CONTINUITY AND CHANGE IN KAKHETIAN INTONATION: A COMPUTATIONAL STUDY OF ARCHIVAL RECORDINGS (1948–1971)

განგრძობადობა და ცვლილება კახურ ინტონაციაში: საარქივო ჩანაწერების გამოთვლითი კვლევა (1948-1971)

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Abstract. This study presents the first corpus-based computational analysis of harmonic interval distributions in traditional Kakhetian polyphony, examining 331 field recordings recorded in Kakheti from the Tbilisi State Conservatoire archive spanning 1952–1967. Using automatic multiple F0 estimation and Gaussian Mixture Model fitting, we extract harmonic intervals from vertical pitch slices and characterize their distributions across temporal, performer-based, geographic, and genre-based dimensions. The Wasserstein distance quantifies distributional shifts between recording periods and analytical strata.

Results reveal a stable core of structural intervals—the perfect fifth (~700 cents) and octave (~1200 cents)—persisting across all recording periods and contexts. Mid-range intervals (thirds and fourths) show greater variability, with later recordings (1962–1967) exhibiting more complex distributions absent in earlier material. Distinct intervallic profiles emerge across performer groups: women's ensembles display more fragmented distributions compared to men's ensembles. Geographic sub-regions within Kakheti show measurable variation, with Telavi recordings standing

apart from other areas. Genre-based analysis reveals differences between feast/table songs (“supruli”) and work songs ("shromis"), the latter showing higher temporal variability.

These findings establish a quantitative "harmonic fingerprint" for Kakhetian polyphony, providing empirical evidence for both continuity and change in intervallic practice across mid-20th century field recordings. The stratification approach with respect to chronology, performer group gender, geography, and genre helps disentangle the contributions of each component to observed variation, while highlighting methodological considerations for corpus-based analysis of archival ethnomusicological collections.

Keywords. Computational ethnomusicology, music information retrieval, historical musicology, audio corpus analysis, harmonic fingerprinting, traditional Kakhetian singing.

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აბსტრაქტი. კვლევა ტრადიციულ კახურ მრავალხმიანობაში ჰარმონიულ ინტერვალთა განაწილების პირველ კორპუსზე დაფუძნებულ გამოთვლით ანალიზს წარმოადგენს, რომლის ფარგლებშიც თბილისის სახელმწიფო კონსერვატორიის არქივში დაცული 1952–1967 წლების 331 კახეთში ჩაწერილი საარქივო ჩანაწერი დამუშავდა. ჩვენ ავტომატური მრავალი F0 განსაზღვრისა და გაუსიანური ნარევის მოდელების გამოყენებით, ბგერათა ვერტიკალებიდან ამოგვაქვს ჰარმონიული ინტერვალები და ვახასიათებთ მათ განაწილებას დროის, შემსრულებელთა ჯგუფის, გეოგრაფიული მდებარეობისა და ჟანრის მიხედვით.

ვასერშტაინის მანძილის გამოყენებით, ვითვლით განაწილების სხვადასხვაობებს ჩანაწერთა შექმნის პერიოდებსა და ანალიტიკურ შრეებში.

შედეგები სტრუქტურული ინტერვალების სტაბილურ საფუძველს ასახავს – წმინდა კვინტასა (~700 ცენტი) და ოქტავას (~1200 ცენტი) – რომლებიც ჩანაწერთა შექმნის ყველა პერიოდსა და კონტექსში ნარჩუნდება. საშუალო დიაპაზონის ინტერვალები (ტერციები და კვარტები) უფრო მეტ ცვალებადობას ავლენს, გვიანდელ ჩანაწერებში (1962–1967) კი უფრო რთული განაწილებები იჩენს თავს, რომლებიც ადრინდელ მასალაში არ გვხვდება. განსხვავებული ინტერვალური პროფილები იკვეთება შემსრულებელთა ჯგუფებში: მამაკაცთა ანსამბლებთან შედარებით, ქალთა ანსამბლები უფრო ფრაგმენტულ განაწილებებს იყენებენ. გაზომვადი სხვაობები იკვეთება კახეთის გეოგრაფიულ ქვერეგიონებში: სხვა რეგიონებისგან გამოირჩევა თელავის ჩანაწერები. ჟანრზე დაფუძნებული ანალიზი სხვაობებს ავლენს სუფრულ და შრომის სიმღერებს შორის – ეს უკანასკნელი უფრო მაღალი დროითი ცვალებადობით ხასიათდება.

ეს მიგნებები კახური მრავალხმიანობის რაოდენობრივი ანალიზის "ჰარმონიულ ანაბეჭს" ადგენს, რაც ემპირიულ მტკიცებულებებს იძლევა მე–20 საუკუნის შუა პერიოდის საველე ჩანაწერებში ასახული ინტერვალური პრაქტიკის უწყვეტობისა და ცვლილებების შესახებ. ქრონოლოგიასთან, შემსრულებელი ჯგუფების სქესთან, გეოგრაფიულ მდებარეობასა და ჟანრთან მიმართებით გამოყენებული სტრატიფიკაციული მიდგომა ხელს უწყობს საკვლევ მასალაში თითოეული კომპონენტის გამორჩევას და ამავდროულად, წინა პლანზე გამოაქვს მეთოდოლოგიური თვალსაზრისით გასათვალისწინებელი საკითხები საარქივო ეთნომუსიკოლოგიური კოლექციების კორპუსზე დაფუძნებული ანალიზისთვის.

საკვანძო სიტყვები. გამოთვლითი ეთნომუსიკოლოგია, მუსიკალური ინფორმაციის ამოკრება, ისტორიული მუსიკოლოგია, აუდიო კორპუსის ანალიზი, ტონალური ორგანიზაცია, ტრადიციული კახური სიმღერა.

