Stability and Variation in Cadence Formulas in Oral and Semi-Oral Chant Traditions — a Computational Approach

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ABSTRACT

This paper deals with current research into melodic stability and variation in cadences as they occur in oral and semi-oral traditions. Creating a new framework for melodic transcription, we have quantized and compared cadences found in Torah trope, strophic melodies from the Dutch folk song collection *Onder de groene linde* and Qur'an recitation. Working within this new transcription framework, we have developed computational methods to analyze similarity and variation in melodic formulas in cadences as they occur in recorded examples of the before-mentioned oral/semi-oral traditions. We have investigated stability and variation using histogram–based scales, melodic contours, and melodic outlines for recorded examples and we interpret our findings with regard to mechanisms of the process of oral transmission in these oral/semi-oral traditions.

I. BACKGROUND

Variation is considered a universal principle in music. In terms of semiotics, variation in music is omnipresent and distinguishes music from language (Middleton, 1990). In oral music traditions, variation is introduced to the music due to the absence of a concrete notation. Chant researchers have long investigated relationships between stability and variation in melodic formulas in and across chant traditions. Scholars have looked to discover how improvised melodies might have developed to become stable melodic entities in given religious communities. A main aspect of recent computational investigations has been to explore the ways in which melodic contour defines melodic identities (Ness et al., 2010; Van Kranenburg et al., 2011). Concentrating on cadences, we have investigated melodic, durational and contour similarities in cadences within individual songs/chants, within chant types and between chant types. Using computational methods we have extracted tone scales from digital audio data. In our opinion these derived scales accurately present pitch-contour relationships within oral and semi-oral musical traditions. Instead of viewing these pitches to be deviations of pre-existing "normalized" scales, our method defines a more differentiated scale from the outset. Comparing the stability of these scales and their resulting contours we can support the theory that melodic stability in Ashkenazi Torah trope cadences is more prevalent than in Sephardic equivalents. We have discovered relationships between

variational embellishment and contour stability within cadences in Indonesian and Dutch-Indonesian Qur'an recitation. We are currently applying similar methods of comparison within Dutch folk song examples.

II. AIMS

The present study employs a computational approach to allow for new possibilities for paradigmatic and syntagmatic analysis of cadences in the three chant types. In particular the question of stability in scale, melodic contour and melodic outline is investigated. Observing the function of melodic cadences in these chant types, we investigate aspects of stability and variation within and across various chant communities. In particular, the stability and variation in histogram–based scales, melodic contours, and melodic outlines are examined in recorded examples from these various traditions. This might give us a better sense of the relationship between melodic gesture and melodic formulae within these chant practices and possibly a new understanding of the relationship between improvisation and notation–based chant in and amongst these divergent traditions.

III. DATA

Jewish Torah trope is "read" using the cantillation signs of the *te'amei hamikra*, developed by the Masorite rabbis between the sixth to the tenth centuries.[1] The melodic formulae of Torah trope govern syntax, pronunciation and meaning and their clearly identifiable melodic design, determined by their larger musical environment, is produced in a cultural realm that combines melodic improvisation with fixed melodic reproduction within a static

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[1]Geoffrey Wigoder, ed. Et als., "Masora," *The Enyclopedia of Judaism* (New York: MacMillan Publishing Company, 1989) 468, "Various opinions have been offered as to the meaning of the word. Some say that it is related to the verb m-s-r, implying transmission, i.e., the handing down of a tradition. Others believe that the word relates to "counting," for those involved in the Masorah, the Masoretes, would count each letter of a book, to make sure that no words were added or left out. Based on Ezekiel 20:37, the connotation of fencing off has also been suggested, in that the Masoretes "fenced off" the text from those who might change it. Originally, the biblical books were written as continuous strings of letters, without breaks between words. This led to great confusion in the understanding of the text. To insure the accuracy of the text, there arose a number of scholars known as the Masoretes in the sixth century CE, and continuing into the tenth century."

system of notation. The *te'amim* consist of thirty graphic signs.[2] Each sign, placed above or below the text, acts as a "melodic idea," which either melodically connects or divides words in order to make the text understandable by clarifying syntax. The signs serve to indicate the melodic shape and movement of a given melody. Even though the notation of the *te'amim* is constant, their pitches are variable. Although the thirty signs of the *te'amim* are employed in a consistent manner throughout the Hebrew Bible, their interpretation is flexible: each sign's modal structure and melodic gesture is determined by the text portion, the liturgy, by pre-conscribed regional traditions as well as by improvisatory elements incorporated by a given "reader." This study employs both archival recordings from the Feher Jewish Music Center in Tel Aviv and from field recordings conducted by Dániel Péter Biró in the Netherlands in 2011.

