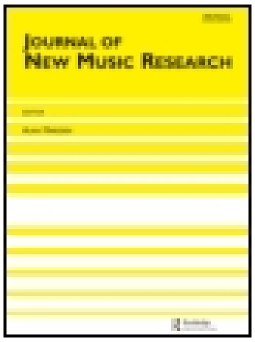

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Weighing Diverse Theoretical Models on Turkish *Maqam* Music Against Pitch Measurements: A Comparison of Peaks Automatically Derived from Frequency Histograms with Proposed Scale Tones

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Abstract

Since the early 20th century, various theories have been advanced in order to mathematically explain and notate modes of Traditional Turkish music known as *maqams*. In this article, *maqam* scales according to various theoretical models based on different tunings are compared with pitch measurements obtained from select recordings of master Turkish performers in order to study their level of match with analysed data. Chosen recordings are subjected to a fully computerized sequence of signal processing algorithms for the automatic determination of the set of relative pitches for each *maqam* scale: f0 estimation, histogram computation, tonic detection + histogram alignment, and peak picking. For nine well-recognized *maqams*, automatically derived relative pitches are compared with scale tones defined by theoretical models using quantitative distance measures. We analyse and interpret histogram peaks based on these measures to find the theoretical models most conforming with all the recordings, and hence, with the quotidian performance trends influenced by them.

1. Introduction

In the Middle East, a *maqam* generally implies a miscellany of rules for melodic composition and improvisation that exhibits diverse characteristics from one geography to another. These rules comprise the tonal/modal compass, direction (ascent/descent) of the 'melodic line' (Touma, 1971), functions of the degrees of the scale(s) and (tri-, tetra-, penta-chordal) genera that are used to construct the scale(s), microtonal inflexions, nuances (vibrato, portamento, etc.) and ornamentations, and possible modulations to or borrowings from other *maqams*.

It is not our foremost concern to delve in this study into the finer, and in our opinion, more abstract particulars of what constitutes the anatomy of a *maqam*, as done in Touma (1934/1999) and Powers (1988). We are more concerned with the intended tuning or intonation of a *maqam*'s fundamental scale(s). As such, the so-called 'lifeless skeleton' (Signell, 1977) of a *maqam*'s intricate pitch continuum—which we believe to be no less musically relevant—is substantially important in satisfactorily pinpointing and standardizing 'relatively stable' relative frequency locations on fixed-pitch instruments such as *qanun*, *tanbur*, *lavta* and even the more rigid microtonal keyboards.

In the following section, we wish to present a very concise review of the *maqam* tuning/intonation literature of the past several centuries for readers unfamiliar with the theory of Turkish *Maqam* music in the hopes that they shall be versed on the influential sources and some established key concepts of this subject matter. For further information, refer to Yarman (2007, 2008), Signell (1977) and Zannos (1990).

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After this, the aims and contributions of this study as well as potential areas of application shall be delineated in Section 1.2. Section 1.3 is devoted to the background and claims of analysed theoretical models. The plan of the manuscript is explained in Section 1.4.

1.1 A very concise review of *edvar/maqam* theory sources and some key concepts

It is well known that *maqams*, whose denominations are shared by people indigenous to Türkiye, Arab countries, Iran and Transoxania, may not only imply unalike scale structures, but may also be tuned or intoned differently even if they do imply the same. How to tune or intone *maqams*, known to the ancients as '*edvar*' (cycles/modes) and composed of '*ajnas*' (tetrachordal and pentachordal genera), has been a controversial theoretical issue for centuries. Islamic Civilization's first music theorist was Al-Kindi (9th century) proposed Pythagorean pitch ratios for Ud fingerings and its complementary *Abjad* (Arabic ABCD) system of notation. Al-Farabi (10th century) and Ibn Sina (11th century), translated the Hellenic lore on diatonic, chromatic and enharmonic divisions of the *diatessaron* to the *lingua franca* that was Arabic at the time in their native land (Yarman, 2007). They made significant contributions to the Islamic theory of music in the manner of rational/just intonation advocates; Archytas, Didymos and Ptolemy (Chalmers, 1992).[1] Legendary Turkish-Abbasid music theorist Safi al-Din Urmavi (13th century) continued this school and also developed a unique 17-tones to the octave Pythagorean scale[2] that was to inspire Rauf Yekta in the 20th century. Abdulkadir Meragi (15th century), musician to the Herat court of Timur the Lame, revived Urmavi's scale in his various tractates. The usage of the term *maqamat* (pl. *maqam*) instead of *edvar* coincides with the lifetime of this famous musician. Somehow, after Meragi, arithmetical calculation of pitches lapsed and did not resurface again for a quadricentennial epoch—though rife with *ilm-i edvar* (music treatises)—deserving to be titled the 'dark ages of *maqam* theory'. It is almost as if music theorists had given up trying to pinpoint the relative pitches of *maqams* and preferred instead the mystical captivation of esoteric chirography. Similarly, during the late Ottoman Era, Dimitrie Kantemir, Nayi Osman Dede, Tanburi Küçük Harutin (all 18th century), Abdulbaki Nas ir Dede, and Hamparsum Limonciyan (both 19th century) developed distinctive pitch notations without as much as a numerical indication to their intended tuning/intonation. The awakening in tangible musical mathematics recommenced with Mikhail Mushaqah of Lebanon (19th century) and reached an apex with modern Turkish music theorists Rauf Yekta, Saadettin Arel and Suphi Ezgi of 20th century Türkiye (Yarman, 2008).

We chance upon *maqam* names similar to the ones used today in works of the Islamic theorists mentioned above. For instance, we observe such names as *Isfahan* and *Selmeki* in Ibn Sina (*ca*. 1030/2004), and *Uşşak*, *Neva*, *Rast*, *Isfahan*, *Rahavi*, *Zirafkand* and *Buzurk* in Urmavi (Arslan, 2007) as we read the chapters on the construction of genera and scales.

Remember, that the ancients called genera *ajnas* and scales *edvar*. To provide an explicit picture of these ancient building blocks predating today's tetrachords/pentachords and *maqams*, let us deliberate on, for example, *Rahavi*, which is a peculiar tetrachordal genus described by Urmavi as 16:15 omitted 16:15 × 15:14 × 14:13 × 13:12, yielding the following scale:

1/1	0.000	unison, perfect prime	
~~16/15~~	~~111.731~~	~~minor diatonic semitone~~	~~(×16:15)~~
8/7	231.174	septimal whole tone	(×15:14)
16/13	359.472	tridecimal neutral third	(×14:13)
4/3	498.045	perfect fourth	(×13:12)

This genus is resemblant of quotidian Arabic rendition of the cadence region of *maqam Segah* extended toward the bass if the finalis was ascribed to 16/13. However, this is a bit of a stretch, since Safi al-Din defines the *Rahavi* genus elsewhere in his *al-Risalat al-Sharafiyya* (Arslan, 2007) as the confluence of three *mujannab-i sebbabe* (anterior index finger position on the *ud*) intervals totalling 5:4, it is more proper for *Rahavi* to be constructed in reverse, yielding a Perso-Arabic rendition of the *Saba* diminished tetrachord with a semi-tonal second degree as shown below:

1/1	0.000	unison, perfect prime	
13/12	138.573	tridecimal 2/3-tone	(×13:12)
7/6	266.871	septimal minor third	(×14:13)
5/4	386.314	major third	(×15:14)
~~4/3~~	~~498.045~~	~~perfect fourth~~	~~(×16:15)~~

Note that Urmavi defines on the *ud* '*mujannabat*' (the three possible *mujannab-i sebbabe* intervals) as 18:17 (99 cents), 162:149 (145 cents) and 54:49 (168 cents) respectively. Moreover, 65536:59049 (180 cents) should be counted as another *mujannab* interval according to the 17-tone Pythagorean tuning.

On the *ud*, the finger positions for *Rahavi* are hinted as:

1. Open string (0 cents),
2. Anterior index finger (99, 145, 168 or 180 cents),

---

[1] Also cf. 'diatonic genus', 'chromatic genus' and 'enharmonic genus' in *Tonalsoft Encyclopedia of Microtonal Music-Theory* by Joseph Monzo, and compare with Ibn Sina, *ca*. 1030/2004.

[2] This scale is constructed via a chain of 4 fifths up and 12 fifths down from the tone of origin.

3. Middle finger known to the ancients (the Pythagorean minor third at 32/27, making 294 cents),
4. The ring finger (the Pythagorean major third at 81/64, making 408 cents and one syntonic *comma* larger than 5/4).

We find the *Rahavi* genus (in bold typeface) in the devir of *Rahavi*, which—when interpreted within the 17-tone Pythagorean tuning—yields the following scale:

1/1	0.000	unison, perfect prime
65536/59049	180.450	Pythagorean diminished third
8192/6561	**384.360**	**Pythagorean diminished fourth**
4/3	**498.045**	**perfect fourth**
262144/177147	**678.495**	**Pythagorean diminished sixth**
128/81	**792.180**	**Pythagorean minor sixth**
16/9	996.090	Pythagorean minor seventh
2/1	1200.000	octave

The Pythagorean *apatome* at 2187:2048 (114 cents) occurs in the above rendition of the *Rahavi* genus twice and functions as another *mujannab*. It can be derived from partitioning the Pythagorean minor third (32:27) into two parts, the other of which is 65536:59049 at 180 cents. Given that Pythagorean augmented prime falls between 99 and 145 cents and Safi al-Din requires two *mujannabs* (in this case, 114 + 180 cents) plus one *limma* (90 cents) to complete a tetrachord, it is doubly requisite to call 114 cents a *mujannab* interval also.

Whilst preserving the *mujannab* + *mujannab* + *mujannab* structure and the character of the *Saba* diminished tetrachord with a semi-tonal second degree,[3] *Rahavi* genus can be re-defined in the following manner:

1/1	0.000	unison, perfect prime
2187/2048	113.685	apotome
32/27	294.135	Pythagorean minor third
81/64	407.820	Pythagorean major third

Maximum absolute difference between any degree of the two renditions of the *Rahavi* genus is no more than 31 cents.

Other genera also have some semblance to quotidian *maqams*. *Zirafkand-i Koutchek*, which is a pentachord first given as 14:13 × 13:12 × 36:35 × 8:7 × 35:32, but quickly revised by Urmavi as 14:13 × 13:12 × 36:35 × 9:8 × 10:9, yields the following scale:

1/1	0.000	unison, perfect prime	
14/13	128.298	2/3-tone	(× 14:13)
7/6	266.871	septimal minor third	(× 13:12)
6/5	315.641	minor third	(× 36:35)
27/20	519.551	acute fourth	(× 9:8)
3/2	701.955	perfect fifth	(× 10:9)

Following Urmavi's *mujannab* + *mujannab* + *limma* structure for *Zirafkand* genus and the instructions for allowing for the presence of two 5:4s, we understand that this pentachord ought to be reversed and all pitches after 5/4 omitted:

1/1	0.000	unison, perfect prime
10/9	182.404	minor whole tone
6/5	315.641	minor third (additional pitch via 4:5 from the perfect fifth)
5/4	386.314	major third
~~9/7~~	~~435.084~~	~~septimal major third~~
~~39/28~~	~~573.657~~	
~~3/2~~	~~701.955~~	~~perfect fifth~~

Zirafkand genus employs the same *ud* finger positions as *Rahavi*, save the final degree of the trichord, which is *Zalzal wosta* (middle finger) at 27/22 (355 cents). If we are to account for the *limma* (256:243 at 90 cents) a higher middle finger is implicated:

1/1	0.000	unison, perfect prime
162/149	144.818	Persian neutral second
32/27	294.135	Pythagorean minor third
8192/6561	384.360	Pythagorean diminished fourth (corrected *Zalzal wosta*)

Notice that there is a 149 cent interval expressible as 2187:2384 which resides between 162/149 and 32/27. This interval is very close 162/149 and constitutes another possible *mujannab* interval, though not strictly defined as such.

Urmavi gives a *mujannab* + *mujannab* + wholetone + ***mujannab*** + ***mujannab*** + ***limma*** + wholetone + *mujannab* scale for the *devir* of *Zirafkand* that contains the *Zirafkand* genus in bold. This scale is produced below in 7-limit Just Intonation with the *Zirafkand* genus in bold:

1/1	0.000	unison, perfect prime
49/45	147.428	Bohlen–Pierce minor semitone
32/27	294.135	Pythagorean minor third
4/3	**498.045**	**perfect fourth**
196/135	**645.473**	
128/81	**792.180**	**Pythagorean minor sixth**
5/3	**884.359**	**(Bohlen–Pierce) major sixth**
15/8	1088.269	classic major seventh
2/1	1200.000	octave

Errors amounting to a maximum absolute of 33 cents per degree would result were we to render the *Zirafkand devir* in the 17-tone Pythagorean scale of Safi al-Din Urmavi:

---

[3] This would imply *Saba Zamzama* instead of *Saba*. Note, that *Zamzama* is synonymous with a half-tone + whole-tone + half-tone diminished tetrachord in modern Arabic *Maqam* music theory.

1/1	0.000	unison, perfect prime
65536/59049	180.450	Pythagorean diminished third
32/27	294.135	Pythagorean minor third
4/3	**498.045**	**perfect fourth**
262144/177147	**678.495**	**Pythagorean diminished sixth**
128/81	**792.180**	**Pythagorean minor sixth**
32768/19683	**882.405**	**Pythagorean diminished seventh**
4096/2187	1086.315	Pythagorean diminished octave
2/1	1200.000	octave

The fact that errors are rather marginal for *Zirafkand* and *Rahavi*[4]. leads us to conjecture that the said 17-tone tuning is merely a flexible fretting guideline for the *ud* with minimal number of tones versus smallest intervallic deviations for various *mujannab* (middle second) intervals.

Here, we might quote from Dr. Albrecht Schneider (article review, 26 March 2009 [email]):

> . . . I would say that this [‘classical’ Persian/Arabian tone system as outlined, probably best of all, by Safi al-Din] basically is a system derived from Pythagorean tradition that, however, is expanded by a very simple yet very effective operation: continue a sequence of pure fifths that starts from a certain tone into both directions (up, down). If you continue this operation long enough (up to 12 fifths in a row), and put back all the tones you have found by this operation into one octave (or, alternatively, into two octaves structured into tetrachordal patterns), you will gain a very elaborated tone system suited to serve as the foundation of several actual tuning options (i.e., selections of pitches per octave depending on where you put your frets on a long-necked lute).

As one proceeds further in history to the era of Meragi, one soon realizes the futility in drawing direct parallels between 15th century scales with today’s *maqams*, since the elaborate arithmetical divisions of tetrachordal and pentachordal genera of the earlier generations are all but abandoned by the music theorists. We witness only the repetition of Urmavi’s 17-tone Pythagorean tuning, the *Abjad* notation it curtails, and explication of *maqams/avazes/şubes/terkibs* via this tone-system and its notation.

Eventually such endeavours too are abandoned by the end of the 15th century. We are left clueless about how pitch inflexions occur or if they occur at all throughout the extent of the ‘dark ages of *maqam* theory’.

Take for instance ‘*Risale-i Musiki*’ by Nizameddin ibn Yusuf of Kırşehir (Sezikli, 2000), where we find *Zirefkend-Kuçek* attributed to the zodiac sign of Cancer and the element of water followed by a cryptic circle where supposedly pitches of the said *devir* is given. Here, Nizameddin is more concerned with which *maqams* are implied when the tonic changes among the few tell-tale *perdes* (notes or tones) he provides.

From this point forward until the 18th century, as the number of *maqams/avazes/şubes/terkibs* increase with treatise after treatise, a modern researcher’s confusion abounds as to which denomination comprises what scale(s). Esoterism has crept in to replace the genuine mathematical approach of Urmavi during the ‘dark ages of *maqam* theory’. A similar situation is true for the music theory of the Greek Orthodox Church within the borders of the Ottoman Empire, where ‘all teaching is done by ear’ (Zannos, 1990).