Introduction

Research problem

Georgian traditional polyphony has long attracted scholarly attention due to its distinctive tuning systems, complex voice interaction, and the central role of vertical relationships in musical organisation (Arakishvili, 1905; Nadel, 1933). Historical sources attest to the long-standing presence and diversity of song genres in Georgian musical culture (Javakhishvili, 1938). Regional traditions are central to understanding the diversity and internal logic of Georgian musical thinking; however, scholarly attention has been unevenly distributed across regions.

In contrast to extensively studied traditions such as, for example, Svaneti, the Kakhetian repertoire has received relatively little systematic musicological investigation. As early as 1962, in the preface to his first collection of Kakhetian songs (one of two collections he published in 1962, 1969) Otar Chijavadze noted that Kakhetian folk song had not yet become the subject of comprehensive scholarly research, despite its importance within Georgian traditional music. While earlier researchers such as Zakaria Paliashvili and Dimitri Arakishvili documented individual songs, these materials did not provide a complete picture of the stylistic diversity of the repertoire. Systematic documentation began in the mid-20th century, particularly through expeditions conducted between 1952 and 1958, resulting in the recording of hundreds of song variants (Chijavadze, 1962).

Previous studies have provided insights into structural and stylistic characteristics of Kakhetian music, especially regarding harmonic organisation, voice interaction, and genre typology (Aslanishvili, 1950; Arakelov, 1990; Gogotishvili, 2003).

This study presents the first corpus-based computational analysis of the intervallic inventory of Kakhetian polyphony. It focuses on harmonic interval structures, employing computational analysis of archival recordings from 1948 to 1971. The analysis is conducted both on the corpus as a whole and across multiple stratified dimensions (temporal, performer group, sub-regional, and genre-based), with the aim of identifying and describing intervallic patterns within and across these domains.

While the method does not capture functional aspects of harmony or detailed processes of voice-leading, it enables the examination of intervallic distributions (i.e. which harmonic intervals appear at what relative frequencies) across different analytical dimensions, including performer group, geographic region, and a limited set of genre categories. It thus provides a systematic and empirical account of variation in vertical interval usage across a large body of archival recordings.

In this sense, the results reflect not the syntactic organisation of harmony, but rather the statistical profile of intervallic usage - what may be described as the "harmonic fingerprint" of the repertoire.

Given the stylistic and genre diversity of the recordings, the corpus is analysed both collectively and through multiple stratification criteria. In addition to temporal grouping, the data are examined according to performer group (men's vs. women's ensembles), geographic sub-regions within Kakheti, and broad genre categories when metadata is available (e.g., table songs and work songs). This multi-dimensional approach allows for a more nuanced assessment of variation within the repertoire, while maintaining a corpus-based perspective.

Background and Previous Research

Existing scholarship on exclusively Kakhetian music has primarily focused on descriptive and stylistic analysis, providing a foundation for understanding the repertoire, but not scrutinising concrete questions such as the harmonic intervallic structure of Kakhetian repertoire.

Within Georgian ethnomusicology, Kakhetian material has rarely been studied independently and is often considered together with Kartlian traditions as part of a unified Kartl-Kakhetian musical domain (Aslanishvili, 1950, 1954; Shilakadze, 1979; Gogotishvili, 2003; Kapanadze, 2005; Garakanidze, 1990, 2007). While this reflects shared principles of polyphonic organisation and intonational norms, the Kakhetian repertoire exhibits distinct stylistic and functional features that justify its consideration as a specific regional variant within this system.

Aslanishvili's foundational work (Aslanishvili, 1950) represents one of the most theoretically thorough studies of Kartl-Kakhetian polyphony. His analysis focuses on harmony as the principal form-defining element in the repertoire, aiming at a systematic generalisation of each harmonic component. As Aslanishvili notes (Aslanishvili, 1950), the study was based primarily on folk song recordings and existing collections of eastern Georgian folk repertoire. The sources included 10 phonograms by D. I. Arakishvili (Arakishvili, 1906, 1916), Z. Paliashvili's collection of Kartl-Kakhetian songs (Paliashvili, 1909), and supplementary transcriptions without phonograms (e.g., I. Kargareteli and A. Benashvili)

Empirical research has largely relied on descriptive documentation and transcription-based analysis. Chijavadze (Chijavadze, 1962, 1969) provides extensive transcriptions and genre-based classifications, while collections such as Paliashvili (Paliashvili, 1910) and Bakradze (Bakradze, 1978) further enrich the archival record. Arakelov (Arakelov, 1990) examines thematic development and large-scale structural processes in dance and round-dance songs. Gogotishvili (Gogotishvili, 2003) analyses modal and intonational features of long table songs, and Mamaladze (1963) documents specific functional genres, including labour songs.

Collectively, these works establish an important descriptive and theoretical basis for understanding Kakhetian musical practice.

Despite these contributions, it is unsurprising that previous research remains largely descriptive and relies on notation or manual analysis, limiting access to fine-grained acoustic detail and precluding

systematic investigation across large archival corpora. In particular, intervallic distributions, voice interaction, and structural regularities in Kakhetian polyphony have yet to be explored quantitatively.

Unlike other regions, such as Svaneti or Guria, where computational and acoustical methods have been applied (Scherbaum, Müller, and Rosenzweig, 2017; Scherbaum et al., 2020, 2021; 2022; Shugliashvili et al., 2024, 2025), the Kakhetian corpus remains largely unexamined using these techniques. Mid-20th century archival recordings offer a unique opportunity to study its development over time, providing the basis for computational analysis of intervallic organisation and a deeper understanding of continuity and change in Kakhetian polyphonic practice.

