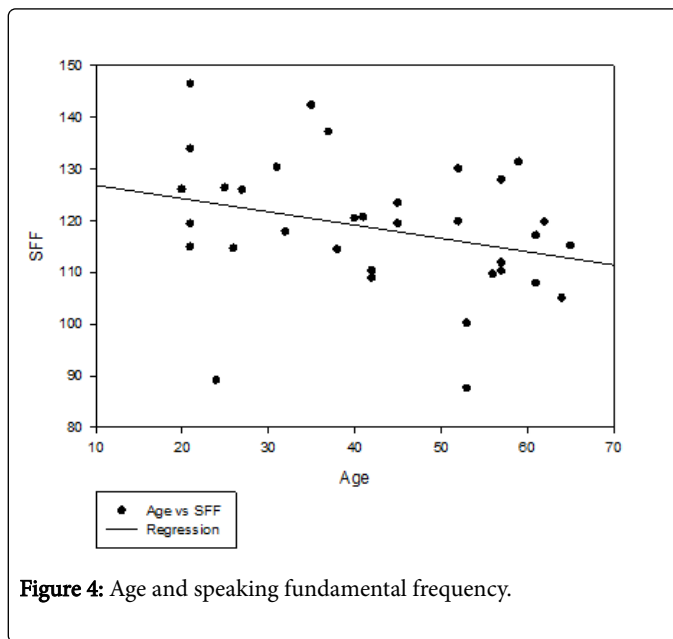


Figure 4: Age and speaking fundamental frequency.

The data from all age groups were analyzed with respect to whether there was a correlation between VC and MPT. A Pearson product-moment correlation was calculated to determine the relationship between VC and MPT. There was no significant correlation between VC and MPT ($r=.323$, $p>.05$). A scatterplot representing the relationship between VC and MPT is presented in Figure 5.

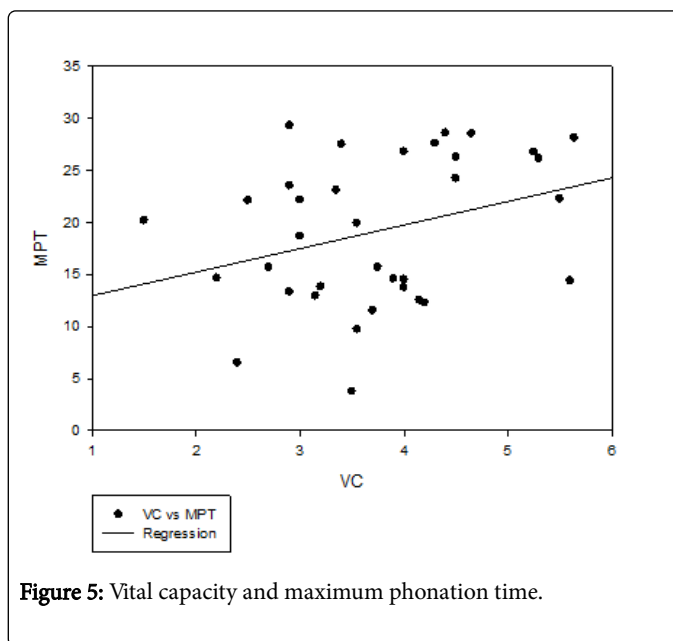


Figure 5: Vital capacity and maximum phonation time.

The data from all age groups were analyzed with respect to whether there was a correlation between MPT and SFF. A Pearson product-

moment correlation was calculated to determine the relationship between MPT and SFF. There was no significant correlation between MPT and SFF ($r=.089$, $p>.05$). A scatterplot representing the relationship between MPT and SFF is presented in Figure 6.

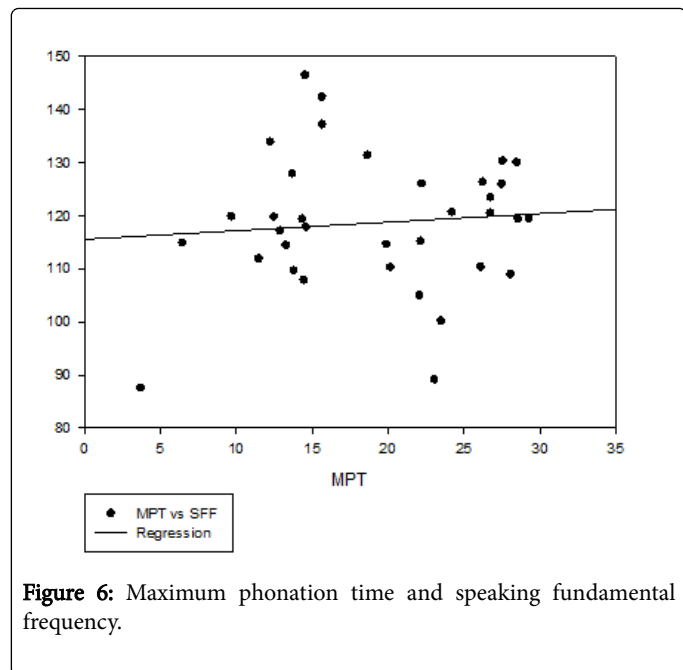


Figure 6: Maximum phonation time and speaking fundamental frequency.

