Statistical Analysis of Vocal Folk Music

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Statistical Analysis of Vocal Folk Music

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Abstract

This study explores the German songs of the *Essen Folk Song Collection* and provides statistical findings from them. The aim has been to study aspects of a contextual nature such as probabilities for different intervals at certain formations of notes, correlations between time domain and pitch domain, or melodic ranges for phrases or songs. The results are relevant to several fields of music science, such as music cognition and algorithmic composition. The study has been done in Matlab into which Kern scores were converted via MIDI. Among the most interesting findings are: A clear correlation between pitch salience and metrical salience. A clear correlation between interval size and note length. That stairs (subsequent notes of small intervals) are more common in a rising formation than in a falling formation. Findings that the melody tends to continue in the same direction when a new direction with small intervals has recently been established. That contour repetition is almost always accompanied by rhythmic repetition at the phrase level. That earlier findings for convex phrase arches seem to mostly be a phenomena of an upward movement in the first phrase of a song and downward movements in the last phrase of a song.

Contents

1 Introduction

This study explores the German songs of the *Essen Folk Song Collection* (Schaffrath, 1995) and provides statistical findings from them. The total number of songs are 5370 and in the statistical examinations different subsets of these songs are used.

The following concepts are important to understand:

- *Note length* - The length of a note. A note with a length of half the measure is called a half note, a note with a length of a quarter of the measure is called a quarter note etc.
- *Measure* - Consists of a repeated pattern of beats.
- *Meter* - The perceived number of beats and the note length of each beat in the measure.
- *Phrase* - A musical sentence consisting of several notes.
- *Pitch* - Note height, a logarithmic interpretation of the fundamental frequency.
- *Interval* - The distance between to subsequent pitches.
- *Tonic* - The first scale degree which means that a song in C major has C as the tonic. The tonic is perceived as a resolution and most songs end on the tonic. The tonic chord is perceived in a similar way.
- *Dominant* - The fifth scale degree which means that a song in C major has G as the dominant. The dominant is perceived as unstable and the dominant chord is perceived in a similar way.

1.1 What are the benefits of statistical analysis in music?

Statistics can both confirm relationships within music, and help to provide insights to why these relationships do exists. Let us look at an example to get acquainted with statistical analysis in music and its benefits.

It has been well known that melodies tend to move down after large leaps upwards in pitch, a phenomena called gap fills (Levitin, 2006) or skip reversals (Huron, 2006). To confirm this statistically is fairly easy. The first step is to scan a large set of songs, a database with data in a format that is accessible. Every interval between two succeeding pitches is evaluated and for the intervals that are positive and larger than a certain threshold (as an example a rise of 6 semi-tones) the notes following that interval are analyzed. If they are on average falling, we have confirmed the theory. However we will not have explained why this is occurring. Is it an expression of style? Or perhaps a consequence of the instrument performing the music?

Huron (2006) has analyzed this and his conclusions are that the rule of skip reversal was in fact formulated wrong to begin with. It is not so that large leaps upwards in pitch are automatically followed by a falling pitch. Instead the phenomena can be completely explained by regression to the mean. That is, melodies always tend to move towards the mean pitch where the mean is defined by the earlier notes of the same melody. When the melody is falling after a large leap it is merely an effect of regression to the mean and the statistical evidence Huron has put forward is the following: If a large leap upwards occurs at the lower register of a melody, so that the note which the leap will land on is positioned below the mean pitch of that same melody, it is statistically more probable with a continued upward motion. However, as most large leaps upwards naturally land above the mean pitch this effects can not be discovered merely by looking at big leaps, disregarding mean pitch. As a conclusion, the phenomena of skip reversal could only be explained when the context in which they occur was taken into consideration.

Why does melodies possess this regression to the mean? In what way does it please listeners? It has been suggested by Meyer (1956) that listeners form expectations about how the pitch of the melody will change based of the range of the instruments playing the melody. If the instrument performs at the top range, the listener will accurately sense a higher probability for a falling melody. Note here that we can as listeners make predictions about an instruments range based on the frequency spectrum of the instruments. Not only is the fundamental frequency important but perhaps more important is the strength of the overtones (an instrument without the ability to alter the harmonic spectrum does not lend much room for expression to the person playing it). The listener will thus have a rough idea about where in its range an instrument is playing even if the instrument is relatively unknown to him or her.

1.2 Aims

The aim of this study is to reveal statistical relationships that has not been studied before. The idea is that melodies are always of a contextual nature and that simple relationships such as the distribution of intervals does not provide the true probabilities for the next pitch of the melody. Instead a broader context must be analyzed. The context is provided by the earlier parts of the melody and can be of the following nature:

- Were in the melodic range of the melody is the current pitch positioned?

- What is the direction of the earlier pitches?

To make use of the answers to these questions we must know how they affect probabilities in music. *This is where this study will be useful as questions of the following nature are answered:*

- *What are common melodic ranges?*
- *How does the earlier directions of the pitch affect probabilities for the next note pitch?*
- *How does metrical position affect pitch probabilities?*

10 different aspects of this nature have been examined and these aspects are presented in section *1.3 Outline of the study.*

The findings are hopefully important in several fields of music science, and the aim has been to foster the development in, amongst others:

- **Algorithmic Composition** - Music composition with computers is dependent on statistical data to model probabilities.
- **Music Information Retrieval** - Retrieval of music information, in particular from audio, will become more accurate with an understanding of statistical probabilities in music.
- **Music Cognition** - With a statistical analysis of music, psychological aspects such as expectation and memory can be better understood.

1.3 Outline of the study

10 different aspects have been examined:

1. **Ambitus** - The range of the melody as the distance between the highest and the lowest note.
2. **Pitch & Meter** - The distribution of pitches, compared across different meters.
3. **Metrical Salience & Pitch** - How the salience of the metrical positions affect the distribution of pitches.
4. **Intervals & Note Length** - The correlation between note length and interval size.

5. **Double Notes** - The distribution of repeated occurrences of two pitches with the same tone height, for different starting positions in the measure.
6. **Stairs** - The distribution of note sequences, with intervals of one pitch step, with continuous direction, examined for different note lengths.
7. **Contour** - The direction of the melody and how this direction changes, examined across metrical positions.
8. **Repetition** - In which ways musical phrases repeat each other.
9. **Phrase Arch** - The contour of the melody examined at a phrase level.
10. **Tonal Resolution** - The pitch distribution at the tonal resolution in the end of each song.

The following sections will deal with these 10 aspects:

- **1.4 Background:** A brief background with statistical findings directly relevant to this study.
- **2 Method:** A brief description of preparations of the data. The approach and relevant considerations is presented separately for each aspect.
- **3 Results:** Results will be presented in the form of graphs and tables separately for each aspect.
- **4 Discussion:** The results are discussed separately for each aspect.
- **5 Conclusions:** The most important conclusion that can be drawn from this study.

1.4 Background

Why can a statistical approach to music, an art form often linked to emotion, be of any use? There seem to be statistical correlations in music wherever you look, and it has been proposed that probable movements in music may be perceived by the listener as pleasurable (Huron, 2006).

A thorough analysis of Danish folk songs has been done by Holm (1984) where he studies interval sizes and their distribution, the highest and lowest notes of the music as well as the melodic range (ambitus). Huron (2006) has examined the phrase contour of the songs in the *Essen Folk Song Collection*, and found an on average convex contour, sometimes referred to as the *melodic arch*. On a similar theme Craig Sapp showed the author (2011) the most common first three notes and the most common last three notes from the *Tirol Folk Songs* (a subset of the *Essen Folk Song Collection*). The most common three-note ending he found was scale notes 3-2-1 and the most common start was 1-2-3 followed by 3-4-5. The author has examined (Elowsson, 2012) the most common three note patterns in 80 000 songs from Themefinder (2011). For the upward motion 1-2-3, 7.5 % of all occurrences were found in the first three notes but for the downward motion 3-2-1 only 1.9 % of all occurrences were found in the first three notes.

Vos & Troost (1989) have studied the distribution of intervals in Western music and found that small intervals more often descend and that large intervals more often ascend. Tonality has been studied by Krumhansl & Kessler (1982 as cited in Huron, 2006) who let listeners rate the goodness of fit, related to major and minor keys, for different pitches. Notice that the key needed to be established beforehand, an element of uncertainty. By analyzing the *Essen Folk Song Collection*, Eerola & Toiviainen (2004) have found a somewhat different distribution. The importance of *contour reversals* was illustrated by Watkins & Dyson (1985) by playing songs with a few notes altered each time. When altered notes occurred at contour reversals listeners were more likely to notice them. It has also been shown by Dowling (1978) that contour is important in our perception of melodies.

That listeners perceive repetition of contour has also been noticed by West, Howell & Cross (1985). The repetitive nature of music has been pointed out by others researchers as well, amongst them Huron (2006). Parncutt (1994 a & 1994 b) has studied listeners perception of metrical accent for repeating patterns giving credence to the notion of metrical salience based on rhythm. Generally speaking the first position in the meter is the most salient and subdivisions are less salient. On a similar theme, rhythmic organization of a melody may be perceptually more salient than the note pattern according to Dowling (1993), and according to Monahan (1993), listeners will group melodies (performed without accompaniment) based on the rhythmic pattern.