By the 18th century, a significant change has occurred. In the treatise of Dmitri Kantemir (1698), we are relieved to find that *maqams* are explained by a sequence of intelligible *perdes* similar to the ones in effect today such as *segah*, *buselik*, *acem*, *sünbüle* etc. Take for instance the definition of *Zirefkend*:

> ***Explanation of the so-called maqam Zir-efken(d):*** *Maqam Zir-efken(d) is explained in two ways. Some say that it starts at muhayyer [e’] and concludes on aşiran [B]. Others claim that it starts at tiz hüseyni [b’] and concludes on dügah [e].*
>
> *Should it start its sonic course from muhayyer [e’], it descends via whole perdes*[5] *[d’, c‡’, b, a] on to çargah [g], and then—after stepping on buselik [f#]—suddenly falls down to rast [d] [by skipping dügah—e]. From thereon—with the perde irak [c‡]—rests on the post of aşiran [B]...*
>
> *Should it start its sonic course from tiz hüseyni [b’], it descends to gerdaniye [d’] over whole perdes [a’, g’, etc.] from the face of sünbüle [f’]. From thereforward, it steps on perde acem [c’] by omitting perde evc [c‡’] and—after descending by whole perdes through hüseyni [b], neva [a], çargah [g] and segah [f‡]—concludes on perde dügah [e].*

While this style of describing a *maqam* lacks any mathematical foundation and even so has little or nothing to do with Urmevi’s *Zirafkand*, it is at least more lucid than the cryptic scribbles of the previous centuries.

Zir-efkand-i Kuçek of the old treatises is also elucidated by Kantemir in a similar manner, though yielding nothing resemblant of Urmavi’s genus of the same name. *Rehavi*, on the other hand, resembles the *Rahavi* genus:

> ***Rehavi:*** *Having drawn perde neva [a] very near to perde çargah [g] and starting its movement from there [ab], comes to perde dügah [e] after stopping by perdes çargah [g] and segah [f‡]. It concludes on perde dügah [e] while also*

---

[4] We have chosen *Zirafkand* and *Rahavi* for demonstration purposes, because they are two rare *maqams* that Urmavi gives both the *genera* and the *edvar* for.

[5] Natural diatonic or ‘whole’ tones (*tam perdeler*) in contrast to half-tones (*nim perdeler*). These are the only indications Kantemir and later Ottoman theorists provide for the distances between *perdes*. Notice the similarity between *maqam* names and *perde* names. A perde is named after a *maqam* because it is a crucial functional degree for that *maqam*.

> *stepping on the nim perde [zirgule/zengule—d#] below dügah.*[6]

While this definition of the old *Rehavi* partially conforms with Urmevi, the contemporary *Rehavi* of Kantemir is: 'nothing but a *Rast maqam* imitating the melody of the trumpet.' An examination of Dede Efendi's *Rast Kar-ı Natık*[7] in the early 19th century will validate the employment of a *Rehavi* cadential phrase that indeed is none other than an arpeggiating *Rast*.

We find a more proper definition of *Zirefkend-i Kuçek* in Kemani Hızır Ağa (Daloğlu, 1985), who, a few decades later and using the same eloquent descriptive style as Kantemir, implies that the *maqam* in question is a descending version of *Saba* using the *perdes gerdaniye*, *evc*, *hüseyni*, *nim* (half-tone of) *saba*, *çargah*, *segah* and *dügah*; a clarification which agrees almost entirely with Urmavi's *Zirafkand*.

The kinship between *Saba*, *Zirefken(d)* and *Kuçek* is soon attested by Abdulbaki Nasır Dede (Nasir, 1796). This fact is emphasized much later by Suphi Ezgi (1940) and Yakup Fikret Kutluğ (2000).

Today, Urmavi's *Zirafkand* could be said to survive as *maqam Kuçek*, and *Rahavi* as *maqam Saba Zemzeme*. Future investigations will certainly reveal the similarities or differences between ancient *edvar* and later *maqams*.

We now conclude our short historical excursion with the theoretical developments in the 20th century.

Since the early 20th century, various theories have been proposed in Türkiye in order to explain and notate *maqams*. Each theory is based on a tuning that is at odds with the others. The 24-tone Pythagorean tuning devised by Rauf Yekta (1922/1986) and modified by Saadettin Arel, Suphi Ezgi and Murat Uzdilek is widely recognized as the official model. It is, for all intents and purposes, an extension of Urmavi's 17-tone Pythagorean scale (Yarman, 2008). The Arel–Ezgi–Uzdilek (AEU) theory (Arel, 1930/1968; Ezgi, 1933) built upon this model and taught in Turkish Music conservatories since 1943 is rivaled by a theory based on a 41-tone subset out of 106 equal divisions of the octave formulated by Abdulkadir Töre and Ekrem Karadeniz (Karadeniz, 1965/1983). However, Töre–Karadeniz (TK) has never gained a significant following in Türkiye. In the last few decades, the method of partitioning the whole tone into 9 and the octave into 53 *commas* has spread among traditionalist circles. Division of the octave into logarithmically 53 equal parts known as Holderian *commas*[8] also embodies the 24-tone Pythagorean tuning with less than a cent error (Yarman, 2007). According to this approach, accidentals of the AEU system are said to deviate from their original positions by *comma* steps for certain *maqams*. A special music notation program called 'Mus2' exploits the Holderian *comma* resolution when interpreting AEU accidentals and rises as a contender. Doubling the pitch detail of the Arabic quarter-tone system is a recently published treatise where *maqams* are tuned according to logarithmically 48 equal divisions[9] of the octave (Yavuzoğlu, 2008). Lastly, a novel 24-tone tuning is introduced by the second author as an alternative to the AEU system (Yarman, 2009).

1.2 Background and claims of modern theoretical models

The background and claims of analysed theoretical models regarding the tuning/intonation of *perdes* and the reliability with which they represent Turkish *Maqam* music on paper is an issue that must be addressed shortly at this point.

We observe that Rauf Yekta admitted to the usage of such intervals as the diminished minor tone (12:11 at 151 cents), augmented *apotome* (15:14 at 119 cents), and augmented *limma* (135:128 at 92 cents) that his 24-tone Pythagorean tuning did not account for (Yekta, 1929).

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[6] The Western note-names are those used by Yalçın Tura.

[7] An instrumental–vocal form of composition meant for music education that demonstrates many *maqams* one after the other.

[8] We have been informed by our second reviewer Dr. Albrecht Schneider that this *comma* of 22.64151 cents is wrongly attributed to William Holder. It was actually discovered by a Belgian Engineer named Jean Galle as reported by Marin Mersenne in 1637. Nicolaus Mercator gave a more mathematically precise description of the said *comma* in 1660. We also observe that Alexander J. Ellis calls the 53-tone equal temperament yielding this artificial *comma* 'Mercator's cycle' (Helmholtz, 1877, pp. 328–329, 436). 'Mercator's cycle' appears afterwards in Isaac Newton's unpublished manuscripts dated 1664–65 and William Holder's treatise of 1684. (cf. Barbieri, 2008). We reproduce this information with permission of and special thanks to our reviewer Dr. Schneider who was generous enough to disclose his identity (emails dated 26 March and 29 April 2009). Due to the fact that this *comma* is known widely in Turkish *Maqam* music circles as the Holderian comma despite attempts to call it other names (cf. Uysal, 2001, pp. 49, 60, 122, 144 ['*uygun*'], and Aksoy, B. *Makam in Tan im ina Doğru*. Musıkişinas, 7. İstanbul, 2000, pp. 70–87 ['*minik*', suggested by Mildan Niyazi Ayomak]), and since William Holder partook in the promulgation of it, we shall keep referring to it as the Holderian *comma* (Hc) in our study.

[9] The first person to employ 1/8 tones to explain modern Turkish genera and *maqams* is Edward J. Hines. Through personal communication, the second author has learned that Mr. Hines has chosen 48-tone equal temperament to notate *maqams* as early as 1989 (Hines, 2009; through private email communication with the second author, 3 May 2009). This information was obtained after the main body of the article was completed; hence, Mr. Hines' approach was not included in the manuscript.

While the latter two might be dismissed for their extreme proximity to the *apotome* (114 cents) and the *limma* (90 cents), the *nakıs büyük mücenneb* given as 12:11, which Yekta acknowledges to be indispensable to achieve the last degree of the *Saba* diminished tetrachord, cannot be brushed aside so easily. If this interval was approximated by the *apotome* as Yekta allowed, the error would be as high as 37 cents. If it was rounded to the minor tone at 180 cents as Yekta says some musicians inclined to, the error would be 29 cents and the effect far removed from that of the *apotome*. Yekta calls these errors 'minute'; however, in a tuning where half the number of tones are placed a *comma* apart from the other half (Signell, 1977), these errors could be anything but 'minute'. Though he is confident that the 24-tone Pythagorean tuning suffices to represent all *maqams* faithfully and that no additional fret is needed in the case of 12:11, it is evident that Yekta was promoting a tone-system which did not comprise all the *mujannabat* so clearly defined by Urmavi on the *ud* centuries ago.

Yekta's followers, Arel and Ezgi, concerned not to provoke the newly founded nation-state poised—for the sake of the Turkification of culture—to abolish any references to the quarter-tones so confidently associated with the Byzantine and the Arabs, were even more eager, alas in vain, to bludgeon nonconforming intervals into the framework of the 24-tone Pythagorean tuning.[10] For example, Suphi Ezgi, who admitted to the usage of 11:10 (165 cents) between *dügah* and *segah* in *maqam Uşşak* in 1933 (Ezgi, 1933) back-pedalled in 1940 (Ezgi, 1940) and corrected the ratio to 125:113 (175 cents), finally approximating that with 65536:59049 (180 cents). Rauf Yekta's slogan: '*there are no quarter-tones in Turkish music*' (Erguner, 2003) became Arel's watchword after he rose to the position of director of Istanbul Conservatory with special privileges. Soon enough, AEU was elevated to the 'national theory of Turkish music'; its pitches rock-steady, unmoving . . . defying a myriad of *mujannab* intervals executed in actual practice.

This state of affairs continued for a long time, until, by the late 1980s, *comma* steps arising from the partitioning of the whole-tone into 9 parts[11] began to be employed to distinguish nonconforming *perdes* in such *maqams* as *Uşşak*, *Saba*, *Karcığar* and *Hüzzam*; a procedure that effectively broke the barriers of AEU and led musicians to embrace the 53 *commas* per octave resolution in which AEU became a subset. Nevertheless, dichotomy between this resolution and the old AEU notation persists even today despite attempts such as the 'Mus2' approach (cf. Appendix) to mitigate it.

Töre–Karadeniz was developed at a time when the AEU theory was reigning supreme. With 41 tones per octave at its arsenal, this new theory—whose foundations are said to be laid by Abdulkadir Töre in the early 20th century if we are to believe Ekrem Karadeniz—was prepared to account for the unruly *perdes* of Turkish *Maqam* music. However, due to its irregular nature and the difficulty with which it was shown on paper, the theory soon lost its allure and was entirely abandoned in favour of the 53 *commas* per octave methodology. The remaining supporters of Karadeniz's treatise were dealt a deadly blow by music theorist Ayhan Zeren (2003), who is even today a staunch advocate of the AEU system. Although, the psycho-acoustics of the treatise is poor in language, science, and facts, the 41-tone subset out of logarithmically 106 equal divisions of the octave merits evaluation, and hence, was included in our study.

With TK out of the way, more alternatives came to the scene. Nail Yavuzoğlu, educated in Classical Western music and Jazz and nurturing a special interest towards Turkish *Maqam* music theory, thought up dividing the octave into 60 equal parts at first (Yavuzoğlu, 1991) but later settled with 48 equal parts (Yavuzoğlu, 2008). While devising temperaments that are multiples of logarithmically 12 equal divisions of the octave is nothing original, this new theory deserves to be investigated, especially concerning its claims to truly represent problematic *perdes* of such *maqams* as *Uşşak*, *Saba* and *Hüzzam*.

A final contender boasting 24 pitches to the octave was proposed by the second author as an alternative to the AEU system using the same microtonal symbols and capable, according to Dr. Yarman, of adequately explaining all *maqams* in a single *ahenk* (diapason) with all due reservations as to a performer's choice of microtonal inflexions for free-pitched instruments.

1.3 The aims and contributions of this study including potential areas of application

The diversity of so many tuning schemes for Turkish *Maqam* music necessitates their comparison with frequency measurements obtained from actual recordings to evaluate their success in representing practice. In the words of Iannis Zannos (1990):

> . . . from a contemporary standpoint, theory should be regarded as an integral part of musical tradition, and its relationship to other kinds of historical or contemporary evidence about musical practice should be carefully examined . . .
>
> In the 19th and 20th century, within the general framework of cultural changes and crises in traditional arts, music theory underwent radical reforms in both Greece and

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[10] For a synopsis of the role of the 24-tone Pythagorean tuning and theory in light of events and ideologies that led to the ban on the education of Turkish *Maqam* music instruments and the prohibition of *Alla Turca* broadcasts during 1934–1936, cf. Yarman (2009).

[11] Initially, a short-hand for the demonstration of *comma*, *limma*, *apotome* and minor tone positions within the whole-tone.

> Turkey. Once more, the subject of the definition of intervals—that is of correct intonation—was taken up, and several proposals were made. None of them offers a perfect solution; even more, none of them can be said to correspond with contemporary empirical study, in the current more advanced state of physical measurement and mathematical modelling.

In this study, we echo these concerns and apply recently developed automatic frequency analysis techniques (Bozkurt, 2008) to recordings of venerable masters of Turkish *Maqam* music and undertake a study, for the first time in the literature, to assess how well the above-mentioned theoretical models reflect practice for a given audio collection and the quotidian performance tradition influenced by that collection.

The automatic analysis system explained in this article accepts an audio file in a given *maqam* as input and produces an optimum set of relative pitches for the given *maqam*. These pitches will be compared with the pitches of *maqam* scales tuned according to suggested theories.

Our pursuit, if we may say so, is not really much different in essence than the hypothetical case of an extra-terrestrial team of researchers attempting to pinpoint an ideal and uncumbersome tone-system for a corpus of instrumental and vocal Classical Western music transmissions notwithstanding how crudely or unwholesomely the resultant tuning scheme (which assuredly would turn out to be 12 equal tones per octave or a sibling cyclic temperament) would represent the intended music.

There are many studies that mention the existence of mismatches between the intervals executed by master musicians and those specified in the Arel–Ezgi–Uzdilek (AEU) theory (Arel, 1930/1968; Ezgi, 1933).[12,13] However, most of these studies either imply an unsubstantiated 53 *commas* to the octave methodology (Özkan, 1998) or are based on pitch determinations deduced from limited data (Karaosmanoğlu & Akkoç, 2003; Tulgan, 2007; Yarman, 2008). The main reason for this is the lack of reliable analysis methods. Despite the existence of abundant signal processing algorithms for Western music, direct application of such methods to Turkish *Maqam* music and/or developing automatic analysis methods therefrom is not practicable due to the indispensable characteristics of *maqams*: it is well known that *perdes* (notes or tones) of *maqams* do not always correspond to fixed pitches; that is to say, dozens of *maqams* employ a large variety of microtones and musicians may differently interpret certain degrees of *maqam* scales.[14] In addition, the concept of absolute pitch is meaningless as there are 12 possible diapasons (called '*ahenk*'). These are significant obstacles in the development of an automatic analysis system that is capable of processing multiple recordings.

