Research Article

The Normative Study of Acoustic and Aerodynamic Characteristics of Voice among Healthy Adult Turkish Speaker Population

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1. Introduction

Healthy voice is of utmost importance for flawless communication. In some cases, communication might be interrupted by some voice disorders. The nature of voice disorders is complex, so is its assessment. For a comprehensive assessment of voice function, one needs to have a comprehensive story of the case, to mind the psychosocial context, and to evaluate the vibrational characteristics of the larynx and vocal folds. Among the means modern clinicians employ to evaluate voice are acoustic, aerodynamic, and endoscopic techniques—besides visual and perceptual assessment methods [1].

A comprehensive voice assessment constitutes a vital phase of an individualized and successful treatment program. The clinician should first conduct a comprehensive oral peripheral examination and a hearing test and should take a language and speech sample. The clinicians are advised to use all available perceptual and instrumental assessment methods they have [2].

In the evaluation of clients with voice disorders, whenever possible, the effect of the pathology on all relevant mechanisms/dimensions is determined by obtaining detailed information from the case about the voice complaint and following the following evaluation steps: auditory-perceptual...
evaluation, laryngeal endoscopic imaging, acoustics and aerodynamics evaluation, and the effect of voice disorder on their daily life [3, 4].

The acoustic analysis of voice function provides flawless noninvasive measurements of voice production, helps in discriminating normal from pathological voice, and measures the changes of voice in time [5]. Acoustic voice analysis helps to get information method in clinical research and useful in detecting underlying laryngeal pathologies with a close examination of signals emanating from the mouth in order to avoid misunderstanding that the voice analysis is the main part of the diagnostic process. Moreover, acoustic measurements are a common and significant means to evaluate the efficiency of voice therapy practices [6].

Aerodynamic measurements indicate the measurements of the flow, volume, and average pressure of the air produced by respiratory, laryngeal, and supralaryngeal airway mechanisms. Experts use aerodynamic measurements to evaluate dysphonia, to monitor voice changes during treatment, and to distinguish laryngeal and respiratory problems from each other [7].

Since human voice has a complex structure and influenced by individual characteristics, the definition of standard normal voice is so important. Voice disorders can be seen in all ages and in all genders; thus, normative values of voice for all age groups should be determined for objective assessment [8].

Phonatory Aerodynamic System (PAS Model 6600) (KayPENTAX Corp., Lincoln Park, NJ) is an instrument used in the assessment of voice disorders. It also enables the researchers to get objective measurements about the acoustic and aerodynamic characteristics of voice. PAS is an evaluation instrument that assesses the effectiveness of surgical interventions, treatments, and therapy for voice disorders. It can be used for the assessment of voice disorders by supporting other perceptual and instrumental methods. PAS consists of seven protocols: (1) air pressure screening (APSC), (2) vital capacity (VC), (3) maximum sustained phonation (MSPH), (4) comfortable sustained phonation (CSPH), (5) variation in sound pressure level (VSPL), (6) voicing efficiency (VOEF), and (7) running speech (RS). By these protocols, 45 acoustic and aerodynamic measurements can be collected.

First known report of adult normative data obtained with PAS 6600 was published in 2013 by Zraick et al. [9]. A sample of 89 female and 68 male participants (157 participants per total) took part in the research, and they were divided into three age groups (18-39, 40-59, and 60+ years). To establish normative data, six PAS protocols were applied to participants. Researchers obtained normative data for 45 acoustic and aerodynamic parameters and investigated whether the data obtained age and gender dependent. In their study, Weinrich et al. aimed to (1) establish normative data of PAS measurements in the pediatric groups and to (2) determine whether age and/or gender has an influence on the outcomes [10]. Finally, Kim reported adult normative data for some phonatory aerodynamic parameters in Korea. In this research, Kim examined 70 male and 100 female participants between the ages of 18 and 49 years. Maximum sustained phonation and voicing efficiency protocols of PAS were applied to participants. Normative data for 25 acoustic and aerodynamic measurements were obtained, and intra-subject reliability was tested. In this study, in contrast to the former two, the age variable was excluded, and only the influence of gender was examined [11].

The primary purpose of the present study is to establish adult normative data for 45 acoustic and aerodynamic parameters obtained with PAS Model 6600 in Turkish-speaking healthy adults without voice disorders, considering the variables of age, gender, and gender-age interaction. In the related literature in Turkish, normative data were only gathered for fundamental frequency and perturbation measurements. Therefore, contribution of the present study is considered so important since it will generate normative data for all measurements—except the mean pitch—by the five protocols of PAS for the very first time.

The main questions of the study are as follows:

(1) Are the acoustic and aerodynamic measurements obtained from PAS protocols influenced by gender, age, and gender-age interaction variables?

(2) What are the norm values of PAS for Turkish-speaking healthy adults?

2. Materials and Methods

2.1. Design. In the present study, normative data for acoustic and aerodynamic parameters of PAS are established by intergroup prospective data acquisition pattern method. The independent variables of the research are age and gender. The dependent variables are 45 phonatory measurements in the five protocols of PAS.

2.2. Participants. Normative data was collected from 206 adults. The ages of the 206 participants (106 females and 100 males) of this research vary from 18 to 87. The participants’ mean ages were 46 and 83 (SD = 17, 45). Female participants’ mean ages are 46 and 64 (SD = 17, 51), and male participants’ mean ages are 47 and 67 (SD = 17, 44). The participants are categorized in three age groups (18-39, 40-59, and 60+), and each age group is categorized into two according to gender. Thus, the total number of groups is six. In the 18–39 age group, there are 41 female participants (mean ages 28, 27 (SD = 7, 07)) and 35 male participants (mean ages 28, 37 (SD = 6, 56)). In the 40–59 age group, there are 35 female participants (mean ages 47, 63 (SD = 5, 70)) and 35 male participants (mean ages 48, 86 (SD = 5, 61)). In the 60+ age group, there are 30 female participants (mean ages 68, 47 (SD = 5, 77)) and 30 male participants (mean ages 68, 80 (SD = 6, 21)).

The participants of the study were monolingual Turkish-speaking volunteer adults who do not have any breathing problems, any hearing and speaking disorders, any neurological problems, and who do not smoke. All participants were evaluated informally and perceptually in terms of language, speech, and voice during the clinical interview by two speech and language therapists who are experts in the field of speech and language therapy. Moreover, the
participants were required to evaluate their own voices and to fill in Voice Handicap Index. Participants who had voice disorders were not included in the research. On the day of data collection, participants who had flu or seasonal allergies and female participants in their menstruation period were also excluded.

