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Tracing Pitch on the Grid Paper: Fu Liu and the Logarithmic Scale Paradigm Before the Digital Era

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Abstract: This paper reconstructs the theoretical rationale and technical implementation of a logarithmic scale paradigm for pitch analysis devised by Chinese phonetician Fu Liu (刘复) in the 1920s. Faced with the challenge of representing tones, which requires both fine-grained measurement and the visualization of psychoacoustically motivated pitch contours, Liu designed a system based on logarithmic spacing and twelve-tone equal temperament. Unlike his European and American contemporaries such as Daniel Jones, Rousselot, and Scripture, who relied on perceptual judgment, proportional musical scales, or direct frequency tracing, Liu sought a reproducible framework for tonal analysis grounded in numerical precision. Drawing on original documents and comparative analysis, this study situates Liu's work within the broader context of early 20th-century phonetics. The logarithmic scale is now widely used in modern acoustic analysis tools, but Liu's accurate implementation of the scale was achieved manually before our digital era, which should be considered as a pioneering contribution. Through the lens of Liu's legacy — often overlooked — we show the importance of cross-cultural and cross-disciplinary exchange in shaping the early development of phonetic sciences.

1 Introduction

At the turn of the 20th century, experimental phonetics was taking shape as a scientific discipline in Europe and North America. Researchers aimed to measure physical properties of speech such as pitch, intensity, and duration, not just to document language variation, but to uncover the underlying physiological and acoustic mechanisms. Pitch, in particular, posed technical and theoretical challenges. Daniel Jones proposed a perception-based notation system relying on trained musical judgment [7]; Abbé Rousselot used acoustic recordings and proportional scales based on just intervals [20]; Wheeler Scripture advocated direct tracing of frequency curves in hertz [22]. While these methods were influential in their time, we have found no evidence that the scholars employed a logarithmic scale or developed a fully standardized system for analyzing and visualizing pitch in tonal or intonational contours.

Within this context, the approach developed by Fu Liu presents a noteworthy departure [26, 14]. Drawing on both Chinese and Western intellectual traditions [15], Liu constructed a logarithmic pitch scale system grounded in twelve-tone equal temperament and anchored to a 435 Hz reference frequency. His method combined lookup tables and semitone-divided grid paper to enable manual yet systematic visualization of pitch movement across speakers and dialects. Although devised without access to modern computing, Liu's paradigm anticipates many of the core principles behind later software tools such as Praat [3]. This paper reconstructs Liu's logarithmic scale paradigm in both its theoretical and technical dimensions and considers its significance in the broader trajectory of phonetic research.

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2 Early 20th-Century Attempts at Pitch Measurement

2.1 Daniel Jones: Perception-Based Notation

Among the early pioneers of experimental phonetics, Daniel Jones proposed a method of pitch analysis that relied primarily on auditory perception. In his 1909 work *Intonation Curves* [7], Jones rejected acoustic measurement procedures as too laborious to be of practical use, arguing that "no one has ever yet analyzed a text of sufficient length to be of practical value to language students." (*Jones 1909*, Introduction, p. IV)

Instead, he proposed a method based on the phonetician's immediate auditory impression, which involved playing a phonograph recording and briefly lifting the needle to isolate a single moment of sound. The listener would then rely on memory to identify the quality and, if the sound was voiced, its pitch. (*Jones 1909*, Introduction, p. V)

This method required the phonetician to have a well-trained musical ear, capable of judging absolute pitch from brief auditory impressions. Using this approach, Jones was able to provide notations for large corpora. An example of the intonational notation of the beginning of *La Samaritaine* by Sarah Bernhardt is shown in Figure 1[1].


30 IV. PASSAGE FROM

LA SAMARITAINE.

(ROSTAND.)

(Tableau II, Scène 3.)*

Il dit encore:

"Soyez doux. Comprenez. Admettez. Souriez.