2 Method

2.1 Preparations

2.1.1 Turning Kern score to MIDI

The first project was to convert the Kern scores to MIDI. *Humdrum* (Huron, 1995) was used and some commands could be derived from the *Humdrum extras extension*. To access the Linux command-line, *Cygwin* (2012) was used. To convert and sort the files in a proper way commands of the following character was used (this command locates all songs of 3/2 meter and sorts them into a new folder) :

```
grep -l -Z 'M3/2' *.krn | xargs -0 mv -t C:/cygwin/Meter/32/ --
```

After this, to turn all Kern scores of all folders into MIDI files the following command was applied:

```
find -type f -name '*.krn' -print0 | xargs -0 -n1 sh -c 'hum2mid -P -C -T "$1"
-o C:/cygwin/Folder/"$(basename ${1%.krn}.mid)"' -
```

2.1.2 Preparation of data

In this study all songs have been converted to C major or A minor, which as an example for C major means that pitch height C represents the tonic, D represents the second etc.

The MIDI-toolbox (Eerola & Toiviainen, 2004) was used to turn the MIDI-files into a proper format in *Matlab* (2012). Easy-accessible Matlab files were created with the most common meters and the number of songs are shown in Table 1.

	2/4	3/4	4/4	6/8	Sub Total
Number of songs in Major	1047	921	1295	574	3837
Number of songs in Minor	69	66	138	81	354

Table 1: Matlab files were created for the following meters.

All songs in Table 1 were extracted with and without the human edited phrase slurs of the *Essen Folk Song Collection*. The number of songs extracted with and without phrase slurs varied slightly due to a few erroneous data. Phrase slurs and measure lines were first converted to MIDI notes to provide the possibility to move them to Matlab with the MIDI-toolbox. They were used in Matlab to align the MIDI files correctly with the meter and to mark up the phrase starts, and then they were removed.

2.2 Examinations

The songs were examined with simple Matlab commands. This is an example of a short Matlab code to calculate the average length of the notes of each interval.

```
for interval = -12:1:12                              %For each Interval
  len = 0;
  cou = 0;
  for jj = 1:length(nm2)                             %For each song
    song = nm2{jj};
    for ii = 1:(length(song)-1)                      %For each note
      if(song(ii,4) == song(ii+1,4) + interval)      %If correct interval
        len = len + (song(ii,2)+ song(ii+1,2));      %Add length
        cou = cou + 1;                               %Add count
      end
    end
  end
  pitchLen(interval+13) = len/(cou*2);               %Calculate ratio
end
plot(pitchLen)                                       %Plot findings
```

2.2.1 Ambitus

A separation into scale tones was accomplished by the scheme in Table 2.

Scale tone	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Semi-tone	1	3	5	7	8	10	12	13	15	17	19	20	22	24
Semi-tone	2	4	6		9	11		14	16	18		21	23	

Table 2: Separation into scale tones from semi-tones.

2.2.2 Pitch & Meter

The number of notes of each pitch as a relation to the total number of notes for each meter was examined. An average was also taken between four different meters. By doing so, the average would not depend on which meter that was most common within the data set.

2.2.3 Metrical Salience & Pitch

To visualize a possible correlation between strong metrical position and important notes of the scale (pitch salience) the pitches were sorted according to three different criteria. The aim was to score the pitch salience of each scale tone, where lower means more salient.

- Salience from the circle of fifths: {C = 1, G = 2, D = 3, A = 4, E = 5, B = 6, F = 7}
- Connection to the chord I (C major) as a relation to the connection to the chord V (G major): {C = 1, E = 2, A = 3, G = 4, F = 5, D = 6, B = 7}
- The total number of notes divided by the number of occurrences of each scale tone.

A relationship to the metrical positions could then be extracted for each criteria by summarizing the weighted pitches. The metrical positions where sorted into groups as described in Table 3.

Meter	4/4	2/4	3/4	6/8
1	{1,3}	{1}	{1}	{1,4}
2	{2,4}	{2}	{2,3}	{3,6}
3	{1.5,2.5,3.5,4.5}	{1.5,2.5}	{1.5,2.5,3.5}	{2,5}
4	{16^{th} notes}	{16^{th} notes}	{16^{th} notes}	{16^{th} notes}

Table 3: Positions in the measure sorted into groups based on metrical salience.

2.2.4 Intervals & Note Length

The code for this examination is displayed in section *2.2 Examinations*. An important aspect in visualizing the results was a cubic fitting. This as the results becomes very noisy for unusual intervals. The average of the length of both notes in each interval was used.

2.2.5 Double Notes

The aim is to show patterns of repeated twin notes with the same pitch and note length. An example of a song built around two notes of the same pitch followed by two new notes of the same pitch etc. is "Twinkle, Twinkle, Little Star". For 8^{th} notes no further examinations was done beyond 4 notes as so few examples was found and the statistical data became uncertain.

2.2.6 Stairs

The idea is to find units of notes with similar length that occur as falling or rising stairs. As different note length are examined the context of note length as affecting the tendency for stair-formations can be analyzed. To make the results generally applicable the total number of repeated notes of the different note lengths are used and the findings for the different note length becomes a ratio between the number of found stairs and the number of total occurrences. A comparison between rising and falling stairs is also interesting and therefore results are plotted both for falling and rising stairs, as well as for the sum of the two.

2.2.7 Contour

As *contour reversals* seem to be perceptually important (Watkins & Dyson, 1985) these were examined separately. To be able to display the results based on position in the meter a decision was made to only use the most common metrical positions. For a 4/4 meter this meant 8 positions an 8^{th} note apart from each other. In the results for *3.7.1 Contour Reversal* and *3.7.2 Direction* all semi-tones are displayed, as interesting relationships would otherwise have been lost.

2.2.8 Repetition

The phrase information in the *Essen Folk Songs Collection* opens the possibility for interesting examinations. When examining repetitions between phrases it has to be decided what actually constitutes a repetition. How much is the phrase allowed to deviate from perfect repetition for it to still count as a repetition? The phrases were examined for repetition in the time domain and in the pitch domain with different degrees of strictness regarding the repetition. In this way the reader gets the possibility to choose relevant data based on the nature of the repetition, and the reader also gets an overview of how the results changes as the demand for perfect repetition is altered.

2.2.9 Phrase Arch

Huron (2006) has done some interesting examinations of phrase contour. The findings were a rising contour in the beginning of the phrase and a falling contour in the end of the phrase as described in the background section. The precision of these examinations was improved by tracking how the phrase contour changes over the course of the song. The first and the last phrase was examined separately as it was expected that these phrases would produce the most distinctive results. Another idea was to produce more generally applicable results. This was achieved by not separating the phrases based on their length as done by Huron. Instead, the 5 first notes and the last 5 notes was examined separately for all phrases. If a phrase had less than 5 notes the missing notes were disregarded.

2.2.10 Tonal Resolution

The end point at which the melody resolves at the tonic is interesting to examine. The examination is done in the pitch domain for a few of the last notes. If the melody did not end at the tonic that song was disregarded. The distance to C was calculated as described in Table 4.

Pitch	C	D	E	F	G	A	B
Distance	0	1	2	3	3	2	1

Table 4: The distance to the tonic C, used in calculations for tonal resolution.

3 Results

3.1 Ambitus

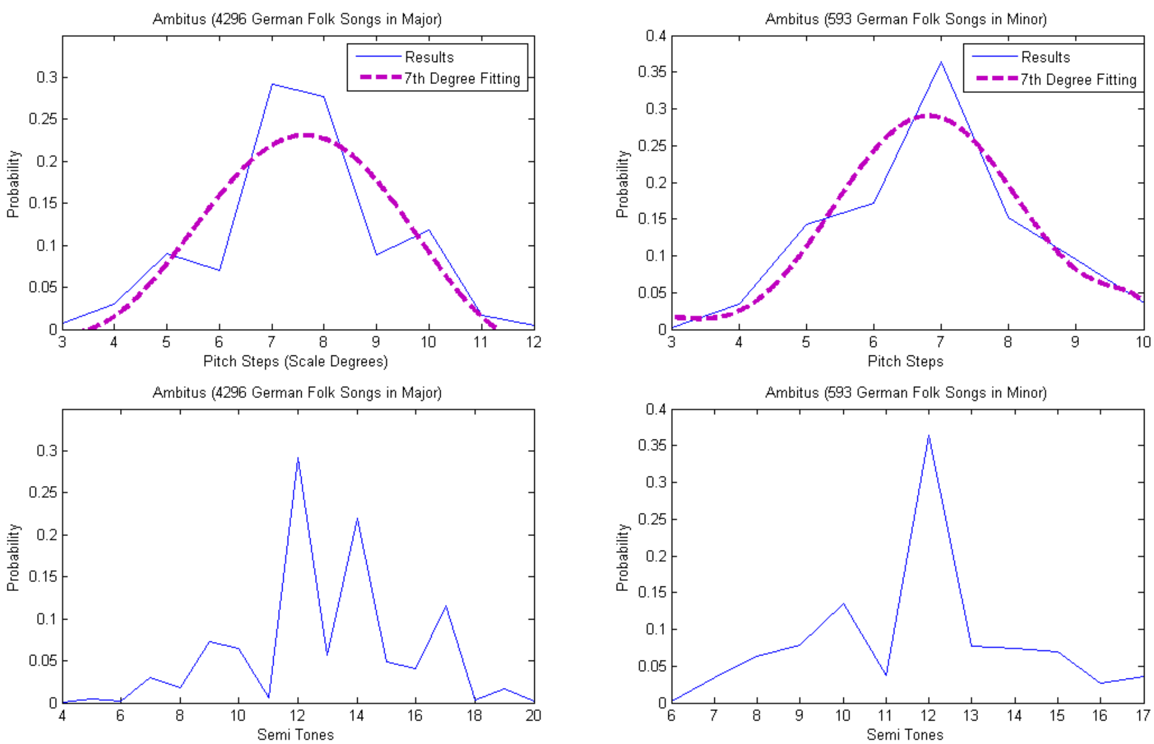

Figure 1: Ambitus in major (left) and minor (right), both displayed as scale tones (top) and semi-tones (bottom).