The performance framework for Qur'an recitation is not determined by text or by notation but by rules of recitation that are primarily handed down orally (Zimmermann 2000, p. 128).[3] Here the hierarchy of spoken syntax, expression and pronunciation play a major role in determining the vocal styles of *Tajwīd*[4] and *Tartīl*[5]. The resulting melodic phrases, performed not as

"song" but "recitation" are, like those of Torah trope, determined by both the religious and larger musical cultural contexts. In the context of "correct" recitation contexts improvisation and repetition exist in conjunction. Such a relationship becomes increasingly complex within immigrant communities that strive to retain a tradition of recitation, as found in the Indonesian Muslim community in the Netherlands. Comparing recorded examples of sura readings from this community with those from Indonesia, one can observe how melodic contour plays a role in defining the identity of cadence functionality. The recordings of Qur'an recitation were done by Dániel Péter Biró in the fall of 2011 in the Netherlands and comprise both plain *murattal* and embellished *mujawwad* readings.[6]

The collection *Onder de groene linde* consists of c. 7000 audio recordings of Dutch folk songs, made during the 1950s till the 1980s by ethnological fieldworkers Will Scheepers and Ate Doornbosch (Grijp, 2008). The collection is currently hosted by the Meertens Institute in Amsterdam, and accessible through the website of the Dutch Song Database.[7] Doornbosch was specifically interested in ballads, of which he collected as many variants as possible.

Most of the singers were at older age at the time of recording. They reproduced the songs they learned during their youth from family members or colleagues. Therefore, although the recordings were from the 1950s, the recorded songs reflect the folk song culture from the beginning of the twentieth century. Most of the singers had a poor working class background. They did not have the luxury of a piano or other instruments, and they did not use musical notation. Therefore, the reproduction of the melodies relies on the memory of the singer. Since musical material in oral circulation is changing continuously, many variants of the 'same' tune can be found among the recordings.

In the collection, we only have 'end points' of this oral tradition. The full oral history of the recorded songs is not available. Yet, the collection specialists at the Meertens Institute classify the songs into *tune families* (Bayard 1950). They base this classification on similarity relations between the melodies and on hypotheses about the oral history.

The collection is a rich resource of melodic material that allows

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[2]The Te'amim actually entail more symbols than necessary for syntactical divisions. Therefore it is clear that part of their original function was representational. Such qualities might have been lost or homogenized by later generations, especially in Sephardic communities, in which many of the te'amim are identical in their melodic structure. The Talmud shows that singing was important in the study of the Torah Talmud Sanhedrin, 99a-99b, as cited by Zimmermann 95, "R' Yehoshua ben Karchach says: whoever learns torah but does not review his learning is like a person who plants but does not harvest, R' Yehoshua says: Whoever learns Torah and forgets his learning is like a woman who gives birth and buries the child. R' Akiva says: Sing ("*zamer*") every day, sing every day." Similarly the signs for such "singing" were also represented by cheironomy. Cheironomy can be described as "a doctrine of hand signs: a form of conducting whereby the leading musician indicates melodic curves and ornaments by means of a system of spatial signs." See Edith Gerson-Kiwi and David Hiley, "Cheironomy," *Grove Music Online*, ed. L. Macy (26 April 2012) http://www.grovemusic.com. While cheironomy is rare among contemporary Ashkenazi Jews, Uri Sharvit has mentioned the use of cheironomy by Yemenite Jews. Because the scroll does not contain the vowels or accents, cheironomy is used to help a reader remember the te'amim. "This phenomenon may be observed during the synagogal services when the performer of the Pentateuch recitation does not remember the cantillation symbols of the text. When this happens, he is helped by a person who stands to his left, who, looking at a printed Bible showing the *te'amim*, moves his right hand in a certain manner, using a little pointer or his index finger." Cited from: "The Musical Realization of Biblical Cantillation Symbols (*te'amim*) in the Jewish Jemenite Tradition, Yuval, Studies of the Jewish Music Research Center (Jerusalem: The Magnes Press, 1982) 26.

