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Vibrato and Open Quotient in the Singing Voices of Female Jazz and Classical Singers

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0282847

a thesis submitted to the Faculty of Humanities in partial fulfilment of the requirements of the degree Master of Arts (MA) in General Linguistics at the University of Amsterdam

Supervisor: Paul Boersma

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Acknowledgments

First of all I would like to thank the singers who agreed to take part in this project voluntarily and at no charge, only being compensated with chocolate. Thank you to Antje, Maribeth, Mieke, Gerlinde, Jule and Mapi, without whom this study would not have been possible. I would also like to thank Ton Wempe, who helped me with setting up the equipment in the recording studio and who found workarounds which in the end allowed smooth and trouble-free recording sessions. I also want to thank Dirk Jaasma who worked at the library when I began my studies and who helped me to buy a bike and whom I always appreciated for his helpfulness and humour.

I am very much indebted to Louis Pols, who was my supervisor back when I started working on my thesis and who has since retired from his position. He was always of great support and despite my many difficulties never stopped motivating, supporting and believing in me. I am very happy that now I am finally finishing my thesis and I am looking forward to sending him a copy along with letting him know how much his support has meant for me.

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I feel the need to say that finishing what has been left unfinished over such a long time means a lot to me, possibly more than I am able to explain in words. Utilising the liberty that one has in writing his acknowledgments, I want to express how bringing this thesis to an end is not just about finishing a thesis. It is about overcoming a jam in which this work has been stuck right in its centre. It is about closing a circle and about how much a closed circle excels every other shape in form and content.

This work is dedicated to and written in memory of my mother, Katharina Kuhlewind.

Aber jetzt in diesen Frühlingswochen
hat mich etwas langsam abgebrochen
von dem unbewußten dunkeln Jahr.
Etwas hat mein armes warmes Leben
irgendeinem in die Hand gegeben,
der nicht weiß was ich noch gestern war.

Die Liebende, Rainer Maria Rilke (Das Buch der Bilder)

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1 Introduction

The aim of this research is to examine the differences between jazz and classical singing voices regarding vibrato and open quotient. Differences between the two singing styles are not difficult to perceive[1] and it would be interesting so see whether these differences can be confirmed by objective measurements of voice properties. Results of this research with regards to vibrato and open quotient that might differ between jazz and classical singing might lead to a better understanding of what distinguishes one singing style from another. In addition, we want to compare our findings to those of others to see whether the results of this thesis comply with them or not.

Six female singers were recorded, which at the time of the recording were all vocal students at the Conservatorium of Amsterdam. Three of the singers were vocal students in the jazz department and the other three were studying at the classical department of the conservatorium. Two songs, the jazz-standard “Autumn Leaves” and the classical song “An die Musik”, were chosen for the recording and sung by all subjects. Out of each song, ten notes of different length and pitch were selected and both the vibrato and open quotient analyses were carried out for these notes.

Vibrato consists of fast undulations of the fundamental frequency of a sung voice. This research will analyse vibrato extent (deviation from mean of the fundamental frequency), vibrato rate (number of vibratory cycles per second) and the vibrato position within a note. As a feature, vibrato is not present in speech and can only be found in singing voices. Seashore (1938) was the first to analyse vocal vibrato and since then the investigation of vibrato has been of interest for phoneticians, vocal pedagogues, and musicologists. It is commonly agreed upon by musicians that "vibrato is seen as a good singing technique and that vibrato is a feature of the voice of trained singers that occurs naturally when the voice is produced with freedom and good technique" (Howes et al. 2004: 1). Titze (2002) reports that vibrato enriches the average spectral content of a sustained tone and thus enhances the overall sound quality. Comparing different samples of vocal vibrato, Diaz and Rothman (2003)

[1] This was confirmed by Thalen and Sundberg (2001), who asked subjects to classify different singing styles as part of their study.

found that a periodic vibrato is generally judged as good singing. Titze et al. (2002: 1) explain the production of vibrato through a reflex resonance model of the glottal source, in which an "agonist–antagonist muscle pair can produce negative feedback instability in vocal-fold length with this long reflex latency, producing oscillations on the order of 5–7 Hz". Arroabarren and Carlosena (2006) fortify those findings by concluding that the pitch undulations of vocal vibrato are generated by the glottal source. In this study, the vibrato was measured by plotting pitch contours of each note, which were subsequently analysed using the scripting function of the program PRAAT[2].

The open quotient of a voice is the percentage of time per vocal fold vibratory cycle in which the vocal folds are apart compared to the time of a full vibratory cycle of the vocal folds. Henrich et al. (2005: 1417) state that "the open quotient Oq is a glottal source parameter of considerable interest, as it has been reported to be related to voice qualities such as 'breathy' and 'pressed' " and Thalen and Sundberg (2001: 82) were able to clearly assign different modes of phonation to different styles of singing, where "Classical was similar to flow phonation, Pop and Jazz to neutral and flow phonation, and Blues to pressed phonation". Mitchell and Kenny (2004: 172) report that the use of the 'open throat' technique (flow phonation[3]) is widely thought of as good singing technique and that the resulting sound is recognised "as balanced and coordinated, free, even or consistent, warm and open". To measure the open quotient, an electroglottograph (EGG) was used. Two electrodes were placed around the subject's neck at the level of the larynx for the EGG to measure impedance changes between those electrodes as the vocal folds vibrate. It outputs a waveform that increases as the contact area of the vocal folds grows and decreases with the vocal folds parting from each other. The open quotient (OQ) of a vocal fold vibratory cycle is defined as OQ = ((To / T) x 100) % (T = duration of vocal fold cycle; To = duration of the vocal folds open phase).

Sundberg (1998: 121, 124) reports that music is often thought of as the "language of emotion" and also that "expressive communication works pretty well in singing".

[2] PRAAT was developed by Paul Boersma and David Weenink from the Institute of Phonetic Sciences at the University of Amsterdam. It can be downloaded from http://www.praat.org

[3] 'Flow phonation' is the phonation type situated between leaky (breathy) and neutral phonation and typically used in classical singing. For a detailed description see Sundberg (2000: 238).

Singing offers various means of expressing emotions, such as intensity, tempo, pitch glides and also vibrato characteristics and mode of phonation. Howes et al. (2004: 216) conclude that vibrato assists "the communication of emotion between singer and audience". In addition, the use of different phonation modes such as pressed or flow should also have an impact on how a listener judges the emotion which the singer wishes to express in her or his interpretation of a song.

Differences regarding both vibrato and open quotient were expected to be found between the groups of jazz and classical singers. Since jazz singers employ more expressiveness which varies strongly between singers, one might expect this to be reflected in both vibrato and open quotient. In general, the voices of the jazz singers appear to be more ‘breathy’ than those of the classical singers and since breathiness of a voice is the result of less vocal fold contact over time, this should result in a comparably higher open quotient for the jazz singers. Also, classical singers undergo a more rigidly structured training (especially when it comes to the interpretation of songs), so this may reflect in more homogenous results within the group of the classical singers. In addition, jazz singers generally perform in smaller and more intimate settings such as smaller jazz clubs whereas classical singers may perform in larger concert halls, possibly having an entire orchestra behind them. It is expected that this results in a more diversified use of expressive means for the jazz singers whereas classical singers would focus more on an overall sound quality that is more prominent and carries better over long distances.

Those assumptions were confirmed while listening to the recordings for the first time. The classical singers' interpretation of the songs did indeed sound more consistent among subjects and the jazz singers seemed to employ a wider range of expressive techniques. Also, the jazz singers' voices sounded more breathy than those of the classical singers

2 Subjects and Recording Procedure

2.1 Subjects

The six female subjects recorded for this study were all voice students of the Conservatorium of Amsterdam within the voice range of mezzo-soprano[4]. The jazz singers will be denoted as J1, J2 and J3 and the classical singers as C1, C2 and C3 respectively. Table 2.1 lists the recorded singers along with information about their age and year of study at the time of the recordings.

Table 2.1 Subjects

Subject	Age	Year of Study
J1	27	4
J2	21	1
J3	23	4
C1	28	1
C2	33	4
C3	25	6

It might be argued that professional singers would be more representative for the investigated singing styles rather than voice students. But due to the tight schedules of most professional singers and since there was no budget involved in this study to pay a professional singer for the recording, the decision for students was made. Despite this, it was assumed that the vocal students had already acquired a singing technique that is typical for their style and were therefore suitable for this research. It can be assumed that all students of voice have started singing from an early age on prior to their studies, both freely and/or through singing lessons. In this period they would already have started to acquire skills and singing characteristics typical for their preferred style of singing.

[4] Initially, an additional jazz singer was recorded but it was decided to exclude the singer from the research for three reasons. One reason was that the singer was neither a student of voice and had never received any singing training in her life. Secondly, many of the measured values for this subject (especially regarding vibrato) were extremely dissimilar to those of the other subjects. Finally, the subject's voice range was alto which made her unable to sing the selected songs in the same key as the other subjects.

All subjects reported to be in a good singing condition and of good health at the time of the recording.

2.2 Recorded Material

Two songs were chosen for the recording, each representing one of the two investigated singing styles. In order to investigate whether singers of a particular style would adapt to another style when being asked to sing a song attributed to the other singing style, both subject groups were asked to sing one jazz and one classical song. To minimize preparation time for the subjects it was decided that the songs should not be too demanding for the singers and also well known. Being a well known jazz-standard, the song “Autumn Leaves” (Music: J. Kosma / Lyrics: J. Mercer) was chosen. It could be assumed that not only the jazz singers but also the classical singers would be familiar with this song and it turned out that none of the subjects encountered any difficulties in sight-singing the song. As a classical song, “An die Musik” (Music: F. Schubert / Lyrics: F. Schober) was selected. Although this song was not known by subjects J1 and J3, it was simple enough for them to learn it within a short amount of time. As it is typical for singers of both styles to be accompanied by musical instruments, a pre-recorded piano accompaniment was provided to the subjects via headphones during the recording. For "An die Musik", the accompaniment created was based on the piano part written by the composer and for the song "Autumn Leaves" a simple accompaniment following the song's chord progression was created. The accompaniments were recorded using a simple PC based music sequencer and a simple piano sound was chosen. In a real performance situation, both singer and accompanist (or band) would often vary the timing of a song for means of expression, however in our accompaniment the timing was held strictly in order to enable a better comparison of vibrato in relation to note length. The tempo chosen for "An die Musik" was 80 beats per minute (Bpm), which roughly corresponds to the composer's tempo indication "Mäßig". For "Autumn Leaves" a tempo of 100 Bpm was chosen as this roughly corresponded to the tempo used in many professional standard recordings. The provided accompaniment guaranteed that all subjects would sing the songs at the same tempo and in the same key. The scores for the two songs including the provided accompaniment can be found in appendix A. During the recording process, the classical singers were asked to sing the entire song “An die Musik” and the first 16 bars of the song “Autumn Leaves”. The jazz singers were asked to sing the song “Autumn Leaves” entirely and the first 7 bars of the song “An die Musik”. Table 2.2 lists the average durations recorded for the entire songs and the recorded excerpts respectively.

Table 2.2 Recording Durations

“An die Musik”		„Autumn Leaves“	
Entire song [s]	1st 7 bars [s]	Entire Song [s]	1st 16 bars [s]
109.8	20.4	68.3	34.2

The ten notes chosen out of each song for later analysis all lay within the first 16 bars of the song “Autumn Leaves” and the first 7 bars of the “An die Musik” respectively.

During the recording, the subjects did not get any instructions as to how to sing both songs. They were not asked to imitate the style they were not so familiar with but to sing the songs in a way in which they would feel most comfortable and that would appear most natural to them.

2.3 Recording Procedure

All recordings were made in the recording studio inside the Institute of Phonetic Sciences of the University of Amsterdam[5]. The studio consists of an anechoic chamber with an adjacent room for noisy equipment. In order to make necessary adjustments during the recording procedure, the recording assistant (author) was placed in the same room as the subjects. The computer used for recording was placed in the adjacent chamber and a low-noise flat screen monitor was used inside the recording room. Figure 2.1 gives a schematic representation of the recording studio along with the set-up for the recordings.

[5] Recordings were done in the former building of the Phonetic Institute located at the Herengracht. The institute has since moved into the main building on Spuistraat.

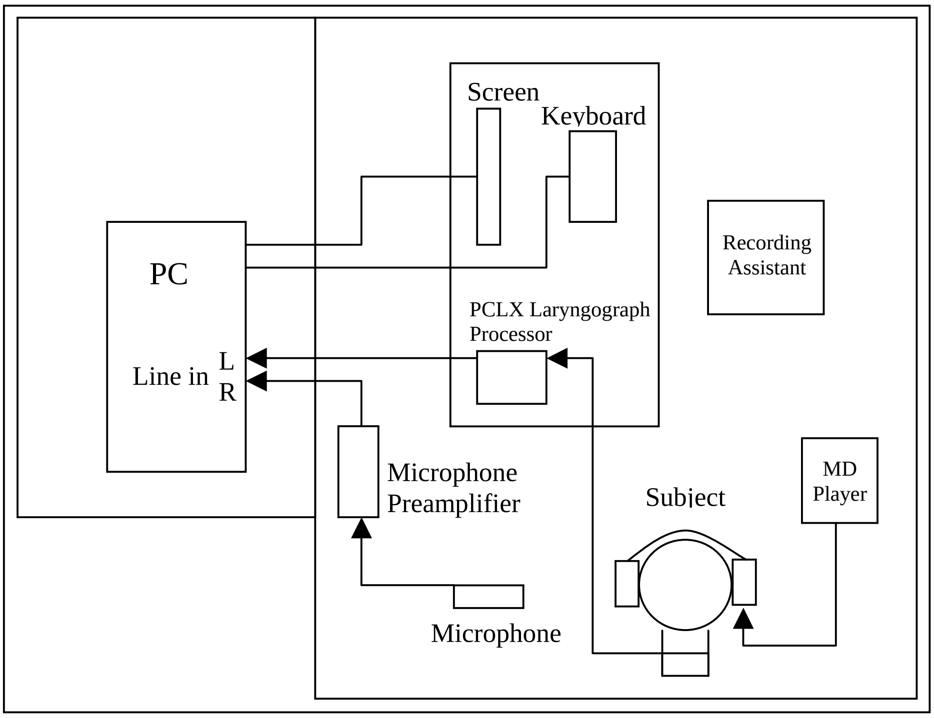

Figure 2.1 Recording Studio

Prior to the recordings, all subjects were given sufficient time to warm up their voices. The volume level of the accompaniment that was provided to the subjects via headphones was set to a level that was not too high to ensure that the subjects could still monitor their own voices well enough to sing comfortably. After the electrodes of the electroglottograph were placed around the subject's neck, they were asked to sing a few phrases in order to set the gain for both the microphone and the laryngograph processor signals to a sufficient level. In order to monitor the signal of the laryngograph processor, the program Winscope 2.51[6] was used. It was often necessary to slightly adjust the position of the electrodes around the subject's neck to obtain an optimal signal. Figure 2.2 shows a screenshot of the program monitoring a random note sung by the author. It gives an example of a good laryngograph signal (waveform at the bottom) along with the signal recorded via the microphone (at the top).

[6] Winscope 2.51 was designed by Konstantin Zeldovich and is distributed as freeware. It can be obtained through http://www.mitedu.freeserve.co.uk/Prac/winscope.htm

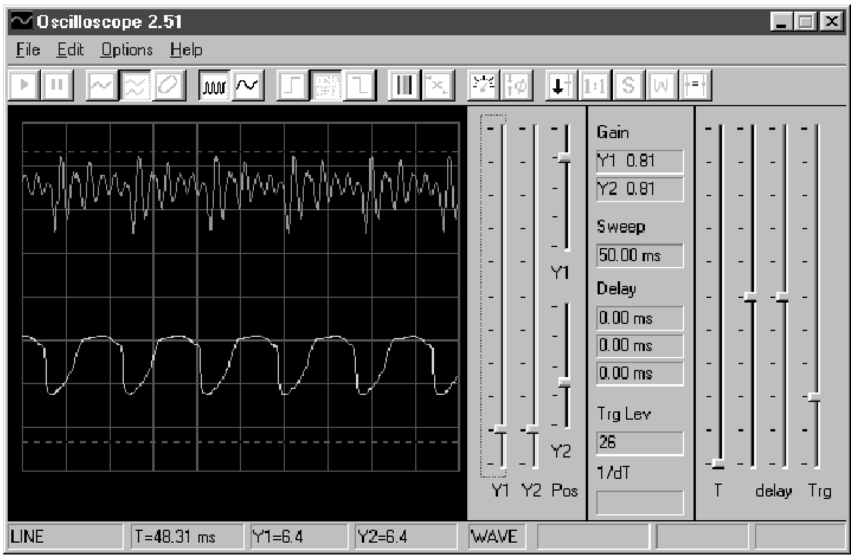

Figure 2.2 Winscope Screenshot

The subjects' singing voices were recorded using a Sennheiser MKH 104 T microphone with a mouth-to-microphone distance of about 30 cm for each singer. The signal was fed through a microphone preamplifier and then recorded to the hard disc of a PC via the right line-input channel. The output signal of the laryngograph processor was recorded simultaneously onto the same computer using the left line-input channel. All signals were recorded at a sample rate of 22.05 kHz and a bit depth of 16 bit per sample.

3 Data Measurements

All measurements were performed using the program PRAAT, version 4.1.28 with extensive use of its inbuilt scripting function. All PRAAT scripts that were written in order to obtain the data can be found in appendix B.

As mentioned above, ten notes out of each song were chosen for analysis. Notes with different durations and of different pitches were chosen to allow later analyses with regards to these attributes. In order to allow better comparisons between songs and singers, notes with similar pitches were chosen from both songs and note of different lengths were selected to make it possible to look for duration dependencies. Table 3.1 gives an overview on the chosen notes along with their note names, pitches and durations. The pitches given refer to equal temperament with a standard tuning of 440 Hz for the A above middle C, as was used in the provided accompaniment. The durations are those that would be achieved by a singer if the note is sung completely legato (starting exactly on the beat and fully covering the indicated number of beats). The actual values for each note did slightly vary from singer to singer.

Table 3.1 The notes chosen for analysis

	„Autumn Leaves" (100 Bpm), in D-minor									
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Note	b^{b}'	c'	a'	g'	b	f'	a'	a'	e'	d'
Pitch [Hz]	466.2	261.6	440.0	392.0	247.0	349.2	440.0	440.0	329.7	293.6
Duration [s]	3.0	0.6	1.2	3.0	0.6	2.4	1.2	1.8	0.6	2.4
	"An die Musik" (80 Bpm), in D-major									
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Note	d''	f#'	b'	f#'	d'	a'	b'	c#'	d'	f#'
Pitch [Hz]	587.3	370.0	493.9	370.0	293.6	440.0	493.9	277.2	293.6	370.0
Duration [s]	0.75	2.25	0.75	0.75	0.75	0.75	0.75	1.13	1.13	1.5

The notes out of the song "Autumn Leaves" are indicated by A1 to A10 and the notes from "An die Musik" from M1 to M10 respectively. The chosen notes are also indicated on the scores in appendix A.

3.1 Measuring the Vibrato

The vibrato of a singer's voice consists of rapid and regular variations of the fundamental frequency (F0) of a sung note. The modulation of F0 during vibrato has a sinusoidal character. The aspects of vibrato that will be investigated are vibrato extent, vibrato rate and vibrato position. The vibrato extent is defined as the average of all peak- and valley-to-mean differences of a note's pitch undulations. Since we perceive pitch logarithmically in relation to frequency, the logarithmic unit cent will be used to express vibrato extent. 100 cents are equal to an equally tempered semitone (two adjacent piano keys) and 1200 cents equal one octave (doubled frequency). With the given frequencies **a** and **b** in Hertz, the difference **c** in cents between those two frequencies would be calculated as $c = 1200 \log_2 (a / b)$. In addition, the maximum vibrato extent of the note (maximum difference from peak or valley to mean) was stored as well. The vibrato rate is the number of vibratory cycles per second expressed in Hertz. Some notes were not entirely sung with vibrato. As for vibrato position, onset time (beginning section of a note that was sung without vibrato), vibrato time and offset time (in case the end section of a note was sung without vibrato) were measured in seconds and their relative percentage regarding to the length of the entire note sung. Some notes were not sung with vibrato at all. For those notes, no vibrato data was taken and no other notes were chosen instead. In addition, the pitch deviation between measured mean F0 and desired F0 of a note (given by the provided piano accompaniment in standard 440 Hz tuning) was calculated for each note.

In PRAAT, the selected notes were first extracted by hand, using the beginning and end of the phonation period as start and end points for each note. In addition, a listening check was done to confirm that those points were set correctly. The notes were then displayed within the analysis window, where the pitch range settings of the window were set to appropriate values for each note to enable proper viewing of the notes' pitch contours. Using the TextGrid function of the analysis window within PRAAT, tiers were set manually that annotated the beginning and end of the note, beginning and end of the note section sung with vibrato and the positions of all maxima and minima of the pitch contour in the section that was sung with vibrato. The start and end of a note's vibrato section was set at the first and last visible peak (or trough) of a regular pitch undulation indicating vibrato.

To give an example, figure 3.1 displays the annotated pitch contour of note M2 sung by subject C3. At the beginning of a note, singers sometimes slide up or down to the target frequency of a note. It was observed that this slide usually occurred during phonation of the words first consonant and would come to a halt at the start of vowel phonation. Therefore, the start point of such a note was defined as the point of first vowel phonation also including a listening check as confirmation. The end of the note was defined likewise as the end of the note's voiced part. The mean pitch for each note was calculated within those boundaries of note start and end. In the example below, the calculated mean pitch of 361.1 Hz is marked by a dotted line.

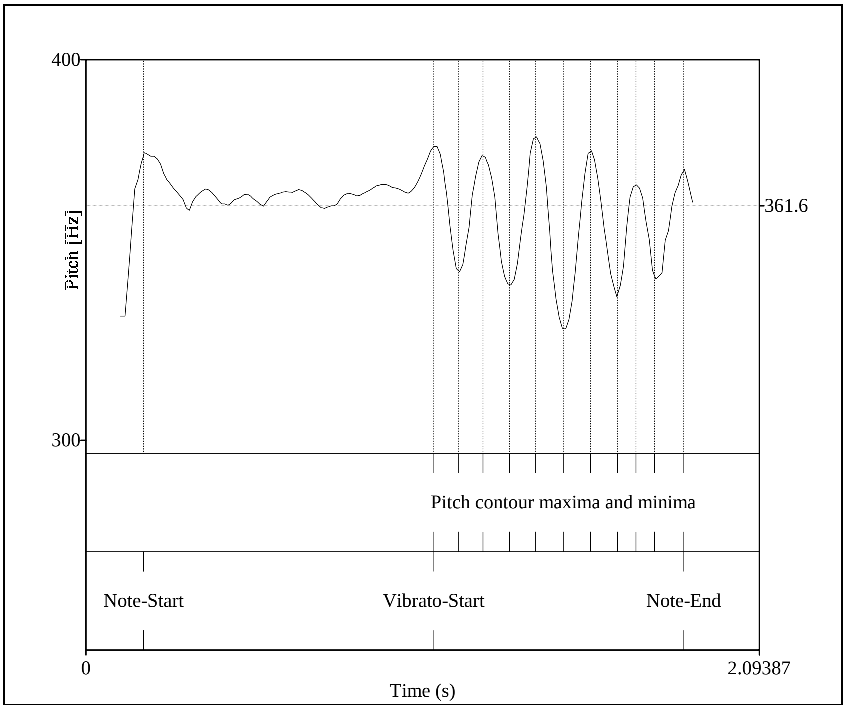

Figure 3.1 Annotated pitch contour for note M2, singer C3

A PRAAT script would then read the sound and TextGrid file and based on those calculate the values regarding vibrato extent, vibrato rate and vibrato position for each note. Eventually, the script would store each singers data into a table for later evaluation. The script can be found in appendix B and table 3.2 displays some of the results calculated by the script for the above example.

Table 3.2 Results for note M2, singer C3

Duration [s]	1.68	**Mean Extent [ct]**	82.54
Onset [s] / [%]	0.9 / 53.7	**Max. Extent [ct]**	161.68
Vibrato [s] / [%]	0.78 / 46.3	**Mean Pitch [Hz]**	361.63
Offset [s] / [%]	0 / 0	**Desired Pitch [Hz]**	370
Vibrato Rate [Hz]	6.43	**Pitch Deviation [ct]**	-39.61

The tables containing the data for each singer and song can be found in appendix C. In each table, the following data were stored for each singer and each note:

Table 3.3 Vibrato data measured for each singer and note

Vibrato data measured for each singer and note	
Dur_[s]	Note duration (voiced part)
OnsT[s]	Vibrato onset time (time between start of note and start of vibrato)
VibT[s]	Vibrato time (duration of the part of note sung with vibrato)
OfsT[s]	Vibrato offset time (time between end of vibrato and end of note)
OnsP[%]	Vibrato onset time percentage in relation to note duration
VibP[%]	Vibrato time percentage in relation to note duration
OfsP[%]	Vibrato offset time percentage in relation to note duration
Rat[Hz]	Vibrato rate, number of full vibratory cycles per second
NumCycl	Number of cycles identified and measured for that note
Ext[Ct]	Average vibrato extent (measured as the average distance between vibratory peaks/troughs and mean pitch)
EMa[Ct]	Maximum vibrato extent for that note
EMi[Ct]	Minimum vibrato extent for that note
MinPosn[s]	Position of minimum vibrato extent, measured in seconds from start of note
MaxPosn[s]	Position of maximum vibrato extent, measured in seconds from start of note
MtM[Ct]	Difference between minimum and maximum vibrato extent
MnP[Hz]	Mean pitch calculated for that note
DsP[Hz]	Desired pitch of the note according to provided accompaniment
Dev[Ct]	Deviation of sung mean pitch from desired pitch

3.2 Measuring the Open Quotient

The electroglottograph (EGG) used to measure the open quotient was the PCLX Laryngograph Processor[7]. The EGG enables monitoring of the vocal tract area non-invasively. Through two electrodes placed on either side of the subject's neck at the level of the larynx, a high frequency modulated current is sent. The EGG then monitors changes in electrical impedance that are due to the opening and closing phases of the vocal folds. Among others, this relationship has been confirmed by Childers et al., who state that "specific EGG features are associated with certain gross vibratory characteristics of both normal and pathological voices" and that "the EGG is confirmed as useful for analysis/synthesis purposes, as well as for modelling laryngeal behaviour" (Childers et al. 1990: 253). The below picture gives an example of the EGG electrodes placed on a subject's neck[8]:

Figure 3.2 EGG electrodes placed on subject's neck

Due to the age of the PCLX system it was not possible to use the interface card that was part of the original system. The PCLX system also included a computer program which (combined with the interface) would have been able to calculate the open quotient from the EGG signal automatically. Since this was not possible, a solution to analyse the EGG signal within the PRAAT program needed to be found. Howard (1995) describes different ways of analysing the EGG signal in order to detect the opening and closing instants of a vocal fold cycle. The approaches described make use of the derivative of the EGG signal (DEGG) in order to detect the closing instant

[7] PCLX Speech, Electro-Laryngograph by Laryngograph Ltd, 1 Foundry Mews, London NW1 2PE, United Kingdom
[8] The picture was taken from the website of the Institute of Phonetic Sciences, Amsterdam: http://www.fon.hum.uva.nl/IFA-SpokenLanguageCorpora/TheNorthWindAndTheSun-glottograph/

of a vocal fold cycle. The closing instant can be identified as a positive peak in the DEGG signal. The opening instant of a vocal fold cycle is defined as the point where the negative going EGG signal crosses an amplitude level that either equals the level at which the start of the closed phase had been defined for that cycle or where the signal crosses an amplitude threshold set to a fraction of that cycles peak-to-peak amplitude. In the latter method, the amplitude thresholds mentioned were either set to 3/7 or 1/4 of the cycle's peak-to-peak amplitude. A disadvantage of this method is that the positive peaks in the DEGG signal that define the closing instant of a vocal fold cycle are sometimes doubled. The results of Henrich et al. indicate “that the double-peak feature is not uncommon, for opening as well as for closing” (2004: 1325). In fact, most of the positive peaks of the DEGG signals that were recorded for this research turned out to be either doubled or imprecise. Figure 3.3 demonstrates the double-peak feature for the closing instant for four cycles of the EGG and DEGG signals of the note A2 sung by subject C3.

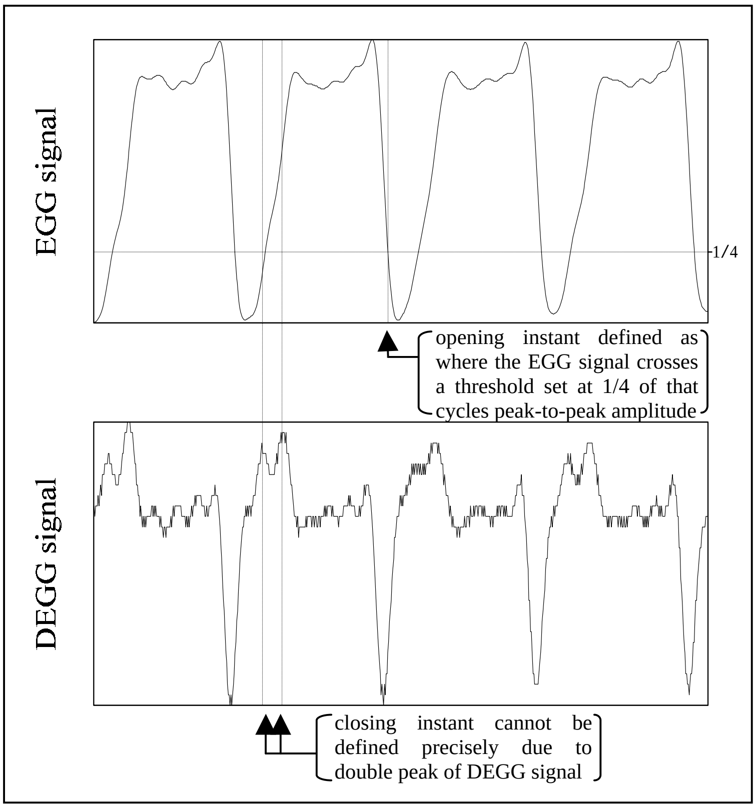

Figure 3.3 EGG and DEGG signal of note A2, subject C3

The two peaks that make it difficult to positively define the closing instant are marked with dotted lines through both signals. In addition, the opening instant (defined as where the EGG signal crosses a threshold set at 1/4 of the cycle's peak-to-peak amplitude) of that cycle is marked with a dotted line in the EGG signal. For these reasons, it was decided to make use of a method that is completely based on an amplitude threshold of the EGG signal where the crossing points between the threshold line and the EGG signal are approximated as the opening and closing instants. Henrich et al. state that “these methods are very convenient for medical purposes, as they are robust and can be applied even on noisy or weak signals” (2004: 1323). A peak-to-peak amplitude threshold of 1/4 was applied to measure the open quotient for all notes. The outcomes of these measurements were later compared to data that would result from an amplitude threshold of 3/7 and 1/2. It was found that (compared to the other threshold values) an amplitude threshold of 1/4 generally provided the smoothest OQ variation over time and was therefore judged to be the most appropriate threshold value for this research. Figure 3.4 demonstrates the measurement of the open quotient for one cycle out of note A3 sung by subject C3 using a peak-to-peak amplitude threshold of 1/4.

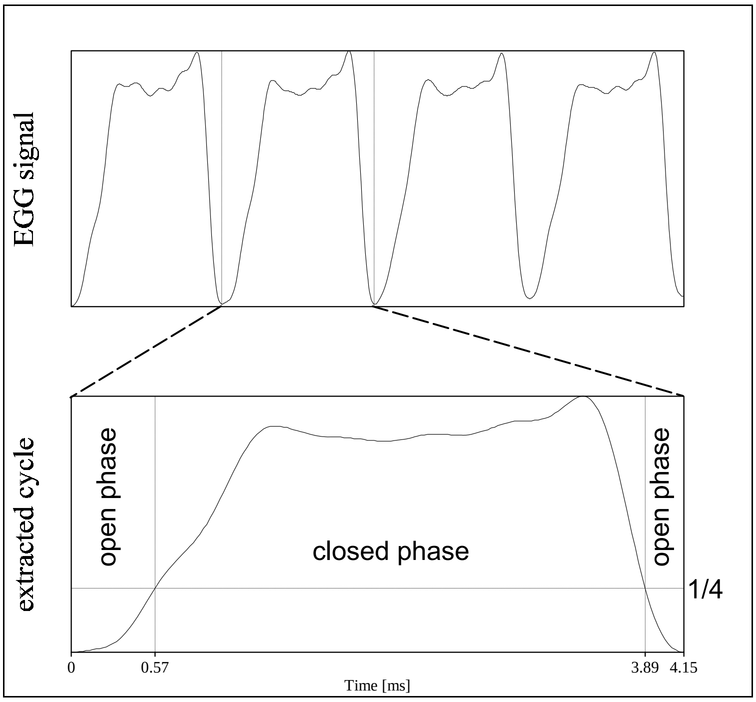

Figure 3.4 OQ measurement with amplitude threshold 1/4

The formula **OQ = ((T_o / T) x 100) %** results in an open quotient of 20% for the EGG cycle presented in figure 3.4. A drawback of this method is that it does not provide information about the exact closing and opening instants of the vocal folds and that the open quotient calculated using this method therefore does not exactly correspond to the time in each glottal cycle where vocal folds are apart. But it provides means by which it is possible to compare the results between and within subjects. Howard states that “in practice, if the only requirement is to look for *trends* in CQ [closed quotient], the actual ratio used is not important provided that it is kept constant” (1995: 165). Mecke et al. (2012) compared closed quotient data measured with three different methods, inverse filtering, electroglottography (EGG) and high speed digital imaging (HSDI). They found that closed quotient (CQ) values obtained with the EGG method were higher than those obtained with the inverse filtering method and that values obtained via HSDI resulted in the lowest values. As OQ=1-CQ, we should expect our data to be considerably lower compared to other data that was obtained using the inverse filtering or the HSDI method. Considering this and also our arbitrary choice of a peak-to-peak amplitude threshold of 1/4 for the EGG signal, we will not be able to compare our data to other sources directly. However, we will still be able to make comparisons to other sources with regards to trends within subjects such as e.g. pitch dependencies and trends between subject groups such as singers of different styles.

