The Influence of Unequal Temperament on Chopin's Piano Works

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Abstract

Frédéric Chopin (1810–1849) composed in the first half of the 19th century, when pianos were tuned in unequal temperaments: different keys displayed subtly different intervallic structures. It is well known that he composed at the piano, making it likely that he took into account the instrument's tuning when writing music. In one of the rare studies of the issue, Miller (2001) discusses the influence of unequal temperaments on Chopin's mazurkas by examining its impact on melodic and harmonic features. Jonathan Bellman (2005) also describes how unequal temperaments can alter performances of Chopin's music by enhancing the differentiation between keys.

The present research builds on Miller and Bellman's studies. Rather than attempting to divine temperament's impact on the sound of individual pieces, it investigates the evidence from within the music that the structure of nineteenth-century keyboard tunings influenced Chopin's compositions. By studying a corpus of his works comprising the entire etudes, mazurkas, nocturnes, polonaises, preludes, and waltzes, I aim to shed light on how temperament may have had repercussions on parameters such as key, modulation, and musical texture.

The first chapter demonstrates why equal temperament was not truly attained before the early 20th century and summarizes the existing research on 19th-century temperaments. Then, I present five tuning systems that may have been available to Chopin during his lifetime. The second chapter delves into the influence of unequal temperament on specific musical features. I address the effect of tuning systems on the chromatic scale, chord colour, and modulation, by providing examples from Chopin's piano music. The chapter ends with a discussion of the potential links between traditional key characteristics, as described by Rita Steblin (2002), and unequal tuning systems.

The final chapter consists of a study in which I evaluate the frequency and prominence of harmonic major thirds—an interval that is significantly affected by temperament—in a corpus of Chopin's piano works. This analysis is based on studies conducted on Bach's *Das Wohltemperierte Klavier* by John Barnes (1979) and Steven Cannon (2007). By considering the use of the interval in light of historical temperaments, I discuss how trends found in Chopin's treatment of chords and musical texture may depend on absolute pitch level. I conduct the study with the Humdrum toolkit, a set of command-line utilities developed by David Huron for assisting in computational analysis.

This thesis adds to the academic discourse on Chopin in that it features original research that provides new awareness of his sensitivity to key and its relationship to temperament. Moreover, illustrating how temperament could serve as an expressive tool for the romantic composer suggests that this type of research could be extended to other piano repertoire of the same era.

Résumé

Frédéric Chopin (1810-1849) composait lors de la première moitié du XIXe siècle, lorsque les pianos étaient accordés en tempérament inégal : la taille des intervalles variait subtilement d'une tonalité à l'autre. Puisque Chopin composait au piano, il est probable que le tempérament de son instrument ait eu une influence sur sa musique. Dans l'une des rares études sur le sujet, Miller (2001) décrit l'impact des tempéraments inégaux sur les mazurkas de Chopin en examinant leur effet sur la mélodie et l'harmonie. Jonathan Bellman (2005) décrit la façon dont un tempérament inégal peut altérer le son de la musique de Chopin en accentuant les différences entre les tonalités.

Cette recherche s'appuie sur les études de Miller et Bellman. Plutôt que de deviner l'impact du tempérament sur des pièces individuelles, j'examine la musique elle-même pour montrer l'évidence que la structure des tempéraments du XIXe siècle a eu une influence sur les compositions de Chopin. En étudiant un corpus de ses œuvres pour piano qui comprend les études, mazurkas, nocturnes, polonaises, préludes et valses, je vise à démontrer comment le tempérament a pu avoir des répercussions sur des aspects musicaux tels que la tonalité, les modulations, et la texture musicale.

Le premier chapitre démontre pourquoi le tempérament égal n'était pas atteignable avant le début du XXe siècle, et résume les recherches ayant été menées sur les tempéraments du XIXe siècle. Par la suite, je présente cinq méthodes d'accord contemporaines à Chopin. Le second chapitre examine l'influence du tempérament inégal sur certains paramètres musicaux. Je décris l'effet que ces systèmes d'accord ont sur la gamme chromatique, la couleur des accords et la modulation, en présentant des exemples tirés du répertoire pour piano de Chopin. Le chapitre se termine par une discussion des liens potentiels entre les systèmes d'accord inégaux et les caractérisations traditionnellement accordées aux tonalités, telles que décrites par Rita Steblin (2002).

Le troisième chapitre consiste en une étude dans laquelle j'évalue la fréquence et l'importance des tierces majeures harmoniques – un intervalle considérablement affecté par le tempérament – dans un corpus d'œuvres de Chopin. Mon analyse est basée sur des études menées sur *Das Wohltemperierte Klavier* de Bach, par John Barnes (1979) et Steven Cannon (2007). En abordant les résultats à la lumière de tempéraments historiques, je discute de la façon dont le traitement de certains accords et textures par Chopin dépend

peut-être de la hauteur absolue. Je mène cette étude à l'aide du Humdrum toolkit, un ensemble d'outils pour ligne de commande développé par David Huron.

Cette thèse de maîtrise ajoute au discours académique sur Chopin par sa recherche originale qui fournit une nouvelle sensibilisation sur l'emploi de différentes tonalités et de leur relation au tempérament. De plus, cette étude démontrant comment le tempérament inégal peut servir de moyen expressif pour le compositeur romantique suggère que ce type de recherche pourrait s'appliquer à d'autre répertoire pour piano de la même époque.

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Introduction

> *"All those with whom I was in most intimate harmony have died and left me. Even Ennike, our best tuner, has gone and drowned himself; and so I have not in the whole world a piano tuned to suit me."*
>
> – Frédéric Chopin, *Correspondance,* August 1848

The only reference to piano tuning penned by Chopin, written towards the end of his life in a letter to his friend Julian Fontana, betrays the crucial role temperament held for him. He was distressed and concerned he could no longer find an instrument tuned to his taste. Scholars and performers alike often presume that Chopin and his contemporaries were playing on equally-tempered keyboard instruments, and this assumption might explain why the relationship between 19th-century composition and keyboard temperament has often been overlooked in academic literature.

The relationship between piano temperament and Chopin's music, however, poses an interesting issue. Since he composed in the first half of the 19th century, he was undoubtedly exposed to a vast array of tuning possibilities that differed from today's standard equal temperament. For instance, tuning manuals and guides available in Europe during the composer's lifetime feature uneven temperaments that allowed for playing in every key while preserving some amount of key colouration.

Chopin is a particularly appropriate case study because he composed and improvised at the piano, making it likely that he was influenced by the subtle differences in intervallic structure between tonalities. Friends and pupils describe how the choice of a key was important for him, both in composing, improvising, and performing. For instance, Jeffrey Kallberg has shown how Chopin refused to transpose some of his manuscripts for the sake of maintaining unity between pieces.[1] In *Impressions et souvenirs,* George Sand reminisces on how Chopin would arpeggiate at the piano until he found the right "colour", describing the "soft colours corresponding to the suave modulations" she heard.[2] The level of attention Chopin gave to the choice of a key indicates that temperament may very realistically have had an influence on the content of his work.

Moreover, Chopin was notoriously selective of the pianos he played. Choosing to teach on Pleyel pianos only, he also expressed his frustration at having to wait for an instrument to be delivered at his Majorca residence during the composition of his 24 Preludes, Op. 28.[3] Piano technician Alfred J. Hipkins notes relate how later in life, Chopin turned to the Broadwood manufacture for his performances in England. The "responsiveness to his sensitive touch"[4] led Chopin to liken the Broadwood instruments to a "real London Pleyel."[5] Eigeldinger attributes Chopin's predilection for the French manufacturer to the subtle nuances, timbral differences, and pedal mechanisms these pianos were capable of.[6] Malou Haine's work offers a thorough description of the features

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[1] Jeffrey Kallberg, "The Chopin Sources: Variants and Versions in Later Manuscripts and Printed Editions," PhD diss. (University of Chicago, 1982): 90-214.

[2] George Sand, *Impressions et souvenirs* (Paris : M. Lévy, 1873): 86. Original text reads: "Nos yeux se remplissent peu at peu des teintes douces qui correspondent aux suaves modulations saisies par le sens auditif. Et puis la note bleue résonné et nous voilà dans l'azur de la nuit transparente." Translated by Jean-Jacques Eigeldinger in "Chopin and 'La Note Bleue': An Interpretation of the Prelude Op.45," *Music & Letters* 78/2 (1997).

[3] Jean-Jacques Eigeldinger, "L'achèvement des Préludes op. 28 de Chopin. Documents autographes," *Revue de Musicologie* 75/2 (1989): 239.

[4] Edith J. Hipkins and Alfred J. Hipkins, *How Chopin Played, From Contemporary Impressions Collected from the Diaries and Note-Books of the Late A.J. Hipkins, F.S.A. With Four Illustrations (*London, J.M. Dent and Sons, 1937):

[5] Jean-Jacques Eigeldinger, "Chopin and Pleyel," *Early Music* 29/3 (2001): 394.

[6] Ibid, 393.

of Pleyel pianos: the soft hammers allowed for a precise dynamic control that was unavailable on the competing Érard pianos.[7]

Historical accounts indicate that Chopin emphasized these subtleties during performances. Describing his playing, Marmontel praises the "transparent vapour" of the "soft and veiled sonorities" that contrast with "brilliant passages" and "loud ringing chords."[8] A review by Berlioz also tellingly praises the variety of dynamics in Chopin's playing:

> *"In order to appreciate him fully, I believe he has to be heard from close by, in the salons rather than the concert hall (…) There are unbelievable details in his Mazurkas; and he has found how to render them doubly interesting by playing them with the utmost degree of softness piano to the extreme, the hammers merely brushing the strings, so much so that one is tempted to go close to the instrument and put one's ear to it."*[9]

Since Chopin was so sensitive to issues of tonality, timbre, and dynamic, it seems probable that he would have taken temperament into account when at the piano. The differentiation between keys offered by 19th-century piano tunings was subtle, but it seems unlikely that the poetically-inclined, detailed-oriented Chopin, who was consciously aware of the different auditory effects he could produce through his instrument, would have been insensitive to such nuances. How would he choose to contrast, for instance, the pure-sounding C major that is rendered by a traditional unequal

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[7] Haine, Malou. "Les facteurs de piano à Paris à l'époque de Frédéric Chopin." In *Interpréter Chopin: actes du colloque des 24 et 26 mai 2005*, edited by Jean-Jacques Eigeldinger, Emmanuel Hondré, and Delphine Delaby (Paris: Cité de la musique, 2006): 36-39.
[8] Quoted from Eigeldiner, *Chopin and Pleyel*, 393.
[9] Quoted from Eigeldiner, *Chopin: pianist and teacher as seen by his pupils*, 71.

temperament and the bright G-flat major, whose tonic chord would have a wider major third in the 19th-century than the ones we can hear on today's pianos? Would he tend to prefer modulations that featured a perceptible change in purity? Would he underline changes in purity by varying musical parameters such as texture or dynamics? This thesis attempts to answer such questions, by investigating the evidence from within the music of how the structure of 19th-century keyboard temperaments influenced Chopin's compositions.

The first chapter offers a succinct review of the history of keyboard temperament, explaining the functioning of meantone, circulating, and equal temperaments. I demonstrate why equal temperament was not truly attained before the early 20th century by analyzing the instructions found in historical tuning manuals. Then, I present five tuning systems that may have been available to Chopin during his lifetime. The chapter also summarizes the existing research on 19th-century temperaments and Chopin's music.

The second chapter delves into the influence of unequal temperament on specific musical features. I address the effect of tuning systems on the chromatic scale, chord colour, and modulation, by providing examples from Chopin's piano music. Through my analysis, I aim to address the following questions: What harmonic and melodic features can be highlighted or modified by unequal temperaments? What features of Chopin's music may have been affected by temperament? Are some types of modulations more frequent in the context of certain keys, and how might this relate to temperament? Finally, can we link these questions to issues of key characteristics? To explore this last question, the chapter ends with a discussion of the potential links between temperament and traditional key characteristics, as described by Rita Steblin.[10] The corpus studied in this chapter comprises Chopin's complete Preludes, Mazurkas, Waltzes, Etudes, Ballades, Nocturnes, Polonaises, and Scherzos.

The third chapter consists of a study in which I evaluate the frequency and prominence of harmonic major thirds—an interval that is significantly affected by temperament—in a corpus of 99 Chopin pieces. This analysis is based on studies conducted on Bach's *Das Wohltemperierte Klavier* by John Barnes[11] and Steven Cannon.[12] Rather than attempting to divine the influence of temperament on individual pieces, I will take a broader approach by studying a corpus of 138 of his works, comprising the entire Mazurkas, Preludes, Etudes, Waltzes and Nocturnes. By considering the use of the major third interval in light of historical temperaments, I discuss how trends found in Chopin's treatment of chords and musical texture may depend on absolute pitch level. I conduct the study with the Humdrum toolkit, a set of command-line utilities developed by David Huron for assisting in computational analysis, and discuss the results in light of Chopin's physical and ergonomic understanding of the piano keyboard, as described by his students and by himself in drafts for a teaching method.

Finally, a conclusion summarizes the findings and offers possible paths for future research.

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[10] Rita Steblin, *A History of Key Characteristics in the Eighteenth and Early Nineteenth Centuries* (Rochester, NY: University of Rochester Press, 2002).