In a recent study (Bozkurt, 2008), a new algorithm was proposed that can overcome said difficulties by aligning frequency histograms acquired from different recordings in an iterative manner. In this article, we present the application of that algorithm to a database of select recordings with the aim of comparing them and the following theoretical models:

(1) Yekta–Arel–Ezgi–Uzdilek (YAEU), taken together since it has been shown in Yarman (2007) that AEU (Arel, 1930/1968; Ezgi, 1933) is no more than a simple modification of the original 24-tone Pythagorean tuning of Yekta (1922/1986);
(2) 'Mus2' is explained further in the Appendix section which uses AEU notation and extends its tone resolution to logarithmically 53 equal divisions of the octave;
(3) Töre–Karadeniz (TK) based on a 41-tone subset out of logarithmically 106 equal divisions of the octave;
(4) an alternative approach featuring a novel 24-tone tuning suggested by the second author referred to as Yarman24 (Yarman, 2009);
(5) a recent theory based on logarithmically 48 equal divisions of the octave referred to as Yavuzoğlu48 (Yavuzoğlu, 2008).

While there are more theoretical models for Turkish *Maqam* music such as a 29-tone tuning by Gültekin Oransay (1959), a subset of 72-tone equal temperament universally applied to Turkish *qanuns* since the widespread utilization of 12 equal semitones per octave temperament tuners imported from the West, 65-tone equal temperament elaborated very recently by the grandson of Rauf Yekta, Mehmet Yektay as a *mandal*[15] affixture scheme for *qanuns*, and a 79-tone tuning

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[12] Cf. Signell, 1977; also Zannos, 1990: 'Using a limited number of degrees is a theoretical concession which inevitably results in disregarding certain details of intonation.'

[13] Admittedly, the utilization of 12-tone equal temperament or a sibling tuning in keyboard and fretted instruments in Classical/Contemporary Western music is not in the least unacceptable, namely, one can perform a piece written for trombone or violin on a piano without grossly misrepresenting or distorting the intended music, whereas, fretting the *tanbur* or affixing mandals on a *qanun* strictly according to the 24-tone Yekta–Arel–Ezgi–Uzdilek tuning will be disastrous for *Maqam* music performance; namely, this tuning scheme will grossly misrepresent or distort the intended music, particularly for *maqams* or modulations to *Saba*, *Uşşak*, *Hüzzam*, *Karcığar*, etc., where the margin of error for certain tones is very narrow.

[14] For example, Zannos (1990) acknowledges: 'The key problem of the diatonic species is a very old one: the position of the degree *segah* (vou) . . . Today, some schools prefer a higher position, some a lower one . . .'

[15] Metallic levers arrayed across the diagonal side of the *qanun* that serve to alter vibrating lengths of the courses on the fly by an amount foreordained at the time of their installation.

proposed elsewhere by the second author and implemented on a unique *qanun* (Yarman, 2008), we have chosen only the aforesaid five models for comparative evaluation. Our choice depends on the criteria that the maximum number of tones per octave is no more than 53, and that notations of works in the given tunings exist unless they were very recently proposed. Since the number of tones per octave in the 72-tone and 79-tone models exceed 53, and works have not been notated in these tunings and even in the less voluminous Oransay29, they were all dismissed. Yavuzoğlu48 and Yarman24 were included despite the fact that they lack a repertory because they were newly conceived.

Although there are predecessors to our study where frequency measurements of Turkish *Maqam* music instruments or recordings were accomplished such as in Signell, (1977)[16] and Yahya (2002),[17] we can confidently say that none of them is as comprehensive and methodical as our work.

The findings of this study are potentially applicable to the solution of practical problems of Turkish *Maqam* music like the clarification of the rudiments of *maqam* intonation—such as which degrees of a *maqam* scale exhibit how much inflexion or fuzziness—so as to facilitate the standardization of fixed-pitch instruments such as *tanbur* and *qanun*. Since the theory in effect has apodictic shortcomings, instrument makers assign frets and *mandals* according to demand or as they see fit. As a consequence, some instrumental tractates provide alternative fret locations for the very same instrument. For example, in Akan (2007) frets are given not just according to AEU theory, but also according to this or that musician. Clarity of intonation in large instrumental ensembles is particularly troublesome for this very reason.

Analysis of empirical data would thus help future development of a theory more compatible with Turkish *Maqam* music practice, which in turn would aid the afore-mentioned standardization process. Implementation of such a theory to music education could serve as a basis for the elucidation of the *seyir* or melodic procedure/progression phenomenon which is so crucial to understanding *maqams*.

In addition, algorithms such as the automatic recognition of the *maqam* of a recorded musical piece and the automatic note transcription therefrom would work much better if the theoretical information provided by the tuning was more conforming with practice. Our achievements could lead to the hands-free transcription and, in favourable tunings, playback of Turkish *Maqam* music recordings by computer notation/sequencer software armed with sampled instrument sounds that closely reflect or mimic actual practice.[18]

1.4 Plan of the manuscript

Our study comprises the following steps explained in detail in subsequent sections: first, a database of acclaimed performers is compiled and master executants are chosen from the literature. For example Tanburi Cemil Bey's recordings are included, since they are considered in various documents such as Tanrıkorur (2004) to be the leading examples for famous musicians like İhsan Özgen, Necdet Yaşar, and Ercument Batanay. As the second step, fundamental frequency (f0) estimation is performed and post-filters are applied to correct the estimations. From the f0 data, pitch histograms are computed. Then we employ an automatic tonic detection algorithm which attempts to align a YAEU *maqam* scale template with the stalagmitic shape of each histogram to initially line up histograms with respect to each other. In an iterative manner, the *maqam* scale template is reconstructed from the lined up histograms and template-histogram alignments are re-performed. Then, histograms from multiple files are combined for each *maqam* based on their tonics. As a result, overall histograms are obtained in each *maqam* category. These histograms are further processed to yield the peak values, which are plotted together with the scale tones of YAEU, Mus2, TK, Yarman24 and Yavuzoğlu48 to provide opportunity for visual comparison.

In addition to the histogram plots used for visual comparison, we also provide quantitative distance information obtained by calculating how far theorized scale tones lie from histogram peaks and taking averages for each tuning. This facilitates the ranking of tunings from best to worst according to their match with measured data, and thus, in a limited sense, with Traditional Turkish music practice. Because scale tones for each *maqam* according to each theoretical model shall be given in Hc and cents, we shall not concern ourselves with how *maqams* are constructed and what type of *seyir* (procedure) they need to follow; information pertaining to these can be obtained from already published treatises.

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[16] Where Karl Signell measures intervals between *perdes* fretted by *tanbur* virtuoso Necdet Yaşar not defined in AEU theory.

[17] Where Gülçin Yahya takes the total percentage of each counted *perde* executed in an *ud taksim* (improvisations) of Yorgo Bacanos using Steinberg WaveLab (we do not know how she ascertains a *perde*'s frequency) and compares that to the percentage of note lengths in her hand-transcriptions of that *taksim*. This operation demonstrates either the failure of the ear (or at least the author's ear) to determine correct note durations, or the hazard of incorrectly identifying a *perde*'s frequency value for comparison with its heard counterpart, or both.

[18] A step toward this direction has already been taken by the third author in his novel publication of a Turkish Music Multimedia Encyclopedia called 'Mus2okur' (www.musiki.org).

Finally in Sections 5 and 6, we present a detailed discussion of the results and share our conclusions.

2. Data collection

Building a database that more or less reflects Turkish *Maqam* music practice is essential in order to evaluate how well different suggested theoretical models represent the genre. Which recordings, from which period of time, based on which forms, and performed by which instruments should be included in the database is open to debate. Unfortunately, we could not find in the literature a work that could guide us toward gathering a list of criteria for the construction of such a database. Aside from our own effort described in Bozkurt et al. (2008), we could not find any publicly available databases either.

As is the case with most traditional musics in the world, masters are considered the leading sources of information for Turkish *Maqam* music. Therefore, we decided to choose recordings only from musicians referred to as 'indisputable masters' in the literature. Aside from the signal-based criteria explained below, no further criteria are applied to the construction of the database, since it is already difficult enough to gather a large collection of monophonic recordings in certain *maqams* from these musicians.

While we consign to the fact that a different database or additional recordings could yield notably different results than those reached in this study, we are confidently assuming that they would not utterly contradict the homogeneity expected of a traditional *Maqam* music performance, and therefore, ought not devastate our conclusions.

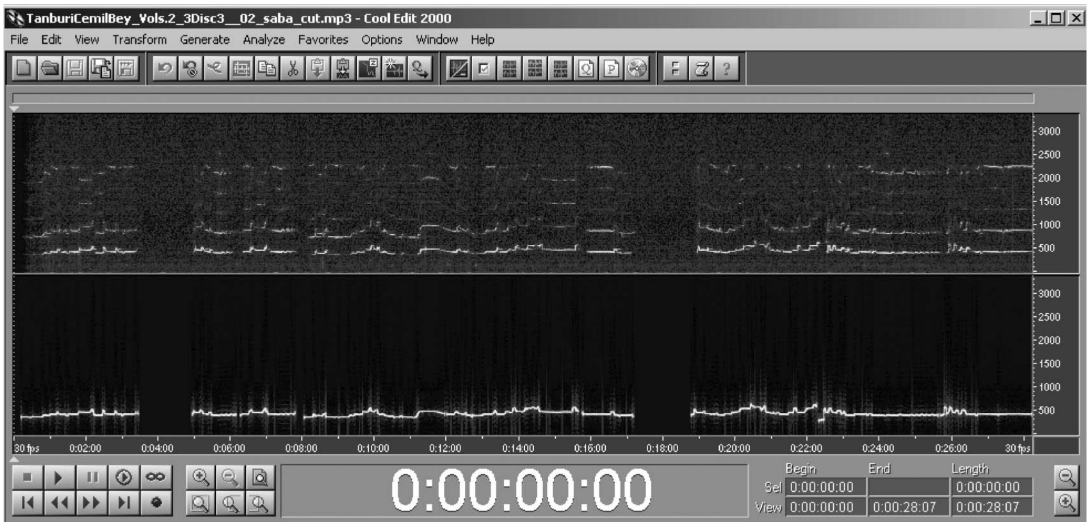
In our database, we included recordings from the following virtuosos: Tanburi Cemil (*tanbur*, *kemençe*, violoncello), Mesut Cemil (*tanbur*, violoncello), Ercüment Batanay (*tanbur*), Fahrettin Çimenli (*tanbur*), Udi Hrant (violin), Yorgo Bacanos (*ud*), Aka Gündüz Kutbay (*ney*), Kani Karaca (vocal), Bekir Sıdkı Sezgin (vocal), Necdet Yaşar (*tanbur*), İhsan Özgen (*kemençe*), Niyazi Sayın (*ney*).

The earliest recordings are those of Tanburi Cemil dated 1910–1914, and the most recent are those of Niyazi Sayın dated 2001 (*Sada: Niyazi Sayın*. Mega Müzik-İstanbul, 2001).

First, a large set of recordings was collected from these musicians. All recordings chosen were monophonic to avoid the complex multi-pitch estimation problem. Pitch/fundamental frequency (f0) analysis was performed as explained in the next section. To check the accuracy of f0 analysis, stereo audio files were created which contain the original recording in one channel and the re-synthesized sinusoidal signal from estimated f0 in the other. To filter recordings where f0 estimation errors were relatively high, stereo audio files were examined through simultaneously listening and observing their narrowband spectrogram. An example is presented in Figure 1, where the upper channel contains the original recording and the lower channel contains the synthetic signal spectrogram.

Some of the recordings were rejected owing to encountered problems such as pitch estimation errors due to the high amount of noise and varying rotational speed of phonographs. In the end, the number of recordings with successful pitch estimation for each *maqam* were determined to be 17 recordings in *maqam Hicaz*, 15 recordings in *maqam Hüseyni*, 13 recordings in *maqam Hüzzam*, 17 recordings in *maqam Kürdilihicazkar*, 12 recordings in *maqam Nihavend*, 16 recordings in *maqam Rast*, 11 recordings in *maqam Saba*, 16 recordings in *maqam Segah* and 11 recordings in *maqam Uşşak*.

All of these are among the most popular *maqams* used in the last century. *Maqams* pertaining to less than 10



	Begin	End	Length
Sel	0:00:00:00		0:00:00:00
View	0:00:00:00	0:00:28:07	0:00:28:07

Fig. 1. An example stereo file created for checking the quality of f0 analysis.

recordings were dropped from the list of *maqams* to be studied.

3. The frequency analysis method

We present below a brief description of the frequency analysis method illustrated in detail in Bozkurt (2008). With the additional peak detection operation, we achieve a completely automatic analysis system that accepts recordings in a given *maqam* as input and derives an optimum set of relative pitches, hence, a scale for that *maqam*. Overall frequency analysis procedure for a given *maqam* category is shown in Figure 2.

3.1 Fundamental frequency (f0) estimation

The well-known YIN algorithm (de Cheveigne & Kawahara, 2002) is used for f0 estimation together with some post-filters designed specifically for Turkish *Maqam* music as described in Bozkurt (2008). An f0 value is estimated for each 10 ms period by YIN and special post-filters are applied to correct some of the errors of YIN such as octave doubling/halving and noise.

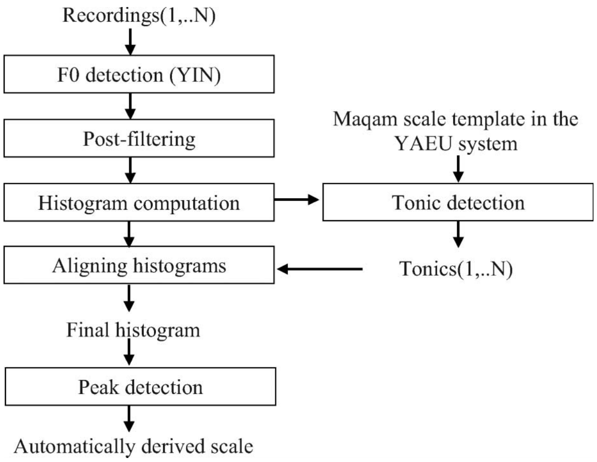


Fig. 2. The overall frequency analysis procedure for a given *maqam* category.

One way of studying the f0 variations is to scrutinize the temporal dynamics of a given recording within the tone grid of a theoretical model as shown in Figure 3.

However, this approach is not very practical for studying mismatches between multiple files and various tunings. The use of histograms for comparison of relative pitches with the tones of suggested *maqam* scales is more practical and common for such investigations (Akkoç, 2002; Karaosmanoğlu & Akkoç, 2003; Zeren, 2003; Karaosmanoğlu, 2004). We also use this approach in our study.

The drawback of using histograms instead of time-varying f0 data for analysis of a tuning is the loss of the temporal dimension and therefore, the musical context of executed intervals. However, as detailed comprehensively in the introduction section to this article, our concern is solely the evaluation of the success of proposed theoretical models in representing the *maqam* scale(s) derived from pitch measurements.