Methods

Multiple F0 Estimation and Harmonic Interval Extraction

As in our previous works, we use our *pypolyphonicanalysis* automatedpipeline to perform corpus-level analysis (Shugliashvili et al., 2025). Our analysis pipeline begins with automatic multiple F0 estimation, converting audio recordings into salience maps that represent the probability distribution of sung pitches over time and frequency. We use a convolutional neural network architecture based on the Polyvocals model (Cuesta et al., 2020), with modifications including residual network blocks and room simulation for training data augmentation, as described in our previous work (Author et al., 2024a; Author et al., 2024b).

The salience maps undergo filtering to remove frequencies outside the typical vocal range (below G2, above G7) and frequencies more than one octave from each recording's mean frequency. A masking filter (Rosenzweig et al., 2019) retains only stable pitch regions. For each time step, we extract harmonic intervals by computing cent differences between detected frequencies, ordered from lowest to highest.

Following Scherbaum et al. (2017), we model the interval distribution of each recording using Gaussian Mixture Models (GMMs). The number of components is determined by peak-finding on a kernel density estimate (KDE) of the interval data. The GMM component mean values can be interpreted as a synoptic scale providing a human-interpretable characterization of the harmonic intervals of each recording, while the full shape of the obtained GMM distribution can serve as the “harmonic fingerprint” of the recording, capturing information about which intervals appear at what relative frequencies and with what level of variance within the recording..

Corpus and Filtering

The recordings analyzed are drawn from the Tbilisi State Conservatoire's archive of field recordings of traditional Georgian music. The corpus contains 412 Kakhetian recordings. To ensure meaningful polyphonic analysis, we excluded recordings where no valid harmonic intervals were detected (i.e., monophonic songs) and recordings where the fitted GMM contained fewer than 2 components - the latter filtering serving to remove songs where occasional octave errors from the multi-F0 estimator produced spurious interval data that did not represent genuine polyphonic content. The filtering yielded us a final corpus of 331 recordings from 1952–1967.

Temporal Analysis

To examine changes in harmonic interval distributions over time, we grouped the recordings by year of recording.. For each year with sufficient data (≥2 recordings):

1. 1. We gather the GMM parameters (weights, means, variances) from all recordings within the window.
2. 2. We analyze the distribution of harmonic intervals across the window by treating the collection of recording GMMs as a cluster. The cluster-level GMM captures the aggregate harmonic interval tendencies for that time period.
3. 3. To measure the magnitude of change between consecutive time windows, we employ the Wasserstein distance (earth mover's distance). For each window transition, we:

- Sample 6,000 points from both the previous and current window GMMs.
- Compute the 1-dimensional Wasserstein distance between the samples.

The Wasserstein distance provides an intuitive measure of distributional difference: it represents the minimum "work" required to transform one distribution into another, where work is defined as the amount of probability mass moved multiplied by the distance it is moved (in cents) (Panaretos, 2018). This effectively gives us a way to quantify the difference between two harmonic fingerprints.

This approach yields a time series of Wasserstein distances characterizing the magnitude of distributional shift at each window transition, enabling identification of periods of relative stability versus significant change.

Stratified Analyses

To disentangle the contributions of various factors to temporal variation, we performed stratified analyses along four dimensions available in the recording metadata:

1. Performer Group Type (MENS vs. WOMENS)

Recordings were categorized by the gender composition of the performing ensemble. For each group, we computed both:

- Aggregate distribution: A single GMM characterizing the overall harmonic interval usage of all recordings by that group
- Temporal trajectories: Window-by-window analysis to examine whether temporal patterns differ by performer group type

The overall MENS vs. WOMENS comparison uses the Wasserstein distance between aggregate GMMs.

2. Geographic Sub-region

Recording site metadata was parsed to extract sub-regional information (e.g., Gurjaani, Telavi, Kvareli, Sighnaghi, Silda). Sub-regions with ≥10 recordings were included in the analysis. For each sub-region pair, we computed the Wasserstein distance between their aggregate GMMs to quantify geographic variation in harmonic practice.

3. Genre (*Supruli* vs. *Shromis*)

Using thematic/genre tags from the catalog metadata, we identified two major functional categories for which annotations were available:

- *Supruli* (feast/table songs): Songs performed during feasts and celebrations - 121 recordings
- *Shromis* (work songs): Songs accompanying agricultural or domestic labor - 28 recordings

While the corpus contained several other genre categories (“sagalobeli”- chant, “sakulto” - cult, etc.), none of the other categories exceeded 11 recordings, leading us to omit them for a simpler genre analysis involving only the two largest groups. For both genre groups, we computed aggregate distributions and temporal trajectories, with the *supruli–shromis* Wasserstein distance characterizing the degree of genre-based harmonic differentiation.

4. Recording Creator (field-recordist) Bias

Different field recordists may introduce systematic biases through their selection of performers, repertoire, recording locations, or technical practices. We analyzed recordings grouped by their primary creator (field recordist) for creators with ≥15 recordings.

To assess potential bias, we computed:

1. Wasserstein distances between each pair of creators' aggregate distributions

1. For each creator, the Wasserstein distance between their aggregate distribution and the aggregate distribution of all Kakheti recordings

Creators whose recordings deviate significantly from the overall distribution may warrant additional scrutiny for recording-specific effects.

Interpreting Wasserstein Distances

Throughout this analysis, the Wasserstein distance serves as our primary metric for distributional comparison. To aid interpretation:

- Values in the range of 20–50 represent modest distributional differences, roughly comparable to a semitone or less.
- Values in the range of 50–100 indicate moderate differences.
- Values exceeding 100 suggest substantial distributional shift.

However, these thresholds are approximate; the significance of any distance depends on the musical context and the sample sizes involved. Distances computed from small samples (e.g., windows with only 3 recordings) should be interpreted with caution due to higher variance.

