Electroglottographic evaluation of age and gender effects during sustained phonation and connected speech

Estella P.-M. Ma, Ph.D. *

School of Health and Rehabilitation Sciences, The University of Queensland

&

Amanda L. Love, B.Sp.Path

School of Health and Rehabilitation Sciences, The University of Queensland

Address for Correspondence:

Dr. Estella P.-M. Ma, Assistant Professor, Division of Speech and Hearing Sciences, The University of Hong Kong, 5/F Prince Philip Dental Hospital, 34 Hospital Road, Hong Kong. Telephone (852) 28590594, Fax: (852) 25590060, Email: estella.ma@hku.hk

***** *The first author (EM) is now affiliated with Division of Speech and Hearing Sciences, The University of Hong Kong*

Abstract

The aim of the present study was to evaluate the effects of age and gender on selected vocal fold vibratory behaviors during vowel prolongation and connected speech using electroglottography (EGG). Forty-six young and older individuals (23 males and 23 females) with normal voices participated in this study. EGG parameters including fundamental frequency and contact quotient were measured during sustained vowel prolongation and connected speech tasks. Significant age by gender interactions were found for both parameters. Moreover, results from discriminant function analyses revealed that the overall accuracies of the parameters in predicting different age and gender groups were higher for the connected speech tasks than for the sustained vowel prolongation task (89.1% and 73.9% for passage and phrase tasks versus 71.7% for vowel prolongation). These findings suggest that reliability of EGG measures can be affected by the test stimuli. Therefore, one should carefully consider the use of the speech material when assessing vocal fold behaviors using EGG. The findings also support the use of connected speech stimulus, preferably at passage level, in electroglottographic evaluation for a better representation of vocal fold vibrating behaviors.

Keywords: *electroglottography (EGG), vocal fold vibratory behaviors, aging, gender, running speech*

Introduction

Age-related changes in laryngeal structures and vocal fold tissues have been well documented in the literature. These changes include degeneration of laryngeal mucosal glands [1], ossification and calcification of laryngeal cartilages [2 3], atrophy of intrinsic laryngeal muscles [4 5], loss of intrinsic laryngeal muscle elasticity [2] and increase in vocal fold stiffness [2]. These age-related structural changes impact on vocal fold vibratory behaviors and glottal configurations [6]. Vocal fold vibrations become more irregular and unstable in the older population [1 3 7]. There is also reduced vocal fold closure as a result of vocal fold atrophy associated with aging [8-12].

The aforementioned age-related declines of laryngeal structures and vocal fold tissues reportedly take place at different rates and patterns in males and females. In general, the age-related changes in the larynx tend to occur earlier and are more extensive in males than females [3]. Calcification and ossification of laryngeal cartilages have been documented to manifest earlier in males than females [1]. The connective tissues of vocal fold ligaments decrease in density in males of advancing age [2]. However, such declines are not as pronounced in older females [2]. In addition, vocal fold edema has been found to be more prevalent in older females than older males, which is possibly related to the hormonal changes following menopause in older females [9]. It is therefore apparent that gender also plays a role in changes of vocal fold vibratory patterns accompanying aging.

Electroglottography (EGG) provides a non-invasive and simple measure of vocal fold contacting behaviors in phonation. The EGG waveform reflects the amount of transverse impedance at the laryngeal level. The amount of impedance decreases as vocal fold contact increases [13]. Therefore, an EGG waveform provides an indirect measure of the relative degree of vocal fold contact in phonation. It denotes vocal fold contacting behaviors in terms of the time and rate of glottal closure and opening [14]. The internationally-recommended orientation of EGG waveform is that an upward-going waveform corresponds to an increasing vocal fold contact area. An acute rise in the EGG waveform corresponds to the quick closing of the vocal folds and is followed by a gradual decline in the waveform [15], which is associated with the separation of the vocal folds as the pressure below the glottis is higher than above, and the natural tendency of the vocal folds to return to their equilibrium position. EGG has been used extensively to investigate vocal fold vibratory functions in normal adults [16-18] and in adults with pathological voice disorders [17 19].