3.2 Histogram computation

A pitch histogram, $Hf_0[n]$, is a mapping that corresponds to the number of f0 values that fall into various disjoint categories (known as bins):

$$Hf_0[n] = \sum_{k=1}^{K} m_k,$$

$$m_k = 1, f_n \le f_0[k] < f_{n+1},$$

$$m_k = 0, \quad \text{otherwise},$$

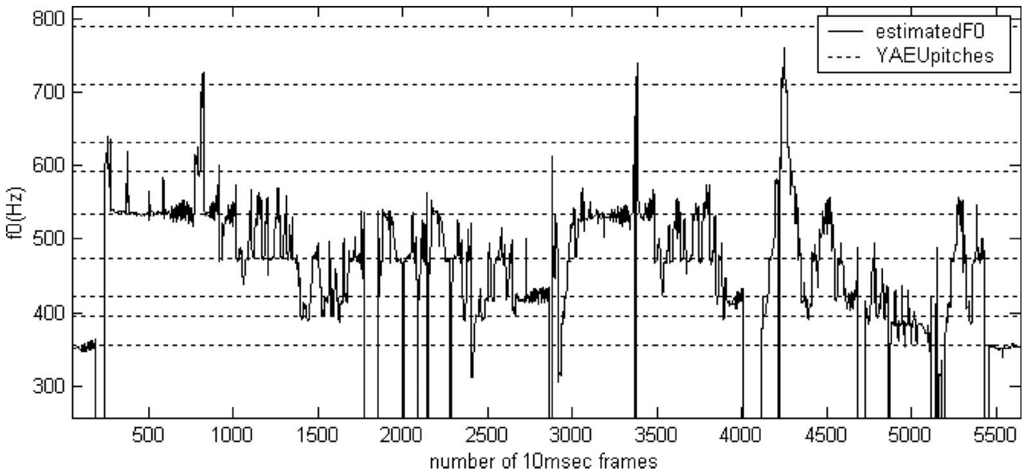


Fig. 3. F0 data in a recording of Tanburi Cemil Bey (Vol 1, Track 2—'Çeçen kızı' (*maqam Hüseyni*) plotted together with YAEU tone grid represented as dashed lines.

where (f_n, f_{n+1}) are boundary values defining the f0 range for the *n*th bin.

The choice of the bin-width $(f_{n+1} - f_n)$, the width of each category, defines the resolution of the histogram. In studies of theoretical models, it is common practice to use uniform sampling of the whole f0 range.

One of the critical choices made in histogram computation is the decision of bin-width where automatic methods are concerned. In automatic processing of histograms, peak detection is one of the basic operations; therefore the detection of note peaks should be of prime concern. A fine grid, i.e. small bin-width, has an advantage in terms of precision but is disadvantageous for automatic peak picking since spurious peaks are produced. The situation is the other way around for a coarse grid, i.e. large bin-width where some peaks are lost. As a result of empirical tests with various grid sizes, we decided to use the 1/3 Holderian *comma*[19] (Hc) resolution, a value that optimizes smoothness and precision of pitch histograms. Moreover, this resolution is the highest master tuning scheme we could find from which a subset tuning is derived for *Maqam* music (as specified in Yarman, 2008). In all the pitch histograms used in this study, the data is measured with 1/3 Hc precision with respect to the tonic. A higher precision of 1/12 Hc is used for rounding the relative pitch values of the five theoretical models in order to avoid too rough a quantization, which yields only one cent maximum absolute error for any given tone of any tuning discussed in this article. For the sake of combining both frequency measurements and *maqam* scales on the same plots, upsampling by a factor of 4 is applied to pitch histograms produced in Section 4.

3.3 Tonic detection and histogram alignment

In the analysis of large databases for Turkish *Maqam* music, the most problematic part is correlating results from multiple files. Due to diapason differences between recordings, lining up the analysed data from various files is impossible without a reference point. Fortunately, the tonic of each *maqam* serves as a viable reference point. Hence, we utilize an automatic tonic detection algorithm that finds, as an initial step, the highest cross-correlation between a YAEU *maqam* scale template and the f0 histogram of a given recording. Then the scale template is redrawn from lined up histograms and alignment with all files is re-performed. Using this approach, all histograms are aligned with respect to each other in an iterative manner and the tonics are found. Once the tonics are found, histograms of all files for a given *maqam* can be collated to compute a final, overall histogram.

The computation of the overall histogram for a given *maqam* is achieved via two different methods. In the first method, simple averaging is used, i.e. all histograms are summed and finally normalized to obtain an overall histogram. This type of histogram is referred to as 'the average histogram'. In the second method, the maximum function is used, which results in an 'envelope histogram' derived from the superposition of all histograms. Examples are produced in the next section.

3.4 Automatic peak detection and scale computation

Once overall histograms are computed, it is straightforward to derive a possible scale by detecting the peaks of the histogram. To achieve robust peak picking, first a 3-tap moving average filter is applied to smooth the overall histogram, then the local maxima are detected. Since the lobes are not necessarily symmetric with respect to their local maxima, the center of gravity is computed from 7 data points taken around each local maximum to find a representative peak for each lobe. The peaks obtained from the average histogram and the envelope histogram are labelled in Figures 4 to 12 (Section 4) as Autopeak-ave. and Autopeak-env.

Given the peak locations and the tonic, it is straightforward to compute relative pitches as the distance from peak locations to the tonic in Hc. As a result, we achieve a completely automatic analysis system that accepts recordings in a given *maqam* as input and derives an optimum scale for the given *maqam*.

3.5 Maximum and average distance between theorized scale tones and measured relative pitches

For studying mismatches between *maqam* scales according to said theoretical models and measured data, it is useful to define a quantitative distance measure. Given the relative pitches I_{ai} computed from the data automatically, and the theorized scale tones I_{ti}, the maximum distance M and the average distance D between the two values for a given *maqam* are computed as

$$M = \max\{|I_{ai} - I_{ti}|\}, \quad i = 1, 2, 3, \ldots, N_x,$$

$$D = \frac{1}{N_x}\sum_{i=1}^{N_x} |I_{ai} - I_{ti}|,$$

where N_x is the total number of scale tones for a given *maqam* that match a measured relative pitch. The number of tones differs for each *maqam* scale from tuning to tuning and the automatically detected set. For this reason, some of the scale tones need to be excluded in the distance computation. Therefore, only the nearest tones within 2.5 Hc vicinity of the measured relative

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[19] It is common practice to use the Holderian *comma* (Hc) as the smallest intervallic unit in Turkish *Maqam* music theoretical parlance. To facilitate comparisons with other models, we also use the Holderian *comma* unit in our figures and tables.

pitches are taken into consideration and the rest are discarded. In other words, the distance measure is computed for a subset of a *maqam* scale from a given tuning that matches the set of automatically detected relative pitches.

In addition to the distance, we also provide an efficiency measure, E, which is the ratio, in percentage, of the number of theorized scale tones within 2.5 Hc vicinity of the measured relative pitches, N_x, to the number of tones of the *maqam* scale defined in the tuning, N_t.

$$E = (N_x/N_t) * 100.$$

To portray the complexity of a given scale with respect to its tuning, one last measure is provided: C, which is the ratio, normalized to a percentage, of the number of unused scale tones, $N_z - N_x$, to the total number of tones in the tuning, N_z.

$$C = (1 - N_x/N_z) * 100.$$

Note that M, D, E and C are calculated for envelope and average histogram peaks separately.

4. Automatic analysis results

In this section, we present the results of the automatic analysis process explained in the previous sections applied to our audio database.

Figures 4 to 12 show the global positioning of five theoretical models with respect to relative pitch measurements through nine *maqam* categories. Envelope and average histograms have been superimposed to save space. Vertical grids indicate the Holderian *comma* and equal semi-tone resolutions.

The data used in the histograms are projected to Tables 1 to 9 accompanying the figures. Maximum and average distances from histogram peaks as well as mean efficiency and mean complexity values are also provided therein. Numbers that have been struck through are not included in the computations. Lowest values are in bold.

5. Discussions: Evaluating theoretical models based on quantitative distance information derived from pitch measurements

In the previous section we have drawn plots that compared automatic analysis results with *maqam* scales according to various theoretical models. Before proceeding any further, it has to be stated that automatic analysis is not free of errors; i.e. signal processes involved in the fully automatic analysis are not immaculate. In addition, there are three important points to consider in the design of the tests that can result in significant changes in the values obtained. The first is the method of 'finding the single closest match' in assigning theorized scale tones to autopeak values. If this is altered, for instance, by assigning all theoretical values to the same peak within the 2.5 Hc vicinity instead of picking only the closest, the results are drastically affected to the level of twisting the ratings. Through trial and error, we have decided that the method of 'finding the closest match' is more preferable in treating examined theoretical models more fairly. The second factor is the 2.5 Hc tolerance applied. Lowering the threshold to 1.5 Hc would change values in 6 rows, to 1 Hc, 23 rows, out of the 45 rows (nine *maqam* categories, five theoretical models) in total. Again, we have determined that the 2.5 Hc threshold is agreeable for most situations. The third important factor is the database itself. The addition of even a single recording has the potential to alter the envelope histogram template of a *maqam* and add a peak or alter the location of a peak. The risk is much lower for average histogram templates. Nevertheless, Turkish *maqam* tradition is relatively homogeneous so we can trust the addition of new recordings will not grossly distort our findings. All in all, distances calculated in the previous section should be treated not as exact measures, but as decent estimates.

The proposed methodology is the first attempt to computationally measure the theory-practice differences via fully automatic analysis of large databases, and is naturally open to further discussions and improvements. To facilitate such developments and data double-checking, we share our Matlab tools and database at: ftp://ftp.iyte.edu.tr/share/ktm-nota/TuningMeasurement.html.

It must also be mentioned in all fairness, that the second author has had the benefit of cross-checking his *maqam* scales with the autopeak values in Figures 4 to 12, which lends Yarman24 an edge against other theories discussed here in terms of tone selection. Nevertheless, Yarman24 scales contrasted with frequency measurements were based foremost of all on *a priori* predictions by the second author regarding which tones a *maqam* should employ. We feel the need to emphasize the fact that Yarman24 was not designed to conform to histogram peaks, but is an altogether separate tuning and theory endeavour (Yarman, 2009).

Let us now start evaluating how the examined theoretical models perform given pitch measurements in nine *maqam* categories acquired from master Turkish executants.

The first *maqam* category is *Rast*, which is based on the superposition of 16 recordings in this *maqam*. All theoretical models are more or less in agreement on the scale of *Rast*. Only Mus2 presents two additional tones at 26 and 36 *commas* which are obviously alterations or modulations to other *maqams*.

The third AutoPeak-ave. is misleading, since the prominent peak appears to be higher than 16.64 *commas*.

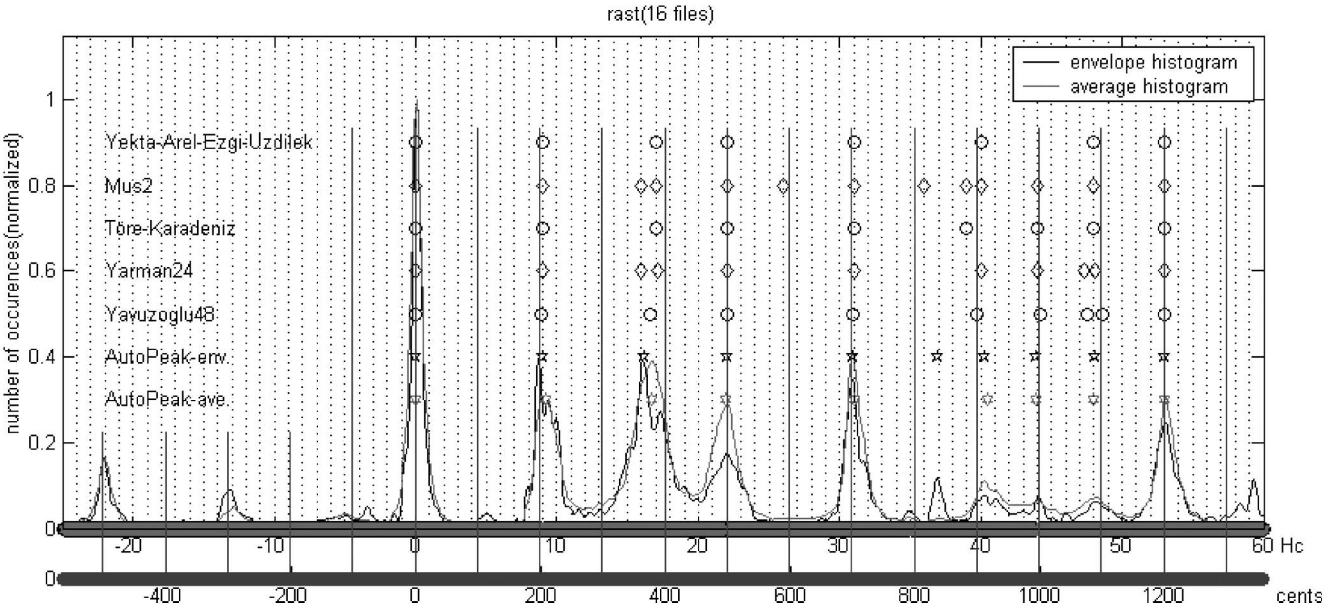

Fig. 4. Histogram computed for *maqam Rast* comparing autopeaks with theorized scales.

Table 1. Data used in histogram for Figure 4 and quantitative comparison of theorized scales with measured relative pitches. M_e, D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. *E*, *C*: mean efficiency and mean complexity in percentage.

Rast	Distance to tonic in Holderian *commas*												M_e	D_e	M_a	D_a	*E*	*C*
YAEU	9.01		16.98	22		31			40.01			47.98	0.85	0.23	**0.4**	0.18	100	75
Mus2	9	16	17	22	~~26~~	31	36	~~39~~	40	44		48	0.93	0.2	0.41	**0.17**	68.2	85.8
TK	9		17	22		31			39	44		48	1.24	0.35	1.41	0.31	100	82.9
Yarman24	9.01	15.88	17.06	22		31			40.01	43.99	47.33	48.07	**0.26**	**0.11**	0.42	0.18	77.8	**70.8**
Yavuzoglu48	8.83		16.56	22.08		30.92			39.75	44.17	47.48	48.58	0.49	0.27	0.66	0.31	87.5	85.4
AutoPeak-env.	9	16.13		21.99		30.88	36.93		40.24	43.94		48.12						
AutoPeak-ave.	9.17		16.64	21.9		31.02			40.41	43.91		48.01						

Rast	Distance to tonic in cents												M_e	D_e	M_a	D_a
YAEU	204		384.5	498.1		701.9			905.9			1086.3	19.2	5.2	**9.1**	4.1
Mus2	203.8	362.2	384.9	498.1	~~588.7~~	701.9	815.1	~~883.0~~	905.7	996.2		1086.8	21.0	4.5	9.3	**3.8**
TK	203.8		384.9	498.1		701.9			883.0	996.2		1086.8	28.1	7.9	31.9	7.0
Yarman24	204	359.5	386.3	498.1		701.9			905.9	996	1071.6	1088.4	**5.9**	**2.5**	9.5	4.1
Yavuzoglu48	200		375	500		700			900	1000	1075	1100	11.0	6.1	14.9	7.0
AutoPeak-env.	203.8	365.2	497.9		699.2	836.2		911.1	994.9		1089.5					
AutoPeak-ave.	207.6		376.8	495.8		702.3			914.9	994.2		1087.0				

This value is suitable solely as a mean of the two nearby peaks. Only Mus2 and Yarman24 make the distinction between the two peaks at 16 and 17 *commas*. While Yavuzoğlu48 conforms to the mean value of 16.64 with a 16.56 *comma* tone, we think it a misrepresentation of the *Rast* scale. To clarify: the 375 cent major third of Yavuzoğlu48 is a poor approximation of either Just Intonation ratio 16/13 (359 cents, corresponding to the 16 *comma* peak) or 5/4 (386 cents, corresponding to the 17 *comma* peak), both of which are present in Yarman24 and finely compensated by Mus2—whereas YAEU can account for only the latter ratio minus a schisma.[20]

A similar mishap concerns the 48 *comma* peak, which Yavuzoğlu48 misses by half a *comma* both to the left and to the right. In contrast, one of the two tones (47.33 and 48.07 *commas*) in Yarman24 conforms with the peaks.

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[20] The ratio of a *schisma* is 32805:32768. It is an miniscule interval of 2 cents attained by subtracting 5 octaves from a stack of 8 pure fifths plus 1 pure major third.