Ayez le regard bon. Ce que vous voudriez

Qu'on vous fit, que ce soit ce qu'aux autres vous faites;

5 Voilà toute la loi, voilà tous les prophètes!

IV. LA SAMARITAINE.* 31

Figure 1. Daniel Jones's intonational notation of *La Samaritaine* as performed by Sarah Bernhardt. *Jones 1909*, p. 30-31.

The choice to use conventional musical notation was driven by its familiarity to students studying foreign languages such as English, German, or French, which is the target audience for this book. In 2020, Ashby conducted a comparative analysis between a modern pitch analysis of Jones's corpora and Jones's original work [1]. His findings revealed a significant convergence between the two, thereby validating Jones's methodology retrospectively, at least in the context of studying English intonation.

However, Fu Liu remained unconvinced of the method. While at University College London, he observed Stephen Jones (an assistant to Daniel Jones) and an Indian student applying the technique to Sanskrit tone studies. Although he did not participate in these experiments, he later commented on them in his 1929 Chinese treatise *Shēngdiào zhī pànduàn jí shēngdiào pànduàn chǐ zhī zhìzào yǔ yòngfǎ* [12], written after his return to China. He described the method as complex, imprecise, and overly reliant on subjective impression, arguing that many pitch determinations were made without sufficient perceptual anchoring and thus lacked consistency and reliability. Yuen Ren Chao (赵元任), who had also experimented with the method, reached a similar conclusion: that the fleeting auditory cues it relied on were inadequate for capturing full pitch trajectories [12].

Liu's ideas about how pitch should be analyzed were much closer to those of Rousselot and Scripture, both of whom had worked at Rousselot's laboratory and placed great importance on acoustic evidence. Liu shared Rousselot and Scripture's view that acoustic data should form the empirical basis of pitch analysis — an aspect notably absent

[1]All historical figures cited in this paper are available in digitized form online. For the reader's convenience, hyperlinks are included in the captions.

from the work of Jones, who emphasized perceptual and physiological data, particularly in *An Outline of English Phonetics* (1922) [8]. While Jones successfully published this handbook as a practical guide, Liu and Chao considered the approach too individualistic and insufficiently replicable. Moreover, even if the method might suffice for describing intonation in stress-based languages like English, it was inadequate for tonal languages such as Mandarin, where pitch contour is lexically contrastive and requires much greater acoustic resolution.

2.2 Rousselot: Acoustic Recording and the Natural Scale

In his 1891 doctoral thesis *Les modifications phonétiques du langage étudiées dans le patois d'une famille de Cellefrouin*, Abbé Rousselot devoted a chapter to pitch measurement ("Mesure de la hauteur des sons") [19]. As a native speaker of the Cellefrouin dialect, he recorded his own speech using an electric laryngeal probe and a kymograph. These devices enabled him to trace glottal vibrations and determine the frequency of each vibratory cycle.

He then plotted his findings on a musical staff, using a proportional scale constructed from simple integer ratios. The reference note *la* (i.e., *A* in the Anglo-German system)[2] was set at 426.26 Hz, reflecting the tuning standard of his instrument-maker, Koenig, and slightly influencing the frequency values he annotated. An example of his pitch transcription, based on the beginning of the tale *Le petit Poucet*, is shown in Figure 2. Rousselot provided pitch notations not only for isolated words and full sentences, but

Figure 2. Rousselot's musical transcription of the tale opening *Le petit Poucet. Rousselot 1891*, p. 133

also for entire folktale openings. He compared his results with transcriptions made by a professional musician and observed a notable correspondence between them.