The data from all age groups were analyzed with respect to whether there was a correlation between VC and SFF. A Pearson product-moment correlation was calculated to determine the relationship between VC and SFF. There was no significant correlation between VC and SFF ($r=.185$, $p>.05$). A scatterplot representing the relationship between VC and SFF is presented in Figure 7.

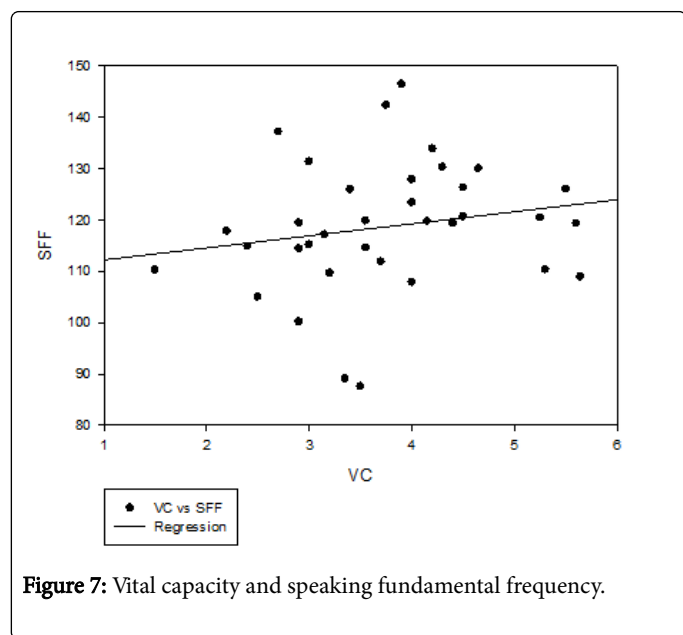


Figure 7: Vital capacity and speaking fundamental frequency.

A one-way ANOVA was calculated between MPT and VC was calculated. The ANOVA revealed no statistical significance between MPT and VC ($F=1.202$, $df=27$, $p=.43$, $p<.05$). The results of the ANOVA are presented in table 3.

| MPT | Sum Squares | of Df | Mean Square | F | Sig. |
|----------------|-------------|-------|-------------|-------|-------|
| Between Groups | 1384.174 | 27 | 51.266 | 1.202 | 0.430 |
| Within Groups | 298.641 | 7 | 42.663 | - | - |
| Total | 1682.814 | 34 | - | - | - |

Table 3: ANOVA of MPT and VC.

Discussion

The research questions proposed in this study are as follows:

- 1) MPT and VC will be related in males
- 2) MPT and VC will decline across age groups in males
- 3) SFF will increase across age groups of males

Regarding the first question, visual inspection of the scatterplot in Figure 5 shows that an increased VC is consistent with an increased MPT. However, the Pearson product-moment found no statistical correlation between MPT and VC, ($r=.323$, $p>.05$). Additionally the ANOVA that was calculated comparing MPT and VC showed no correlation, ($F=1.202$, $df=27$, $p=.43$, $p<.05$). The lack of correlation could be attributable to several factors. Firstly, this study was comprised of only thirty five participants. The scatterplot shown in Figure 5 visually suggests a correlation but statistical tests failed to show a correlation. Perhaps with more participants a statistical significance would have been reached. Alternatively, participants with lower vital capacities may be able to effectively compensate while producing MPTs.

Regarding the second hypothesis, MPT and age were not found to be statistically significant, ($r=-1.46$, $p>.05$). VC and age were also not found to be statistically significant ($r=-3.08$, $p>.05$). However, a visual inspection of Figure 2 comparing MPT with age and Figure 3 comparing VC with age visually show a negative correlation of both measures with age. The failure to reach statistical significance could be attributable to a small number of participants. Additionally, chronological age may not be a strong predictor of these measures; rather, other factors including physiological age, height, weight, and activity levels may be better predictive factors.