2.3. Instrumentation. In this study, PAS Model 6600 was used to obtain acoustic and aerodynamic data from the participants. The PAS is a computer-based software and hardware system designed to measure airflow, air pressure, and other acoustic and aerodynamic characteristics about voice, and it includes measurements of mean phonatory flow velocity, sound pressure level, base frequency, vital capacity, subglottal resistance and subglottal pressure, and efficiency measurements. PAS is able to record and monitor phonatory aerodynamic data simultaneously [5]. PAS consists of seven protocols: air pressure screening, vital capacity, maximum sustained phonation, comfortable sustained phonation, variation in sound pressure level, voicing efficiency, and running speech. These protocols provide 45 acoustic and aerodynamic measurements. With the data acquired by PAS, 29 statistics can be calculated, and the wave for each of the sound can be sampled and played on the computer card. The hardware of the portable PAS device consists of an integrated microphone, an airflow cap, a mask and an airflow tube, and an intraoral tube. The software uses Microsoft Windows 2000/XP.

2.4. Procedure. This study was approved by the Ethical Committee of Anadolu University. Participant notification and consent forms were presented to the attention of all participants; they were informed about the research, their rights, responsibilities, and the researchers’ responsibilities in detail. The participants who read the consent form and enrolled the participant were required to continue with the following:

(i) Air pressure screening (APSC): The main aim of this protocol was screening. Intraoral tube and leak tube were used together in this protocol. Intraoral tube was positioned between the lips and the leak tube on the corner of the two lips. The participant was required to apply a pressure of 5 cm H2O for 5 seconds. The participants who passed this protocol were required to continue with the following

(ii) Vital capacity (VC): The participant, while the mask was on, was required to take a deep breath and exhale into the mask as if she was exhaling towards a candle at a distance until she was run out of breath. The measurements obtained from this protocol included expiratory airflow duration, peak expiratory airflow, and expiratory volume

(iii) Maximum sustained phonation (MSPH): The participant was required to take a deep breath with the mask on and to sustain the phonation /ʌ:ʌ/ in natural pitch and volume as long as she can. The measurements obtained from this protocol included maximum SPL, minimum SPL, mean SPL, SPL range, mean SPL during voicing, mean pitch, phonation time, peak expiratory airflow, mean expiratory airflow, and expiratory volume

(iv) Comfortable sustained phonation (CSPH): The participant was required to take a deep breath with the mask on and to sustain the phonation /ʌ:ʌ/ in natural pitch and volume for seven seconds. The first and the last seconds were excluded from the analysis, and five seconds in between was analyzed. The measurements obtained from this protocol included maximum SPL, minimum SPL, mean SPL, SPL range, mean pitch, phonation time, peak expiratory airflow, mean expiratory airflow, and expiratory volume

(v) Variation in sound pressure level (VSPL): The participant, with the mask on, was required to repeat the syllable /pa:pa:pa/ three times without any phonation break in three different loudness levels (comfortable, soft, and loud). The measurements obtained from this protocol included maximum SPL, minimum SPL, mean SPL, SPL range, mean pitch, pitch range, and target airflow
And this data is categorized into age and gender groups for and range of normative data obtained from 157 participants. Acoustic and aerodynamic PAS parameters were established. Analyzed according to the variables of age, gender, and Table 1. ANOVA results of all parameters of PAS protocol among groups, Holm-Sidak test was employed to determine variance. In the cases where a significant difference was detected among groups, Holm-Sidak test was employed to determine which group was the source of difference.

3. Results

In this research, normative data for 45 acoustic and aerodynamic measurements of PAS were acquired, and the influence of age, gender, and gender-age interaction was analyzed. The findings indicated that age variables influenced 19 parameters, gender variables influenced 30 parameters, and gender-age interaction influenced 6 parameters. The remaining 10 parameters did not reach statistical significance. P values of PAS parameters, intergroup comparison findings, and data on power analysis can be found in Table 1. ANOVA results of all parameters of PAS protocol can be found in Table 2.

For the second aim of the study, the acquired data was analyzed according to the variables of age, gender, and gender-age interaction, and the normative data for the acoustic and aerodynamic PAS parameters were established. Table 3 includes the data on the means, standard deviations, and range of normative data obtained from 157 participants. And this data is categorized into age and gender groups for all parameters of all PAS protocols.

4. Discussion

The main aim of this study is to establish normative data for the acoustic and aerodynamic characteristics of voice in Turkish-speaking healthy adults, by using PAS protocols. The study examines the influence of the variables of age, gender, and gender-age interaction. The present study is the third research in the literature after the researches of Zraick et al. [9] and Kim [11]. The findings of the present study were initially compared with the findings of these two because such a comparison with other studies is limited since different tools were used in each study, and their age groups were different from each other. However, other studies were cited when possible.

In this section, the comparison among these studies primarily demonstrated the influence of the variables of age, gender, and gender-age interaction on the parameters. Then, for the second aim of the study, the parameters of PAS protocol were categorized in groups such as airflow measurement, sound pressure level measurement, pitch measurement, and air pressure measurement. The influences of the variables age, gender, and gender-age interaction on these measurements were compared to the findings of other studies.

4.1. Age Effects. Age variable has effects on expiratory volume in vital capacity protocol; on maximum SPL, minimum SPL, SPL range, phonation time, peak expiratory airflow, and expiratory volume in maximum sustained phonation protocol; on mean SPL, pitch range, and target airflow in variation in sound pressure level protocol; and on maximum SPL, mean SPL, expiratory airflow duration, peak air pressure, mean peak air pressure, expiratory volume, aerodynamic resistance, and acoustic ohms measurements in voicing efficiency protocol.

4.2. Gender Effects. Gender variable has effects on expiratory volume, expiratory airflow duration, and peak expiratory airflow in vital capacity protocol; on mean pitch, phonation time, peak expiratory airflow, mean expiratory airflow, and expiratory volume in maximum sustained phonation protocol; on mean pitch, peak expiratory airflow, mean expiratory airflow, and expiratory volume in comfortable sustained phonation protocol; on minimum SPL, mean SPL, mean pitch, pitch range, and target airflow in variation in sound pressure level protocol; and on mean pitch, pitch range, expiratory airflow duration, peak air pressure, mean peak air pressure, peak expiratory airflow, target airflow, expiratory volume, mean airflow during voicing, aerodynamic power, aerodynamic resistance, acoustic ohms, and aerodynamic efficiency measurements in voicing efficiency protocol.

4.3. Age and Gender Interaction. Age-gender interaction variable has effects on minimum SPL, SPL range, and mean pitch in maximum sustained phonation protocol; on mean pitch in comfortable sustained phonation protocol; on mean pitch in variation in sound pressure level protocol; and on mean pitch measurements in voicing efficiency protocol.