From the recorded EGG signal, the chosen notes were extracted based on the note positions obtained from the vibrato measurements (see section 3.1). In order to properly calculate the open quotient from the EGG signal, it was necessary to make some adjustments to the recorded EGG signal. For the EGG signal of each note, a high-pass filter was applied to filter out low frequencies that were caused by slow up- and down-movements of the larynx (e.g. caused by swallowing). The minimum frequency was measured for each signal and the frequencies below the minimum F0 were filtered out using a Hann-shaped filter with a smoothing frequency of 100 Hz. Figure 3.5 shows the EGG signal for note M3, subject C2 before and after applying the high-pass filter.

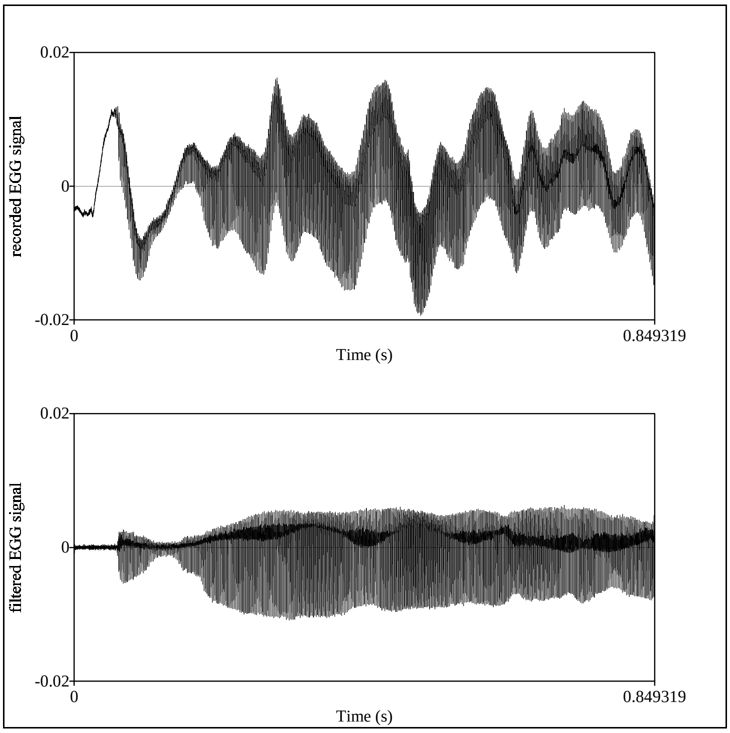

Figure 3.5 Original and high-pass filtered EGG signal for note M3, subject C2

Eventually, a Hann-shaped high-pass filter with a smoothing frequency of 100 Hz was applied to filter out frequencies above 2000 Hz in order to remove noise from the signal. A PRAAT script was written that extracts each cycle from the EGG signal in order to measure the open quotient on a cycle-to-cycle basis. The script detects the periodic minima of the signal and extracts each cycle based on these points as can be seen in figure 3.4. To enable a visual check to confirm if each cycle was extracted correctly, each cycle was plotted to the computer screen during the procedure. In cases where a glottal cycle was not detected properly, its boundaries were either corrected by hand or (if this was not possible due to an un-interpretable shape of the waveform) the section was cut out before analysis. Parts that had to be cut out were those that showed no clear indications regarding the closing instant of the glottal cycle. Figure 3.6 displays a section from note M8 (subject J2) that could not be interpreted properly.

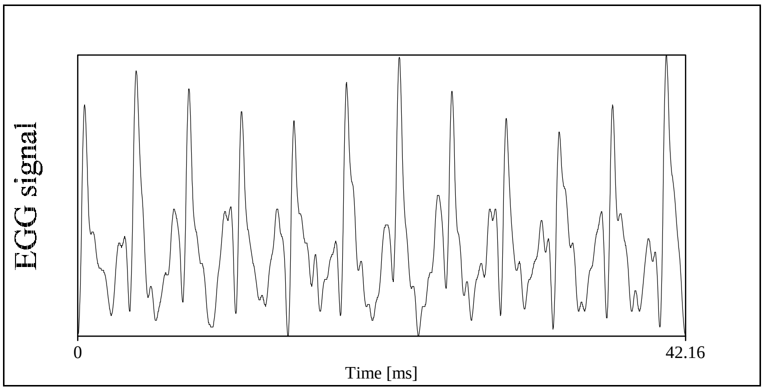

Figure 3.6 Part of EGG signal, note M8, subject J2

Table 3.4 gives an overview on how much had to be cut out from the original EGG for each subject and song before the data could be analysed. For each song, it lists the total duration of all notes sung by each subject, the total duration of segments that were finally used for analysis and the percentage of material that had to be omitted. For instances where entire notes had to be left out of the analysis, this is indicated on the right hand side.

For subjects C2 and J3, very little or no EGG cycles had to be omitted. For all other subjects, between 25% and 35% of the signal had to be cut out before analysis. Although the EGG signal was visually checked and the electrodes were adjusted prior to the recordings in order to gain a proper signal, it may be that the electrodes moved during the recording procedure which led to a weaker and thus non-interpretable signal. However, there was still enough material available to allow analysis and to compare results between subjects and subject groups.

Table 3.4 Overview on EGG signal sections cut out before analysis

	"Autumn Leaves"				**"An die Musik"**			
	Total length of all notes [s]	Total length of analysed sections [s]	Cut out [%]	Discarded notes	Total length of all notes [s]	Total length of analysed sections [s]	Cut out [%]	Discarded notes
C1	12.57	9.39	25%		9.09	8.02	12%	
C2	12.74	12.74	0%		9.16	8.56	7%	
C3	11.93	7.9	34%		8.71	6.18	29%	
J1	13.19	9.76	26%	A2, M5	7.84	5.36	32%	
J2	9.86	6.39	35%	A1, A5	9.07	6.73	26%	
J3	8.57	8.1	5%		7.23	7.23	0%	

The PRAAT script that eventually performed the OQ measurements on a cycle to cycle basis can be found in appendix B. The following data were subsequently stored in tables for later analysis:

Table 3.5 Open Quotient data measured for each singer and note

Open Quotient data measured for each singer and note	
OQ	Average open quotient of entire note
StdDev	Standard deviation of the OQ based on single cycles
OQmax	Maximum OQ value within the note
OQmin	Minimum OQ value within the note
Dur[s]	Duration of section that was interpretable
NumCyc	Number of OQ cycles analysed within the note
Pitch[Hz]	Mean pitch of the analysed section
ViSD[%]	Percentage of OQ values within standard deviation
ViSD2[%]	Percentage of OQ values within double standard deviation
OQxcl	Number of OQ values outside double standard deviation

4. Vibrato Data Analysis

4.1 Position of Vibrato within a Note

As already mentioned in section 3.1, not all of the notes selected for analysis were sung with vibrato. It was also found that in many cases the vibrato was not sung throughout the entire note. In those cases, vibrato onset- and offset times were measured in addition[9]. The following diagrams (figures 4.1 to 4.12) are schematic representations of note length and vibrato position. Each diagram presents all measured notes for each singer and each song. Being ordered by note length from bottom to top, each note is plotted as a line showing it's duration on the horizontal

[9] The vibrato onset time is the time after which the vibrato starts within a sung note while the vibrato offset is the remaining time of a sung note after the vibrato has stopped. E.g. figure 3.1 displays the pitch contour of a note that has a vibrato onset time.

axis. Parts of the notes that are sung without vibrato are drawn as continuous black lines and those parts sung with vibrato are drawn as a dotted line.

The first observation, namely that the shortest note sung with vibrato was (apart from two exceptions[10]) always longer than the longest note sung without vibrato suggests that for each individual subject, notes need to exceed a certain length to be sung with vibrato. It was therefore decided to include vibrato, vibrato onset, and vibrato offset threshold areas into the diagrams (indicated by grey rectangles). The vibrato threshold area is defined as the difference in note length between the longest note sung without vibrato and the shortest note sung with vibrato. Based on the conjecture that notes need to be of a certain length to be sung with vibrato, this should be the area within a sung note in which vibrato usually begins for a subject. Therefore, the vibrato threshold time was defined as the midpoint of the vibrato threshold area Similarly, the vibrato onset threshold area is defined as the are between the duration of the longest note without vibrato onset time and that of the shortest note with vibrato onset time, as this area indicates the note length which is necessary for a vibrato onset time to occur. In the same way, the vibrato offset threshold area is defined as the difference between the duration of the longest note sung without vibrato offset and the shortest note sung with vibrato offset. Again, onset and offset threshold times were defined as the midpoints of the respective areas. Given the limited number of notes analysed, it was not always possible to determine vibrato, onset, and offset threshold areas. Some subjects did not show vibrato offset times for the selected notes and subject C1 for instance sang all selected notes of the songs "An die Musik" with vibrato throughout.

[10] There are only two cases in which (for the same subject and song) a note sung without vibrato is longer than another one sung with vibrato. Those are J3, Autumn Leaves, note 8 and J1, An die Musik, note 8.

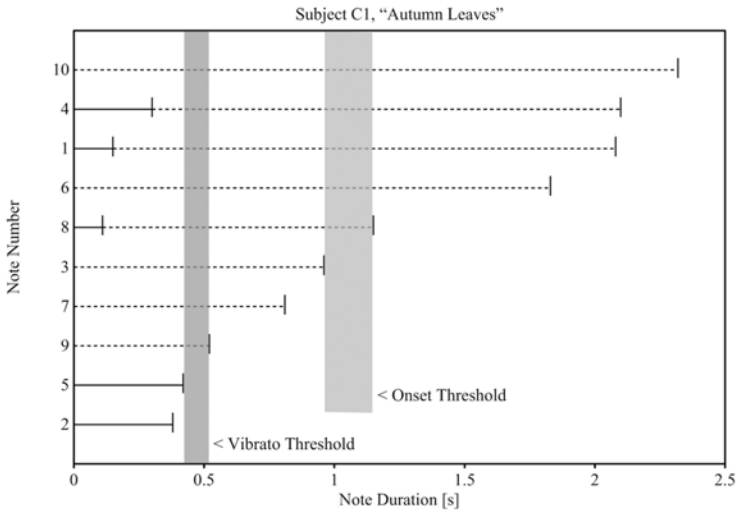

Figure 4.1

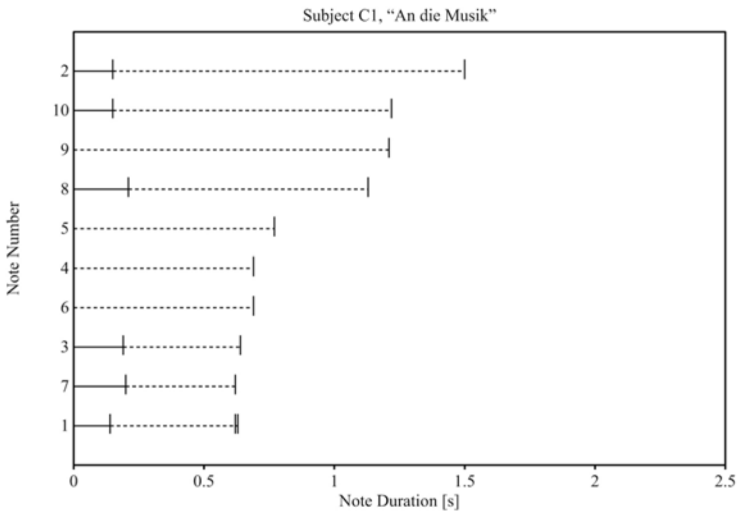

Figure 4.2

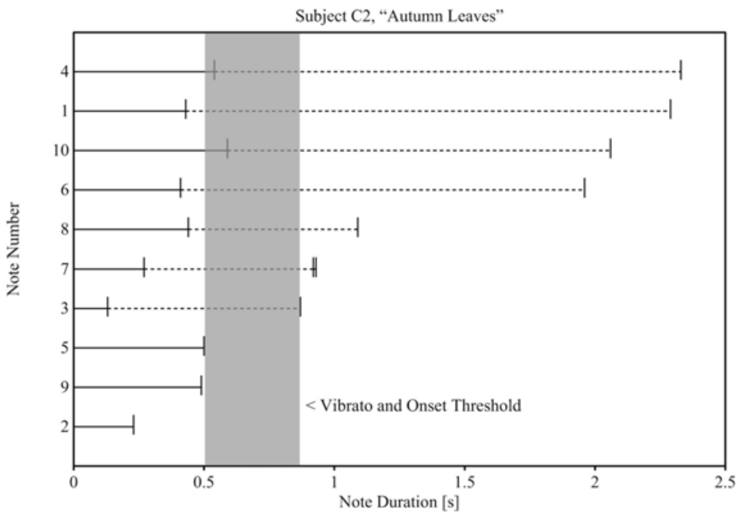

Figure 4.3

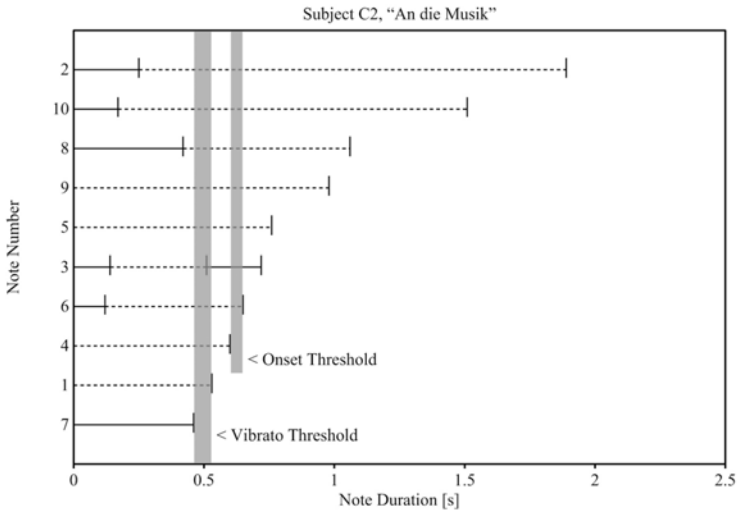

Figure 4.4

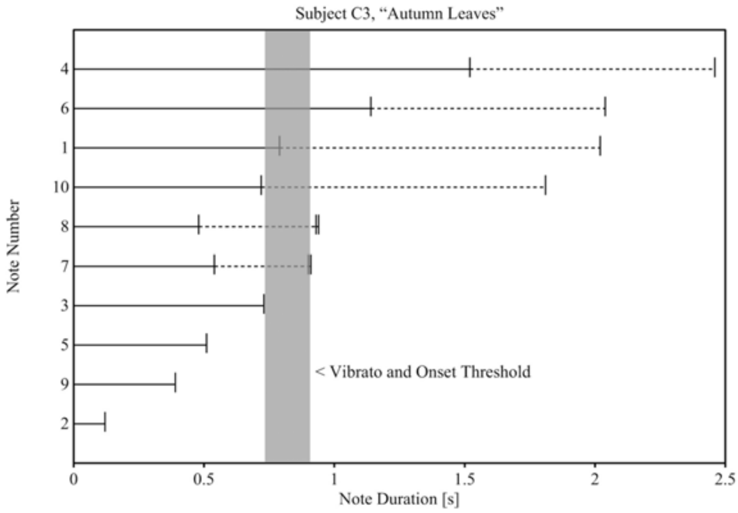

Figure 4.5

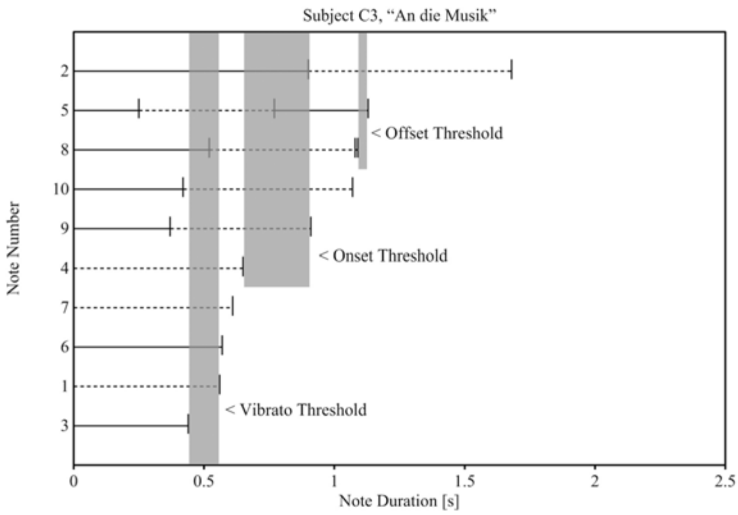

Figure 4.6

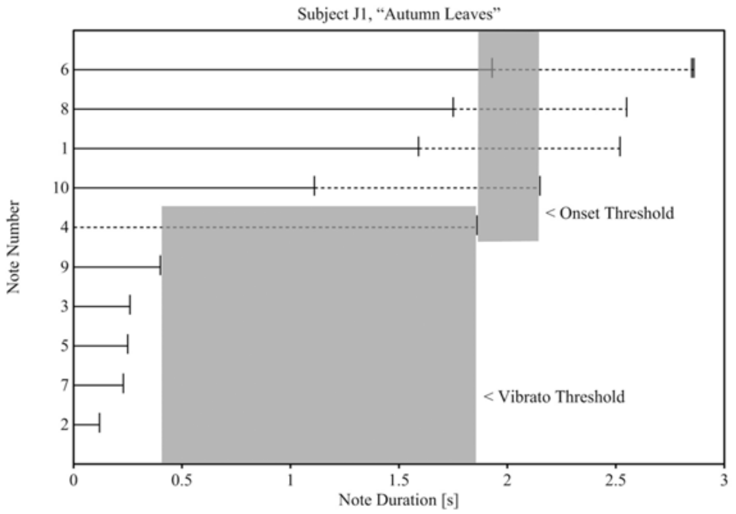

Figure 4.7

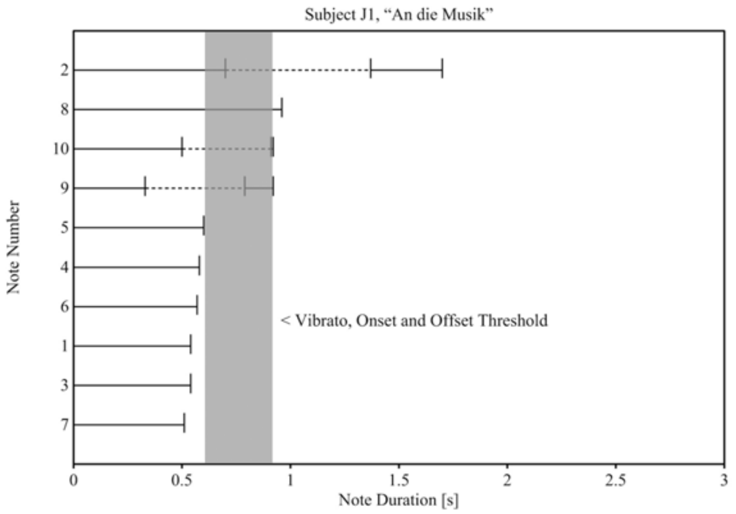

Figure 4.8

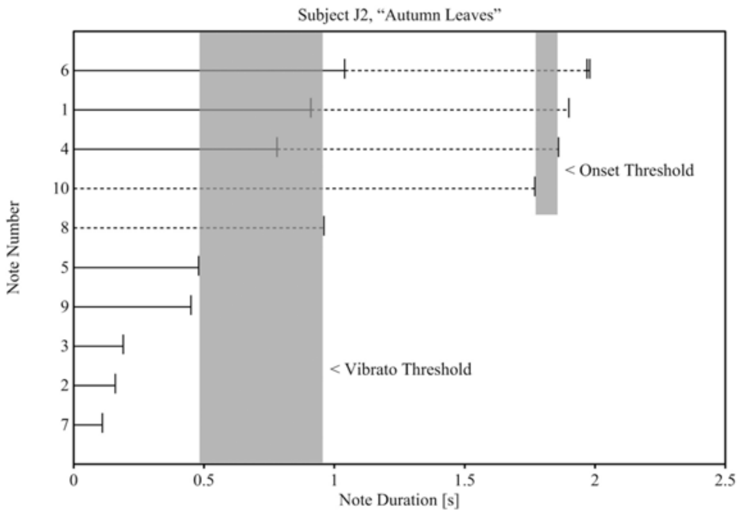

Figure 4.9

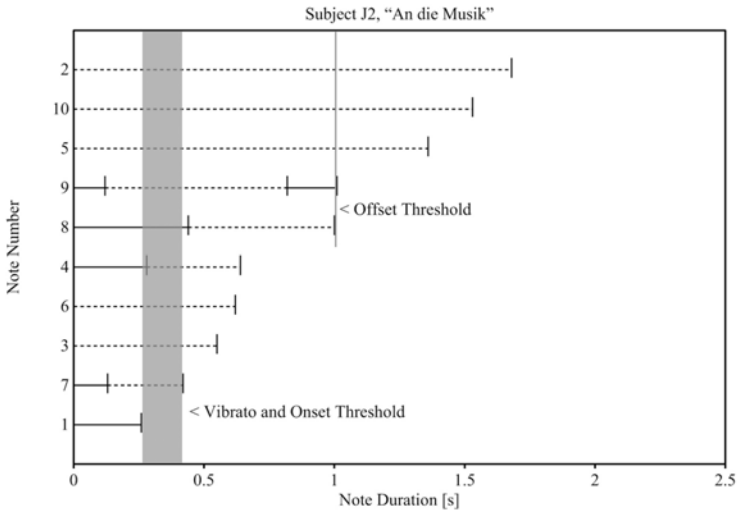

Figure 4.10

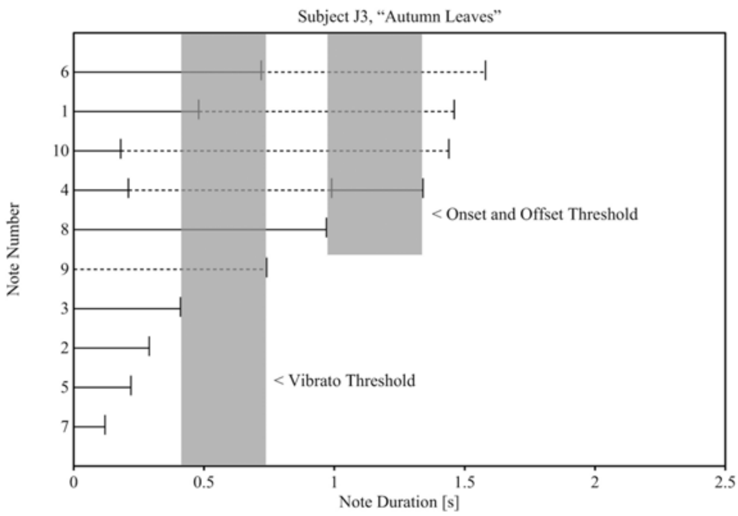

Figure 4.11

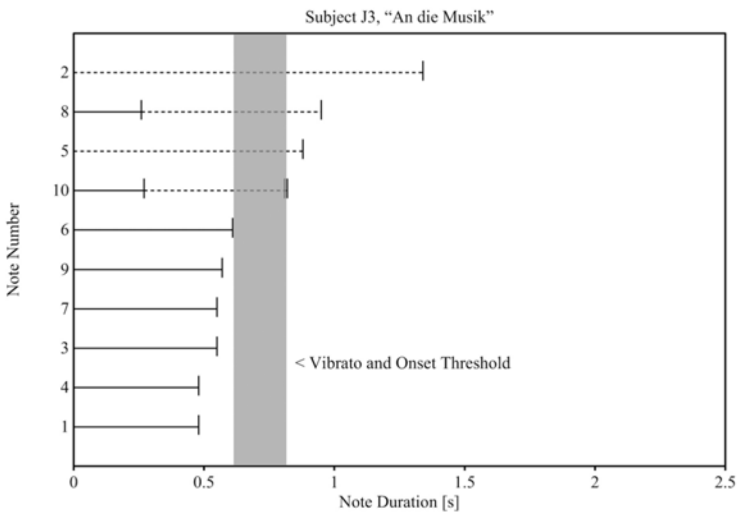

Figure 4.12

Table 4.1 presents the vibrato, onset and offset threshold times for all subjects and both songs. The vibrato threshold time for subject J1, "Autumn Leaves" is stated in italics as the big difference in length between notes 9 and 4 lead to a big uncertainty regarding this value.

Table 4.1 Vibrato, onset and offset threshold times

	"Autumn Leaves"			"An die Musik"		
	Vibrato Threshold [s]	Onset Threshold [s]	Offset Threshold [s]	Vibrato Threshold [s]	Onset Threshold [s]	Offset Threshold [s]
C1	0.47	1.06	-	-	-	-
C2	0.69	0.69	-	0.50	0.63	-
C3	0.82	0.82	-	0.50	0.78	1.11
J1	*1.13*	2.10	-	0.76	0.76	0.76
J2	0.72	1.82	-	0.34	0.34	1.01
J3	0.58	1.04	1.04	0.72	0.72	-

It can be seen that (with only two exceptions) the vibrato threshold area starts at approximately 0.5 seconds for all subject and both songs. Furthermore, the vibrato onset threshold area is either identical to or lies higher than the vibrato threshold area for all subjects. This suggests that notes need to be of certain length to be sung with vibrato and that vibrato onset time requires even longer notes. Also, this length seems to be independent of the employed singing style and song.

Table 4.2 lists the vibrato onset times for all singers along with average values per group and song. It is interesting to see that (apart from subject C1 who has very similar values) all singers show longer vibrato onsets in "Autumn Leaves" and also that the difference between averages of both songs is considerably higher in the group of Jazz singers. This suggests that jazz singers show a higher variability in their use of vibrato, employing this variation as means of expressiveness. Classical singers on the other hand seem to adjust slightly when singing the jazz song but the comparably low level of adjustment may indicate that they are more used to and trained to employ a rather constant and regular vibrato onset.

Table 4.2 Vibrato onset times

	Vibrato Onset [s]	
	"Autumn Leaves"	"An die Musik"
C1	0.19	0.17
C2	0.4	0.22
C3	0.87	0.49
AVR	*0.49*	*0.29*
J1	1.6	0.51
J2	0.91	0.24
J3	0.4	0.27
AVR	*0.97*	*0.34*

In their investigation on the relationship between measured vibrato characteristics and perception, Howes et al. (2003) report average vibrato onset times between 0.05 and 0.38 seconds for recordings of eleven famous opera singers. Analysing the vibrato characteristics of six female singers, Mitchell et al. (2003) report average vibrato onset times between 0.12 and 0.33 seconds. Apart from subject C3, vibrato onset times for the group of classical singers fall into both ranges while the jazz singers only show similar values in the classical song.

It may be debatable as of when one should consider a note to have vibrato onset time. A possible convention could be that the time between the start of phonation and the occurrence of the first vibratory cycle should exceed the same singers' average vibrato cycle length. More data on vibrato onset time would be required in order to find a meaningful definition of vibrato onset.

Since we only had a limited amount of data at hand, more data is needed to further verify this observation. However, there is enough data to suggest the aforementioned trends.

4.2 Vibrato Rate

Our data analysis in this section is based on the vibrato rate averaged over the whole vibrato part of each note. Prame (1994) observed that the vibrato rate typically increased at the end of each tone and therefore omitted the last three vibrato cycles when calculating average vibrato rates and his observation was confirmed by Bretos and Sundberg (2003). Since a considerable amount of notes in this investigation proved to have rather short vibrato parts (sometimes only three or four vibrato cycles), none of the vibrato cycles were excluded here. When comparing our data to the results of Prame (1994) and Bretos and Sundberg (2003), this may lead to slightly higher values of vibrato rate on our side.

4.2.1 Vibrato Rate in General

The following two diagrams present the average vibrato rates for all singers and all notes that were sung with vibrato. Black dots indicate the vibrato rates for each individual note whereas larger dots with horizontal lines show the average vibrato rate for each subject.

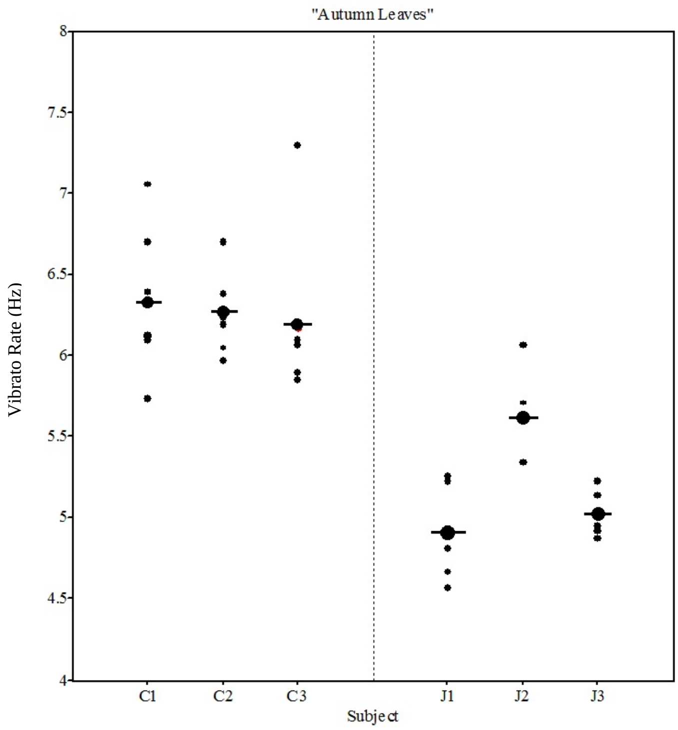

Figure 4.13 Vibrato rates, "Autumn Leaves"

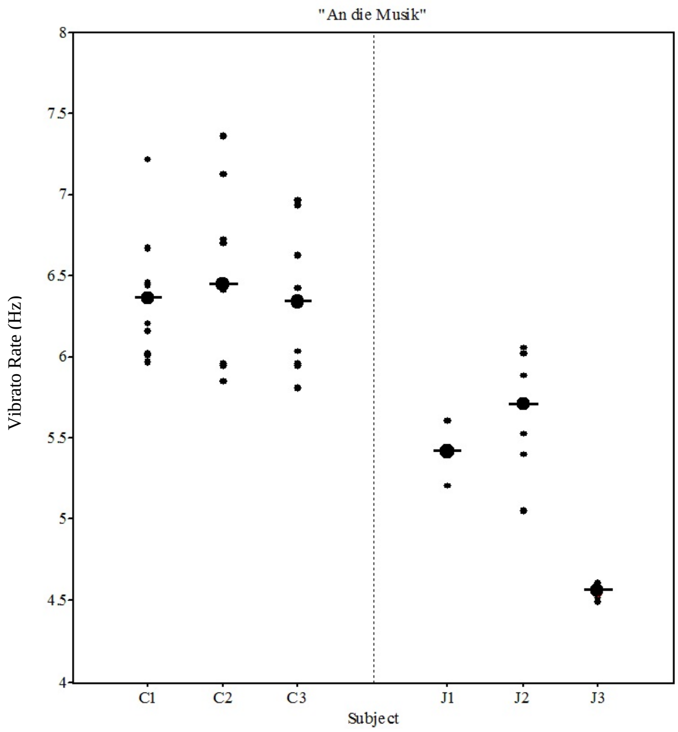

Figure 4.14 Vibrato rates, "An die Musik"

For both songs, the vibrato rates for the classical singers averaged over all notes are remarkably higher than those for the jazz singers. While the classical singers show average rates between 6.12 and 6.33 Hz ("Autumn Leaves") and 6.34 and 6.45 Hz ("An die Musik"), the jazz singers' average rates are considerably lower and range from 4.67 to 5.35 Hz ("Autumn Leaves") and from 4.56 to 5.72 Hz ("An die Musik"). An unpaired t-test between the average values of both subject groups (df=4) confirms that the difference between groups is significant in "An die Musik" with t=3.3 and p=0.03 and very significant in "Autumn Leaves" with t=4.9 and p=0.008.