The literature has documented the use of EGG to examine the effects of age and gender on vocal fold vibratory behaviors [8 20]. Higgins and Saxman [8] compared the fundamental frequency and duty cycle (i.e., ratio of vocal fold opening to the glottal period) in 41 healthy young and older adults of both genders. In their study, the EGG parameters were analyzed from the vowel /ae/ during sustained vowel phonation and syllable /baep/ repetition. Results revealed a significant age by gender interaction for fundamental frequency, which was characterized by higher fundamental frequency for older than young males, and lower fundamental frequency for older than young females. As the authors expected, there was significantly greater duty cycle (i.e., less vocal fold contact) for older than younger males. Interestingly, smaller duty cycle for older than young females was revealed, suggesting that there was longer period of vocal fold contact during phonation for older females compared to young females. Higgins and Saxman [8] suggested that menopause-related vocal fold edema might have increased vocal fold contact in older females and recommended further investigations to validate their findings.

Recently, Chen and colleagues [20] studied vocal fold vibratory behaviors during modal and vocal fry phonations in 10 adults (five males and five females, mean ages 42 and 47 years, respectively) using EGG. The EGG waveforms were obtained from sustained vowel phonations. Three parameters were derived from the waveforms, including the fundamental frequency and the durations of opening and closing phases of a glottal cycle. As the authors expected, a significantly higher fundamental frequency was found for females compared to males during modal phonation. The authors also found that females demonstrated a significantly longer opening phase per glottal cycle than males during both modal and vocal fry phonations. This result suggests that females have relatively less vocal fold contact during phonation than males, which may be due to the presence of a glottal chink in females.

The two studies reviewed above demonstrate the use of EGG in studying age-related and gender-related differences in vocal fold vibratory behaviours. However, the EGG waveforms reported in these studies were obtained from vowels elicited during sustained vowel phonation and syllable repetition tasks. Some authors argue that voice samples gathered from either sustained phonation or syllable repetition tasks for EGG measurements are not sufficient to represent daily, functional connected speech [21]. Connected speech tasks may reveal more distinct phonatory patterns than sustained vowel phonation due to the different laryngeal mechanisms involved such as co-articulation and intonation [22 23]. However, whether the use of connected speech for EGG measurements provides a better representation of normative data as sustained vowel phonation in measure of vocal fold contact has yet to be proved. An understanding of the speech task that is the most powerful in discriminating different age and gender groups has significant clinical relevance [21].

It was therefore the aim of the present study to investigate the effects of age and gender on vocal fold vibratory behaviors during sustained vowel phonation and connected speech. The study also set out to evaluate the accuracy of EGG parameters obtained from connected speech tasks in predicting voice samples of different age and gender, and to compare with those obtained from sustained vowel prolongation. With the global increase in aging population, voice clinicians have an increasing role in the assessment and management of voice problems in older adults. Therefore, it is important to be able to distinguish changes that are associated with normal aging process from those that are associated with pathological processes co-occurring with aging [24].

Methods

Participants

Forty-six individuals (23 females and 23 males) participated in the present study. The participants were divided into two age groups, a young group (aged from 20 to 32 years) and an older group (aged 65 years or more). The young group comprised 12 females (mean age=25.00 years, SD=3.16) and 11 males (mean age=24.18 years, SD=3.28). The older group comprised 11 females (mean age=69.73 years, SD=3.69) and 12 males (mean age=69.67 years, SD=3.87).

Each participant was judged perceptually as having normal vocal quality by both the second author (AL) who is a final year speech pathology student, and a qualified speech pathologist who has over 10 years of clinical experiences in assessing voice patients on daily basis. The two judges achieved 100% agreement with each other. Participants were excluded from this study if they had a previous or current history of voice, speech, language, or hearing problem. The participants were required to be non-smoking, be native English speaking and had no previous professional singing or speaking training. All participants reported to be in good general health.

Instrumentation and procedures

Electroglottographic (EGG) evaluations were performed with the digital Fourcin Laryngograph Processor (Laryngograph Ltd., London). The digital laryngograph processor is an EGG device and is also called electrolaryngograph (ELG) [25]. The output waveform recorded is termed as Lx waveform [26,27]. Alternative terms that have been used in the literature include Lx/EGG waveform [27] and ELG waveform [28]. The orientation of the Lx waveform is consistent with the official recommendation that an upward-going waveform corresponds to an increasing vocal fold contact area [27]. The processor consisted of a pair of surface electrodes for detecting Lx signals. All the Lx signals were directly recorded using the Speech Studio software (Version 1.04) from Laryngograph Ltd. The Speech Studio software provides real-time displays of an individual's Lx signals during phonation on the computer screen.