The changes in voice resulting from ageing consist of pitch changes, irregular vocal fold vibrations, glottal inefficiencies, air loss and breathy voice, laryngeal tension, and muffled voice. As Kahane [12] claims, the indications of ageing are more obvious in male voices; however, both male and female voices age. The findings of perceptual, physiologic, and acoustic studies show that the changes in voice resulting from ageing depend on the transformation of larynx tissues and on anatomic and physiologic transformations. In our study, the findings of the measurements related to the airflow, i.e., expiratory volume, peak expiratory airflow, mean expiratory airflow during voicing, target airflow, and mean airflow during voicing, show that anatomical and physiologic transformation in the laryngeal mechanism due to ageing affects airflow: Airflow measurements decrease due to ageing. Related literature includes many studies that show ageing has different effects on the phonatory behaviors of
| Protocol and parameter | P value | Post hoc results | Power |
|------------------------|---------|------------------|-------|
| Vital capacity         |         |                  |       |
| Expiratory airflow     |         |                  |       |
| Gender                 | <0.001  | Males > females  | 0.942 (80) |
| Peak expiratory airflow| <0.001  | Males > females  | 0.988 (80) |
| Expiratory volume      | <0.001  |                  |       |
| Age                    | <0.05   | Younger adults > older adults | 1.000 (80) |
| Gender                 | <0.05   | Middle-aged adults > older adults | 1.000 (80) |
| Maximum sustained phonation |   |                  |       |
| Maximum SPL            |         |                  |       |
| Age                    | <0.05   | Middle-aged adults > younger adults | 0.621 (60) |
| Minimum SPL            |         |                  |       |
| Age                    | <0.01   | Younger adults > older adults | 0.621 (60) |
| Gender-age             | <0.05   |                  |       |
| 18-39 age              |         | Males > females  | 0.627 (60) |
| Females                | <0.05   | Females > males  |       |
| Erkek                  | NS      | Younger adults > older adults | Middle-aged adults > older adults |
| SPL range              |         |                  |       |
| Age                    | <0.01   | Older adults > younger adults | Middle-aged adults > younger adults | 0.924 (80) |
| Gender-age             | <0.05   | Males > females  | Middle-aged adults > younger adults |
| 18-39 age              | <0.05   |                |       |
| 40-59 age              | <0.05   |                |       |
| Females                | <0.05   | Older adults > middle-aged adults | Middle-aged adults > younger adults | 0.619 (60) |
| Males                  | NS      | Younger adults > older adults | Middle-aged adults > younger adults |
| Mean pitch             |         | Females > males  | 1.000 (80) |
| Gender                 | <0.001  |                  |       |
| Gender-age             | <0.001  |                  |       |
| 18-39 age              | <0.05   | Females > males  |       |
| 40-59 age              | <0.05   | Females > males  |       |
| 60+ age                | <0.05   | Females > males  |       |
| Females                | <0.05   | Middle-aged adults > older adults | 0.996 (80) |
| Males                  | <0.05   | Older adults > middle-aged adults | Middle-aged adults > younger adults |
| Phonation time         |         |                  |       |
| Age                    | <0.05   | Younger adults > older adults | 0.996 (80) |
| Gender                 | <0.001  | Males > females  | 0.996 (80) |
| Protocol and parameter          | $P$ value | Post hoc results                      | Power    |
|-------------------------------|-----------|--------------------------------------|----------|
| Peak expiratory airflow       |           |                                      |          |
| Age                           | <0.05     | Middle-aged adults > younger adults  | 0.518    |
| Gender                        | <0.001    | Males > females                       | 0.919 (>)|
| Mean expiratory airflow       |           |                                      |          |
| Gender                        | <0.001    | Males > females                       | 1.000 (>)|
| Expiratory volume             | <0.001    |                                      |          |
| Age                           | <0.05     | Younger adults > older adults         | 0.986 (>)|
| Gender                        | <0.001    | Middle-aged adults > older adults     | 1.000 (>)|
| Comfortable sustained phonation|           |                                      |          |
| Mean pitch                    |           |                                      |          |
| Gender                        | <0.001    | Females > males                       | 1.000 (>)|
| Gender-age                    | <0.001    |                                      |          |
| 18-39 age                     | <0.05     | Females > males                       |          |
| 40-59 age                     | <0.05     | Females > males                       |          |
| 60+ age                       | <0.05     | Females > males                       |          |
| Females                       | <0.05     | Younger adults > older adults         | 0.983 (>)|
| Males                         | <0.05     | Middle-aged adults > older adults     |          |
| Mean expiratory airflow       |           |                                      |          |
| Gender                        | <0.01     | Males > females                       | 0.698 (>)|
| Mean expiratory airflow       |           |                                      |          |
| Gender                        | <0.001    | Males > females                       | 1.000 (>)|
| Expiratory volume             | <0.001    | Males > females                       | 1.000 (>)|
| Variation in SPL              |           |                                      |          |
| Minimum SPL                   | <0.05     | Males > females                       | 0.621 (>)|
| Mean SPL                      | <0.001    | Males > females                       | 0.621 (>)|
| Age                           | <0.001    | Older adults > younger adults         | 0.921 (>)|
| Mean pitch                    |           |                                      |          |
| Gender                        | <0.001    | Females > males                       | 1.000 (>)|
| Gender-age                    | <0.001    |                                      |          |
| 18-39 age                     | <0.05     | Females > males                       | 1.000 (>)|
| 40-59 age                     | <0.05     | Females > males                       | 1.000 (>)|
| 60+ age                       | <0.05     | Females > males                       | 1.000 (>)|
| Females                       | <0.05     | Younger adults > older adults         |          |
| Males                         | <0.05     | Older adults > younger adults         |          |
| Pitch range                   |           |                                      |          |
| Age                           | <0.05     | Middle-aged adults > younger adults   | 0.619 (>)|
| Gender                        | <0.001    | Females > males                       | 0.993 (>)|
| Target airflow                |           |                                      |          |
| Age                           | <0.05     | Middle-aged adults > older adults     | 0.479    |
Table 1: Continued.

| Protocol and parameter                      | $P$ value | Post hoc results                        | Power  |
|---------------------------------------------|-----------|-----------------------------------------|--------|
| Gender                                      | <0.001    | Males > females                         | 1.000  (>80) |
| Voicing efficiency                          |           |                                         |        |
| Maximum SPL                                 |           |                                         |        |
| Age                                         | <0.05     | Middle-aged adults > younger adults     | 0.631  (>60) |
| Mean SPL                                    |           |                                         |        |
| Age                                         | <0.05     | Middle-aged adults > younger adults     | 0.609  (>60) |
| Mean pitch                                  |           |                                         |        |
| Gender                                      | <0.001    | Females > males                         | 1.000  (>80) |
| Gender-age                                  | <0.001    |                                         |        |
| Females                                     | <0.001    | Younger adults > older adults           | 1.000  (>80) |
| Males                                       | <0.001    | Middle-aged adults > older adults       |        |
| Pitch range                                 | <0.001    | Females > males                         | 1.000  (>80) |
| Expiratory airflow duration                 |           |                                         |        |
| Age                                         | <0.01     | Older adults > younger adults           | 0.998  (>80) |
| Gender                                      | <0.05     | Middle-aged adults > younger adults     | 0.383  |
| Peak air pressure                           | <0.05     | Females > males                         |        |
| Age                                         | <0.05     | Older adults > younger adults           | 0.786  (>60) |
| Gender                                      | <0.001    | Males > females                         | 0.909  (>80) |
| Mean peak air pressure                      |           |                                         |        |
| Age                                         | <0.01     | Older adults > younger adults           | 0.684  (>60) |
| Gender                                      | <0.01     | Males > females                         | 0.786  (>60) |
| Peak expiratory airflow                     |           |                                         |        |
| Gender                                      | <0.001    | Males > females                         | 1.000  (>80) |
| Target airflow                              |          |                                         |        |
| Gender                                      | <0.001    | Males > females                         | 1.000  (>80) |
| Expiratory airflow                          |           |                                         |        |
| Age                                         | <0.01     | Middle-aged adults > younger adults     | 0.772  (>60) |
| Gender                                      | <0.001    | Males > females                         | 1.000  (>80) |
| Mean airflow during voicing                 | <0.001    | Males > females                         | 1.000  (>80) |
| Aerodynamic power                           | <0.001    | Males > females                         | 1.000  (>80) |
| Aerodynamic resistance                      | <0.001    | Older adults > middle-aged adults       | 0.892  (>80) |
| Age                                         | <0.05     | Older adults > middle-aged adults       | 0.894  (>80) |
| Gender                                      | <0.05     | Females > males                         | 0.383  |
| Acoustic ohms                               | <0.001    | Older adults > middle-aged adults       |        |
| Age                                         | <0.05     | Older adults > middle-aged adults       | 0.892  (>80) |
| Gender                                      | <0.05     | Females > males                         | 0.383  |
| Aerodynamic efficiency                      |           |                                         |        |
| Gender                                      | <0.01     | Females > males                         | 0.671  (>60) |
Table 2: ANOVAs run for each parameter within each protocol.

