Open Quotient (EGG) measurements of young and elderly voices: Results of a production and perception study

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This paper presents the results of Open Quotient measurements in EGG signals of young (18 to 30 year old) and elderly (59 to 82 year old) male and female speakers. The paper further presents quantitative results on the relation between the OQ and the perception of a speaker's age. Higgins & Saxman (1991) found a decreased OQ_{EGG} with increasing age for females, whereas the OQ_{EGG} in sustained vowel material increased for males as the speakers age increased. In Linville (2002), however, the spectral amplitudes in the region of F_0 (obtained by LTAS-measurements of read speech material) increased with increasing age independent of gender; this could be interpreted indirectly as an increasing OQ. We measured the OQ_{EGG} not only for sustained vowels, but also in vowels taken from isolated words. In order to analyse the relation between breathiness in terms of an increased OQ and the mean perceived age per stimulus a perception test was carried out in which listeners were asked to estimate speaker's age based on sustained /a/-vowel stimuli varying in vocal effort (soft - normal - loud) during production. The results indicated the following: (i) The decreased OQ for elderly females originally found by Higgins & Saxman is not apparent in our data for sustained /a/-vowels. For our female speakers no significant difference between the OQ of young and old speakers was found; for elderly males, however, we also found an increasing OQ with increasing age.(ii) In addition, a statistically significant increased OQ_{EGG} occurs for the group of the elderly males for the vowels from the word material. (iii) Our results show a strong positive relation between perceived age and OQ in male voices. Regarding (i) and (ii), at least the male speaker's voice becomes more breathy as age increases. Considering (iii), increased breathiness may contribute to the listener's perception of increased age.

1. Introduction

Age recognition from voice is possible with reasonable accuracy (e.g. Ptacek & Sander, 1966). Shipp & Hollien (1969) suggest that there is an identifiable set of measurable parameters that contribute to the perception of age from voice. Several features such as F_0 (pitch), jitter, shimmer and spectral tilt (voice quality) as well as temporal features like segment durations and pauses (speech tempo/timing) have been identified as markers of chronological and perceived age (for details see Linville, 2000).

Asked to describe the most salient features of aged voices, listeners reported increased breathiness among other features, at least for male voices (Hartman & Danhauer, 1976; Hartman, 1979). Winkler et al. (2003) qualitatively analysed the EGG signals and the Long-Term Average Spectra (LTAS) of sustained vowels and found that in males increased perceived age was linked to more sinusoidal EGG signals and considerable less spectral energy between two and four kHz. For female speakers this tendency did not occur. The increased spectral tilt values in males resulting from the energy drop around 2 kHz are another characteristic of breathy voice.

A stronger perceived breathiness is linked physiologically to an increased Open Quotient (e.g. Klatt & Klatt, 1990), as was indirectly measured by Higgins & Saxman (1991) for EGG signals of sustained /a/-vowels. They found decreased OQ_{EGG} values with increasing chronological age for females, whereas the OQ_{EGG} increased for males as the speakers' chronological age increased. The increase of OQ values in male voices could be interpreted as a consequence of laryngeal changes with increasing age. Although laryngeal degeneration due to increased age in females seems to occur to a lesser extent (e.g. Honjo & Isshiki, 1980), the decrease of OQ values in elderly female voices could not be explained.

According to Hanson et al. (2001) it is expected that as OQ increases, the glottal waveform more closely approximates a sinusoid of the fundamental frequency. Therefore in the frequency domain the amplitude of the first harmonic increases relative to the amplitudes of the higher harmonics. In Linville (2002) the spectral amplitudes in the region of F_0 (obtained by LTAS-measurements) increased with increasing age, independent of gender, which could be interpreted indirectly as increasing OQ values for both females and males in their read speech material.

Although results were derived from sustained vowels and read speech by means of analysing EGG signals and LTAS respectively, results from the literature regarding Open Quotient and the voices of chronologigal old speakers are contradictory.