In figure 1 we find that an ambitus of 7 or 8 scale tones is the most common in major mode and that an ambitus of 7 scale tones is the most common in minor mode.

3.2 Pitch & Meter

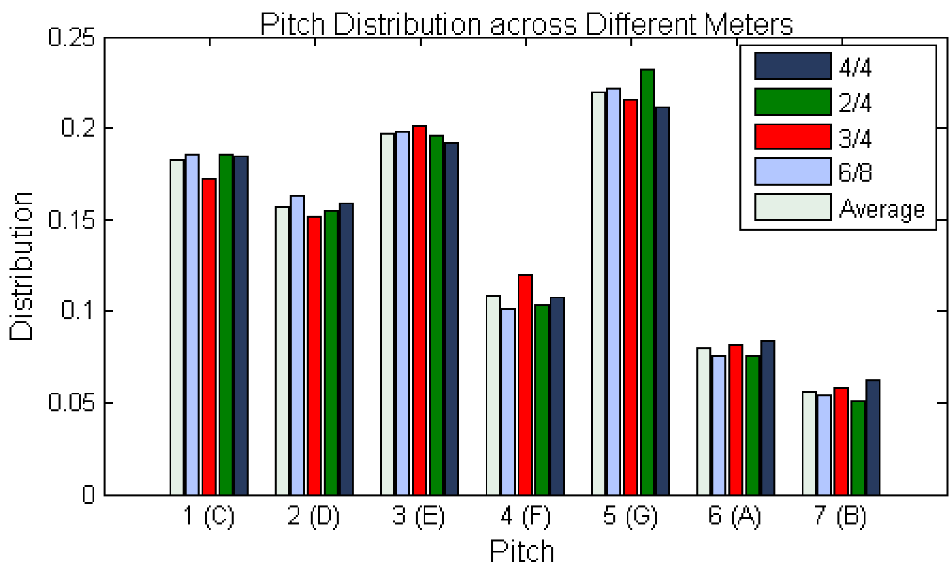

Figure 2: The distribution of pitches in different meters.

No significance difference in the pitch distribution across different meters was found (Figure 2).

3.3 Metrical Salience & Pitch

For each meter a table (Tables 5-8) shows the relative distribution of the scale pitches for different positions in the measure, and a figure (Figures 3-7) plots the correlation between pitch salience and metrical salience.

3.3.1 4/4 - Major

Beats/Pitches	C	D	E	F	G	A	B
1	0.3076	-0.1339	0.0828	-0.2562	0.0039	-0.0409	-0.343
1.5	-0.2813	0.2274	-0.2059	0.4519	-0.0733	0.0796	0.249
2	-0.1004	0.0669	0.1039	-0.0118	-0.0319	0.0102	-0.0788
2.5	-0.2419	0.1693	0.0144	0.4156	-0.2879	0.243	0.1715
3	0.0212	0.0758	0.0545	-0.1181	0.0064	-0.0827	-0.131
3.5	-0.1363	-0.0523	-0.3032	0.4375	0.0841	0.1241	0.2641
4	-0.0155	-0.0599	-0.1652	-0.0993	0.2338	-0.0152	0.1079
4.5	-0.322	-0.0307	0.0509	0.4671	-0.1684	0.0305	0.6015
16^{th} notes	-0.1039	0.1985	-0.0593	0.2115	-0.2661	-0.0207	0.5516

Table 5: Relative distribution of pitches at metrical positions in 4/4 meter and major mode.

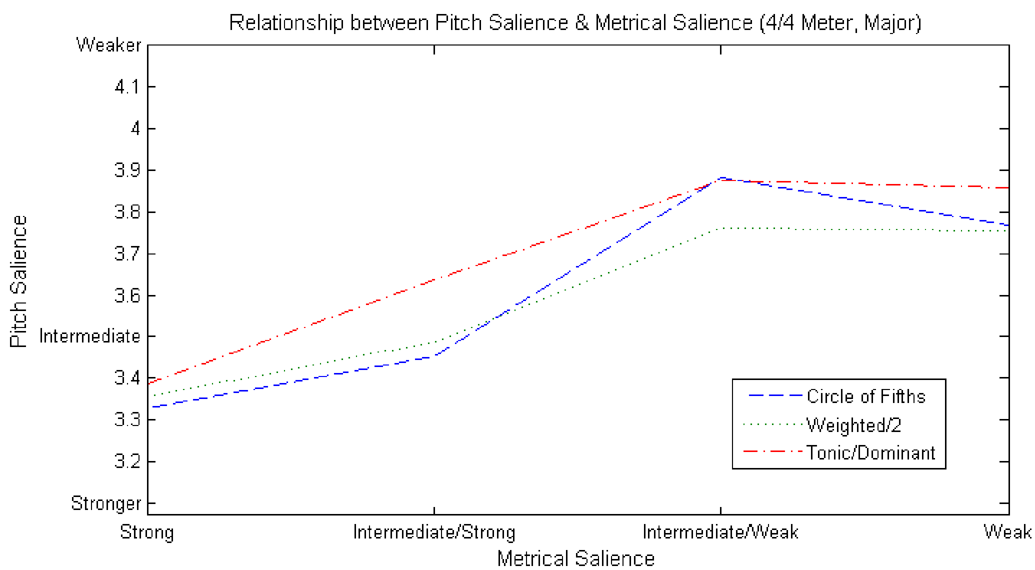

Figure 3: The relationship between metrical salience and pitch salience in 4/4 meter and major mode.

The similarity between *Intermediate/Weak* {1.5,2.5,3.5,4.5} and *Weak* {16^{th} notes} in Figure 3 indicates that there is no increase of pitch salience between the respective positions in 4/4 meter.

3.3.2 2/4 - Major

Beats/Pitches	C	D	E	F	G	A	B
1	0.3271	-0.1804	-0.0441	-0.2115	0.0735	-0.0758	-0.2655
1.5	-0.1256	0.004	-0.0073	0.1698	0.0619	-0.072	-0.0465
2	-0.0619	0.1164	0.1412	-0.1005	-0.0992	-0.0505	0.0589
2.5	-0.1539	0.0289	-0.1016	-0.0122	0.1332	0.1032	0.1292
16^{th} notes	-0.2914	0.178	0.0152	0.6571	-0.3585	0.2296	0.4154

Table 6: Relative distribution of pitches at metrical positions in 2/4 meter and major mode.

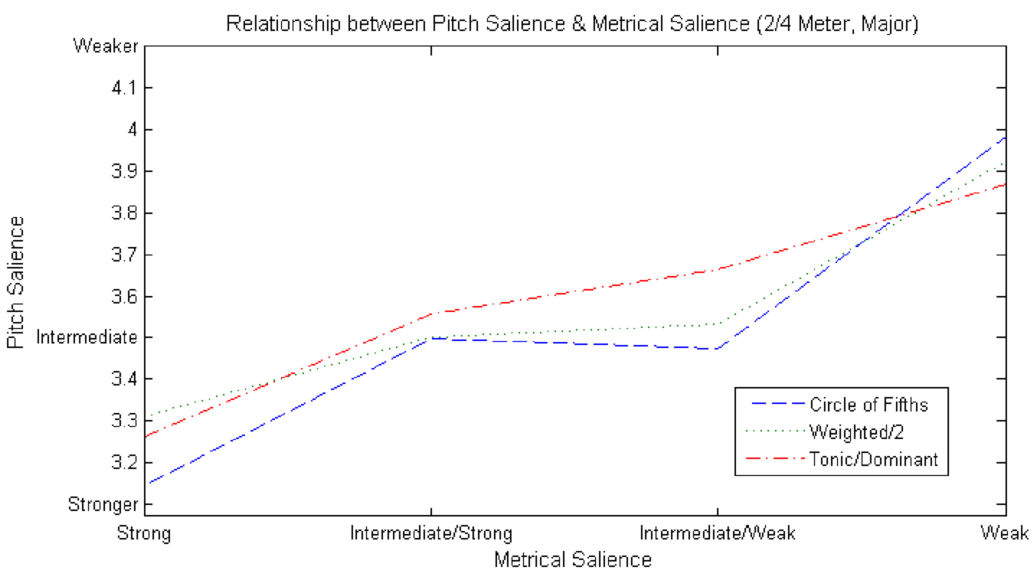

Figure 4: The relationship between metrical salience and pitch salience in 2/4 meter and major mode.

The similarity between *Intermediate/Strong* {2} and *Intermediate/Weak* {1.5,2.5} in Figure 4 indicates a relatively small increase in pitch salience between the respective positions in 2/4 meter.

3.3.3 3/4 - Major

Beats/Pitches	C	D	E	F	G	A	B
1	0.3316	-0.1367	-0.0114	-0.2112	0.0667	-0.1038	-0.2538
1.5	-0.248	-0.0601	0.046	0.1369	-0.0504	0.1588	0.4171
2	0.0684	0.0534	0.0522	-0.0454	-0.0524	-0.0922	-0.1063
2.5	-0.2611	0.0494	-0.07	0.2249	0.0365	0.26	-0.0789
3	-0.0654	0.0384	0.0065	-0.1014	0.0511	-0.0648	0.1839
3.5	-0.3031	0.0535	0.0076	0.3088	-0.0629	0.1188	0.1622
16^{th} notes	-0.3522	0.2706	-0.0769	0.5444	-0.2455	0.253	0.0325

Table 7: Relative distribution of pitches at metrical positions in 3/4 meter and major mode.