In *Principes de phonétique expérimentale* [21], Rousselot formalized the system further by elaborating the theoretical basis of his proportional scale, which he called the *gamme naturelle*[3]. Unlike equal temperament, this scale was derived from just intonation ratios such as 9:8, 4:3, and 5:4. He further extended these ratios to calculate all semitones and provided detailed correspondence tables between frequencies and semitone positions, covering nine octaves (ranging from 16.3125 Hz to 7830 Hz), as shown in Figure 3. This version of the scale was anchored to 435 Hz, consistent with the French diapason standard of the time. Rousselot provided frequency-to-semitone conversion tables covering nine octaves, enabling systematic analysis across a wide pitch range. For graphical represen-

[2]Throughout this paper, solfège pitch notation (e.g., la_3, ut_0) follows the French system commonly used in early phonetic studies. Where relevant, equivalent pitch names from the international (Anglo-German) letter system (e.g., A_4, C_1) are provided in parentheses for clarity.

[3]Rousselot's use of the term *gamme naturelle* refers to a just-intonation scale based on harmonic proportions, not to a diatonic scale in the sense of a seven-note stepwise sequence such as C–D–E–F–G–A–B.

Notes	Octaves								
	Ut_{-2}	Ut_{-1}	Ut_1	Ut_2	Ut_3	Ut_4	Ut_5	Ut_6	Ut_7
Ut....	16,3125	32,625	65,25	130,5	261	522	1044	2088	4176
Ré....	18,3515625	36,703125	73,40625	146,8125	293,625	587,25	1174,5	2349	4698
Mi....	20,390625	40,78125	81,5625	163,125	326,25	652,5	1305	2610	5220
Fa.....	21,75	43,5	87	174	348	696	1392	2784	5568
Sol....	24,46875	48,9375	97,875	195,75	391,5	783	1566	3132	6264
La.....	27,1875	54,375	108,75	217,5	435	870	1740	3480	6960
Si ♭...	29,3625	58,725	117,45	234,9	469,8	939,6	1879,2	3758,4	7516,8
Si.....	30,5859375	61,171875	122,34375	244,6875	489,375	978,75	1957,5	3915	7830
Ut ♯..	16,9921875	33,984375	67,96875	135,9375	271,875	543,75	1087,5	2175	4350
Ré ♯..	19,1162109375	38,232421875	76,46484375	152,9296875	305,859375	611,71875	1223,4375	2446,875	4893,75
Fa ♯..	22,65625	45,3125	90,625	181,25	362,5	725	1450	2900	5800
Sol ♯..	25,48828125	50.9765625	101,953125	203,90625	407,8125	815,625	1631,25	3262,5	6525
La ♯..	28,3203125	56,640625	113,28125	226,5625	453,125	906,25	1812,5	3625	7250

Figure 3. Frequency-to-semitone table across nine octaves in Rousselot's proportional system. *Roussselot 1897-1901*, p. 12

tation, he allocated equal horizontal spacing to each semitone, diverging from traditional musical notation. This is shown in Figure 4. The frequency curves generated by these

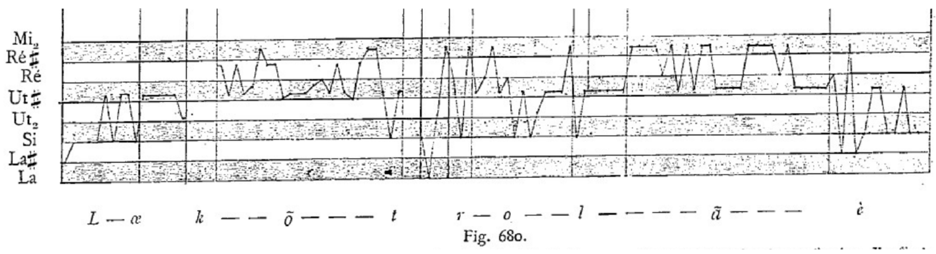

Figure 4. Graphical design of Rousselot's system with uniform semitone spacing, diverging from traditional music notation. *Roussselot 1897-1901*, p. 1004

recordings appeared jagged and uneven, requiring substantial manual smoothing, a difficulty also noted by Fu Liu in his later writings. While Rousselot adopted the terminology of twelve semitones per octave, these intervals were not equally spaced logarithmically. Rather, they were constructed from harmonic ratios in line with the principles of just intonation. This distinguishes his proportional scale from the equal-tempered system later adopted by Fu Liu.