Considerations

Several statistical/methodological considerations affect interpretation:

1. Recordings are not uniformly distributed across 1952–1967, with some years having no data (1953–1954, 1959, 1961, 1965–1966) and others having small samples.
2. Recording creator, time period, and geographic focus are interrelated - certain recordists recorded primarily in specific years and locations, making it difficult to fully separate these effects.
3. Not all recordings have complete metadata for all stratification dimensions; analyses are limited to recordings with available metadata for each dimension.

Results

Our computational analysis provides a statistical representation of the intervallic inventory of Kakhetian polyphony, focusing on the distribution of stable vertical intervals rather than their sequential organisation or voice-leading. This representation is examined across multiple analytical dimensions, including temporal, performer-based, geographic, and genre-based groupings.

1. Temporal Dynamics of Intervallic Distribution

Window	Recordings	Components	Component means (cents)	Wasserstein Distance
1952	89	7	296.0, 361.2, 503.1, 703.7, 882.9, 989.1, 1195.2	—
1955	3	8	158.5, 336.3, 419.6, 533.7, 650.3, 755.3, 958.4, 1192.6	158.77
1957	35	9	277.0, 341.7, 499.1, 694.9, 725.7, 862.8, 909.8, 1007.8, 1193.3	194.33
1958	68	7	274.9, 353.5, 501.1, 708.2, 880.6, 955.9, 1195.0	68.11

1960	29	6	289.7, 359.3, 475.5, 702.1, 929.9, 1188.9	106.00
1962	45	10	64.4, 235.7, 347.1, 445.7, 522.0, 653.6, 712.5, 857.0, 983.5, 1192.8	63.65
1963	30	9	180.2, 305.2, 396.5, 488.6, 556.2, 708.0, 877.6, 1001.6, 1192.2	76.16
1964	3	8	203.9, 301.8, 361.4, 549.7, 694.3, 717.2, 887.8, 1194.8	115.41
1967	29	8	96.8, 270.9, 346.1, 410.6, 504.0, 712.1, 920.0, 1186.1	158.33

Table 1: overview of aggregate Gaussian mixture models for each time period, with difference between current and previous period quantified using Wasserstein distance for each period

Aggregate GMM distributions were computed for each recording year with sufficient data (≥2 recordings). The Wasserstein distance between consecutive windows quantifies the magnitude of distributional shift.

Across all temporal windows, intervals near approximately 700 cents (perfect fifth) and 1200 cents (octave) are consistently present.

Mid-range intervals (approximately 270–500 cents), corresponding broadly to thirds and fourths, show variability across time. The 1952 window displays prominent peaks at approximately 296, 361, and 503 cents, whereas later windows, particularly 1962–1963, exhibit more fragmented distributions with a greater number of components.

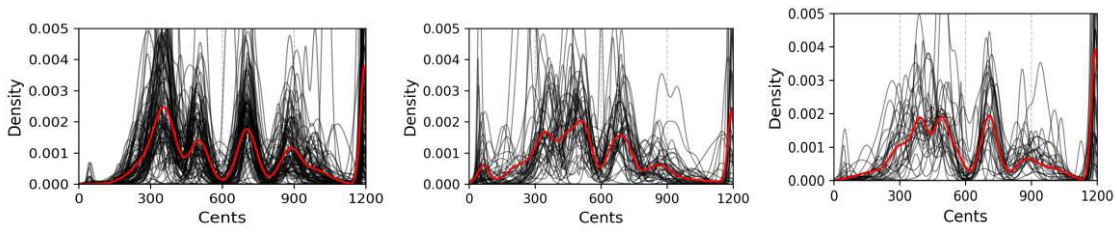

Fig. 1-3 Harmonic interval distribution plots for 1952, 1962, and 1963. Each cluster's average distribution is plotted in red, while the distributions of intervals in individual recordings in the cluster are plotted in black.

Occasional small-interval components (below approximately 100 cents) appear in some later recordings (e.g., 1962 and 1967). These components are limited in scope and may reflect performance-specific factors rather than stable features of the harmonic system.

In several windows, the fifth appears as two distinct components, for example in 1957 (approximately 695 and 726 cents) and 1964 (approximately 694 and 717 cents).

The largest distributional shifts occur between 1955–1957 (194.33), 1952–1955 (158.77), and 1964–1967 (158.33). Smaller shifts are observed in transitions such as 1957–1958 (68.11) and 1962–1963 (76.16).

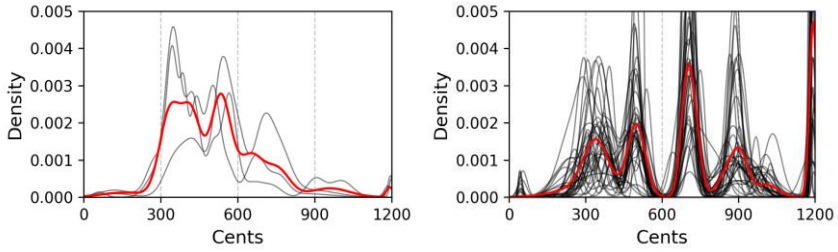

Fig. 4-5 Harmonic interval distribution plots for 1955 and 1957, corresponding to the largest distribution shift identified with Wasserstein distance

2. Variation across Performer Groups

Group	Recordings	Components	Scale Means (cents)
MENS	278	8	147.0, 251.5, 322.2, 385.7, 501.0, 706.2, 909.1, 1193.3
WOMENS	36	10	88.5, 225.3, 332.7, 426.0, 508.2, 633.7, 712.6, 846.2, 984.3, 1189.5

Table 2: overview of aggregate Gaussian mixture models performer groups by gender.