[3]"Like the Hebrew *miqra'* the primary name 'Koran' derives from the root q-r, i.e., 'reading': the visual implication of text is not implied with this root. Rather the concepts 'pronounce, calling, reciting' are expressed with the word, so that an adequate translation of Koran (Qur' ān) could be 'the recited'" (Translation from the German by Dániel Péter Biró). Heidi Zimmermann, *Tora und Shira: Untersuchungen zur Musikauffassung des rabbinischen Judentums* (Bern: Peter Lang, 2000) 27.

[4]"*Tajwīd* [is] the system of rules regulating the correct oral rendition of the Qur'an. The importance of *Tajwīd* to any study of the Qur'an cannot be overestimated: *Tajwīd*, preserves the nature of a revelation whose meaning is expressed as much as by its sound as by it content and expression, and guards it from distortion by a comprehensive set of regulations which govern many of the parameters of the sound production, such as duration of syllable, vocal timbre and pronunciation." Kristina Nelson, *The Art of Reciting the Koran* (Austin: University of Texas Press, 1985) 21.

[5]"*Tartīl*, another term for recitation, especially implies slow deliberate atten-

tion to meaning, for contemplation." Neubaurer and Doubleday, *Grove Music Online*. Accessed December 15, 2011. <http://www.grovemusic.com. ezproxy.library.uvic.ca>

[6]Eckhard Neubauer and Veronica Doubleday. "Islamic religious music." *Grove Music Online*. 14 May. 2012 <http://www.oxfordmusiconline. com.ezproxy.library.uvic.ca/subscriber/article/grove/ music/52787>. *Tajwid* is the exact science of correct recitation. For 300 years Egypt has been regarded as the centre of Qur'anic recitation both for accuracy and artistry, and its Qur'an readers are very respected and highly paid. There are two distinctive styles: *murattal* (ex.1), a plain style used in private devotion and for teaching, and *mujawwad* (ex.2), an embellished style reserved for public audition, performed by specialists trained in *tajwid* (sharing the same Arabic root as *mujawwad*). *Tajwid*, the system of rules regulating the correct oral rendition of the Qur'an, governs many parameters of sound production. These include precise duration of syllable, vocal timbre and pronunciation, with characteristic use of nasality and special techniques of vibration. Echoing silences between text sections add to the dynamic nature of presentation. Public Qur'anic recitation has a distinctive sound which has been profoundly influential as an aesthetic ideal."

[7]http://www.liederenbank.nl

research of melodic patterns in oral tradition. The history of most melodies is obscure. Of a number of texts we have nineteenth-century copies on broadsides. These broadside ballads were sold at market places. Usually, the melody was only indicated by a title ("To be sung to the tune of . . . "). In rare cases the documentalists of the institute traced the origin of a melody. For example, the aria "Contre les chagrins de la vie" from the opera *Le petit matelot* (1796) by Pierre Gaveaux (1761–1825) ended up as the Dutch folk song "Zoete lieve Gerritje". In the folk version, the rhythm has been simplified. In general, the vast majority of the melodies in *Onder de groene linde* is tonal and is in a major key. Only a few melodies show modal characteristics. The most common meters are 6/8 and 4/4.

One of the research questions we pose is to what extent the melodies in *Onder de groene linde* show stylistic unity. Was there one melodic oral culture in the Netherlands in the first decades of the twentieth century? Do the melodies show structural correspondences in syntactic-melodic properties? What are the structural units of these melodies? Are there stable melodic formulae that recur among or between tune families? What is common in the entire corpus, and what is common to a specific tune family only?

From a large number of tune families, we have more than one member melody. This allows paradigmatic investigation of melody groups to understand what parts of the melodies remain stable and what parts are less stable in oral transmission. As a first step, we will investigate cadential patterns. Since cadences have the clear syntactical function to indicate closure, or 'ending', we expect a number of stable patterns. By exhaustively comparing all cadence patterns computationally, we will test whether this is the case indeed. A subset of recordings of Dutch folksongs have been manually segmented at the level of melodic phrases. Each phrase is supposed to end with a cadence pattern. As with the examples of Torah trope and Qur'an recitation we are examining similarities and variation in melodic contour, melodic scale and melodic outline in cadence formulae.