All the assessments were conducted in the Motor Speech Research Unit at The University of Queensland. Each participant was seated comfortably in an upright position. The participant's skin over the thyroid lamina was cleaned using alcohol swab in order to remove any skin oil and to maximize electrode-to-skin contact. The two electrolaryngographic surface electrodes, which were attached to a neckband, were then placed externally on the participant's neck on each side of his/her thyroid lamina. The neckband was sufficiently tight as to ensure adequate electrode-to-skin contact. Before the actual recording, each participant was asked to sustain the vowel /a/ for three seconds at his/her most comfortable pitch and loudness. The Lx waveform displayed on the computer screen was then inspected until a clear waveform with the largest amplitude was captured. This procedure was performed to ensure the electrode placement was correct and the most optimal Lx signal was captured.

Three speech tasks were administered for the Lx measurements. The first task required the participant to sustain the vowel /a/ for six seconds at his/her most comfortable pitch and loudness. This task was repeated five times. The remaining two tasks were performed to examine vocal fold vibratory behaviors in connected speech context. Each participant was required to read the phrase 'A baby boy' five times at his/her most comfortable pitch and loudness. Each participant was also required to read the English passage “North Wind and the Sun” (see Appendix) at his/her most comfortable pitch and loudness.

Data analysis

All the Lx signals were analyzed using the Speech Studio software (Version 1.04). This software has been shown to be able to perform electroglottographic analyses on both sustained phonation and connected speech samples [29]. The middle three (i.e., the 2^{nd}, 3^{rd} and 4^{th}) trials of the sustained vowel phonations were analyzed for each participant. Each sample was analyzed by including the middle three-second portion of the whole sample. Similarly, the middle three (i.e., the 2^{nd}, 3^{rd} and 4^{th}) trials of the phrase were analyzed for each participant by including the whole phrase “A baby boy”. For passage task, the whole passage was used for analysis.

Measures

For recordings obtained for the sustained vowel prolongations, average fundamental frequency (in Hertz) and average contact quotient (in percent) were calculated from the Lx waveform on a cycle-by-cycle basis. Contact quotient is the ratio between peak width at 70% down from peak of the Lx waveform and the total period of the same glottal cycle [27]. For recordings obtained for the phrase and passage tasks, the distributions of the fundamental frequency and the contact quotient value of all vocal fold cycles in the voice sample were plotted in histograms using quarter-tone and 1% bins respectively. The mean of laryngeal frequency distribution (mean DFx1, measured in Hertz) and the mean of contact quotient distribution (mean DQx1, measured in percent) were calculated for each of these two speech tasks.

Due to the nature of voice production and voice perception, analysis of fundamental frequency data in linear scale (in the unit of Hertz) was not valid. Therefore, all the fundamental frequency data was converted to logarithmic scale (in the unit of semitone relative to an arbitrary musical note A1 or 55Hz) prior to statistical analysis.

Reliability of measurements

Since the segmentation of voice samples for electroglottographic measurements required visual judgment of the phonation onset and offset on the Lx waveforms, the reliability of this procedure needed to be established. Voice samples of the three speech tasks (i.e., sustained vowel prolongation, phrase and passage) of 12 randomly selected participants (i.e., 25% of the 46 participants) were analyzed by the second author (AL) on two occasions separated by two weeks. This was used to evaluate intra-judge reliability. The voice samples were also analyzed by another judge to evaluate inter-judge reliability. Correlational analyses revealed very good intra-judge reliability (mean fundamental frequency: Pearson's r=1.00; mean contact quotient: Pearson's r=0.98; both p=0.0001). The inter-judge reliability coefficients were also good (mean fundamental frequency: Pearson's r=0.98; mean contact quotient: Pearson's r=0.97; both p=0.0001).