In a study of Debruyne & Decoster (1999) possible acoustic correlates of age judgements based on sustained vowel material were analysed. Vowels unani-

mously judged as young or old were acoustically analysed. Among other distinctions between the vowels judged as young or old they found a smaller difference between the first and the second harmonic in the spectrum (H1-H2) for the vowels of the speakers judged unanimously as old. This difference was statistically significant for female voices only. Their findings could be indirectly interpreted as decreased OQ as a marker of perceived age. Although Debruyne & Decoster did not find a single acoustic feature that could explain the age judgements of their listeners, the decreased OQ especially for the elderly male voices do not match the results of Hartman & Danhauer (1976) and Hartman (1979).

The aim of the first part of this study was to measure OQ_{EGG} values not only for sustained vowels, but also for vowels taken from isolated words. With the extended stimulus material we are able not only to replicate the results of Higgins & Saxman but also to analyse whether the OQ_{EGG} values depend on stimulus type. The aim of the second part of this study was to quantify the relation between OQ_{EGG} values and the perception of a speaker's age. For this purpose a perception test was carried out in which listeners were asked to estimate the speaker's age based on sustained vowel material varying in vocal effort.

2. Open Quotient (EGG) and Chronological Age

2.1. Recordings

Our data consist of the sustained German vowel /a/ and /a/-vowels taken from words spoken one by one from a list of words. For the sustained vowel material the speakers were instructed to produce the vowel as stable as possible with self-selected comfortable pitch and loudness. For the words from the wordlist the speakers were instructed to speak the word as naturally as possible. The whole list contained 23 different words; the /a/-vowels used in this study were taken from two words. To account for the possible influence of word stress on voice quality two vowel versions were used: One vowel originated from the unstressed syllable of "l[a]wine" (avalanche), the second version from the stressed syllable in "kohlr[a]bi" (kohlrabi). From each sustained vowel, an interval of 500 ms centred on the midpoint of the vowel was selected for the analysis of the Open Quotient. In the word material the whole duration of the vowel segment was used to calculate the mean OQ_{EGG}. The recordings consist of an audio channel and a channel with the EGG signal; in this study only the laryngographic signals were used.

Table 1: Descriptive statistics (number of speakers, mean chronological age, standard deviation, minimum and maximum chronological age in years) for the speakers used in this study.

	Female					Male				
Group	**N**	**Mean**	**SD**	**Min**	**Max**	**N**	**Mean**	**SD**	**Min**	**Max**
					/a/ (sustained)					
Young	9	26.00	1.80	24	28	13	25.62	4.21	18	33
Elderly	9	69.33	6.67	61	82	9	63.56	3.32	59	70
					/a/ (words)					
Young	11	26.27	1.85	24	29	12	25.50	4.38	18	33
Elderly	16	69.56	5.85	61	82	12	66.75	7.44	59	82

We recorded 52 speakers: 27 female speakers and 25 males. The corpus of female data consists of 11 young (24-29 years old) and 16 elderly speakers (61-82 years of age). Regarding male speakers, our corpus includes recordings of 13 young (18-33 years old) and 12 elderly males (59-82 years of age). The details of the age distribution of the speakers can be found in Table 1. The number of speech items per stimulus type differs because not all speech items were available for all stimulus types and speakers. In addition abnormal EGG waveforms displaying any signs of voice disorders were excluded from the analysis. Because of the possible relationship between age and general health particular attention was taken to record healthy elderly speakers judged by a physician.