For this study, we are collecting and comparing data from field recordings done in the Netherlands, Indonesia, Israel and the United States. These recordings have manually been segmented. The recordings of Torah trope have been segmented into the individual te'amim. The recordings of Qur'an recitation have been segmented in terms of syntactical units corresponding to a given sura. The Dutch folksongs have been segmented in terms of phrase units for comparison. Each Qur'an and Torah recording has been converted to a sequence of frequency values using the SWIPEP fundamental frequency estimator (Camacho 2007) by estimating the fundamental frequency in non-overlapping time-windows of 10ms. The Dutch recordings have been converted by the YIN algorithm (De Cheveigne & Kawahara 2002), which appeared to be better able to cope with the typical kinds of distortion in the Dutch recordings. The frequency sequences have been converted to sequences of real–valued MIDI pitches with a precision of 1 cent (which is 1/100 of an equally tempered semitone, corresponding to a frequency difference of about 0.06%).

In order to visualize and navigate through the data consisting of annotated segments and the frequency estimation results of the pitch extraction we have developed a web-based interactive interface. This interface combines both visual and auditory modalities, allowing the researcher to see and listen to the results of some of the algorithms we use in this paper.

IV. PITCH HISTOGRAM AND MELODIC SCALE

Instead of analyzing pitch contours in terms of pre-defined melodic scales, we derive a scale from the audio-recording. First we construct a pitch histogram, showing for each pitch the relative frequency of occurrence of that pitch during the recording. Since the melodies show some pitch deviation, we use a kernel density estimation procedure. By adding a Gaussian kernel for the detected pitch in each 10ms window, we obtain a smoothed pitch density estimation. In a next step, the scale degrees are obtained form the pitch histogram by performing a peak-detection algorithm. Two parameters are important for the results of this procedure, namely the standard deviation of the Gaussian kernel and the minimal distance between the scale degrees. Choosing a larger value for the standard deviation of the kernel results in a smoother, but less precise pitch histogram. Choosing a larger value for the minimal distance between the scale degrees results in less dense melodic scales. Currently, we determine for each recording the optimal parameter values by aurally and visually comparing the histograms and scales for various settings of the parameters.

V. METHODS FOR TORAH TROPE

For each of the Torah recordings, we derive a melodic scale from a pitch histogram. Of the resulting scale degrees, we choose those two that occur most frequently and use them to scale the pitches in the non-quantized contours. As a result, different trope performances, sung at different absolute pitch heights, are comparable. On the thus acquired scaled pitch contours we apply an alignment algorithm, interpreting the alignment score as similarity measure. An automatic alignment of two contour segments results in an alignment score, which can be interpreted as a similarity measure for each pair of segments. The better the alignment succeeds, the more similar the contours, the higher the resulting score. Further details about this method have been published in (Van Kranenburg et al., 2011).

Since each audio segment represents the rendition of a *ta'am*, we employ the similarity values of pairs of segments to assess the stability in performance. For that, we use standard evaluation measures from Information Retrieval. We take each segment as query, and for each of the query segments we construct a ranked list of all other segments by ordering them according to the alignment score with the query segment. All renditions of the same *ta'am* as the query segment are considered relevant items. Next, for each *ta'am* we compute the mean average precision (MAP), which is the average precision of all relevant items for all queries. The MAP value reflects to what extent all relevant items are at the top positions of the ranked lists. The more similar all renditions of
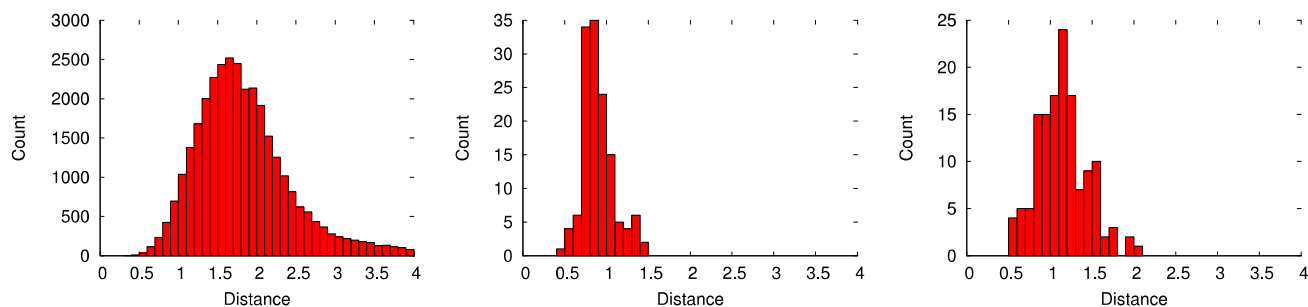
Figure 1. Distributions of distances between unrelated segments (left), between *sof pasuq* renditions in Hungarian (middle) and Moroccan (right) readings.

the same *ta'am*, the higher the MAP value. Thus, the MAP value can be interpreted as an indicator of stability in performance of the *te'amim*.