Results

Differences between genders for the young and the older groups

Tables 1 and 2 list the group means and standard deviations of the two EGG parameters as a function of age, gender and speech task. Data obtained from sustained vowel and connected speech tasks were analysed separately. For sustained vowel, results of each parameter were analysed using two-way ANOVA to investigate the main and interaction effects of age and gender. For connected speech tasks, results of each parameter were analysed using three-way mixed ANOVA with age (young versus older) and gender (female versus male) as between-subject factors and speech task (phrase versus passage) as within-subject factor. For each parameter, because Mauchly's test of sphericity for within-subject factor speech task was significant (p<0.001), the assumption of compound symmetry was violated. Therefore, results of within-subject effects with Greenhourse-Geisser epsilon correction were reported. When a significant three-way interaction (age x gender x speech task) was found, follow-up two-way ANOVA (age x gender) was performed within each speech task to further evaluate the main and interaction effects of age and gender. For these follow-up analyses, the *alpha* level was adjusted to 0.025 (0.05/2) using Bonferroni correction in order to avoid any potential Type I errors [8].

Mean fundamental frequency. For sustained vowel prolongation, a significant age by gender interaction ($F_{1,42}$=6.42, p=0.02) was found. This was characterised by the lower mean fundamental frequency for the older than young females, and the slight increase in mean fundamental frequency for the older than young males. For connected speech tasks, significant main effect for age ($F_{1,42}$=5.46, p=0.02) was found, which was characterized by the lower mean fundamental frequency for the older adults in comparison to the young adults. Results also revealed a significant main effect for gender ($F_{1,42}$=206.86, p=0.0001), with females exhibiting higher mean fundamental frequency than males. Moreover, there was a significant age by gender interaction ($F_{1,42}$=5.93, p=0.02). This was characterized by the significantly lower mean fundamental frequency for the older than young females, and the slight increase in mean fundamental frequency for the older than young males (see Table 1 and Figure 1). A significant main effect for speech task ($F_{1,42}$=18.21, p=0.0001) was found. Post-hoc Bonferroni comparisons revealed significantly lower mean fundamental frequency in the phrase task than the passage task (p=0.0001).

Put Table 1 and Figure 1 here

<u>*Mean contact quotient.*</u> For sustained vowel prolongation, a significant age by gender interaction ($F_{1,42}$=4.86, p=0.03) was found. This was characterised by the slight increase in contact quotient for the older than young females, and the decrease in mean contact quotient for the older than young males. For connected speech tasks, there was a significant age by gender by speech task interaction found for contact quotient ($F_{1,42}$=7.55, p=0.009). Follow-up two-way ANOVAs were therefore administered within phrase and passage tasks to examine the main and interaction effects on the factors of age and gender. Results revealed a significant age by gender interaction ($F_{1,42}$=14.13, p=0.001) only for the passage task.

<u>Put Table 2 and Figure 2 here</u>

Discriminant function analyses

The accuracy of mean fundamental frequency and mean contact quotient in discriminating among age and gender groups was evaluated using direct-entry discriminant function analysis. Both parameters were entered as predicting variables. Because there were three speech tasks, three discriminant function analyses were carried out with one for each task. Table 3 lists the prediction accuracies for the three analyses. Results revealed that the combination of both Lx measures obtained from the sustained vowel prolongation and the phrase tasks were able to correctly classify subjects with an overall accuracy of 71.7% and 73.9%, respectively. The classification accuracy increased to 89.1% when the Lx measures were obtained from the passage task.

<u>Put Table 3 here</u>

Discussion

Electroglottography (EGG) provides an indirect measure of vocal fold contacting behavior in phonation. The first objective of the present study was to investigate the effects of age and gender on vocal fold vibratory behaviours during sustained phonation and connected speech using an EGG perspective. The second objective was to evaluate the accuracy of EGG parameters obtained from connected speech tasks in predicting voice samples of different age and gender, and to compare with those obtained from sustained vowel prolongation.

Age and gender effects on vocal fold vibratory patterns

As expected from the anatomical and physiological differences between male and female larynges, the mean fundamental frequency in females was significantly higher than in males. Results also showed a significant decrease in mean fundamental frequency with advancing age in the female group. These findings are consistent with those reported in the existing literature [8 10 30 31] and may be attributed to the endocrinal changes that occur following menopause. After menopause, an imbalance in the testosterone-oestrogen levels may cause edema in vocal folds. This increases vocal fold mass and consequently, lowers the speaking fundamental frequency in aged females [3 8 9]. The mean fundamental frequency of the older males was only slightly higher than that of young males. This is consistent with the findings in Higgins and Saxman [8]. In their study, they also found only slight age-related increase in fundamental frequency in aged males.