In our investigation, the jazz singers' average vibrato rate of 5.28 Hz lies below the classical singers' average vibrato rate of 6.34 Hz. Furthermore, the jazz singers show a much wider variation of average vibrato rates between subjects (1.16 Hz difference between lowest and highest average rate) than the classical singers (only 0.33 Hz difference).

To put our values into perspective further, table 4.3 compares our values to those from other sources and figure 4.15 displays those values using the abbreviations given on the table[11].

Table 4.3 Vibrato rates measured by others

Source	Singer / style	Abbrev. / diagram	Aver. Vibrato Rates [Hz] Min.	Max
Classical Singers	classical	Cc	6.34	6.45
(this thesis)	classical	Cj	6.19	6.33
Jazz singers	jazz	Jc	4.56	5.72
(this thesis)	jazz	Jj	4.91	5.61
Ramig et al. (1987) *Nine singers from the Stockholm Opera*			5.52	
Dromey et al. (2003)	chest	ch	4.5	5.8
Twelve students of voice, chest and head register	head	hd	4.9	5.7
Prame (1994) *Ten professional classical singers*			6.1	
Mitchell and Kenny (2004) *Six female singers, advanced students*			5.71	6.15
de Almeida Bezerra et al. (2009)	lyric	C	4.55	6.25
Ten lyric and ten sertanejo male singers	sertanejo	*S*	5.0	6.56
Pecoraro et al. (2013)	Opera	C	4.95	6.76
Three different singing styles with five singers each	Rock	R	3.88	6.38
Hakes et al. (1988)	normal	no	4.81	6.54
Recordings of ten early music singers	exagger.	ex	5.09	6.77
Bretos and Sundberg (2003)	note F5	F5	5.5	6.7
Two notes of an aria found in ten commercial recordings	note A5	A5	5.2	7.1
Howes et al. (2004) *Eleven famous opera singers*			6.48	7.59

[11] Abbreviations for subjects of this study: 'Cj' for classical singers singing the jazz song, 'Jc' vice versa etc. / Dromey et al. (2003): 'ch' for chest and 'hd' for head voice. / De Almeida Bezerra et al. (2009): 'C' for classical and 'S' for singers of the sertanejo style. / Pecoraro et al. (2013): 'C' for classical and 'R' for rock singers. / Hakes et al. (1988): 'no' for normal and 'ex' for exaggerated vibrato. / Bretos and Sundberg (2003): 'F5' and 'A5' refer to the notes that were analysed.

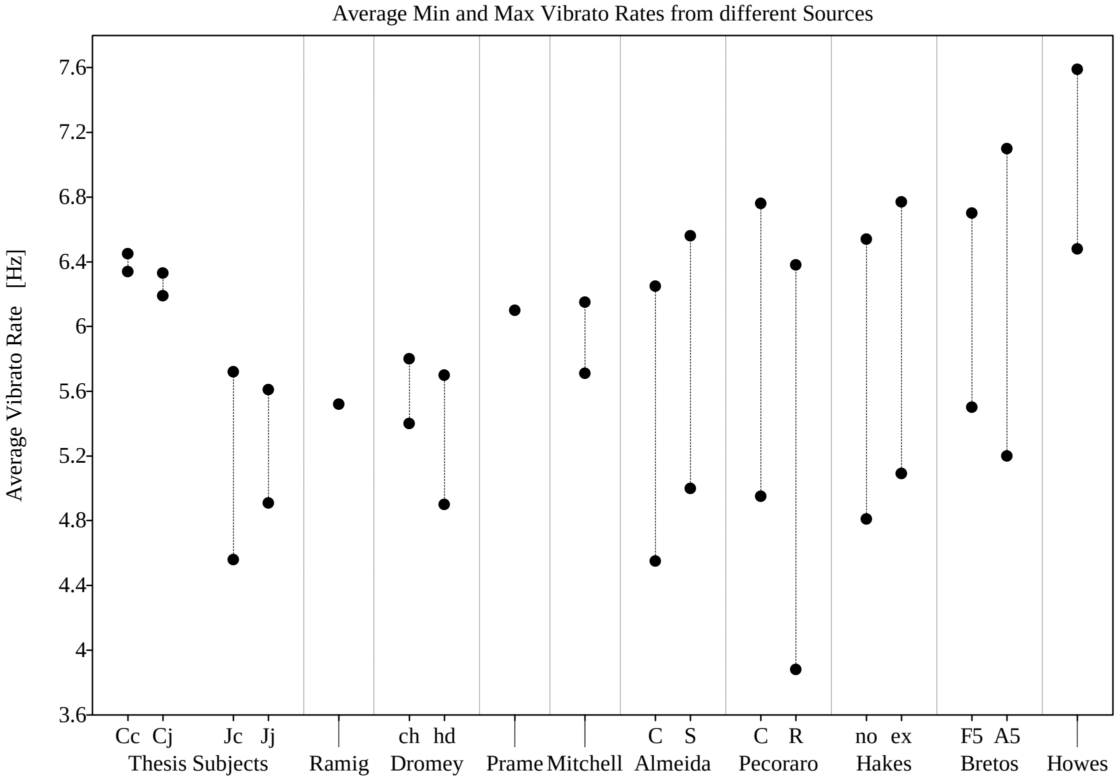

Figure 4.15 Vibrato rates measured by others

Our classical singers show similar values to those of Prame (1994), who measured the vibrato rates of ten professional classical singers and found 6.1 Hz to be the mean vibrato rate across all investigated singers and Mitchell and Kenny (2004), who measured the vibrato rates of six advanced students of voice. Furthermore, the classical singers' maximum average vibrato rate (AVR) values are similar to those measured by de Almeida Bezerra et al. (2009), Pecoraro et al. (2013), Hakes et al. (1988) and Bretos and Sundberg (2003), however, all of the latter report significantly higher differences between minimum and maximum AVR values. Howes et al. (2004) measured maximum AVR values much higher than the results obtained in this study. Ferrante (2011: 1), who investigated the vibrato of the same note sung by 75 professional singers on recordings made over the last century, observed a "clear decrease of the mean vibrato rate during the last century". A comparison of our data to the above may support this finding, as Hakes et al. (1988) analysed singers of early music and both Bretos and Sundberg (2003) and Howes et al. (2004) analysed recordings dating back to the 1930s, and in those three investigations the measured AVR values where higher than those obtained in this study.

The AVRs measured for our jazz singers are similar to the values obtained by Ramig et al. (1987) and those of Dromey et al. (2003), who investigated notes sung by twelve students of voice, comparing vibrato characteristics for notes sung in chest and head voice. Although our jazz singers' AVRs fall into the ranges reported by de Almeida Bezerra et al. (2009), Pecoraro et al. (2013) and Hakes et al. (1988), all other sources report significantly higher maximum AVR values, which further confirms our observation that jazz singers employ lower vibrato rates than classical singers. Lastly, it is interesting to note Pecoraro et al. (2013), who compared vibrato characteristics of opera and rock singers, found lower vibrato rates among rock singers. Seeing that both rock and jazz music are thought to belong to the category of 'popular' music and that classical music is referred to as 'serious' music, one may suspect that the differences regarding vibrato rates could be extended to the categories of 'popular' and 'serious' music. However, more research would be necessary to solidify this conjecture.

Table 4.4 lists the average, highest, and lowest vibrato rates for each singer and song. It also displays the difference between the singers' maximum and minimum rates and the inter-tone variations calculated for each singer and song[12].

Table 4.4 Vibrato rates and inter-tone variations

	"Autumn Leaves"					"An die Musik"				
	Avr. [Hz]	Min. [Hz]	Max. [Hz]	Diff. [Hz]	Int-tn [%]	Avr. [Hz]	Min. [Hz]	Max. [Hz]	Diff. [Hz]	Int-tn [%]
C1	6.33	5.74	7.06	1.32	10.4%	6.37	5.97	7.22	1.25	11.8%
C2	6.27	5.97	6.70	0.73	5.9%	6.45	5.85	7.36	1.51	11.7%
C3	6.19	5.85	7.30	1.45	11.7%	6.34	5.81	6.97	1.16	9.2%
Avr				1.17	9.3%				1.31	10.9%
J1	4.91	4.57	5.26	0.69	7.0%	5.42	5.21	5.61	0.40	3.7%
J2	5.61	5.34	6.07	0.73	6.5%	5.72	5.06	6.06	1.00	8.7%
J3	5.02	4.88	5.23	0.35	5.2%	4.56	4.49	4.61	0.12	1.3%
Avr				0.59	6.2%				0.51	4.6%

In both songs. the classical singers show higher variations between their personal minimum and maximum vibrato rates than the jazz singers. The classical singers have an average difference of 1.17 Hz ("Autumn Leaves") and 1.31 Hz ("An die Musik"), whereas the jazz singers only show 0.59 and 0.51 Hz respectively. Exceptions are subject C2, whose difference of 0.73 Hz is low compared to the group

[12] The inter-tone variation is calculated as the average between the difference of minimum to average and maximum to average vibrato rate.

in "Autumn Leaves" and subject J2, whose difference of 1 Hz is comparably high. The same holds for the inter-tone variations, where classical singers show average values of 9.3% and 10.9% and jazz singers 6.2% and 4.6% respectively. Prame (1994) observed an average inter-tone variation of about ±10% for his subjects. We can confirm this with regard to our classical singers, who show similar inter-tone variations, whereas our jazz singers' inter-tone variations lie much lower.

It is interesting to note that the classical singers' average values of vibrato rate lie much closer together than those of the jazz singers but that at the same time the classical singers tend to have higher inter-tone variations than the jazz singers.

4.2.2 Vibrato Rate in relation to Note Pitch

In the following six diagrams (one per subject), the vibrato rates are plotted against the mean pitch of the according notes. Marks that indicate values of notes of the song "Autumn Leaves" are plotted as open circles and those for the song "An die Musik" as closed circles[13]. Table 4.5 lists all correlation coefficients separately.

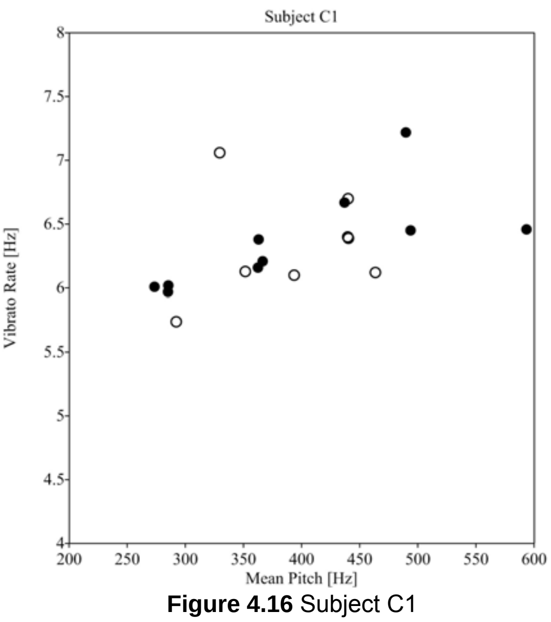

Figure 4.16 Subject C1

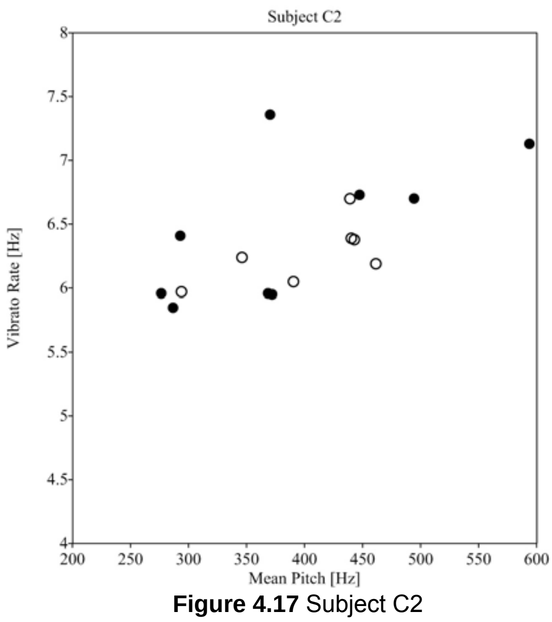

Figure 4.17 Subject C2

[13] These indications will be used throughout the entire thesis.

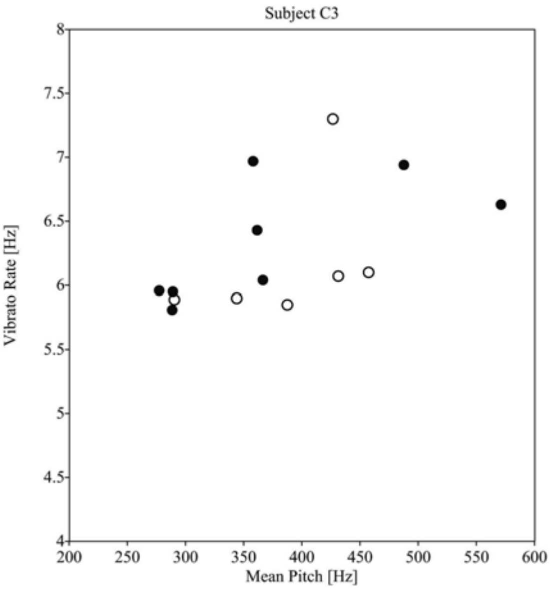

Figure 4.18 Subject C3

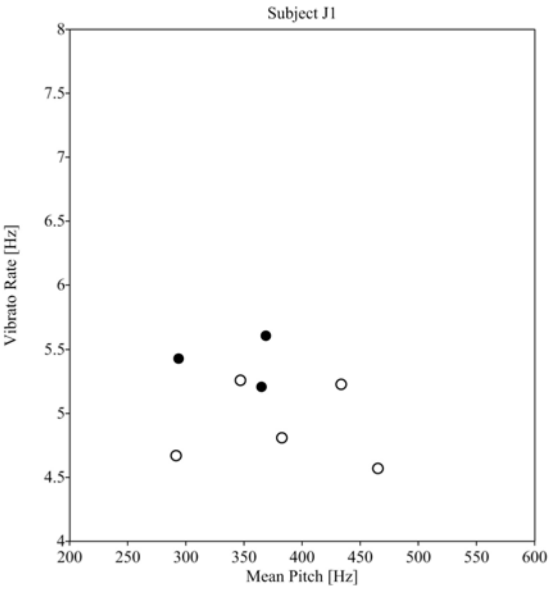

Figure 4.19 Subject J1

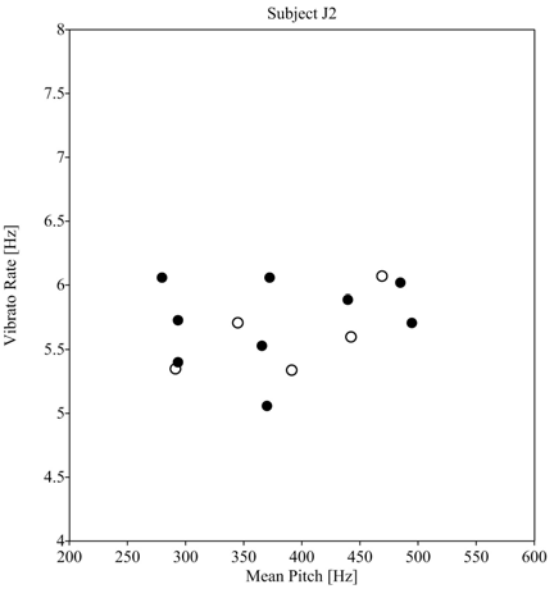

Figure 4.20 Subject J2

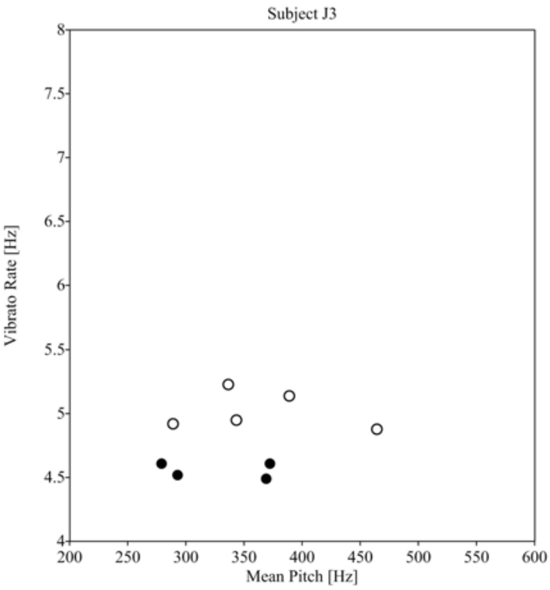

Figure 4.21 Subject J3

Table 4.5 Linear correlation coefficients, vibrato rate as a function of F0

Linear correlation coefficients (ρ). vibrato rate as a function of F0		
	"Autumn Leaves"	"An die Musik"
C1	0.17	0.7
C2	0.63	0.64
C3	0.42	0.68
J1	-0.03	-0.01
J2	0.65	0.18
J3	-0.2	-0.19

Apart from one exception (J2, "AUT", ρ=0.65), the jazz singers show no correlation between vibrato rate and note pitch. In the song "An die Musik", the vibrato rates of all classical singers show somewhat high correlations between ρ=0.64 (C2) and ρ=0.7 (C1). In "Autumn Leaves", only subject C2 shows a high correlation of ρ=0.63, while subjects C1 and C3 show low correlations of ρ=0.17 and ρ=0.42 respectively.

Prame (1994) and Bretos & Sundberg (2003) did not observe any pitch dependence of their vibrato data. However, the data at hand suggests at least a slight dependence at least for the group of the classical singers. This may be in close connection to classical singers employing a higher inter-tone variation of vibrato rate while still having very similar mean values in both songs. However, more data would be needed to further confirm this relationship.

4.2.3 Vibrato Rate in relation to Note Duration

The following diagrams show vibrato rate as a function of note duration. Table 4.6 lists all respective correlation coefficients separately.

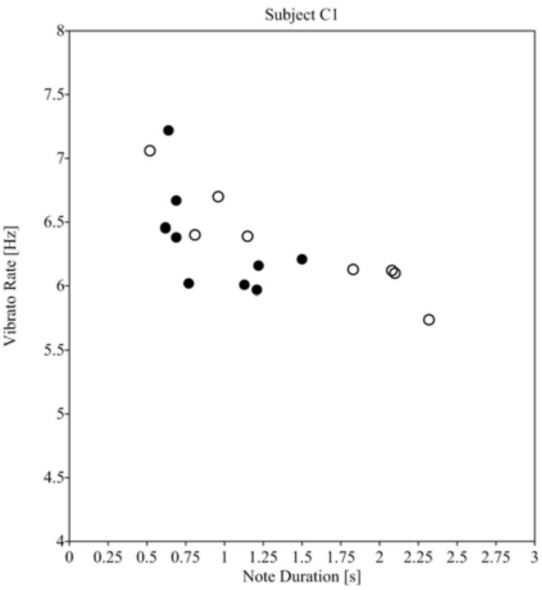

Figure 4.22 Subject C1

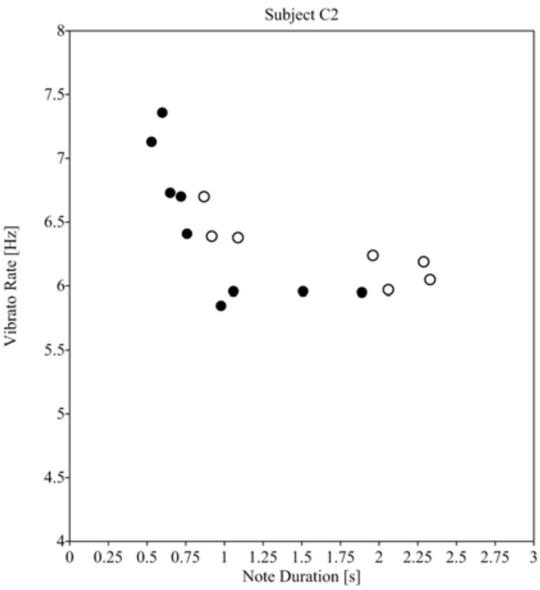

Figure 4.23 Subject C2

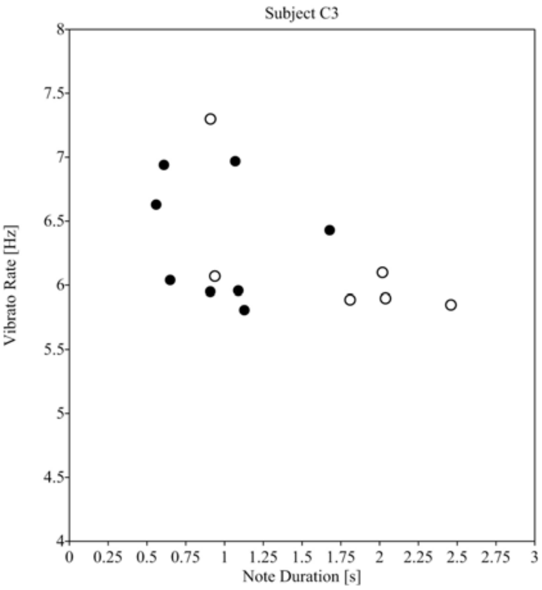

Figure 4.24 Subject C3

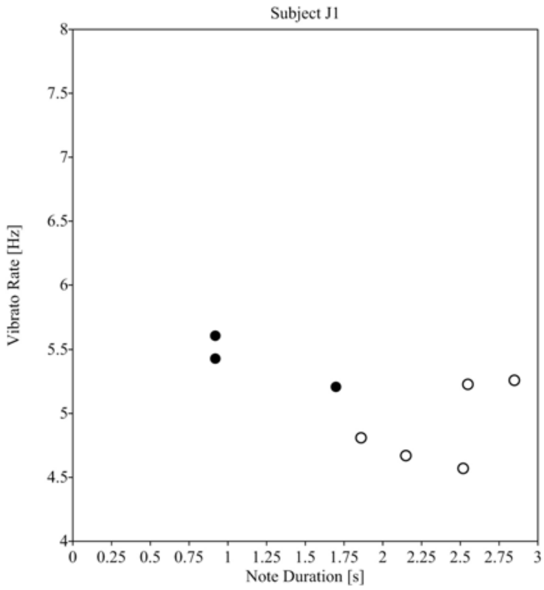

Figure 4.25 Subject J1

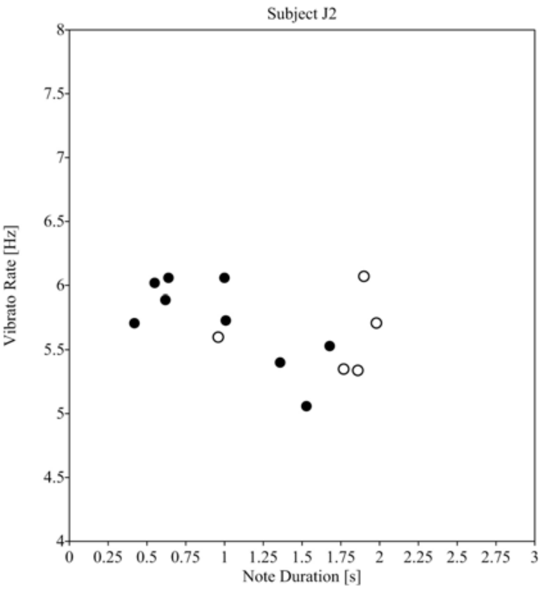

Figure 4.26 Subject J2

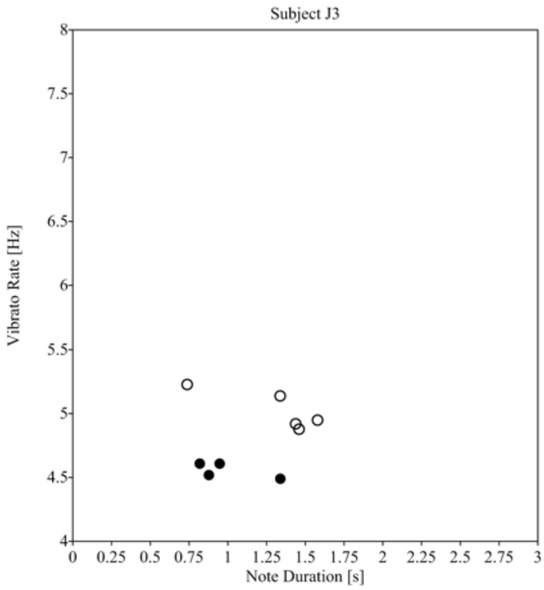

Figure 4.27 Subject J3

Table 4.6 Linear correlation coefficients, vibrato rate as a function of note duration

Linear correlation coefficients (ρ). vibrato rate as a function of note duration		
	"Autumn Leaves"	"An die Musik"
C1	-0.91	-0.59
C2	-0.85	-0.75
C3	-0.68	-0.18
J1	0.57	-0.89
J2	0.13	-0.73
J3	-0.84	-0.70

Apart from subjects J1 and J2 (AUT), all subjects show negative correlations between vibrato rate and note duration. For these subjects, only C3 (MUS) has a low negative correlation of ρ=-0.18. All other subjects show somewhat high negative correlations below ρ=-0.5. In "Autumn Leaves", the classical singers show high negative correlations between ρ=-0.68 (C3) and ρ=-0.91 (C2) and the jazz singers show high negative correlations in "An die Musik", ranging from ρ=-0.7 (J3) to ρ=-0.98 (J1).

Prame (1994) found a correlation of ρ=-0.69 (average across all subjects) and explains this dependency with his observation that vibrato rates increase towards the end of a note. We can confirm the data of Prame with respect to the classical singers, who show an average correlation of ρ=-0.66. The jazz singers show an average correlation of ρ=-0.41, which is rather low. This suggests that in contrast to classical singers, jazz singers might not show any systematic dependency between vibrato rate and note duration and that while singing the classical song, the jazz singers adapted to a more 'classical' style of singing by employing a higher dependency of vibrato rate with regards to note duration. In general, a shorter note might require a higher vibrato rate in order for that note to be sung with vibrato at all. A certain minimum number of vibrato cycles may be required for a note, which would explain both the vibrato threshold time suggested in section 4.1 and the negative correlation between vibrato rate and note duration.

Sundberg (1997) found that changes from one note to the next are always in phase with the singer's vibrato cycle and Desain et al. (1999) conclude that this suggests a "tight relationship between timing and vibrato" (p.2) and also report higher vibrato rates for shorter notes. Referring back to Prame (1994) who observed that the vibrato rate increased towards the end of a tone, one may presume that this acceleration could be necessary in order to facilitate both the vibrato cycle and the note change to be in phase.

4.3 Vibrato Extent

4.3.1 Vibrato Extent in General

The following two diagrams present the vibrato extent values for all singers and all notes sung with vibrato. Again, larger dots with horizontal lines indicate the average vibrato extent for each subject.

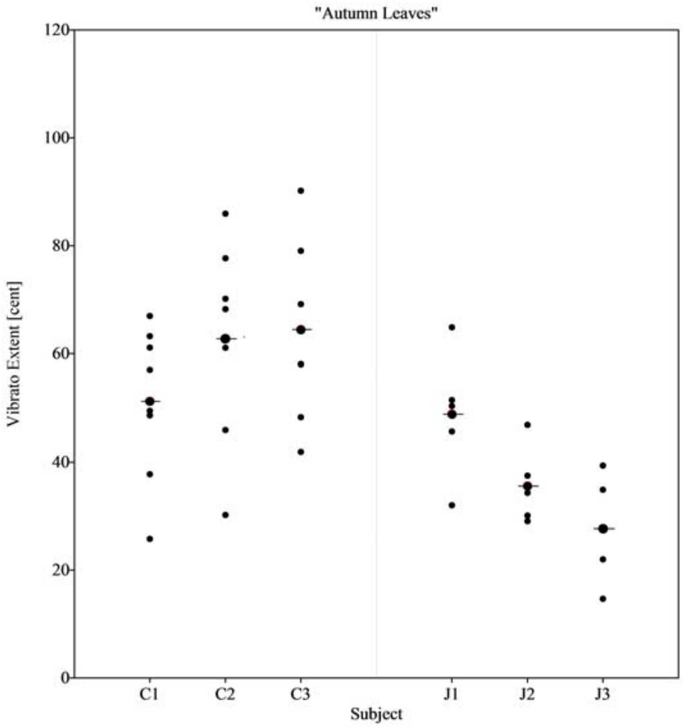

Figure 4.28 Vibrato extent "Autumn Leaves"

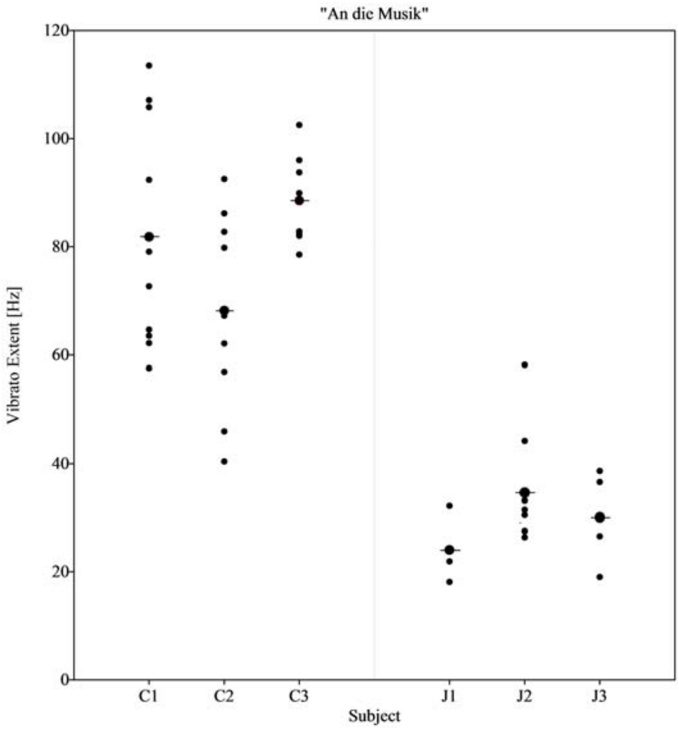

Figure 4.29 Vibrato extent "An die Musik"

In both songs, the classical singers show higher vibrato extents than the jazz singers. With average values ranging from 51.3 to 64.5 cent (AUT) and from 68.2 to 88.5 cent (MUS), they show substantially higher average vibrato extents than the jazz singers, whose average values range from 27.7 to 48.9 cent (AUT) and from 24.1 to 34.7 cent (MUS) respectively.

A t-test confirms that the differences between mean values for both subject groups (df=4) are very significant in "An die Musik" with t=7.42 and p=0.002 and significant in "Autumn Leaves" with t=2.97 and p=0.041. The overall averages for each subject group are 58.9 cent (AUT) and 79.3 cent (MUS) for the classical singers and 37.4 cent (AUT) and 31.6 cent (MUS) for the jazz singers.

To compare our data to other sources, table 4.7 displays our findings to those of others and diagram 4.30 displays those values using the abbreviations given on the table[14].

[14] Abbreviations for subjects of this study: 'Cj' for classical singers singing the jazz song, 'Jc' vice versa etc. / De Almeida Bezerra et al. (2009): 'C' for classical and 'S' for singers of the sertanejo style. / Bretos and Sundberg (2003): 'F5' and 'A5' refer to the notes that were analysed.