2.3 Wheeler Scripture: Hertz-Based Acoustic Curves

Wheeler Scripture maintained a close professional relationship with Rousselot and visited his laboratory in Paris, where he conducted experiments using various instruments and recording techniques. Sharing Rousselot's emphasis on physical measurement, Scripture strongly advocated grounding intonational research in acoustic analysis.

In his book *Elements of Experimental Phonetics* (1902) [22], he argued that the constantly changing nature of speech pitch made it virtually impossible to capture accurate melodic contours by ear alone. Instead, he promoted the use of phonographic devices to trace pitch variation continuously over time, a principle especially relevant to tonal languages like Chinese.

Scripture's empirical work relied exclusively on frequency-based acoustic measurements, expressed in hertz. His work ranged from single sentences to various speech forms, including a performance of *Rip Van Winkle's Toast* by actor John Jefferson and a public address by Senator Depew. An illustrative example appears in Figure 5, depicting

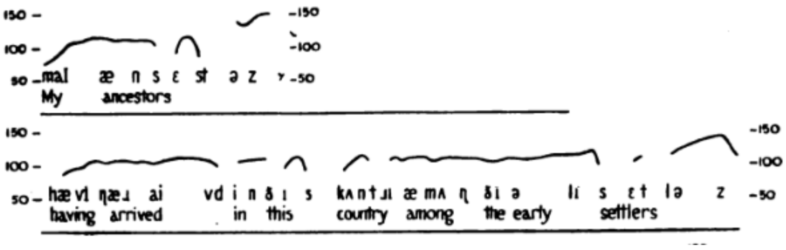

Figure 5. Scripture's pitch tracing of the beginning of Senator Depew's public address, measured in hertz. *Scripture 1923*, p. 11.

the pitch contour of the beginning of senator Depew's address taken from *The Study of English Speech by New Methods of Phonetic Investigation* [23].

Unlike Rousselot, Scripture made no attempt to systematize pitch using musical frameworks, whether proportional or logarithmic. His contribution was instead rooted in the direct acoustic visualization of pitch movement.

2.4 Jean Poirot: Interval Percentages and Cross-Linguistic Inquiry

Before moving to Paris, where he was appointed to the Institut de Phonétique, Jean Poirot held a chair in phonetics at the University of Helsinki. During his time there, he published extensively on various languages, including detailed studies on the Lappish dialect of Finland. He was particularly interested in the "musical accent" of this language. Poirot provided acoustic data from recordings of a diverse range of examples, measured in vibrations per second (Hz). To analyze the melodic movements, he employed a method adapted from Pipping, a specialist in Finno-Ugric languages also based in Helsinki. This method involved calculating pitch intervals as a percentage of the lowest fremquency in a given comparison [17, 18]. Notably, Pipping's method has not gained traction outside of Finland. In his writings, Poirot also reflected on the variety of pitch scales then in use, including tempered scales.

None of these leading phoneticians of the time utilized a logarithmic pitch scale. To investigate whether any others may have, we examined the two primary journals publishing experimental phonetics at the time: *La Revue de Phonétique* (edited by Rousselot & Pernot, 1911–1929) and *VOX* (edited by H. Gutzmann, Panconcelli-Calzia, 1913–1922). Our search did not yield a single article featuring the logarithmic scale. While our research is not exhaustive and we cannot definitively conclude that the logarithmic scale was used by phoneticians at the beginning of the 20th century, it appears to have been rare and not a dominant trend in the field.