[11] John Barnes, "Bach's Keyboard Temperament: Interval Evidence from the Well-Tempered Clavier," *Early Music* 7/2 (1979): 236–249.

[12] Steven Cannon, "Deducing Temperament from Analysis of the *Well-Tempered Clavier:* Contradictory or Complementary Evidence?" McGill University, 2007.

Chapter 1 – A Review of 19th-century Keyboard Temperaments

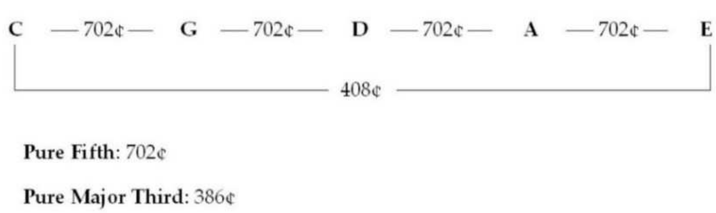
1.1 Unequal keyboard temperaments in the 18th and 19th centuries

Eighteenth-century Europe saw significant changes in keyboard tuning technologies, such as the shift from meantone to circulating temperaments. To fully showcase the implications of this change for musical performance and composition, I will begin by describing the structure of these two temperaments.

a) Meantone temperaments

In use since the late 1400s,[1] meantone temperaments feature slightly tempered perfect fifths that allow for pure major thirds in most keys. In any tuning system, the size of fifths directly influences the thirds; as shown in Figure 1.1, tuning pure fifths produces major thirds that are too wide by a syntonic comma, or 22¢.[2]

Figure 1.1 Wide major third as a result of four pure fifths

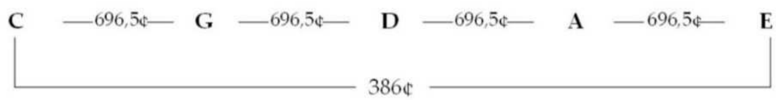


A tuner can distribute this error equally by reducing each of the four fifths by a quarter of the comma, approximately 5,5¢. Figure 1.2 shows how these slight, almost inaudible,

[1] J. Murray Barbour, *Tuning and Temperament: A Historical Survey* (East Lansing: Michigan State College Press, 1951), 25.
[2] The formula for converting ratios to cents is (log(x/y)/log(2)) x 1200, where x/y is the ratio. In the case of a major third, the ratio is 3/2.

adjustements to the fifths result in a pure major third, a considerable improvement from the 408¢ created by pure fifths.

Figure 1.2 Pure major third as a result of four tempered fifths



To tune meantone temperament, a tuner can consequently temper each fifth by ¼ of a comma from E♭-B♭ to C♯-G♯. This creates pure major thirds beginning on E♭, B♭, F, C, G, D, A, and E. The diminished sixth G♯ - E♭ that closes the chain of fifths is clearly out of tune at 738¢. Notes from B and sharpwards on the circle of fifths cannot serve as the root of a major third, because the span of four fifths that generates them encompasses this "wolf" fifth. The meantone tuning system was first described in detail by Pietro Aron in in his *Toscanello de la Musica* (1523).[3] Figure 1.3 provides a circular representation of this particular form of meantone temperament.[4] To calculate the size of an interval, add the number of cents from its root to its second note. For example, the interval C♯-F (696,5 + 738 + 696,5 + 696,5 = 427,5) measures 427,5¢[5] which is too large to be considered a major third. Figure 1.4 gives a summary of the temperament by showing the distance of every major third and perfect fifth from just intonation. To sum up, meantone temperament privileges certain keys with pure thirds at the expense of others that become unplayable.

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[3] Barbour, *Tuning and Temperament*, 26.
[4] Aron's ¼-comma meantone temperament is only one of the multiple variants of meantone temperament. For a thorough study of similar temperaments, see: Owen Jorgensen, *Tuning: Containing the Perfection of Eighteenth-Century Temperament, the Lost Art of Nineteenth-Century Temperament, and the Science of Equal Temperament, Complete with Instructions for Aural and Electronic Tuning* (East Lansing: Michigan State University Press, 1991).
[5] Modulo 1200.

Figure 1.3 $^{1}/_{4}$-comma meantone temperament

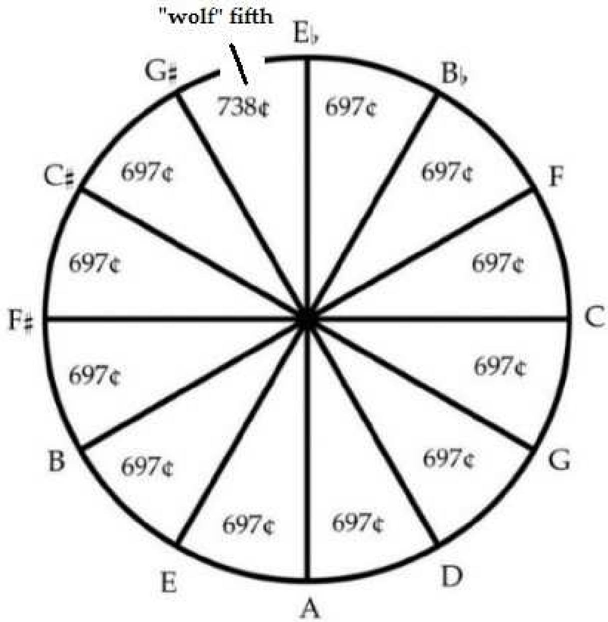


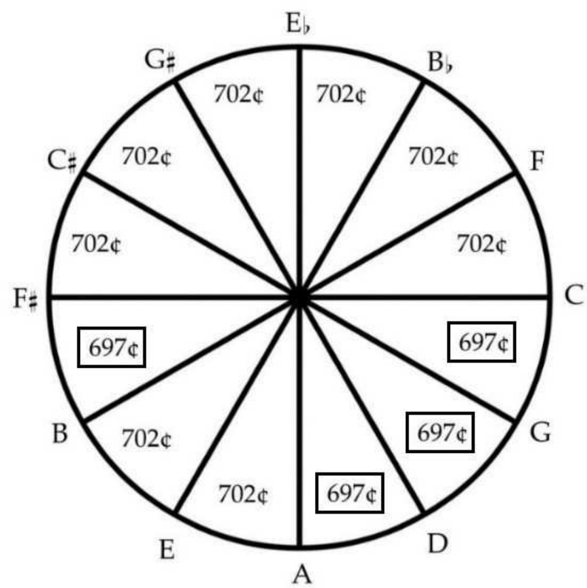
Figure 1.4 ¼-comma meantone temperament - ¢ wide from just intonation

	Eb	Bb	F	C	G	D	A	E	B	F#	C#	G#
Major Thirds	0	0	0	0	0	0	0	0	41.5	41.5	41.5	41.5
Perfect Fifths	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	36

b) Circulating temperaments

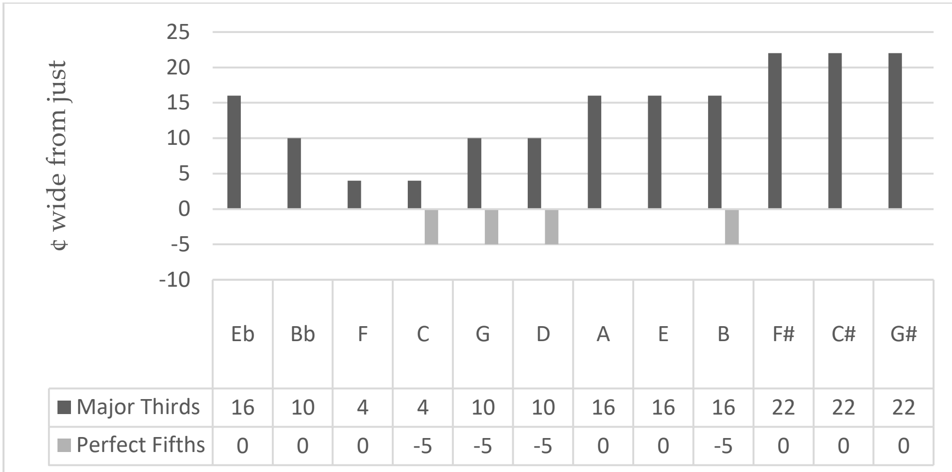
Systems that remediate this problem by allowing for playing in every key are called well, unequal, or circulating temperaments. Figure 1.5 displays a 1691 temperament published by Werckmeister, in which four fifths are tempered by ¼ of a Pythagorean comma[6] while the rest remain pure.[7] As shown in Figure 1.6, spreading the tempered fifths throughout the circle allows for a playable major third in every key. The uneven distribution of the quarter commas around the circle of fifths creates audible differences in the size of major thirds and of other imperfect consonances: compare the third C-E, which is very close to just intonation at 390¢, with the third C♯-E♯, whose 408¢ renders the major third very bright, almost dissonant.[8] These audible discrepancies colour each key individually, giving them recognizable personalities and characteristics. This feature has been erased with the rise of modern equal temperament, where any transposition of an interval has the same size.

Figure 1.5 Circulating temperament – Werckmeister I (1691)



[6] The Pythagorean comma, which measures roughly 23.46¢, is the difference between twelve stacked perfect fifths and seven octaves. It is very close in size to the 21.51¢ Syntonic comma, which is the difference between the major third obtained by stacking four perfect fifths and a pure major third.
[7] Pierre-Yves Asselin, *Musique et temperament* (Paris: Éditions Jobert, 2000), 94.
[8] Werckmeister's 1691 temperament favours traditionally "purer" keys such as F, C, and G major, and is therefore representative of 17th-century tuning practices. It is, however, only one of the countless possible versions of circulating temperament. See Jorgensen (1991) for a thorough discussion of 17th-century tuning possibilities.

Figure 1.6 Werckmeister I - ¢ wide from just intonation



A tuner may adjust the fifths of a temperament as desired, in any order. This flexibility gives rise to an infinite variety of possible unequal tuning systems. Owen Jorgensen's wide-range book on historical temperaments is a testament to this variety.[9] Moreover, even the most exhaustive list of published tuning systems would not wholly take into account the myriad of available options. In fact, it is likely that composers and tuners took published systems of temperaments as a starting point, subsequently adjusting them to their own taste[10].

Along with the rise of unequal temperament, ideas about equal temperament were also being shared. Both systems existed concurrently, and different authors endorse one or the other of them. Because 19th-century temperaments allowed for playing in every key, it is often assumed that they were equal, as today. For this reason, academic literature on 19th-century unequal tuning systems is quite scarce. Even J. Murray Barbour's

[9] Owen Jorgensen, *Tuning: Containing the Perfection of Eighteenth-Century Temperament, the Lost Art of Nineteenth-Century Temperament, and the Science of Equal Temperament, Complete with Instructions for Aural and Electronic Tuning* (East Lansing: Michigan State University Press, 1991).
[10] Jorgensen, *Tuning*, 5.

comprehensive survey on temperament skims over this era,[11] while Mark Lindley does not discuss instances of unequal temperaments after the beginning of the 19th century.[12]

Historical evidence, however, suggests that pianos were still tuned unequally late into the century. It seems that while equal temperament was theoretically understood, attempts to tune it on a keyboard fell short of today's precision. An 1885 study by Alexander Ellis shows that temperaments in use at the time were sufficiently unequal to induce different key colours. In his translation of Helmholtz's *On the sensations of tone as a physiological basis for the theory of music*, Ellis analyses the work of seven famous tuners to prove that exact equal temperament had not yet been attained on the keyboard. The results of his study are reproduced in Figure 1.7, showing how temperaments 2 through 8 are often inaccurate by several cents compared to equal temperament, shown in the first row of the table. Ellis writes that

> *"These examples must probably be considered the best that pianoforte tuning by ear can accomplish… it this is the work of a clever tuner in constant practice for many hours daily for many years, in tuning one kind of temperament only, what are we to expect from those who attempt to realise new intervals?"* [13]

The discrepancy between some notes and their equal-tempered equivalent (row 1) is very small. Most scholars in musical perception agree, however, that the threshold for

[11] Barbour, *Tuning and Temperament.*
[12] Mark Lindley, "Temperaments," in *Grove Music Online*, Oxford Music Online, http://www.oxfordmusiconline.com/subscriber/article/grove/music/27643 (accessed May 26, 2009).
[13] Alexander J. Ellis, "Additions by the Translator," in Helmholtz, *On the Sensation of Tone*, 485.

recognizing changes in intonations is 5 to 6 cents.[14] Moreover, some these tunings would not have passed modern Registered Piano Technician tuning exams, since the threshold of tolerance for error is ±3¢.