Table 4.7 Vibrato extents measured by others

Source	Singer / style	Abbrev. / diagram	Aver. Vibrato Extents [ct] Min.	Max
Jazz singers	jazz	Jc	24	35
(this thesis)	jazz	Jj	28	49
Classical Singers	classical	Cc	68	98
(this thesis)	classical	Cj	51	65
Bretos and Sundberg (2003)	note F5	F5	26	56
Two notes of an aria found in ten commercial recordings	note A5	A5	23	80
Prame (1997) *Ten professional classical singers*			57	86
Howes et al. (2003) *Eleven famous opera singers*			67	122
Mitchell and Kenny (2004) *Six female singers, advanced students*			67	132
de Almeida Bezerra et al. (2009)	lyric	C	54	166
Ten lyric and ten sertanejo male singers	sertanejo	*S*	54	95
Hakes et al. (1988) *Recordings of ten early music singers*			39	175
Ramig et al. (1987) *Nine singers from the Stockholm Opera*			137	

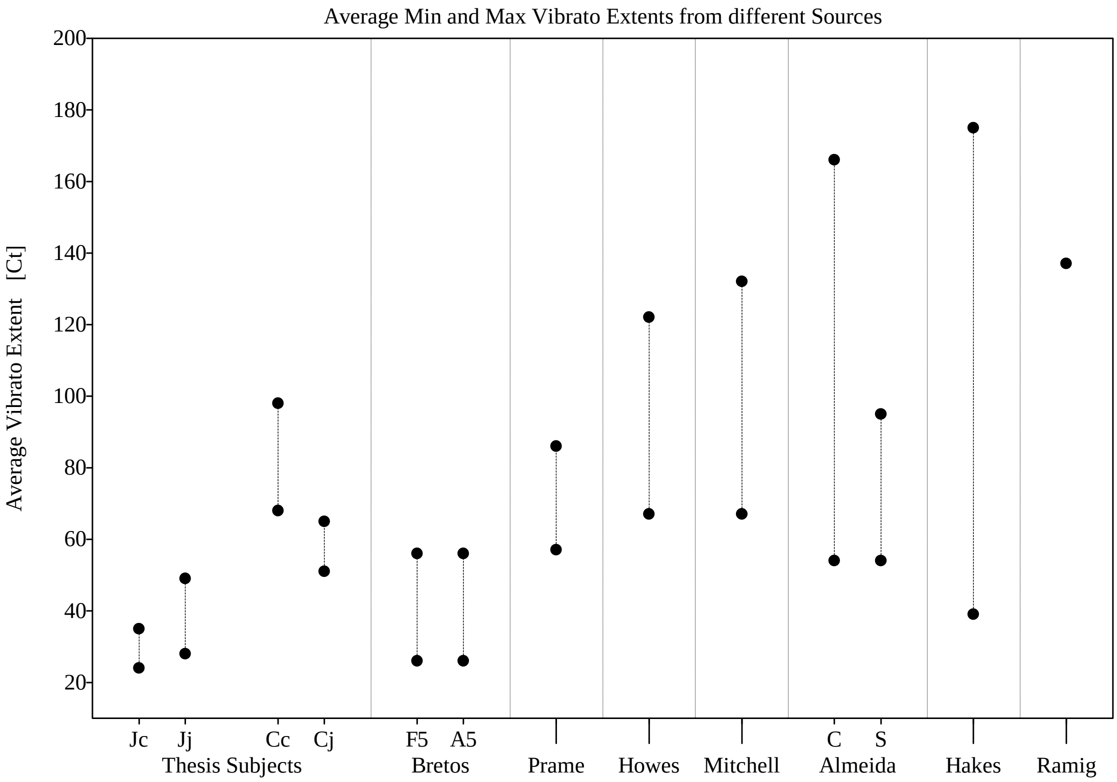

Diagram 4.30 Vibrato extents measured by others

The vibrato extent (VE) values obtained from our classical singers singing the classical song are similar to those reported by Prame (1997), Howes et al. (2003) and Mitchell and Kenny (2004). They also fall into the range of values reported for classical singers by de Almeida Bezerra et al. (2009) and to those of Hakes et al. (1988), although the latter measured higher differences between minimum and maximum vibrato extent.

The jazz singers, whose VEs are lower, show values more similar to those reported by Bretos and Sundberg (2003). However, the fact that all other sources report generally higher VE values confirms our observation that jazz singers show lower VE than classical singers. De Almeida Bezerra et al. (2009) report comparably lower maximum VE values for rock singers which is in line with our conjecture made in section 4.2.1 on the difference between singers being extendable to the categories of 'popular' and 'serious' music.

Table 4.8 lists average, minimum and maximum extent values for all singers along with the differences between minimum and maximum and the singers' average inter-tone variations.

Table 4.8 Vibrato extents and inter-tone variations

	"Autumn Leaves"					"An die Musik"				
	Avr. [Ct]	Min. [Ct]	Max. [Ct]	Diff. [Ct]	Int-tn [Ct]	Avr. [Ct]	Min. [Ct]	Max. [Ct]	Diff. [Ct]	Int-tn [Ct]
C1	51.3	25.8	67.0	41.2	±20.6	81.9	57.6	107.0	49.4	±24.7
C2	62.8	30.2	86.0	55.8	±27.9	68.2	40.4	92.6	52.2	±26.1
C3	64.5	41.9	90.2	48.3	±24.2	88.5	78.5	103.0	24.5	±12.3
Avr				48.4	±24.2				42.0	±21.0
J1	48.9	32.0	64.9	32.9	±16.5	24.1	18.1	32.2	14.1	±7.1
J2	35.6	29.1	46.9	17.8	±8.9	34.7	26.4	58.2	31.8	±15.9
J3	27.7	14.7	39.4	24.7	±12.4	30.2	19.1	38.6	19.5	±9.8
Avr				25.1	±12.6				21.8	±10.9

Similar to the vibrato rate variation discussed in section 4.3.1, the classical singers also show higher inter-tone variations in vibrato extent than the jazz singers. The average inter-tone variations for the classical singers are ±24.2 cent (AUT) and ±21 cent (MUS) and those for the jazz singers are ±12.6 cent (AUT) and ±10.9 cent (MUS) respectively. With a variation of only ±12.3 cent, subject C3 is an exception within the group of the classical singers.

4.3.2 Vibrato Extent in relation to Note Pitch

This section investigates whether there is any correlation between vibrato extent and the mean pitch of a sung note. Figures 4.31 to 4.36 show vibrato extent as a function of mean pitch for each singer and each note, and table 4.9 lists the linear correlation coefficients for vibrato extent as a function of fundamental frequency for each singer and song.

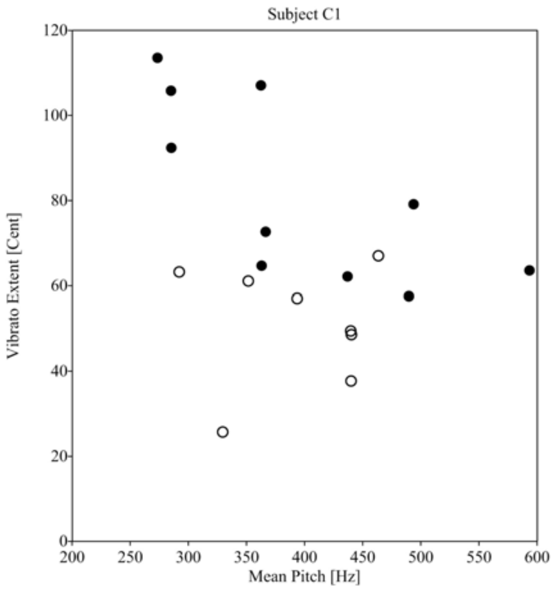

Figure 4.31 Vibrato extent vs. F0, Subject C1

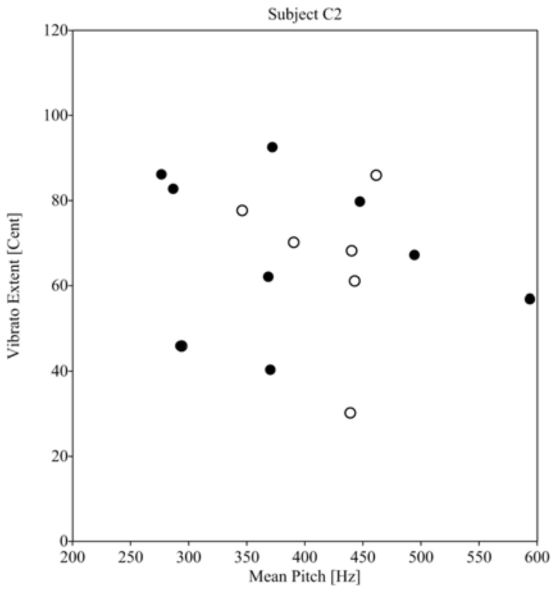

Figure 4.32 Vibrato extent vs. F0, Subject C2

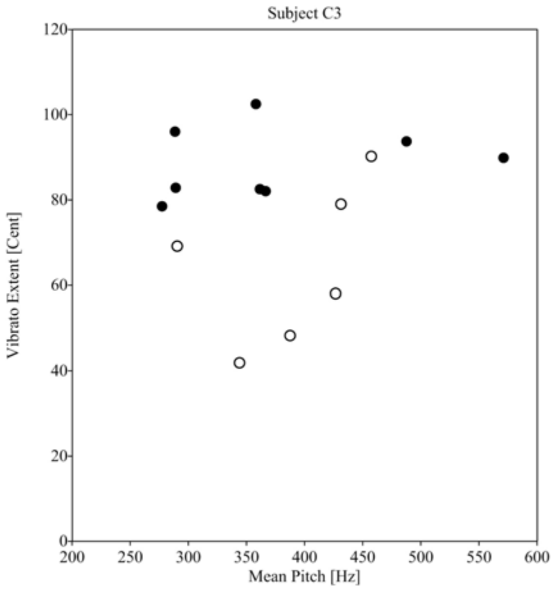

Figure 4.33 Vibrato extent vs, F0. Subject C3

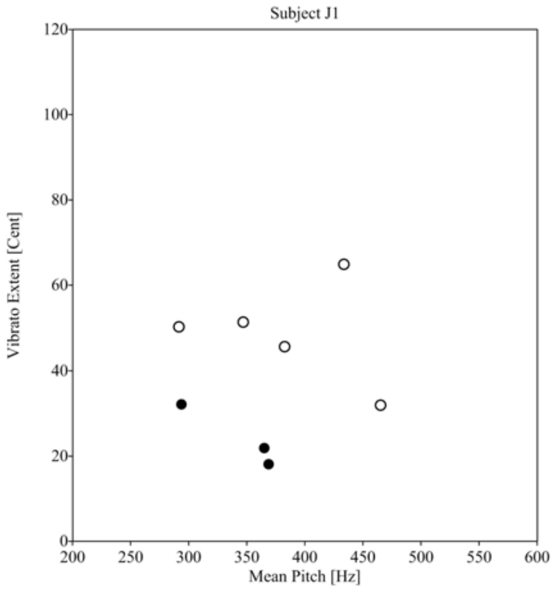

Figure 4.34 Vibrato extent vs. F0, Subject J1

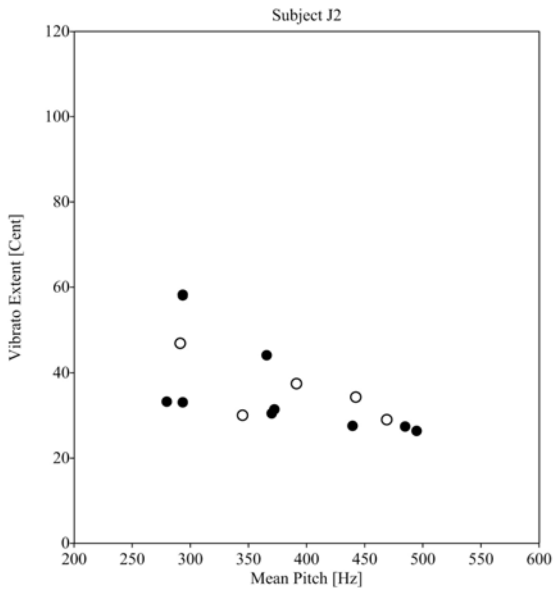

Figure 4.35 Vibrato extent vs. F0, Subject J2

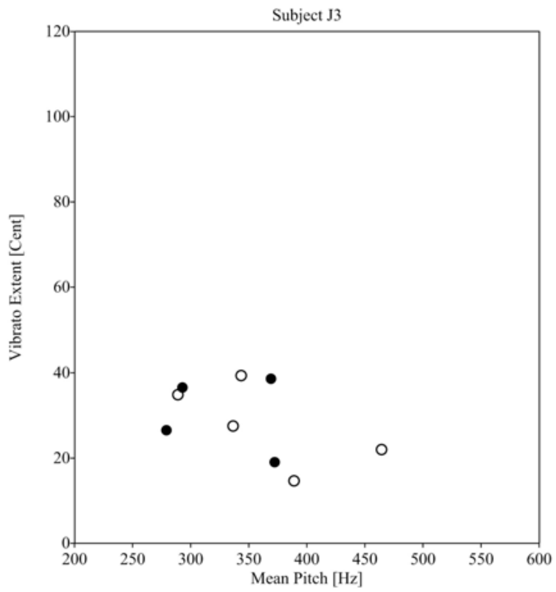

Figure 4.36 Vibrato extent vs. F0, Subject J3

Table 4.9 Linear correlation coefficients, vibrato extent as a function of F0

Linear correlation coefficients (ρ). vibrato extent as a function of F0		
	„Autumn Leaves“	„An die Musik“
C1	0.05	-0.73
C2	0.17	-0.18
C3	0.47	0.26
J1	-0.25	-0.98
J2	-0.7	-0.59
J3	-0.64	-0.14

Somewhat significant negative correlations ($\rho<-0.5$) can be found in five cases, one for subject C1-MUS and the other four in the group of the jazz singers. Here, only subject J2 shows negative correlations above -0.5 in both songs. As for subject J2, higher fundamental frequencies seem to go together with lower vibrato extents in both songs. Subject C2 shows no significant correlations between those aspects in any of the songs.

Bretos and Sundberg (2003) found an increase of extent to correlate with a decrease of mean pitch of a note. We can only confirm this correlation in the song "An die Musik" for subjects C1, J1 and J2 and subject J3 in "Autumn Leaves". However, since our data vary strongly between the subjects and songs, it is not possible to observe any clear trend.

4.3.3 Vibrato Extent in relation to Duration

The following six diagrams present vibrato extent in relation to note duration for each singer and song and table 4.10 lists the correlation coefficients between average vibrato extent and note duration for all singers and both songs.

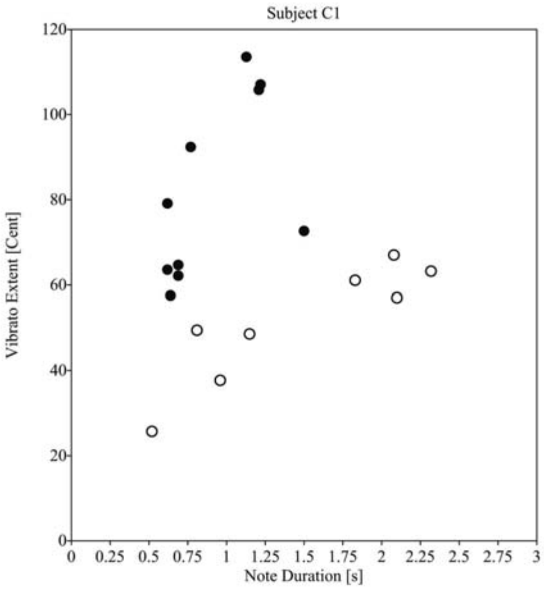

Figure 4.37 Extent vs. duration, Subject C1

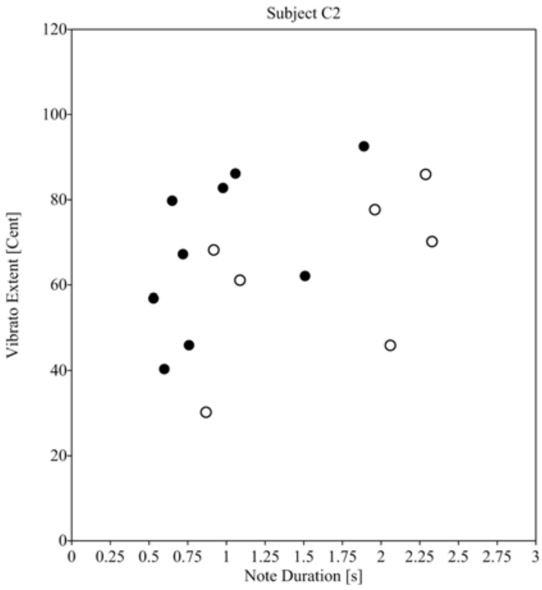

Figure 4.38 Extent vs. duration, Subject C2

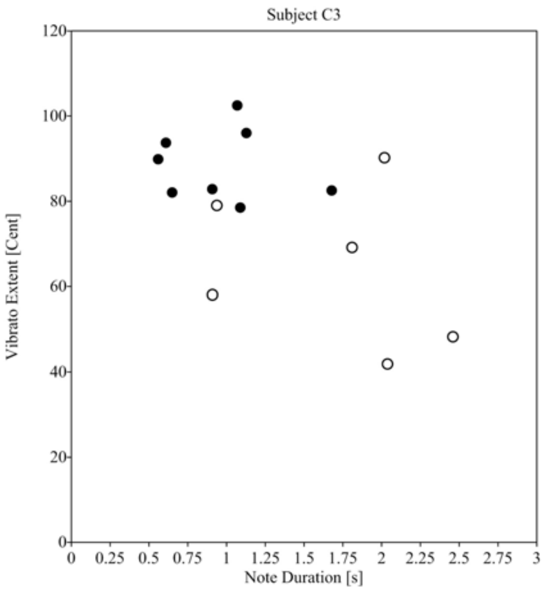

Figure 4.39 Extent vs. duration, Subject C3

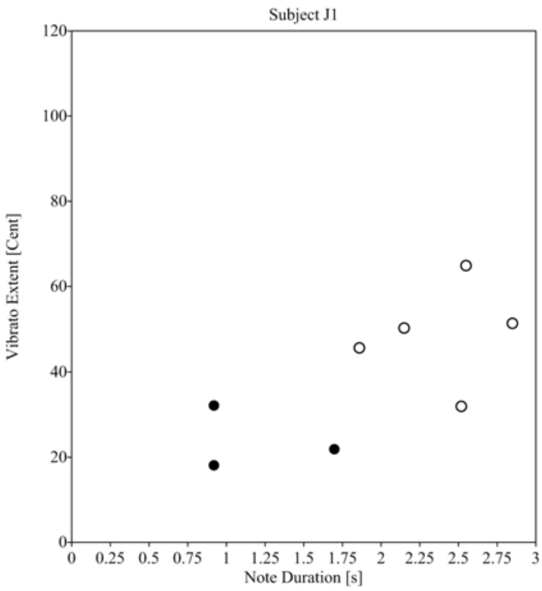

Figure 4.40 Extent vs. duration, Subject J1

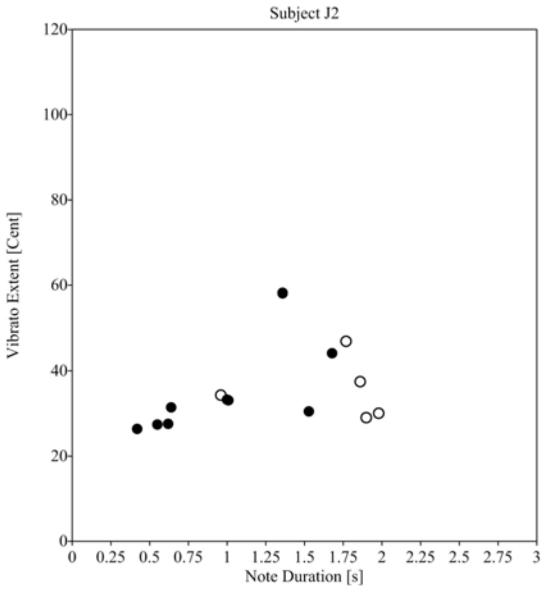

Figure 4.41 Extent vs. duration, Subject J2

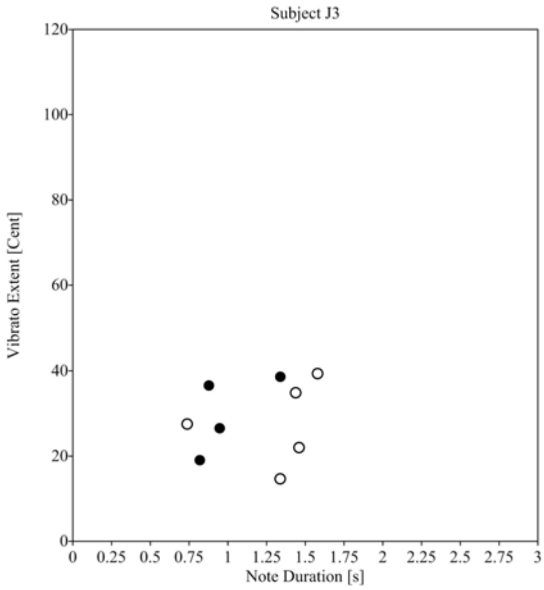

Figure 4.42 Extent vs. duration, Subject J3

Table 4.10 linear correlation coefficients, vibrato extent as a function of note duration

Linear correlation coefficients (ρ). vibrato extent as a function of note duration		
	„Autumn Leaves“	„An die Musik“
C1	0.89	0.58
C2	0.53	0.55
C3	-0.29	-0.13
J1	0.16	0.26
J2	-0.07	0.65
J3	0.22	0.67

In his investigation of ten professional classical singers, Prame (1997) found a negative correlation between vibrato extent and note duration of ρ=-0.44 but our data do not confirm his findings. On the contrary, subjects C1. C2. and J3 show positive correlations which complies more with the findings of Ferrante (2011), who reports a positive correlation of ρ=0.3. All other correlations measured in this study are not significant (both positive and negative) and our data vary too strongly between and within subjects to indicate any trend.

4.3.4 Vibrato Extent in relation to Vibrato Rate

Sundberg (1994: 53) states that "it has sometimes been assumed that there is an interaction between vibrato rate and extent, such that great extents often appear in combination with low rates and vice versa" and that "not much empirical support has been reported for that assumption". Ferrante (2011) could confirm this assumption, reporting a clear negative correlation of ρ=-0.62.

The diagrams 4.43 to 4.48 display vibrato extent plotted against vibrato rate and table 4.11 presents the linear correlation coefficients for all subjects and songs.

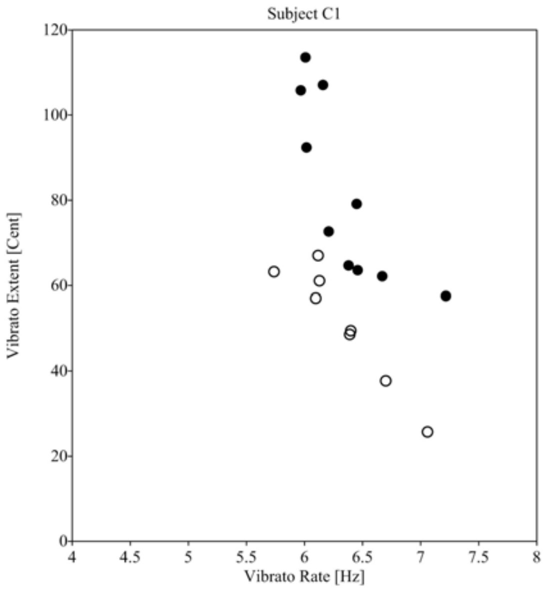

Figure 4.43 Extent vs. rate, Subject C1

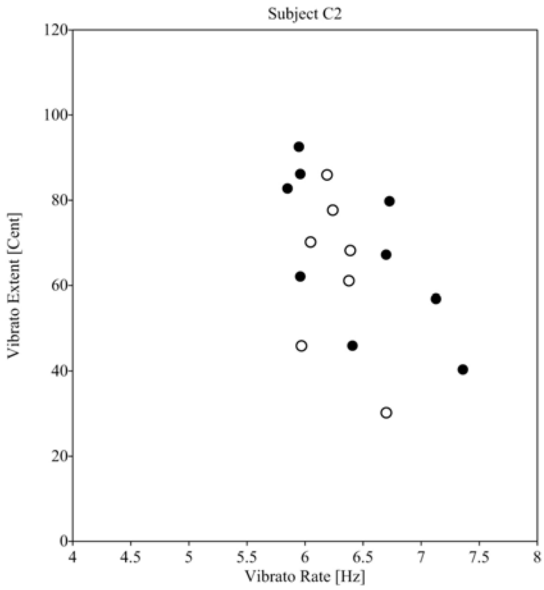

Figure 4.44 Extent vs. rate, Subject C2

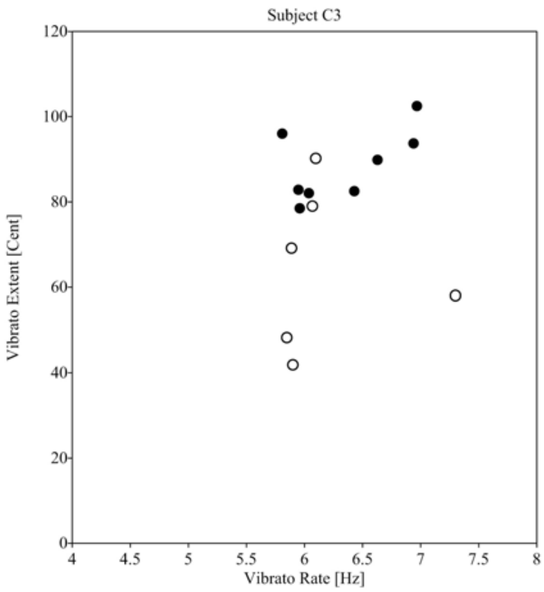

Figure 4.45 Extent vs. rate, Subject C3

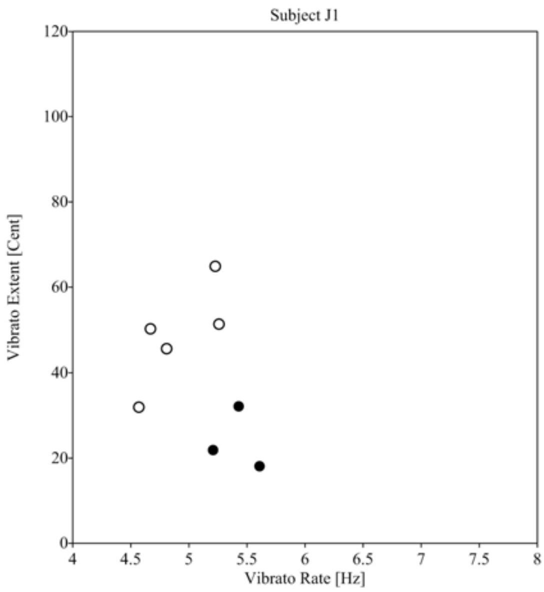

Figure 4.46 Extent vs. rate, Subject J1

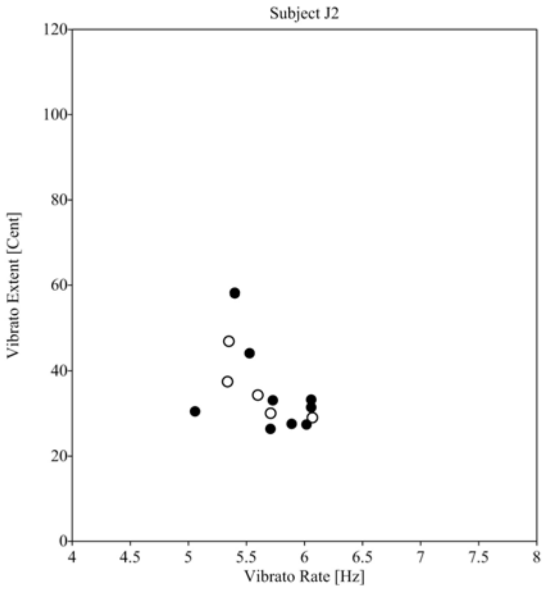

Figure 4.47 Extent vs. rate, Subject J2

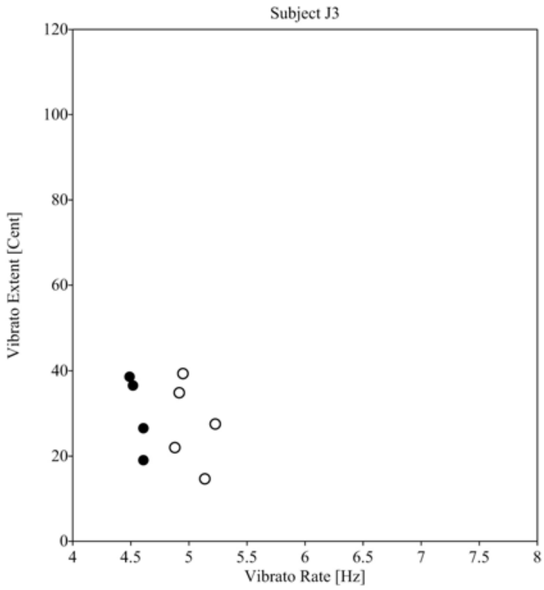

Figure 4.48 Extent vs. rate, Subject J3

Table 4.11 linear correlation coefficients, vibrato extent as a function of vibrato rate

Linear correlation coefficients (ρ). vibrato extent as a function of vibrato rate		
	„Autumn Leaves“	„An die Musik“
C1	-0.94	-0.79
C2	-0.44	-0.68
C3	-0.01	0.58
J1	0.78	-0.2
J2	-0.81	-0.41
J3	-0.39	-0.94

The data presented in table 4.11 partially confirm the above-mentioned assumption. Apart from subjects C3 and J1, all subjects show slight or even high negative correlations between vibrato extent and rate in one of the two songs.

4.2.5 Vibrato Extent in relation to Intonation

This section explores whether there is any correlation between vibrato extent and the deviation of the actual sung pitch from the desired pitch of a sung note. The desired pitch of a note refers to the standard tuning of the provided accompaniments for both songs (note A4 equals 440 Hz). In the following six diagrams, vibrato extent is plotted against the deviation from desired pitch in cent for each note and each subject. Apart from subjects C3 and J1, whose sung pitches were almost entirely lower than the desired pitches, all other subjects showed positive as well as negative deviations from the desired pitch. In order to calculate meaningful correlations, the according linear correlation coefficients shown above the diagrams were calculated for the absolute values of pitch deviation.

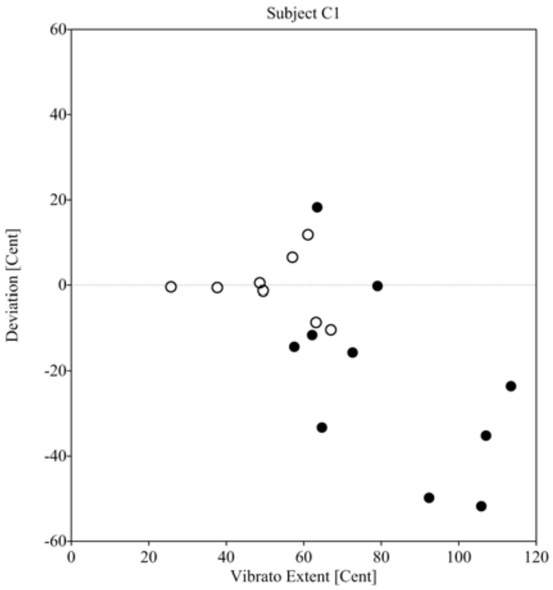

Figure 4.49 Subject C1

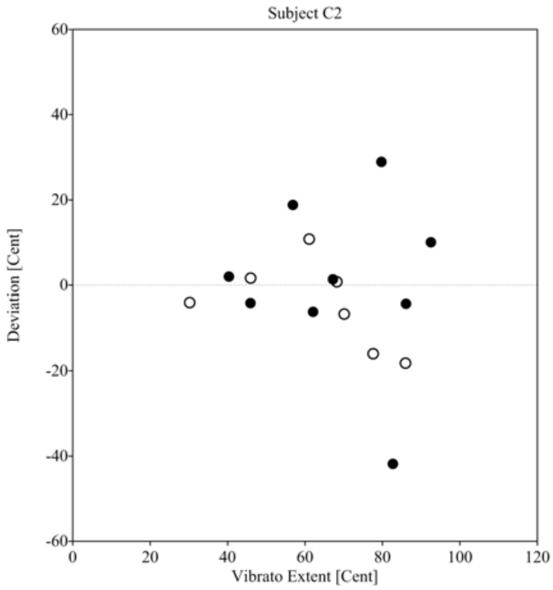

Figure 4.50 Subject C2

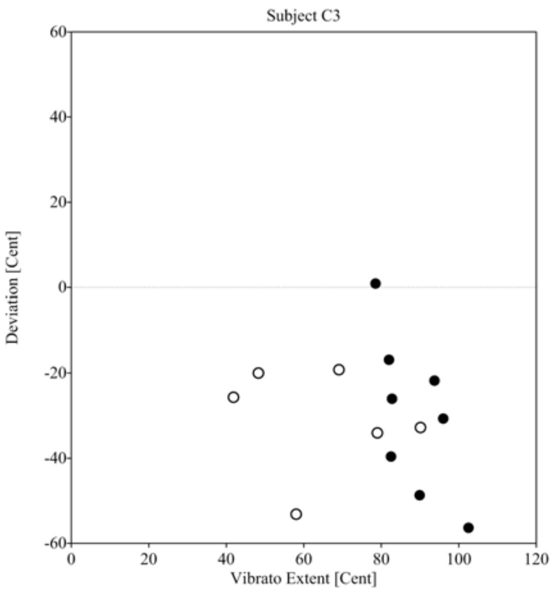

Figure 4.51 Subject C3

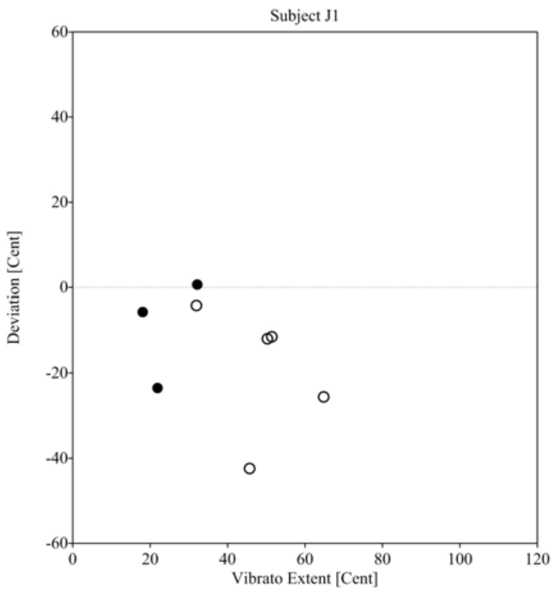

Figure 4.52 Subject J1

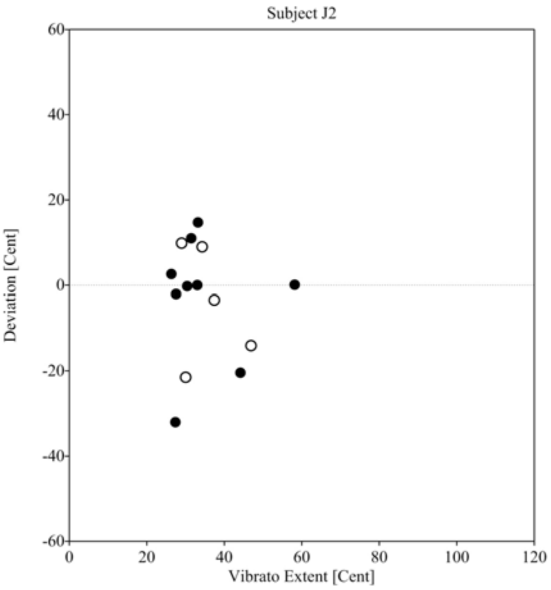

Figure 4.53 Subject J2

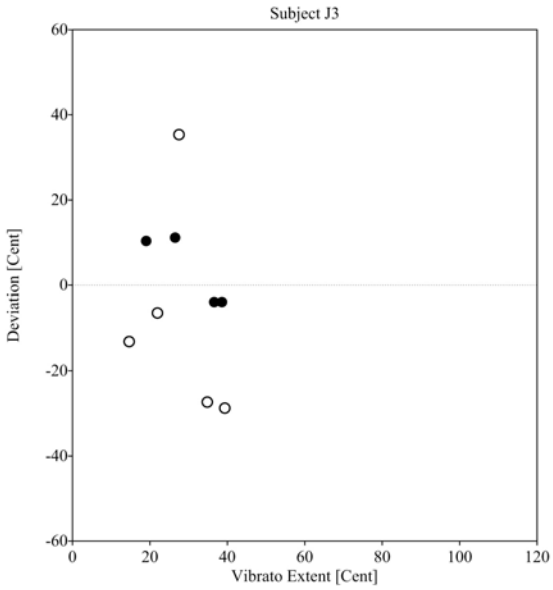

Figure 4.54 Subject J3

Table 4.12 linear correlation coefficients, intonation as a function of vibrato extent

Linear correlation coefficients (ρ). intonation as a function of vibrato extent		
	"Autumn Leaves"	"An die Musik"
C1	0.84	0.55
C2	0.68	0.42
C3	0.16	0.67
J1	0.35	-0.45
J2	-0.14	-0.14
J3	0.68	-0.91

Table 4.12 lists the linear correlation coefficients for all singers and both songs. Apart from the cases of C3, AUT and C2, MUS, all classical singers show a positive correlation above 0.5 with subject C1 (AUT) showing a very strong correlation of ρ=0.84. Except subject J3, AUT with a positive correlation of ρ=0.68, all jazz singers have either low positive (ρ<0.5) or negative correlations between vibrato extent and pitch variation. Subject J3, MUS shows a strong negative correlation of ρ=-0.91.