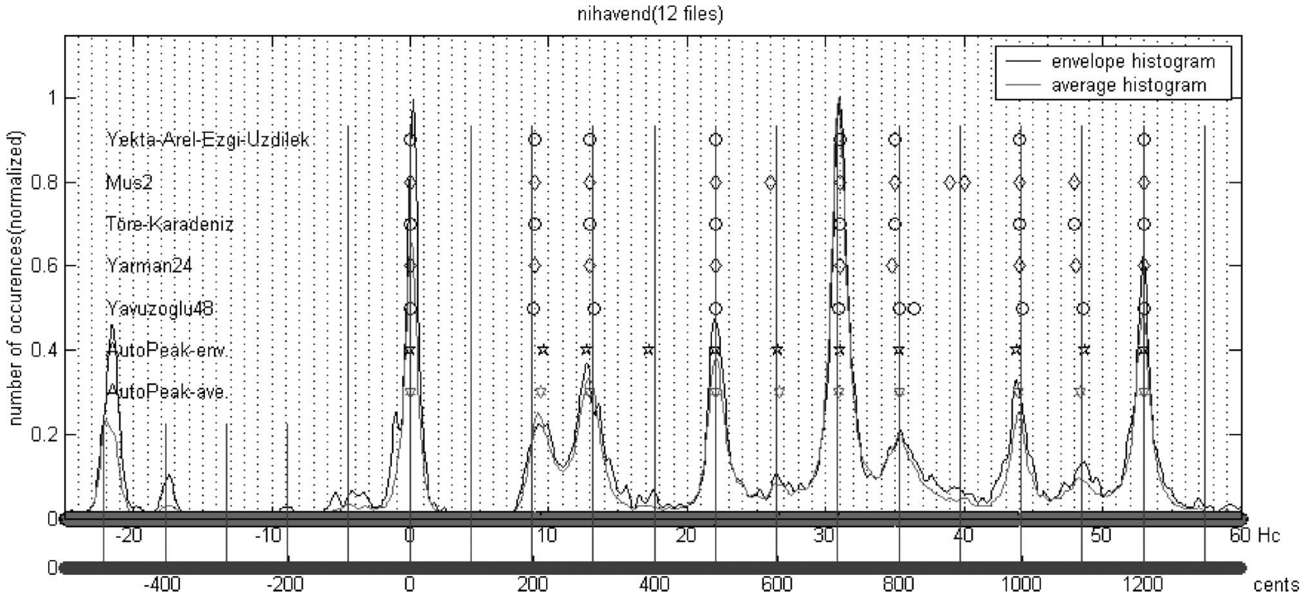

Fig. 5. Histogram computed for *maqam Nihavend* comparing autopeaks with theorized scales.

Table 2. Data used in histogram for Figure 5 and quantitative comparison of theorized scales with measured relative pitches. M_e, D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. *E*, *C*: mean efficiency and mean complexity in percentage.

Nihavend	Distance to tonic in Holderian *commas*												M_e	D_e	M_a	D_a	*E*	*C*
YAEU	9.01	12.99		22		31	34.99				43.99		**0.57**	**0.24**	**0.37**	**0.16**	100	75
Mus2	9	13		22	26	31	35		~~39~~	~~40~~	44	48	0.63	0.32	0.68	0.25	80	84.9
TK	9	13		22		31	35				44	48	0.63	0.3	0.38	0.19	100	82.9
Yarman24	9.01	12.9		22		31	34.82				43.99	48.07	0.58	0.3	0.49	0.19	100	**70.8**
Yavuzoglu48	8.83	13.25		22.08		30.92	35.33	~~36.44~~			44.17	48.58	0.75	0.25	0.55	0.2	87.5	85.4
AutoPeak-env.	9.58	12.74	17.26	22.08	26.48	31	35.35				43.8	48.63						
AutoPeak-ave.	9.38	12.9		22.07	26.68	30.95	35.31				43.94	48.36						

Nihavend	Distance to tonic in cents												M_e	D_e	M_a	D_a
YAEU	204	294.1		498.1		701.9	792.2				996		**12.9**	**5.4**	**8.4**	**3.6**
Mus2	203.8	294.3		498.1	588.7	701.9	792.5		~~883.0~~	~~905.7~~	996.2	1086.8	14.3	7.2	15.4	5.7
TK	203.8	294.3		498.1		701.9	792.5				996.2	1086.8	14.3	6.8	8.6	4.3
Yarman24	204	292.1		498.1		701.9	788.4				996	1088.4	13.1	6.8	11.1	4.3
Yavuzoglu48	200	300		500		700	800	~~825~~			1000	1100	17.0	5.7	12.5	4.5
AutoPeak-env.	216.9	288.5	390.8	499.9	599.5	701.9	800.4				991.7	1101.1				
AutoPeak-ave.	212.4	292.1		499.7	604.1	700.8	799.5				994.9	1094.9				

Similarly, Mus2 suggests two tones (39 and 40 *commas*) in the region of 40 *commas* one of which conforms with the peaks. TK and Yavuzoğlu48 deviate considerably at this point, where TK yields the worst score.

Mus2's *M* with respect to AutoPeak-env. is high due to the modulatory tone at 36 *commas*, which should have been 37 *commas* that is also available in Mus2's arsenal. Even so, *M* with respect to Autopeak-ave. is fairly low, signifying closeness of match with performance.

Immediately striking the eye is the lowness of *C* and overall high level of match with Yarman24. In comparison, YAEU lags behind in all but one measure despite the fact that its tuning possesses the same number of tones per octave.

The five theoretical models are ranked according to their average *M* and *D* measures in *maqam Rast* as follows:

1. Yarman24 *M*: 0.34, *D*: 0.15
2. Yavuzoğlu48 *M*: 0.58, *D*: 0.29
3. YAEU *M*: 0.63, *D*: 0.21
4. Mus2 *M*: 0.67, *D*: 0.19
5. TK *M*: 1.33, *D*: 0.33

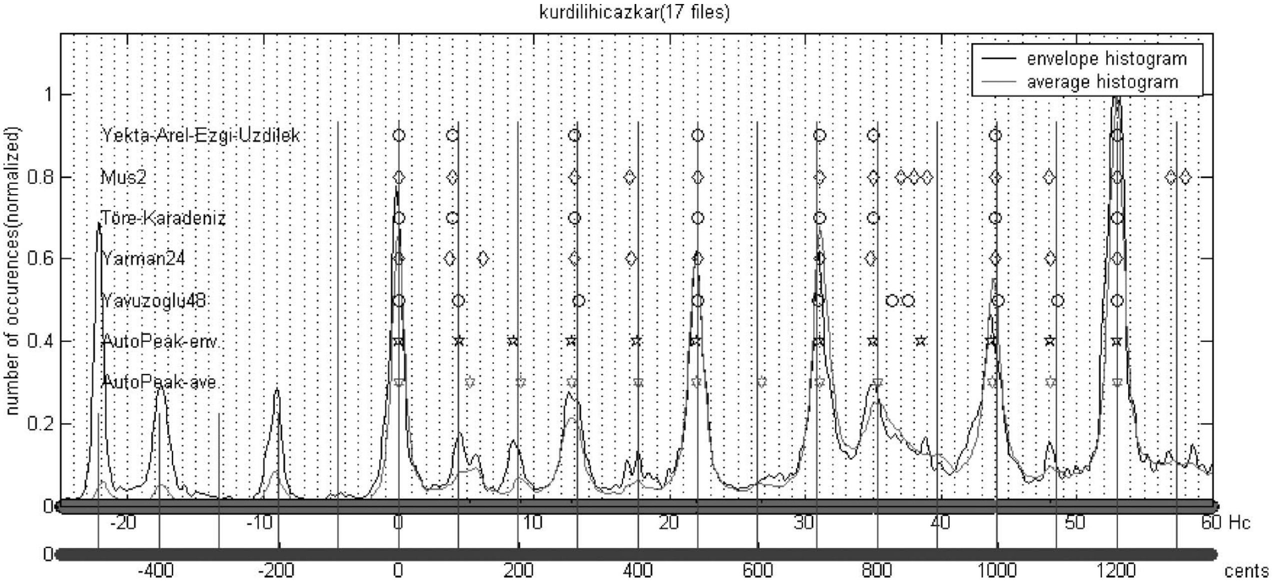

Fig. 6. Histogram computed for *maqams Kürdilihicazkar* comparing autopeaks with theorized scales.

Table 3. Data used in histogram for Figure 6 and quantitative comparison of theorized scales with measured relative pitches. M_e, D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. *E*, *C*: mean efficiency and mean complexity in percentage.

K.Hicazkar	Distance to tonic in Holderian *commas*														M_e	D_e	M_a	D_a	*E*	*C*
YAEU	3.99			12.99		22		31	34.99				43.99		0.53	0.2	1.27	0.39	100	75
Mus2	4			13	17	22		31	35	~~37~~	~~38~~	39	44	48	0.58	0.25	1.26	0.38	77.3	84.0
TK	4			13		22		31	35				44		**0.52**	**0.2**	1.26	0.39	100	85.4
Yarman24	3.73	6.29		12.9	17.06	22		31	34.82				43.99	48.07	2.19	0.47	**1.03**	**0.35**	94.4	**64.6**
Yavuzoglu48	4.42			13.25		22.08		30.92	36.44		37.54		44.17	48.58	1.46	0.54	1.09	0.54	93.7	84.4
AutoPeak-env.	4.52	8.48		12.76	17.58	21.93		31.02	34.98		38.55		43.67	48.06						
AutoPeak-ave	5.26		9	12.71	17.64	21.9	26.74	31.1	35.35				43.77	48.05						

K.Hicazkar	Distance to tonic in cents														M_e	D_e	M_a	D_a
YAEU	90.3			294.1		498.1		701.9	792.2				996		12	4.5	28.8	8.8
Mus2	90.6			294.3	384.9	498.1		701.9	792.5	~~837.7~~	~~860.4~~	883	996.2	1086.8	13.1	5.7	28.5	8.6
TK	90.6			294.3		498.1		701.9	792.5				996.2		**11.8**	**4.5**	28.5	8.8
Yarman24	84.5	142.4		292.1	386.3	498.1		701.9	788.4				996	1088.4	49.6	10.6	**23.3**	**7.9**
Yavuzoglu48	100			300		500		700	825		850		1000	1100	33.1	12.2	24.7	12.2
AutoPeak-env.	102.3		192	288.9	398.0	496.5		702.3	792		872.8		988.8	1088.2				
AutoPeak-ave	119.1		203.8	287.8	399.4	495.8	605.434	704.1509	800.4				991	1087.9				

We continue with *Nihavend*, the data for which is gathered from the superposition of 12 recordings in this *maqam*. We are satisfied to observe that AutoPeak-env. and AutoPeak-ave. values are very much in accord except for the 17.26 *comma* peak. This and the 26.5 *comma* peaks are very likely alterations or modulatory tones. Mus2 matches the latter peaks with a 26 *comma* tone and produces two more tones at 39 and 40 *commas* that have no corresponding peaks and seem out of place. Aside from these, all the theoretical models are in agreement as to the scale of *Nihavend*.

Only Yavuzoğlu48 suggests two proximal tones separated by 25 cents. They occur at 35.33 and 36.44 *commas* respectively although only the former has been paired with the peaks.

The best tuning for *Nihavend* is clearly YAEU, with Yarman24 and TK in hot pursuit. We accentuate Yarman24 before TK due to much lower complexity and a lower M_e value. Mus2 scores the worst for this

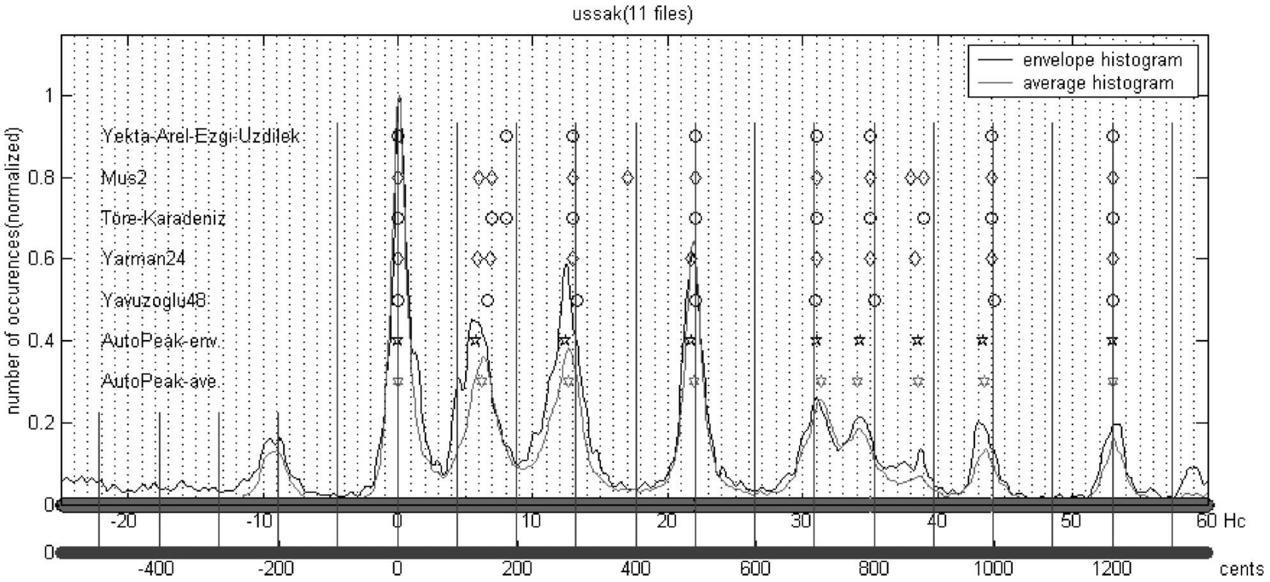

Fig. 7. Histogram computed for *maqam Uşşak* comparing autopeaks with theorized scales.

Table 4. Data used in histogram for Figure 7 and quantitative comparison of theorized scales with measured relative pitches. M_e, D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. E, C: mean efficiency and mean complexity in percentage.

Uşşak	Distance to tonic in Holderian *commas*										M_e	D_e	M_a	D_a	E	C
YAEU		7.97	12.99		22	31	34.99			43.99	2.24	0.74	1.69	0.68	100	75
Mus2	6	~~7~~	13	~~17~~	22	31	35	~~38~~	39	44	0.74	0.43	1.01	0.45	70	86.8
TK	7	~~8~~	13		22	31	35		39	44	1.27	0.57	1.01	0.52	87.5	82.9
Yarman24	5.84	~~6.87~~	12.99		21.74	31	34.99	38.33		43.99	**0.73**	**0.34**	**1**	**0.44**	87.5	**70.8**
Yavuzoglu48	6.63		13.25		22.08	30.92	35.33			44.17	1.07	0.68	1.35	0.61	100	87.5
AutoPeak-env.	5.73		12.41		21.78	31.04	34.26	38.52		43.34						
AutoPeak-ave.	6.28		12.62		21.89	31.36	33.99	38.53		43.43						

Uşşak	Distance to tonic in cents										M_e	D_e	M_a	D_a
YAEU		180.5	294.1		498.1	701.9	792.2			996	50.7	16.8	38.3	15.4
Mus2	135.8	158.5	294.3	~~384.9~~	498.1	701.9	792.5	~~860.4~~	883	996.2	16.8	9.7	22.9	10.2
TK	158.5	181.1	294.3		498.1	701.9	792.5		883	996.2	28.8	12.9	22.9	11.8
Yarman24	132.2	~~155.5~~	294.1		492.2	701.9	792.2	867.8		996	**16.5**	**7.7**	**22.6**	**10**
Yavuzoglu48	150		300		500	700	799.9			1000	24.2	15.4	30.6	13.8
AutoPeak-env.	129.7		281		493.1	702.8	775.7	872.2		981.2				
AutoPeak-ave.	142.2		285.7		495.6	710.0	769.6	872.4		983.3				

maqam despite sharing common tones with YAEU. This is apparently due to the inclusion of modulatory tones.