Figure 1.7 eight 'equal' temperaments measured in ¢ (From Ellis' analyses)[15]

C	C♯	D	D♯	E	F	F♯	G	G♯	A	A♯	B	C
0	100	200	300	400	500	600	700	800	900	1000	1100	1200
0	96	197	297	392	498	590	700	797	894	990	1089	1201
0	99	200	305	411	497	602	707	805	902	1008	1102	1206
0	100	200	300	395	502	599	702	800	897	999	1100	1200
0	101	199	299	399	500	598	696	800	899	999	1100	1200
0	101	192	297	399	502	601	702	806	898	1005	1099	1201
0	98	200	298	396	498	599	702	800	898	999	1099	1199
0	100	200	300	399	499	600	700	800	900	1001	1099	1200

19th-century treatises and tuning occasionally display the tension that existed between equal and unequal temperaments. *The Tuner's Guide,* an anonymous book first published in 1840 in England, exemplifies the tension between tuning systems. The author states that "a good tuner can accommodate the temperament to the taste of those who play in particular keys, which they wish to be more perfect than the rest,"[16] clearly advocating for the use of unequal temperaments. Earlier on, however, we read:

> *The system which we have explained is that of equal temperament; it is that generally adopted throughout Europe. Various systems of unequal temperament have been proposed,*

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[14] Beatus Dominik Loeffler, "Instrument Timbres and Pitch Estimation in Polyphonic Music." (MA thesis, Georgia Institute of Technology, 2006), 6.

[15] Ellis, "Additions by the Translator," 485.

[16] *The Tuner's Guide: Containing a Complete Treatise on Tuning the Piano-Forte, Organ, Melodeon, and Seraphine: Together with a Specification of Defects and their Remedies* (Boston: O. Ditson; New York: Gould & Berry, 1852), 40.

> *[…] in which some of the major thirds or fifths are to be tuned perfect, others modified in various degrees. These have all one capital defect, which is, that while some few keys are tuned more harmoniously than by the system of equal temperament, all the remaining keys are much less perfect; so that it becomes impossible to modulate into them without disgusting the ear.*[17]

The author who wrote this has a bias towards equal temperament, while apparently disliking the bright sound that unequal temperament lends to certain keys. Jorgensen explains that the *Guide* was plagiarized from different sources, creating contradictions within itself.[18] His realization of the book's temperaments show that they were unequal, indicating that while equal temperament was discussed in early 19th-century England, consistent equal temperament by today's standards had yet to be attained.

French tuning manuals followed the same trend. In *An Essay on Temperament* (1832), Jean Jousse "gave one the freedom of choice as to whether one desired to pursue equal temperament or well temperament,"[19] also recognizing that both practices were in use during the first part of the nineteenth-century. At the end of a 1797 piano method, Pleyel and Dussek provide their reader with two sets of instructions for tuning unequal temperaments.[20] This historical evidence indicates equal temperament by modern

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[17] Ibid., 16.
[18] Jorgensen, *Tuning,* 430.
[19] Cited in Jorgensen, *Tuning*, 418.
[20] Ignaz Pleyel, Ludwig Wenzel Lachnith, Louis Félix Despréaux, F. P. Ricci, Ducray-Duminil, Jean François Tapray, Anton Bemetzrieder, et al. *Piano forte: méthodes et leçons pour piano-forte ou clavecin* (Courlay, France: Editions J.M. Fuzeau, 2001).

standards, while understood theoretically, was likely not attainable at the time Chopin was composing. In the next section, I will address the reasons for this by delving into the difficulties of tuning consistent twelve-tone equal temperament.

1.2 Tuning a keyboard: the practical and theoretical challenges

Exact 12-tone equal temperament is a fairly simple theoretical concept. In order to get rid of the Pythagorean comma while keeping all fifths equal, one needs to spread it equally across the circle of fifths. This can be achieved by lowering each fifth by one twelfth of the comma, or approximately 1.8¢. This tiny change allows the tempered fifths to be very close to their pure equivalent. This causes major thirds to be relatively close to their Pythagorean equivalents, and therefore considerably wider than pure. Since each fifth is equally altered, every interval has the same size as all its transpositions. In Europe, the first tuning instructions for equal temperament were given in Giovanni Maria Lanfranco's 1533 *Scintille de musica.*[21] Several other theoretical descriptions or tuning directions for equal temperament have been given by authors such as Mersenne, Werckmeister, Hummel, amd Ellis[22]. Several theorists and musicians have also advocated for this tuning system. For instance, in his first two treatises, *Traité de l'harmonie* (1722) and *Nouveau système* (1726), Rameau discussed the advantages of unequal temperament's expressive qualities. Starting with the 1737 publication of *Génération Harmonique,* however, Rameau became an ardent defender of equal temperament, calling upon nature

[21] Barbour, *Tuning and Temperament*, 45.
[22] Martin B. Tittle offers a comprehensive overview of publications on different tuning systems from 540 B.C. to 1851. Martin B. Tittle, *A Performer's Guide Through Historical Keyboard Tunings* (Ann Arbor: Anderson Press, 1987).

as a justification to privilege purer fifths rather than thirds.[23] Despite the quantity of historical treatises and debates, scholars generally agree that consistent equal temperament was not truly attained until the early 20th century, around the time of the publication of William White's *Modern Piano Tuning and Allied Arts.*[24] This discrepancy between theory and practice probably existed because tuning manuals often did not give precise instructions for tuning equal temperament, which is in fact quite difficult to tune correctly. The authors of tuning manuals usually provided no more than a bearing plan accompanied with vague steps to attain the desired tuning. In the following section, I will discuss the instructions given in 19th-century tuning manuals to show how they would have resulted in unequal temperament, and explain why White's method was the first to guarantee consistent equal temperament.

Pierre-Yves Asselin writes that in historical French temperaments, the exact amount by which the fifths should be tempered is rarely precise.[25] This is the case in *Méthode pour le pianoforte,* published in 1797 by Pleyel and Dussek. Ignace Pleyel, father of Camille Pleyel, is also founder of the piano manufacturing company so appreciated by Chopin. At the end of the method, the authors present two ways to tune the pianoforte and harpsichord. The first one, "invented by Mr. Kirnberger," is praised as being "preferable to all the ones that existed before, because it is only achieved by tuning just

[23] Rita Steblin offers a detailed account of Rameau's reasoning, and of the subsequent debates they caused with Rousseau and the other Encyclopédistes. Rita Steblin, *A History of Key Characteristics in the Eighteenth and Early Nineteenth Centuries* (Rochester, NY: University of Rochester Press, 2002), Chapter 5.
[24] White, William Braid. *Modern Piano Tuning and Allied Arts: Including Principles and Practice of Piano Tuning, Regulation of Piano Action, Repair of the Piano, Elementary Principles of Player-Piano Pneumatics, General Construction of Player Mechanisms, and Repair of Player Mechanism* (New York: E.L. Bill, 1917).
[25] Asselin, *Musique et tempérament,* 108.

fifths and a single major third."[26] The tuner is to tune just fifths starting on D♭ up to D, tune the third C-E, then tune the E-B and B-F♯ fifths. The remaining note, A, is to be tempered to fit satisfactorily between D and E. While the bearing plan presents the order in which notes should be tuned, some specifications about the exact size of the intervals are missing. Pleyel and Dussek are probably describing Kirnberger III, a temperament in which 8 fifths should be tuned pure, while the last 4 should be tempered by ¼ of a Pythagorean comma,[27] but this is not specified by the authors. They explain that the seven fifths between D♭ and D should be just, but do not specify the size of the others. Moreover, no instructions are given on how to tune the major third C-E, which should be pure in Kirnberger III. Therefore, while the temperament might have been inspired by Kirnberger's, applying the instructions could result in several variations in temperament.

Pleyel and Dussek's second method, "the best there is for the most perfect tuning," is also of little help in communicating its intended result.[28] While the instructions indicate that some fifths should be tuned "strong" or "weak," no indication is provided regarding the amount by which the interval should be tempered. Figures 1.8 and 1.9 show two possible realizations of this temperament. In the first, strong and weak fifths are tuned one cent higher or lower than just. The second realization features strong fifths half a cent above just, and weak fifths tempered by four cents. These subtle discrepancies have audible repercussions on the size of major thirds: they range from 406 to 412¢ in the first realization, and from 400 to 410¢ in the second. Tempering the fifths by larger amounts,

[26] Pleyel and Dussek, *Méthode de Piano,* 73.
[27] Jorgensen, *Tuning,* 319.
[28] Pleyel and Dussek, *Méthode de Piano,* 74.

for instance $^{1}/_{3}$ or $^{1}/_{4}$ of a comma, would affect the shape of the temperament in an even more significant way. These examples show that the instructions provided by Pleyel and Dussek leave a lot to the tuner's discretion.

Figure 1.8 Pleyel and Dussek's temperament, first realization

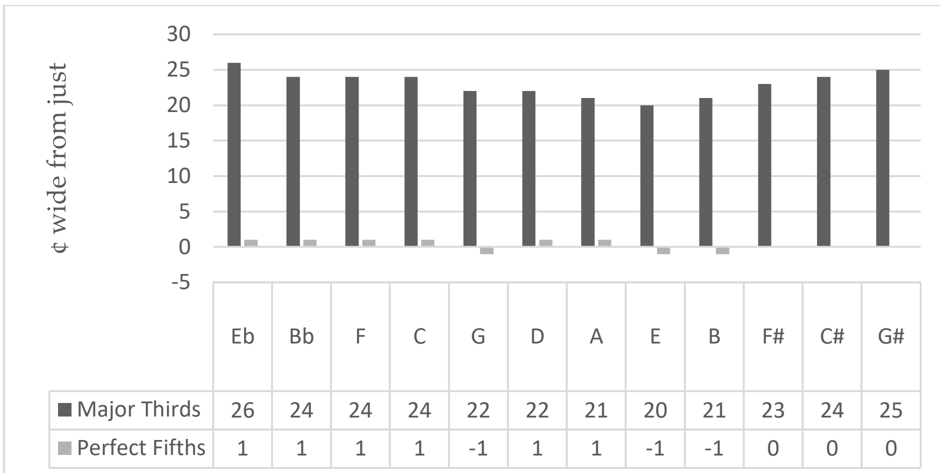
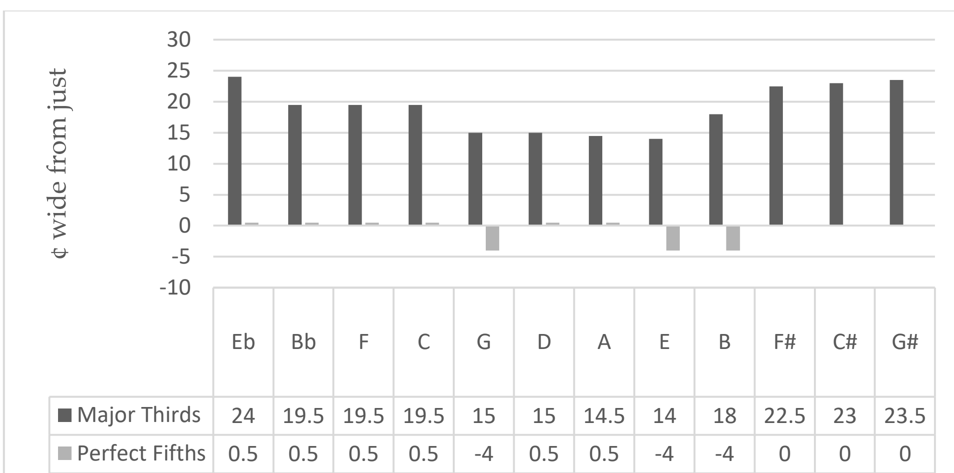


Figure 1.9 Pleyel and Dussek's temperament, second realization



During Chopin's active years as a pianist and composer, Johann Nepomuk Hummel published a treatise in which he gives instructions for equal temperament. He instructs the tuner to tune each fifth "a notch lower" than pure.[29] While this corresponds to the theoretical explanation of equal temperament, in which each fifth is tempered by $^{1}/_{12}$ of the Pythagorean comma, there is no guarantee that a tuner following these instructions would be able to temper every fifth by the exact same amount. The resulting temperament might be an approximation of equal temperament, or some form of circulating temperament, but it is unlikely that someone could attain exact equal temperament following Hummel's instructions. A more precise method would be required.

As Alexander Ellis has shown, "the best piano tuners of his time" were still unable to tune exact equal temperament.[30] He attributes this lack of precision to the difficulty of altering an interval by two cents without attending to the beats, and suggests his own equal-beating method as an alternative. His "Rule for tuning in equal temperament at any pitch between c′ 256 and c′ 270" is shown in Figure 1.10. Ellis instructs the tuner to make the fifths narrower and the fourths larger than perfect.[31] In Figure 1.10, the numbers between the names of the notes represent the number of beats per 10 seconds, and the tuner should carefully attend to them to reach an approximation of equal temperament. In Ellis's rule, all fifths are shown to beat at 10 beats per 10 seconds, and all fourths at 6 beats per 10 seconds. Beat speeds, however, increase with pitch – having all fifths beating exactly the same way would not result in perfectly equal temperament. Ellis

[29] Johann Nepomuk Hummel, *Méthode complète théorique et pratique pour le piano-forte* (Genève: Minkoff Reprint, 1981), 467. My translation. "Aucune quinte ne doit être accordée parfaitement juste… il faut qu'elle soit une idée plus basse."
[30] Alexander J. Ellis, "Additions by the Translator," in Helmholtz, *On the Sensation of Tone*, 485.
[31] Ibid., 489.

acknowledges that his method is approximate: "But for the purposes of the rule all the beats of Fifths are supposed to be the same throughout the tuning octave […] The errors will be found to correct each other, and in no case to exceed the permissible limits."[32]

Owen Jorgensen explains that to tune a theoretically correct temperament, "the tuner must refer to a chart of beat speeds for that particular temperament […] Cross-checking of beat speeds of all the tempered intervals is then applied to determine if any errors were made."[33] The first chart of the sort for equal temperament was published in 1917 by William Braid White. As shown in Figure 1.11, his table shows beat rates, rounded to the first decimal, for consonant intervals above each note of the scale. White acknowledges the difficulty of aurally recognizing these different beat speeds, but encourages willing tuners to try anyway, stating that "it is […] the only method that can be used in practical work, and the method, therefore, that we must develop to the highest possible degree of excellence."[34] White encourages the tuner to carefully check the beating of all tempered intervals, for instance observing carefully the rise in beat-rate of the ascending thirds and sixths.