2.2. Methods

Derived Measures: Two alternative measurements of the Open Quotient (EGG) were taken. The time instant of glottal closure is well detectable as a positive peak in the time derivative (DEGG) of the EGG signal, but there is no agreement on defining the time instant of glottal opening. In the past, the minimum of DEGG has been used as marker for the glottal opening (Henrich et al., 2004), but often there does not exist any clear minimum during a glottal cycle. Even if there is a clear minimum, there is no agreement on whether this is actually the instant of glottal opening or not. An alternative approach to analyse the vibrational patterns of a glottal cycle in an EGG signal is to define a time instant corresponding to the point of intersection between the (falling edge of the) EGG signal and a threshold line. With the threshold intersection criterion different values have been placed at points representing 25%, 30%,40%, 50% and 75% of the signal peak-to-peak amplitude (Higgins & Saxman, 1991;

Orlikoff et al., 1997; Sapienza et al., 1998). There is an agreement on the fact that the results within a study do not strongly depend on the threshold value as long as a constant value is consistently used.
Generally the OQ is defined as the ratio between the duration of the phase where the glottis is open and the whole duration of the glottal cycle, multiplied by 100 to express the values in percent. In this study two OQ values were calculated: OQ1 uses the minimum of DEGG as the time instant of glottal opening, whereas OQ2 uses the threshold intersection criterion (30%) to define the time instant of glottal opening.

Statistical Analysis: One key question of this study was whether the OQ_{EGG} rises or falls with increasing chronological age of the speakers. Because the number of speakers is rather small we decided to use a non-parametric test. In order to compare the means of OQ1 and OQ2 between the group of young and old speakers, the Kolmogorov-Smirnov test for two independent samples was applied for the sustained vowel material as well as for the stressed and unstressed vowels from words. Because the process of aging as well as the voice characteristics generally differ between males and females, statistical analyses were arranged for each sex separately.

*2. 3. Result*s

The means of OQ1 and OQ2 were computed for every speaker and speaking condition. The mean value of one token represents the average value over every glottal cycle of the EGG signal under investigation. After computation of the means of the single tokens these means were again averaged to obtain group means for young and elderly speakers. The group means broken according to sex and age group can be found in Table 2.

Female speakers: For the sustained vowels the OQ_{EGG} values were greater for the older than the younger female speakers. The OQ1 group mean, where values originated from the time derivation of the EGG, rises from 52.12% (young) to 54.13% (elderly). The OQ2 group mean increases from 44.07% to 48.12%. Both measurements of Open Quotient show a tendency of increased breathiness with advanced age. Both differences were not statistically significant. Therefore, the increase can only be interpreted as a trend.
For the unstressed vowels from the word material the OQ1 group mean decreases from the young (56.34%) to the elderly (54.05%) speakers. The group means of OQ2 - 49.56% for the young and 49.36% for the elderly speakers - are nearly identical. The decrease of OQ1 as well as the very small decrease of OQ2 were not statistically significant.

Table 2: Means and standard deviations for OQ1 and OQ2 separated by sex, and age group.

	Females				Males			
	Young		Elderly		Young		Elderly	
Condition	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
OQ1 (Minimum in DEGG) [%]								
/a/ (sustained)	52.12	8.10	54.13	6.21	49.09	6.81	53.97	4.54
/a/ (unstressed)	56.34	9.55	54.05	7.74	48.17	6.58	59.49	8.47
/a/ (stressed)	54.06	6.96	53.01	6.44	47.79	6.69	56.75	6.65
OQ2 (Threshold criterion 30%) [%]								
/a/ (sustained)	44.07	8.36	48.12	8.25	48.91	5.43	50.92	5.41
/a/ (unstressed)	49.56	6.99	49.36	7.66	47.91	4.87	55.03	8.90
/a/ (stressed)	47.69	7.39	49.27	7.67	47.17	3.70	51.40	7.31

For the stressed /a/-vowels the OQ1 group mean of the young females (54.06%) decreases to 53.01% for the group of the elderly females. In contrast, the OQ2 group mean increases from 47.69% for the young group to 49.27% for the group of elderly females. Because the decrease of OQ1 as well as the increase of OQ2 was not statistically significant, the contradiction should not be overestimated. There is neither a trend for an increasing nor a trend for a decreasing OQ in stressed vowels.