(a)

| Source                          | Vital capacity   |   |   |   |
|---------------------------------|------------------|---|---|---|
| Expiratory airflow duration     | F                | P | Power |
| Age                             | 1.061            | 0.348 | 0.0575 |
| Gender                          | 12.595           | <0.001*** | 0.942 |
| Gender-age                      | 0.523            | 0.594 | 0.0500 |
| Peak expiratory airflow         | F                | P | Power |
| Age                             | 2.569            | 0.079 | 0.318 |
| Gender                          | 15.794           | <0.001*** | 0.988 |
| Gender-age                      | 1.149            | 0.542 | 0.0500 |
| Expiratory volume               | F                | P | Power |
| Age                             | 27.081           | <0.001*** | 1.000 |
| Gender                          | 111.939          | <0.001*** | 1.000 |
| Gender-age                      | 1.867            | 0.157 | 0.189 |

*** Sidak < 0.001.

(b)

| Source                          | Maximum sustained phonation |   |   |   |
|---------------------------------|-----------------------------|---|---|---|
| Maximum SPL                     | F                            | P | Power | Phonation time | Power |
| Age                             | 4.324                        | 0.015* | 0.621 | 12.319 | <0.001*** | 0.996 |
| Gender                          | 0.535                        | 0.535 | 0.0500 | 19.458 | <0.001*** | 0.996 |
| Gender-age                      | 0.770                        | 0.770 | 0.0500 | 1.863 | 0.158 | 0.188 |
| Minimum SPL                     | F                            | P | Power | Peak expiratory airflow | Power |
| Age                             | 4.402                        | 0.08** | 0.632 | 3.678 | 0.027* | 0.518 |
| Gender                          | 1.088                        | 0.298 | 0.0568 | 11.623 | <0.001*** | 0.919 |
| Gender-age                      | 4.367                        | 0.014* | 0.014 | 0.102 | 0.903 | 0.0500 |
| Mean SPL                        | F                            | P | Power | Mean expiratory airflow | Power |
| Age                             | 1.830                        | 0.163 | 0.183 | 2.565 | 0.079 | 0.317 |
| Gender                          | 1.500                        | 0.222 | 0.101 | 34.733 | <0.001*** | 1.000 |
| Gender-age                      | 0.833                        | 0.436 | 0.0500 | 0.310 | 0.734 | 0.0500 |
| SPL range                       | F                            | P | Power | Expiratory volume | Power |
| Age                             | 7.662                        | <0.001*** | 0.924 | 10.393 | <0.001*** | 0.986 |
| Gender                          | 1.634                        | 0.203 | 0.116 | 89.935 | <0.001*** | 1.000 |
| Gender-age                      | 4.127                        | 0.018* | 0.591 | 2.124 | 0.122 | 0.235 |
| Mean SPL during voicing         | F                            | P | Power | Mean pitch | Power |
| Age                             | 2.342                        | 0.099 | 0.275 | 1.869 | 0.157 | 0.189 |
| Gender                          | 0.015                        | 0.747 | 0.0500 | 321.984 | <0.001*** | 1.000 |
| Gender-age                      | 1.236                        | 0.293 | 0.0839 | 12.307 | <0.001*** | 0.996 |

*Sidak < 0.05. *** Sidak < 0.001.
### (c)

| Source                  | Comfortable sustained phonation | Mean pitch | Variation in sound pressure level | Target airflow |
|-------------------------|--------------------------------|------------|-----------------------------------|---------------|
| **Maximum SPL**         |                                |            |                                   |               |
| Age                     | 1.485                          | 0.229      | 0.124                             | 3.456         |
| Gender                  | 0.314                          | 0.576      | 0.050                             | 0.033         |
| Gender-age              | 0.522                          | 0.594      | 0.050                             | 0.033         |
| **Minimum SPL**         |                                |            |                                   |               |
| Age                     | 0.572                          | 0.566      | 0.050                             | 3.298         |
| Gender                  | 1.138                          | 0.287      | 0.062                             | 6.203         |
| Gender-age              | 0.695                          | 0.500      | 0.050                             | 1.539         |
| **Mean SPL**            |                                |            |                                   |               |
| Age                     | 1.830                          | 0.163      | 0.183                             | 1.345         |
| Gender                  | 1.500                          | 0.222      | 0.101                             | 322.828       |
| Gender-age              | 0.833                          | 0.436      | 0.050                             | 10.108        |
| **SPL range**           |                                |            |                                   |               |
| Age                     | 1.637                          | 0.197      | 0.149                             | 3.298         |
| Gender                  | 1.291                          | 0.257      | 0.078                             | 6.203         |
| Gender-age              | 0.0912                         | 0.913      | 0.050                             | 1.539         |

*Sidak < 0.05. **Sidak < 0.001.

### (d)

| Source                  | Phonation time | Peak expiratory airflow | Mean expiratory airflow | Expiratory volume | Target airflow |
|-------------------------|----------------|-------------------------|-------------------------|-------------------|---------------|
| **Maximum SPL**         |                |                         |                         |                   |               |
| Age                     | 1.125          | 0.327                   | 0.0670                  |                   |               |
| Gender                  | 0.00679        | 0.934                   | 0.0500                  |                   |               |
| Gender-age              | 0.339          | 0.713                   | 0.0500                  |                   |               |
| **Minimum SPL**         |                |                         |                         |                   |               |
| Age                     | 0.829          | 0.438                   | 0.0501                  |                   |               |
| Gender                  | 7.121          | 0.008**                 | 0.0520                  |                   |               |
| Gender-age              | 0.652          | 0.522                   | 0.0562                  |                   |               |

*Sidak < 0.05. **Sidak < 0.001.**

**Source:** FP

**Power:**
women and men. Our findings are in accord with the findings of these studies [9, 13–17]. The shared finding about age and gender is that the effects of ageing are much more obvious on male voices than on female voices. As for the gender variable in airflow measurements, again in consistency with our findings, the literature shows that airflow measurements of men are significantly higher than those of women in all age groups [9, 11, 14, 18, 19]. This is claimed to be the result of anatomic, physiologic, and structural differences in their respiratory and laryngeal systems.