To sum up, historical evidence shows that true equal temperament could not be attained in practice until the early 20th century. Thus, Chopin likely composed on a piano that was unequally tempered. In the following section, I discuss the literature that

[32] Ibid.
[33] Owen Jorgensen, *The Equal-Beating Temperaments: A Handbook for Tuning Harpsichords and Fortepianos, with Tuning Techniques and Tables of Fifteen Historical Temperaments* (Raleigh [N.C.]: Sunbury Press, 1981), 8.
[34] White, *Modern Piano Tuning*, 105.

exists on the influence of such temperaments on musical composition, and describe the work that has already been done on Chopin and temperament.

Figure 1.10 Ellis' equal-beating *Rule for tuning equal temperament at any pitch between c'256 and c'270*

c' 10 ***g*** 6 ***d'*** 10 ***a*** 6 ***e'*** 10 ***b*** 10 ***f#*** 6 ***c'#*** 10 ***g#*** 6 ***d'#*** 10 ***a#*** 10 ***f***

Figure 1.11 White's beat-rate chart[35]

TABLE III. APPROXIMATE NUMBER OF BEATS PER SECOND WITH ASCENDING INTERVALS FROM C_2 TO C_4 IN EQUAL TEMPERAMENT

Note	Frequency	Minor Third	Major Third	Perfect Fourth	Perfect Fifth	Minor Sixth	Major Sixth
Pitch Ratio Coinciding Partials		5:6 6:5	4:5 5:4	3:4 4:3	2:3 3:2	5:8 8:5	3:5 5:3
C_2	129.3	7.0	5.1	.60	.45	8.5	6.0
C♯—D♭	137.0	7.5	5.5	.60	.50	9.0	6.5
D	145.1	8.	6.	.65	.50	9.5	7.0
D♯—E♭	153.7	8.5	6.1	.70	.55	10.0	7.0
E	162.9	9.	6.5	.75	.55	10.5	7.5
F	172.6	9.5	7.	.80	.60	11.0	8.0
F♯—G♭	182.8	10.	7.5	.85	.65	11.5	8.5
G	193.7	10.5	8.	.90	.65	12.5	9.0
G♯—A♭	205.2	11.	8.5	.95	.70	13.0	9.5
A	217.5	12.	9.	1.00	.75	14.0	10.0
A♯—B♭	230.4	12.5	9.5	1.00	.80	14.5	10.5
B	244.1	13.	10.	1.10	.85	15.5	11.0
C_3	258.6	14.	10.5	1.20	.90	16.5	12.0
C♯—D♭	274.0	15.	11.	1.25	.95	17.5	12.5
D	290.2	16.5	11.5	1.30	1.00	18.5	13.0
D♯—E♭	307.5	17.5	12.5	1.40	1.10	19.5	14.0
E	325.9	18.	13.	1.50	1.20	20.5	...
F	345.3	19.	14.	1.60	1.20	...	...
F♯—G♭	365.7	21.	14.5	1.70	...	...	...
G	387.5	21.	15.	1.80	...	...	...
G♯—A♭	410.5	22.	16.5	...	...	...	...
A	435.0	23.5	...	...	...	...	...
A♯—B♭	460.8	...	...	...	...	...	...
B	488.2	...	...	...	...	...	...
C_4	517.3	...	...	...	...	...	...

1.3 Literature review

Meantone temperament, which sacrifices some keys to privilege others, has an obvious impact on musical compositions: composers have no choice but to avoid out-of-

[35] William Braid White, *Modern Piano Tuning and Allied Arts: Including Principles and Practice of Piano Tuning, Regulation of Piano Action, Repair of the Piano, Elementary Principles of Player-Piano Pneumatics, General Construction of Player Mechanisms, and Repair of Player Mechanism,* New York: E.L. Bill (1917) : p. 87.

tune sonorities. Circulating temperaments, however, allow for playing in every key. Distinguishable differences still exist between tonalities, and these discrepancies might have been taken into account by composers.

The influence of such temperaments on musical performance and composition has been sporadically studied since the 1970s. These studies on tuning can be roughly separated into two branches. The first type of study observes to what extent internal evidence, or musical content, may reveal a composer's tuning of choice. The second compares the effect of different historical temperaments on repertoire that is more commonly played on equally-tempered modern pianos. These two approaches have the same end goal, which is to determine the type of temperament for which a particular piece or repertoire may have been intended. The difference between the two approaches lies in the means taken to reach a conclusion: the first type of study takes the music as a starting point to make conclusions about temperament, while the second begins with pre-determined temperaments to draw conclusions on the music.

Scholars using the first approach have seemed to have a particular predilection for Bach's *Well-Tempered Clavier*, in which each major and minor key is equally represented. Speculations about which temperament may have been intended for the two books have generated several studies and heated discussions. In 1976, John Barnes conducted an intervallic analysis of the 24 major-key preludes, weighing and rating all the harmonic major thirds to uncover what may have been Bach's temperament of choice.[36] To

[36] John Barnes, "Bach's Keyboard Temperament: Interval Evidence from the Well-Tempered Clavier", *Early Music* 7/2 (1979): 236–249.

complement this study, Steven Cannon used a refined version of Barnes' method to analyse the minor preludes.[37] His results suggest that Bach's contrasting treatment of major thirds in major and minor keys may indicate that he conceived the sound and affect of both modes in opposite ways. Other studies on the *Well-Tempered Clavier*'s temperament have been based on unusual, and somewhat strange, features of the work. In a recent pair of polemical articles, Bradley Lehman posits that the decoration on the first page of the *WTC* manuscript is in fact a series of tuning instructions.[38] This claim has prompted much discussion and rebuttals from the temperament community. Tuning scholar Mark Lindley entered into a published feud with Lehman, while Ponsford et. al. have also expressed reservations and suggested corrections to Lehman's statements.[39] There also exists an online debate on the topic, where both amateur and professional musicians discuss tuning systems and their possible relationship to Bach's music. Continuing in this vein, we can cite some work by Herbert A. Kellner and Christian Meyer, who claim to have reconstituted Bach's tuning system, and who describe how its characteristic numbers, linked to the baroque number-alphabet, contribute to the Well-Tempered Clavier's unity.[40]

Other authors have focused on the relationship between temperaments and the works of other European composers. In his 1996 master's thesis, Fabrice Contri discussed

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[37] Steven Cannon, "Deducing Temperament from Analysis of the *Well-Tempered Clavier:* Contradictory or Complementary Evidence?" Unpublished paper, McGill University, 2007.
[38] Bradley Lehman, "Bach's Extraordinary Temperament: Our Rosetta Stone: 1," *Early Music* 33/1 (2005): 3–23; "Bach's Extraordinary Temperament: Our Rosetta Stone: 2," *Early Music* 33/2 (2005): 211–231.
[39] David Ponsford et al., "Tempering Bach's Temperament," *Early Music* 33/3 (2005): 545–548.
[40] Herbert Anton Kellner and Christian Meyer, "Le temperament inégal de Werckmeister/Bach et l'alphabet numérique de Henk Dieben," *Revue de musicologie* 80/2 (1992): 283–298; "Das woltemperierte Clavier: Implications de l'accord inégal pour l'oeuvre et son autographe," *Revue de Musicologie* 71/1/2 (1985): 143–157.

the possible influence of French unequal temperaments in the keyboard works of Couperin.[41] John Meffen addressed English music, discussing how Purcell's keyboard works tend to remain within the bounds of meantone temperament by generally avoiding enharmonic equivalents of E♭ and G♯ such as D♯ and A♭.[42]

These studies relate to 17th and 18th-century temperaments, while studies on 19th-century keyboard tunings remain rare. As mentioned earlier, these tuning systems are often thought of as equal, but historical evidence indicates that true equal temperament had yet to be attained in the first half of the nineteenth century. The majority of studies on the issue address Chopin's music and belong to the second branch discussed above, in which an author takes a particular temperament as a point of departure for studying music. In a 2005 article, Jonathan Bellman offers an enlightening historical performance analysis by devising his own temperament, based on Jean Jousse's 1832 tuning instructions, and by discussing the effect it has on excerpts of Chopin's music.[43] Two particularly comprehensive doctoral studies also approach the issue. In his 2001 dissertation, Willis G. Miller discusses the influence of eight unequal temperaments on Chopin's mazurkas.[44] He examines the impact of different tuning systems on the sound of pieces by considering large-scale tonal areas, harmonic progressions, and melody. He ties his discussion of temperament to ideas on key characteristics that were circulating in

[41] Fabrice Contri, "Les tempéraments français inégaux à travers l'oeuvre de clavecin de François Couperin" (M.A. Thesis, Université de Paris-Sorbonne, 1996).
[42] John Meffen, "A Question of Temperament: Purcell and Croft," *The Musical Times* 119/1624 (1978): 504–506.
[43] Jonathan Bellman, "Toward a Well-Tempered Chopin," In *Chopin in Performance: History, Theory, Practice*, edited by Artur Szklener, 25–38, Warsaw: Narodowny Instytut Fryderyka Chopina, 2005.
[44] Willis G. Miller III, "The Effects of Unequal Temperament on Chopin's Mazurkas" (PhD diss., University of Houston, 2001).

Europe before and during Chopin's lifetime, and thoroughly discusses the inherent musical qualities and features of the eight temperaments. His main goal seems to be the choice of a temperament suited for a modern, historically-informed performance of Chopin's mazurkas, in order to "resurrect some of Chopin's original intents."[45] For Miller, locating internal musical evidence that Chopin may have been influenced by temperament remains a secondary endeavour. He admits, however, that tuning surely had some influence on the compositional process of some romantic composers. For instance, he claims that "Liszt, who spent much time improvising and composing a work at the keyboard itself, may have penned compositions that would have been affected by whatever temperament in which the instrument may have been during that time.[46]" Since Chopin often played his compositions in the intimate setting of the salon, rather than giving exuberant performances in large halls like Liszt, I argue that Chopin was even more influenced by the subtle nuances and internal discrepancies of unequal temperaments. Miller's musings lead him to question whether changes in temperament led to musical innovations, or if musical innovations gave rise to developments in temperament.

In her 2012 doctoral dissertation, Angeline Van Evera discusses how Schubert may have used the different colours created by unequal temperament as an expressive tool.[47] By calculating chord beats, she devises an analytical method to calculate *Temperaturfarben,* the "timbral colors created through the uniquely sized intervals in well temperament."

[45] Miller, *The Effects of Unequal Temperament,* 106-107.
[46] Ibid, 107.
[47] Angeline Ashley Smith Van Evera, "Rediscovering Forgotten Meanings in Schubert's Song Cycles: Towards an Understanding of Well Temperament as an Expressive Device in the Nineteenth Century Lied" (PhD diss., the Catholic University of America, 2012).

She argues that "Schubert exploited the colors of keys and chords to create musico-literary tools," and discusses how this takes place some of Schubert's best-known song cycles, *Winterreise*, *Die Schöne Müllerin*, and *Schwanengesang*. [48]

Apart from Bellman, Miller, and Van Evera, the only other author who addressed the issue of 19th-century tuning is the renowned Chopin scholar Jean-Jacques Eigeldinger. A passing reference to tuning is made in a 1989 article, in which he argues that a melodic cell present throughout the *24 Préludes* (op. 28) reflects the structure of Chopin's temperament.[49] A footnote promises a follow-up study on this rather mysterious claim, but it remains to this day Eigeldinger's only mention of Chopin's temperament.

There also exist some recordings of Chopin's music on pianos tuned in historical temperaments. Such projects aim to recreate the sound of Chopin's pianos, in the hopes of bringing out characteristics of his music that have been erased or attenuated by equal temperament. In a 2000 lecture-recital at the Philadelphia Museum of Art, Eben Goresko discussed how the music of Bach and Chopin sounds different in meantone, unequal, and equal temperaments.[50] Drawing an analogy between a piece of early music played on equal temperament and a painting seen in black and white, Goresko wishes to show how unequal temperaments can enhance specific intervals, characterize some keys, and cause mood changes within a piece. For instance, he shows how the contracted, narrow minor thirds in the opening of the funeral-march movement of Chopin's second piano sonata

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48 Ibid., Introduction.

49 Jean-Jacques Eigeldinger, "Les Vingt-quatre Préludes op. 28 de Chopin : Genre, Structure, Signification,"Revue de Musicologie 75/2 (1989): 217.

50 Eben Goresko, "Piano Tuner Shows Classical Repertoire Performed in Historical Tunings, " Filmed [2000], YouTube Video, 19:27, Posted [January 2011], https://www.youtube.com/watch?v=TBt6APk21tU.

contrast with the bright, D♭-major middle section. This key, notes Goresko, is often paired with a *pianissimo* dynamic to alter the startling sound of the wide D♭-major chord.