Male speakers: For the sustained vowels the OQ1 group mean increases from the group of the young males (49.09%) to the group of elderly speakers (53.97%). The increase is apparent in the OQ2 measurement as well. The OQ2 group mean increases from 48.91% for the young to 50.92% for the elderly males. Although the group mean difference of OQ1 is slightly higher, this difference as well as the difference of OQ2 is not statistically significant.

The OQ1 group mean increases in the case of unstressed vowels from 48.17% for the young to 59.49% for the elderly males. A somewhat smaller difference is apparent between the OQ2 values. The group mean increases from 47.91% for the young to 55.03% for the elderly male speakers. Both differences are remarkably high, but only the group mean difference of OQ1 is statistically significant ($p<0.05$).

Similar in appearance are the OQ values for the stressed vowels from words. The OQ1 group mean increases from 47.79% for the young to 56.75% for the elderly males. The OQ2 group mean also increases from 47.17% for the young to 51.40% for the elderly males. Similar to the unstressed vowel versions, both

differences are high, but only the group mean difference of OQ1 is statistically highly significant (p=0.01).
For the sustained vowels results from both kinds of OQ measurements lead to the same trend. Regardless of the sex of the speakers, although not statistically significant, there is a weak trend for a higher OQ for the elderly compared to the younger speakers. The difference between the group of the younger and the older speakers is around 2% and 5%. Results from the vowels of the word material of the female speakers do not lead to any trend. In contrast, results from male speakers are clear. Both OQ measurements show an increase from the young to the elderly males. For the OQ1 measurement the difference for the vowels in unstressed as well as in stressed syllables is statistically significant. Although the differences for the OQ2 measurement are not statistically significant, the difference of approximately 7% for the unstressed vowels is remarkably high.

3. Open Quotient (EGG) and Perceived Age

Results from Hodge (2001) as well as from the first part of this study suggest that the Open Quotient consistently increases in the voice of elderly speakers, at least for males. Therefore a perception test was carried out to analyse whether the Open Quotient (derived by means of EGG) is a potential correlate of the perception of a speaker's age, at least for the distinction between the young and the elderly speakers. In order to expand the range of the acoustic correlates of perceived voice qualities of the stimulus set, special versions of the sustained /a/-vowel were used. According to e.g. Dromey et al. (1992), Hodge et al. (2001) and Sundberg et al. (2005) measures of vocal function strongly depend on vocal loudness. To capture a wide varity of different vocal functions, in addition to the sustained /a/-vowels from the first part of the study, /a/-vowels with systematic variation in vocal effort during production were included in the stimulus set. For the perception test all stimuli were normalized with respect to amplitude so that the task of the speaker was masked and the listener's focus was shifted to variations in perceived voice quality only.

3.1. Stimuli and Listeners

For the purpose of this perception experiment speakers were asked to produce two versions of the German vowel /a/. One instruction was to sustain the vowel as softly as possible but without whispering; the second instruction was to sustain the vowel as loudly as possible but without shouting. Three to five trials dependent on success of the speaker were recorded. For the perception experiment a 500 ms interval of the most stable token centred on the midpoint of