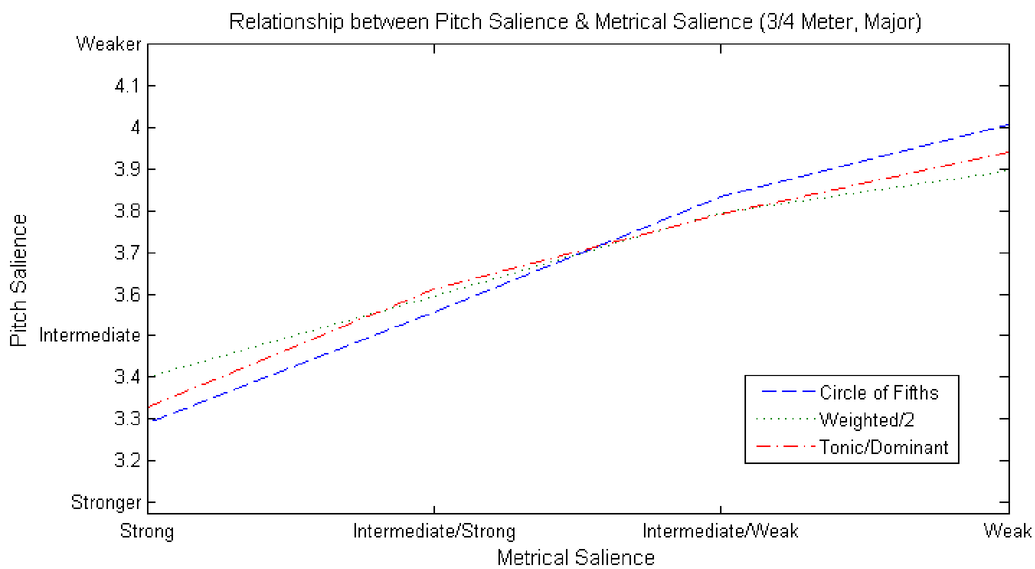

Figure 5: The relationship between metrical salience and pitch salience in 3/4 meter and major mode.

A steady increase of pitch salience with increased metrical salience for 3/4 meter (Figure 5).

3.3.4 6/8 - Major

Beats/Pitches	C	D	E	F	G	A	B
1	0.2894	-0.211	0.1241	-0.2749	0.0715	-0.1401	-0.3936
2	-0.1712	0.0234	-0.0168	0.3265	-0.1991	0.356	0.2841
3	-0.0057	0.0458	0.0728	0.0149	-0.0573	-0.044	-0.1147
4	0.0493	0.1669	-0.0202	-0.0831	-0.0031	-0.1632	-0.1995
5	-0.0947	0.0317	-0.0652	0.4068	-0.4409	0.262	1.1397
6	-0.1723	-0.056	-0.1319	-0.0977	0.3007	-0.0233	0.2235
16^{th} notes	-0.4038	0.3207	-0.061	0.9068	-0.5114	0.6767	0.0977

Table 8: Relative distribution of pitches at metrical positions in 6/8 meter and major mode.

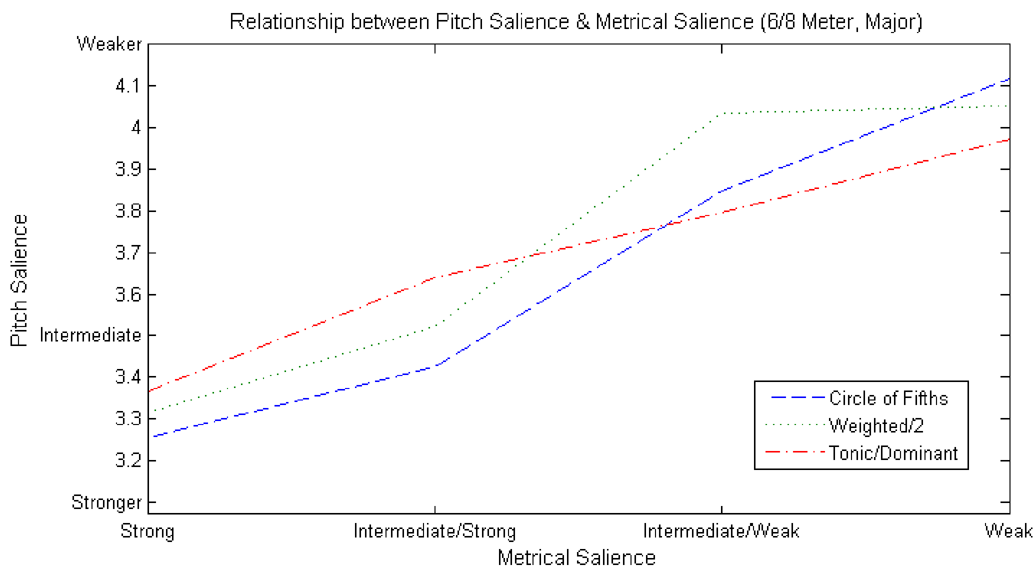

Figure 6: The relationship between metrical salience and pitch salience in 6/8 meter and major mode.

A relatively steady increase of pitch salience with increased metrical salience can be observed for 6/8 meter (Figure 6).

3.3.5 Combined

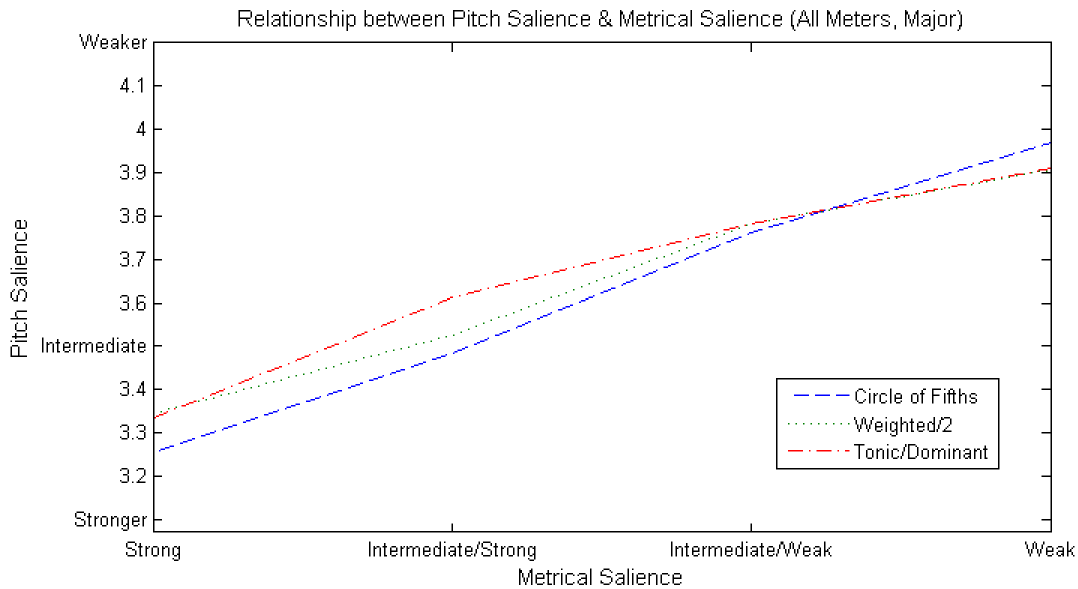

Figure 7: The relationship between metrical salience and pitch salience as an average of all examined meters.

Overall the idea of increasing pitch salience with increasing metrical salience seems to comply with the data as can be seen in Figure 7. However, for notes that belong to the dominant chord and not the tonic chord (B & D with the highest weightings in *tonic/dominant*) there are indications in Tables 5-8 of an even stronger difference depending on the positioning *start/end* of the measure.

3.4 Intervals & Note Length

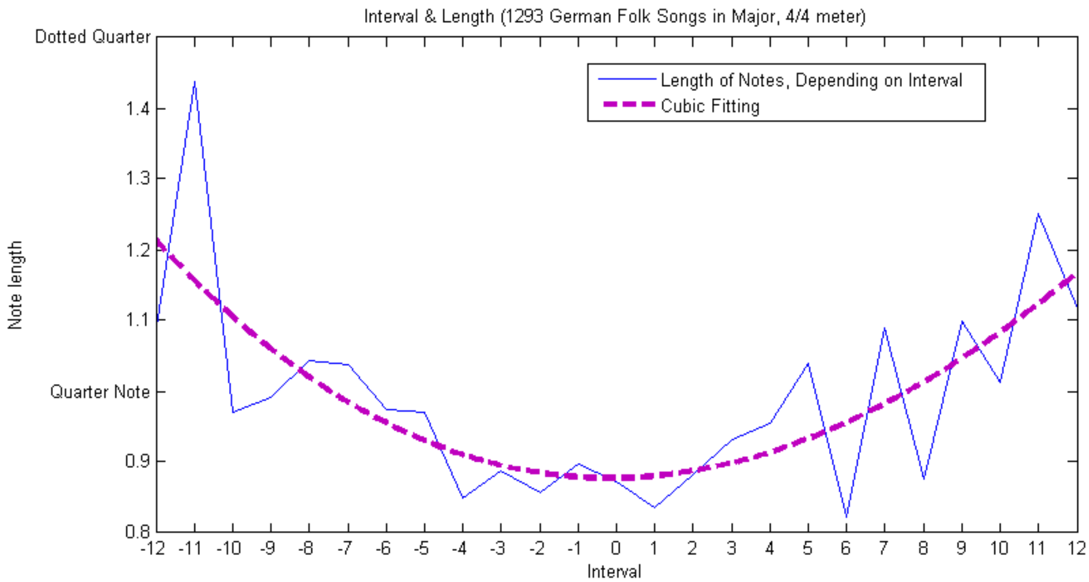

Figure 8: The average note lengths for different intervals. Note length is calculated as the average note length of the two notes that constitute the interval. A cubic fitting has been applied to illustrate the concave pattern with shorter note lengths for smaller intervals and longer note lengths for larger intervals.

We find in Figure 8 that large intervals occur between longer notes and small intervals occur between shorter notes.