Pianists Michele d'Ambrosio and Adolfo Barabino gave concerts of Chopin's works on a 120-year old piano tuned unequally.[51] While there are no professional recordings available, some of the performances are accessible on YouTube; Ambrosio's interpretation of the *24 Préludes* is especially well executed. Pianist Enid Katahn also recorded Chopin's *Fantaisie-Impromptu* Op. 66 on an unequally tempered piano. This performance of the piece is a track on *Six Degrees of Tonality*, a CD in which Katahn performs pieces by Scarlatti, Haydn, Mozart, Beethoven, Chopin, and Grieg on different temperaments that may have been in use during these composers' lifetimes.[52] Finally, the accompanying website to Miller's dissertation is worth a mention. Each musical example provided by Miller is available in nine temperaments, allowing for focused, attentive listening for their differences.[53]

With the above literature review, I hope to have shown that while 19th-century unequal temperament remains an understudied area, some scholars have made extremely valuable contributions to the field, especially in relationship to Chopin's and Schubert's music. The abundance of Web-based discussions and debates on the topic show that it is

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[51] Latribe, "Chopin 24 Preludes in Unequal Temperament PART 1," YouTube Video, 15:24, Posted [December 2010], https://www.youtube.com/watch?v=qdsFLIo9l88; "Chopin 24 Preludes in Unequal Temperament PART 2," YouTube Video, 14:04, Posted [December 2010], https://www.youtube.com/watch?v=A34K-fj5nHs; "Chopin 24 Preludes in Unequal Temperament PART 3," YouTube Video, 15:29, Posted [December 2010], https://www.youtube.com/watch?v=XpqrynlohR4; , "Adolfo Barabino Chopin in Unequal Temperament (better sound recording)," YouTube Video, 4:16, Posted [March 2010], https://www.youtube.com/watch?v=9zxNrQuxfNY.

[52] Enid Kahtan, *Six Degrees of Tonality*, © 2001 by Precision Piano Works, Compact Disc.

[53] Willis G. Miller, "The Effects of Non-Equal Temperament on Chopin's Mazurkas," accessed March 10 2016, www.unequaltemperament.com.

still a pressing question in the musical world, both for amateurs and professionals. Studies on Chopin and temperament have focused on the way temperament affects the sound of his music, and on how to choose an appropriate tuning system to enhance key colours and other musical aspects. By building on these studies, this thesis aims to examine whether internal evidence from Chopin's music can help in deducing how temperament affected his compositional process.

1.4 Five temperaments available in 19th-century Europe

Hundreds of possibilities of unequal temperaments may have been available in 19th-century France, and five of them will be presented in the following section. I do not claim that any of these temperaments were definitely used by Chopin. Jorgensen insightfully points out that if some temperaments were published, it is because they probably introduced something new that was not in practice at the time.[54] Nonetheless, I believe that the five temperaments I have narrowed down give a useful generalization that covers the main tuning possibilities of the time. For each temperament, I provide a table that shows the size of fifths and thirds in comparison to just intonation. There is also a line representing equal temperament. These indications are meant to guide the reader in noticing the changes between the interval sizes within these historical temperaments, as well as the variations between these older temperaments and modern equal temperament.

[54] Owen Jorgensen, *Tuning the Historical Temperaments by Ear: A Manual of Eighty-Nine Methods for Tunings Fifty-One Scales on the Harpsichord, Piano, and Other Keyboard Instruments* (Marquette: Northern Michigan University Press, 1977), 4.

a) Pleyel and Dussek's temperament (1797)

The first temperament I present is contained in Pleyel and Dussek's *Méthode pour le pianoforte*. I have already discussed above how the vague instructions provided by the two authors could result in several temperaments that could enhance the differentiation between keys in varying degrees. The bearing plan was published at the very end of the 18th-century, and may have been a bit out of fashion during Chopin's career in Paris; the author Ignace Pleyel, however, is the father of Camille Pleyel, of Pleyel pianos. Chopin's preference for these pianos, their subtle, soft sound and responsive touch, has been widely documented since the mid-19th century.[55] This temperament could give an indication of how Pleyel pianos were tuned, as well as a hint of how musicians might have tuned their own instruments in the early 19th century.

b) Jean Jousse's temperament (1832)

Jean Jousse's temperament, published in 1832 in *An Essay on Temperament*, is represented in Figure 1.13.[56] The largest third is B-D# is almost 22¢ larger than pure. The temperament follows the traditional shape of unequal temperaments, where the tonalities on white keys render chords that sound closer to pure, reserving the brighter sound of larger major thirds for tonalities with more accidentals. As I mentioned above, Jousse advocated for the use of both equal and unequal temperament; knowing that his *Essay* was published in France during Chopin's lifetime, when piano tuning technologies did not allow for consistent equal temperament, it is likely that his instructions to tune equal

[55] Jean-Jacques Eigeldinger, "Chopin and Pleyel," *Early Music* 29/3 (2001): 388–396.
[56] Based on Jorgensen, *Tuning*, 420.

temperament remained purely theoretical. Chopin plausibly composed and played on pianos tuned in a similar way.

This opinion is shared by Bellman, who suggests that Chopin might have indeed preferred an unequal temperament that followed traditional key characteristics. Bellman quotes an excerpt from Chopin's late correspondence in which the composer mourns the death of Ennike, deploring that no one in the world can now tune a piano to his taste.[57] Bellman infers that Chopin's complaint suggests a preference for a temperament that was out of fashion at the end of his life. He was inspired by Jousse's bearing plan to construct a temperament that he feels represents well Chopin's taste, and that would be well-suited to performances of his music.

c) Johann Nepomuk Hummel's temperament (1832)

Eigeldinger writes that Chopin appreciated Hummel's[58] 1832 *Méthode Complète Théorique et Pratique pour le Piano Forte*.[59] In his *Méthode*, Hummel presents two bearing plans to tune equal temperament. The second one is reproduced in Figure 1.14. As I mentioned above, Hummel's indications are not sufficient to create exact equal temperament. Nonetheless, it shows that equal temperament was a matter of discussion in the early 19th-century. Published in the same year as Jousse's unequal system, it shows the range of options that was available to tuners of the time.

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[57] "All those with whom I was in most intimate harmony have died and left me. Even Ennike, our best tuner, has gone and drowned himself; and so I have not in the whole world a piano tuned to suit me." *Selected Correspondence of Fryderyk Chopin*, ed. and trans. Arthur Hedley (London: Heinemann, 1962), 330.

[58] Chopin had a special admiration for Hummel's Op. 67 (1815), a set of 24 preludes in all the major and minor keys, which may have served as the model for key ordering Chopin's Op. 28 (1835-39). Both sets are organized in relative pairs following the circle of fifths, so adjacent preludes are closely tonally related.

[59] Jean-Jacques Eigeldinger, "L'achèvement des Préludes op. 28 de Chopin. Documents autographes," *Revue de Musicologie* 75/2 (1989), n. 50.

d) Augustus de Morgan's temperament (1843)

Unequal temperaments traditionally favour keys with roots close to C in the cycle of fifths, such as F and G major. As shown in the temperaments discussed above, the major thirds present in those tonic triads are smaller and closer to just intonation. The temperament of Figure 1.15, designed by Augustus De Morgan in 1843, has the opposite shape. In *The Penny Cyclopaedia*, De Morgan proposes a temperament where

> *"Each fifth in the order of modulation [is] decreased in increments of one forty-eighth ditonic comma through half of the circle of fifths. At this point, each fifth [is] then increased by the same amounts toward the beginning fifth of the circle. The effect of this [is] an unequal temperament containing modulatory variety that contain[s] very even key-colour changes."*[60]

As figure 1.15 shows, the fifths are indeed decreasing regularly by small amounts. Morgan's temperament favours pure fifths in the white keys, reversing the traditional key-colouring. The largest, brightest thirds are now F-A, B♭-D, at 403.6¢. Jorgensen writes that Chopin's music would sound smoother in this temperament[61] - since Chopin often writes in keys with more accidentals, this tuning system would indeed make the major thirds of those keys sound sweeter. Despite Jorgensen's claim, it is difficult to know if De Morgan's temperament was used in practice or remained hypothetical. Remarkably, it is one of the tuning system used by Enid Kahtan in *Six Degrees of Tonality.*

[60] Jorgensen, *Tuning*, 455.
[61] Ibid., 456.

e) Victorian temperament (1885)

Using the data from Ellis's 1885 study of seven piano tunings, Jorgensen assembled a temperament illustrative of the tuning possibilities of the Victorian era.[62] This Representative Victorian temperament is reproduced in Figure 1.16. As expected, the temperament follows the traditional unequal temperament shape. In use late into the 19th-century, these temperaments were generally thought of as equal. Jorgensen explains that "All of the Victorian fifths sounded like equal temperament fifths. No wonder nineteenth-century musicians were deceived into thinking that it was equal temperament."[63] Indeed, the table indicates all fifths in the Representative Victorian temperament are extremely close to 700¢, the size of an equal tempered fifth. The slight tuning errors add up rapidly, creating a noticeable difference in the size of major thirds which vary from 395.7¢ to 401.7¢. Because of this discrepancy, "Victorian temperament is acoustically a form of well temperament. A small amount of key-coloration supporting the characters of the keys still existed."[64] Chopin died well before Ellis conducted his analyses; consequently, he may have used a temperament where key distinctions were similar or more pronounced than in Victorian temperaments.

This temperament is also noteworthy because the Broadwood's 'Best' temperament, one of the Victorian tunings analyzed by Ellis, was "prepared for

[62] Ibid., 538.
[63] Ibid.
[64] Ibid.

examination through the kindness of Mr. A. J. Hipkins, of that house."[65] Hipkins' obituary testifies to his interest for tuning:

> *It was due to him, more perhaps than to anyone else, that the 'diapason normal' was finally adopted in England… As a matter of chronology, it is curious to find that the system of equal temperament was so far from being established in England in 1844, that young Hipkins, who was led to his deep study of the subject through his devotion to Sebastian Bach, was a pioneer of the system among the tuners of the Broadwood firm.*[66]

According to Jorgensen, "Hipkins had a strong working relationship with Chopin, [who] insisted that Hipkins tune his pianos whenever possible."[67] Towards the end of his life, Chopin traveled to London and was taken by the sound of Broadwood pianos. Hipkins was working at the factory and took careful notes of their interactions. His impressions of the musician, chronicled in a book by his daughter, are an invaluable testimony of Chopin's playing and personal taste.

If we consider Ellis's analyses, this excerpt indicates that circulating temperaments were commonly confused with equal temperament. Ellis's analyses date from later in the century, but the relationship of the Victorian temperaments with the Broadwood firm, which produced pianos loved by Chopin, suggests that these tuning systems might be representative of Chopin's taste.

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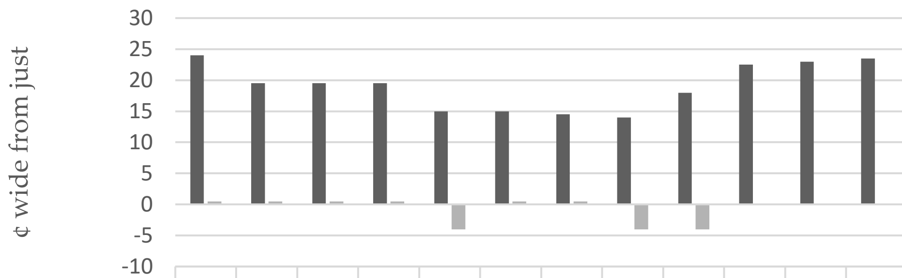
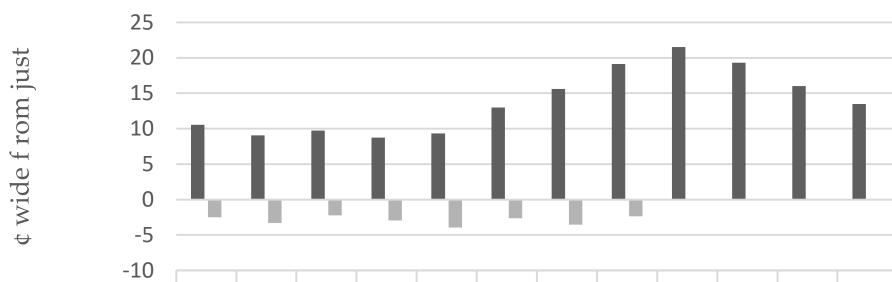
[65] Ellis, "Additions by the translator", 485.
[66] Edith J. Hipkins and Alfred J. Hipkins. *How Chopin Played, From Contemporary Impressions Collected from the Diaries and Note-Books of the Late A.J. Hipkins, F.S.A. With Four Illustrations* (London, J.M. Dent and Sons, 1937), 34.
[67] Jorgensen, *Tuning*, 535.