The corpus was stratified by performer group type (men's vs. women's ensembles).

The men's aggregate distribution shows prominent peaks at approximately 706 cents (fifth), 1193 cents (octave), and 501 cents (fourth), with a total of 8 components.

The women's aggregate distribution exhibits 10 components, including additional intervals at approximately 426 cents, 634 cents, and 846 cents.

Differences are also observed in the third region: men's ensembles show peaks at approximately 252 and 322 cents, while women's ensembles show peaks at approximately 225 and 333 cents.

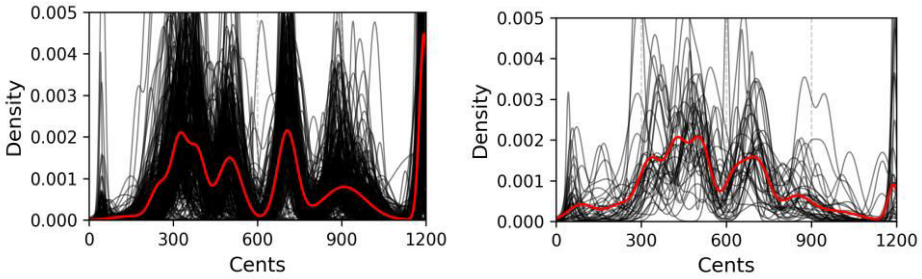

Figure 6-7: Harmonic interval distributions of recordings grouped by gender (MENS on the left, WOMENS on the right)

Window	Recordings	Wasserstein Distance
1952	76	—
1957	32	34.82
1958	67	62.06
1960	27	101.62
1962	15	61.25
1963	29	41.30
1964	3	94.03
1967	29	129.21

Table 3: overview of temporal windows of mens' performer groups. For each window, the change in the distribution compared to the previous window is quantified with Wasserstein distance.

Window	Recordings	Wasserstein Distance
1955	3	—
1957	3	188.53
1962	30	156.01

Table 4:
overview of temporal windows of women's performer groups. For each window, the change in the distribution compared to the previous window is quantified with Wasserstein distance.

The women's recordings show higher variability across temporal windows, with larger Wasserstein distances, and are concentrated primarily in the 1962 recording campaign.

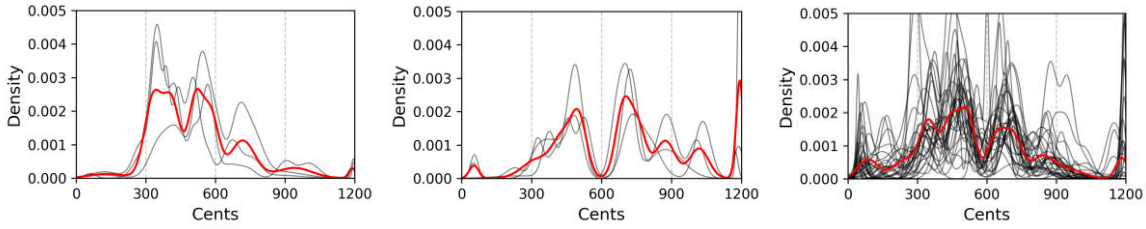

Figure 8-10: Harmonic interval distributions of temporal groups of WOMENS recordings - 1955, 1957, and 1962

3. Sub-regional Variation within Kakheti

Subregion	Recordings	Components	Component Means (cents)
Gurjaani	94	7	281.5, 359.6, 491.7, 709.5, 885.4, 985.4, 1193.2
Telavi	90	10	67.0, 283.2, 368.1, 502.2, 661.7, 708.1, 759.1, 895.5, 989.4, 1194.8

Kvareli	47	11	126.4, 239.4, 324.8, 400.7, 481.6, 541.8, 668.5, 733.8, 873.9, 1003.5, 1194.1
Shilda	27	10	77.7, 254.6, 366.2, 459.3, 537.6, 683.2, 733.3, 884.3, 992.7, 1190.5
Sighnaghi	18	8	270.8, 322.5, 390.3, 508.2, 703.5, 890.2, 995.0, 1189.0

Table 4: overview of distributions for each subregion.

Recordings were grouped by sub-region within Kakheti.

Telavi recordings show large Wasserstein distances in comparison with other sub-regions (e.g., Gurjaani, Sighnaghi, and Shilda). Gurjaani exhibits a 7-component distribution with peaks at approximately 282 (third), 492 (fourth), 710 (fifth), and 1193 cents (octave). Kvareli and Shilda show relatively low pairwise distances (approximately 20–41), indicating similar distributions.

Sighnaghi shows a distribution positioned between simpler and more complex patterns.

Subregion 1	Subregion 2	Recordings	Wasserstein Distance
Telavi	Sighnaghi	90 / 18	201.72
Gurjaani	Telavi	94 / 90	135.76
Telavi	Silda	90 / 27	134.73
Kvareli	Sighnaghi	47 / 18	112.51

Table 5: a selection of notable pairwise distances between subregion aggregate distributions of harmonic intervals.

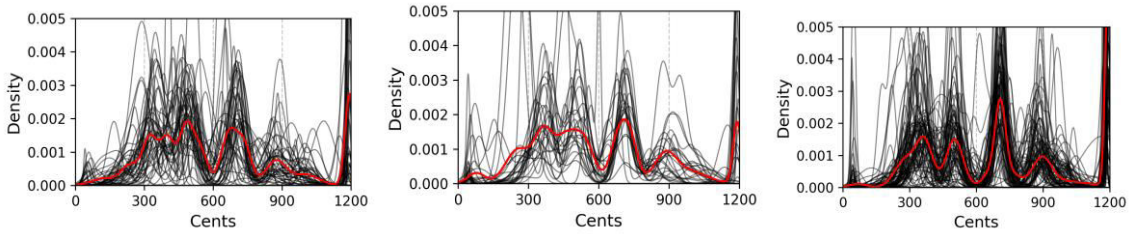

Figure 11-13: Harmonic interval distributions of recordings from Kvareli, Shilda, and Telavi

4. Genre-based Differences

Genre	Recordings	Components	Scale Means (cents)
Supruli(table songs)	127	9	232.9, 305.6, 376.9, 471.4, 518.5, 706.1, 889.3, 986.8, 1194.2
Shromis (work songs)	59	8	61.8, 230.9, 325.4, 379.4, 499.9, 703.2, 887.7, 1194.1

Table 6: overview of the aggregate distributions of harmonic intervals for genre groups

Recordings were categorised into *supruli* and *shromis* songs.