3.5 Double Notes

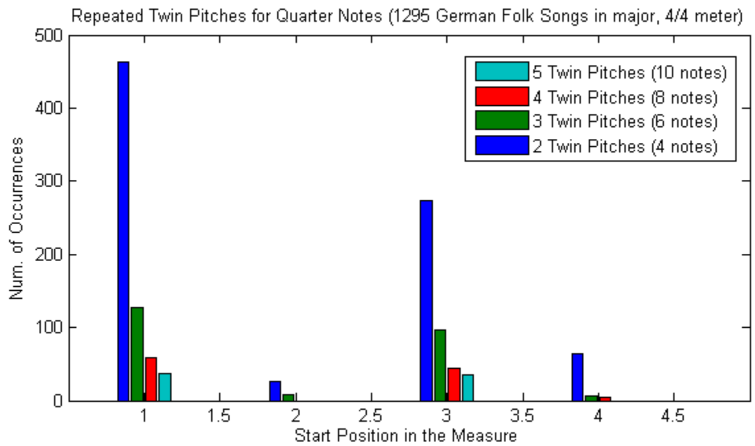

Figure 9: The number of twin pitches (two repeated pitches followed by two new repeated pitches etc.) for quarter notes with start position for the whole pitch succession displayed in the measure.

Notice (Figure 9) how the stronger metrical position {1,3} take precedence over {2,4}, and that there are no occurrences at {1.5,2.5,3.5,4.5}. The formation of 2 twin pitches (4 notes) occurs 0.64 times per song.

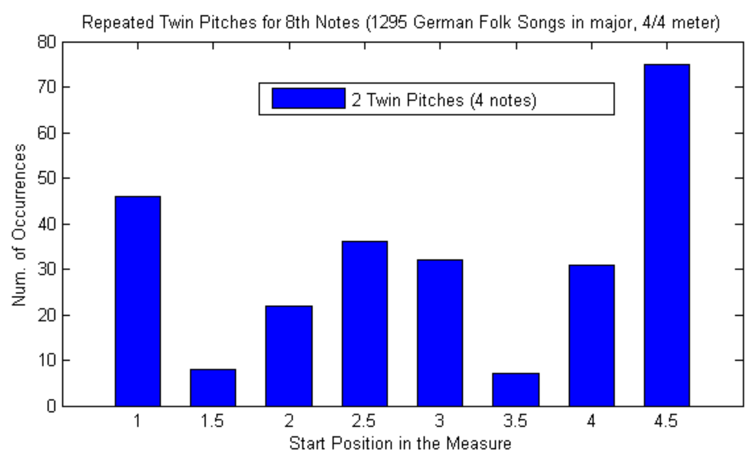

Figure 10: The number of twin pitches (two repeated pitches followed by two new repeated pitches etc.) for 8^{th} notes with start position for the whole pitch succession displayed in the measure.

For the 8^{th} notes (Figure 10) the results are harder to interpret. There are fewer matches overall and there seems to be a repeating pattern for the first four 8th notes and the last four 8th notes of the measure.

3.6 Stairs

Notice that for this part the measure (4/4 meter) was divided into 8 positions, meaning that starts on 16th positions was not taken into consideration.

	16th	8th	Quarter	Half	.	16th	8th	Quarter	Half	.	16th	8th	Quarter	Half
Total	103	8693	12640	429	.	103	5752	8751	192	.	32	3427	5962	101
Rising	39	2051	1437	113	.	28	835	501	22	.	0	192	137	6
Falling	11	783	840	21	.	3	213	236	0	.	0	50	42	0
Stair of	3	3	3	3	-	4	4	4	4	.	5	5	5	5

Table 9: A summary of the findings for stairs. The *Total* count represents the total number of notes with the same length.

As evident in Table 9, for five 16th notes the total count of occurrences was only 32 and the statistical data became very uncertain. Notice that if three 16th notes comes in a row a fourth follows every time in the data.

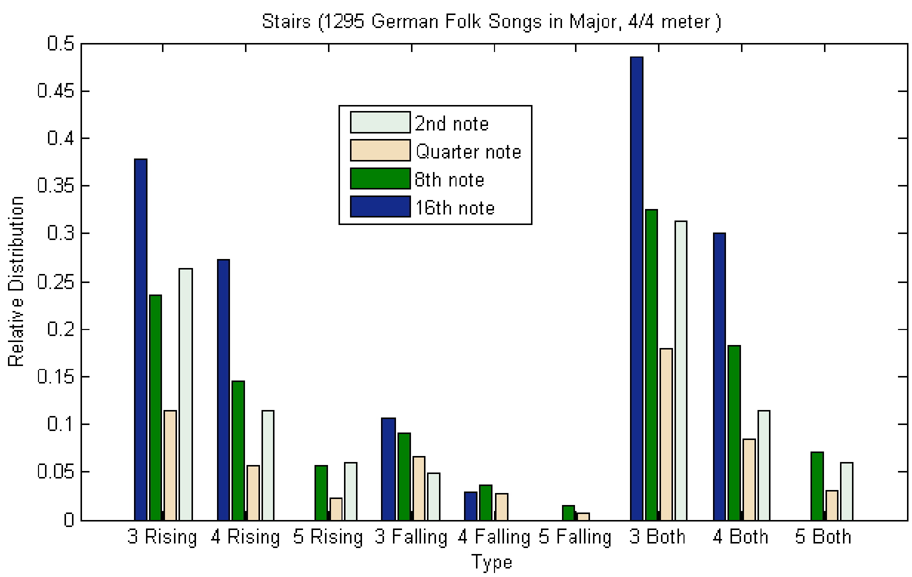

Figure 11: Relative distribution for stairs of varying length, with varying note lengths.

Notice (Figure 11) that rising stairs are significantly more common than falling stairs. Notice also that stairs are more common for faster note progressions. However half notes seem to be more common than quarter notes.

3.7 Contour

Notice that for this part the measure (4/4 meter) was divided into 8 positions, meaning that starts on 16^{th} positions were not taken into consideration.

3.7.1 Contour Reversal

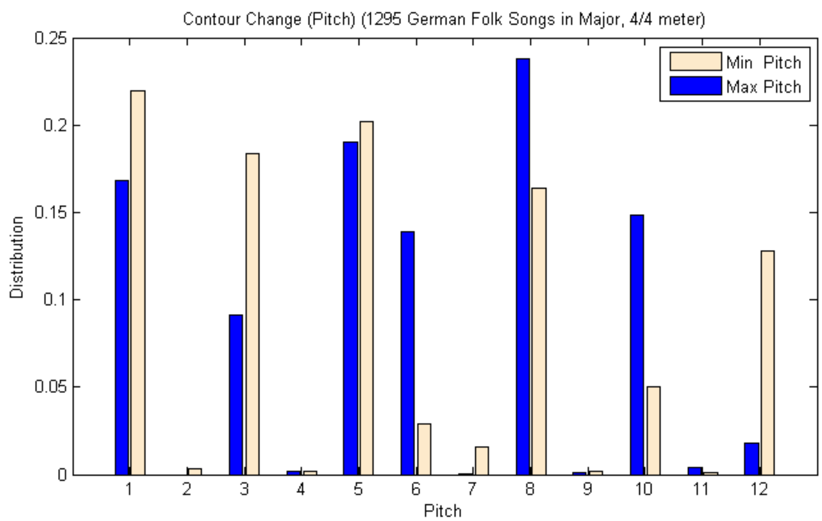

Figure 12: The distribution of contour reversals for different pitches.

As we study the results based on pitch (Figure 12) we find that 5 (E) and 8 (G) are most common as maximum pitches and that 1 (C) and 3 (E) are most common as minimum pitches in a *contour reversal*. For the two notes in C major that are non-pentatonic, 6 and 12 (F and B), there are large differences between minimum and maximum. A succession of three notes in a row far from the tonic in C major 6, 8 and 10 (F, G and A) are all maximum pitches. A succession of four notes in a row close to the tonic 12, 1, 3 and 5 (B, C, D and E) are all minimum pitches.

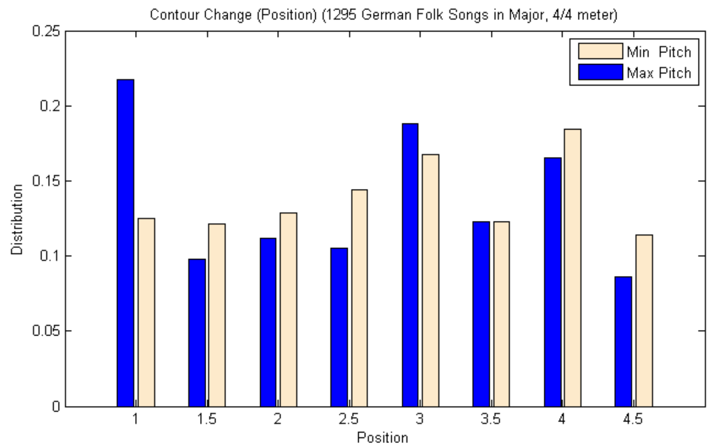

Figure 13: The distribution of contour reversals for different positions in the measure.

The maximum position tends to occur on (salient) beats and the first beat is especially common (Figure 13). The results for the minimum position is more inconclusive.