A positive correlation of ρ=0.39 between vibrato extent and intonation was observed by Prame (1997). His findings can be confirmed at least for the group of classical singers for whose high vibrato extent values seem to be accompanied by higher deviations from the desired pitch. One possible explanation might be that it is more difficult for a subject to intonate a note precisely while employing a higher vibrato extent but on the contrary it could also be that higher vibrato extents are used by singers in order to hide (or mask) false intonation. Looking at this matter from another angle, it might be interesting to note that Daffern et al. (2012) observed that a higher vibrato extent has a negative impact on subjects trying to accurately match the pitch of a sung note in a listening test.

4.4 Vibrato Analysis Summary

With regards to the position of vibrato within the notes (and not considering the singer who sang vibrato throughout all notes entirely) it was observed for all subjects that notes needed to be of a certain length (defined as the vibrato threshold) to be sung with vibrato and that this lengths vary among subjects. Thresholds were also defined for vibrato onset and offset time and it was found that the vibrato threshold time was either lower or equal to the vibrato onset threshold which itself was either lower or equal to the vibrato offset threshold. It was found that the vibrato threshold area starts at approximately 0.5 seconds for all subjects and both songs and in this respect there was no indication for any differences between the classical and jazz singers. Apart from one exception, all singers showed longer vibrato onset times in the song "Autumn Leaves" and comparing the two subject groups, the jazz singers showed significantly higher differences of average values between both songs. This suggests that jazz singers show a higher variability in their use of vibrato whereas classical singers show rather constant vibrato onset times.

The average vibrato rates and the inter-tone variations of the vibrato rate of the classical singers were distinctively higher than those of the jazz singers, again leading to the conclusion that jazz singers show a higher variation in their use of vibrato. Our data regarding the vibrato rates of classical singers comply with the findings of Prame (1994), whereas the jazz singers proved to have lower values for both vibrato rate and inter-tone variation.

In contrast to Prame (1994) and Bretos and Sundberg (2002), who did not observe any dependency of vibrato rate on pitch. our data suggests at least a slight dependency. All classical singers showed slight or even strong positive correlations between vibrato rate and pitch. Within the group of the jazz singers, only subject J2 showed a higher positive correlation. We also found vibrato rate to correlate negatively with note duration, especially for the classical singers. Averaged over the whole group, the jazz singer's correlation coefficients were clearly below those of the classical singers. These findings agree with Prame (1994), who also found these aspects to correlate negatively.

The classical singers also showed higher average vibrato extents than the jazz singers. Again, the same holds for the inter-tone variation of vibrato extent for the jazz singers. Our findings for the classical singers comply with data provided by Prame (1997) and Howes et al. (2004), whereas the classical singers showed substantially lower vibrato extents. A comparison of our findings to De Almeida Bezerra et al. (2009), who compared found rock singers to have lower average vibrato extent values than classical singers, might imply that the singing styles of 'rock' and 'jazz' show similar characteristics and differentiate themselves from the classical singing style in a similar way.

As for vibrato extent as a function of pitch, our data varied strongly between subjects. Although some subject showed slight or even strong negative correlations, no clear trend could be observed. Apart from one exception, all subjects had slight or even strong correlations between vibrato extent and note duration. This is in clear contrast to Prame (1997), who found vibrato extent and note duration to correlate negatively. Furthermore, we found vibrato extent to correlate negatively with vibrato rate for most subjects. This corresponds to a remark by Sundberg (1994), who states that an interaction between those aspects of vibrato has been assumed. The vibrato extent was also found to correlate positively with false intonation in the case of the classical singers. This is in accordance with the findings of Prame (1997), who also found a positive correlation of these aspects among his subjects.

In contrast to the jazz singers, the classical singers showed strong positive correlations between vibrato rate and pitch and between vibrato extent and intonation. With regards to vibrato rate in relation to note duration, both subject groups showed negative correlations while the classical singers' correlations were higher than those of the jazz singers.

The two aspects that distinguish both groups most from one another are vibrato rate and extent. Figure 4.55 presents average vibrato extent plotted against average vibrato rate for all subjects. Average values for the song "Autumn Leaves" are indicated by open circles and values for "An die Musik" by closed circles. A dotted line is drawn diagonally across the diagram which clearly divides both subject groups with respect to vibrato extent and rate. It can be summarized that jazz singers differ from classical singers most in employing both lower vibrato extents and rates.

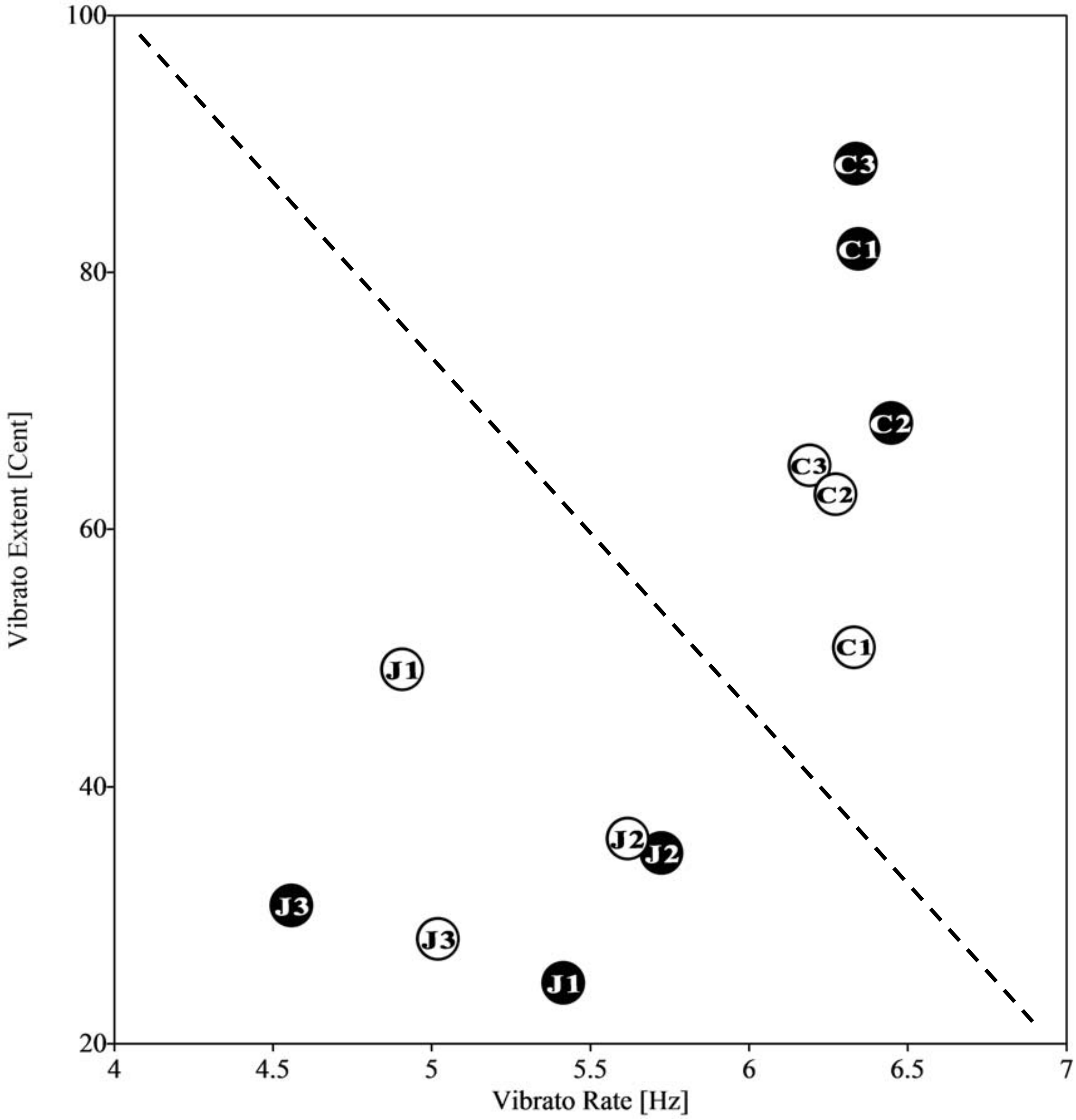

Figure 4.55 Average vibrato extents and rates

5. Open Quotient Data Analysis

5.1 Open Quotient

The following two diagrams display the average open quotient (OQ) for all notes and all singers. The OQ averages over all notes for each singer are indicated by larger dots and horizontal lines.

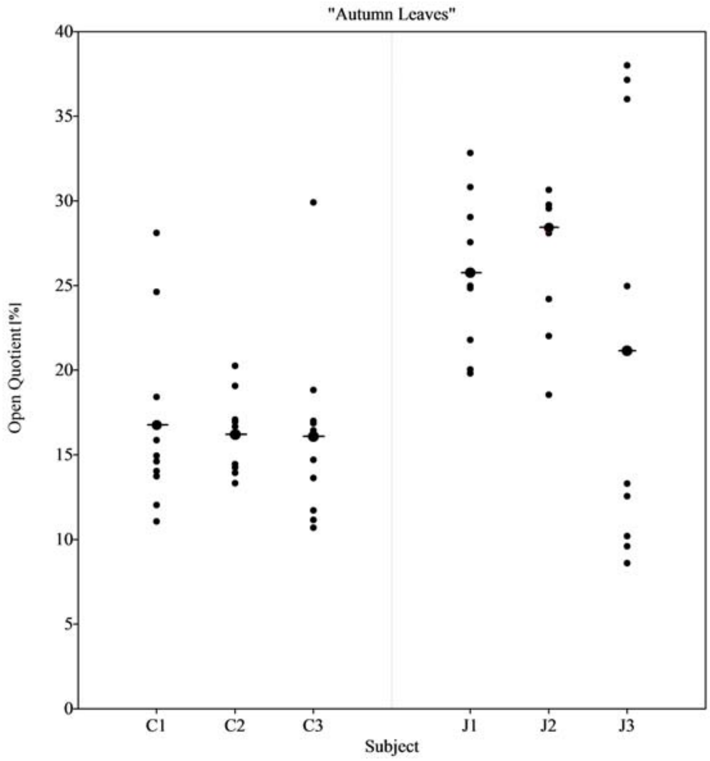

Figure 5.1 OQ values, "Autumn Leaves"

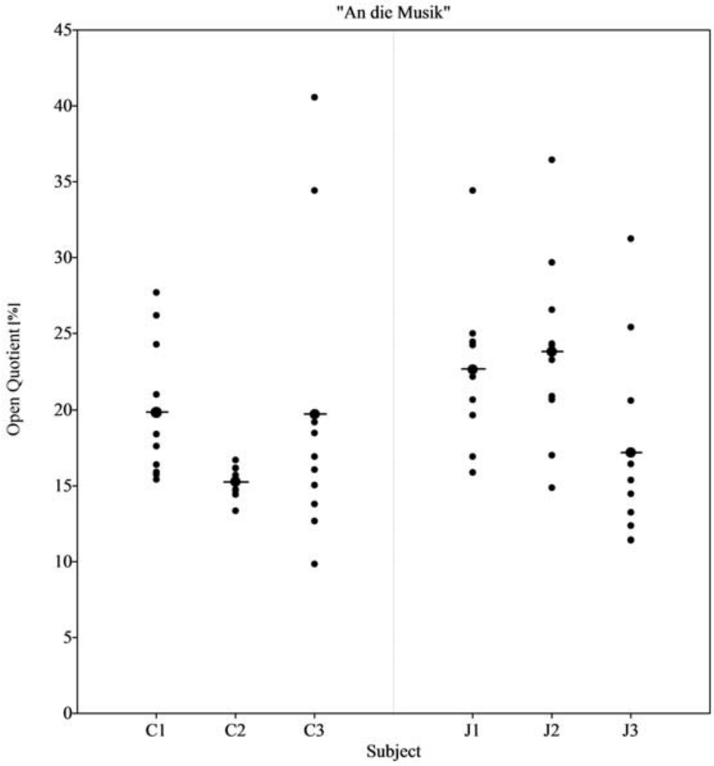

Figure 5.2 OQ values, "An die Musik"

Table 5.1 lists the average note values for each song along with values of variation (distance from minimum and maximum to mean) and the average absolute deviations from mean. The column on the right shows the differences between the mean values of both songs for all singers.

Table 5.1 Average OQ values, variation and style differences

	„Autumn Leaves“ Open Quotient [%]				„An die Musik“ Open Quotient [%]				Style Difference
	Aver.	Min.	Max.	Dev.	Aver.	Min.	Max.	Dev.	Diff.
C1	16.75	11.07	28.11	±8.53	19.88	15.42	27.7	±6.14	-3.13
C2	16.22	13.33	20.26	±3.47	15.29	13.36	16.7	±1.67	0.93
C3	16.1	10.7	29.91	±9.61	19.71	9.86	40.57	±15.36	-3.61
J1	25.75	19.82	32.84	±6.51	22.61	15.88	34.43	±9.28	3.14
J2	28.41	18.55	44.42	±12.94	23.81	14.88	36.45	±10.79	4.6
J3	21.16	8.6	38.0	±14.7	17.21	11.42	31.25	±9.91	3.95

With regards to "Autumn Leaves", the average OQ (AOQ) values over all notes of the jazz singers are substantially higher than those of the classical singers. In "An die Musik", the AOQ values of both subject groups lie much closer together. Here, only J1 and J2 have AOQ values exceeding those of the classical singers. The classical singers show an average OQ of 16.36 percent in "Autumn Leaves" and 18.29 percent in "An die Musik". The jazz singers have values of 25.11 cent (AUT) and 21.21 percent (MUS) respectively. A t-test between the mean values of both subject groups (df=4) confirms that in "Autumn Leaves" the difference is statistically significant with t=4.11 and p=0.015. With values of t=1.16 and p=0.31, the difference is not significant in the song "An die Musik".

Looking at the style differences, it appears that jazz singers generally employ higher OQ when singing a classical song and that classical singers (with the exception of C2) employ a lower OQ when singing a jazz songs, meaning that both seem to adjust to the other singing style. Comparing the absolute values of style differences between both subject groups through a t-test shows that the difference is not significant with t=1.45 and p=0.22. This suggests that singers of both groups adjust to the other singing style to the same degree. Howard et al. (2012: 63) investigated the voice qualities of a soprano singer in three different early music singing styles and found that "Larynx CQ values do vary between the three styles, indicating that CQ is available to the singer for modification when singing in different styles."

Björkner (2008) analysed voice differences between western operatic (WO) and musical theater (MT) singers and found that MT singers to have higher CQ values than WO singers. Barlow and Lovetri (2010) confirmed her findings analysing the voices of twenty female voice students aged between 12 and 17 years. Assuming that MT singing is more closely related to jazz singing than classical singing, those findings would contradict our data (OQ=1-CQ). However, this assumption needs to be assessed critically as the MT and jazz singing styles still are different to one another with regards to voice quality (lyrics in MT singing need to be highly comprehensible) and expressiveness (jazz singing offers more room for expressiveness due to the usually more intimate setting of a jazz concert venue and smaller ensembles).

Thalen and Sundberg (2001) analysed the first authors' voice source in four different singing styles (classical, pop, jazz and blues) and found higher closed quotient (CQ) values for the jazz compared to the classical singing style. We cannot confirm these findings when comparing our two subject groups, as the jazz singers showed lower

CQ values than the classical singers. Comparing between the two songs for each subject group we can confirm their findings for the singers C1 and C3 who had higher CQ values when singing the classical song but not for subject C2 and the jazz singers who all showed lower CQ values in the classical song compared to the jazz song. Thalen and Sundberg (2001: 88) distinguished singing styles by finding that classical singing was similar to flow phonation and jazz singing to neutral and flow phonation. Seeing that flow phonation is connected to a higher open quotient compared to neutral phonation, our findings contradict their classification.

With an overall average of ±10.69 percent, the jazz singers show a somewhat higher inter-tone variation of OQ than the classical singers with ±7.46 percent. The lowest variation is ±1.67 (C2, MUS) and the highest is ±14.7 (J3, AUT).

5.2 Open Quotient in relation to Note Pitch

This section assesses if any systematic dependence of the open quotient can be confirmed with regards to pitch. In his investigation of the closed quotient (CQ = 1-OQ) of trained and untrained adult female singers, Howard (1995: 9) found that (a) "CQ tends to be reduced for pitches below D4 and increased for pitches higher than B4 with training" and that (b) "the CQ/F0 gradient within the pitch ranges: G3 to G#4, and B4 to G5 tends to correlate positively with the number of years in singing training/experience". In the following section, we will compare our data to both findings (a) and (b) of Howard.

5.2.1 Average Note Values

In the following six diagrams, the average OQ values for each note are plotted against the mean pitch of the corresponding note. With reference to Howard (1995), the pitches for notes D4 (293.5 Hz) and B4 (493.9 Hz) are indicated by dotted lines. Table 5.2 lists the according the linear correlation coefficients for all subjects and songs along with their year of study.

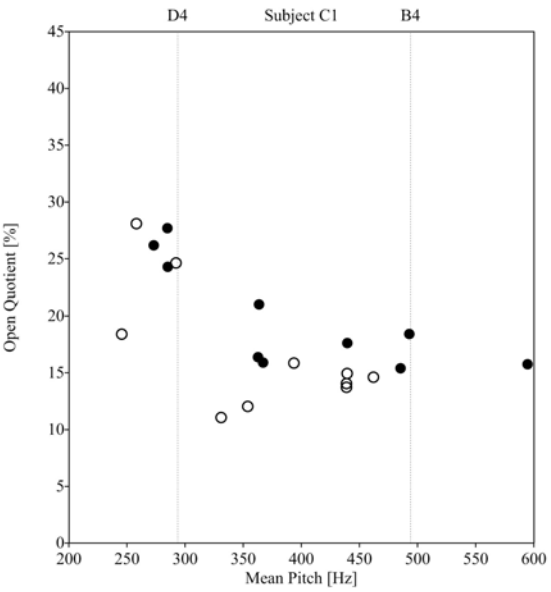

Figure 5.3 Subject C1

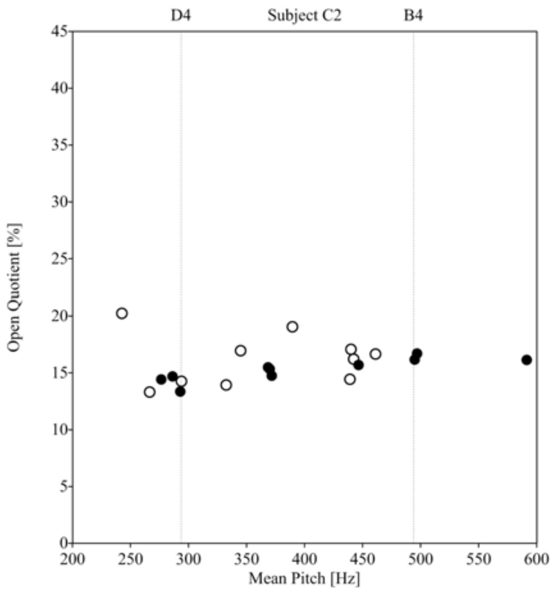

Figure 5.4 Subject C2

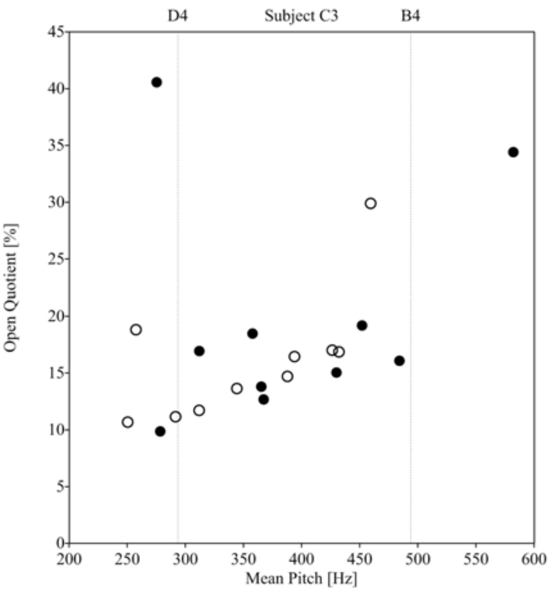

Figure 5.5 Subject C3

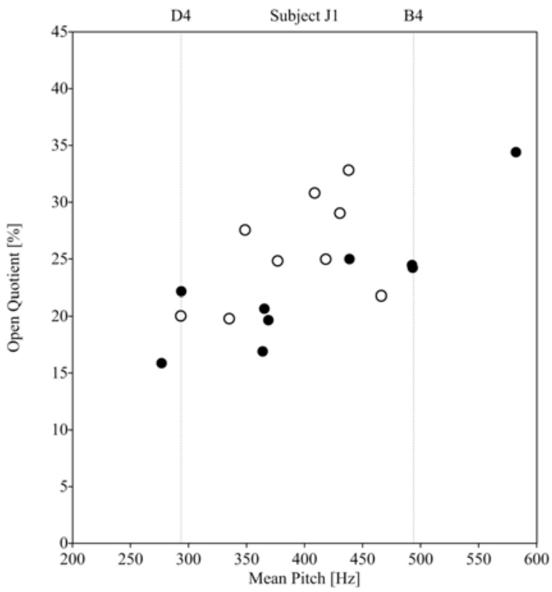

Figure 5.6 Subject J1

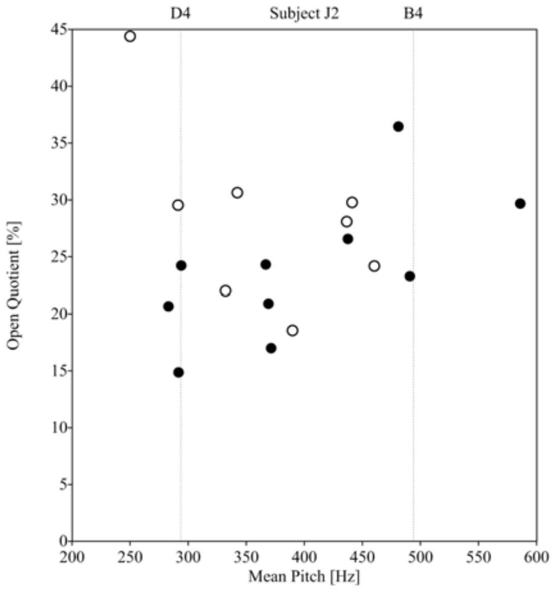

Figure 5.7 Subject J2

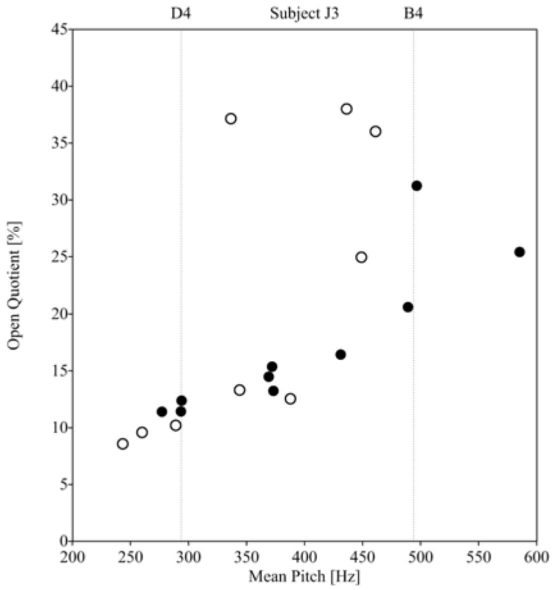

Figure 5.8 Subject J3

T**able 5.2** linear correlation coefficients, OQ as a function of F0

Linear correlation coefficients (ρ), OQ as a function of F0			
Subject	„Autumn Leaves“	„An die Musik“	Year of Study
C1	-0.63	-0.77	1
C2	0.022	0.85	4
C3	0.62	0.18	6
J1	0.51	0.86	4
J2	-0.56	0.67	1
J3	0.71	0.87	4

Only the data of subject C1 (figure 5.3) comply partially with observation (a) of Howard (1995) in showing higher OQ values below the pitch of D4[15]. Apart from subject C2, who shows somewhat steady OQ values across different pitches, all other subjects show slight trends for higher pitches being connected to higher OQ values. Our findings do not comply with observation (b) of Howard (1995). On the contrary, subjects that had studied voice over a longer period tend to have negative correlations between closed quotient and F0. It must be stated that Howard found the positive correlation within the pitch range of G3 (196 Hz) and G#4 (415 Hz) whereas our data includes notes between B3 (247 Hz) and D5 (587 Hz). Despite this differences in pitches analysed, we could not even observe a trend towards his

[15] Higher OQ values being equivalent to lower CQ values.

observation. It should also be noted that the term "years of singing/training experience" may be a hard term define. Probably all professional singers and students of voice started singing well before entering professional training at a Conservatorium. Most of them are also very likely to have had years of regular singing lessons before that and therefore the number of years in professional training may not be a very good indication of the amount of years they received training.

5.2.2 Glottal Cycles

To investigate the relationship between OQ and pitch further and in more detail, OQ and pitch were measured using consecutive extracts from each note. In order to get a high number of samples per note and in order to minimize the effect that one misinterpreted glottal cycle of the EGG signal might have on the results (see section 3.2 for details), it was decided to calculate the OQ and pitch over succeeding extracts of five glottal cycles each. For each note, the average OQ for each extract was then plotted against the average pitch of that extract. To give an example, figure 5.9 shows the scatter plots along with linear correlation coefficients for all notes of subject J3 (MUS).

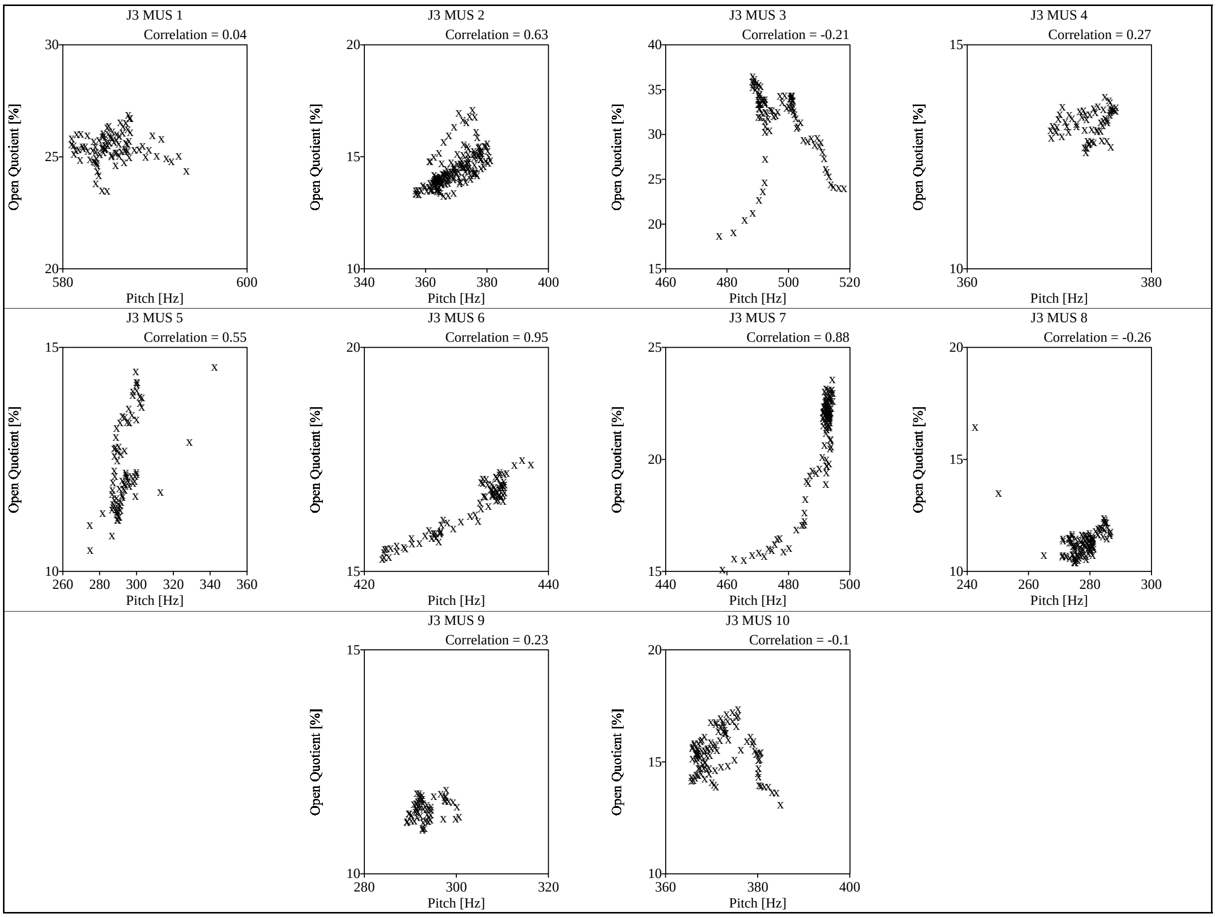

Figure 5.9 OQ as a function of pitch, subject J3, "An die Musik"

The resulting correlation coefficients for each note (CCN) were then plotted against pitch, but no subject showed any indication of a higher correlation of CCN and mean pitch of a note in the frequency regions described by Howard (1995)[16]. It should be noted that the notes investigated here did not cover the two octave scale recorded by Howard (G3 to G5). The lowest note investigated was B3 (247 Hz) and the highest was D5 (587.3 Hz). Figure 5.10 gives an example of CCN plotted against mean pitch of each note for subject C2. Notes for "Autumn Leaves" are plotted as open and notes for "An die Musik" as closed circles.

[16] Those regions were G3 to G#4 (196 to 404 Hz and B4 to G5 (493 to 784 Hz).