Figure 1.12 Pleyel and Dussek's temperament (1797)



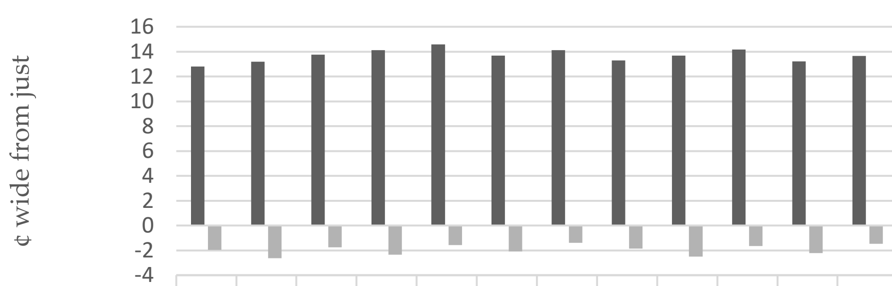
	Eb	Bb	F	C	G	D	A	E	B	F#	C#	G#
Major Thirds	24	19.5	19.5	19.5	15	15	14.5	14	18	22.5	23	23.5
Perfect Fifths	0.5	0.5	0.5	0.5	-4	0.5	0.5	-4	-4	0	0	0

Figure 1.13 Jousse's well-temperament (1832)



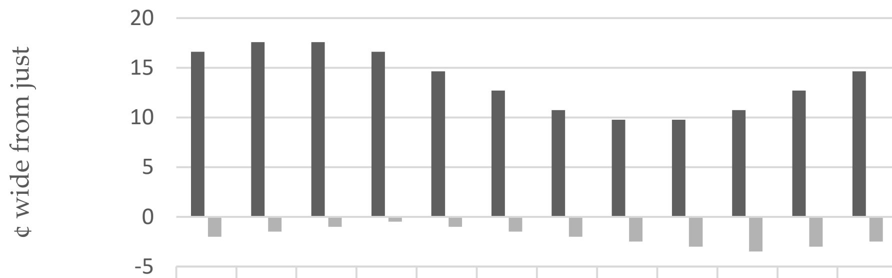
	Eb	Bb	F	C	G	D	A	E	B	F#	C#	G#
Major Thirds	10.53	9.06	9.73	8.74	9.34	12.98	15.62	19.15	21.51	19.33	16.02	13.49
Perfect Fifths	-2.49	-3.32	-2.22	-2.96	-3.95	-2.64	-3.53	-2.36	0	0	0	0

Figure 1.14 Hummel's Twelve-Tone Equal Temperament (1832)



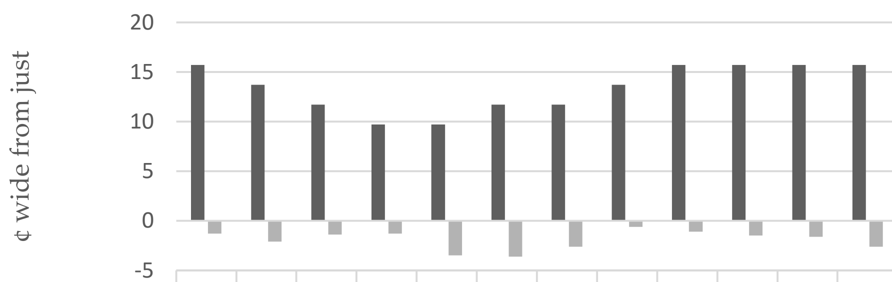
	Eb	Bb	F	C	G	D	A	E	B	F#	C#	G#
Major Thirds	12.8	13.2	13.75	14.11	14.59	13.67	14.11	13.29	13.67	14.18	13.21	13.66
Perfect Fifths	-1.97	-2.63	-1.76	-2.35	-1.57	-2.09	-1.39	-1.86	-2.49	-1.66	-2.21	-1.48

Figure 1.15 Augustus De Morgan's temperament (1843)



	Eb	Bb	F	C	G	D	A	E	B	F#	C#	G#
Major Thirds	16.62	17.59	17.59	16.62	14.66	12.71	10.75	9.78	9.78	10.75	12.71	14.66
Perfect Fifths	-2	-1.5	-1	-0.5	-1	-1.5	-2	-2.5	-3	-3.5	-3	-2.5

Figure 1.16 Jorgensen's Representative Victorian Temperament (1885)



	Eb	Bb	F	C	G	D	A	E	B	F#	C#	G#
Major Thirds	15.7	13.7	11.7	9.7	9.7	11.7	11.7	13.7	15.7	15.7	15.7	15.7
Perfect Fifths	-1.3	-2.1	-1.4	-1.3	-3.5	-3.6	-2.6	-0.6	-1.1	-1.5	-1.6	-2.6

Chapter 2 – Unequal Temperament and Pitch-Related Parameters

In the previous section, I explained why unequal temperaments were still in use during Chopin's lifetime and presented some of the tuning options that may have been available to him. In this chapter, I discuss the characteristics of the unequal temperaments described in the previous chapter, in order to illustrate why and how they could be a factor in musical composition. I begin by examining the impact that unequal-sized semitones have on melody and harmony. Then, I address the influence of temperament on harmony, first discussing chord colour at the local level, then modulation at a larger-scale level. The studied corpus comprises Chopin's complete Preludes, Mazurkas, Waltzes, Etudes, Ballades, Nocturnes, Polonaises, and Scherzos. Finally, I discuss temperaments in light of emotional characteristics that have been traditionally ascribed to keys.

2.1 Influence of unequal temperament on the chromatic scale

In equal temperament, the tempering of each fifth by $1/12^{th}$ of a comma results in intervals that are all equivalent. Consequently, an ascending chromatic scale increases in equal increments of 100¢ as all semitones are equal. In unequal temperaments, the varying size of fifths results in unequal semitones. Figure 2.1 shows the semitone size in cents of the five circulating temperaments discussed at the end of Chapter 1. For each temperament, the biggest and smallest semitones are highlighted. They range from 96¢ to 107¢. These discrepancies and the effect they have on a performance have already been addressed by scholars. For instance, a complete chapter of Miller's dissertation is devoted to "The Effects of Unequal Temperament on Melodic Lines in the [Chopin] Mazurkas."[1] In order to illustrate the changes to melodies brought on by the use of different temperaments, Miller devises a labelling method comparing the size of tempered melodic intervals to their pure equivalent. By doing so, he aims to guide performers in choosing a temperament that would emphasize significant intervals. For instance, he discusses the prominent D-E♭ semitone in the melody of the Mazurka, Op. 67 No. 2 in G minor. His Figure 4.5 is reproduced in Figure 2.2. The values above the staff indicate the difference between the intervals of a given temperament and their pure version. Using De Morgan's temperament would render a minor second that is 16¢ narrower than pure, while Rameau's and Jousse's temperaments would give a closer approximation to just intonation, at only 7¢ narrower than pure. Miller suggests that a performer could choose to give less significance to the melodic interval by choosing the latter option, or to emphasize it by increasing its size with the former. [2]

Figure 2.1 Size in cents of semitones in 5 unequal temperaments, compared to equal temperament

Large semitone

Narrow semitone

	C-C♯	C♯-D	D-E♭	E♭-E	E-F	F-F♯	F♯-G	G-A♭	A♭-A	A-B♭	B♭-B	B-C
ET	100	100	100	100	100	100	100	100	100	100	100	100
Jousse	98.5	98.5	105.5	92.5	105.5	96	102.5	101.5	96	105.5	92.5	105.5
Rep. Victorian	100	99	101	97	103	99.5	101	100	97	103	98	101.5
De Morgan	100	102.5	96	104.5	96	102.5	100	97.5	104	95.5	104	97.5
Hummel	100.5	99.5	101	99.5	100	99.5	99.5	101	99.5	101	99.5	99.5
Pleyel & Dussek	103.5	97	107	98	107	89	101	103	97.5	107	93.5	96.5

[1] Miller, "The Effects of Unequal Temperament," 86-104.
[2] Ibid, 93.

Figure 2.2 Distance in cents from pure intonation in 9 temperaments (Miller, Figure 4.5)

Figure 4.5
Mazurka Op. 67 no. 2 in g minor, mm. 33-40

Werckmeister	-10	-6	-12	-4	-22	-10	-6	-12	-4	-22	-10	12	-4	-16	-4	-16	-16	-4	0	-10	-10
Rameau	-7	-5	-11	0	-29	-7	-5	-11	0	-29	-7	11	5	-36	5	-11	-20	0	0	-6	-7
Rousseau	-10	-4	-6	-10	-20	-10	-4	-6	-10	-20	-10	6	-6	-18	-8	-15	-11	-10	-1	-11	-10
Stanhope	-8	-7	-17	-2	-22	-8	-7	-17	-2	-22	-8	10	0	-20	-5	-19	-18	-2	0	-12	-8
Jousse	-7	-3	-7	-9	-22	-7	-3	-7	-9	-22	-7	7	-6	-19	-7	-16	-11	-9	0	-13	-7
DeMorgan	-16	-2	-3	-12	-13	-16	-2	-3	-12	-13	-16	1	-15	-8	-16	-8	-15	-12	-4	-9	-16
"Usual"	-12	-6	-10	-6	-20	-12	-6	-10	-6	-20	-12	6	-5	-17	-8	-14	-16	-6	-1	-9	-12
"Best"	-12	-5	-9	-7	-19	-12	-5	-9	-7	-19	-12	6	-6	-17	-8	-14	-15	-7	-1	-10	-12
"Equal"	-12	-2	-4	-12	-16	-12	-2	-4	-12	-16	-12	4	-12	-12	-12	-12	-12	-12	-2	-12	-12

Miller is describing how a performer can choose a temperament that affects the sound of certain musical features, but does not address how the unequal melodic intervals of a temperament could be a factor in the compositional process. There is no definite way to determine this, but we can make some hypotheses about what type of sounds Chopin may have been exposed to and how he may have emphasized them in his music. For instance, a traditionally wider semitone has a different affect than a smaller semitone. It has been shown that violinists and other musicians playing on flexible pitch instruments tend to colour some half-steps by narrowing the distance between a leading tone and a tonic or between scale degrees $\hat{4}$ and $\hat{3}$. We could argue that if wide and narrow semitones are built into a temperament, composers might - intentionally or not - emphasize them rhetorically.

In traditionally shaped unequal temperaments that privilege purity in white keys such as C, F and G major, the largest semitone tends to be E to F. As shown in Figure 2.1, this is the case in the Jousse, Representative Victorian, and Pleyel & Dussek temperaments. The A-B♭ and D–E♭ semitones are also usually larger.

In his study, Miller emphasizes only the melodic aspect of the unequal chromatic scale. The harmonic implications of these differences, however, would also have audible repercussions. Let us take the large E–F semitone as an example. The move from a C♯ minor triad to its parallel major, C♯ or D♭ major, requires this semitone motion. Shifting from the narrow third C♯-E to the large major third C♯-E♯ (often enharmonically spelled as D♭-F) would create a noticeable change in affect, as the third of the major triad is further from pure, or "brilliant". The shift to a major harmony is already a change in mood, and would be emphasized by the inequality of the tuning system.

In a corpus that comprises the Mazurkas, Waltzes, Etudes, Ballades, Nocturnes, Polonaises, and Scherzos, the most frequently used minor key by Chopin is C♯ minor, with a total of 13 pieces. Of these, 8 present a shift to the major tonic, either through a Picardy third or a section in the new key. Perhaps Chopin found the transition from C♯ minor to D♭ major particularly appealing. We can also find the reverse in some pieces, such as the Prelude Op. 28 No. 15 in D♭ major**,** with its ominous C♯ minor section. The change to the parallel key is also frequent in A minor, where all of the analyzed 11 pieces feature a shift to A major. Figure 2.1 shows how the C-C♯ semitone is generally close to an equal temperament semitone, as it ranges between 98.5 and 103.5. In F minor, Chopin's third most used minor key, only 2 out of 10 pieces feature a move to the parallel major. Perhaps progressing from F minor to F major, which is traditionally closer to pure intonation in unequal temperaments, did not have such a striking effect as the other key-changes mentioned above. Other traditionally large semitones (D-E♭, A-B♭, and B-C) are not emphasized as prominently through parallel-key modulations. [3]This suggests that while the common opposition of D♭ major and C♯ minor might be linked to tuning, other factors--such as keyboard topography and key characteristics, which will be discussed in the following chapter--are probably at play.

Example 2.1 shows musical instances of shifts between C♯ minor and C♯ major. In Chopin's Nocturne Op. 49 in C♯ minor, the final tonic harmony is major. The two hands divide in arpeggios that explore the extreme registers of the keyboard. The bright, shimmering sound of the C♯ - E♯ major third, coupled with the extremely soft dynamic, would contrast with the previous minor chord. The juxtaposition between D♭ major and minor is central to the Mazurka Op. 30 No. 2 in D♭ major. Chopin highlights the final upward motion from F♭ to F natural and the resulting wide major third by a *forte,* and by voicing the chord so the F stands out as the highest note. The beats between the root and the F a tenth above could be heard particularly well as they are in the register usually used for setting a temperament's bearing. The whole B section of the Fantaisie-impromptu is in the parallel major key. The descending C♯-minor arpeggios are followed by the dominant chord, which resolves to a broken D♭ major harmony, emphasized by the change in texture, tempo, and the *pesante*. The newly raised third degree, highlighted as the highest note of the D♭-major arpeggio, is echoed in the opening gesture of the *sotto voce* melody. In the Nocturne Op. 27 No. 1 in C♯ minor, the semitone motion E - E♯ is highlighted in the first four bars as it is in the soprano while the tonic chord transforms into an applied

[3] Modulations between B major and minor, F♯ minor and major, and A♭ minor and major are not uncommon, as shown in figures 2.6 and 2.7, but Chopin clearly preferred the parallel relationship between D♭ major and C♯ minor.

dominant of iv. In all the above examples, the shift between D♭ major and C♯ minor is either used as a final gesture, accompanied with significant changes in texture and mood, or strongly emphasized in the melody. We can imagine that the inequalities of the chromatic scale may have been influential in Chopin's compositional process, and that he sometimes chose to musically highlight them.