The present results also revealed a significant age by gender interaction for mean contact quotient in both sustained vowel prolongation and passage tasks. This was characterised by the significantly smaller contact quotient (i.e., less degree of vocal fold contact) for older males compared with young males, and greater contact quotient (i.e., increased vocal fold contact) for older than young females. Similar findings were reported by Higgins and Saxman [8], who attributed the decrease in vocal fold contact in older males to laryngeal muscle atrophy associated with aging. Atrophy of the laryngeal muscles has reportedly resulted in the development of glottal gaps or vocal fold bowing in older males, thus reducing vocal fold closure [2 32-34]. Based on these anatomical changes, it is therefore not unexpected to find smaller contact quotients in older males than young males. For females, the greater contact quotients in older females might be due to the presence of vocal fold oedema following menopause in older females [8]. The presence of vocal fold oedema might have changed the shape and viscoelasticity of the vocal fold tissues. Vocal fold approximation is therefore enhanced, and consequently an increase in EGG contact quotient.

Interestingly in the present study, each gender group demonstrated different magnitudes of change associated with aging across EGG parameters. As shown in Figure 1, the extent of increase in mean fundamental frequency in aged males was only slight. However, the male group demonstrated a significant decrease of mean contact quotient with aging (see Figure 2). Similar observations were not noted in females. Apparently, aging has different influence on different vocal fold vibratory characteristics even though in the same group of speakers. Therefore, combined use of different measures is recommended for a more representative picture of age and gender effects on vocal fold vibratory behaviours.

Speech task effects on vocal fold vibratory patterns

The present study found significant statistical main effect of speech task for fundamental frequency regardless of age and gender. Interestingly, the mean fundamental frequency obtained from passage task was significantly higher than that obtained from the phrase task (about one semitone difference). This is possibly due to the nature of speech stimuli in the two tasks. The more prosodic and emotional variations involved in reading a story passage (‘North Wind and the Sun’) than in an isolated short phrase (“A baby boy”) could have contributed to the higher mean fundamental frequency in the passage task.

For contact quotient, significant age by gender interaction effect was found only in the passage task but not in the phrase task. The results suggest that connected speech context of longer duration, as in passage reading, can give a better representation of contact quotient measure than reading a short phrase.

Discriminant function analyses

The present findings offer some supports to the use of connected speech over sustained vowel prolongations as test materials in evaluating vocal fold vibratory behaviors. Results of discriminant function analyses revealed that that the overall accuracies of the Lx parameters in predicting different age and gender groups were higher for the connected speech tasks than for sustained vowel prolongation (89.1% and 73.9% for passage and phrase tasks versus 71.7% for vowel prolongation, see Table 3). These results suggest that Lx measures obtained from connected speech are more accurate than those obtained from sustained vowel prolongation in classifying individuals of different age and gender. This may due to the fact that connected speech is more representative to one's daily speech characteristics than sustained phonation and hence, the Lx measures obtained from connected speech context offer a more accurate representation of age-related changes in vocal fold vibratory behaviors between genders.

Nevertheless, the classification accuracy for measures from the phrase task was only slightly higher than that of the sustained vowel phonation task. In other words, the use of short connected speech stimuli was only slightly better than sustained vowel. It is apparent that a short phrase may not give adequate phonemic and prosodic representations of an individual's use of voice in connected speech. On the other hand, connected speech material of longer duration can give a more secure source of information. In this regard, Fourcin recommended test materials of two minutes in duration for EGG evaluation in connected speech context [28]. The present results support the use of connected speech, preferably at passage level, in electroglottographic evaluation for a better representation of vocal fold vibrating behaviors.

Conclusions and future research

In conclusion, this study has contributed to the existing literature by furthering the understanding of age and gender effects on fundamental frequency and contact quotient under different speech context using an EGG perspective. Such age and gender effects suggest that attention should be paid when assessing vocal fold vibratory behaviors in older speakers. Results also encourage the use of connected speech context at passage level for a more accurate and reliable evaluation of vocal fold vibratory patterns. Future research is warranted by including middle-age speakers to investigate the progressive aging-related changes in vocal fold vibratory behaviors. It would also be interesting to replicate the study with dysphonic individuals to investigate if similar findings would be generalized to pathological groups.