the vowel were selected. Furthermore 500 ms intervals of the vowels used in the first part of the study were added to the stimulus material.
The stimuli were produced essentially by the speakers described in subsection 2.1. Four female and two male speakers, neither chronological young nor old, were added to the corpus to maximize the number of speakers. Thus the full stimulus set consists of 60 stimuli from 22 female, and 72 stimuli from 24 male speakers, three stimuli each. For the female speakers four stimuli of the loud, and two stimuli of the soft production were excluded because of serious deviations regarding naturalness judged by the experimenter. The intensity of all stimuli was (peak-)normalized to suggest to the listeners a variation in voice quality features instead of an intensity variation.
Twenty subjects (six male, 14 female) listened to the female voice samples and 40 subjects (20 male/ 20 female) took part in the perception test with the male voices. For the experiment with the female voices the mean age of the listeners was 35.35 years (SD = 7.22 years). The mean age of all 40 listeners in the experiment with the male voices was 26.23 years (SD = 4.39 years). All listeners claimed not to have or know of any hearing problems either at present or in the past.
Listeners seated in front of a computer screen wearing earphones. After the presentation of one item the task of the listener was to rate the chronological age of the speaker immediately. In case of female voice stimuli the listeners rated on a five years scale from 20 to 95 years of age. Listeners rated the chronological age of the speaker in years directly for the male voices. One whole presentation consisted of three repetitions of each vowel signal (500 ms each) separated by a silent interval (500 ms). Subjects were able to listen to a stimulus only once. They were instructed to judge immediately after listening. The test started with a pre-presentation of five items to enable the listeners to adapt to the speed of the perception test.

3.2. Methods

The values of the mean perceived age per stimulus resulting from the perception experiment, that were computed by averaging the single values across all listeners, are quasi-continuous. These values were correlated with the values of the Open Quotient measured in the first part of this study. The single correlations for the condition of soft, normal or loud production level were not analysed in the context of this study because the task was given only to verify whether the OQ_{EGG} could be used as a predictor for perceived age.

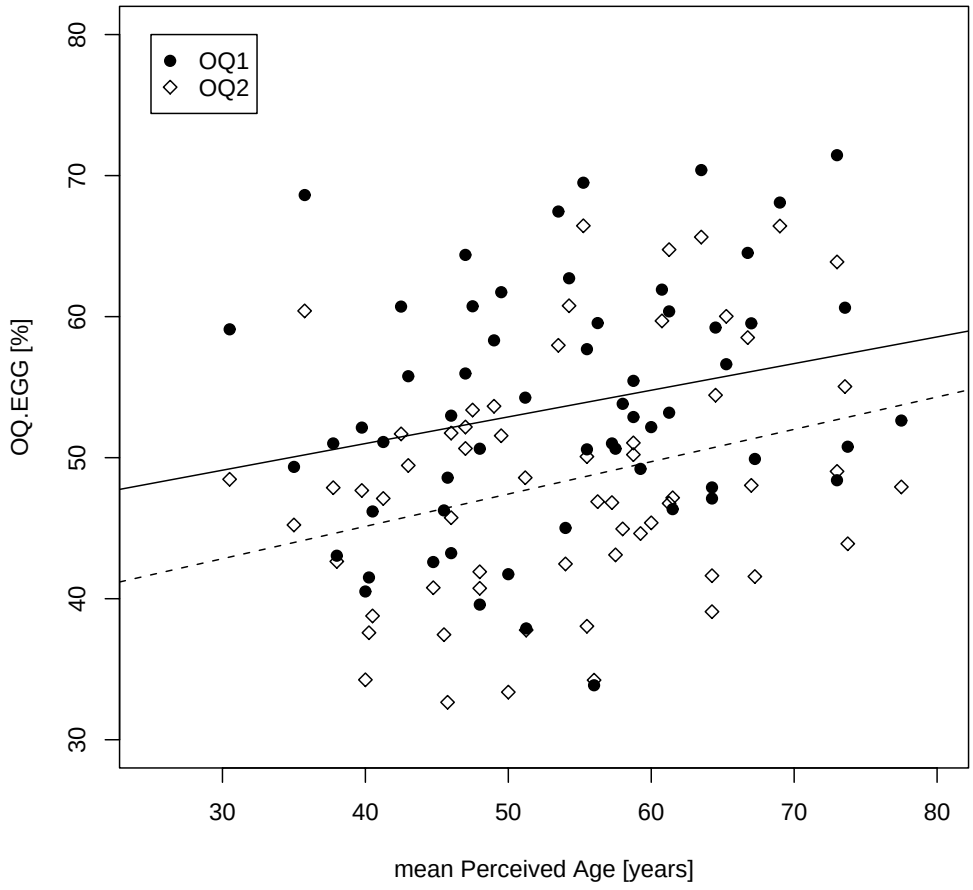

Figure 1: Relation and straight line fit between mean perceived age per stimulus and two versions of the Open Quotient (EGG) for female speakers.