Our findings in mean pitch and pitch range measurements are also consistent with the findings in the related literature [9, 11, 20]. In all age groups, the mean pitch of female voice is higher than that of male voice. However, the pitch of the female voice decreases with age, while that of the male voice increases.

Our findings in sound pressure level measurements, such as maximum SPL, minimum SPL, mean SPL during voicing, and SPL range, are all higher in all age and gender groups than the findings in the studies of Zraick et al. [9] and Kim [11]. This is considered the result of the stressed structure of Turkish language. According to our findings, sound pressure levels increase with age. Although there is no statistically significant difference between age groups, the correlations between age and sound pressure levels in our findings are in consistency with those of Zraick et al.

### Voicing efficiency Power

| Source                        | F       | P     | Mean peak air pressure | Acoustic ohms |
|-------------------------------|---------|-------|------------------------|---------------|
| **Maximum SPL**               |         |       |                        |               |
| Age                           | 4.394   | 0.014 | 5.777                  | 0.461         |
| Gender                        | 0.200   | 0.655 | 76.064                 | <0.001***     |
| Gender-age                    | 0.236   | 0.790 | 0.0500                 | 1.000         |
| **Mean SPL**                  |         |       |                        |               |
| Age                           | 4.248   | 0.016 | 0.609                  | 0.148         |
| Gender                        | 0.386   | 0.535 | 70.980                 | <0.001***     |
| Gender-age                    | 0.143   | 0.867 | 0.0500                 | 1.000         |
| **Mean SPL during voicing**   |         |       |                        |               |
| Age                           | 2.893   | 0.058 | 0.378                  | 0.005**       |
| Gender                        | 0.223   | 0.223 | 37.879                 | <0.001***     |
| Gender-age                    | 0.538   | 0.538 | 0.0500                 | 1.000         |
| **Mean pitch**                |         |       |                        |               |
| Age                           | 1.071   | 0.345 | 0.0590                 | 0.162         |
| Gender                        | 3.730   | 0.055 | 68.253                 | <0.001***     |
| Gender-age                    | 0.364   | 0.364 | 0.0511                 | 0.797         |
| **Pitch range**               |         |       |                        |               |
| Age                           | 0.632   | 0.532 | 0.0500                 | 0.504         |
| Gender                        | 25.499  | <0.001*** | 1.000                  | 0.605         |
| Gender-age                    | 0.538   | 0.538 | 0.0500                 | 0.0500        |
| **Expiratory airflow duration** |       |       |                        |               |
| Age                           | 13.205  | <0.001*** | 0.998                  | 7.006         |
| Gender                        | 3.928   | 0.049 | 3.899                  | 0.050         |
| Gender-age                    | 0.249   | 0.780 | 0.0500                 | 0.987         |
| **Peak air pressure**         |         |       |                        |               |
| Age                           | 5.654   | 0.004 | 0.786                  | 1.728         |
| Gender                        | 11.254  | <0.001*** | 0.909                  | 6.791         |
| Gender-age                    | 1.619   | 0.201 | 1.425                  | 1.691         |
| **Mean peak air pressure**    |         |       |                        |               |
| Age                           | 4.770   | 0.009 | 0.684                  | 7.053         |
| Gender                        | 8.407   | 0.004 | 3.928                  | 0.049**       |
| Gender-age                    | 0.662   | 0.517 | 0.0500                 | 0.238         |

*Sidak < 0.05. **Sidak < 0.01. ***Sidak < 0.001.
Table 3: Complied norms for each protocol.

(a) Vital capacity

| Protocol parameter          | 18–39 y (n = 76)          | 40–59 y (n = 70)          | 60–87 y (n = 60)          |
|-----------------------------|---------------------------|---------------------------|---------------------------|
| Vital capacity Mean (SD) Min–Max | Mean (SD) Min–Max | Mean (SD) Min–Max | Mean (SD) Min–Max | Mean (SD) Min–Max |
| Female                      | 6.15 (2.39) 2.41-13.57 6.42 (2.88) 2.40-14.26 | 5.57 (1.83) 2.07-9.31 | | | |
| Expiratory airflow duration (s) | 0.94 (0.62) 0.27-3.18 1.16 (0.96) 0.29-5.15 | 1.18 (0.73) 0.30-3.78 | | | |
| Expiratory volume (L)       | 2.42 (0.63) 1.03-3.58 2.21 (0.61) 0.91-3.66 | 1.70 (0.55) 0.86-2.92 | | | |
| Male                        | 7.91 (3.21) 3.22-14.73 7.27 (3.09) 2.40-14.71 | 7.12 (1.65) 1.65-13.50 | | | |
| Expiratory airflow duration (s) | 1.43 (1.02) 0.17-5.19 1.93 (1.35) 0.28-6.71 | 1.59 (0.91) 0.28-3.42 | | | |
| Expiratory volume (L)       | 3.83 (1) 1.63-6.04 3.35 (0.86) 1.05-5.20 | 2.59 (0.87) 0.68-4.11 | | | |