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Appendix

North Wind and the Sun

The North Wind and the Sun were disputing which was the stronger, when a traveller came along wrapped in a warm cloak. They agreed that the one who first succeeded in making the traveller take his cloak off should be considered stronger than the other. Then the North Wind blew as hard as he could, but the more he blew the more closely did the traveller fold his cloak around him; and at last the North Wind gave up the attempt. Then the Sun shined out warmly, and immediately the traveller took off his cloak. And so the North Wind was obliged to confess that the Sun was the stronger of the two.

Table 1. Group means and (standard deviations, SD) for mean fundamental frequency (in Hertz) across speech tasks

		Mean fundamental frequency (Hz)					
Speech task	**Gender**	**Young**		**Older**		**Total**	
		Mean	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**
Sustained vowel	Female	224.05	(18.79)	186.05	(34.79)	205.87	(33.22)
	Male	120.95	(18.32)	123.50	(18.16)	122.28	(17.86)
	Total	174.74	(55.69)	153.41	(41.66)	164.08	(49.81)
Phrase	Female	191.41	(17.68)	160.15	(15.30)	176.46	(22.75)
	Male	108.03	(12.45)	110.00	(18.32)	109.06	(15.47)
	Total	151.53	(45.17)	133.98	(30.50)	142.76	(39.13)
Passage	Female	196.97	(16.20)	171.39	(15.16)	184.73	(20.16)
	Male	114.26	(11.89)	114.63	(18.84)	114.45	(15.55)
	Total	157.41	(44.49)	141.77	(33.50)	149.59	(39.74)

Table 2. Group means and (standard deviations, SD) for mean contact quotient across speech tasks

		Mean contact quotient (%)					
Speech task	**Gender**	**Young**		**Older**		**Total**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Sustained vowel	Female	47.37	(6.27)	49.24	(6.27)	48.26	(6.20)
	Male	51.95	(3.78)	46.15	(6.71)	48.92	(6.15)
	Total	49.56	(5.62)	47.63	(6.55)	48.59	(6.11)
Phrase	Female	48.03	(3.86)	48.91	(3.54)	48.45	(3.65)
	Male	50.48	(3.38)	45.88	(6.80)	48.08	(5.81)
	Total	49.20	(3.77)	47.33	(5.59)	48.26	(4.80)
Passage	Female	47.61	(3.78)	50.05	(4.71)	48.78	(4.33)
	Male	52.76	(3.58)	45.12	(5.71)	48.77	(6.11)
	Total	50.07	(4.46)	47.48	(5.72)	48.77	(5.24)

Table 3. Number of subjects (percentage) predicted by mean fundamental frequency and mean contact quotient using discriminant function analysis.

a) Sustained vowel prolongation

Group of subjects		**Number of subjects (percentage) predicted**				
		Female		**Male**		
		Young	**Older**	**Young**	**Older**	**Total**
Female	Young	**11 (91.7)**	1 (8.3)	0 (0)	0 (0)	12 (100.0)
	Older	3 (27.3)	**6 (54.5)**	2 (18.2)	0 (0)	11 (100.0)
Male	Young	0 (0)	1 (9.1)	**7 (63.6)**	3 (27.3)	11 (100.0)
	Older	0 (0)	1 (8.3)	2 (16.7)	**9 (75.0)**	12 (100.0)
Total		14	9	11	12	**46**

Overall prediction accuracy: 71.7% (33 out of 46 participants)

b) Phrase task

Group of subjects		**Number of subjects (percentage) predicted**				
		Female		**Male**		
		Young	**Older**	**Young**	**Older**	**Total**
Female	Young	**10 (83.3)**	2 (16.7)	0 (0)	0 (0)	12 (100.0)
	Older	3 (27.3)	**8 (72.7)**	0 (0)	0 (0)	11 (100.0)
Male	Young	0 (0)	0 (0)	**9 (81.8)**	2 (18.2)	11 (100.0)
	Older	0 (0)	2 (16.7)	3 (25.0)	**8 (58.3)**	12 (100.0)
Total		13	12	11	10	**46**