3.3. Results

Female speakers: The mean perceived age per vowel stimulus slightly increases with increasing OQ1 as well as increasing OQ2 values. The relation between the mean perceived age per stimulus and the OQ_{EGG} values is depicted in Figure 1. The Pearson correlation coefficient between the mean perceived age and OQ1 is 0.24 (p=0.06, two sided). Between the mean perceived age and OQ2 the Pearson correlation coefficient is 0.30 and statistically significant (p=0.02).
From Figure 1 it appears that the OQ_{EGG} values scatter remarkably. There are quite a number of vowel stimuli with OQ_{EGG} values above 65% which (with one exception) were judged between 52 and 75 years old by the listeners. The stimuli with an OQ_{EGG} below 40% were judged between 40 and 55 years. The stimuli judged older than 40 years use nearly the whole range of OQ values

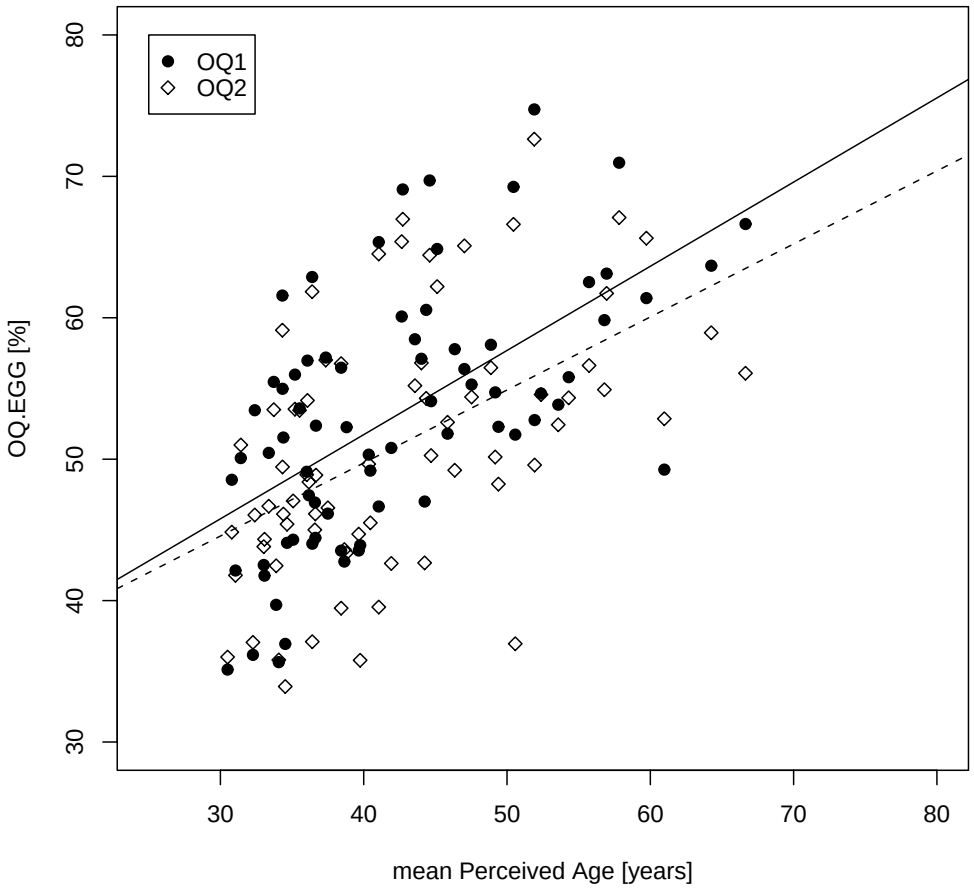

Figure 2: Relation and straight line fit between mean perceived age per stimulus and two versions of the Open Quotient (EGG) for male speakers.

between 30% and 70%. It seems that other features or combination of features guide the listener in judging a female speaker's age.