VI. RESULTS FOR TORAH TROPE

In comparing a Hungarian to a Moroccan reading of the first verses of the book *Shir Ha-Shirim* (Song of songs), the obtained mean average precisions are 0.656 for the Hungarian rendition and 0.299 for the Moroccan one, indicating a much higher stability in rendition for the Hungarian reading. These findings are particularly interesting when observed in connection with musicological and music historical studies of Torah trope. It has long been known that the variety of melodic formulae in Ashkenazi trope exceeded that of Sephardic trope renditions. The *te'amim* actually entail more symbols than necessary for syntactical divisions. Therefore it is clear that part of their original function was representational. Such qualities might have been lost or homogenized by later generations, especially in Sephardic communities, in which many of the *te'amim* are identical in their melodic structure. Simultaneously, one can see how the Ashkenazi trope melodies show a definite melodic stability. Observing the trope melodies for *sof pasuq* and *tipha* in the Hungarian tradition, one can derive that they inhibit a definite melodic stability. For the *sof pasuq* we obtain a mean average precision as high as 0.996 and for the *tipha* 0.649 (for comparison, the figures for the Moroccan performance are 0.554 and 0.296 respectively). This indicates that the 17 *sof pasuqs* in the Hungarian rendition are both similar to each other and distinct from all other *te'amim*. This applies to a somewhat lesser extent to the 24 *tiphas* as well. The same can be observed by inspecting the distribution of distances between *sof pasuqs* in both readings, as is depicted in Figure 1. Here, the alignment scores have been converted to distance values. For comparison, the distribution of distances between all unrelated segments is also shown in Figure 1. Clearly, the *sof pasuqs* in the Hungarian rendition are more similar to each other. Such a melodic stability might have been due to the influence of Christian Chant on Jewish communities in Europe, as is the thesis of Hanoch Avenary (Avenary, 1978). Simultaneously, our approach using two structurally important pitches also corresponds to the possible influence of recitation and final tone as being primary

tonal indicators within Ashkenazi chant practice, thereby allowing for a greater melodic stability per trope sign than in Sephardic chant.

As another finding for the Torah trope, Figure 2 shows pitch histograms of two sections of the beginning of the Hebrew Bible as read by Amir Naamani in November 2011. This graph on the left side shows the pitches employed for the reading of Chapters 1–4 and the graph on the right side shows the pitches employed for the reading of Chapters 5. In comparing the data of the two graphs it is clear that there was a high degree of pitch stability in his reading of these chapters.