Work songs share core intervals with *supruli* songs, though they show higher temporal variability.

Supruli song recordings show two components in the fourth region (approximately 471 and 519 cents), while work songs show a single component at approximately 500 cents.

Both genres share intervals near approximately 703–706 cents (fifth), 887–889 cents (major sixth), and 1194 cents (octave).

Work songs display higher temporal variability, with Wasserstein distances reaching up to 235.68.

Window	Recordings	Wasserstein Distance
1952	20	—
1958	8	103.26
1962	10	235.68
1963	11	164.74
1967	8	106.60

Table 7: Differences in harmonic interval distributions between temporal groups for shromis songs.

In contrast, *supruli* song recordings show decreasing Wasserstein distances over time (88 → 78 → 83 → 40 → 32).

Window	Recordings	Wasserstein Distance
1952	44	—
1957	21	88.02
1958	43	78.36
1960	4	82.71
1963	8	40.43
1967	6	31.81

Table 8: Differences in harmonic interval distributions between temporal groups for supruli songs.

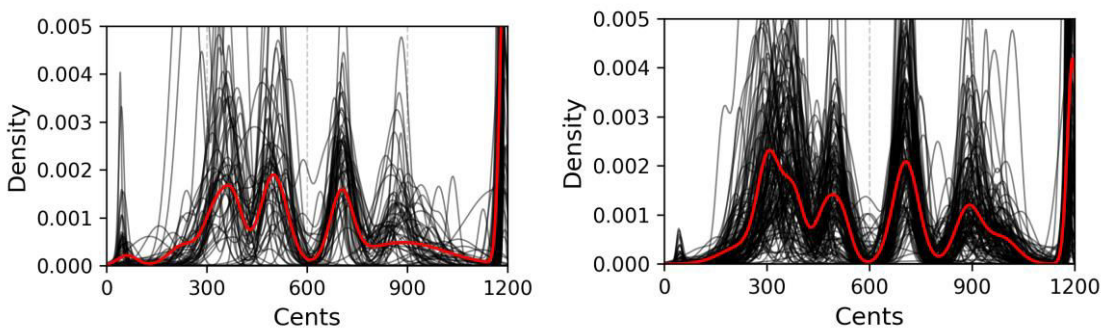

Figure 14-15: Harmonic interval distributions of shromis and supruli recordings

Discussion

The results presented above allow for a more detailed interpretation of intervallic organisation in Kakhetian polyphony, particularly with regard to the balance between stability and variation across temporal, performer-based, geographic, and genre-based dimensions.

Intervallic organisation: tertian and non-tertian structures

A central issue in the interpretation of the data concerns the relative role of third-based versus non-third intervallic structures. This question has been fundamental in earlier theoretical accounts. Aslanishvili (Aslanishvili, 1950), for instance, emphasises the importance of tertian harmonic organisation in Kartl-Kakhetian polyphony, while also acknowledging the potential structural role of non-tertian formations, especially those involving the perfect fourth.

The present results provide a quantitative perspective on this issue. The consistent presence of core intervals- most notably the perfect fifth (~700 cents), the octave (~1200 cents), and the fourth (~500 cents) - confirms their function as stable structural anchors of the harmonic system. While smaller mid-range intervals (approximately 270–400 cents) show more variability, reflecting flexible and context-dependent usage, 500–700–1200 cent intervals appear consistently across recordings and regions, highlighting their structural significance in Kakheti polyphony.

In particular, the data indicate a tendency toward the increasing prominence of third-based vertical structures in mid-20th century recordings, compared to a more balanced distribution of interval types in earlier material. This observation is consistent with earlier claims regarding the growing prevalence of parallel thirds in Kakhetian folk song (Garakanidze, 2007; referencing Arakishvili, 1925). At the same time, the continued presence and variability of fourth-based and other non-tertian intervals suggest that the harmonic system cannot be reduced to a purely tertian model.

In this respect, the results support a more nuanced interpretation of Kartl-Kakhetian harmonic organisation, in which tertian structures may become more dominant over time, while still coexisting with older or alternative intervallic configurations. This is in line with Aslanishvili's suggestion that non-tertian formations, particularly those involving the fourth, may reflect earlier stages in the development of Georgian polyphony (Aslanishvili, 1950).

Temporal dynamics and microtonal variation

The temporal analysis further refines this picture by revealing both continuity and change in intervallic usage. While the stability of fifths and octaves persists across all recording periods, other aspects of the intervallic distribution show notable shifts.

The appearance of "split" fifths in several temporal windows (e.g., components around ~695 and ~725 cents) further suggests variability in tuning practices. This may indicate the coexistence of different intonational norms—such as narrower and wider fifths—or reflect differences across performer groups and local traditions.

At the same time, periods of relative stability (e.g., 1957–1958 and 1962–1963) suggest that these changes are not linear, but rather occur in phases, potentially linked to specific recording expeditions or shifts in repertoire selection.