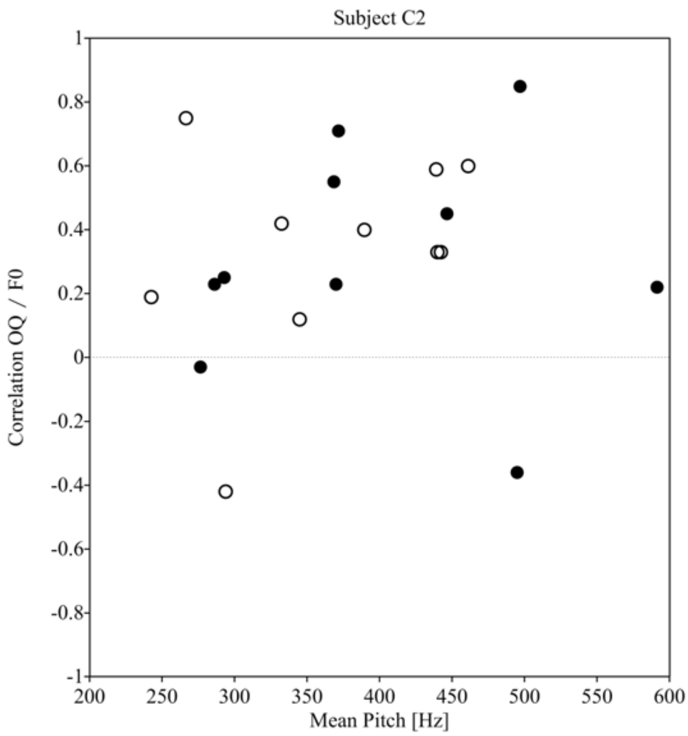

Figure 5.10 CCN as a function of pitch, subject C2

The following two diagrams show the correlation coefficients for each subject and each note for both songs. The average correlation coefficients for each subject are indicated by larger dots with horizontal lines.

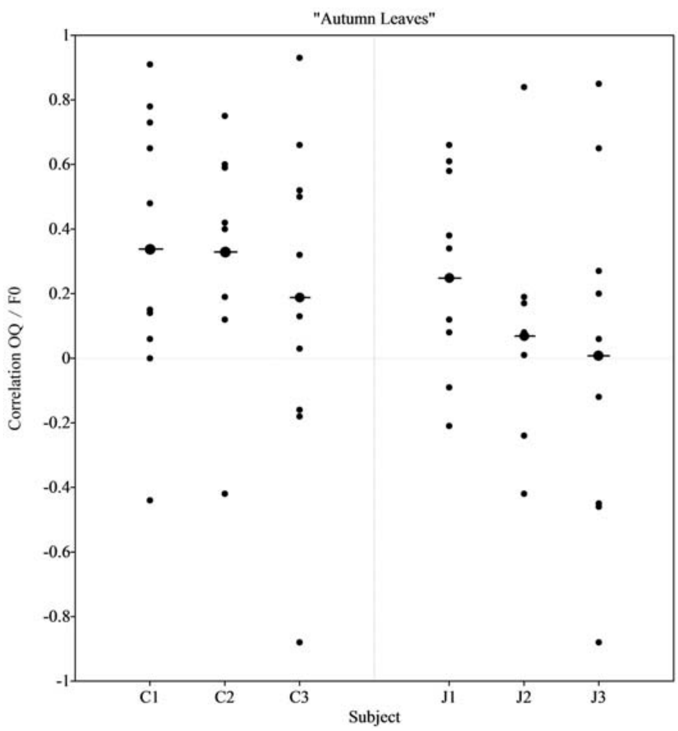

Figure 5.11 Correlation coefficients, "Autumn Leaves"

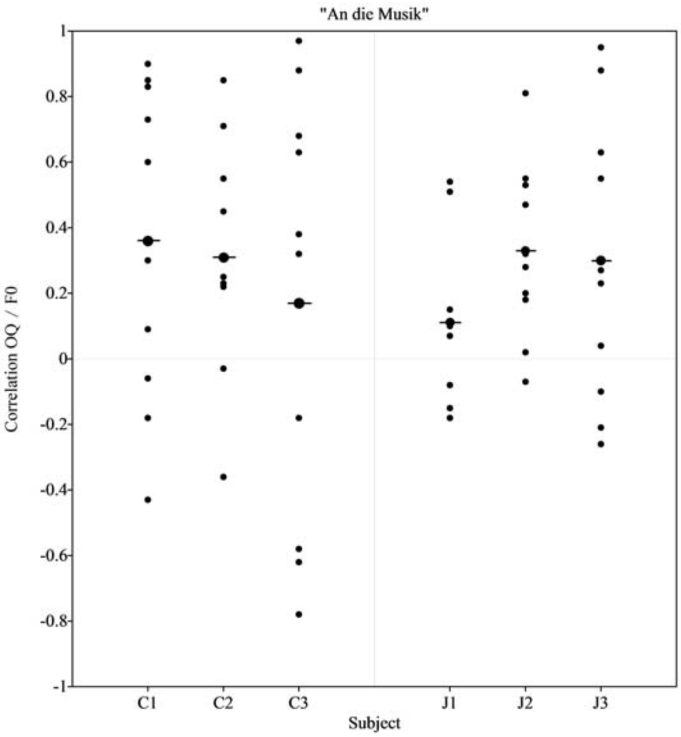

Figure 5.12 Correlation coefficients, "An die Musik"

The average correlation coefficients over all ten notes for each song are stated in table 5.3 along with the minimum and maximum correlation values.

Table 5.3 Average. minimum and maximum correlation values

	„Autumn Leaves"			**„An die Musik"**		
	Correlation OQ/F0			Correlation OQ/F0		
	Avr.	Min.	Max.	Avr.	Min.	Max.
C1	0.34	-0.44	0.91	0.36	-0.43	0.9
C2	0.33	-0.42	0.75	0.31	-0.36	0.85
C3	0.19	-0.88	0.93	0.17	-0.78	0.97
J1	0.25	-0.21	0.66	0.11	-0.18	0.54
J2	0.07	-0.42	0.84	0.33	-0.07	0.81
J3	0.01	-0.88	0.85	0.3	-0.26	0.95

On average, both subject groups show very slight positive correlations between OQ and pitch. The classical singers show an overall average correlation of $p=0.28$ and the jazz singers average correlation is lower with $p=0.18$. However, due to the strong variation of coefficients in our data, these averages might not be particularly significant. However, both subject groups show a slight tendency for positive correlations between OQ and pitch based on the measurement taken within each note.

A t-test between the mean values of both subject groups confirms that the differences are not statistically significant in both songs. A t-test for "Autumn Leaves" resulted in $t=2.03$ and $p=0.11$ and for "An die Musik" in $t=0.37$ and $p=0.73$.

5.3 Open Quotient Analysis Summary

In the song "Autumn Leaves", the jazz singers show a significantly higher OQ on average than the classical singers. In "An die Musik", the jazz singers values are only slightly above those of the classical singers. This leads to the assumption that a higher OQ is typical for jazz singing (and vice versa) and that singers of both groups adjust to the other respective style that is appropriate for the song. Comparing the jazz to the classical singers, it was also found that the differences between the extent of adjustment is not significant. In addition, the jazz singers showed a somewhat higher inter-tone variation of OQ on average compared to the classical singers, which might imply that (similar to their use of vibrato) jazz singers show bigger variation regarding OQ than classical singers.

Thalen and Sundberg (2001) found CQ values to be higher for jazz singers as compared to classical singers but we could not confirm their findings comparing our two subject groups. On the contrary, our data contradict their findings also with regards to their classification of phonation types in different styles of singing.

For the reasons explained in 5.2, our data could not be compared properly to the findings of Howard (1995). However, with one exception, all subjects exposed slight positive correlations between OQ and pitch on average. Here, the classical singers had slightly higher correlations on average than the jazz singers. But since correlations varied strongly between notes for all subjects, these averages may not be particularly representative.

6 Thesis Summary

Aspects that distinguish the jazz singers from the classical singes could be found with regards to vibrato as well as open quotient.

The classical singers showed both higher vibrato rates and extents than the jazz singers and higher inter-tone variations in both songs and those two aspects were found to distinguish both subject groups the most. The classical singers' results concerning vibrato rate are in accordance with the findings of Prame (1994) and the results regarding vibrato extend agree with the data of both Prame (1997) and Howes et al. (2004). It is therefore assumed that lower vibrato rates and as well as extents are characteristic for jazz singing. In addition, a positive correlation between vibrato rate and pitch, as well as a trend for vibrato rate correlating negatively with note duration could only be found for classical singers. Only for the group of classical singers we found deviation from desired pitch to correlate positively with vibrato extent. No significant differences between both subject groups could be found with regards to vibrato onset and offset time, correlation between vibrato rate and note duration, and correlation between vibrato rate and vibrato extent. With the classical singers showing a slightly higher positive correlation, both subject groups showed a positive correlation between vibrato rate and note duration, corresponding to the findings of Prame (1994). Lastly, a trend was found for vibrato rate to correlate positively with vibrato extent, agreeing with a statement made in this respect by Sundberg (1994). As presumed initially, jazz singers showed a greater variability with regards to vibrato than classical singers. Interestingly, jazz singers had lower inter-tone variations regarding both vibrato and open quotient.

As expected, the jazz singers showed higher open quotient values than the classical singers, resulting in a more 'breathy' sound of the jazz singers. This difference was most pronounced with regards to the jazz song. In the classical song, the jazz singers' overall average OQ was only slightly above the overall average of the classical singers. It is therefore assumed that the style of jazz singing is connected to higher OQ values and that the jazz singers adapted a more "classical" style of singing during "An die Musik" by increasing their open quotients. Although all subjects showed slight trends of higher OQ values connected to higher pitches, these trends were not very significant and (due to lack of data) could not fully be compared to the observations of Howard (1995). Comparing our OQ data to the results of Sundberg and Thalen (2001) we can confirm that the jazz singers employ a more 'breathy' phonation mode as compared to the classical singers. However, Sundberg and Thalen measured higher OQ values for the classical singing style which contradicts our findings.

It should be stated that. although it was possible to find numerous aspects that distinguish jazz singing from classical singing, more data and further investigations would be necessary in order to shed more light onto these differences.

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Appendices

Appendix A - Scores of the chosen songs

The notes that were selected for analysis are marked with A1 to A2 for "Autumn Leaves" and M1 to M10 for "An die Musik". The scores contain the accompaniment which was provided to the singers during the recording procedure.

An die Musik

Lyrics: Schober

Music: Franz Schubert


21
Oft hat ein Seuf - zer, dei - ner Harf ent -
26
flos - sen, ein sü - sser, hei - li - ger Ak kord von dir
31
den Him - mel bess - rer Zei - ten mir er schlos - sen, du
35
hol - de Kunst, ich dan - ke dir da - für du hol - de Kunst, ich dan - ke
39
dir!

Appendix B - The PRAAT scripts

Below are the two main Praat scripts that were written in order the measure and analyse the vibrato and open quotient data. Other smaller scripts written for simple repetitive tasks (e.g. creating diagrams) are not included here.

B.1 The script to calculate vibrato

This is the script that measures and calculates the data regarding vibrato. It acts on the sound objects of the notes and their respective annotated TextGrid elements.

```
form Enter filename                                   # ask for the filename of the extracted note
  word Note
endform

note = 'note$'                                        # select the desired pitch of the note
if ((note=3) or (note=7) or (note=8))
  desired_pitch = 440
elsif (note=1)
  desired_pitch = 466.2
elsif (note=2)
  desired_pitch = 261.6
elsif (note=4)
  desired_pitch = 392
elsif (note=5)
  desired_pitch = 247.0
elsif (note=6)
  desired_pitch = 349.2
elsif (note=9)
  desired_pitch = 329.7
elsif (note=10)
  desired_pitch = 293.6
endif

select TextGrid Note_'note$'                          # select the TextGrid object of the note
  tier1$ = Get tier name... 1
  Extract tier... 1                                   # extract the tier marking pitch minima and maxima
Down to TableOfReal (any)                             # count the number of vibratory cycles
  rows_1 = Get number of rows
  cycext_no = (rows_1 - 1) / 2
  a = Get value... rows_1 1
  b = Get value... 1 1
  c = a - b
  cycext_length = (a - b) / cycext_no
rate = round( (1 / cycext_length)*100 ) / 100         # calculate vibrato rate

  i = 1
  while (i <= rows_1)                                 # get positions of pitch minima and maxima
    freq_'i' = Get value... i 1
  i = i + 1
  endwhile

select TextGrid Note_'note$'                          # extract tier marking beginning and end of vibrato phase
  tier2$ = Get tier name... 2
  Extract tier... 2
Down to TableOfReal (any)
  rows_2 = Get number of rows

  i = 1
  while (i <= rows_2)                                 # calculate voiced part of the note
    val_'i' = Get value... i 1
  i = i + 1
  endwhile
```

```
note_duration = (val_'rows_2' - val_1)

if (rows_2 = 2)                                             # calculate vibrato, vibrato onset and offset time
  vibrato_time = note_duration
  onset_time = 0
else
  onset_time = (val_2 - val_1)
  vibrato_time = (val_3 - val_2)
endif

if (rows_2 = 4)
  offset_time = (val_4 - val_3)
  offset_perc = (offset_time * 100) / note_duration
else
  offset_time = 0
  offset_perc = 0
endif

onset_perc = (onset_time * 100) / note_duration             # ...calculate corresponding percentages
vibrato_perc = (vibrato_time * 100) / note_duration

select Sound Note_'note$'                                   # select the sound object of the note
To Pitch... 0 200 1000                                      # ... and create a pitch object
draw_to = Get finishing time
mean_pitch = Get mean... val_1 val_'rows_2' Hertz
mean_pitch = round(mean_pitch*100) / 100                    # calculate mean pitch of the note
#mean_pitch = Get mean... a b Hertz

  step = 1 / (rows_1-1)
  max_extent = 0                                            # calculate vibrato extent values
  min_extent = 1000
  dev_add = 0
  i = 1
  while (i <= rows_1)                                       # for each vibratory cycle...
    pitch = Get value at time... freq_'i' Hertz Linear
    if (pitch < mean_pitch)
      f_low = pitch
      f_high = mean_pitch
    else
      f_low = mean_pitch
      f_high = pitch
    endif
    dev_'i' = 3986.3137 * ( log10(f_high) - log10(f_low) )  # ... calculate vibrato extent
    dev_add = dev_add + dev_'i'
    pos = (step * i) - step
    if (dev_'i' > max_extent)                               # ... get value and position of maximum extent
      max_extent = dev_'i'
      max_pos = pos
    endif
    if (dev_'i' < min_extent)                               # ... get value and position of minimum extent
      min_extent = dev_'i'
      min_pos = pos
    endif
  i = i + 1
  endwhile                                                  # go to next vibratory cycle

extent = round ((dev_add / rows_1)*100) / 100               # calculate average vibrato extent
max_extent = round(max_extent*100) / 100
min_extent = round(min_extent*100) / 100
difference = round ((max_extent - min_extent) * 100) / 100  # calculate difference between min and max extent
max_pos = round(max_pos*100) / 100
min_pos = round(min_pos*100) / 100

deviation = 3986.3137 * ( log10(mean_pitch) -               # calculate deviation from desired pitch
log10(desired_pitch) )
deviation = round(deviation*100) / 100

Erase all
Draw... 0 0 200 700 yes
Draw line... 0 mean_pitch draw_to mean_pitch                # draw a pitch contour for a visual check
pause This is the visual check...

select TextTier 'tier1$'
plus TableOfReal 'tier1$'
plus TextTier 'tier2$'
plus TableOfReal 'tier2$'
plus Pitch Note_'note$'
```

```
Remove                                            # delete created objects

fig_1 = round(note_duration*100) / 100            # round values
fig_2 = round(onset_time*100) / 100
fig_3 = round(vibrato_time*100) / 100
fig_4 = round(offset_time*100) / 100
fig_5 = round(onset_perc*10) / 10
fig_6 = round(vibrato_perc*10) / 10
fig_7 = round(offset_perc*10) / 10
fig_8 = rate
fig_9 = cycext_no
fig_10 = extent
fig_11 = max_extent
fig_12 = min_extent
fig_13 = min_pos
fig_14 = max_pos
fig_15 = difference
fig_16 = mean_pitch
fig_17 = desired_pitch
fig_18 = deviation

select TableOfReal TableOfReal                    # store values in TableOfReal object
note = 'note$'
i = 1
while (i <= 18)
   Set value... i note fig_'i'
i = i + 1
endwhile
Erase all
Draw as numbers... 1 0 free 5

## end of script
```

B.2 The script to calculate the open quotient

This is the script that measures and calculates the data regarding open quotient. It acts on the EGG signals recorded for each note.

```
form Enter filename                                                    # ask for name of files
  word Filename
endform

nn = 1
while (nn <= 10)                                                       # for each note ...

Read from file... C:\Dokumente und                                       # read the respective file
Einstellungen\Florian\Desktop\Opening Quotient\All Single
Notes\'filename$'_'nn'.wav
select Sound 'Filename$'_'nn'

To Pitch... 0 75 800                                                     # create a pitch object
meanP = Get mean... 0 0 Hertz                                            # calculate mean pitch
Remove                                                                   # remove pitch object

select Sound 'Filename$'_'nn'                                            # select sound file again
To PointProcess (periodic, peaks)... 75 800 no yes                       # find periodic minima
number = Get number of points                                            # count periodic minima
a = Get time from index... 1
b = Get time from index... number
file_duration = b - a                                                    # calculate duration of periodic part

total_time = 0                                                           # set variables for open and total time to zero
open_time = 0
i = 1
while i < number                                                         # for each periodic cycle ...
  ip = i + 1

  select PointProcess 'Filename$'_'nn'
  beg = Get time from index... i                                                 # get its beginning and end point
  end = Get time from index... ip

  select Sound 'filename$'_'nn'                                                  # extract the cycle
  Extract part... beg end Rectangular 1 no

    min = Get minimum... 0 0 Sinc70                                              # set zero vals to 1/4 of peak-to-peak amplitude
    max = Get maximum... 0 0 Sinc70
    diff = abs(min) + abs(max)
    zero = diff*0.25
    addval = (zero - abs(min))*-1
    Add... addval

  To PointProcess (zeroes)... yes yes                                            # find zero crossings
  start = Get starting time
  finish = Get finishing time
     Add point... start
     Add point... finish
  zeroes = Get number of points
  vor = zeroes - 1
  cyc_dur = finish - start

  a = Get time from index... 1                                                   # get positions of zero crossings
  b = Get time from index... 2
  c = Get time from index... vor
  d = Get time from index... zeroes

  Remove
  select Sound 'filename$'_'nn'_part
  Remove                                                                         # remove PointProcess and cycle objects

  tot_op = (b - a) + (d - c)                                                     # calculate OQ of cycle
```

```
oq_cycle'i' = (tot_op / cyc_dur) * 100                              # store OQ value in array
   open_time = open_time + tot_op                                   # add values to open and total time
   total_time = total_time + cyc_dur

   i = i + 1
endwhile                                                       # jump to next OQ cycle

oq_mean = (open_time / total_time) * 100                       # calculate mean OQ of note

oq_max = 0                                                     # find min and max OQ values of note
oq_min = 100
n = number - 1
sigma = 0
oq_add = 0
k = 1
while (k < number)
    oq_dummy = oq_cycle'k'
    sigma = sigma + ((oq_mean - oq_dummy) * (oq_mean -
oq_dummy))
    if (oq_dummy > oq_max)
       oq_max = oq_dummy
    endif
    if (oq_dummy < oq_min)
       oq_min = oq_dummy
    endif
k = k + 1
endwhile

n_dummy = 1 / (n-1)                                            # calculate standard deviation (SD) of OQ for the note
std_dev = sqrt (n_dummy * sigma)
oben = oq_mean + std_dev
oben2 = oq_mean + (std_dev*2)
unten = oq_mean - std_dev
unten2 = oq_mean - (std_dev*2)

n_1std = 0                                                     # count number of values outside SD and SD*2
n_2std = 0
oq_sum = 0
i = 1
k = 1
while (k < number)
   oq_s = oq_cycle'k'
   if ((oq_s < oben) and (oq_s > unten))
      n_1std = n_1std + 1
      n_2std = n_2std + 1
         oq_sum = oq_sum + oq_s
         i = i + 1
   elsif ((oq_s < oben2) and (oq_s > unten2))
      n_2std = n_2std + 1
         oq_sum = oq_sum + oq_s
         i = i + 1
   endif
k = k + 1
endwhile

oq_excl = oq_sum / i                                           # round values
p_1std = (100 * n_1std) / n
p_2std = (100 * n_2std) / n

oq_mean = round(oq_mean*100) / 100
oq_excl = round(oq_excl*100) / 100
std_dev = round(std_dev*100) / 100
oq_max = round(oq_max*100) / 100
oq_min = round(oq_min*100) / 100
total_time = round(total_time*100) / 100
p_1std = round(p_1std*10) / 10
p_2std = round(p_2std*10) / 10
meanP = round(meanP*10) / 10

select TableOfReal TableOfReal                                 # store values in TableOfReal Object
Set value... 1 nn oq_mean
Set value... 2 nn std_dev
Set value... 3 nn oq_max
Set value... 4 nn oq_min
Set value... 5 nn total_time
Set value... 6 nn n
Set value... 7 nn meanP
```

```
Set value... 8 nn p_1std
Set value... 9 nn p_2std
Set value... 10 nn oq_excl

nn=nn+1
endwhile                                  # jump to next note

## end of script
```

Appendix C - TableOfReal objects

This section presents all TableOfReal (ToR) objects created with Praat. For each singer and song, one ToR holds the vibrato data and another one holds the open quotient data. All analysis is based on this data.

C.1 Vibrato data

Table C1 Abbreviations

Vibrato data measured for each singer and note	
Dur_[s]	Note duration (voiced part)
OnsT[s]	Vibrato onset time (time between start of note and start of vibrato)
VibT[s]	Vibrato time (duration of the part of note sung with vibrato)
OfsT[s]	Vibrato offset time (time between end of vibrato and end of note)
OnsP[%]	Vibrato onset time percentage in relation to note duration
VibP[%]	Vibrato time percentage in relation to note duration
OfsP[%]	Vibrato offset time percentage in relation to note duration
Rat[Hz]	Vibrato rate, number of full vibratory cycles per second
NumCycl	Number of cycles identified and measured for that note
Ext[Ct]	Average vibrato extent (measured as the average distance between vibratory peaks/troughs and mean pitch)
EMa[Ct]	Maximum vibrato extent for that note
EMi[Ct]	Minimum vibrato extent for that note
MinPosn[s]	Position of minimum vibrato extent, measured in seconds from start of note
MaxPosn[s]	Position of maximum vibrato extent, measured in seconds from start of note
MtM[Ct]	Difference between minimum and maximum vibrato extent
MnP[Hz]	Mean pitch calculated for that note
DsP[Hz]	Desired pitch of the note according to provided accompaniment
Dev[Ct]	Deviation of sung mean pitch from desired pitch

Table C2 Subject C1, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	2.08	0.38	0.96	2.1	0.42	1.83	0.81	1.15	0.52	2.32
OnsT[s]	0.15	0	0	0.3	0	0	0	0.11	0	0
VibT[s]	1.93	0	0.96	1.8	0	1.83	0.81	1.04	0.52	2.32
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	7	0	0	14.3	0	0	0	9.8	0	0
VibP[%]	93	0	100	85.7	0	100	100	90.2	100	100
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.12	0	6.7	6.1	0	6.13	6.4	6.39	7.06	5.74
NumCycl	11.5	0	5.5	10.5	0	11	5	6.5	3	12.5
Ext[Ct]	67	0	37.75	57.09	0	61.13	49.53	48.67	25.77	63.25
EMa[Ct]	97.49	0	61.01	83.89	0	117.76	75.67	68.26	51.69	107.57
EMi[Ct}	13.1	0	7.4	20.01	0	11.22	15.62	17.83	1.59	14.38
MinPosn	0	0	0.09	0.95	0	0.09	0	0	1	0.08
MaxPosn	0.35	0	0.55	0.81	0	0.05	0.7	0.46	0	0.96
MtM[Ct]	84.39	0	53.61	63.88	0	106.54	60.05	50.43	50.1	93.19
MnP[Hz]	463.43	258.12	439.86	393.48	245.37	351.6	439.67	440.15	329.63	292.14
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	-10.32	-23.19	-0.55	6.52	-11.45	11.86	-1.3	0.59	-0.37	-8.63

Table C3 Subject C1, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.62	1.5	0.64	0.69	0.77	0.69	0.62	1.13	1.21	1.22
OnsT[s]	0.14	0.15	0.19	0	0	0	0.2	0.21	0	0.15
VibT[s]	0.49	1.35	0.45	0.69	0.77	0.69	0.42	0.92	1.21	1.07
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	21.7	9.9	29.4	0	0	0	32.3	18.8	0	12.1
VibP[%]	78.3	90.1	70.6	100	100	100	67.7	81.2	100	87.9
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.46	6.21	7.22	6.38	6.02	6.67	6.45	6.01	5.97	6.16
NumCycl	3	8	2.5	3	3.5	4	2.5	5.5	6.5	6.5
Ext[Ct]	63.56	72.68	57.62	64.7	92.37	62.19	79.11	113.54	105.83	107.13
EMa[Ct]	87.88	111.57	97.68	97.23	121.98	101.08	108	203.03	147.28	143.59
EMi[Ct}	23.92	3.78	8.53	6.86	53.9	14	51	47.78	43.58	56.76
MinPosn	0	0.94	1	0	0	0.25	1	0	0	1
MaxPosn	0.5	0.56	0.4	0.5	0.71	0.5	0.4	1	0.23	0.69
MtM[Ct]	63.96	107.79	89.15	90.37	68.08	87.08	57	155.25	103.7	86.83
MnP[Hz]	593.53	366.66	489.84	362.96	285.28	437.07	493.85	273.45	284.95	362.56
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	18.27	-15.7	-14.29	-33.26	-49.77	-11.57	-0.18	-23.58	-51.77	-35.17

Table C4 Subject C2, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	2.29	0.23	0.87	2.33	0.5	1.96	0.92	1.09	0.49	2.06
OnsT[s]	0.43	0	0.13	0.54	0	0.41	0.27	0.44	0	0.59
VibT[s]	1.86	0	0.74	1.79	0	1.55	0.66	0.65	0	1.47
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	18.8	0	15.4	23.1	0	20.9	28.8	40.3	0	28.8
VibP[%]	81.2	0	84.6	76.9	0	79.1	71.2	59.7	0	71.2
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.19	0	6.7	6.05	0	6.24	6.39	6.38	0	5.97
NumCycl	11	0	4.5	10	0	9.5	4	4	0	8
Ext[Ct]	85.96	0	30.22	70.18	0	77.69	68.24	61.11	0	45.97
EMa[Ct]	155.49	0	68.11	113.49	0	125.99	117.03	83.92	0	88.33
EMi[Ct}	12.89	0	7.93	17.94	0	20.46	32.38	40.09	0	20.85
MinPosn	0	0	1	0.95	0	0.95	0	0	0	0.44
MaxPosn	0.64	0	0.56	0.15	0	0.21	0.63	0.38	0	0.75
MtM[Ct]	142.6	0	60.18	95.55	0	105.53	84.65	43.83	0	67.48
MnP[Hz]	461.33	266.47	439	390.5	243.96	346	440.19	442.76	333.71	293.88
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	-18.18	31.96	-3.94	-6.64	-21.43	-15.94	0.75	10.83	20.93	1.65

Table C5 Subject C2, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.53	1.89	0.72	0.6	0.76	0.65	0.46	1.06	0.98	1.51
OnsT[s]	0	0.25	0.14	0	0	0.12	0	0.42	0	0.17
VibT[s]	0.53	1.64	0.37	0.6	0.76	0.53	0	0.64	0.98	1.34
OfsT[s]	0	0	0.21	0	0	0	0	0	0	0
OnsP[%]	0	13.1	19.1	0	0	19	0	39.5	0	11.2
VibP[%]	100	86.9	51.9	100	100	81	0	60.5	100	88.8
OfsP[%]	0	0	29	0	0	0	0	0	0	0
Rat[Hz]	7.13	5.95	6.7	7.36	6.41	6.73	0	5.96	5.85	5.96
NumCycl	3	9.5	2.5	3.5	4	3.5	0	3.5	4.5	8
Ext[Ct]	56.94	92.55	67.26	40.42	45.98	79.81	0	86.16	82.76	62.12
EMa[Ct]	92.4	148.19	120.7	71.55	78.46	100.31	0	123.11	138.21	90.71
EMi[Ct}	8.46	14.33	7.9	7.52	0.47	49.16	0	7.48	32.82	11.88
MinPosn	0.17	0	0	1	0.75	0	0	1	0.11	0
MaxPosn	0.83	0.53	0.8	0.57	0.38	0.43	0	0.57	0.44	0.19
MtM[Ct]	83.94	133.86	112.8	64.03	77.99	51.15	0	115.63	105.39	78.83
MnP[Hz]	593.72	372.16	494.3	370.43	292.91	447.42	493.02	276.52	286.6	368.69
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	18.82	10.08	1.4	2.01	-4.07	28.95	-3.08	-4.25	-41.78	-6.14

Table C6 Subject C3, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	2.02	0.12	0.73	2.46	0.51	2.04	0.91	0.94	0.39	1.81
OnsT[s]	0.79	0	0	1.52	0	1.14	0.54	0.48	0	0.72
VibT[s]	1.23	0	0	0.94	0	0.9	0.36	0.45	0	1.09
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	39	0	0	61.8	0	55.9	60	51.6	0	39.7
VibP[%]	61	0	0	38.2	0	44.1	40	48.4	0	60.3
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.1	0	0	5.85	0	5.9	7.3	6.07	0	5.89
NumCycl	7.5	0	0	5	0	4.5	2.5	2.5	0	6
Ext[Ct]	90.2	0	0	48.32	0	41.9	58.09	79.06	0	69.17
EMa[Ct]	149.85	0	0	75.97	0	96.7	92.68	117.36	0	134.42
EMi[Ct}	34.91	0	0	30.59	0	8.94	24.95	25.13	0	42.51
MinPosn	0	0	0	1	0	1	0.6	0	0	0.33
MaxPosn	1	0	0	0.6	0	0.67	0.4	0.4	0	0.25
MtM[Ct]	114.94	0	0	45.38	0	87.76	67.73	92.23	0	91.91
MnP[Hz]	457.47	269.07	435.48	387.51	250.11	344.06	426.71	431.44	310.06	290.36
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	-32.73	48.72	-17.87	-19.94	21.64	-25.67	-53.1	-34.01	-106.33	-19.21

Table C7 Subject C3, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.56	1.68	0.44	0.65	1.13	0.57	0.61	1.09	0.91	1.07
OnsT[s]	0	0.9	0	0	0.25	0	0	0.52	0.37	0.42
VibT[s]	0.56	0.78	0	0.65	0.52	0	0.61	0.56	0.54	0.65
OfsT[s]	0	0	0	0	0.36	0	0	0	0	0
OnsP[%]	0	53.7	0	0	22.4	0	0	48.2	40.3	39.4
VibP[%]	100	46.3	0	100	45.8	0	100	51.8	59.7	60.6
OfsP[%]	0	0	0	0	31.7	0	0	0	0	0
Rat[Hz]	6.63	6.43	0	6.04	5.81	0	6.94	5.96	5.95	6.97
NumCycl	3	5	0	3	3	0	4	3	3	4.5
Ext[Ct]	89.92	82.54	0	82.04	96.03	0	93.75	78.54	82.83	102.53
EMa[Ct]	169.78	161.68	0	119.34	126.49	0	158.16	111.16	127.6	201.17
EMi[Ct}	43.34	25.7	0	54.59	41.98	0	26.43	41.08	37.81	44.86
MinPosn	1	0.8	0	0	0	0	1	1	1	0.22
MaxPosn	0.83	0.5	0	0.33	0.83	0	0.38	0.5	0.67	0.56
MtM[Ct]	126.44	135.98	0	64.75	84.51	0	131.73	70.08	89.79	156.31
MnP[Hz]	571.03	361.63	487.7	366.42	288.44	429.38	487.74	277.35	289.22	358.15
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	-48.64	-39.61	-21.87	-16.83	-30.7	-42.32	-21.73	0.94	-26.02	-56.35

Table C8 Subject J1, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	2.52	0.12	0.26	1.86	0.25	2.85	0.23	2.55	0.4	2.15
OnsT[s]	1.59	0	0	0	0	1.93	0	1.75	0	1.11
VibT[s]	0.93	0	0	1.86	0	0.93	0	0.8	0	1.04
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	63	0	0	0	0	67.5	0	68.5	0	51.5
VibP[%]	37	0	0	100	0	32.5	0	31.5	0	48.5
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	4.57	0	0	4.81	0	5.26	0	5.23	0	4.67
NumCycl	4	0	0	8	0	4.5	0	4	0	4.5
Ext[Ct]	32.01	0	0	45.71	0	51.5	0	64.89	0	50.39
EMa[Ct]	64.38	0	0	84.83	0	92.55	0	130.2	0	106.55
EMi[Ct}	3.61	0	0	4.76	0	13.72	0	21.67	0	18.4
MinPosn	0.25	0	0	0.06	0	0.56	0	0.75	0	0
MaxPosn	1	0	0	0.94	0	0.89	0	0.88	0	1
MtM[Ct]	60.77	0	0	80.07	0	78.83	0	108.53	0	88.15
MnP[Hz]	465.09	251.97	434.67	382.51	429.93	346.9	419.87	433.55	334.32	291.58
DsP[Hz]	466.2	261.6	440	392	440	349.2	440	440	329.7	293.6
Dev[Ct]	-4.13	-64.95	-21.09	-42.43	-40.08	-11.44	-81.07	-25.57	24.08	-11.95