3.7.2 Direction

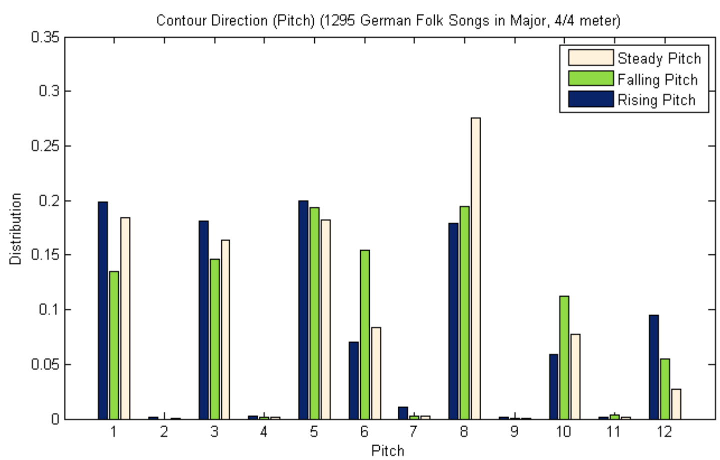

Figure 14: The distribution for the subsequent direction from different pitches.

As can be seen in Figure 14, pitch 12 (B) tends to move upwards and pitch 6 and 10 (F and A) tends to move downwards whereas pitch 8 (G) is often steady.

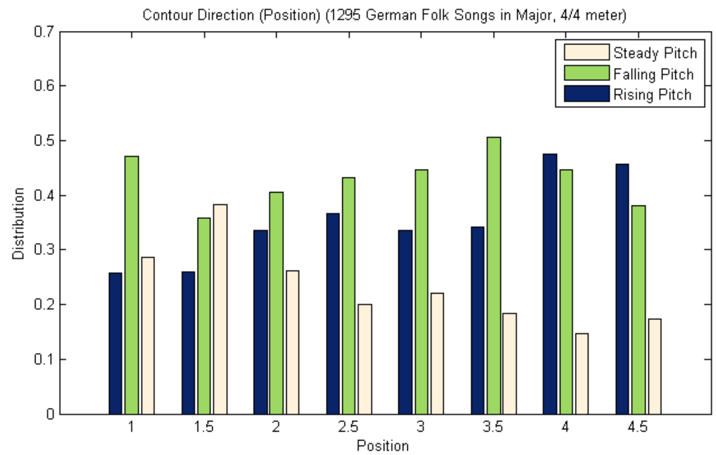

Figure 15: The distribution for the subsequent direction from different positions.

From Figure 15 we find that the positions from where the pitch rises are mainly in the end of the measure. The steady pitches are more common in the beginning. The results for the positions from where the pitch is falling are inconclusive.

3.7.3 Good Continuation

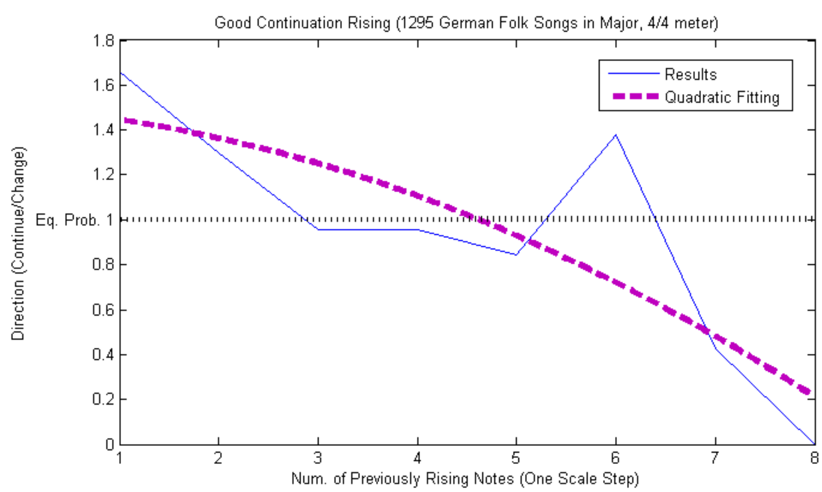

Figure 16: The probabilities for more rising intervals after x number of rising intervals of one pitch step.

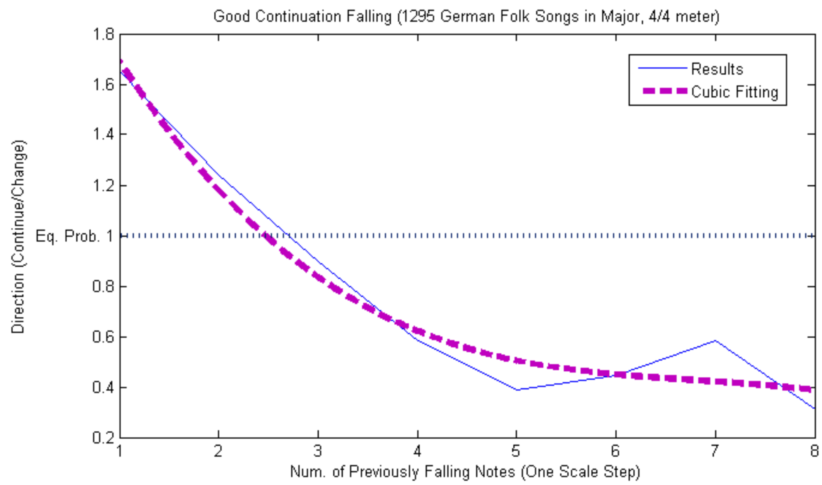

Figure 17: The probabilities for more falling intervals after x number of falling intervals of one pitch step.

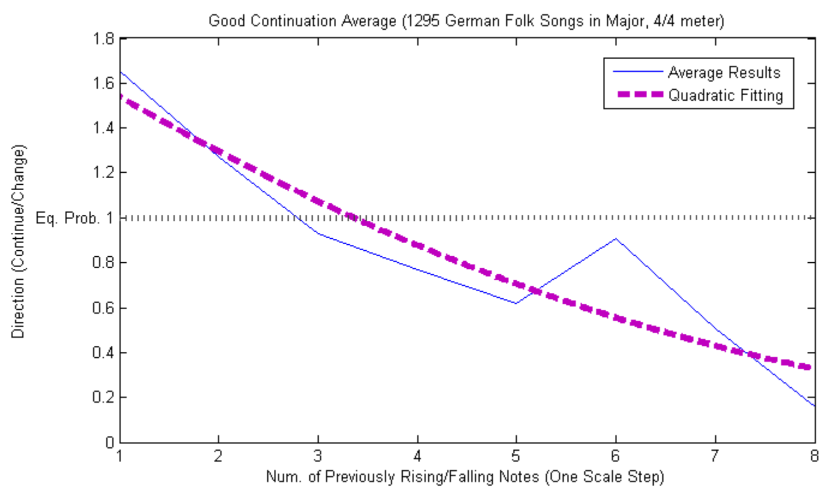

Figure 18: The probabilities for intervals to continue in the same direction after x number of intervals of one pitch step in that direction.

The findings in Figures 16-18 for good continuation indicate the following correlation: *When a new directions has been established the probabilities to continue in the same direction are high. As more notes follow in the same direction the probabilities are lowered.*

3.8 Repetition

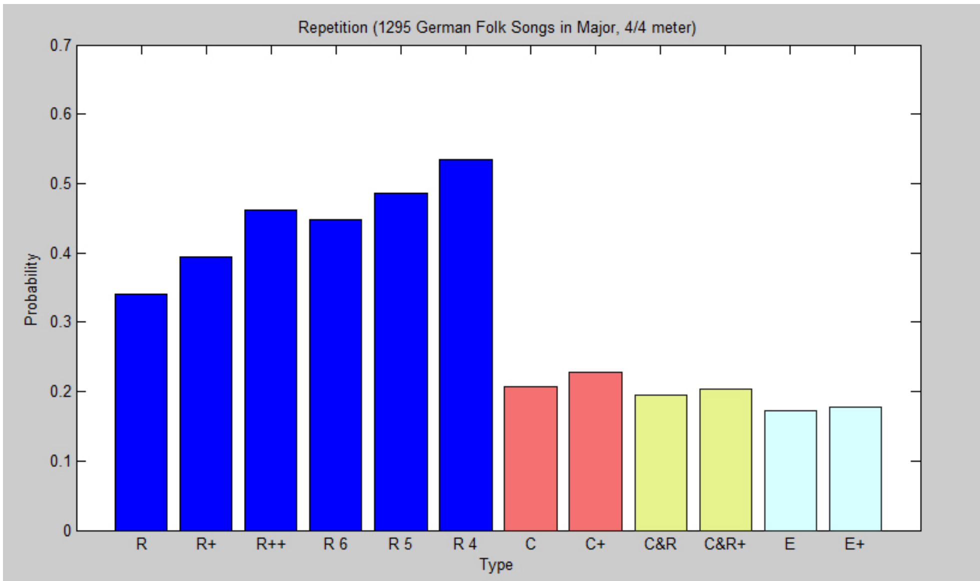

Figure 19: The probabilities for different forms of phrase repetition. The probabilities represents how likely it is for any given phrase of a song to be a repetition of an earlier phrase. This means that if one phrase repeats another in a song of two phrases it is counted as 0.5, there is a 50 % probability for a randomly chosen phrase to be repeated. For a song of three phrases where they all repeat each other the score will be 0.67. The probability will never reach 1 as the first phrase does not repeat any earlier phrase.

R = Rhythm, C = Contour, C&R = Contour & Rhythm, E = Exact repetition with identical pitches, + = Varying phrase length, ++ = Varying phrase length and one note different, {4,5,6} = Number of the first notes of a phrase that are repeated.

Figure 19 shows the results for phrase repetition. As the first phrase is also counted and as this phrase will of course not repeat any earlier phrases the probabilities are somewhat underestimated.