While multiple methods for pitch analysis were proposed and tested, none adopted a log-based scale as a standard for visualization. It is within this context of methodological fragmentation and limited systematization that Fu Liu's work stands out: he appears to be the only phonetician of his generation to have built a complete graphical system grounded in logarithmic pitch mapping. This system was fully quantified and based on the twelve-tone equal temperament, an idea that resonates not only with Western tuning theory but also with the sixteenth-century Chinese mathematician and music theorist, Zaiyu Zhu[4]. Liu's system was more than a pragmatic solution to the challenge of pitch visualization; it represented a paradigm shift in how tonal variation could be captured, compared, and reproduced. The following section reconstructs this system from its conceptual foundations to its manual implementation, examining how it reconciled

[4]Zaiyu Zhu is the modern pinyin romanization of 朱載堉. He is also referred to as Chu Tsai-yü in some earlier English-language publications.

mathematical rigor, acoustic theory, and pedagogical design long before the digital age.

3 Fu Liu's Logarithmic Scale Paradigm: Theory, Implementation, and Impact

3.1 From Frequency to Form: Conceptualizing a Logarithmic Pitch Scale

As previously discussed, one of the key challenges for early twentieth-century phoneticians was how to visualize tonal variation in a way that captured both acoustic precision and perceptual relevance. Conventional musical systems such as just intonation provide a foundation for understanding pitch intervals, but these intervals are not equal in terms of physical frequency (e.g. a pure fifth spans 702 cents, while a pure major third spans 386 cents). When plotted on a linear frequency axis, the same interval occupies different distances depending on its register, resulting in perceptual distortion of pitch contours.

A typical example can be found in C. B. Bradley's 1911 tonal study of Siamese [4], in which both frequency and musical notes were marked on the chart. However, the actual curves were plotted based on frequency values alone, and the musical notes served only as approximate references, failing to account for the non-linear nature of human pitch perception.

Fu Liu recognized that a more systematic approach was needed for tonal languages such as Chinese, where small intervallic differences carry phonological significance. During his training in London and Paris, he adopted a logarithmic axis for pitch plotting, constructing what he called a "fixed scale". In this system, each frequency ratio corresponded to a fixed graphical distance: an octave (2:1) occupied the same vertical span regardless of its absolute frequency, and each semitone in the twelve-tone equal temperament was equally spaced.

He adopted the concept of equal temperament from Western music theory, in which the octave is divided into twelve equal parts, each semitone corresponding to a frequency ratio of $2^{1/12}$. When plotted on a $\log_2$ scale, this structure ensures that pitch contours retain their shape across registers. Fu Liu's adoption of this idea provided a unified coordinate system for tonal comparison, allowing tone curves to be measured, drawn, and compared with precision.

It is worth noting, however, that the idea of dividing the octave into equal intervals had a parallel mathematical formulation in China. In the late sixteenth century, Ming dynasty mathematician and music theorist Zaiyu Zhu systematically derived the structure of the twelve-tone equal temperament in his treatise *Lüxue Xinshuo*, calculating the frequency ratios of semitones with remarkable precision (up to 24 decimal places). Deeply versed in classical Chinese pitch theory and simultaneously trained in modern acoustic phonetics, Fu Liu's use of a logarithmic frequency axis in tonal visualization can be seen as a conceptual transfer the principles of equal-tempered tuning into the domain of speech acoustics. His system thus fused traditions across continents and centuries to construct a novel method for tonal visualization.

3.2 Designing a Quantitative Pitch Axis: As early as Zaiyu Zhu

To realize his pitch visualization system, Liu constructed a pitch axis with uniform increments designed to reflect equal perceived differences in pitch. Such an idea was not without precedent: it can be traced back to both Chinese and Western traditions.

In China, as previously mentioned, Zaiyu Zhu proposed the twelve-tone equal temperament system in the late sixteenth century, dividing the octave into twelve equal intervals (semitones) and computing their frequency ratios with high precision. This system also resolved a long-standing problem in Chinese tuning theory, known as the "inability to restore Huangzhong" (黄钟不能还原) in the *sānfēn sǔnyì* (三分损益) method[5] [16].