Table C9 Subject J1, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.54	1.7	0.54	0.58	0.6	0.57	0.51	0.96	0.92	0.92
OnsT[s]	0	0.7	0	0	0	0	0	0	0.33	0.5
VibT[s]	0	0.67	0	0	0	0	0	0	0.46	0.41
OfsT[s]	0	0.33	0	0	0	0	0	0	0.14	0
OnsP[%]	0	40.9	0	0	0	0	0	0	35.4	55.1
VibP[%]	0	39.4	0	0	0	0	0	0	49.9	44.9
OfsP[%]	0	19.6	0	0	0	0	0	0	14.7	0
Rat[Hz]	0	5.21	0	0	0	0	0	0	5.43	5.61
NumCycl	0	3.5	0	0	0	0	0	0	2.5	2
Ext[Ct]	0	21.93	0	0	0	0	0	0	32.2	18.13
EMa[Ct]	0	44.5	0	0	0	0	0	0	62	28.27
EMi[Ct}	0	13.52	0	0	0	0	0	0	1.86	10.83
MinPosn	0	0.43	0	0	0	0	0	0	0.2	1
MaxPosn	0	0.29	0	0	0	0	0	0	0.4	0.75
MtM[Ct]	0	30.98	0	0	0	0	0	0	60.14	17.44
MnP[Hz]	582.73	365.02	492.34	363.89	285.59	437.58	494.68	277.42	293.71	368.79
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	-13.54	-23.46	-5.47	-28.82	-47.9	-9.56	2.74	1.4	0.65	-5.67

Table C10 Subject J2, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	1.9	0.16	0.19	1.86	0.48	1.98	0.11	0.96	0.45	1.77
OnsT[s]	0.91	0	0	0.78	0	1.04	0	0	0	0
VibT[s]	0.99	0	0	1.08	0	0.93	0	0.96	0	1.77
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	48	0	0	42	0	52.8	0	0	0	0
VibP[%]	52	0	0	58	0	47.2	0	100	0	100
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.07	0	0	5.34	0	5.71	0	5.6	0	5.35
NumCycl	6	0	0	5.5	0	5	0	4.5	0	9
Ext[Ct]	29.06	0	0	37.51	0	30.09	0	34.32	0	46.94
EMa[Ct]	62.04	0	0	82.64	0	63.5	0	59.82	0	98.45
EMi[Ct}	6.34	0	0	9.01	0	9.17	0	6.42	0	7.52
MinPosn	0.08	0	0	0.09	0	0.3	0	0.56	0	0
MaxPosn	0.58	0	0	1	0	1	0	0.89	0	0.72
MtM[Ct]	55.7	0	0	73.63	0	54.33	0	53.4	0	90.93
MnP[Hz]	468.86	253.06	427.06	391.23	248.17	344.9	460.19	442.3	331.7	291.23
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	9.85	-57.49	-51.67	-3.4	8.16	-21.45	77.68	9.03	10.46	-14.03

Table C11 Subject J2, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.26	1.68	0.55	0.64	1.36	0.62	0.42	1	1.01	1.53
OnsT[s]	0	0	0	0.28	0	0	0.13	0.44	0.12	0
VibT[s]	0	1.68	0.55	0.36	1.36	0.62	0.29	0.56	0.7	1.53
OfsT[s]	0	0	0	0	0	0	0	0	0.19	0
OnsP[%]	0	0	0	44	0	0	31.3	44	11.5	0
VibP[%]	0	100	100	56	100	100	68.7	56	69.4	100
OfsP[%]	0	0	0	0	0	0	0	0	19.1	0
Rat[Hz]	0	5.53	6.02	6.06	5.4	5.89	5.71	6.06	5.73	5.06
NumCycl	0	9	2.5	1.5	7	3	1.5	3	4	7.5
Ext[Ct]	0	44.2	27.47	31.49	58.23	27.57	26.37	33.25	33.13	30.52
EMa[Ct]	0	117.08	41.98	40.67	105.37	46.66	43.07	57.42	62.7	72.78
EMi[Ct}	0	1.62	4.37	22.54	16.63	5.71	9.16	13.81	10.11	15.09
MinPosn	0	0.17	0.8	0	0	0	0.33	1	0.88	0.27
MaxPosn	0	0.94	0	1	0.64	1	1	0.17	0.38	0.93
MtM[Ct]	0	115.46	37.61	18.13	88.74	40.95	33.91	43.61	52.59	57.69
MnP[Hz]	581.71	365.66	484.86	372.37	293.62	439.49	494.65	279.57	293.6	369.95
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	-16.56	-20.43	-31.98	11.05	0.12	-2.01	2.63	14.74	0	-0.23

Table C12 Subject J3, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	1.46	0.29	0.41	1.34	0.22	1.58	0.12	0.97	0.74	1.44
OnsT[s]	0.48	0	0	0.21	0	0.72	0	0	0	0.18
VibT[s]	0.98	0	0	0.78	0	0.86	0	0	0.74	1.26
OfsT[s]	0	0	0	0.35	0	0	0	0	0	0
OnsP[%]	33	0	0	15.7	0	45.5	0	0	0	12.4
VibP[%]	67	0	0	57.9	0	54.5	0	0	100	87.6
OfsP[%]	0	0	0	26.3	0	0	0	0	0	0
Rat[Hz]	4.88	0	0	5.14	0	4.95	0	0	5.23	4.92
NumCycl	4.5	0	0	4	0	4	0	0	3.5	6
Ext[Ct]	21.99	0	0	14.67	0	39.37	0	0	27.58	34.91
EMa[Ct]	38.52	0	0	34.68	0	89.64	0	0	46.94	55.42
EMi[Ct}	8.35	0	0	1.9	0	5.76	0	0	1.38	10.85
MinPosn	0.78	0	0	1	0	1	0	0	1	0.75
MaxPosn	0.89	0	0	0.88	0	0.88	0	0	0.14	0.83
MtM[Ct]	30.17	0	0	32.78	0	83.88	0	0	45.56	44.57
MnP[Hz]	464.49	262.85	420.5	389.05	245.08	343.45	448.29	435.38	336.51	289
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	-6.36	8.22	-78.49	-13.08	-13.5	-28.74	32.3	-18.28	35.39	-27.34

Table C13 Subject J3, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.48	1.34	0.55	0.48	0.88	0.61	0.55	0.95	0.57	0.82
OnsT[s]	0	0	0	0	0	0	0	0.26	0	0.27
VibT[s]	0	1.34	0	0	0.88	0	0	0.69	0	0.54
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	0	0	0	0	0	0	0	27.1	0	33.5
VibP[%]	0	100	0	0	100	0	0	72.9	0	66.5
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	0	4.49	0	0	4.52	0	0	4.61	0	4.61
NumCycl	0	5.5	0	0	3.5	0	0	3	0	2.5
Ext[Ct]	0	38.64	0	0	36.61	0	0	26.54	0	19.05
EMa[Ct]	0	59.4	0	0	58.97	0	0	48.96	0	31.15
EMi[Ct}	0	22.87	0	0	9.44	0	0	10.56	0	4.03
MinPosn	0	0	0	0	0.29	0	0	0.33	0	0.6
MaxPosn	0	0.09	0	0	0.57	0	0	0.5	0	0
MtM[Ct]	0	36.53	0	0	49.53	0	0	38.4	0	27.12
MnP[Hz]	585.18	369.19	497.61	373.06	292.95	431.07	492.24	279	293.2	372.23
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	-6.25	-3.79	12.95	14.28	-3.84	-35.48	-5.83	11.21	-2.35	10.4

C.2 Open quotient data

Table C14 Abbreviations

Open Quotient data measured for each singer and note	
OQ	Average open quotient of entire note
StdDev	Standard deviation of the OQ based on single cycles
OQmax	Maximum OQ value within the note
OQmin	Minimum OQ value within the note
Dur[s]	Duration of section that was interpretable
NumCyc	Number of OQ cycles analysed within the note
Pitch[Hz]	Mean pitch of the analysed section
ViSD[%]	Percentage of OQ values within standard deviation
ViSD2[%]	Percentage of OQ values within double standard deviation
OQxcl	Number of OQ values outside double standard deviation

Table C15 Subject C1, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	14.62	28.11	13.74	15.87	18.42	12.04	14.05	14.95	11.07	24.63
StdDev	2.15	7.32	1.17	2.51	1.05	2.13	0.94	1.81	1.29	5.02
OQmax	21.98	43.73	16.51	21.61	21.15	35.51	16.19	20.66	14.64	34.36
OQmin	6.9	9.99	10.73	9.58	15.72	5.34	11.6	9.24	8.34	10.56
Dur[s]	0.97	0.36	0.48	1.64	0.55	1.11	0.58	0.95	0.57	2.18
NumCyc	449	94	212	647	135	393	253	418	189	636
Pitch[Hz]	461.9	258	438.8	393.5	245.5	353.9	438.7	439.5	331	292.1
ViSD[%]	72.6	71.3	70.8	64	71.1	83.7	67.6	73.9	69.3	64.2
ViSD2[%]	94.4	94.7	93.4	97.7	94.8	95.9	95.7	93.3	94.7	97.3
OQxcl	14.6	28.44	13.82	15.85	18.19	12.13	13.98	14.87	10.96	24.92

Table C16 Subject C1, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	15.76	15.92	15.42	16.4	24.29	17.63	18.42	26.2	27.7	21.03
StdDev	1.16	1.95	1.16	1.98	2.64	1.27	1.9	3.47	3.78	4.68
OQmax	17.65	20.09	16.62	20.62	34.35	20.15	22.58	32.42	43.91	29.6
OQmin	8.44	12.47	12.38	12.12	14.98	15.09	14	16.78	17.11	10.35
Dur[s]	0.71	1.25	0.16	0.71	0.74	0.43	0.55	1.12	1.21	1.14
NumCyc	420	459	79	257	211	188	269	306	344	416
Pitch[Hz]	594.5	367.2	485.5	362.7	285	439.6	492.9	273	284.7	363.7
ViSD[%]	80.2	58.4	79.7	58.4	69.2	61.7	66.9	65	70.9	57.5
ViSD2[%]	95.5	99.3	93.7	97.7	96.2	100	95.5	98	95.3	99.5
OQxcl	15.89	15.9	15.41	16.37	24.25	17.57	18.4	26.21	27.76	21.2

Table C17 Subject C2, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	16.68	13.33	14.45	19.08	20.26	16.95	17.08	16.21	13.94	14.26
StdDev	4.32	0.46	2.06	2.65	1.39	1.17	3	2.71	0.44	1.96
OQmax	27.73	14.41	19.66	26.04	28.39	20.05	22.66	21.96	14.98	18.95
OQmin	10.66	12.41	11.57	13.17	15.62	13.54	11.74	10.9	13.01	5.23
Dur[s]	2.18	0.21	1.15	2.4	0.58	2.07	0.83	1.06	0.56	2.02
NumCyc	1005	55	507	936	140	715	367	468	185	593
Pitch[Hz]	461.3	266.5	439	389.6	242.6	344.9	440.1	442.2	332.5	294
ViSD[%]	65.6	69.1	62.7	64.1	78.6	67.3	60.2	64.5	67.6	75.4
ViSD2[%]	95.1	98.2	96.8	98.2	97.1	96.5	100	99.6	96.2	93.8
OQxcl	16.27	13.07	14.31	19.04	20.03	16.94	17.06	16.16	13.84	14.38

Table C18 Subject C2, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	16.16	14.77	16.7	15.35	13.36	15.72	16.19	14.43	14.7	15.5
StdDev	1.09	0.97	2.31	1.38	0.65	1.54	2.26	1.17	1.38	1.02
OQmax	18.8	17.09	22.9	17.13	14.48	18.39	19	16.11	16.97	18.18
OQmin	13.69	11.76	13.07	11.33	11.11	12.54	11.96	10.41	11.03	12.58
Dur[s]	0.5	1.66	0.61	0.62	0.67	0.49	0.44	1.09	1.01	1.47
NumCyc	298	616	303	230	195	220	218	302	288	540
Pitch[Hz]	591.5	371.8	496.9	370	292.8	446.6	494.8	276.5	286.2	368.5
ViSD[%]	62.8	63.1	69	72.2	74.4	59.5	60.6	69.5	67.7	71.9
ViSD2[%]	97.7	97.1	93.7	94.3	94.9	99.5	100	94.7	94.4	93.9
OQxcl	16.07	14.8	16.35	15.5	13.38	15.69	16.1	14.55	14.86	15.58

Table C19 Subject C3, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	29.91	18.83	16.45	14.71	10.7	13.64	17.01	16.87	11.72	11.16
StdDev	3.06	8.67	2.52	1.17	1.89	1.01	3.72	1.92	1.2	0.74
OQmax	39.92	34.79	22.07	20.85	16.05	17.28	25.63	22.3	15.69	13.75
OQmin	20.35	9.77	9.98	10.93	8.04	10.96	9.9	13.85	9.12	9.54
Dur[s]	0.71	0.21	0.31	1.86	0.56	1.82	0.73	0.43	0.53	0.74
NumCyc	325	53	122	721	140	625	310	186	164	215
Pitch[Hz]	459.5	257.4	393.9	387.9	250.3	344.3	426.4	432.1	312	291.5
ViSD[%]	72.6	66	82	80	79.3	74.2	60.3	66.7	73.8	70.7
ViSD2[%]	92.9	100	92.6	93.3	92.9	93.6	96.1	95.7	93.9	94.9
OQxcl	29.69	17.86	16.96	14.58	10.28	13.57	16.62	16.56	11.5	11.03

Table C20 Subject C3, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	34.43	13.8	16.08	12.68	16.94	15.06	19.21	9.86	40.57	18.49
StdDev	2.24	1.73	2.43	0.99	4.12	1.03	4.96	0.97	11.85	4.68
OQmax	43.32	19.01	20.16	14.92	29.91	17.16	34.39	13.8	60.92	27.4
OQmin	27.71	11.89	12.24	10.99	9.53	12.94	15.75	8.08	6.47	8.85
Dur[s]	0.42	0.95	0.34	0.54	0.3	0.44	0.2	0.96	1.11	0.92
NumCyc	244	348	166	197	94	189	92	268	306	328
Pitch[Hz]	582.1	365.4	484.2	367.4	312	430	452.1	278.3	275.3	357.7
ViSD[%]	75.4	77.6	57.8	59.9	60.6	64	83.7	77.6	67.6	52.1
ViSD2[%]	93.4	94.5	100	97	98.9	97.4	89.1	93.3	93.1	99.7
OQxcl	34.27	13.53	15.96	12.58	16.7	14.96	17.88	9.65	43.69	18.31

Table C21 Subject J1, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	21.8	0	29.04	24.85	30.82	27.56	24.99	32.84	19.82	20.04
StdDev	2.8	0	3.52	4.73	5.06	6.64	3.96	5.5	2.86	5.42
OQmax	32.99	0	39.38	42.14	47.87	48.32	39.02	51.34	28.68	37.63
OQmin	13.76	0	22.4	13.88	17.32	8.99	17.98	18.82	14.22	9.5
Dur[s]	2.15	0	0.27	1.09	0.45	1.84	0.17	1.75	0.32	1.72
NumCyc	1000	0	116	411	184	640	72	767	108	504
Pitch[Hz]	466	0	430.4	376.8	408.7	348.6	418.2	438.1	335	293.2
ViSD[%]	71.2	0	66.4	67.2	69	67.2	72.2	69.1	70.4	64.1
ViSD2[%]	95.4	0	96.6	95.9	95.1	96.6	97.2	95.4	94.4	96.4
OQxcl	21.63	0	28.47	24.35	30.63	27.32	24.33	32.21	19.13	19.42

Table C22 Subject J1, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	34.43	20.68	24.46	16.93	0	25.01	24.24	15.88	22.16	19.66
StdDev	2.24	3.41	2.81	3.5	0	4.03	2.26	3.26	4.24	5.45
OQmax	43.32	35.26	31.56	27.87	0	36.85	30.6	24.36	33.68	34.44
OQmin	27.71	12.15	11.89	9.36	0	11.53	16.41	9.11	12.92	7.61
Dur[s]	0.42	0.94	0.46	0.39	0	0.59	0.4	0.71	0.75	0.7
NumCyc	244	343	227	141	0	258	196	196	221	257
Pitch[Hz]	582.1	365.3	492.5	363.9	0	438.6	493.1	276.7	293.9	368.8
ViSD[%]	75.4	68.2	68.3	67.4	0	70.2	68.4	62.8	65.6	69.6
ViSD2[%]	93.4	95	96	95	0	93.8	95.4	96.9	96.4	95.3
OQxcl	34.27	20.22	24.43	16.52	0	24.85	24.11	15.68	21.63	18.94

Table C23 Subject J2, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	0	44.42	28.1	18.55	0	30.65	24.2	29.77	22.02	29.55
StdDev	0	3.92	3.72	2.15	0	3.49	3.33	5.64	2.53	8.82
OQmax	0	49.35	39.74	24.86	0	39.91	31.51	46.64	26.33	52.21
OQmin	0	37.17	18.13	9.01	0	20.18	16.5	15.2	11.44	10.8
Dur[s]	0	0.15	0.58	1.54	0	1.85	0.08	0.62	0.25	1.32
NumCyc	0	38	252	600	0	632	36	273	82	383
Pitch[Hz]	0	249.9	436.4	389.9	0	342.4	460.4	441.2	332.2	291.2
ViSD[%]	0	60.5	68.3	71.8	0	69.9	66.7	67	79.3	61.4
ViSD2[%]	0	100	94	94.5	0	94.5	94.4	96.3	95.1	97.9
OQxcl	0	43.24	27.96	18.67	0	30.65	23.52	29.2	22.11	29

Table C24 Subject J2, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	29.69	24.33	36.45	17.02	14.88	26.57	23.27	20.68	24.24	20.92
StdDev	3.82	2.66	11.78	1.85	2.47	4.25	4.29	5.94	3.74	2.51
OQmax	42.21	32.28	59.63	22.6	27.05	38.22	31.22	39.7	36.58	31.41
OQmin	18.27	13.55	12.52	12.24	10.48	11.43	15.3	8.36	9.13	13.15
Dur[s]	0.47	0.89	0.5	0.39	0.89	0.75	0.46	0.36	0.83	1.19
NumCyc	276	326	242	144	260	327	226	103	245	438
Pitch[Hz]	586	366.7	481.1	371.4	291.8	437.5	490.8	282.9	294.1	369.2
ViSD[%]	71	70.6	55.4	66	85	70.9	57.5	71.8	72.2	73.5
ViSD2[%]	94.9	95.1	99.6	97.2	95.8	95.7	100	96.1	94.7	95.2
OQxcl	29.4	24.55	36.46	16.91	14.43	26.85	23.16	20.39	24.06	20.73

Table C25 Subject J3, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	36.02	9.6	0	12.56	8.6	13.31	24.97	38	37.15	10.2
StdDev	5.17	2.58	0	1.1	0.58	1.8	5.02	5.9	5.5	2.1
OQmax	40.58	17.64	0	15.82	10.34	19.27	37.5	54.69	54.57	21.24
OQmin	18.06	7.29	0	9.54	7.78	9.29	14.01	16.62	23.32	7.42
Dur[s]	1.65	0.29	0	1.37	0.27	1.31	0.13	0.97	0.77	1.34
NumCyc	763	76	0	530	66	449	59	424	260	386
Pitch[Hz]	461.2	259.9	0	387.7	243.3	344.1	449	436.1	336.4	288.9
ViSD[%]	88.1	88.2	0	67.2	69.7	65.9	71.2	76.2	72.7	86.8
ViSD2[%]	91	90.8	0	95.7	97	96.7	91.5	94.1	94.6	93
OQxcl	37.54	8.68	0	12.48	8.41	13.18	24.68	37.93	36.75	9.7

Table C26 Subject J3, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	25.42	14.48	31.25	13.26	12.38	16.44	20.62	11.42	11.45	15.38
StdDev	0.78	0.84	4.43	0.34	1.06	0.64	2.4	0.92	0.27	1
OQmax	27.34	17.4	37	14.07	14.94	17.65	23.81	16.82	12.11	17.66
OQmin	22.45	13.01	17.07	12.34	10.05	15.15	14.74	10.19	10.77	13.01
Dur[s]	0.47	1.28	0.56	0.5	0.84	0.58	0.64	1.14	0.6	0.81
NumCyc	276	474	276	188	246	249	314	317	176	303
Pitch[Hz]	585.4	369.2	496.6	373.1	294.2	431.3	489	277.1	293.4	372.1
ViSD[%]	70.3	72.2	74.3	64.9	66.3	63.1	73.6	90.2	69.3	65.3
ViSD2[%]	95.3	94.5	94.2	96.3	96.3	99.6	94.6	96.8	95.5	96
OQxcl	25.37	14.33	31.85	13.2	12.28	16.39	20.89	11.24	11.39	15.34

Appendices

Appendix A - Scores of the chosen songs

The notes that were selected for analysis are marked with A1 to A2 for "Autumn Leaves" and M1 to M10 for "An die Musik". The scores contain the accompaniment which was provided to the singers during the recording procedure.

An die Musik

Lyrics: Schober

Music: Franz Schubert


21
Oft hat ein Seuf - zer, dei - ner Harf ent -
26
flos - sen, ein sü - sser, hei - li - ger Ak kord von dir
31
den Him - mel bess - rer_ Zei - ten mir_ er schlos - sen, du
35
hol - de Kunst, ich_ dan - ke dir da - für du hol - de Kunst,_ ich dan - ke
39
dir!

Appendix B - The PRAAT scripts

Below are the two main Praat scripts that were written in order the measure and analyse the vibrato and open quotient data. Other smaller scripts written for simple repetitive tasks (e.g. creating diagrams) are not included here.

B.1 The script to calculate vibrato

This is the script that measures and calculates the data regarding vibrato. It acts on the sound objects of the notes and their respective annotated TextGrid elements.

```
form Enter filename                                  # ask for the filename of the extracted note
  word Note
endform

note = 'note$'                                       # select the desired pitch of the note
if ((note=3) or (note=7) or (note=8))
  desired_pitch = 440
elsif (note=1)
  desired_pitch = 466.2
elsif (note=2)
  desired_pitch = 261.6
elsif (note=4)
  desired_pitch = 392
elsif (note=5)
  desired_pitch = 247.0
elsif (note=6)
  desired_pitch = 349.2
elsif (note=9)
  desired_pitch = 329.7
elsif (note=10)
  desired_pitch = 293.6
endif

select TextGrid Note_'note$'                         # select the TextGrid object of the note
  tier1$ = Get tier name... 1
  Extract tier... 1                                  # extract the tier marking pitch minima and maxima
Down to TableOfReal (any)                            # count the number of vibratory cycles
  rows_1 = Get number of rows
  cycext_no = (rows_1 - 1) / 2
  a = Get value... rows_1 1
  b = Get value... 1 1
  c = a - b
  cycext_length = (a - b) / cycext_no
rate = round( (1 / cycext_length)*100 ) / 100        # calculate vibrato rate

  i = 1
  while (i <= rows_1)                                # get positions of pitch minima and maxima
    freq_'i' = Get value... i 1
  i = i + 1
  endwhile

select TextGrid Note_'note$'                         # extract tier marking beginning and end of vibrato phase
  tier2$ = Get tier name... 2
  Extract tier... 2
Down to TableOfReal (any)
  rows_2 = Get number of rows

  i = 1
  while (i <= rows_2)                                # calculate voiced part of the note
    val_'i' = Get value... i 1
  i = i + 1
  endwhile
```

```
note_duration = (val_'rows_2' - val_1)

if (rows_2 = 2)                                             # calculate vibrato, vibrato onset and offset time
  vibrato_time = note_duration
  onset_time = 0
else
  onset_time = (val_2 - val_1)
  vibrato_time = (val_3 - val_2)
endif

if (rows_2 = 4)
  offset_time = (val_4 - val_3)
  offset_perc = (offset_time * 100) / note_duration
else
  offset_time = 0
  offset_perc = 0
endif

onset_perc = (onset_time * 100) / note_duration             # ...calculate corresponding percentages
vibrato_perc = (vibrato_time * 100) / note_duration

select Sound Note_'note$'                                   # select the sound object of the note
To Pitch... 0 200 1000                                      # ... and create a pitch object
draw_to = Get finishing time
mean_pitch = Get mean... val_1 val_'rows_2' Hertz
mean_pitch = round(mean_pitch*100) / 100                    # calculate mean pitch of the note
#mean_pitch = Get mean... a b Hertz

  step = 1 / (rows_1-1)
  max_extent = 0                                            # calculate vibrato extent values
  min_extent = 1000
  dev_add = 0
  i = 1
  while (i <= rows_1)                                       # for each vibratory cycle...
    pitch = Get value at time... freq_'i' Hertz Linear
    if (pitch < mean_pitch)
      f_low = pitch
      f_high = mean_pitch
    else
      f_low = mean_pitch
      f_high = pitch
    endif
    dev_'i' = 3986.3137 * ( log10(f_high) - log10(f_low) )  # ... calculate vibrato extent
    dev_add = dev_add + dev_'i'
    pos = (step * i) - step
    if (dev_'i' > max_extent)                               # ... get value and position of maximum extent
      max_extent = dev_'i'
      max_pos = pos
    endif
    if (dev_'i' < min_extent)                               # ... get value and position of minimum extent
      min_extent = dev_'i'
      min_pos = pos
    endif
  i = i + 1
  endwhile                                                  # go to next vibratory cycle

extent = round ((dev_add / rows_1)*100) / 100               # calculate average vibrato extent
max_extent = round(max_extent*100) / 100
min_extent = round(min_extent*100) / 100
difference = round ((max_extent - min_extent) * 100) / 100  # calculate difference between min and max extent
max_pos = round(max_pos*100) / 100
min_pos = round(min_pos*100) / 100

deviation = 3986.3137 * ( log10(mean_pitch) -               # calculate deviation from desired pitch
log10(desired_pitch) )
deviation = round(deviation*100) / 100

Erase all
Draw... 0 0 200 700 yes
Draw line... 0 mean_pitch draw_to mean_pitch                # draw a pitch contour for a visual check
pause This is the visual check...

select TextTier 'tier1$'
plus TableOfReal 'tier1$'
plus TextTier 'tier2$'
plus TableOfReal 'tier2$'
plus Pitch Note_'note$'
```

```
Remove                                            # delete created objects

fig_1 = round(note_duration*100) / 100            # round values
fig_2 = round(onset_time*100) / 100
fig_3 = round(vibrato_time*100) / 100
fig_4 = round(offset_time*100) / 100
fig_5 = round(onset_perc*10) / 10
fig_6 = round(vibrato_perc*10) / 10
fig_7 = round(offset_perc*10) / 10
fig_8 = rate
fig_9 = cycext_no
fig_10 = extent
fig_11 = max_extent
fig_12 = min_extent
fig_13 = min_pos
fig_14 = max_pos
fig_15 = difference
fig_16 = mean_pitch
fig_17 = desired_pitch
fig_18 = deviation

select TableOfReal TableOfReal                    # store values in TableOfReal object
note = 'note$'
i = 1
while (i <= 18)
   Set value... i note fig_'i'
i = i + 1
endwhile
Erase all
Draw as numbers... 1 0 free 5

## end of script
```

B.2 The script to calculate the open quotient

This is the script that measures and calculates the data regarding open quotient. It acts on the EGG signals recorded for each note.

```
form Enter filename                                              # ask for name of files
  word Filename
endform

nn = 1
while (nn <= 10)                                                 # for each note ...

Read from file... C:\Dokumente und                                # read the respective file
Einstellungen\Florian\Desktop\Opening Quotient\All Single
Notes\'filename$'_'nn'.wav
select Sound 'Filename$'_'nn'

To Pitch... 0 75 800                                              # create a pitch object
meanP = Get mean... 0 0 Hertz                                     # calculate mean pitch
Remove                                                            # remove pitch object

select Sound 'Filename$'_'nn'                                     # select sound file again
To PointProcess (periodic, peaks)... 75 800 no yes                # find periodic minima
number = Get number of points                                     # count periodic minima
a = Get time from index... 1
b = Get time from index... number
file_duration = b - a                                             # calculate duration of periodic part

total_time = 0                                                    # set variables for open and total time to zero
open_time = 0
i = 1
while i < number                                                  # for each periodic cycle ...
  ip = i + 1

  select PointProcess 'Filename$'_'nn'
  beg = Get time from index... i                                       # get its beginning and end point
  end = Get time from index... ip

  select Sound 'filename$'_'nn'                                        # extract the cycle
  Extract part... beg end Rectangular 1 no

    min = Get minimum... 0 0 Sinc70                                    # set zero vals to 1/4 of peak-to-peak amplitude
    max = Get maximum... 0 0 Sinc70
    diff = abs(min) + abs(max)
    zero = diff*0.25
    addval = (zero - abs(min))*-1
    Add... addval

  To PointProcess (zeroes)... yes yes                                  # find zero crossings
  start = Get starting time
  finish = Get finishing time
     Add point... start
     Add point... finish
  zeroes = Get number of points
  vor = zeroes - 1
  cyc_dur = finish - start

  a = Get time from index... 1                                         # get positions of zero crossings
  b = Get time from index... 2
  c = Get time from index... vor
  d = Get time from index... zeroes

  Remove
  select Sound 'filename$'_'nn'_part
  Remove                                                               # remove PointProcess and cycle objects

  tot_op = (b - a) + (d - c)                                           # calculate OQ of cycle
```

```
oq_cycle'i' = (tot_op / cyc_dur) * 100                                  # store OQ value in array
   open_time = open_time + tot_op                                       # add values to open and total time
   total_time = total_time + cyc_dur

   i = i + 1
endwhile                                                           # jump to next OQ cycle

oq_mean = (open_time / total_time) * 100                           # calculate mean OQ of note

oq_max = 0                                                         # find min and max OQ values of note
oq_min = 100
n = number - 1
sigma = 0
oq_add = 0
k = 1
while (k < number)
    oq_dummy = oq_cycle'k'
    sigma = sigma + ((oq_mean - oq_dummy) * (oq_mean -
oq_dummy))
    if (oq_dummy > oq_max)
       oq_max = oq_dummy
    endif
    if (oq_dummy < oq_min)
       oq_min = oq_dummy
    endif
k = k + 1
endwhile

n_dummy = 1 / (n-1)                                                # calculate standard deviation (SD) of OQ for the note
std_dev = sqrt (n_dummy * sigma)
oben = oq_mean + std_dev
oben2 = oq_mean + (std_dev*2)
unten = oq_mean - std_dev
unten2 = oq_mean - (std_dev*2)

n_1std = 0                                                         # count number of values outside SD and SD*2
n_2std = 0
oq_sum = 0
i = 1
k = 1
while (k < number)
   oq_s = oq_cycle'k'
   if ((oq_s < oben) and (oq_s > unten))
      n_1std = n_1std + 1
      n_2std = n_2std + 1
         oq_sum = oq_sum + oq_s
         i = i + 1
   elsif ((oq_s < oben2) and (oq_s > unten2))
      n_2std = n_2std + 1
         oq_sum = oq_sum + oq_s
         i = i + 1
   endif
k = k + 1
endwhile

oq_excl = oq_sum / i                                               # round values
p_1std = (100 * n_1std) / n
p_2std = (100 * n_2std) / n

oq_mean = round(oq_mean*100) / 100
oq_excl = round(oq_excl*100) / 100
std_dev = round(std_dev*100) / 100
oq_max = round(oq_max*100) / 100
oq_min = round(oq_min*100) / 100
total_time = round(total_time*100) / 100
p_1std = round(p_1std*10) / 10
p_2std = round(p_2std*10) / 10
meanP = round(meanP*10) / 10

select TableOfReal TableOfReal                                     # store values in TableOfReal Object
Set value... 1 nn oq_mean
Set value... 2 nn std_dev
Set value... 3 nn oq_max
Set value... 4 nn oq_min
Set value... 5 nn total_time
Set value... 6 nn n
Set value... 7 nn meanP
```

```
Set value... 8 nn p_1std
Set value... 9 nn p_2std
Set value... 10 nn oq_excl

nn=nn+1
endwhile                                          # jump to next note

## end of script
```

Appendix C - TableOfReal objects

This section presents all TableOfReal (ToR) objects created with Praat. For each singer and song, one ToR holds the vibrato data and another one holds the open quotient data. All analysis is based on this data.