VII. METHODS FOR QUR'AN RECITATION

In comparing an Indonesian version of the sura *Al Qadr* with versions performed by Indonesian immigrants in the Netherlands, we have found similarities in terms of scale and contour stability. After segmenting the syntactical units found in each reading of the sura we derived melodic scales by detecting the peaks in a non-parametric density estimation of the distribution of pitches, using a Gaussian kernel. These histogram-based scales have been compared in terms of their melodic contour and pitch identity and such comparison helps to demonstrate salient structural features of oral transmission within this recitation tradition. Taking recordings of a prominent reciter in Indonesia (Hajja Maria Ulfa) and comparing the scale content of her recitation to reciters in a predominantly Indonesian mosque in The Hague, recorded by Dániel Péter Bíró in the fall of 2011, we have investigated relationships between histogram–based scales, melodic contour and melodic outline in this chant tradition. We are currently investigating how such a melodic outline is employed in recorded examples of the more embellished *mujawwad* readings, as performed in Indonesia and the Netherlands. Using archival and field recordings, we are presently comparing histogram scales and melodic contours of *mujawwad* readings to one–another and to examples of *murattal* readings, thereby investigating how stable and variational melodic outlines come to being. In addition, by comparing examples of Indonesian with Indonesian–Dutch Qur'an reciation, we might be able to ascertain how such a culture of recitation develops within a new cultural framework of recitation in the Netherlands, as the reading is performed predominantly by and
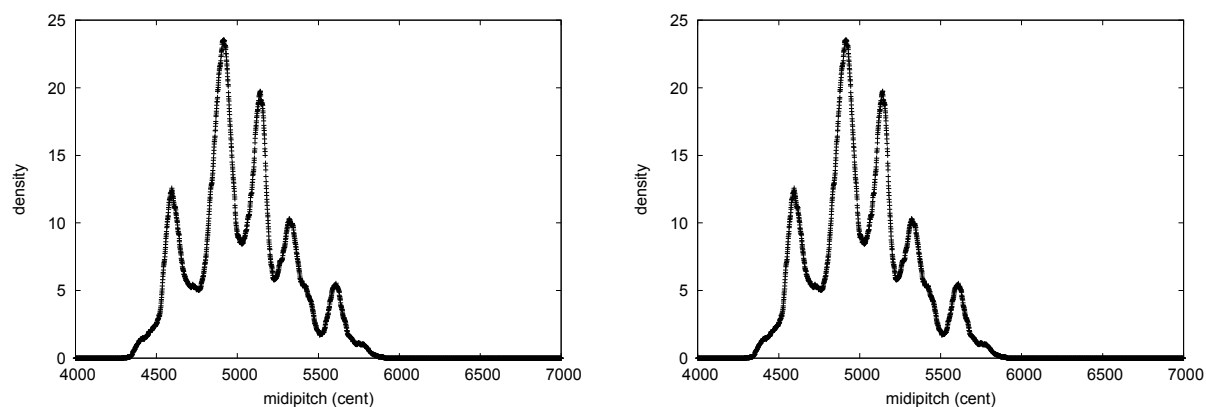
Figure 2. Pitch-Histograms of Genesis 1–4 (left) and Genesis 5 (right) as read in The Hague by Amir Naamani in November 2011.
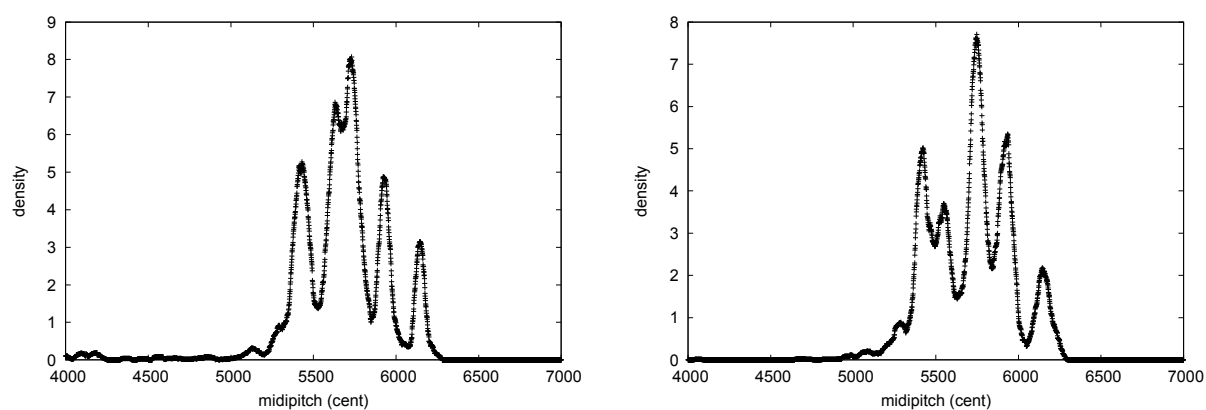

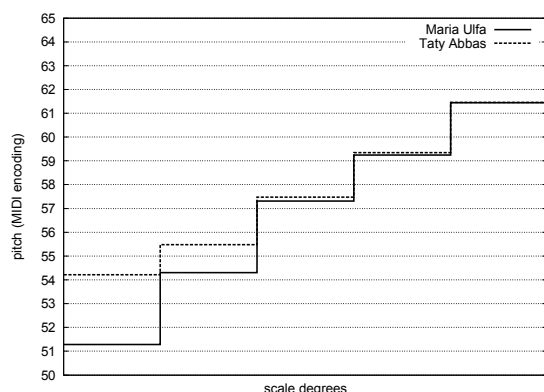**Figure 3. Pitch histograms of Indonesian (left) and Dutch (right) recitation of sura al Qadr.**

Figure 4. Scale degrees derived from Indonesian (solid) and Dutch (dashed) pitch histograms for sura al Quadr.

for an immigrant population.