3.9 Phrase Arch

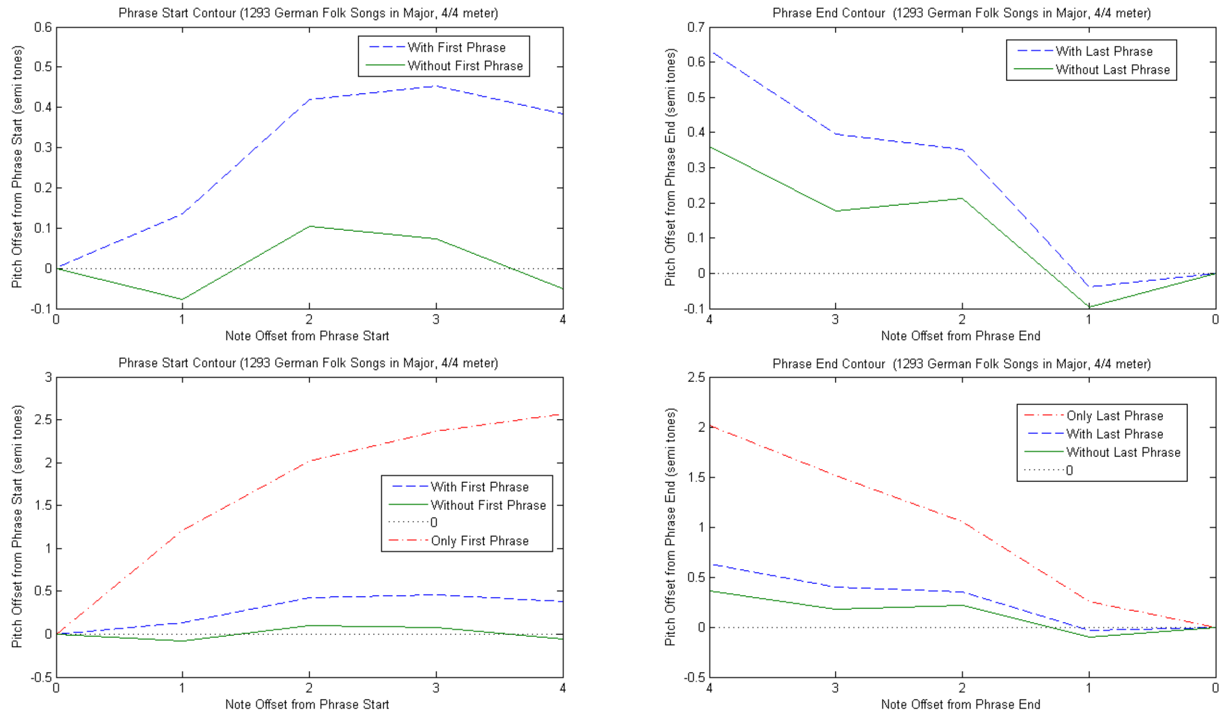

Figure 20: The average contour for the beginning (left) and the end (right) of each phrase.

Notice (Figure 20) that the rising contour for the beginning of the phrases is strongest for the first phrase (bottom, left). If the first phrase is removed no rising contour can be detected (top, left). Notice also that the falling contour for the end of the phrases is strongest for the last phrase (bottom, right). If the last phrase is removed there is however still a small tendency for a falling contour in the end (top, right).

3.10 Tonal Resolution

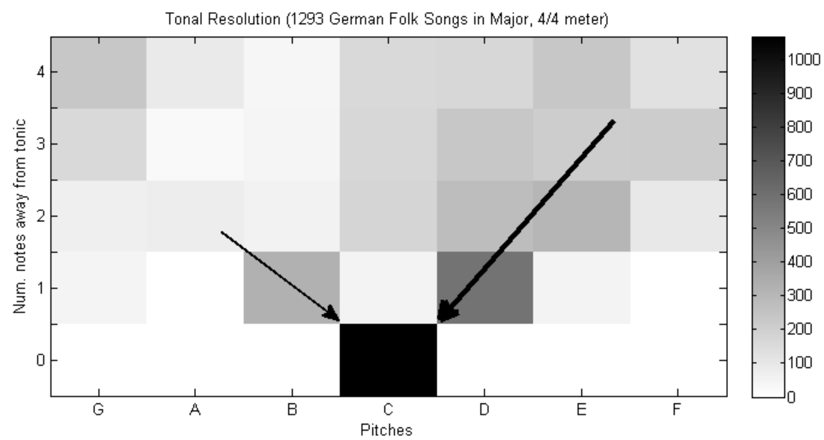

Figure 21: The pitches of the last notes of a song. The songs have been transposed to C and only the songs that ends on the tonic C were evaluated. Arrows indicate common movements.

A falling motion is common in the end of a song as visualized by the thicker arrow (Figure 21).

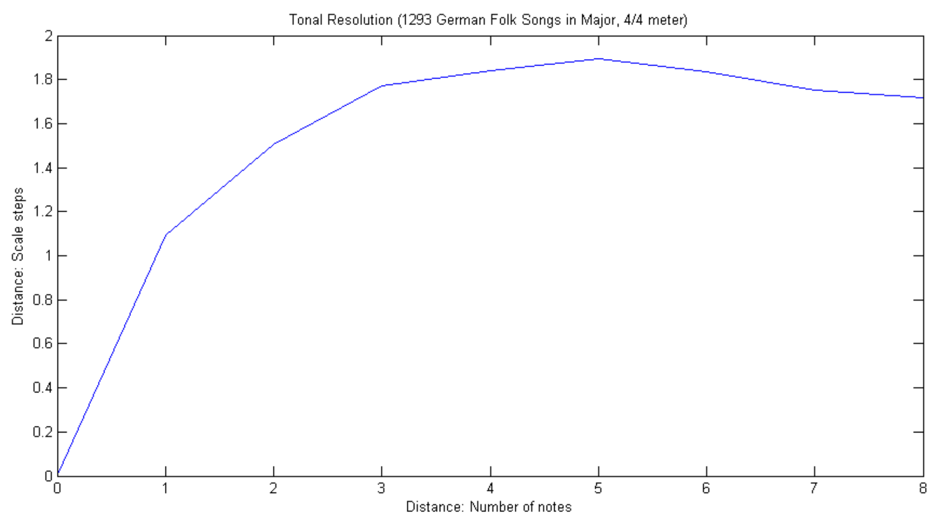

Figure 22: The distance in scale steps to the tonic C for the last notes of a song. The songs have been transposed to C and only the songs that ends on the tonic C were evaluated.

When there are five notes left the distance to the tonic (C) starts to decrease (Figure 22).

4 Discussion

4.1 Ambitus

The findings for ambitus in Figure 1, section 3.1, are in line with earlier findings from Danish folk songs (Holm, 1984). The tendency for a lower ambitus for the songs in minor are somewhat interesting and could be further examined. Perhaps a correlation to the length of the examined melody can be found as well. Also notice from the semi-tone figures that the ambitus for songs in minor is smoother than the ambitus for songs in major. Perhaps this is due to the characteristics of the minor scale where in A minor the notes F, $F^{\#}$, G and $G^{\#}$ all occur frequently (Krumhansl & Kessler, 1982 as cited in Huron, 2006; Eerola & Toiviainen, 2004).

4.2 Pitch & Meter

The pitch distribution in Figure 2, section 3.2, is very similar between different meters. One could imagine that there would be deviations in pitch distribution, as certain genres with different distributions of the pitches would perhaps use different meters, but none was found.

4.3 Metrical Salience & Pitch

We find strong indications of a correlation between pitch salience and metrical salience (Figures 3-7, section 3.3). A correlation has been found for all three examined weightings of the pitches. The fact that this correlation exists in such a similar way, independently of if you regard pitch salience as depending on the *Circle of Fifths*, *Weights*, or the *Tonic/Dominant* scheme, tells us that there is accuracy in the findings.

It is also interesting to examine the pitch deviations in Tables 5-8, section 3.3. We find that notes belonging to the dominant chord but not the tonic chord (B and D) are more common towards the end of the measure whereas C is most common at the first position in the measure. This could be studied further.

4.4 Intervals & Note Length

The findings in Figure 8, section 3.4, clearly indicate a correlation between the length of the notes and the size of the interval as large intervals often occur between longer notes and small intervals are more often found between shorter notes. For unusual intervals (such as certain large intervals) the statistical foundation becomes smaller, producing more random results, and the cubic fitting comes in handy to visualize the correlation. A next step could be to plot common note lengths in the x-axis and their average interval in the y-axis. Perhaps the transition between different note lengths will be less smooth than the transition between different intervals.

4.5 Double Notes

For quarter notes (Figure 9, section 3.5) the most interesting findings were that the first note of *double notes* much more often start at the more metrically salient {1,3} than the less salient {2,4}. With 0.64 occurrences per song of two twin pitches in a row (for quarter notes), the phenomena is fairly common.

For the 8^{th} notes (Figure 10, section 3.5) there seems to be a repeating pattern for the first four 8^{th} notes and the last four 8^{th} notes of the measure. One possible interpretation is that *double notes* have a tendency to start with metrically salient positions also for 8^{th} notes. They may start an 8^{th} note before but not an 8^{th} note after the metrically salient position to include that position early on in the double note formation.

4.6 Stairs

We find in Figure 11 and Table 9 of section 3.6 that stairs are more common for faster note lengths if the total number of repeated notes of the different note lengths are taken into consideration. As quarter notes and 8^{th} notes are more common the statistical findings for these two is more reliable. Here we find that for all nine types, the 8^{th} note stair is more common than the quarter note stair if their relative commonality is taken into consideration. We also find that for all nine types where the 16^{th} notes are represented they are more common than the quarter note stairs. Stairs for the half notes are relatively common despite their length. One reason may be that they are as long as the length of shorter chords. For a stair of one pitch step per note this means that all notes can harmonize well with the chords which is not possible for stairs of shorter note lengths.