Male speakers: Similar to the pattern found for female voices the judged age increases as OQ values increase. The Pearson correlation coefficient between the mean perceived age per vowel stimulus and the OQ1 values is 0.59 (p=0.00), and 0.51 (p=0.00) between the mean perceived age and the OQ2 values. The relation between mean perceived age and the OQ values per stimulus is given in Figure 2. Both Pearson correlation coefficients are statistically highly significant.

From Figure 2 it appears that there is a strong relation between the mean perceived age and the OQ values. This strong relation is represented in the high correlation coefficients. For male voices there is a more systematic pattern in contrast to the female voices. Vowel stimuli judged as young (approximately 30

to 40 years old) have OQ values smaller than 65%, whereas stimuli judged older than approximately 50 years have OQ values between 50% and 75%.
Results from the second part of the study suggest that the relation between the Open Quotient and the mean perceived age per vowel stimulus is stronger for male than for female speakers. Although at least one of the correlations between OQ and mean perceived age in female voices is statistically significant, the two coefficients are rather small. Neither a consistent decrease nor a consistent increase of OQ_{EGG} is apparent in our data of female voices regarding the chronological age of the speakers; the relation between OQ and mean perceived age is only weak. The OQ_{EGG} for the group of elderly men is consistently higher in comparison to the group of the young speakers.

4. Summary & Conclusions

The increase of OQ_{EGG} for male elderly voices is apparent in our data; however, we did not find the decrease in OQ_{EGG} values for elderly female speakers originally found by Higgins & Saxman (1991) for sustained vowels. We further found a statistically significant increase in OQ_{EGG} values for the group of elderly male speakers in comparison to younger males for the vowels originated from words. These results are in line with findings of Linville and are plausible in terms of laryngeal changes which occur with advanced chronological age. The finding of significant differences between young and old males in stressed and unstressed vowels from words suggests that sustained vowels could be more affected by compensatory phonatory behaviour in terms of adjusted vocal effort or strain than the word material. Furthermore, our results for the female voices match the results of Sapienza & Dutka (1996), who did not find any significant changes in their amplitude-based airflow measurements related to the chronological age of their female speakers.
Regarding the perception of age, in case of male voices our results agree with the results of Hartman & Danhauer (1976) and Hartman (1979); and correlations give quantitative support to the impressions the listeners supplied in the two cited studies. For the female voices our results do not match the results of Debruyne & Decoster (1999) who found a significantly decreased OQ for vowels unanimously judged as old. In our material the OQ_{EGG} seems to have only minor importance in characterising the voices of chronological old female speakers as well as perceptually old female voices. Our results do not suggest any dependency between the stimulus type and the mean OQ_{EGG} values.
Perceptual judgments most likely depend on multiple acoustic cues. Furthermore human listeners seem to differ in the relative importance they give to different aspects of vocal quality. This is suggested by Kreiman et al. (1994) for the description of pathological voices by means of breathiness and hoarseness

ratings of expert listeners. Because the recognition of age by a group of listeners is possible to some extent, Shipp & Hollien (1969) stated that there is an identifiable set of acoustic parameters that contribute to the perception of age from voice. In our study listeners seem to be influenced in their judgements about the male elderly voice by increased OQ values. This could explain the relatively strong relation between the OQ_{EGG} and the mean perceived age in the second part of this study.
Finally it should be noted, however, that the maximum variation in voice quality features contained in the stimuli of the perception test usually does not appear in everyday speech. Other vocal qualities such as fundamental frequency which contribute to the perception of age, have not been analysed in the speech material of this study so far. In a next step it will be explored to what extent this feature is of perceptual relevance compared to other voice quality features.

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