This is an instance where automatic analysis fails to faithfully represent the actual situation. In truth, highest M values for the core scale of *Nihavend* belong to Yavuzoğlu48, signifying the greatest amount of mismatch. Nevertheless, we proceed in the same fashion as with *Rast*, and rank the five theoretical models according to their average M and D measures:

1.	YAEU	M: 0.47, D: 0.20
2.	TK	M: 0.51, D: 0.25
3.	Yarman24	M: 0.54, D: 0.25
4.	Yavuzoğlu48	M: 0.65, D: 0.23
5.	Mus2	M: 0.66, D: 0.29

Now comes *Kürdilihicazkar* with 17 recordings superposed. This is a problematic *maqam* due to being a composite of *Nihavend* using the *kürdi* note and *maqam Hicazkar*. Immediately noticeable is the high

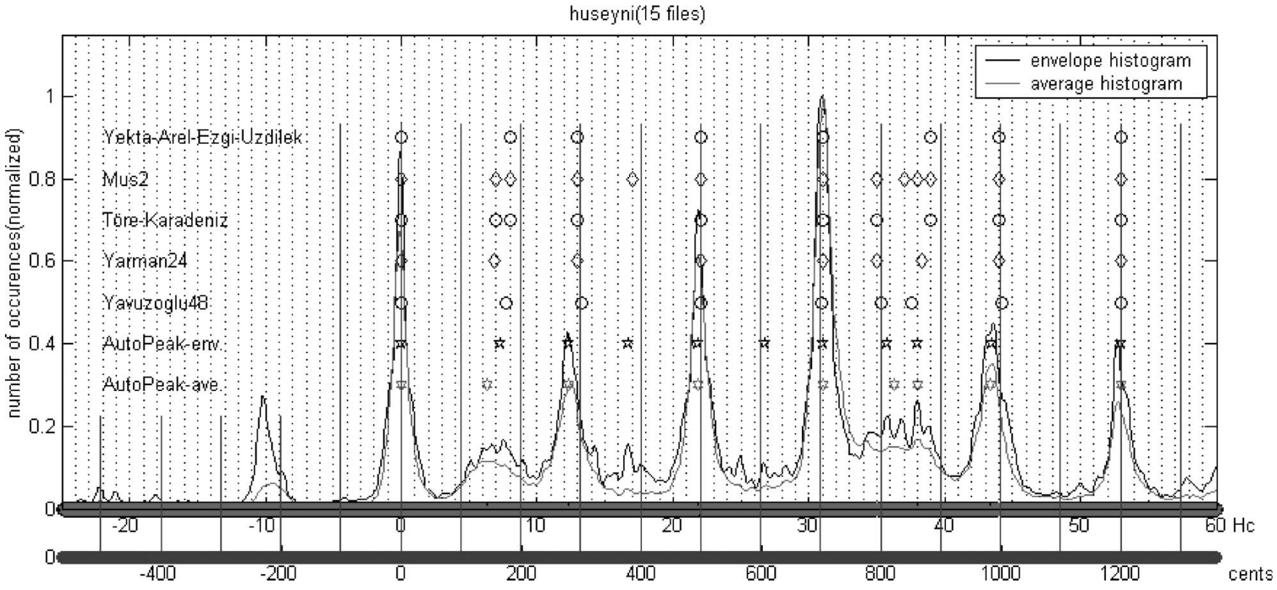

Fig. 8. Histogram computed for *maqam Hüseyni* comparing autopeaks with theorized scales.

Table 5. Data used in histogram for Figure 8 and quantitative comparison of theorized scales with measured relative pitches. M_e, D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. *E*, *C*: mean efficiency and mean complexity in percentage.

Hüseyni	Distance to tonic in Holderian *commas*											M_e	D_e	M_a	D_a	*E*	*C*
YAEU	7.97		12.99		22		31				38.97	43.99	0.96	0.52	1.6	0.68	100	75
Mus2	7	~~8~~	13	17	22		31	35	37	38	~~39~~	44	**0.71**	**0.34**	**0.66**	**0.41**	68.2	85.8
TK	7	~~8~~	13		22		31	34.99		38.33	39	44	0.99	0.5	1.34	0.65	87.5	82.9
Yarman24	6.87		12.99		22		31	35.33		37.54		43.99	0.73	0.42	1.35	0.53	100	**70.8**
Yavuzoglu48	7.73		13.25		22.08		30.92	35.71		38.01	43.38	44.17	0.92	0.48	1.36	0.7	100	85.4
AutoPeak-env.	7.28		12.33	16.74	21.81	26.76	30.98	36.34		37.98	43.36							
AutoPeak-ave.	6.37		12.35		21.81		31.05											

Hüseyni	Distance to tonic in cents											M_e	D_e	M_a	D_a
YAEU	180.5		294.1		498.1		701.9				882.3	996	21.7	11.8	36.2	15.4
Mus2	158.5	~~181.1~~	294.3	384.9	498.1		701.9	792.5	837.7	860.4	~~883~~	996.2	**16.1**	**7.7**	**14.9**	**9.3**
TK	158.5	~~181.1~~	294.3		498.1		701.9	792.5			883	996.2	22.4	11.3	30.3	14.7
Yarman24	155.5		294.1		498.1		701.9	792.2		867.8		996	22.4	9.5	30.6	12
Yavuzoglu48	175		300		500		700	800		850		1000	16.5	10.9	30.8	15.8
AutoPeak-env.	164.8		279.2	379	493.8	605.9	701.4	808.5		860.6	982.2		20.8			
AutoPeak-ave.	144.2		279.6		493.8		703.0		822.8	859.9	981.7					

2.19 *comma* deviation for M_e in Yarman24. Here is another situation where the quantitative distance measures should not be taken at face value. Because the Yarman24 tone of 3.73 *commas* has been paired with the 4.52 and 5.26 *comma* autopeaks, the Yarman24 tone of 6.29 *commas* (much characteristic of *Kürdilihicazkar* according to the second author) has been paired with the 8.48 *comma* Autopeak-env. (clearly a modulatory tone) instead of the much closer 5.26 *comma* peak, whereas Yarman24 boasts a 9.01 *comma* tone that is much closer to the 8.48 *comma* AutoPeak-env. which could serve as an alteration but is not given here due to not being part of the core scale of *Kürdilihicazkar*. A careful scrutiny of the histogram in Figure 6 confirms that there indeed is another peak close to the 6.29 *comma* tone of Yarman24 that AutoPeak-ave. fails to capture. Instead, AutoPeak-ave. targets the bottom of the valley between the two peaks.

This situation is rectified with M_a and D_a values, where Yarman24 comes out as the best tuning with

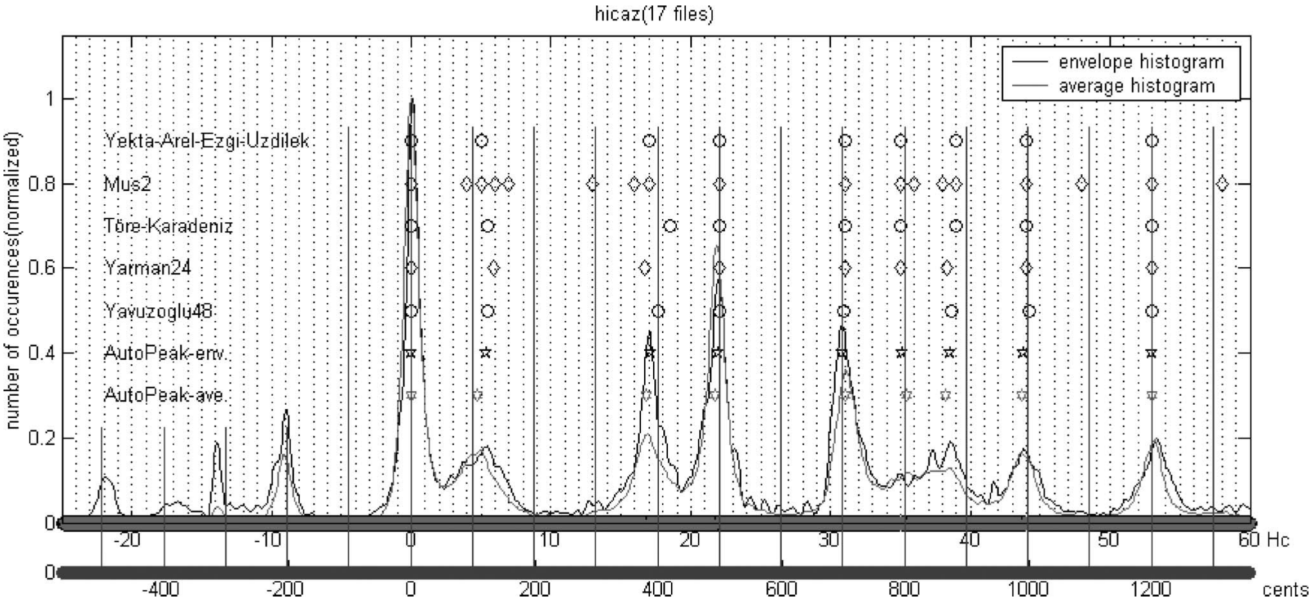

Fig. 9. Histogram computed for *maqam Hicaz* comparing autopeaks with theorized scales.

Table 6. Data used in histogram for Figure 9 and quantitative comparison of theorized scales with measured relative pitches. M_e, D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. E, C: mean efficiency and mean complexity in percentage.

Hicaz	Distance to tonic in Holderian *commas*																M_e	D_e	M_a	D_a	E	C
YAEU		5.02					16.98	22	31	34.99				38.97	43.99		**0.4**	**0.18**	0.74	0.32	100	**70.8**
Mus2	~~4~~	5	~~6~~	~~7~~	~~13~~	~~16~~	17	22	31	35	~~36~~	38		39	44	~~48~~	0.43	0.19	**0.38**	**0.25**	46.7	86.8
TK		5.5					18.5	22	31	35				39	44		1.46	0.38	1.69	0.61	100	82.9
Yarman24		5.84					16.79	22	31	34.99		38.33			43.99		0.54	0.23	1.19	0.33	100	**70.8**
Yavuzoglu48		5.52					17.67	22.08	30.92					38.65	44.17		0.62	0.26	0.87	0.51	100	87.5
AutoPeak-env.		5.3					17.04	21.92	30.84	35.05			38.57		43.75							
AutoPeak-ave.		4.65					16.81	21.79	31.09	35.38			38.23		43.7							

Hicaz	Distance to tonic in cents																M_e	D_e	M_a	D_a
YAEU		113.7					384.9	498.1	701.9	792.2				882.3	996		**9.1**	**4.1**	16.8	7.2
Mus2	~~90.6~~	113.2	~~135.8~~	~~158.5~~	~~294.3~~	~~362.3~~	384.9	498.1	701.9	792.5	~~815.1~~	860.4		883	996.2	~~1086.8~~	9.7	4.3	**8.6**	**5.7**
TK		124.5					418.9	498.1	701.9	792.5				883	996.2		33.1	8.6	38.3	13.8
Yarman24		132.2					380.2	498.1	701.9	792.2		867.8			996		12.2	5.2	26.9	7.5
Yavuzoglu48		125					400	500	700					875	1000		14	5.9	19.7	11.5
AutoPeak-env.		120					385.8	496.3	698.3	793.6			873.3		990.6					
AutoPeak-ave.		105.3					380.6	493.4	703.9	801.1			865.6		989.4					

the lowest complexity. Even then, Yarman24's average of M and D values yield the worst results due to taking into account the glitch with the 6.29 *comma* shade.

In retrospect, Yavuzoğlu48 suggests two proximal tones separated by 25 cents at the 37 *comma* location that miss the peaks by a long shot and literally fall on the hillside between them. In the meantime, TK, YAEU and Mus2 scores appear homogeneous.

The five theoretical models are ranked according to their average M and D measures in *maqam Kürdilihicazkar* as follows:

1. TK M: 0.89, D: 0.30
2. YAEU M: 0.90, D: 0.30
3. Mus2 M: 0.92, D: 0.32
4. Yavuzoğlu48 M: 1.28, D: 0.41
5. Yarman24 M: 1.61, D: 0.54

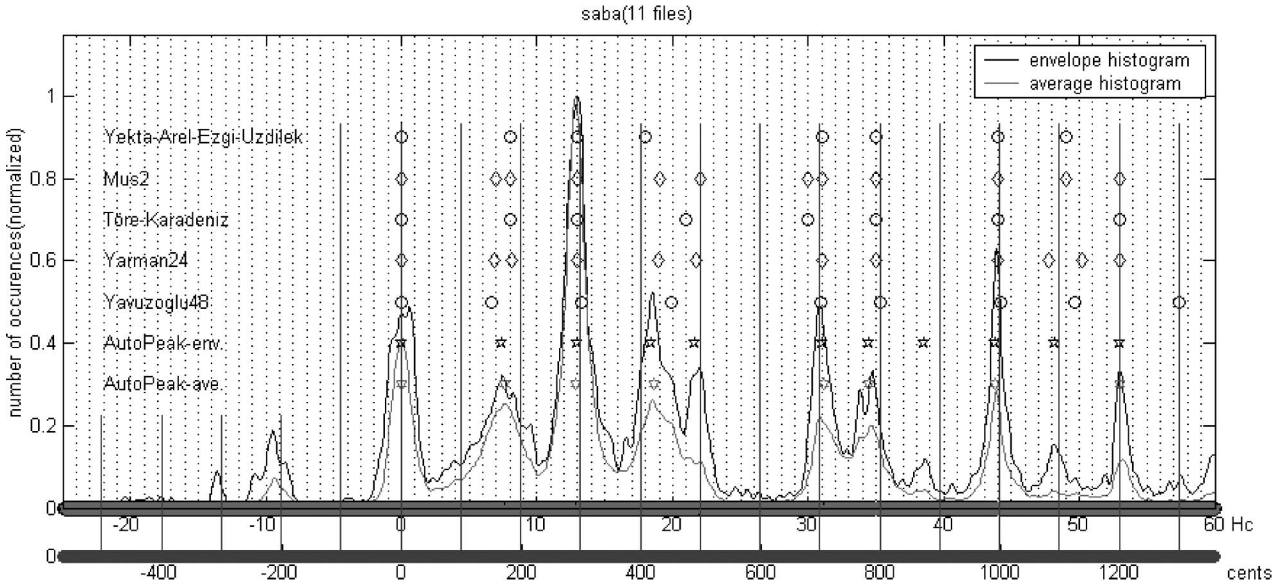

Fig. 10. Histogram computed for *maqam Saba* comparing autopeaks with theorized scales.

Table 7. Data used in histogram for Figure 10 and quantitative comparison of theorized scales with measured relative pitches. M_e,D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. *E*, *C*: mean efficiency and mean complexity in percentage.