VIII. RESULTS FOR QUR'AN RECITATION

Figure 3 shows the similar, although not identical content, of the pitch histograms derived from the recordings of Hajja Maria Ulfa (Indonesia) and Taty Abbas (Netherlands). Figure 4 shows the corresponding melodic scale degrees. In comparing the two recordings for the final line of sura *Al Qadr* we can also observe salient aspects of stability and variation in regard to melodic contour and scale employment. This is interesting for scholars, in that such characteristics point to how such melodic cadences come into being in an aural/oral text–based recitation tradition. In analyzing the recording of Qur'an from Hajja Maria Ulfa we discovered more melodic embellishment in her reading, while Taty Abbas performed a similar melodic phrase although lacking the embellishment. In this way, one can observe how the salient melodic identity is carried forward by melodic contour, the scale pitches acting as structural pillars for a similar melodic outline. Employing such a melodic outline the reciters can integrate elements of melodic improvisation and embellishment within their reading (Figure 5).

While this study has great relevance for the practice of Qur'an recitation, it also has relevance for the study of Jewish Torah trope and the early development of Christian Gregorian chant. In terms of Torah trope, such a study underlines the relationship between orality and fixed rules of recitation, allowing for a cross–cultural comparison.[8] This research might also help to shed light on the

early history of Gregorian chant, as it demonstrates how melodic outlines become formed in a text–based chant tradition without pitch notation.[9]

IX. DUTCH FOLK SONGS

We are currently comparing cadences in examples of Dutch folksongs, developing methods to investigate the degree of melodic stability and variation in scale types and melodic contours in song cadences. Comparing scales and melodic contours in cadences of songs belonging within the same tune family, we are presently testing the degree of similarity among these cadences. As with our previous research we are employing histogram based scales to determine melodic contour of these cadences. In this way, we hope to reveal how melodic contours and melodic scales interact to form the identities of cadence formulae in this oral song repertoire.

Figure 6 shows two pitch histograms for a melody from the Dutch tune family *Soldaat kwam uit de oorlog*, basically revealing a pentatonic scale. Here the histograms were derived using Gaussian kernels with standard deviations of 40 cents and 5 cents respectively. In each recorded example, it is necessary for the musicologist and programmer to find the optimal value that allow for the most optimal scale analysis. As each chant repertoire employs its own particular tempered scale system and a greater or lesser degree of melodic embellishment, such settings become crucial for hearing the salient pitch information in a given recording and in given chant repertoires.

X. CONCLUSIONS AND FURTHER RESEARCH

In terms of the analysis of Torah trope, Qur'an recitation and Dutch Folksongs a number of important questions arise. Are there melodic, durational, contour similarities in cadences within individual chant recitations, within chant types and between chant types? What are the geographical and historical determinants for such similarity/variation? How does the analysis of melodic formulas in cadences contribute to existing or make possible the development of new hypotheses about borrowings among and between traditions? Within designated communities, how stable are melodic formulas as they exist in Qur'an recitation as practiced in their local framework? How might the performance practice of melodic formulas in Qur'an recitation remain stable or transform within a globalized oral-culture framework?