C.1 Vibrato data

Table C1 Abbreviations

Vibrato data measured for each singer and note	
Dur_[s]	Note duration (voiced part)
OnsT[s]	Vibrato onset time (time between start of note and start of vibrato)
VibT[s]	Vibrato time (duration of the part of note sung with vibrato)
OfsT[s]	Vibrato offset time (time between end of vibrato and end of note)
OnsP[%]	Vibrato onset time percentage in relation to note duration
VibP[%]	Vibrato time percentage in relation to note duration
OfsP[%]	Vibrato offset time percentage in relation to note duration
Rat[Hz]	Vibrato rate, number of full vibratory cycles per second
NumCycl	Number of cycles identified and measured for that note
Ext[Ct]	Average vibrato extent (measured as the average distance between vibratory peaks/troughs and mean pitch)
EMa[Ct]	Maximum vibrato extent for that note
EMi[Ct]	Minimum vibrato extent for that note
MinPosn[s]	Position of minimum vibrato extent, measured in seconds from start of note
MaxPosn[s]	Position of maximum vibrato extent, measured in seconds from start of note
MtM[Ct]	Difference between minimum and maximum vibrato extent
MnP[Hz]	Mean pitch calculated for that note
DsP[Hz]	Desired pitch of the note according to provided accompaniment
Dev[Ct]	Deviation of sung mean pitch from desired pitch

Table C2 Subject C1, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	2.08	0.38	0.96	2.1	0.42	1.83	0.81	1.15	0.52	2.32
OnsT[s]	0.15	0	0	0.3	0	0	0	0.11	0	0
VibT[s]	1.93	0	0.96	1.8	0	1.83	0.81	1.04	0.52	2.32
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	7	0	0	14.3	0	0	0	9.8	0	0
VibP[%]	93	0	100	85.7	0	100	100	90.2	100	100
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.12	0	6.7	6.1	0	6.13	6.4	6.39	7.06	5.74
NumCycl	11.5	0	5.5	10.5	0	11	5	6.5	3	12.5
Ext[Ct]	67	0	37.75	57.09	0	61.13	49.53	48.67	25.77	63.25
EMa[Ct]	97.49	0	61.01	83.89	0	117.76	75.67	68.26	51.69	107.57
EMi[Ct}	13.1	0	7.4	20.01	0	11.22	15.62	17.83	1.59	14.38
MinPosn	0	0	0.09	0.95	0	0.09	0	0	1	0.08
MaxPosn	0.35	0	0.55	0.81	0	0.05	0.7	0.46	0	0.96
MtM[Ct]	84.39	0	53.61	63.88	0	106.54	60.05	50.43	50.1	93.19
MnP[Hz]	463.43	258.12	439.86	393.48	245.37	351.6	439.67	440.15	329.63	292.14
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	-10.32	-23.19	-0.55	6.52	-11.45	11.86	-1.3	0.59	-0.37	-8.63

Table C3 Subject C1, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.62	1.5	0.64	0.69	0.77	0.69	0.62	1.13	1.21	1.22
OnsT[s]	0.14	0.15	0.19	0	0	0	0.2	0.21	0	0.15
VibT[s]	0.49	1.35	0.45	0.69	0.77	0.69	0.42	0.92	1.21	1.07
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	21.7	9.9	29.4	0	0	0	32.3	18.8	0	12.1
VibP[%]	78.3	90.1	70.6	100	100	100	67.7	81.2	100	87.9
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.46	6.21	7.22	6.38	6.02	6.67	6.45	6.01	5.97	6.16
NumCycl	3	8	2.5	3	3.5	4	2.5	5.5	6.5	6.5
Ext[Ct]	63.56	72.68	57.62	64.7	92.37	62.19	79.11	113.54	105.83	107.13
EMa[Ct]	87.88	111.57	97.68	97.23	121.98	101.08	108	203.03	147.28	143.59
EMi[Ct}	23.92	3.78	8.53	6.86	53.9	14	51	47.78	43.58	56.76
MinPosn	0	0.94	1	0	0	0.25	1	0	0	1
MaxPosn	0.5	0.56	0.4	0.5	0.71	0.5	0.4	1	0.23	0.69
MtM[Ct]	63.96	107.79	89.15	90.37	68.08	87.08	57	155.25	103.7	86.83
MnP[Hz]	593.53	366.66	489.84	362.96	285.28	437.07	493.85	273.45	284.95	362.56
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	18.27	-15.7	-14.29	-33.26	-49.77	-11.57	-0.18	-23.58	-51.77	-35.17

Table C4 Subject C2, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	2.29	0.23	0.87	2.33	0.5	1.96	0.92	1.09	0.49	2.06
OnsT[s]	0.43	0	0.13	0.54	0	0.41	0.27	0.44	0	0.59
VibT[s]	1.86	0	0.74	1.79	0	1.55	0.66	0.65	0	1.47
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	18.8	0	15.4	23.1	0	20.9	28.8	40.3	0	28.8
VibP[%]	81.2	0	84.6	76.9	0	79.1	71.2	59.7	0	71.2
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.19	0	6.7	6.05	0	6.24	6.39	6.38	0	5.97
NumCycl	11	0	4.5	10	0	9.5	4	4	0	8
Ext[Ct]	85.96	0	30.22	70.18	0	77.69	68.24	61.11	0	45.97
EMa[Ct]	155.49	0	68.11	113.49	0	125.99	117.03	83.92	0	88.33
EMi[Ct}	12.89	0	7.93	17.94	0	20.46	32.38	40.09	0	20.85
MinPosn	0	0	1	0.95	0	0.95	0	0	0	0.44
MaxPosn	0.64	0	0.56	0.15	0	0.21	0.63	0.38	0	0.75
MtM[Ct]	142.6	0	60.18	95.55	0	105.53	84.65	43.83	0	67.48
MnP[Hz]	461.33	266.47	439	390.5	243.96	346	440.19	442.76	333.71	293.88
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	-18.18	31.96	-3.94	-6.64	-21.43	-15.94	0.75	10.83	20.93	1.65

Table C5 Subject C2, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.53	1.89	0.72	0.6	0.76	0.65	0.46	1.06	0.98	1.51
OnsT[s]	0	0.25	0.14	0	0	0.12	0	0.42	0	0.17
VibT[s]	0.53	1.64	0.37	0.6	0.76	0.53	0	0.64	0.98	1.34
OfsT[s]	0	0	0.21	0	0	0	0	0	0	0
OnsP[%]	0	13.1	19.1	0	0	19	0	39.5	0	11.2
VibP[%]	100	86.9	51.9	100	100	81	0	60.5	100	88.8
OfsP[%]	0	0	29	0	0	0	0	0	0	0
Rat[Hz]	7.13	5.95	6.7	7.36	6.41	6.73	0	5.96	5.85	5.96
NumCycl	3	9.5	2.5	3.5	4	3.5	0	3.5	4.5	8
Ext[Ct]	56.94	92.55	67.26	40.42	45.98	79.81	0	86.16	82.76	62.12
EMa[Ct]	92.4	148.19	120.7	71.55	78.46	100.31	0	123.11	138.21	90.71
EMi[Ct}	8.46	14.33	7.9	7.52	0.47	49.16	0	7.48	32.82	11.88
MinPosn	0.17	0	0	1	0.75	0	0	1	0.11	0
MaxPosn	0.83	0.53	0.8	0.57	0.38	0.43	0	0.57	0.44	0.19
MtM[Ct]	83.94	133.86	112.8	64.03	77.99	51.15	0	115.63	105.39	78.83
MnP[Hz]	593.72	372.16	494.3	370.43	292.91	447.42	493.02	276.52	286.6	368.69
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	18.82	10.08	1.4	2.01	-4.07	28.95	-3.08	-4.25	-41.78	-6.14

Table C6 Subject C3, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	2.02	0.12	0.73	2.46	0.51	2.04	0.91	0.94	0.39	1.81
OnsT[s]	0.79	0	0	1.52	0	1.14	0.54	0.48	0	0.72
VibT[s]	1.23	0	0	0.94	0	0.9	0.36	0.45	0	1.09
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	39	0	0	61.8	0	55.9	60	51.6	0	39.7
VibP[%]	61	0	0	38.2	0	44.1	40	48.4	0	60.3
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.1	0	0	5.85	0	5.9	7.3	6.07	0	5.89
NumCycl	7.5	0	0	5	0	4.5	2.5	2.5	0	6
Ext[Ct]	90.2	0	0	48.32	0	41.9	58.09	79.06	0	69.17
EMa[Ct]	149.85	0	0	75.97	0	96.7	92.68	117.36	0	134.42
EMi[Ct}	34.91	0	0	30.59	0	8.94	24.95	25.13	0	42.51
MinPosn	0	0	0	1	0	1	0.6	0	0	0.33
MaxPosn	1	0	0	0.6	0	0.67	0.4	0.4	0	0.25
MtM[Ct]	114.94	0	0	45.38	0	87.76	67.73	92.23	0	91.91
MnP[Hz]	457.47	269.07	435.48	387.51	250.11	344.06	426.71	431.44	310.06	290.36
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	-32.73	48.72	-17.87	-19.94	21.64	-25.67	-53.1	-34.01	-106.33	-19.21

Table C7 Subject C3, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.56	1.68	0.44	0.65	1.13	0.57	0.61	1.09	0.91	1.07
OnsT[s]	0	0.9	0	0	0.25	0	0	0.52	0.37	0.42
VibT[s]	0.56	0.78	0	0.65	0.52	0	0.61	0.56	0.54	0.65
OfsT[s]	0	0	0	0	0.36	0	0	0	0	0
OnsP[%]	0	53.7	0	0	22.4	0	0	48.2	40.3	39.4
VibP[%]	100	46.3	0	100	45.8	0	100	51.8	59.7	60.6
OfsP[%]	0	0	0	0	31.7	0	0	0	0	0
Rat[Hz]	6.63	6.43	0	6.04	5.81	0	6.94	5.96	5.95	6.97
NumCycl	3	5	0	3	3	0	4	3	3	4.5
Ext[Ct]	89.92	82.54	0	82.04	96.03	0	93.75	78.54	82.83	102.53
EMa[Ct]	169.78	161.68	0	119.34	126.49	0	158.16	111.16	127.6	201.17
EMi[Ct}	43.34	25.7	0	54.59	41.98	0	26.43	41.08	37.81	44.86
MinPosn	1	0.8	0	0	0	0	1	1	1	0.22
MaxPosn	0.83	0.5	0	0.33	0.83	0	0.38	0.5	0.67	0.56
MtM[Ct]	126.44	135.98	0	64.75	84.51	0	131.73	70.08	89.79	156.31
MnP[Hz]	571.03	361.63	487.7	366.42	288.44	429.38	487.74	277.35	289.22	358.15
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	-48.64	-39.61	-21.87	-16.83	-30.7	-42.32	-21.73	0.94	-26.02	-56.35

Table C8 Subject J1, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	2.52	0.12	0.26	1.86	0.25	2.85	0.23	2.55	0.4	2.15
OnsT[s]	1.59	0	0	0	0	1.93	0	1.75	0	1.11
VibT[s]	0.93	0	0	1.86	0	0.93	0	0.8	0	1.04
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	63	0	0	0	0	67.5	0	68.5	0	51.5
VibP[%]	37	0	0	100	0	32.5	0	31.5	0	48.5
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	4.57	0	0	4.81	0	5.26	0	5.23	0	4.67
NumCycl	4	0	0	8	0	4.5	0	4	0	4.5
Ext[Ct]	32.01	0	0	45.71	0	51.5	0	64.89	0	50.39
EMa[Ct]	64.38	0	0	84.83	0	92.55	0	130.2	0	106.55
EMi[Ct}	3.61	0	0	4.76	0	13.72	0	21.67	0	18.4
MinPosn	0.25	0	0	0.06	0	0.56	0	0.75	0	0
MaxPosn	1	0	0	0.94	0	0.89	0	0.88	0	1
MtM[Ct]	60.77	0	0	80.07	0	78.83	0	108.53	0	88.15
MnP[Hz]	465.09	251.97	434.67	382.51	429.93	346.9	419.87	433.55	334.32	291.58
DsP[Hz]	466.2	261.6	440	392	440	349.2	440	440	329.7	293.6
Dev[Ct]	-4.13	-64.95	-21.09	-42.43	-40.08	-11.44	-81.07	-25.57	24.08	-11.95

Table C9 Subject J1, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.54	1.7	0.54	0.58	0.6	0.57	0.51	0.96	0.92	0.92
OnsT[s]	0	0.7	0	0	0	0	0	0	0.33	0.5
VibT[s]	0	0.67	0	0	0	0	0	0	0.46	0.41
OfsT[s]	0	0.33	0	0	0	0	0	0	0.14	0
OnsP[%]	0	40.9	0	0	0	0	0	0	35.4	55.1
VibP[%]	0	39.4	0	0	0	0	0	0	49.9	44.9
OfsP[%]	0	19.6	0	0	0	0	0	0	14.7	0
Rat[Hz]	0	5.21	0	0	0	0	0	0	5.43	5.61
NumCycl	0	3.5	0	0	0	0	0	0	2.5	2
Ext[Ct]	0	21.93	0	0	0	0	0	0	32.2	18.13
EMa[Ct]	0	44.5	0	0	0	0	0	0	62	28.27
EMi[Ct}	0	13.52	0	0	0	0	0	0	1.86	10.83
MinPosn	0	0.43	0	0	0	0	0	0	0.2	1
MaxPosn	0	0.29	0	0	0	0	0	0	0.4	0.75
MtM[Ct]	0	30.98	0	0	0	0	0	0	60.14	17.44
MnP[Hz]	582.73	365.02	492.34	363.89	285.59	437.58	494.68	277.42	293.71	368.79
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	-13.54	-23.46	-5.47	-28.82	-47.9	-9.56	2.74	1.4	0.65	-5.67

Table C10 Subject J2, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	1.9	0.16	0.19	1.86	0.48	1.98	0.11	0.96	0.45	1.77
OnsT[s]	0.91	0	0	0.78	0	1.04	0	0	0	0
VibT[s]	0.99	0	0	1.08	0	0.93	0	0.96	0	1.77
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	48	0	0	42	0	52.8	0	0	0	0
VibP[%]	52	0	0	58	0	47.2	0	100	0	100
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	6.07	0	0	5.34	0	5.71	0	5.6	0	5.35
NumCycl	6	0	0	5.5	0	5	0	4.5	0	9
Ext[Ct]	29.06	0	0	37.51	0	30.09	0	34.32	0	46.94
EMa[Ct]	62.04	0	0	82.64	0	63.5	0	59.82	0	98.45
EMi[Ct}	6.34	0	0	9.01	0	9.17	0	6.42	0	7.52
MinPosn	0.08	0	0	0.09	0	0.3	0	0.56	0	0
MaxPosn	0.58	0	0	1	0	1	0	0.89	0	0.72
MtM[Ct]	55.7	0	0	73.63	0	54.33	0	53.4	0	90.93
MnP[Hz]	468.86	253.06	427.06	391.23	248.17	344.9	460.19	442.3	331.7	291.23
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	9.85	-57.49	-51.67	-3.4	8.16	-21.45	77.68	9.03	10.46	-14.03

Table C11 Subject J2, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.26	1.68	0.55	0.64	1.36	0.62	0.42	1	1.01	1.53
OnsT[s]	0	0	0	0.28	0	0	0.13	0.44	0.12	0
VibT[s]	0	1.68	0.55	0.36	1.36	0.62	0.29	0.56	0.7	1.53
OfsT[s]	0	0	0	0	0	0	0	0	0.19	0
OnsP[%]	0	0	0	44	0	0	31.3	44	11.5	0
VibP[%]	0	100	100	56	100	100	68.7	56	69.4	100
OfsP[%]	0	0	0	0	0	0	0	0	19.1	0
Rat[Hz]	0	5.53	6.02	6.06	5.4	5.89	5.71	6.06	5.73	5.06
NumCycl	0	9	2.5	1.5	7	3	1.5	3	4	7.5
Ext[Ct]	0	44.2	27.47	31.49	58.23	27.57	26.37	33.25	33.13	30.52
EMa[Ct]	0	117.08	41.98	40.67	105.37	46.66	43.07	57.42	62.7	72.78
EMi[Ct}	0	1.62	4.37	22.54	16.63	5.71	9.16	13.81	10.11	15.09
MinPosn	0	0.17	0.8	0	0	0	0.33	1	0.88	0.27
MaxPosn	0	0.94	0	1	0.64	1	1	0.17	0.38	0.93
MtM[Ct]	0	115.46	37.61	18.13	88.74	40.95	33.91	43.61	52.59	57.69
MnP[Hz]	581.71	365.66	484.86	372.37	293.62	439.49	494.65	279.57	293.6	369.95
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	-16.56	-20.43	-31.98	11.05	0.12	-2.01	2.63	14.74	0	-0.23

Table C12 Subject J3, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Dur[s]	1.46	0.29	0.41	1.34	0.22	1.58	0.12	0.97	0.74	1.44
OnsT[s]	0.48	0	0	0.21	0	0.72	0	0	0	0.18
VibT[s]	0.98	0	0	0.78	0	0.86	0	0	0.74	1.26
OfsT[s]	0	0	0	0.35	0	0	0	0	0	0
OnsP[%]	33	0	0	15.7	0	45.5	0	0	0	12.4
VibP[%]	67	0	0	57.9	0	54.5	0	0	100	87.6
OfsP[%]	0	0	0	26.3	0	0	0	0	0	0
Rat[Hz]	4.88	0	0	5.14	0	4.95	0	0	5.23	4.92
NumCycl	4.5	0	0	4	0	4	0	0	3.5	6
Ext[Ct]	21.99	0	0	14.67	0	39.37	0	0	27.58	34.91
EMa[Ct]	38.52	0	0	34.68	0	89.64	0	0	46.94	55.42
EMi[Ct}	8.35	0	0	1.9	0	5.76	0	0	1.38	10.85
MinPosn	0.78	0	0	1	0	1	0	0	1	0.75
MaxPosn	0.89	0	0	0.88	0	0.88	0	0	0.14	0.83
MtM[Ct]	30.17	0	0	32.78	0	83.88	0	0	45.56	44.57
MnP[Hz]	464.49	262.85	420.5	389.05	245.08	343.45	448.29	435.38	336.51	289
DsP[Hz]	466.2	261.6	440	392	247	349.2	440	440	329.7	293.6
Dev[Ct]	-6.36	8.22	-78.49	-13.08	-13.5	-28.74	32.3	-18.28	35.39	-27.34

Table C13 Subject J3, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Dur[s]	0.48	1.34	0.55	0.48	0.88	0.61	0.55	0.95	0.57	0.82
OnsT[s]	0	0	0	0	0	0	0	0.26	0	0.27
VibT[s]	0	1.34	0	0	0.88	0	0	0.69	0	0.54
OfsT[s]	0	0	0	0	0	0	0	0	0	0
OnsP[%]	0	0	0	0	0	0	0	27.1	0	33.5
VibP[%]	0	100	0	0	100	0	0	72.9	0	66.5
OfsP[%]	0	0	0	0	0	0	0	0	0	0
Rat[Hz]	0	4.49	0	0	4.52	0	0	4.61	0	4.61
NumCycl	0	5.5	0	0	3.5	0	0	3	0	2.5
Ext[Ct]	0	38.64	0	0	36.61	0	0	26.54	0	19.05
EMa[Ct]	0	59.4	0	0	58.97	0	0	48.96	0	31.15
EMi[Ct}	0	22.87	0	0	9.44	0	0	10.56	0	4.03
MinPosn	0	0	0	0	0.29	0	0	0.33	0	0.6
MaxPosn	0	0.09	0	0	0.57	0	0	0.5	0	0
MtM[Ct]	0	36.53	0	0	49.53	0	0	38.4	0	27.12
MnP[Hz]	585.18	369.19	497.61	373.06	292.95	431.07	492.24	279	293.2	372.23
DsP[Hz]	587.3	370	493.9	370	293.6	440	493.9	277.2	293.6	370
Dev[Ct]	-6.25	-3.79	12.95	14.28	-3.84	-35.48	-5.83	11.21	-2.35	10.4

C.2 Open quotient data

Table C14 Abbreviations

Open Quotient data measured for each singer and note	
OQ	Average open quotient of entire note
StdDev	Standard deviation of the OQ based on single cycles
OQmax	Maximum OQ value within the note
OQmin	Minimum OQ value within the note
Dur[s]	Duration of section that was interpretable
NumCyc	Number of OQ cycles analysed within the note
Pitch[Hz]	Mean pitch of the analysed section
ViSD[%]	Percentage of OQ values within standard deviation
ViSD2[%]	Percentage of OQ values within double standard deviation
OQxcl	Number of OQ values outside double standard deviation

Table C15 Subject C1, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	14.62	28.11	13.74	15.87	18.42	12.04	14.05	14.95	11.07	24.63
StdDev	2.15	7.32	1.17	2.51	1.05	2.13	0.94	1.81	1.29	5.02
OQmax	21.98	43.73	16.51	21.61	21.15	35.51	16.19	20.66	14.64	34.36
OQmin	6.9	9.99	10.73	9.58	15.72	5.34	11.6	9.24	8.34	10.56
Dur[s]	0.97	0.36	0.48	1.64	0.55	1.11	0.58	0.95	0.57	2.18
NumCyc	449	94	212	647	135	393	253	418	189	636
Pitch[Hz]	461.9	258	438.8	393.5	245.5	353.9	438.7	439.5	331	292.1
ViSD[%]	72.6	71.3	70.8	64	71.1	83.7	67.6	73.9	69.3	64.2
ViSD2[%]	94.4	94.7	93.4	97.7	94.8	95.9	95.7	93.3	94.7	97.3
OQxcl	14.6	28.44	13.82	15.85	18.19	12.13	13.98	14.87	10.96	24.92

Table C16 Subject C1, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	15.76	15.92	15.42	16.4	24.29	17.63	18.42	26.2	27.7	21.03
StdDev	1.16	1.95	1.16	1.98	2.64	1.27	1.9	3.47	3.78	4.68
OQmax	17.65	20.09	16.62	20.62	34.35	20.15	22.58	32.42	43.91	29.6
OQmin	8.44	12.47	12.38	12.12	14.98	15.09	14	16.78	17.11	10.35
Dur[s]	0.71	1.25	0.16	0.71	0.74	0.43	0.55	1.12	1.21	1.14
NumCyc	420	459	79	257	211	188	269	306	344	416
Pitch[Hz]	594.5	367.2	485.5	362.7	285	439.6	492.9	273	284.7	363.7
ViSD[%]	80.2	58.4	79.7	58.4	69.2	61.7	66.9	65	70.9	57.5
ViSD2[%]	95.5	99.3	93.7	97.7	96.2	100	95.5	98	95.3	99.5
OQxcl	15.89	15.9	15.41	16.37	24.25	17.57	18.4	26.21	27.76	21.2

Table C17 Subject C2, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	16.68	13.33	14.45	19.08	20.26	16.95	17.08	16.21	13.94	14.26
StdDev	4.32	0.46	2.06	2.65	1.39	1.17	3	2.71	0.44	1.96
OQmax	27.73	14.41	19.66	26.04	28.39	20.05	22.66	21.96	14.98	18.95
OQmin	10.66	12.41	11.57	13.17	15.62	13.54	11.74	10.9	13.01	5.23
Dur[s]	2.18	0.21	1.15	2.4	0.58	2.07	0.83	1.06	0.56	2.02
NumCyc	1005	55	507	936	140	715	367	468	185	593
Pitch[Hz]	461.3	266.5	439	389.6	242.6	344.9	440.1	442.2	332.5	294
ViSD[%]	65.6	69.1	62.7	64.1	78.6	67.3	60.2	64.5	67.6	75.4
ViSD2[%]	95.1	98.2	96.8	98.2	97.1	96.5	100	99.6	96.2	93.8
OQxcl	16.27	13.07	14.31	19.04	20.03	16.94	17.06	16.16	13.84	14.38

Table C18 Subject C2, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	16.16	14.77	16.7	15.35	13.36	15.72	16.19	14.43	14.7	15.5
StdDev	1.09	0.97	2.31	1.38	0.65	1.54	2.26	1.17	1.38	1.02
OQmax	18.8	17.09	22.9	17.13	14.48	18.39	19	16.11	16.97	18.18
OQmin	13.69	11.76	13.07	11.33	11.11	12.54	11.96	10.41	11.03	12.58
Dur[s]	0.5	1.66	0.61	0.62	0.67	0.49	0.44	1.09	1.01	1.47
NumCyc	298	616	303	230	195	220	218	302	288	540
Pitch[Hz]	591.5	371.8	496.9	370	292.8	446.6	494.8	276.5	286.2	368.5
ViSD[%]	62.8	63.1	69	72.2	74.4	59.5	60.6	69.5	67.7	71.9
ViSD2[%]	97.7	97.1	93.7	94.3	94.9	99.5	100	94.7	94.4	93.9
OQxcl	16.07	14.8	16.35	15.5	13.38	15.69	16.1	14.55	14.86	15.58

Table C19 Subject C3, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	29.91	18.83	16.45	14.71	10.7	13.64	17.01	16.87	11.72	11.16
StdDev	3.06	8.67	2.52	1.17	1.89	1.01	3.72	1.92	1.2	0.74
OQmax	39.92	34.79	22.07	20.85	16.05	17.28	25.63	22.3	15.69	13.75
OQmin	20.35	9.77	9.98	10.93	8.04	10.96	9.9	13.85	9.12	9.54
Dur[s]	0.71	0.21	0.31	1.86	0.56	1.82	0.73	0.43	0.53	0.74
NumCyc	325	53	122	721	140	625	310	186	164	215
Pitch[Hz]	459.5	257.4	393.9	387.9	250.3	344.3	426.4	432.1	312	291.5
ViSD[%]	72.6	66	82	80	79.3	74.2	60.3	66.7	73.8	70.7
ViSD2[%]	92.9	100	92.6	93.3	92.9	93.6	96.1	95.7	93.9	94.9
OQxcl	29.69	17.86	16.96	14.58	10.28	13.57	16.62	16.56	11.5	11.03

Table C20 Subject C3, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	34.43	13.8	16.08	12.68	16.94	15.06	19.21	9.86	40.57	18.49
StdDev	2.24	1.73	2.43	0.99	4.12	1.03	4.96	0.97	11.85	4.68
OQmax	43.32	19.01	20.16	14.92	29.91	17.16	34.39	13.8	60.92	27.4
OQmin	27.71	11.89	12.24	10.99	9.53	12.94	15.75	8.08	6.47	8.85
Dur[s]	0.42	0.95	0.34	0.54	0.3	0.44	0.2	0.96	1.11	0.92
NumCyc	244	348	166	197	94	189	92	268	306	328
Pitch[Hz]	582.1	365.4	484.2	367.4	312	430	452.1	278.3	275.3	357.7
ViSD[%]	75.4	77.6	57.8	59.9	60.6	64	83.7	77.6	67.6	52.1
ViSD2[%]	93.4	94.5	100	97	98.9	97.4	89.1	93.3	93.1	99.7
OQxcl	34.27	13.53	15.96	12.58	16.7	14.96	17.88	9.65	43.69	18.31

Table C21 Subject J1, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	21.8	0	29.04	24.85	30.82	27.56	24.99	32.84	19.82	20.04
StdDev	2.8	0	3.52	4.73	5.06	6.64	3.96	5.5	2.86	5.42
OQmax	32.99	0	39.38	42.14	47.87	48.32	39.02	51.34	28.68	37.63
OQmin	13.76	0	22.4	13.88	17.32	8.99	17.98	18.82	14.22	9.5
Dur[s]	2.15	0	0.27	1.09	0.45	1.84	0.17	1.75	0.32	1.72
NumCyc	1000	0	116	411	184	640	72	767	108	504
Pitch[Hz]	466	0	430.4	376.8	408.7	348.6	418.2	438.1	335	293.2
ViSD[%]	71.2	0	66.4	67.2	69	67.2	72.2	69.1	70.4	64.1
ViSD2[%]	95.4	0	96.6	95.9	95.1	96.6	97.2	95.4	94.4	96.4
OQxcl	21.63	0	28.47	24.35	30.63	27.32	24.33	32.21	19.13	19.42

Table C22 Subject J1, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	34.43	20.68	24.46	16.93	0	25.01	24.24	15.88	22.16	19.66
StdDev	2.24	3.41	2.81	3.5	0	4.03	2.26	3.26	4.24	5.45
OQmax	43.32	35.26	31.56	27.87	0	36.85	30.6	24.36	33.68	34.44
OQmin	27.71	12.15	11.89	9.36	0	11.53	16.41	9.11	12.92	7.61
Dur[s]	0.42	0.94	0.46	0.39	0	0.59	0.4	0.71	0.75	0.7
NumCyc	244	343	227	141	0	258	196	196	221	257
Pitch[Hz]	582.1	365.3	492.5	363.9	0	438.6	493.1	276.7	293.9	368.8
ViSD[%]	75.4	68.2	68.3	67.4	0	70.2	68.4	62.8	65.6	69.6
ViSD2[%]	93.4	95	96	95	0	93.8	95.4	96.9	96.4	95.3
OQxcl	34.27	20.22	24.43	16.52	0	24.85	24.11	15.68	21.63	18.94

Table C23 Subject J2, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	0	44.42	28.1	18.55	0	30.65	24.2	29.77	22.02	29.55
StdDev	0	3.92	3.72	2.15	0	3.49	3.33	5.64	2.53	8.82
OQmax	0	49.35	39.74	24.86	0	39.91	31.51	46.64	26.33	52.21
OQmin	0	37.17	18.13	9.01	0	20.18	16.5	15.2	11.44	10.8
Dur[s]	0	0.15	0.58	1.54	0	1.85	0.08	0.62	0.25	1.32
NumCyc	0	38	252	600	0	632	36	273	82	383
Pitch[Hz]	0	249.9	436.4	389.9	0	342.4	460.4	441.2	332.2	291.2
ViSD[%]	0	60.5	68.3	71.8	0	69.9	66.7	67	79.3	61.4
ViSD2[%]	0	100	94	94.5	0	94.5	94.4	96.3	95.1	97.9
OQxcl	0	43.24	27.96	18.67	0	30.65	23.52	29.2	22.11	29

Table C24 Subject J2, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	29.69	24.33	36.45	17.02	14.88	26.57	23.27	20.68	24.24	20.92
StdDev	3.82	2.66	11.78	1.85	2.47	4.25	4.29	5.94	3.74	2.51
OQmax	42.21	32.28	59.63	22.6	27.05	38.22	31.22	39.7	36.58	31.41
OQmin	18.27	13.55	12.52	12.24	10.48	11.43	15.3	8.36	9.13	13.15
Dur[s]	0.47	0.89	0.5	0.39	0.89	0.75	0.46	0.36	0.83	1.19
NumCyc	276	326	242	144	260	327	226	103	245	438
Pitch[Hz]	586	366.7	481.1	371.4	291.8	437.5	490.8	282.9	294.1	369.2
ViSD[%]	71	70.6	55.4	66	85	70.9	57.5	71.8	72.2	73.5
ViSD2[%]	94.9	95.1	99.6	97.2	95.8	95.7	100	96.1	94.7	95.2
OQxcl	29.4	24.55	36.46	16.91	14.43	26.85	23.16	20.39	24.06	20.73

Table C25 Subject J3, Autumn Leaves

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
OQ	36.02	9.6	0	12.56	8.6	13.31	24.97	38	37.15	10.2
StdDev	5.17	2.58	0	1.1	0.58	1.8	5.02	5.9	5.5	2.1
OQmax	40.58	17.64	0	15.82	10.34	19.27	37.5	54.69	54.57	21.24
OQmin	18.06	7.29	0	9.54	7.78	9.29	14.01	16.62	23.32	7.42
Dur[s]	1.65	0.29	0	1.37	0.27	1.31	0.13	0.97	0.77	1.34
NumCyc	763	76	0	530	66	449	59	424	260	386
Pitch[Hz]	461.2	259.9	0	387.7	243.3	344.1	449	436.1	336.4	288.9
ViSD[%]	88.1	88.2	0	67.2	69.7	65.9	71.2	76.2	72.7	86.8
ViSD2[%]	91	90.8	0	95.7	97	96.7	91.5	94.1	94.6	93
OQxcl	37.54	8.68	0	12.48	8.41	13.18	24.68	37.93	36.75	9.7

Table C26 Subject J3, An die Musik

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
OQ	25.42	14.48	31.25	13.26	12.38	16.44	20.62	11.42	11.45	15.38
StdDev	0.78	0.84	4.43	0.34	1.06	0.64	2.4	0.92	0.27	1
OQmax	27.34	17.4	37	14.07	14.94	17.65	23.81	16.82	12.11	17.66
OQmin	22.45	13.01	17.07	12.34	10.05	15.15	14.74	10.19	10.77	13.01
Dur[s]	0.47	1.28	0.56	0.5	0.84	0.58	0.64	1.14	0.6	0.81
NumCyc	276	474	276	188	246	249	314	317	176	303
Pitch[Hz]	585.4	369.2	496.6	373.1	294.2	431.3	489	277.1	293.4	372.1
ViSD[%]	70.3	72.2	74.3	64.9	66.3	63.1	73.6	90.2	69.3	65.3
ViSD2[%]	95.3	94.5	94.2	96.3	96.3	99.6	94.6	96.8	95.5	96
OQxcl	25.37	14.33	31.85	13.2	12.28	16.39	20.89	11.24	11.39	15.34