(b) Maximum sustained phonation

| Protocol parameter          | 18–39 y (n = 76)          | 40–59 y (n = 70)          | 60–87 y (n = 60)          |
|-----------------------------|---------------------------|---------------------------|---------------------------|
| Maximum sustained phonation Mean (SD) Min–Max | Mean (SD) Min–Max | Mean (SD) Min–Max | Mean (SD) Min–Max | Mean (SD) Min–Max |
| Female                      | 99.50 (4.98) 91.68-112.26 101.17 (5.33) 93.43-112.71 | 100.78 (4.23) 94.09-110.36 | | | |
| Maximum SPL (dB)            | 68.05 (12.56) 44.85-88.43 63.86 (11.96) 46.78-92.70 | 56.18 (11.77) 42.58-85.43 | | | |
| Minimum SPL (dB)            | 94.47 (5.02) 86.82-105.39 95.35 (5.20) 87.66-105.86 | 94.06 (4.76) 84.78-103.17 | | | |
| Mean SPL (dB)               | 31.44 (12.68) 6.4-60.7 37.25 (12.31) 12.94-61.53 | 44.64 (12.69) 12.46-63.43 | | | |
| SPL range (dB)              | 94.75 (4.99) 86.91-106.28 95.34 (7.43) 64.75-108.42 | 95.09 (4.63) 85.44-103.56 | | | |
| Mean pitch (Hz)             | 222.47 (22.33) 161.99-260.87 222.64 (27.76) 155.93-257.32 | 202.39 (29.15) 142.21-245.33 | | | |
| Phonation time (s)          | 17.53 (4.87) 6.88-29.56 16.51 (5.52) 7.45-27.64 | 14.26 (4.23) 8.88-23.03 | | | |
| Peak expiratory airflow (L/s) | 0.21 (0.10) 0.03-0.6 0.34 (0.22) 0.08-1.01 | 0.25 (0.11) 0.01-0.47 | | | |
| Mean expiratory airflow (L/s) | 0.10 (0.04) 0.02-0.2 0.11 (0.04) 0.05-0.23 | 0.10 (0.05) 0.0067-0.21 | | | |
| Expiratory volume (L)       | 1.77 (0.77) 0.31-3.31 1.81 (0.59) 0.59-2.89 | 1.37 (0.56) 0.06-2.28 | | | |
| Male                        | 99.28 (3.25) 91.89-105.47 102.05 (5.44) 91.94-112.37 | 101.35 (4.62) 90.59-107.38 | | | |
| Maximum SPL (dB)            | 62.18 (14.04) 43.09-90.14 58.80 (12.17) 42.98-83.55 | 61.76 (10.09) 46.02-81.35 | | | |
| Minimum SPL (dB)            | 93.53 (3.27) 84.17-101.32 96.55 (5.46) 85.01-108.18 | 94.14 (7.60) 74.32-103.92 | | | |
| Mean SPL (dB)               | 37.13 (14.66) 8.44-59.42 43.24 (11.48) 11.31-61.49 | 39.59 (9.10) 20.85-57.46 | | | |
| SPL range (dB)              | 93.93 (3.30) 84.63-101.49 97.30 (5.31) 86.71-108.47 | 97.42 (7.19) 77.51-103.99 | | | |
| Mean pitch (Hz)             | 131.19 (18.67) 100.81-171.67 148.74 (27.90) 107.42-210.70 | 158.48 (39.17) 97.52-255.04 | | | |
| Phonation time (Sn)         | 22.75 (5.07) 11.59-29.58 18.45 (6.19) 6.29-29.74 | 17.00 (5.89) 6.11-29.44 | | | |
| Protocol parameter                  | 18–39 y (n = 76) | 40–59 y (n = 70) | 60–87 y (n = 60) |
|------------------------------------|------------------|-----------------|-----------------|
| **Maximum sustained phonation**    |                  |                 |                 |
| Mean (SD)                          | 0.34 (0.15)      | 0.49 (0.52)     | 0.43 (0.50)     |
| Min–Max                            | 0.08–0.95        | 0.06–2.76       | 0.05–2.98       |
| **Mean expiratory airflow (L/s)**  | 0.15 (0.05)      | 0.16 (0.07)     | 0.13 (0.06)     |
| Min–Max                            | 0.04–0.26        | 0.02–0.32       | 0.01–0.26       |
| **Expiratory volume (L)**          | 3.28 (1.04)      | 2.84 (1.07)     | 2.32 (1.03)     |
| Min–Max                            | 0.97–5.08        | 0.50–5.03       | 0.14–3.56       |

(c) Comfortable sustained phonation

| Protocol parameter                  | 18–39 y (n = 76) | 40–59 y (n = 70) | 60–87 y (n = 60) |
|------------------------------------|------------------|-----------------|-----------------|
| **Comfortable sustained phonation**|                  |                 |                 |
| Mean (SD)                          |                  |                 |                 |
| Female                             | n = 41           | n = 35          | n = 30          |
| Maximum SPL (dB)                   | 97.28 (5.03)     | 98.23 (5.52)    | 98.68 (5.04)    |
| Min–Max                            | 89.44–107.59     | 87.99–109.99    | 90.67–111.03    |
| Minimum SPL (dB)                   | 92.78 (5.11)     | 93.31 (5.37)    | 93.09 (4.92)    |
| Mean (SD)                          | 83.45–103.22     | 84.36–102.84    | 84.21–104.69    |
| SPL range (dB)                     | 95.04 (5.02)     | 95.84 (5.32)    | 95.95 (4.97)    |
| Mean pitch (Hz)                    | 4.51 (1.37)      | 4.92 (2.31)     | 5.69 (2.28)     |
| Phonation time (s)                 | 227.80 (22.52)   | 226.20 (27.58)  | 206.68 (29.16)  |
| Peak expiratory airflow (L/s)      | 5.00 (0.00)      | 5.00 (0.00)     | 5.00 (0.00)     |
| Mean (SD)                          | 6.83–8.58        | 6.95–8.92       | 6.50–7.72       |
| Mean expiratory airflow (L/s)      | 0.14 (0.06)      | 0.17 (0.07)     | 0.15 (0.07)     |
| Expiratory volume (L)              | 0.03–0.34        | 0.05–0.40       | 0.01–0.39       |
| Mean (SD)                          | 173.99–255.92    | 226.20 (27.58)  | 206.68 (29.16)  |
| Male                               | n = 35           | n = 35          | n = 30          |
| Maximum SPL (dB)                   | 97.79 (4.45)     | 100.57 (5.83)   | 99.14 (5.33)    |
| Min–Max                            | 86.28–108.37     | 88.60–114.89    | 87.06–108.31    |
| Minimum SPL (dB)                   | 92.50 (5.61)     | 95.35 (8.37)    | 92.75 (9.89)    |
| Mean (SD)                          | 80.82–103.90     | 64.22–112.35    | 57.36–104.37    |
| Mean SPL (dB)                      | 95.49 (4.51)     | 98.19 (6.10)    | 96.00 (7.12)    |
| SPL range (dB)                     | 83.46–106.15     | 86.50–113.95    | 77.93–106.19    |
| Mean pitch (Hz)                    | 5.32 (2.48)      | 5.22 (6.53)     | 6.50 (6.27)     |
| Phonation time (s)                 | 130.33 (18.01)   | 147.87 (33.02)  | 155.83 (45.89)  |
| Peak expiratory airflow (L/s)      | 5.00 (0.00)      | 5.00 (0.00)     | 5.00 (0.00)     |
| Mean (SD)                          | 6.83–7.68        | 7.01–8.15       | 6.35–7.45       |
| Mean expiratory airflow (L/s)      | 0.227 (0.08)     | 0.33 (0.57)     | 0.07–5.37       |
| Expiratory volume (L)              | 0.05–0.38        | 0.03–0.41       | 0.04–0.35       |
| Mean (SD)                          | 0.18 (0.09)      | 0.16 (0.08)     | 0.10–5.37       |
| Female                             | n = 35           | n = 35          | n = 30          |
| Maximum SPL (dB)                   | 0.16 (0.07)      | 0.17–1.58       | 0.13–2.05       |
| Expiratory volume (L)              | 0.03–0.31        | 0.92 (0.45)     | 0.82 (0.41)     |
| Mean (SD)                          | 0.18 (0.09)      | 0.16 (0.08)     | 0.21–1.76       |
### (d) Variation in sound pressure level