In the West, similar attempts were made in the early seventeenth century by Italian musician Vincenzo Galilei and Flemish mathematician Simon Stevin [24], but their proposals were not widely accepted [2]. It was not until the eighteenth century, driven by the needs of keyboard modulation, that twelve-tone equal temperament became the dominant tuning method [6, 25]. Later, in 1885, British scholar Alexander J. Ellis introduced the concept of "cents" in his work *On the Musical Scales of Various Nations*, defining the octave as 1200 cents and each semitone as 100 cents [5], thereby enabling fine-grained numerical representation of pitch.

Fu Liu applied the principles of equal temperament and the cent system in constructing his pitch axis. He subdivided each semitone into five parts, such that each small step represented 20 cents, with a frequency ratio of approximately $2^{1/60} \approx 1.0116$. He selected the French standard reference pitch of $la_3 = 435$ Hz (corresponding in pitch to A_4 in the Anglo-German system, though slightly lower in frequency) as the baseline frequency and calculated downward to ut_0 (C_1) $= 32.3$ Hz, thus generating a frequency table (figure 6) covering approximately four octaves.

In his doctoral dissertation [9], Liu compiled Table I, which lists the frequencies (in Hz) and common logarithms ($\log_{10}$)[6] for each semitone and their respective sharps and flats (e.g., *ré#*). He noted that since the frequency ratio between adjacent semitones is constant at $2^{1/12}$, their logarithmic difference should also be constant. For example, the $\log_{10}$ difference between 435 Hz (la_3) and the next semitone at 410.6 Hz is approximately 0.0251. This constant was denoted as D. Dividing D by 5 yields the difference between adjacent 1/5-semitone intervals ($d = 0.00502$), corresponding to 20-cent steps.

To facilitate pitch plotting, Liu extended Table I by calculating the frequencies for each 1/5-semitone increment using the constant ratio $r = 2^{1/60}$. Starting from $ut_0 = 32.3$ Hz, he generated a complete set of values such as 32.7 Hz, 33.1 Hz, and so on, up to $la_3 = 435$ Hz (see Table II). These values established a direct mapping between acoustic frequency and vertical position on graph paper, where each 1 mm step represented a 20-cent increment. For example, a measured f_0 of 125 Hz could be located between ut_2 (C_3) and si_1 (B_2) at approximately 40–60 cents, enabling rapid and precise plotting without the need for real-time logarithmic calculation.

3.3 Tonal Contour Drawing Procedures and Methodological Implications

Once the tables were complete, Fu Liu established a standard procedure for drawing tonal curves. In processing tonal data, he used a kymograph to record vibration trajectories, then measured the frequency for each cycle, matched it to the corresponding value on his logarithmic scale, and marked the points along the time axis, as shown in figure 7. These points were then smoothly connected manually to form a continuous pitch contour.

Liu emphasized that the smoothing process was crucial: the curve should not be mechanically interpolated point-by-point, but drawn according to the overall trend, thereby

[5] *Huangzhong*, literally "Yellow Bell," is the foundational pitch in traditional Chinese music theory, serving as the reference pitch from which the entire tuning system is constructed. Under the *sanfen sunyi* method, which constructs pitches by iteratively multiplying or dividing by 3/2 or 4/3, the system fails to return to the original *Huangzhong* pitch after a full cycle of intervals. Zaiyu Zhu's equal temperament reform addressed this issue by proposing a mathematically closed system where each semitone is spaced equally on a logarithmic scale.

[6] Liu used base-10 ($\log_{10}$) logarithms to tabulate frequency values, as shown in figure 6. While this differs from the $\log_2$ transformation more commonly used in modern phonetics, the intervallic structure remains identical due to the constant frequency ratio per step. For consistency with modern practice, we adopt log2 notation elsewhere in this paper, while retaining Liu's original log10 values where relevant.