Saba	Distance to tonic in Holderian *commas*												M_e	D_e	M_a	D_a	*E*	*C*
YAEU	7.97		12.99	18.01			31	34.99		43.99		49.02	0.88	0.37	0.69	0.33	92.8	72.9
Mus2	7	8	13	19	22	~~30~~	31	35		44		49	0.86	0.37	0.46	0.28	70	86.8
TK	8		13		21		30	35		44			0.97	0.49	2.3	0.78	100	85.4
Yarman24	6.87	8.06	12.99	18.88	21.74		31	34.99		43.99	47.72	~~50.28~~	**0.52**	0.27	**0.45**	0.26	70	**70.8**
Yavuzoglu48	6.63		13.25	19.88			30.92	35.33		44.17		49.69	1.55	0.76	1.18	0.67	92.8	86.5
AutoPeak-env.	7.39		12.89	18.42	21.67		30.97	34.53	38.49	43.85		48.14						
AutoPeak-ave.	7.61		12.79	18.7			31.14	34.54		43.81								

Saba	Distance to tonic in cents												M_e	D_e	M_a	D_a
YAEU	180.5		294.1	407.8			701.9	792.2		996		1109.9	19.9	8.4	15.6	7.5
Mus2	158.5	181.1	294.3	430.2	498.1	~~679.2~~	701.9	792.5		996.2		1109.4	19.5	8.4	10.4	6.3
TK	181.1		294.3		475.5		679.2	792.5		996.2			22	11.1	52.1	17.7
Yarman24	155.5	182.5	294.1	427.5	492.2		701.9	792.2		996	1080.5	~~1138.4~~	**11.8**	**6.1**	**10.2**	**5.9**
Yavuzoglu48	150		300	450			700	800		1000		1125	35.1	17.2	26.7	15.2
AutoPeak-env.	167.3		291.8	417.1	490.6		701.2	781.8	871.5	992.8		1090				
AutoPeak-ave.	172.3		289.6	423.4			705.1	782.0		991.9						

The *Uşşak* category is derived from the superposition of 11 recordings. This is a *maqam* where non-conformance with current theory is the highest. The histogram in Figure 7 shows the awry distribution of suggested scale tones between 6 and 8 *commas*. Aside from the Mus2 modulatory tone at 17 *commas*, the scale of *Uşşak* is pretty much uniform for all theoretical models. The crux of *Uşşak* is confirmed to be the 6–8 *comma* region. YAEU scores the worst and TK the second worst for misrepresenting this region, whereas TK is in possession of a tone in its tuning that is closer to the peaks but not given as part of the scale. Yavuzoğlu48 suggests at least one tone that brushes the higher peak of said region while grossly missing the 12.5 and 34 *comma* peaks. On the other hand, Yarman24 and Mus2 are on a par in matching the peaks and perform rather admirably.

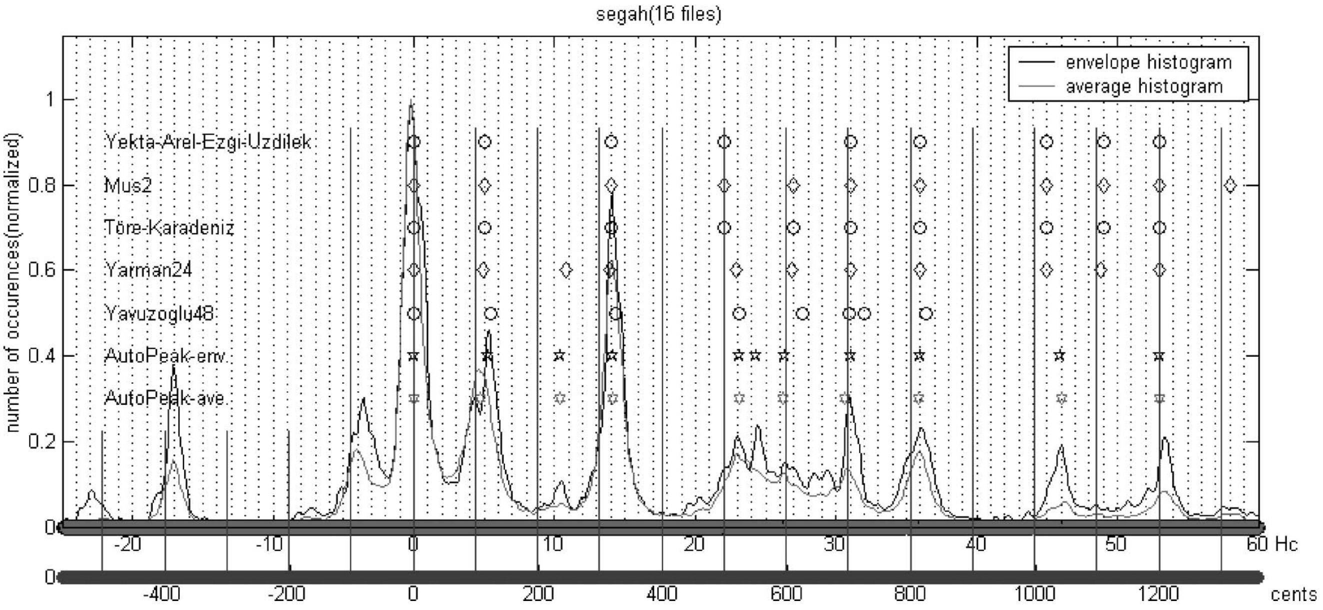

Fig. 11. Histogram computed for *maqam Segah* comparing autopeaks with theorized scales.

Table 8. Data used in histogram for Figure 11 and quantitative comparison of theorized scales with measured relative pitches. M_e, D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. *E*, *C*: mean efficiency and mean complexity in percentage.

Segah	Distance to tonic in Holderian *commas*											M_e	D_e	M_a	D_a	*E*	*C*
YAEU	5.02		14.03	22			31		36.02	45.03	~~49.02~~	1.08	0.4	1.11	0.49	85.7	75
Mus2	5		14	22		27	31		36	45	~~49~~	1.08	0.45	1.11	0.53	87.5	86.8
TK	5		14	22		27	31		36	45	~~49~~	1.08	0.45	1.11	0.53	87.5	82.9
Yarman24	4.93	10.82	13.94	22.95		26.93	31		35.94	44.94	~~48.84~~	**0.96**	**0.34**	**1.06**	**0.4**	88.9	**66.7**
Yavuzoglu48	5.52		14.35	23.19		27.6	30.92	~~32.02~~	36.44			1.29	0.42	1.34	0.55	85.7	87.5
AutoPeak-env.	5.23	10.33	14.15	23.08	24.28	26.31	31.03		35.95	45.9							
AutoPeak-ave.	4.68	10.32	14.08	23.11		26.27	30.69		35.87	46.01							

Segah	Distance to tonic in cents											M_e	D_e	M_a	D_a
YAEU	113.7		317.7	498.1			701.9		815.5	1019.5	~~1109.9~~	24.5	9.1	25.1	11.1
Mus2	113.2		317	498.1		611.3	701.9		815.1	1018.9	~~1109.4~~	24.5	10.2	25.1	12
TK	113.2		317	498.1		611.3	701.9		815.1	1018.9	~~1109.4~~	24.5	10.2	25.1	12
Yarman24	111.6	245	315.6	519.6		609.7	701.9		813.7	1017.5	~~1105.8~~	**21.7**	**7.7**	**24**	**9.1**
Yavuzoglu48	125		325	525		625	700	~~725~~	825			29.2	9.5	30.3	12.5
AutoPeak-env.	118.4	233.9	320.4	522.6	549.7	595.7	702.6		814	1039.2					
AutoPeak-ave.	106	233.7	318.8	523.2		594.8	694.9		812.2	1041.7					

As a side note, we think the protrusion at 4 *commas* in Figure 7 definitely indicates a modulation to another *maqam*.

The five theoretical models are ranked according to their average *M* and *D* measures in *maqam Uşşak* as follows:

1. Yarman24 *M*: 0.87, *D*: 0.39
2. Mus2 *M*: 0.88, *D*: 0.44
3. TK *M*: 1.14, *D*: 0.55
4. Yavuzoğlu48 *M*: 1.21, *D*: 0.65
5. YAEU *M*: 1.97, *D*: 0.71

A sibling of *Uşşak* is *Hüseyni*, the data for which have been gathered from the superposition of 15 recordings in this *maqam*. Although the second note of *Hüseyni* is not as distinct as the second note of *Uşşak*, the perfect fifth counterpart of this note is just as varied. The crux of *Hüseyni* appears to be this very region residing between 36–38 *commas*.

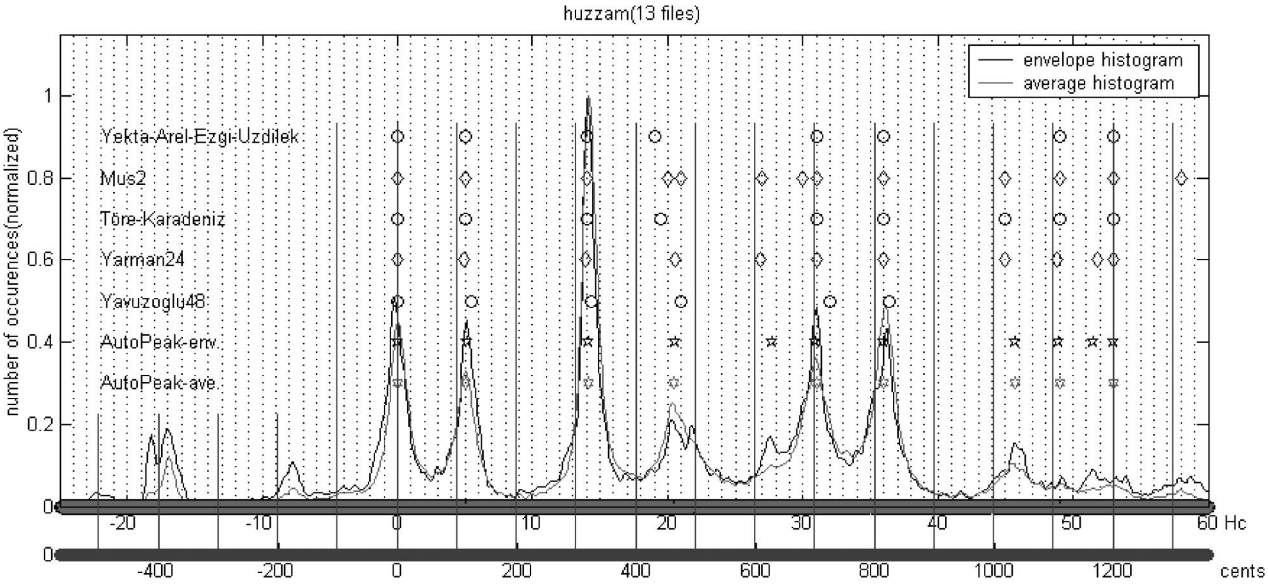

Fig. 12. Histogram computed for *maqam Hüzzam* comparing autopeaks with theorized scales.

Table 9. Data used in histogram for Figure 12 and quantitative comparison of theorized scales with measured relative pitches. M_e, D_e: maximum and average distance values computed with respect to AutoPeak-env. M_a, D_a: maximum and average distance values computed with respect to AutoPeak-ave. *E*, *C*: mean efficiency and mean complexity in percentage.

Hüzzam	Distance to tonic in Holderian *commas*											M_e	D_e	M_a	D_a	E	C
YAEU	5.02	14.03	19.05				31	36.02		49.02		1.42	0.3	1.4	0.28	100	75
Mus2	5	14	20	~~21~~	27	~~30~~	31	36	45	49		**0.75**	**0.29**	**0.66**	**0.2**	75	85.8
TK	5	14	19.5				31	36	45	49		0.97	0.3	0.95	0.27	100	82.9
Yarman24	4.93	13.94	20.59		26.93		31	35.94	44.94	48.84	51.81	0.82	0.3	0.71	**0.2**	88.9	**66.7**
Yavuzoglu48	5.52	14.35	20.98				32.02	36.44				1.11	0.54	1.05	0.54	100	89.6
AutoPeak-env.	5.11	14.12	20.47		27.75		30.91	35.98	45.74	48.95	51.46						
AutoPeak-ave.	4.99	14.17	20.45				30.97	36.03	45.66	48.98							

Hüzzam	Distance to tonic in cents											M_e	D_e	M_a	D_a
YAEU	113.7	317.7	431.3				701.9	815.5		1109.9		32.2	6.8	31.7	6.3
Mus2	113.2	317	452.8	~~475.5~~	611.3	~~679.2~~	701.9	815.1	1018.9	1109.4		**17**	**6.6**	**14.9**	**4.5**
TK	113.2	317	441.5				701.9	815.1	1018.9	1109.4		22	6.8	21.5	6.1
Yarman24	111.6	315.6	466.2		609.7		701.9	813.7	1017.5	1105.8	1173.1	18.6	6.8	16.1	**4.5**
Yavuzoglu48	125	325	475				725	825				25.1	12.2	23.8	12.2
AutoPeak-env.	115.7	319.7	463.5		628.3		699.8	814.6	1035.6	1108.3	1165.1				
AutoPeak-ave.	113	320.8	463.0				701.2	815.8	1033.8	1109					

Mus2 fills this region with virtually every *comma* step in its arsenal and comes up as the winner. Yarman24 and Yavuzoğlu48 follow the trail of Mus2. YAEU and TK are equal in failing to represent *Hüseyni*.

The five theoretical models are ranked according to their average *M* and *D* measures in *maqam Hüseyni* as follows:

1. Mus2 *M*: 0.69, *D*: 0.38
2. Yarman24 *M*: 1.04, *D*: 0.48
3. Yavuzoğlu48 *M*: 1.14, *D*: 0.59
4. TK *M*: 1.17, *D*: 0.58
5. YAEU *M*: 1.28, *D*: 0.60

One of the more popular *maqams* is next. The data gathered from 17 recordings in *maqam Hicaz* are shown in Figure 9 and Table 6. Mus2 employs a lot of *commas* for the scale of this *maqam*, a great concentration of which are gathered at the second and the sixth notes. Needless to say, Mus2 tones that do not correspond to any peaks are doubtlessly alterations or modulations to other *maqams*. Aside from Mus2, all theoretical models are in full agreement as to the scale of *Hicaz*.

The histogram in Figure 9 tells us that the second note between 4–7 *commas* and the sixth note between 35–39 *commas* are quite fluid. These flexible notes are clearly characteristic of *Hicaz*. The high concentration of *commas* by Mus2 in said regions corroborate this observation.

Not surprisingly, Mus2 boasts the best scores, followed by YAEU, Yavuzoğlu48 and Yarman24. The worst scores are that of TK for this *maqam* due to its suggestion of the wrong tone for the third note despite the existence of a tone closer to the peaks that is 1 Holderian *comma* lower in its tuning.

The five theoretical models are ranked according to their average M and D measures in *maqam Hicaz* as follows:

1.	Mus2	M: 0.41, D: 0.22
2.	YAEU	M: 0.57, D: 0.25
3.	Yavuzoğlu48	M: 0.75, D: 0.39
4.	Yarman24	M: 0.87, D: 0.28
5.	TK	M: 1.58, D: 0.50

Saba is a very piquant and famous *maqam* in Traditional Turkish music. Pitch measurements from 11 recordings were superposed for the analysis of *Saba*. As was the case with *Uşşak*, the second note is a peculiar, albeit less pronounced, feature of this *maqam*. Yavuzoğlu48 misses the autopeaks here by a *comma*. TK is in possession of a tone that is closer to AutoPeak-env. but not given here as part of the scale. A more peculiar aspect is the fourth note. Yavuzoğlu48 and TK miss these autopeaks, with the latter falling into a deep ravine, despite possessing tones in their tunings that represent the region better but not given as part of their scales. In contrast, both Mus2 and Yarman24 suggest a pair of tones each for the second and fourth note of *Saba* in accord with the autopeaks. Also, YAEU seems to represent *Saba* well even without the *commatic* inflexions that are considered a requisite of this *maqam*.

The protrusion at 34 *commas* in Figure 10 appears to be a *commatic* inflexion that has no corresponding tone in YAEU and Yarman24. Though Mus2, TK and Yavuzoğlu48 can come up with tones from their tunings that could compensate this protrusion, their inclusion in their proposed scales for *Saba* would not affect the scores in the slightest.

The 38.49 and 48.14 *comma* AutoPeak-env. values most likely signify alterations as part of the *Saba maqam*. The latter peak is best represented by Yarman24, and worst represented by Yavuzoğlu48.