| Protocol parameter | Variation in sound pressure level | 18–39 y (n = 76) | Mean (SD) | Min–Max | 40–59 y (n = 70) | Mean (SD) | Min–Max | 60–87 y (n = 60) | Mean (SD) | Min–Max |
|--------------------|-----------------------------------|------------------|-----------|---------|------------------|-----------|---------|------------------|-----------|---------|
|                     | Female                            |                  | n = 41    |         |                  | n = 35    |         |                  | n = 30    |         |
| Maximum SPL (dB)    |                                   | 106.01 (4.35)    | 96.90-113.21 | 108.14 (4.35) | 97.36-114.27 | 107.72 (3.84) | 99.12-113.74 |
| Minimum SPL (dB)    |                                   | 83.20 (6.92)     | 63.06-91.81 | 84.97 (6.83) | 64.70-93.59 | 85.83 (10.26) | 63.42-100.04 |
| Mean SPL (dB)       |                                   | 95.12 (4.27)     | 87.02-103.85 | 97.54 (3.67) | 90.28-104.31 | 98.00 (3.85) | 88.21-104.32 |
| SPL range (dB)      |                                   | 22.72 (6.62)     | 11.92-41.28 | 22.98 (8.62) | 9.90-46.54 | 21.77 (9.82) | 6.93-47.72 |
| Mean pitch (Hz)     |                                   | 221.96 (19.28)   | 181.99-249.51 | 211.76 (16.35) | 182.79-241.59 | 202.92 (20.82) | 163.04-249.19 |
| Pitch range (Hz)    |                                   | 90.97 (40.59)    | 31.06-173.36 | 106.76 (35.01) | 47.14-163.35 | 91.15 (36.12) | 27.51-179.06 |
| Target airflow (L/s)|                                   | 0.11 (0.05)      | 0.01-0.22  | 0.14 (0.05) | 0.03-0.30 | 0.10 (0.05) | 0.0067-0.24 |
|                     | Male                              |                  | n = 35    |         |                  | n = 35    |         |                  | n = 30    |         |
| Maximum SPL (dB)    |                                   | 107.38 (4.58)    | 90.17-114.47 | 107.22 (6.99) | 75.85-115.25 | 108.80 (4.08) | 100.33-114.17 |
| Minimum SPL (dB)    |                                   | 86.87 (5.63)     | 62.35-96.93 | 85.05 (11.60) | 61.65-99.02 | 90.73 (5.92) | 75.48-99.41 |
| Mean SPL (dB)       |                                   | 97.39 (5.67)     | 76.41-107.60 | 99.11 (5.42) | 84.40-109.22 | 100.61 (4.86) | 88.34-108.12 |
| SPL range (dB)      |                                   | 20.64 (6.28)     | 10.61-45.55 | 23.09 (10.26) | 9.96-43.86 | 18.06 (4.95) | 6.85-32.87 |
| Mean pitch (Hz)     |                                   | 139.04 (21.71)   | 110.99-191.94 | 149.15 (23.64) | 105.36-198.93 | 162.40 (29.01) | 114.39-211.05 |
| Pitch range (Hz)    |                                   | 61.00 (32.26)    | 10.76-134.33 | 80.08 (36.12) | 15.15-168.20 | 82.59 (35.71) | 25.07-195.33 |
| Target airflow (L/s)|                                   | 0.23 (0.10)      | 0.03-0.43  | 0.26 (0.11) | 0.07-0.53 | 0.22 (0.11) | 0.02-0.43 |

### (e) Voicing efficiency

| Protocol parameter | Voicing efficiency | 18–39 y (n = 76) | Mean (SD) | Min–Max | 40–59 y (n = 70) | Mean (SD) | Min–Max | 60–87 y (n = 60) | Mean (SD) | Min–Max |
|--------------------|--------------------|------------------|-----------|---------|------------------|-----------|---------|------------------|-----------|---------|
|                     | Female             |                  | n = 41    |         |                  | n = 35    |         |                  | n = 30    |         |
| Maximum SPL (dB)    |                    | 98.13 (5.0)      | 89.85-109.47 | 99.92 (5.66) | 90.71-111.52 | 99.84 (5.16) | 90.31-111.37 |
| Mean SPL (dB)       |                    | 94.70 (4.53)     | 87.70-104.52 | 96.67 (5.37) | 88.17-107.73 | 96.43 (5.07) | 87.26-107.75 |
| Mean SPL during voicing (dB) |        | 94.87 (4.48) | 87.70-104.47 | 96.69 (5.32) | 88.17-107.73 | 96.46 (5.06) | 87.29-107.74 |
| Mean pitch (Hz)     |                    | 217.44 (24.14)   | 162.73-262.45 | 214.83 (28.45) | 145.61-252.34 | 194.00 (25.84) | 154.93-244.84 |
| Pitch range (Hz)    |                    | 32.95 (25.70)    | 8.38-98.25  | 33.26 (32.53) | 10.31-154.53 | 34.54 (30.11) | 9.19-134.60 |
| Expiratory airflow duration (s) |             | 0.91 (0.30)    | 0.39-1.85  | 1.08 (0.24) | 0.55-1.67 | 1.19 (0.30) | 0.69-1.79 |
| Peak air pressure (cm H₂O) |            | 9.47 (3.57)     | 4.95-22.81  | 10.61 (3.45) | 6.03-20.93 | 10.87 (2.87) | 6.49-17.83 |
| Mean peak air pressure (cm H₂O) |            | 7.67 (2.33)     | 3.81-14.92  | 8.39 (2.56) | 4.95-15.53 | 8.88 (2.43) | 5.10-15.05 |
| Peak expiratory airflow (L/s) |         | 0.15 (0.09)    | 0.03-0.51  | 0.17 (0.06) | 0.06-0.34 | 0.15 (0.08) | 0.01-0.32 |
| Target airflow (L/s) |                     | 0.09 (0.04)    | 0.01-0.26  | 0.12 (0.05) | 0.04-0.22 | 0.10 (0.06) | 0.0033-0.24 |
| Expiratory volume (L) |                     | 0.08 (0.05)    | 0.01-2.26  | 0.13 (0.06) | 0.03-0.30 | 0.13 (0.10) | 0.0033-0.36 |
| Mean airflow during voicing (L/s) |         | 0.09 (0.04)    | 0.01-0.27  | 0.11 (0.04) | 0.03-0.21 | 0.09 (0.06) | 0.0033-0.24 |
| Aerodynamic power (W) |                     | 0.08 (0.06)    | 0.01-0.37  | 0.10 (0.05) | 0.03-0.22 | 0.08 (0.06) | 0.0047-0.23 |
### Table 3: Continued.