Stair formations tend to occur more often in a rising formation. This is especially interesting when put in the context of the most common direction of the melody as found in 4.7.2, where we find that falling pitches are more common than rising pitches. It is also the opposite of what have been found to be true for intervals in general, that small intervals more often descend than ascend (Vos & Troost, 1989). There seems to be something special with stairs that makes them more common as rising than falling. Perhaps stairs can be perceived as moving more clearly towards a specific goal for a rising contour than a falling contour, making rising stairs more useful to the composer.

4.7 Contour

4.7.1 Contour Reversal

If we examine the total number of occurrences as maximum or minimum pitch for the different pitches in Figure 12 of section 3.7.1 we find that the most common pitches overall are more common as *contour reversals*. There are big differences for many pitches in their tendency to be the maximum pitch and the minimum pitch at a contour reversal. Pitch 12 (B) occurs 7 times more often as a minimum pitch than a maximum pitch and pitch 6 (F) occurs almost 5 times as often as a maximum pitch than as a minimum pitch. Why does this happen? One reason may be that both of these extremes are found for notes that are non-pentatonic. We find that the tendency in pitch 6 (F) to become the maximum pitch may be explained by its close connection to pitch 5 (E) one semi-tone away. The same reasoning can be applied to pitch 12 (B) that has a strong tendency to move towards pitch 1 (C) one semi-tone away. An answer may also be found in counterpoint which constitute that the tritone interval (6 semi-tones) is forbidden between any of 3 subsequent notes (Girton, 2001). This could make 12 (B) less likely to be reached from below and and 6 (F) less likely to be reached from above.

Another interesting result, as also was pointed out in the section 3.7.1, is that a succession of three notes in a row far from the tonic in C major 6, 8 and 10 (F, G and A) are all maximum pitches. A succession of four notes in a row close to the tonic 12, 1, 3 and 5 (B, C, D and E) are all minimum pitches. Why does this happen? Here a conclusive answer is harder to give. Perhaps it is an effect that arises as a result of the fact that two notes within the scale in a row, 10 and 12 (A and B), does not belong to the tonic chord. If we assume that the tonic chord is the most common, that melodies tend to move with small intervals and that it is unusual for two notes in a row in melodies to not belong to the chord, pitch 10 and 12 creates a barrier. Notes above the barrier {12,1,3} etc. will move away from the barrier upwards and notes below the barrier {6,8,10} will move away from the barrier downwards.

As we study where in the measure the maximum and the minimum pitch occur, we find - as concluded in the section 3.7.1 - that the maximum position tends to occur on (salient) beats and that the first beat is especially common (Figure 13). The results for the minimum position is more inconclusive. A tendency for them to occur later in the measure seems to exist. We finally conclude that differences for maximum and minimum pitch are much stronger in the pitch domain than in the time domain.

4.7.2 Direction

When rising and falling contours are examined (Figures 14-15, section 3.7.2) the tendency that can be observed for *contour reversal* is once again apparent. Pitch 12 (B) tends to move upwards and pitch 6 (F) tends to move downwards (Figure 14). A similar explanation (non-pentatonic notes moving one semi-tone) may be applied here as well. Overall the findings for *direction* is less clear than the findings for *contour reversal*. Interesting is also the tendency for 8 (G) to be steady. One explanation may be that G belongs to the two most common chords I (tonic chord) and V (dominant chord). G can therefore occur repeatedly and still belong to the chord. The higher tendency for 10 (A) to fall may be explained by the movement to the steady and common G and the movement away from the earlier proposed barrier that A and B forms.

In the measure (Figure 15) we find that the rising intervals occur towards the end of the measure and the steady intervals (same pitch) occur towards the beginning. The falling pitch is perhaps a little more common towards the end but the findings are inconclusive. An explanation for steady intervals in the beginning of the measure can perhaps be traced to the chords. In the beginning of a measure a new chord has often recently been introduced and the melody can rest steadily at chord notes. In the end of the measure we instead soon have a new chord with different pitches to which the melody must move.

We again conclude that differences are much stronger in the pitch domain than in the time domain.

4.7.3 Good Continuation

The probability to continue in the same direction when a new direction has just been established is high both for rising and falling contours (Figures 16-17, section 3.7.3). They however differ between the 4^{th} and the 6^{th} note. Perhaps the fact that rising stairs are more common than falling stairs (Figure 11, section 3.6) offer an explanation here. The higher scores for rising contour between the 4^{th} and the 6^{th} note would in that case be a result of our predisposition to these rising stair lengths. Overall the findings in Figure 18, section 3.7.3 can be summarized in the following way:

If a new direction has been established by an interval of one pitch step, new intervals of one pitch step tends to continue in the same direction. As 3-5 notes have passed in the same direction the probabilities are instead higher for a change of direction.

The decrease in probability as more notes are added in the same direction can probably be connected to the ambitus (Figure 1, section 3.1). The melody can only continue in the same direction for a certain number of notes before the melodic range is reached. For each note added in the same direction the probabilities to reach the melodic range increases. As was pointed out in the introduction, with the role of regression towards the mean pitch (section 1.1), different aspects of the melody must be taken into consideration. This is a similar case where regression to the mean can also be applied in a meaningful way.

4.8 Repetition

In Figure 19 of section 3.8 we found that about 40 % of any randomly chosen phrase in the data will be a rhythmical repetition of an earlier phrase. This if we accept phrases with identical rhythm but different lengths as an approved repetition. For repeated contour the probability is close to 20 %. Notice (by comparing *C* and *C&R* in Figure 19) that almost all contour repetitions are rhythm repetitions as well. We have 0.196 for *C&R* and 0.207 for only *C*. If we accept varying length we have 0.204 for *C&R* and 0.228 for *C*. This last phenomena can be interpreted in the following way:

If we have a repetition, one of two cases, which have about the same probability is likely be true. Either it is a rhythmical repetition or it is a repetition of both rhythm and contour.

That contour is so rarely repeated on its own is interesting as it in a way contradict the notion that listeners can perceive repeated contour independently (West et al., 1985). However it has been repeatedly observed (Dowling, 1993; Monahan, 1993) that the rhythmic organization is perceptually more salient.

4.9 Phrase Arch

One of the most interesting findings of this study is for phrase arches (Figure 20, section 3.9). It highlights the uncertainties in statistical music analysis, where it is hard for the researcher to know what is actually studied in the music. What seemed to be a rising contour in the beginning of the phrase may instead turn out to be a rising contour in the beginning of the song. What seemed to be a falling contour in the end of the phrases may instead turn out to be a falling contour in the end of each song. As pointed out by one of my supervisors Anders Friberg, with this data it seems like there is a phrase arch present in each song and not in each phrase. The same phenomena was also observed by Huron (2006) in the original study of phrase arches. When he took the average pitch height of all phrases an arch-like structure appeared. The phenomena could be referred to as song arch and further studies of it will be done.

Let us analyze the results for the start and the end of the phrase separately. For the beginning of the phrase we see that for the first phrase of the songs, at the fifth note (interval 4 in Figure 20) the melody has risen with about 2.5 semi-tones, but when the first phrase is excluded and all the other phrases observed, the melody has instead fallen 0.05 semi-tones. At the point where the contour has risen the most when excluding the first phrase we find that it has risen 0.1 semi-tones and that this occur at the third note (interval 2 in the figures). At the same position for the first phrase the contour has risen 2 semi-tones. The difference is striking and highlights the importance of the first phrase concerning rising phrase contour.

Lets look at the contour at the end of the phrase. We find that when 4 intervals remain the contour for the last phrase of the song will on average still have 2 semi-tones left to fall. At this position if we exclude the last phrase we instead find 0.36 semi-tones left to fall. Once again a big difference has been found. This time however, the tendency for a falling contour in the end of a phrase still has some merit.

In conclusion the idea of a rising contour in the beginning of a phrase seems to be entirely connected to a rising contour in the first phrase. The idea of a falling contour in the end of a phrase is strongly connected to a falling contour in the last phrase but also present if the last phrase is removed.

4.10 Tonal Resolution

As could perhaps be expected the melody gradually moves closer to the tonic C in the end of the songs before the actual tonic is reached (Figure 22, section 3.10). We see how the tendency for the melody to approach the last note from above (as described for phrase arch) is reflected in the large number of occurrences for D and E just before the end (Figure 21, section 3.10). Arrows have been applied to mark what seems to be common movements.

There is a small tendency for the melody to move away from C, 4-6 notes before the end (evident in Figure 22). The distance from C is higher there (1.90) than the average distance for the whole song, which is 1.73. This finding is certainly interesting, but the deviation is perhaps to small for any distinct conclusions.

5 Conclusions

We have found correlations between pitch and time for several aspects. It is evident from *3. Metrical Salience & Pitch, 5. Double Notes* and *7. Contour* that pitch in various ways is affected by metrical position. For *4. Intervals & Note Length* and *6. Stairs* we have found correlations between intervals and note length. Interesting findings for phrases was found in *8. Repetition* and *9. Phrase Arch.* An overview of melodic range in vocal music was provided in *1. Ambitus* and the tonal resolution at the end of a song was visualized in *10. Tonal Resolution.*

Among the most interesting findings are:

- A clear correlation between pitch salience and metrical salience.
- A clear correlation between interval size and note length.
- That stairs are more common in a rising formation than in a falling formation.
- Findings that the melody tends to continue in the same direction when a new direction with small intervals has recently been established.
- That contour repetition is almost always accompanied by rhythmic repetition at the phrase level.
- That earlier findings for convex phrase arches seem to mostly be a phenomena of an upward movement in the first phrase of a song and a downward movement in the last phrase of a song.

6 Acknowledgments

This study was supervised by Anders Askenfelt who gave important advice concerning the text in this report. Technical supervision concerning the statistical findings was done by Anders Friberg.

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