TABLE I

DT.	VD.	L.	D.	d.
la$_3$	435,0	2,6385	0,0251	0,00502
sol$_3$♯	410,6	2,6134	0,0251	0,00502
sol$_3$	387,5	2,5883	0,0250	0,00500
fa$_3$♯	365,8	2,5633	0,0251	0,00502
fa$_3$	345,3	2,5382	0,0251	0,00502
mi$_3$	325,9	2,5131	0,0251	0,00502
ré$_3$♯	307,6	2,4880	0,0252	0,00504
ré$_3$	290,3	2,4628	0,0250	0,00500
ut$_3$♯	274,0	2,4378	0,0250	0,00500
ut$_3$	258,7	2,4128	0,0252	0,00504
si$_2$	244,1	2,3876	0,0252	0,00504
la$_2$♯	230,4	2,3624	0,0249	0,00498
la$_2$	217,5	2,3375	0,0251	0,00502
sol$_2$♯	205,3	2,3124	0,0250	0,00500
sol$_2$	193,8	2,2874	0,0252	0,00504
fa♯$_2$	182,9	2,2622	0,0252	0,00504
fa$_2$	172,6	2,2370	0,0251	0,00502
mi$_2$	162,9	2,2119	0,0250	0,00500
ré$_2$♯	153,8	2,1869	0,0249	0,00498
ré$_2$	145,2	2,1620	0,0253	0,00506
ut$_2$♯	137,0	2,1367	0,0251	0,00502
ut$_2$	129,3	2,1116	0,0249	0,00498

TABLE I (*suite*)

DT.	VD.	L.	D.	d.
si$_1$	122,1	2,0867	0,0252	0,00504
la$_1$♯	115,2	2,0615	0,0248	0,00496
la$_1$	108,8	2,0367	0,0252	0,00504
sol$_1$♯	102,7	2,0115	0,0252	0,00504
sol$_1$	96,9	1,9863	0,0249	0,00498
fa$_1$♯	91,5	1,9614	0,0254	0,00508
fa$_1$	86,3	1,9360	0,0248	0,00496
mi$_1$	81,5	1,9112	0,0253	0,00506
ré$_1$♯	76,9	1,8859	0,0250	0,00500
ré$_1$	72,6	1,8609	0,0252	0,00504
ut$_1$♯	68,5	1,8357	0,0248	0,00496
ut$_1$	64,7	1,8109	0,0256	0,00512
si$_0$	61,0	1,7853	0,0249	0,00498
la$_0$♯	57,6	1,7604	0,0248	0,00496
la$_0$	54,4	1,7356	0,0255	0,00510
sol$_0$♯	51,3	1,7101	0,0253	0,00506
sol$_0$	48,4	1,6848	0,0249	0,00498
fa$_0$♯	45,7	1,6599	0,0244	0,00488
fa$_0$	43,2	1,6355	0,0259	0,00518
mi$_0$	40,7	1,6096	0,0241	0,00482
ré$_0$♯	38,5	1,5855	0,0256	0,00512
ré$_0$	36,3	1,5599	0,0246	0,00492
ut$_0$♯	34,3	1,5353	0,0261	0,00522
ut$_0$	32,3	1,5092		

Figure 6. Fu Liu's Table I: Frequencies and logarithmic values of equal-tempered semitones, including base-10 logarithmic differences (D) and their subdivisions (d). *Liu 1925*, p. 14-15.

filtering out noise or error introduced by equipment limitations. This method was applied in his 1925 doctoral dissertation *Étude expérimentale sur les tons du chinois* [9], where he presented tone curves for ten Chinese dialects, including Beijing, Jiangyin, and Cantonese, across monosyllabic, disyllabic, and continuous speech contexts. The results demonstrated a remarkable level of precision and comparability, allowing typological and stylistic analyses to be conducted on a shared quantitative basis.