Variation across performer groups

Differences between men's and women's ensembles suggest distinct intervallic profiles associated with performer group. While both share the same core structural intervals, the women's recordings exhibit a more complex and fragmented distribution, with a higher number of components.

This may reflect differences in vocal technique, ensemble organisation, or stylistic conventions. Differences in the third region (e.g., neutral vs. more clearly differentiated thirds) suggest distinct scalar preferences or intonational tendencies between performer groups. However, these observations must be interpreted cautiously, given the smaller size and temporal concentration of the women's corpus.

Sub-regional variation

The geographic analysis demonstrates that intervallic organisation also varies across sub-regions within Kakheti. While some areas (e.g., Kvareli, Shilda) exhibit relatively similar distributions, others—most notably Telavi - stand apart with more complex intervallic profiles, including a more differentiated fifth region.

By contrast, Gurjaani displays a comparatively "clean" distribution, with fewer components and clearly defined peaks, suggesting a more standardised or internally consistent harmonic profile.

These differences point to the existence of localised intonational practices within the broader Kakhetian tradition, supporting the view that regional variation operates not only at the level of repertoire and style, but also in fine-grained intervallic organisation.

Genre-based differences

The comparison between *supruli* songs and work songs reveals further differentiation in harmonic practice. While both genres share core structural intervals, work songs display a distinct small-interval component (around ~60 cents), which is absent in the *supruli* song aggregate.

Although a small-interval component appears in the work song subset, its limited and context-specific occurrence suggests that it should not be interpreted as a genre-defining feature.

Moreover, the higher temporal variability observed in work songs suggests either a greater degree of stylistic flexibility or the presence of multiple sub-types within the genre, recorded across different expeditions.

Methodological considerations and interpretive scope

Although direct comparison with earlier historical stages is not possible due to the absence of early recordings, the present data allow for an indirect assessment of long-term tendencies through the analysis of mid-20th century material. The results make it possible to identify which intervals are systematically present, which are marginal, and how their relative distribution changes across time and context. At the same time, the findings must be interpreted in light of methodological limitations, including uneven sample sizes across strata, temporal clustering of recordings, and the interdependence of variables such as recording date, geographic focus, and field recordist selection.

Conclusion

This study has presented the first systematic computational analysis of harmonic interval distributions in Kakhetian polyphony, applying automatic multiple F0 estimation and statistical modeling to 331 archival field recordings spanning 1952–1967. The multi-dimensional analytical framework - encompassing temporal, performer-based, geographic, and genre-based stratifications - has yielded several key findings regarding the intervallic organisation of this repertoire.

The analysis confirms the structural centrality of the perfect fifth and octave as stable anchors of the Kakhetian harmonic system, consistent across all recording periods, performer groups, sub-regions, and genres examined. At the same time, mid-range intervals (thirds and fourths) exhibit considerable variability, both over time and across analytical strata. The temporal analysis reveals a tendency toward increased distributional complexity in later recordings (1962–1967), including the emergence of small-interval components and "split" fifths that may reflect either evolving performance practices or differences in the material recorded during specific expeditions.

The stratified analyses demonstrate that variation in harmonic interval usage is not attributable to any single factor. Differences between men's and women's ensembles, geographic sub-regions, and functional genres each contribute to the observed diversity. Notably, Telavi recordings exhibit distinct intervallic profiles compared to other Kakhetian sub-regions, while work songs show higher temporal variability than *supruli* songs.

From a methodological perspective, the Wasserstein distance has proven effective for quantifying distributional shifts, enabling both temporal trend analysis and cross-stratum comparisons. The approach provides an empirical basis for characterizing the "harmonic fingerprint" of a musical tradition - the range and relative prominence of vertical intervals that constitute its sonic profile - without requiring assumptions about harmonic function or sequential organisation.

Several limitations warrant acknowledgment. The corpus exhibits uneven temporal coverage, with gaps in certain years and small sample sizes for some strata (particularly women's ensembles and certain sub-regions). The interdependence of variables - recording date, geographic focus, fieldworker identity, and repertoire selection - makes it difficult to fully isolate the contribution of any single factor. Furthermore, the method captures statistical distributions of intervals rather than their syntactic organisation, harmonic function, or voice-leading processes.

Despite these limitations, the findings contribute to our understanding of Kakhetian polyphony in several respects. They provide quantitative confirmation of the structural role of fifths and octaves noted in earlier theoretical accounts, while also revealing previously undocumented variation across performer groups, sub-regions, and genres. The temporal analysis offers indirect evidence of change in intervallic practice over the mid-20th century, complementing earlier observations regarding the increasing prominence of tertian structures in eastern Georgian folk music.

Future research might extend this approach in several directions: conducting comparative analyses with other Georgian regional traditions; incorporating additional metadata dimensions (e.g., individual performers, specific song types); and developing methods to examine sequential interval patterns and voice-leading alongside the vertical distributions analyzed here. The present study establishes a foundation for such work, demonstrating the potential of computational corpus analysis to illuminate both stability and change in traditional musical practice.