Overall prediction accuracy: 73.9% (34 out of 46 participants)

c) Passage task

Group of subjects		**Number of subjects (percentage) predicted**				
		Female		**Male**		
		Young	**Older**	**Young**	**Older**	**Total**
Female	Young	**11 (91.7)**	1 (8.3)	0 (0)	0 (0)	12 (100.0)
	Older	2 (18.2)	**9 (81.8)**	0 (0)	0 (0)	11 (100.0)
Male	Young	0 (0)	0 (0)	**10 (90.9)**	1 (9.1)	11 (100.0)
	Older	0 (0)	0 (0)	1 (8.3)	**11 (91.7)**	12 (100.0)
Total		13	10	11	12	**46**

Overall prediction accuracy: 89.1% (41out of 46 participants)

Note.

Figures in **bold** typeface represent correct predictions and corresponding percentages.

FIGURE CAPTIONS

Figure 1 Mean fundamental frequency (in semitone) of young and older groups in both genders

Figure 2 Mean contact quotient (in percent) of young and older groups in both genders

Figure 1 Mean fundamental frequency (in semitone) of young and older groups in both genders

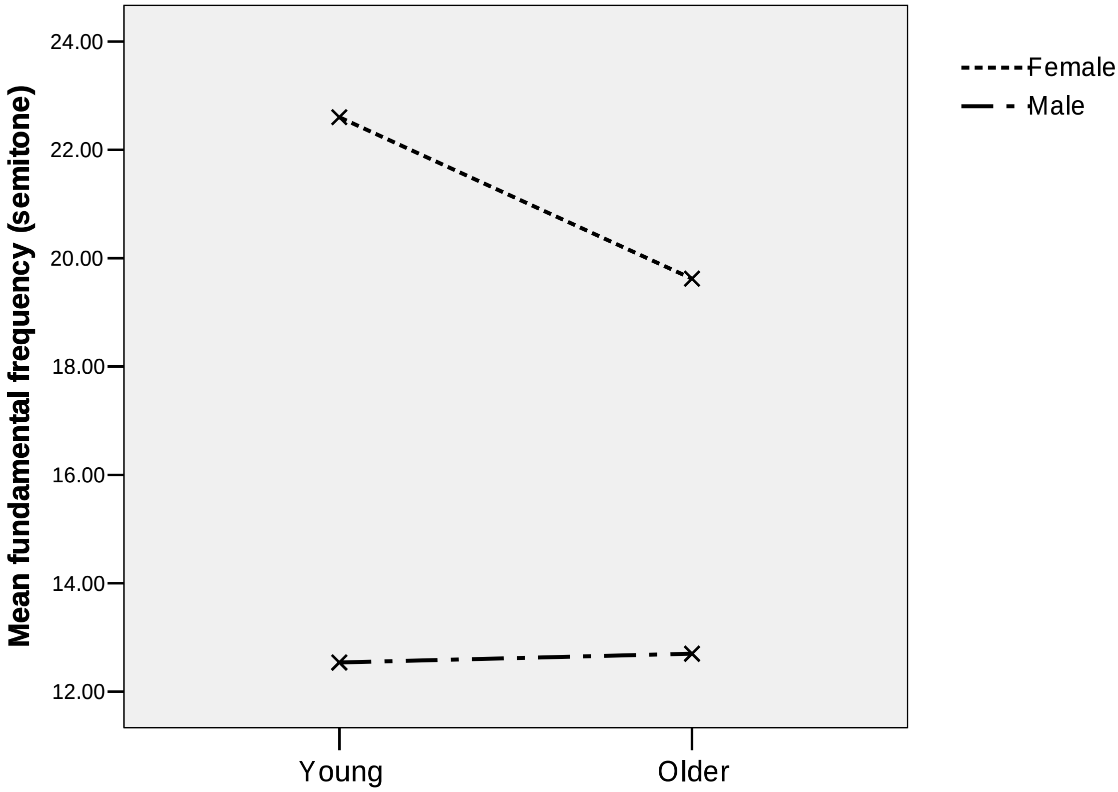

Figure 2 Mean contact quotient (in percent) of young and older groups in both genders