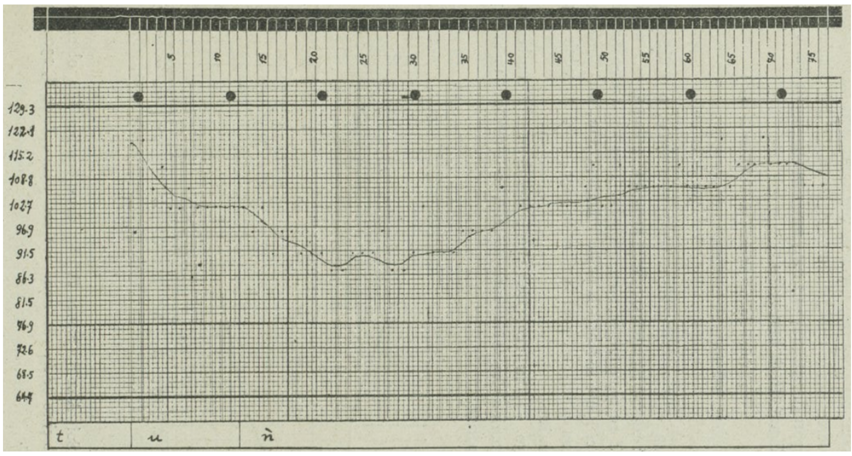

Figure 7. Smoothed pitch contour manually drawn using Fu Liu's logarithmic pitch scale on grid paper *Liu 1925*, p. 19.

Liu's entire workflow constituted a reproducible methodological framework. By standardizing the grid paper (with 20-cent vertical divisions) and using a consistent lookup table, researchers could plot and compare tonal data on a common coordinate system. Though developed decades before the advent of digital tools, it captured key elements of what would later become standard in phonetic analysis: perceptual scaling, graphic precision, and inter-speaker comparability.

To be clear, Liu's method did not directly influence the development of software such as Praat [3], nor was it informed by the psychoacoustic pitch scales (such as the Mel or Bark scales) introduced later in the twentieth century. However, the mathematical logic of his scale, which expresses pitch in semitone steps relative to a fixed reference frequency (435 Hz), is formally equivalent to the logarithmic conversions widely used in modern systems. In this sense, Liu's method can be seen as an independent and remarkably early solution to the problem of how to represent tone variation in both acoustic and perceptual terms. Rather than anticipating specific tools, his work prefigured a broader methodological shift in phonetics: from descriptive approximations to precise, repeatable measurements. By building a full-scale, log-based coordinate system for pitch drawing by hand, he laid empirical foundations for later cross-linguistic tonal comparisons.

Liu's contributions extended beyond experimental techniques. In works such as *Pípá jí tā zhǒng xián yuèqì zhī děnglǜ dìng pǐn fǎ* [10], *Shí'èr děnglǜ de fāmíng zhě Zàiyǔ Zhū* [13], and *Cóng wǔyīn liùlǜ shuō dào sānbǎi liùshí lǜ* [11], he traced the evolution of tuning systems in Chinese traditions, showing deep awareness of both mathematical and cultural dimensions of pitch. His work exemplifies an early and original attempt to bridge acoustic phonetics, perceptual modeling, and cross-cultural theoretical insight.

4 Conclusion

This study has reconstructed the theoretical rationale and technical implementation of the logarithmic framework developed by Fu Liu for tonal analysis. Situated within the broader context of early 20th-century phonetics, Liu's approach is distinguished by its integration of a logarithmic scale and twelve-tone equal temperament, a combination largely absent from the major European phonetic traditions of the time. Rather than constituting a derivative or marginal contribution, Liu's system offers an original and integrative attempt to formalize pitch measurement with internal consistency and reproducibility. Bridging musical acoustics, phonetic theory, and empirical observation, it embodies methodological principles that would only become widespread in phonetics decades later. As such, Liu's legacy not only enriches our historical understanding of phonetic science, but also calls for a more inclusive reassessment of contributions that emerge outside the mainstream European canon.

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