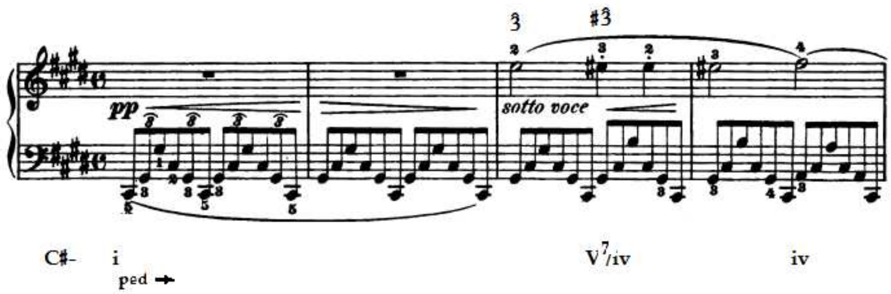
Example 2.1 Shifts between C♯ minor and C♯/D♭ major

a) Chopin, Nocturne in C♯ minor, B. 49, mm. 61-64

b) Chopin, Mazurka in D♭ Major, Op. 30 No. 3, mm. 93-95

c) Chopin, Fantaisie-impromptu, Op. 66, mm. 37-44

d) Chopin, Nocturne in C♯ minor, Op. 27 No. 1, mm. 1-4



2.2 Influence of unequal temperament on harmony

1) Chord colour

With the above examples, I have begun to address descriptions of chord colour, and how they are a direct result of unequal temperament. Qualifying chords with adjectives such as bright, dark, shimmering, and smooth at first seems like a subjective concept that is difficult to theorize. Both Miller and Van Evera have thoroughly addressed the topic and proposed ways to quantify chord colour. Both authors also provide enlightening analyses of musical excerpts that are affected by discrepancies between chords. In this section, I will attempt to succinctly summarize their arguments and to provide examples from Chopin's music where chord colour might have been a compositional factor.

In his chapter "The Effects of Unequal Temperament on Harmonic Progressions in the Mazurkas," Miller posits that the variety of chord colour created by unequal temperaments is closely intertwined with the beats caused by out-of-tune intervals. For each of his discussed temperaments, he constructs charts showing the beat rates of major and minor triads[4]. To calculate the beat rates of a triad, Miller adds the beat rates per second of all intervals that make up the chord. For example, Miller would calculate the total beats of an equal tempered D♭4 major triad at A 440 in the following way:

D♭4 = 277.18 Hz
F4 = 349.23 Hz
A♭4 = 415.30 Hz

Beats between D♭ and F

$$f_b = \left|349.23 - 277.18(\frac{5}{4})\right|$$
$$f_b = |349.23 - 346.475|$$
$$f_b = 2.755$$

Beats between D♭ and A♭

$$f_b = \left|415.30 - 277.18(\frac{3}{2})\right|$$
$$f_b = |415.30 - 415.77|$$
$$f_b = 0.47$$

Beats between F and A♭

$$f_b = \left|415.30 - 349.23(\frac{6}{5})\right|$$
$$f_b = |415.30 - 419.076|$$
$$f_b = 3.776$$

Beats in D♭ major triad

2.755 + 0.47 + 3.776 **= 7.001**

Using the beat values he calculates for triads, Miller constructs "beat speed contours" that illustrate the high and low points of tension throughout a progression. His graph for the opening of the Mazurka Op. 41 No. 2 in E minor is shown in Figure 2.3. Miller explains that all the displayed temperaments, except the De Morgan, follow the

[4] Beats are an acoustic phenomenon that occur when two frequencies that are not in tune with each other sound at the same time. The number of beats per second is the same as the difference in frequency between the two tones. The number of beats can be calculated using the formula

$$f_b = |f_1 - f_2|.$$

For example, an A tuned at 440 Hz and another A tuned at 443 Hz would beat at 3 beats per second

$$3 = |440 - 443|$$

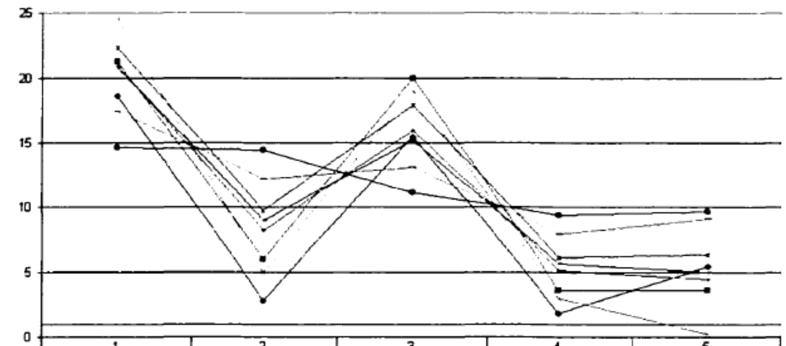
Beats between the two tones of an interval occur because the upper partials of the tones are not in tune with each other. For instance, an equal-tempered third C-E would beat because the E is higher than the C's 4th partial. To calculate the number of beats between two tones of a tempered interval, the frequency in Hz of both tones and the ratio representing the pure version of the interval need to be known. The formula is

$$f_b = \left|f_1 - f_2(\frac{x}{y})\right|,$$

Where $\left(\frac{x}{y}\right)$ is the interval ratio.

same "tension-resolution" scheme, also noting that dominant harmonies (V^7/iv and V^7) resolving to their respective tonics feature a release of the tension caused by rapid beats.

Figure 2.3. Beat Speed Contour Graph (Miller, Figure 3.6)



	1	2	3	4	5
Werckmeister	18.6	2.77	15.45	1.84	5.43
Rameau	21.21	5.99	19.98	3.61	3.63
Rousseau	20.7	9.21	16.38	5.95	8.38
Stanhope	24.57	4.98	19.03	3.01	0.21
Jousse	22.25	9.73	17.9	6.15	6.32
DeMorgan	14.6	14.41	11.15	9.39	9.67
Usual	20.9	8.24	15.95	5.17	4.46
Best	20.83	8.98	15.2	5.66	5.02
Equal	17.43	12.18	13.06	7.92	9.12

Miller is using the beat speed contours to aid a performer in choosing a well-suited temperament for a performance. If we already have a piece to analyse, it is convenient to compare beat-speeds to choose an appropriate temperament. This method, however, does not necessarily represent how chord colour may have influenced the compositional process. Avoidance of solid chords for the sake of a broken, arpeggiated texture may be indicative of a dislike for the sound of particular chords; conversely, the repeated use of blocked chords and of a thick texture could indicate a liking for the given chordal colour.

While Miller's classifying method has the advantage of visually showing the tension and release in a progression, it only lends itself well to pieces with a particular texture, where chords are held long enough for the beats to be audible, and where all chords are voiced in a similar way and in the same register. Chopin's Mazurkas, with their chordal accompaniment, work especially well for this. Beat rates, however, are dependent on too many factors – such as register and voicing - to be the only indicator of chord colour. For instance, the same triad would beat twice as rapidly when transposed up an octave. In equal temperament, all chords have the same brightness because all fifths are tempered by the same amount. Despite the equal size of chords, beat speeds still vary with register: a C major chord beats slower than its transposition up a major sixth. Therefore, I suspect that while beat rates have an important relationship to chord colour, they are not the only factor at play; register and the width of intervals probably also have a large role to play in chord colour.

Van Evera also discusses the role of beats in chord colour, stating that "non-beating intervals will sound neutral, [and] fast-beating intervals will create a sense of agitation or excitement."[5] Her methodology to describe chord colour, however, is based on interval width and tempering. She devises a methodology to describe how unequal temperaments may have influenced composition, using Schubert Lieder as a case study. She calls the various timbral colours caused by unequal temperament *Temperaturfarben*. To quantify *Temperaturfarben,* she observes the amount by which an interval is tempered: the more tempered it is, the more dissonant it sounds, and the higher the *Temperaturfarben* degree. In irregular temperaments that privilege C as the purest third, *farben* increases along the

[55] Van Evera, "Rediscovering Forgotten Meanings," 44.

circle of fifths, eventually decreasing as it comes back towards C. In a given temperament, Van Evera rates the tonic, subdominant, and dominant harmonies of each major tonality according to the purity of their major thirds. The higher the rating number, the higher the impurity and the more colour there is. Figure 2.4 shows Van Evera's ranking by *Temperaturfarben* of all major keys in Thomas Young's 1799 temperament. She explains that in sharp keys, as they move further from C major, the move to the dominant is characterized by an increase in *Temperaturfarben.* Conversely, the tonic-dominant progression in flat keys presents a decrease in colour intensity. She writes that "perhaps the dominant chord's role in the creation of *Temperaturfarben* is the reason that throughout history, sharp keys have often been characterized as being more animated and excited and the flat keys as more solemn and calm."[6]

Figure 2.4 Classification of keys by *Temperaturfarben* - Young's 1799 Temperament (Van Evera, Table 2.4)

Table 2.4: Average *Temperaturfarben* ranking of major keys based on the tonic, dominant, and subdominant triads

I	V	IV	Mean
C: 1	G: 2	F: 2	1.66
F: 2	C: 1	B♭: 3	2
G: 2	D: 3	C: 1	2
B♭: 3	F: 2	E♭: 4	3
D: 3	A: 4	G: 2	3
E♭: 4	B♭: 3	A♭: 5	4
A: 4	E: 5	D: 3	4
A♭: 5	E♭: 4	D♭: 6	5
E: 5	B: 6	A: 4	5
D♭/C♯: 6	A♭: 5	G♭/F♯: 7	6
B: 6	G♭/F♯: 7	E: 5	6
G♭/F♯: 7	D♭/C♯: 6	C♭/B♯: 6	6.33

Miller and Van Evera's classifications and description of chord colour show that the inequality of a temperament causes chords to have varying beat rates or interval sizes.

[6] Ibid, 69.

In the following section, I discuss how Chopin might have taken this into account while composing. Browsing through his piano output, we can see how certain chords would have a striking, bright colour when played in an unequal temperament.

In Chopin's Prelude Op. 28 No. 7 in A major, shown in Example 2.2, the second phrase is surprisingly interrupted by an F♯ dominant-seventh chord. It acts as the applied dominant of ii, which is eventually reached in the next bar. Because of its dominant function and the following pause, the chord creates a sense of surprise and expectation. The effect of surprise would be emphasized by the bright chord colour in an unequal temperament. In a traditionally-shaped unequal tuning system such as Jousse's, the wide major third of the dominant seventh sonority would have one of the widest major thirds, as it is opposite to the purest key, C major, on the circle of fifths. In the case of the A-major prelude, the large F♯-A♯ third creates a very bright sound which contrasts with the home key, A major. The unexpected chord is rhetorically emphasized by Chopin with an accent, a crescendo, several doublings and a thick texture – lingering on the chord could make audible the faster beats – and the subsequent pause.

In the Polonaise Op. 40 No. 2 in in C minor, shown in Example 2.3, the B section begins with a loud D♭ major triad, the Neapolitan sixth. As it is more remote in the cycle of fifths, this chromatic chord would have a striking colour, the width of its major third contrasting with the C minor and E♭ major harmonies that were frequent in the A section.

We can also consider the effect unequal temperament would have on a sequence, in which harmonies follow others in a rapid succession. This type of progression is meant to have a destabilizing effect, as harmonic function is temporarily suspended while we wait for the next tonal center to be confirmed. In an unequal temperament, in the descending fifth sequence in measures 5 to 8 of the Mazurka Op. 6 No. 1 in F♯ minor, shown in Example 2.4, the rapid succession of chords would have an even more destabilizing effect contrasting with the tonal stability of the previous bars. This type of sequence is very typical of Chopin – maybe he enjoyed the destabilizing effect brought on by rapid movement through chords, and the way it was emphasized by the rapid changes in chord colour.[7]

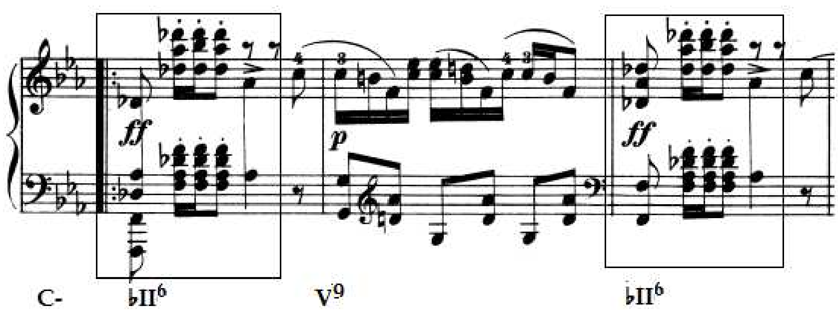
Bellman points out yet another way in which changes in chord colour could have an audible effect on music. In Chopin's Nocturne Op. 72 No. 1 in E minor, harmonies change under a repeated B in the melody. Bellman explains how "one of the most striking effects, when it can be heard, is the way changing harmonies can, as a result of the beat-patterns of the various upper harmonics, add varieties of vibrato-like texture to melody notes."[8] Since this could be audible in a performance, it suggests that Chopin could have exploited the difference in key colour between chords containing a common tone. Suzannah Clark has discussed how Schubert often uses chords related by common tone as a way to organize complete pieces[9] or as a kind of pivot to modulate. This is a technique that Chopin uses occasionally, for instance in the third ballade, Op. 47, as shown in

[7] Dmitri Tymoczko discusses how in this particular progression, along with other sequences, Chopin uses descending chromatic displacements to move between seventh chords. This results in passing seventh chords between the main harmonies of the sequence, therefore creating more harmonies that contribute to destabilizing the tonal center. Dmitri Tymoczko, *A Geometry of Music Harmony and Counterpoint in the Extended Common Practice* (New York: Oxford University Press, 2011): 405-418.
[8] Bellman, "Toward a Well-Tempered Chopin," 30.
[9] Suzannah Clark, "On the Imagination of Tone in Schubert's *Liedesend* (D473), *Trost* (D523), and *Gretchens Bitte* (D564)" in *The Oxford Handbook of Neo-Riemannian Music Theories*, ed. Edward Gollin and Alexander Rehding (New York: Oxford University Press).