REFERENCES

Arakelov, Kristepore. (1990). "Tematizmi da pormiskmnadoba Kartlisa da Kakhetis sapekhulo, sats'ekvao da satamasho simgherebshi. II nats'ili: masht'abur-tematuri strukturebi sapekhulo, sats'ekvao da satamasho simgherebshi" [Thematism and Form-Building in Kartlian and Kakhetian Round-Dance, Dance and Play Songs. Part II: Large-Scale Thematic Structures]. In Samecniero shromebis krebuli, edited by Rusudan Tsurtsumia, 131–167. Tbilisi: Tbilisi State Conservatory. (in Georgian)

Aslanishvili, Shalva. (1950). Kartl-Kakhetis khalkhuri sagundo simgherebis harmonia [Harmony of Kartl-Kakhetian Folk Choral Songs]. Tbilisi: Sakhelgami. (in Georgian)

Aslanishvili, Shalva. (1954). Nark'vevebi kartuli khalkhuri simgherebis shesakheb. Vol. 1 [Essays on Georgian Folk Songs]. Tbilisi: Khelovneba. (in Georgian)

Bakradze, Mamia, comp. (1978). Kartuli khalkhuri simgherebis krebuli: Kakheti [Collection of Georgian Folk Songs: Kakheti]. Tbilisi: Ministry of Culture of the Georgian SSR, Republican House of Folk Creativity. (in Georgian)

Chijavadze, Otar. (196)2. Kartuli kakhuri khalkhuri simgherebi, vol. 1 [Georgian Kakhetian Folk Songs]. Tbilisi: Tsodna. (in Georgian)

Chijavadze, Otar. (1969). Kartuli khalkhuri simgherebi: Kakhuri, vol. 2 [Georgian Folk Songs: Kakhetian]. Tbilisi: Ganatleba. (in Georgian)

Garakanidze, Edisher. (1990). Kartuli musikaluri dialektebi da mati urtiertmimarteba [Georgian Musical Dialects and Their Interrelations]. Candidate dissertation, Tbilisi State Conservatory. (in Georgian)

Garakanidze, Edisher. (2007). Kartuli khalkhuri simgheris shemsrulebloba [Performance of Georgian Folk Song]. Tbilisi: Intellect. (in Georgian)

Gogotishvili, Vladimer. (200)3. "Kartl-Kakheturi grdzel supruli simgherebis kilo-intonatsiuri tsqobis zogierti taviseburebis shesakheb" [On Some Modal-Intonational Features of Kartl-Kakhetian Long Table Songs]. In Proceedings of the First International Symposium on Traditional Polyphony, edited by Rusudan Tsurtsumia and Joseph Jordania, 306–323. Tbilisi: International Research Centre for Traditional Polyphony. (in Georgian and English)

Javakhishvili, Ivane. (1938). Kartuli musikis istoriis dziritadi sakitkhebi [Fundamental Issues of the History of Georgian Music]. Tbilisi: Sakhelgami. (in Georgian)

Kapanadze, Otar. (2005). Aghmosavlet Sakartvelos mtisa da Kartl-Kakheturi sapekhulo simgherebis urtiertmimarteba [Interrelations of Eastern Georgian Mountain and Kartl-Kakhetian Round-Dance Songs]. [Place/Publisher not specified]. (in Georgian)

Mamaladze, Tamar. (1963). Shromis simgherebi Kakhetshi [Labour Songs in Kakheti]. Tbilisi: Publishing House of the Georgian SSR Academy of Sciences. (in Georgian)

Nadel, Siegfried F. (1933). Georgische Gesänge. Leipzig: Harrassowitz.

Paliashvili, Zakaria, comp. (1909). Kartuli khalkhuri simgherebis krebuli (Imeruli, Guruli, Rachuli, Svanuri da Kartl-Kakheturi) [Collection of Georgian Folk Songs (Imeretian, Gurian, Rachian, Svan, and Kartl-Kakhetian)]. Tbilisi: Tbilisi Georgian Philharmonic Society. (in Georgian and Russian)

Shilakadze, Manana. (19790. "Kartuli musikaluri dialektebi" [Georgian Musical Dialects]. Mse 20: 85–91. Tbilisi: Metsniereba. (in Georgian)

Shugliashvili, Levan, Mjavanadze, Nana, Shugliashvili, David, Scherbaum, Frank. (2024)."Tracking Changes In Harmonic Interval Structures Of Svan Songs Based On Computational Analysis Of Field Recordings From 1959-1971". Gori: *History, Archaeology, Ethnology*

Shugliashvili, David, Mjavanadze, Nana, Shugliashvili, Levan, Scherbaum, Frank. (2025). "kartuli t'raditsiuli mravalkhmianobis harmoniuli int'ervaluri st'rukt'ura: saarkivo savele chanats'erebis (1948-1973) k'omp'iut'eruli analizis monatsemebi ". Tbilisi: KADMOS - ჰუმანიტარულ კვლევათა ჟურნალი 17.2025: 7-32.

Scherbaum, F., Müller, M., & Rosenzweig, S. (2017, October). Analysis of the Tbilisi State Conservatory recordings of Artem Erkomaishvili in 1966. Paper presented at the 7th International Workshop on Folk Music Analysis, Malaga, Spain

Scherbaum, F. & Mzhavanadze, N. (2020). Svan funeral dirges (Zär): Musical acoustical analysis of a new collection of field recordings. Musicologist, 4(2), 138-167. https://doi.org/10.33906/musicologist.782094

Scherbaum, F., Mzhavanadze, N., Arom, S., Rosenzweig, S., & Müller, M. (2021). Analysis of tonal organization and intonation practice in the Tbilisi State Conservatory recordings of Artem Erkomaishvili of 1966. Sixth Analytical Approaches to World Music Conference, June 9-12, 2021, Musée de l'Homme, Paris/France. https://www.youtube.com/watch?v=tfjy_q71WUQ

Scherbaum, F., Rosenzweig, S., Esfahani, R. D., Mzhavanadze, N., Schwär, S., & Müller, M. (2022). Novel representations of traditional Georgian vocal music in times of online access.

https://www.uni-potsdam.de/fileadmin/projects/soundscapelab/PapersMusic/2023/Novel_Representations_of_Traditional_Georgian_Vocal_Music_V02.pdf

Аракишвили, Димитрий. (1905). *Краткий очерк развития грузинской, карталино-кахетинской народной песни с приложением нотных примеров и 27 песен*. Москва: Типогр. К. Л. Меньшова.

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