The five theoretical models are ranked according to their average M and D measures in *maqam Saba* as follows:

1.	Yarman24	M: 0.49, D: 0.27
2.	Mus2	M: 0.66, D: 0.33
3.	YAEU	M: 0.79, D: 0.35
4.	Yavuzoğlu48	M: 1.37, D: 0.72
5.	TK	M: 1.64, D: 0.64

Segah is a savory and popular *maqam*. 16 recordings were compiled for the analysis of *Segah*. Immediately noticeable is the 22–23 *comma* dichotomy above the tonic. YAEU, Mus2 and TK consider the fourth note a pure fourth above the first, while the latter two theoretical models take an acute fourth above the tonic. We must warn the reader that YAEU, Mus2 and TK all possess tones in their tunings that are exactly 1 *comma* above the ones they suggest for their scales corresponding to the peak at 23 *commas*. Therefore, quantitative distance results will probably be misleading for YAEU, Mus2 and TK.

Except for the lack of a 27 *comma* tone by YAEU and the addition of a 10.82 *comma* tone by Yarman24 (clearly a modulation to *Segah*'s sister *maqam Müstear*), all theoretical models agree on the scale of *Segah*. Only the Yavuzoğlu48 scale is left incomplete and does not reach the octave of the finalis.

We cannot identify the AutoPeak-env. at 24.28 *commas* and the protrusion at 4 *commas* with anything significant. This are probably quirks or scordaturas in the execution of the *maqam* by one or more performers in our database.

The five theoretical models are ranked according to their average M and D measures in *maqam Segah*. Mus2 and TK distance scores and efficiency results were the same, so complexity was taken into account in ranking them:

1.	Yarman24	M: 1.01, D: 0.37, C: 66.7
2.	YAEU	M: 1.10, D: 0.45, C: 75
3.	TK	M: 1.10, D: 0.49, C: 82.9
4.	Mus2	M: 1.10, D: 0.49, C: 86.8
5.	Yavuzoğlu48	M: 1.32, D: 0.49, C: 87.5

A variant of *Segah* is the sorrowful *Hüzzam*. 13 recordings in this *maqam* were compiled for analysis. Theoretical models for *Hüzzam* appear pretty much uniform, save for the lack of any tone for the 27.75 *comma* peak except by Mus2 and Yarman24, and the absence of the YAEU counterpart of the 45.7 *comma* peak as well as the incompleteness of the Yavuzoğlu48 scale just as it was the case with *Segah*.

The characteristic region of *Hüzzam* is the zone around 20–22 *commas*. Unfortunately, the automatic peak detection algorithm missed the 22 *comma* peak which might be just as important and peculiar to *Hüzzam* as the 20.5 *comma* peak. However, it is likely a modulation to *Segah* with a pure fourth above the tonic instead of an acute fourth.

Once more, TK is in possession of a tone in its tuning that represents the above-said zone better although not given as part of the scale of *Hüzzam*.

The unpronounced octave above the tonic is puzzling. We identify the AutoPeak-env. at 51.46 *commas* as a scordatura of the octave of the finalis of *Hüzzam*.

The five theoretical models are ranked according to their average *M* and *D* measures in *maqam Hüzzam* as follows:

1. Mus2 *M*: 0.71, *D*: 0.25
2. Yarman24 *M*: 0.77, *D*: 0.25
3. TK *M*: 0.96, *D*: 0.29
4. Yavuzoğlu48 *M*: 1.08, *D*: 0.54
5. YAEU *M*: 1.41, *D*: 0.29

6. Conclusions

In our weighing of theorized scales against quantitative distance information gathered from pitch histograms, we believe that every one of the five theoretical models listed in this article have been mistreated to some level. That is to say, incorrect peak detections, matching of the measured relative pitches with the wrong scale tones, failure to take into account tones that are already available in a tuning but not included in the theorized scales, and injustice in the calculations arising from the presence of alterations or peripheral modulatory tones occurred at least once for all the competitors. However, considering the variety of recordings (diversity of the recording environment, executants, instruments, etc.), the fact that *maqams* employ a plethora of intervals, and that the examined theoretical models feature different number of tones within an octave, the consistency obtained in the results are rather high. Although we are of the opinion that TK, Mus2 and Yarman24 were much wronged compared to Yavuzoğlu48 and YAEU, it is safe to assume that the scores are quite reliable.

Of course, there is always a risk that the complex microstructure in the temporal sequence of *perdes* will not be discernable in an overall histogram from multiple recordings—especially when dealing with a musical genre that places such a great emphasis on the tiniest pitch inflexions that also vary from musician to musician. This was most evident in our interpretations of the results in the previous section. However, as we have stressed thoroughly, our priority and focus is the extracting of *maqam* scale information from overall histograms for comparison with theorized *maqam* scales. How these scales are employed and how the tones should be bent in a musical context is of secondary importance to us at this juncture.

We deem it significant that the *M*, *D*, *E* and *C* values are averaged for all theoretical models through all *maqam* categories for a global assessment. In Table 10, the mean of all maximum and average distance data from histogram autopeaks as well as the grand average of all mean efficiency and mean complexity values have been calculated. From the mean of M_{em}, D_{em} and M_{am}, D_{am}, we have derived M_{m}, D_{m}. Finally, we have scaled these with C_{m} to obtain M_{c} and D_{c}. These last two values

Table 10. Average of M, D, E and C values through nine *maqam* categories for all theoretical models. M_{em}, D_{em}: Mean of all maximum and average distance values computed with respect to AutoPeak-env. M_{am}, D_{am}: Mean of all maximum and average distance values computed with respect to AutoPeak-ave. $\mathrm{E_m}$, C_{m}: Grand average of all mean efficiency and mean complexity values in percentage. M_{m}, D_{m}: Average of mean of all maximum and average distance values with respect to both autopeaks. M_{c}, D_{c}: Scaling of M_{m} and D_{m} by C_{m}.

	M_{em}	D_{em}	M_{am}	D_{am}	$\mathrm{E_m}$	C_{m}	M_{m}	D_{m}	M_{c}	D_{c}
128 files (Hc)										
YAEU	0.99	0.35	1.03	0.39	97.62	74.31	1.01	0.37	0.75	0.28
Mus2	**0.75**	0.32	**0.74**	**0.32**	71.42	85.95	**0.74**	0.32	0.64	0.28
TK	1.01	0.39	1.27	0.47	95.83	83.47	1.14	0.43	0.95	0.36
Yarman24	0.81	**0.31**	0.86	**0.32**	89.72	**69.21**	0.84	**0.31**	**0.58**	**0.22**
Yavuzoglu48	1.03	0.47	1.05	0.51	94.15	86.58	1.04	0.49	0.90	0.42
128 files (cents)										
YAEU	22.4	7.9	23.3	8.8	97.62	74.31	22.9	8.4	17.0	6.3
Mus2	**17.0**	7.2	**16.8**	**7.2**	71.42	85.95	**16.8**	7.2	14.5	6.3
TK	22.9	8.8	28.8	10.6	95.83	83.47	25.8	9.7	21.5	8.2
Yarman24	18.3	**7.0**	19.5	**7.2**	89.72	**69.21**	19.0	**7.0**	**13.1**	**5.0**
Yavuzoglu48	23.3	10.6	23.8	11.5	94.15	86.58	23.5	11.1	20.4	9.5

signify a hypothetical case where all the theoretical models are scaled to possess the same number of tones per octave. Such a hypothetical case helps us picture which of the theorized scales would perform best if the complexity was even for all the competitors.

For 128 recordings in *maqams Rast*, *Nihavend*, *Kürdilihicazkar*, *Uşşak*, *Hüseyni*, *Hicaz*, *Saba*, *Segah* and *Hüzzam*, Mus2 and Yarman24 produce the best scores with regard to the mean of maximum and average absolute errors from AutoPeak-env. and AutoPeak-ave. and their mean M_m, D_m. The advantage of the Holderian *comma* resolution to Mus2 is clear. Nevertheless, Yarman24, with less than half the number of tones per octave compared to Mus2, and despite the unfair scoring in *Kürdilihicazkar*, yields highly satisfactory results and performs better than its closest competitor YAEU (particularly in *Rast*, *Uşşak*, *Hüseyni*, *Saba*, *Segah* and *Hüzzam*). As expected, Yarman24's grand average of all mean complexities is the lowest.

We find it concerning that TK, with a fewer number of tones per octave compared to Yavuzoğlu48 and Mus2, produced the most mediocre scores. This somewhat justifies the criticisms pitted against it. However, it is obvious that the inferior competence of TK is mostly due to inappropriate tone selections. In other words, TK could not correctly determine which scale tones out of its 41-tone tuning it should employ for several *maqams*. Even so, this is a serious shortcoming.

A graver issue is that, Yavuzoğlu48 cannot do better than YAEU despite possessing twice the number of tones per octave, and cannot accomplish nearly as much as Mus2 even though featuring a voluminous resolution only 5 tones short of logarithmically 53 equal tones to the octave. Just a glimpse at the grand average of all mean complexities reveals that Yavuzoğlu48 is a more complex theoretical model than Mus2. Indeed, it is the most complex model in our study.

A brief look at the grand average of all mean efficiencies reveals that better scores are more or less inversely proportional to E_m. In short, greater efficiency does not necessarily signify a positive aspect of theorized scales. Nevertheless, YAEU and Yarman24 are very efficient with their scales given the simplicity with their tunings compared to Mus2.

In contrast, we regard the complexity measure important and utilize it for the scaling of all theoretical models to a hypothetical equalness in size via which we can compare them on an even competing ground. M_c and D_c values portray a speculative situation regarding how well the theoretical models in question would match pitch measurements were they in possession of the same number of tones per octave.

This operation turns the tables over and raises Yarman24 to the top position with Mus2 in close pursuit. The rest of the ranking is still the same, YAEU is still the third while TK and Yavuzoğlu48 are equally wanting.

In conclusion, Mus2 and Yarman24 are highly preferable tuning options for fixed-pitch instruments such as *kanun* and *tanbur* for the given set of data on Turkish *Maqam* music practice superseding by far YAEU, TK and Yavuzoğlu48. For a great amount of detail and the ability to transpose to every degree faultlessly, 'Mercator's cycle' utilized by Mus2 is the obvious choice. For conformity to 24 tones per octave, an easier learning curve, and the ability to satisfactorily represent problematic fickle tones in *maqams* such as *Uşşak*, *Saba*, *Hüzzam* and *Karcığar* with less than 1 Holderian *comma* maximum deviation, the obvious choice is Yarman24.

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Appendix: Mus2

According to the official Turkish *Maqam* music theory (the AEU system), there are only 24 notes in an octave. But starting with Mildan Niyazi Ayomak (1888–1947) some theorists (for instance, Özkan, 1998) pointed out that tones of Turkish *Maqam* music (perdes) must be interpreted within the context of 53 *commas* to the octave. However, these theorists are not concerned with which specific notes are required of a given *maqam*. They only provide additional information such as: 'this note is played 1–2 *comma* flat or sharp with respect to the note indicated on the staff'.

A more direct method of projecting microtonal information is to indicate the *comma* deviations on the accidentals by way of numerals. This approach has been used in Turkish folk music notation and Kemal İlerici (1970/1981) employed the same method for microtonally harmonizing folk pieces. Given the existence of a large collection of scores produced this way, it is possible to statistically analyse the pitches used for each *maqam*.

Mus2, a special *Maqam* music notation program, makes it possible to prepare scores of Turkish music pieces and play them in 53-tone equal octave temperament on a computer. Nearly 2000 Turkish music pieces were notated and AEU tones were calibrated by Holderian *commas* interactively using this program in order to achieve as close a rendition of actual practice as possible. Most of the scores were notated in a form where

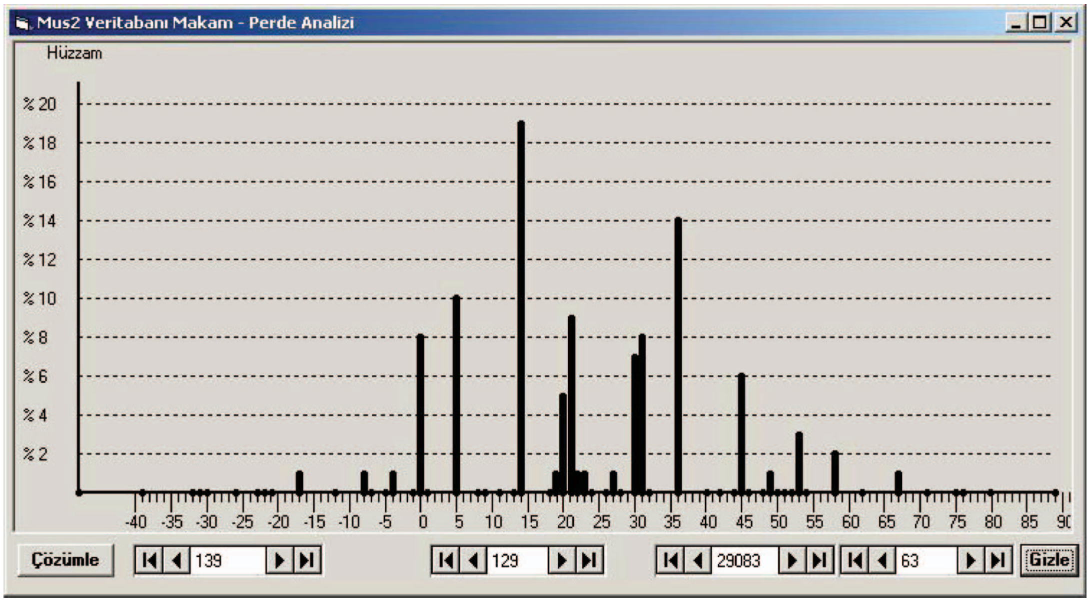

Fig. 13. The distribution of distinct relative pitches for a total of 129 pieces (29083 notes) in *maqam Hüzzam* in the Mus2 database.

the *comma* values on AEU accidentals were indicated. Sharps and flats were attached *comma* numbers not only on key signatures, but also on altered notes. These scores have been used by members of Çirağan Musiki Derneği, an amateur music society. Later on, these music sheets were published by Nota Yayıncılık (www.notamuzik.com) as a series of 20 fascicles, alas without the *comma* numerals on AEU accidentals due to commercial considerations, but with accompanying CDs featuring original 53-tone equal octave temperament based audio tracks synthesized from MIDI sounds.

Mus2 *maqam* scales in the figures of this paper were obtained from analysing the Mus2 collection. Scores in the Mus2 database are in 139 different *maqams*. For example, 129 of nearly 2000 pieces are in *maqam Hüzzam*, and these pieces comprise 63 distinct pitches in a total of 29,083 notes. In Figure 13, the distribution of distinct relative pitches in pieces composed in *maqam Hüzzam* is shown.

The horizontal axis indicates the relative pitch in Hc with respect to the tonic (*segâh* note/tone (*perde*) for *maqam Hüzzam*). The most frequently used note is *nevâ* at 14 Hc distance to the tonic, then *gerdâniye* at 36 Hc, and then *çargâh* at 5 Hc, etc. The clustering regions around 20 Hc and 30 Hc (*hisâr* and *eviç*) can be explained in the following manner: *Hisâr* is represented in AEU notation as a flattened *hüseyni* (E) note using a 4-*comma* slashed flat sign. However, all musicians agree that *hisâr* is not that flat, but characteristically only 2 *commas* flatter. Likewise, *eviç* is not 4, but 3 *commas* sharper from *acem*. Also, lots of modulations to different *maqams* occur in *Hüzzam* pieces around the neighbourhood of *hisâr*. Consequently, 1, 2, 3 and 4 *comma* flats from *hüseyni* have all been used.

To derive a scale in a given *maqam* from Mus2, a threshold is applied on the distribution of pitches in the database. Notes with a frequency of occurrence higher than or equal to %2 of the total amount are retained. The Mus2 *maqam* scales indicated in Figures 4 to 12 and Tables 1 to 9 are obtained by this approach.