Regarding the third hypothesis, SFF will increase with age; the results of this study revealed a statistically significant negative correlation of age and SFF in males by calculating a Pearson product-moment ($r=-3.06$, $p<.05$). Figure 4 shows a decrease in SFF with age. These results were inconsistent with previous reports of fundamental frequency increasing with age in males. It has been suggested that the possibility for elderly men to attempt to compensate for high-pitched unstable voice and for elderly woman to attempt to avoid a deep voice [48]. Perhaps, men compensated for a natural increase in fundamental frequency while reading the passage.

Limitations of the study

There were several limitations to this study and the results represent preliminary data of a pilot study. The most significant limitation was the number of participants, $N=35$.

This study was also limited by type of instrumentation used. Despite being a medical grade hand-held spirometer it was only accurate to .05 liters. Additionally, spirometer was analog, therefore requiring the experimenter to read the volume.

There were several known influencers of VC, MPT, and SFF that were not included in the study. There were no controls for the height or weight of participants which are both known influencers of both VC and F0 [25]. Additionally, the study did not control for the activity levels of participants. The activity level of a participant would be assumed to directly affect VC. Race and ethnic background were not considered in the participation criteria or organization of the data and groups. Race and voice interactions have been suggested by [25].

CONCLUSION

The purpose of this study was to examine the effects of age on acoustic and respiratory measures and the interaction between VC and MPT. Data analysis demonstrated that there were no statistically significance between MPT and VC, and similarly no interaction between MPT and VC with age. There was however, a statistically significant interaction between age and speaking fundamental frequency. There was a decrease in SFF as a function of age. Even though the knowledge gained from this study is extremely modest, it is relevant for diagnosis and assessing treatment outcomes using acoustic and aerodynamic measurements as more studies in this area are carried out. Clinical Implications.

VC and MPT are measures routinely used by speech-language pathologists during informal assessments and are incorporated within assessment protocols. These measures are used by clinicians to make judgments about breath support for speech production. Breathe support has been defined as the reservoir of available air for speech production along with the efficiency of valving and air control at the level of the vocal folds. VC is a measure of the total amount of air available for phonation, while MPT provides a measure regarding an individual's functional ability to use available air. A large VC paired with a low MPT could indicate that an individual is unable to functionally use all of the air available during a sustained vowel task. Conversely, a low VC paired with a high MPT could indicate a high level of efficiency at the glottal level. This study did not yield a statistical correlation between these two measures, nevertheless, a reduced VC or MPT both reflect an underlying deficit of the speech and respiratory system. Given the results of this study, a clinician cannot measure either variable and reliably assume about the other. It must be noted that any correlations or lack of correlation between MPT and VC in healthy speakers may not be true of those with vocal disorders or other disease processes. When analyzing functional use of voice, MPT is a test of maximum performance; therefore, it might not accurately reflect an individual's ability to use their voice during everyday speech tasks.

Interest in VC and MPT extends beyond the identification and treatment of vocal pathologies. VC and MPT are of clinical interest for individuals experiencing difficulty with adequate respiratory volume or ability to produce speech for sustained durations during activities such as lecturing, singing, and continued talking. Improvement of VC may result in an individual possessing a larger volume of air to use for phonation. An increase in VC could result in an increased ability to functionally use one's voice for longer durations and at increased volume. This study's findings that VC and MPT are not statistically correlated suggest that an individual interested in improving the length

of ability to speak should not be primarily concerned with increasing VC.

The lack of correlation between both MPT and VC with age is important for clinicians making judgments about an individual's speech and respiratory system. The clinician should consider factors such as physiological age, height, weight, and activity levels in addition to chronological age.

Previous research has shown an increase in fundamental frequency with age in males; however this study showed a decrease in speaking fundamental frequency with age. Fundamental frequency is often obtained using a single vowel sound while SFF is obtained using connected speech. Co-articulatory factors across a speech sample could influence the average fundamental frequency resulting in a lower frequency than when measured in isolated vowel sounds. The result of this study show an age related reduction in SFF similar to that which was displayed in females in Awan [34]. This demonstrates that a reduction in SFF within males is typical with age.

It has also been suggested that perhaps elderly men to attempt to compensate for high-pitched unstable voice [47]. If indeed men's fundamental frequency increases with age and the results of this study reflect a compensatory behavior in men. If this is so, clinicians need to consider the results of data collected on measures like SFF considering the possibility of compensatory behaviors, not just physiologic changes.

Future research

Despite the clinical reliance on MPT, VC, and SFF during voice evaluations these measures have not been used extensively in the same research design and directly compared to each other. A future study could examine the interaction of these measures in both males and females in the same research design. A future study could group participants based on height, weight, physiologic age, and activity levels. Other parameters of respiratory function could also be included such as phonation quotient and peak expiratory flow.

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