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[8]Zimmerman 144, "Die Einführung eines Notationssystems, wie es die masoretischen Akzente darstellen, läßt sich unter dem Stichwort der Traditionssicherung mit Aleida Assmann und Jan Assmann kulturhistorisch beschreiben als eine Maßnahme, die für eine Gruppe "im Dienst der Rezitation der kulturellen Überlieferungen des Indentitätssichernden Wissens" steht und in den Funktionsbereich des 'kulturellen Gedächtnisses'" gehört. Weil aber der Gegenstand der Notation — die Kantillation der Schrift — sich gegen eine lineare Aufspaltung in abstrakte Parameter sperrt, ist auch diese Schriftkultur "im Funktionsbereich 'Tradition'" oral geblieben." "The introduction of a system of notation, as presented in the Masoretic accents, can be place within the subject heading that Aleida Assmann and Jan Assmann describe in cultural-historical terms as a measure, which exists
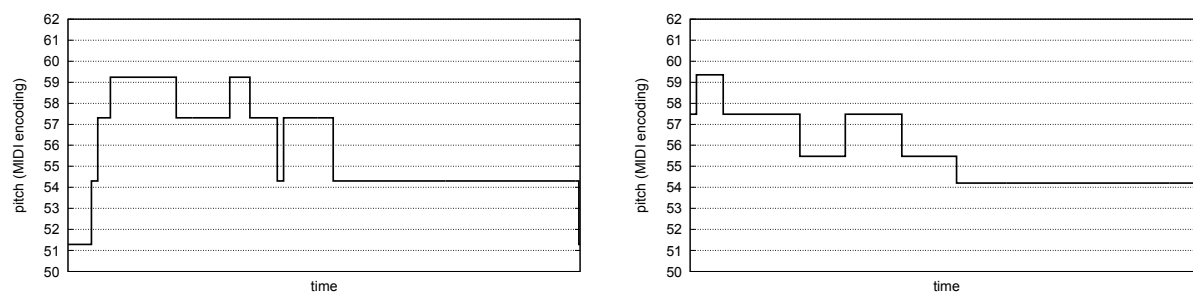
for a group 'that serves recitation in order to transmit knowledge that safeguards identity,' belonging within the functional category of "cultural memory." Because the object notation — the cantillation of the text — does not allow itself to be split into an abstract parameter, even this culture of text, existing in the "functional realm of tradition," can remain oral." (English translation by Dániel Péter Biró).

[9]Leo Treitler, "The Early History of Music Writing in the West" in the *Journal of the American Musicological Society*, Volume 35, (Chicago: University of Chicago Press, 1982), 237. "The fact that the Gregorian Chant tradition was, in its early centuries, an oral performance practice... The oral tradition was translated after the ninth century into writing. But the evolution from a performance practice represented in writing, to a tradition of composing, transmission, and reading, took place over a span of centuries."

Figure 5. Contours of the same cadence as sung by Indonesian (left) and Dutch (right) reciters quantized according to the derived scale degrees.
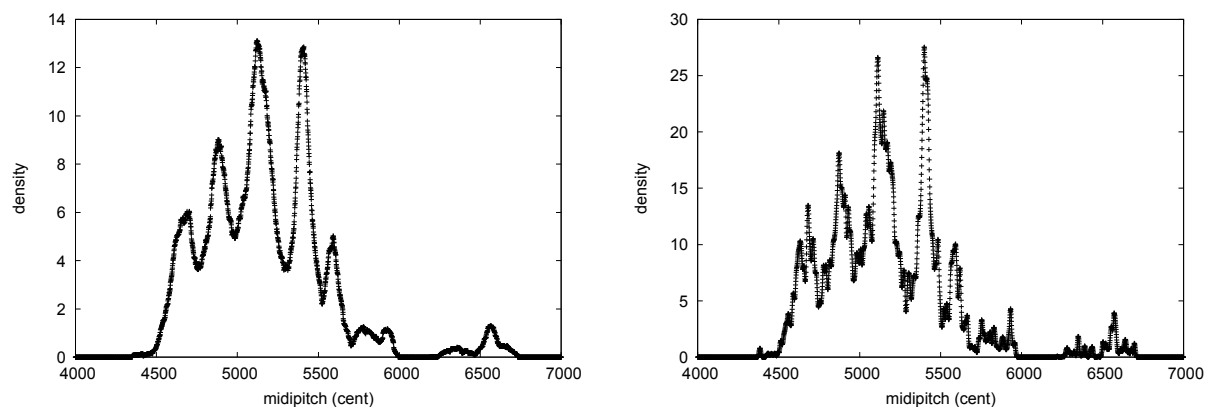

Figure 6. Two pitch histograms for a melody from the Dutch tune family *Soldaat kwam uit de oorlog*, with kernel width 40 cents (left) and kernel width 5 cents (right).

By developing computational models for analyzing these three chant types we are developing a methodology to test stability and variation in terms of melodic scale and melodic contour. By extending possibilities for musical transcription via the employment of a new computational platform we test the subjective bias of the ethnomusicologist as well as test previous theories of the historical development of chant. This new form of computational analysis presents new means to re-examine variation and stability within melodic formulas within these chant traditions.

The presented methods prove useful for the recordings under investigation. We are currently collecting data, with the aim to further study stability and variation between and within performance traditions of Torah trope, Qur'an recitation and Dutch folk songs on a large scale, integrating the results into ongoing musicological and historical research on this topic.

The two recordings of Torah trope used in this study can be consulted at: `http://pierement.zoo.cs.uu.nl/icmpc2012`.

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