| Protocol parameter                    | 18–39 y (n = 76) | 40–59 y (n = 70) | 60–87 y (n = 60) |
|---------------------------------------|------------------|------------------|------------------|
|                                       | Mean (SD) | Min–Max          | Mean (SD) | Min–Max          | Mean (SD) | Min–Max          |
| Voicing efficiency                    |           |                  |           |                  |           |                  |
| Aerodynamic resistance (cm H₂O/L/Sn)  | 130.38 (142.60) | 36.75–756.10     | 87.83 (52.89) | 25.75–229.71     | 380.36 (692.39) | 35.86–3167.15    |
| Acoustic ohms (dynes cm³)             | 132.96 (145.43) | 37.48–771.06     | 89.53 (53.71) | 26.26–234.26     | 389.02 (705.74) | 36.56–3299.80    |
| Aerodynamic efficiency (dynes cm³)    | 22325.21 (59863.48) | 299–385353     | 16485.89 (20175.95) | 882.02–84885.30 | 49606.61 (112786.19) | 1198.12–533250.63 |
| Male                                  |           |                  |           |                  |           |                  |
| Maximum SPL (dB)                      | 97.85 (4.40) | 85.55–106.57     | 100.85 (5.88) | 90.23–111.63     | 100.18 (5.11) | 84.01–110.85     |
| Mean SPL (dB)                         | 94.73 (4.57) | 81.82–103.25     | 97.63 (6.83) | 78.23–109.04     | 96.82 (5.15) | 80.36–105.87     |
| Mean SPL during voicing (dB)          | 94.82 (4.50) | 81.82–103.25     | 97.85 (6.55) | 82.81–109.04     | 99.53 (17.10) | 80.38–186.33     |
| Mean pitch (Hz)                       | 123.03 (14.69) | 98.04–154.05     | 137.22 (24.85) | 94.77–201.48     | 149.709 (28.96) | 103.40–215.93    |
| Pitch range (Hz)                      | 14.63 (15.14) | 4.86–93.16       | 16.01 (9.89)  | 4.65–60.54       | 21.58 (12.68) | 9.29–62.20       |
| Expiratory airflow duration (Sn)      | 0.83 (0.32)  | 0.38–1.65        | 1.05 (0.31)  | 0.47–1.66        | 1.05 (0.30)  | 0.60–1.74        |
| Peak air pressure (cm H₂O)            | 10.81 (5.00) | 8.45–32.68       | 11.85 (5.54) | 4.46–23.22       | 14.64 (6.06) | 7.11–33.90       |
| Mean peak air pressure (cm H₂O)       | 8.71 (4.01)  | 3.82–26.04       | 9.25 (3.96)  | 3.58–20.60       | 10.98 (3.90) | 5.13–17.59       |
| Peak expiratory airflow (L/s)         | 0.38 (0.27)  | 0.03–1.03        | 0.38 (0.18)  | 0.08–0.86        | 0.31 (0.17)  | 0.0067–0.70      |
| Target airflow (L/s)                  | 0.21 (0.11)  | 0.02–0.46        | 0.23 (0.10)  | 0.05–0.53        | 0.19 (0.11)  | 0.001–0.44       |
| Expiratory volume (L)                 | 0.17 (0.11)  | 0.10–0.59        | 0.24 (0.14)  | 0.04–0.57        | 0.20 (0.14)  | 0.001–0.59       |
| Mean airflow during voicing (L/s)     | 0.20 (0.11)  | 0.02–0.46        | 0.22 (0.10)  | 0.05–0.51        | 0.18 (0.11)  | 0.001–0.43       |
| Aerodynamic power (W)                 | 0.20 (0.16)  | 0.01–0.59        | 0.22 (0.15)  | 0.03–0.59        | 0.21 (0.15)  | 0.002–0.59       |
| Aerodynamic resistance (cm H₂O/L/Sn)  | 100.49 (236.97) | 20.46–1386.54   | 48.61 (30.97) | 13.33–173.04     | 174.85 (420.55) | 12.09–2285.61    |
| Acoustic ohms (dynes cm³)             | 102.87 (241.53) | 22.64–1413.97   | 49.38 (31.66) | 13.59–176.47     | 178.31 (428.87) | 12.34–2330.83    |
| Aerodynamic efficiency (ppm)          | 11102.94 (38165.33) | 229.66–227839.41 | 8507.71 (8648.68) | 105.53–35164.99 | 9594.30 (14383.53) | 1259.95–78035.27 |
The pressure on laryngeal muscles increases with age, and the participants have to make more effort to start phonation; therefore, the sound pressure levels increase.

In air pressure measurements, significant differences between age and gender groups are observable. These findings are consistent with the findings of Higgins and Saxman [14], in which subglottal pressures of male participants over 69 years of age are significantly higher than those of young males from 20 to 31 years of age. Age variable is expected to affect subglottal pressure values, such as vocal fold tension and incomplete glottal closure [13]. The significant differences in our findings between gender groups are consistent with Kim [11], in which the measurements of male participants are higher than those of females.

For the second purpose of the study, the 157 participants were categorized into three age groups (18-39, 40-59, and 60+), and the normative data for all acoustic and aerodynamic measurements in PAS were determined. In Kim’s study (2014), there is only one age group (18-49), and the norms are determined only for the acoustic and aerodynamic measurements in the two protocols, i.e., maximum sustained phonation and voicing efficiency. Therefore, the findings of the present study can only be compared with those of Zraick et al. [9]. In both studies, the normative data and standard deviations of airflow measurements such as expiratory airflow duration, maximum expiratory airflow, expiratory volume, mean expiratory airflow, target airflow, expiratory airflow duration, mean airflow duration during voicing, and phonation duration are expectedly similar. However, the normative data and standard deviations in sound pressure level measurements of PAS protocols, such as maximum sound pressure level, minimum sound pressure level, mean sound pressure level, sound pressure level interval, and mean sound pressure during voicing, are higher in our findings than in those of Zraick et al. [9] in all age and gender groups. This difference is considered the result of the stressed structure of Turkish language. Norms and standard deviations in pitch measurements of PAS protocols, such as mean pitch and pitch range, are also higher in our findings. These findings indicate that healthy Turkish-speaking adults use their voice in higher pitches. Similarly, the norms for measurements of air pressure in the voicing efficiency protocol are higher than those of Zraick et al.’s study [9]. This difference is considered the result of the language used by participants and their efforts to start voicing.

Finally, the subjects of the study have not been endoscopically examined because they have had no breathing or voice problem on the day of data collection. Moreover, subjects were perceptually evaluated by two experienced clinicians with expertise in speech and language therapy. This is considered as the limitation of the study, and laryngeal examination is recommended in similar studies.

The findings of the present study show that acoustic and aerodynamic measurements are responsive to age and gender differences, and these findings are consistent with those of other studies in the related literature [9, 11, 17]. Further research may be designed for norm generation using PAS with a wider group of participants. The age groups may be narrowed, so that the number of age groups may increase.

5. Conclusions

In this study, our findings indicate that acoustic and aerodynamic measurements, which are so crucial in voice assessment, are so sensitive to age and gender differences. Therefore, normative data used as reference in voice assessment should be generated according to age and gender differences.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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