Example 2.5. The repeated C in the right hand is used as a link between the A♭ major harmony, which would be more tempered and therefore brighter, to the subsequent C major chord, which would be purer and calmer.

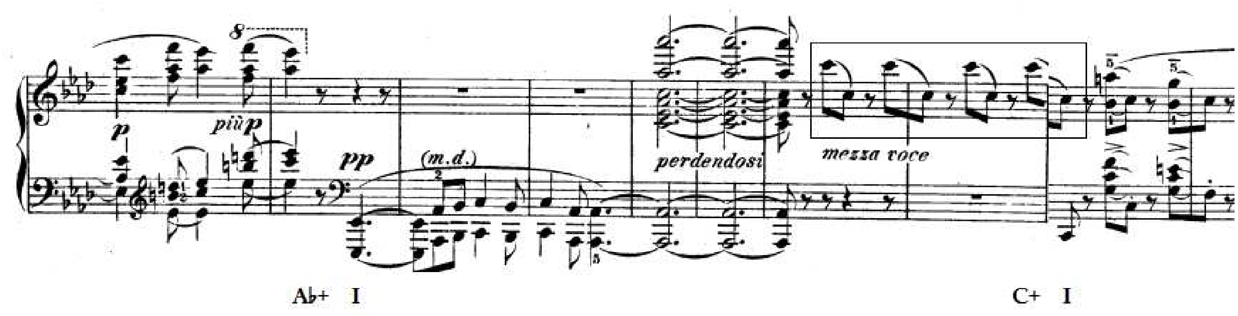
Ex. 2.2 Chopin, Prelude in A Major, Op. 28 No. 7, mm. 8-14

Ex. 2.3 Chopin, Polonaise in C minor, Op. 40 No. 2, mm. 35-37



Ex. 2.4 Chopin, Mazurka in F♯ minor, Op. 6 No. 1, mm. 1-11

Ex. 2.5 Chopin, Ballade in A♭ major, Op. 47, mm. 46-54



2) Modulation

In equal temperament, different modulations have the same effect when they are transposed. For instance, modulating from C major to E major has the same effect as modulating from G♭ major to B♭ major. Since all keys are equally tempered, the only audible difference between these two key relationships is the pitch level.

In unequal temperament, however, the difference in character between tonalities caused by the varying semitone sizes could emphasize or modify the effect of some modulations. Moving from A♭ major to C major in a temperament that is traditionally shaped would be a move from a tempered to a purer key. The effect is reversed if the same modulation takes place at a different pitch level, for instance moving from the relatively pure G major to the tempered B major. Temperaments are designed[10] so that keys separated by a fifth progressively increase or decrease in purity, depending on the direction we're moving on the circle of fifths. As a result, modulating to a closely related key such as the dominant, the subdominant, or the relative minor/major would not cause

[10] Miller, "The Effects of Unequal Temperament," 46.

a significant change in character. Modulations to distant keys could however be highlighted by changes in purity.

It is possible that Chopin exploited these features when composing. Several accounts relate that the choice of a key was a crucial aspect of composition, performance, and improvising. In his diary, Ignaz Moscheles explains how "the harsh modulations which strike me as disagreeable when I was playing his compositions no longer shocked me, because [Chopin] glides over them in a fairy-like way with his delicate fingers."[11] The harsh modulations described by Moscheles may have sounded odd to his ear because of the difference in purity between keys – moving from C major to G♭ major, for instance, would certainly sound striking.[12]

The subtleties made available by the Pleyel piano may also have allowed Chopin to enhance and underline key changes during a performance. Hipkins discusses how "Chopin's use of the pedal, particularly that of the soft pedal in transfusion with his touch was in arpeggios and in sustained chords of a beauty indescribable,"[13] while Christopher Clarke describes Pleyel's "direct and supple mechanics… that allow for a precise control of the dynamics."[14]

[11] Edith J. Hipkins and Alfred J. Hipkins. *How Chopin Played,* 12.
[12] Moscheles was not alone in questioning or criticizing modulations he found too strong. In a 1824 review of some Schubert *Lieder*, critic Gottfried Wilhelm Fink notes that their modulations "[are] free, very free, and sometimes rather more than that" and that the composer indulges in "eccentricities which are hardly or not at all justified." Describing the modulations in "Auf der Donau," Op. 21 No. 1, he writes that a particular progression "is a neat little cobbler's patch [that] may be recommended to pianoforte tuners to test purity of intonation." This suggests that Fink's shock at the unusual modulations might have partly been caused by the rapid shift through keys, at a time when unequal tuning was still an issue. Erich Deutsch (ed.), *Schubert: A Documentary Biography*, translated by Eric Blom (London: J. M. Dent, 1946): 24 June 1824, 352–355.
[13] Edith J. Hipkins and Alfred J. Hipkins. *How Chopin Played,* 18.
[14] Christopher Clarke, "Les particularités de Pleyel," in *Interpréter Chopin: actes du colloque des 25 et 26 mai 2005*, edited by Jean Jacques Eigeldinger, Emmanuel Hondré, and Delphine Delaby (Paris: Cité de la musique, 2006), 36.

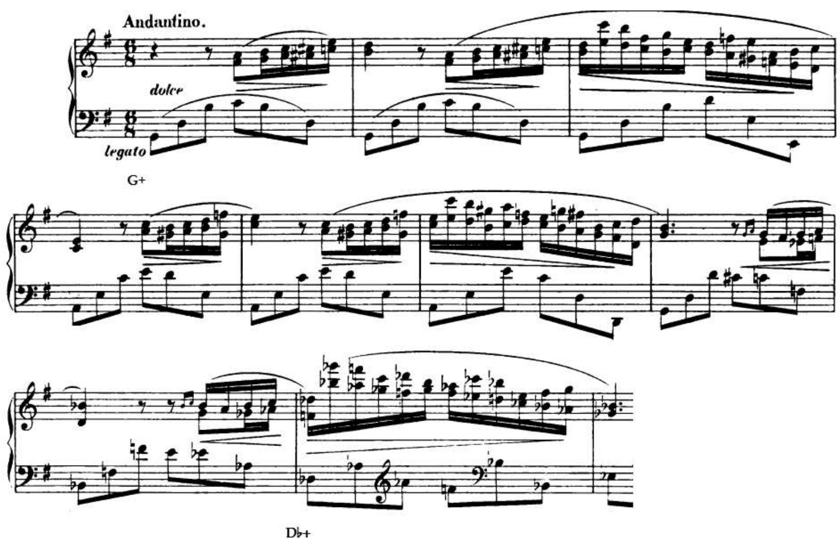
Moreover, scholars have discussed the distinctive roles held by some keys in Chopin's compositions. For instance, William Rothstein coined the term "B-major complex" when describing Chopin's use of the key. He remarks how some of the music the composer wrote in that key "[has] a quality of stillness and serenity that seem[s] to evoke some distant, happy memory."[15] For Rothstein, Chopin might have employed modulations to B major to invoke a specific mood or effect, therefore suggesting that the inherent sound of a key in relationship to others might have been a factor in Chopin's compositional process.

Since the choice of a key seems to have been of a certain importance to Chopin, we can conclude that he may have used the differences in character of an unequal temperament to his advantage when writing modulations. In any of the purer, white-note keys, the arrival of a distant chromatic tonality would be characterized by a harsher or brighter sound. Conversely, the shift to a key closer to just intonation when coming from a bright-sounding tonality could have a soothing or calming effect. In the Nocturne Op. 37 No. 2 in G major, shown in Example 2.6, the modulation to D♭ major in the second phrase entails a shift to a brighter sound. In the Nocturne Op. 15 No. 3 in G minor, in Example 2.7, the arrival of a *religioso* chorale in F major immediately after a louder section in F♯ major would offer an even starker contrast than in equal temperament because of the difference of purity between keys. Here, we can even argue that Chopin varied some of the other musical parameters – changing the dynamic to *piano*, using a slower surface

[15] William Rothstein, "Chopin and the B-major complex: a study in the psychology of composition," *Ostinato rigore, revue international d'études musicales* 15 (2000): 149.

rhythm, replacing the waltz-like chords and the animated bass line with the calmer and thinner texture of a chorale – to emphasize this change in character. A similar phenomenon happens in the final Example 2.8, the Nocturne, Op. 9 No. 1 in B♭ minor. Passages in D♭ major alternate with slower *pianissimo* passages in D major, the former being more tempered while the latter is closer to just intonation.

Ex. 2.6 Chopin, Nocturne in G major, Op. 37 No. 2, mm. 1-9



Ex 2.7 Chopin, Nocturne in G minor, Op. 15 No. 3, mm. 80-99

Ex 2.8 Chopin, Nocturne in B♭ minor, Op. 9 No. 1, mm. 21-30

If Chopin did use modulation as a means of expression, it is likely that he may have treated different keys in varying ways. A particular modulation may be very frequent in the context of a particular key and rare in another one, depending on Chopin's taste or intention. In order to determine if certain modulations happen more frequently than others, I analyzed the key changes in Chopin's complete Preludes, Mazurkas, Waltzes, Etudes, Ballades, Nocturnes, Polonaises, and Scherzos. Most of these are small-scale pieces that contain few modulations, making any key change especially significant. Bellman believes that Chopin preferred to exploit the subtleties of unequal tuning in shorter salon pieces such as these, because the small, intimate setting could better showcase the differences between chords and keys[16]. Figure 2.5 shows the number of pieces present in each key within this corpus. Keys remote from C major are more

[16] Bellman, "Toward a Well-Tempered Chopin," 32.

frequent; according to Hugh MacDonald, "[Chopin] may have been drawn in that direction by the comfort and disposition of his fingers, by the sonority of remoter keys, or by the very notion of distance and depth implicit in the exploration of keys far from the terra firma of C."[17]

Figure 2.5 Key distribution in the corpus

Pieces in a major key	83
Pieces in a minor key	81
Total number of pieces	**164**

Key	# of pieces	Key	# of pieces
C+	9	C-	8
G+	5	G-	6
D+	4	D-	2
A+	2	A-	11
E+	6	E-	6
B+	7	B-	6
F♯/G♭+	6	F♯-	6
D♭+	7	C♯-	13
A♭+	19	G♯-	4
E♭+	6	E♭-	4
B♭+	6	B♭-	5
F+	6	F-	10

When analyzing the pieces, I considered that there was a key change if the music adheres to any of the following conditions:

1. There is a change in key signature;
2. A key is tonicized for four bars or more. If we only hear the dominant of a key but there is no resolution to the tonic, I still consider that there is a tonicization.
3. There is a clear key change confirmed by a cadence.

[17] Hugh MacDonald, "[G-flat Major Key Signature]," *19th-Century Music* 11/3 (1988): 225-26.

Figures 2.6 and 2.7 group all pieces by home key, and the percentage values represent the total proportion of bars spent away from the home key. For instance, 8.5% of bars in all analyzed pieces in A♭ major are spent in IV (D♭ major), 5.8% are spent in V (E♭ major), 5.7% in ♭VI (E major), and so on.

For all major tonalities, the majority of bars spent away from the home key are in IV, V, or vi. This is to be expected as they are frequent modulations in tonal music, and the keys involved are closely related. Observing the modulations to distant tonalities, however, yields interesting data and suggests that Chopin preferred certain modulations in the context of certain keys. We can make the following observations:

- Pieces in G major and D♭ major are more likely to spend time in the parallel minor. In the total of pieces written in these keys, the parallel minor is tonicized for 9.1% of the time. For all other major keys, the amount stays below 2.8%. Perhaps Chopin found these particular modulations more effective – I have already noted how the E-F semitone that allows for the switch between D♭ major and C♯ minor is usually larger than the others. The B-B♭ semitone required for changing between G major and minor, conversely, is often one of the narrowest semitones in an unequal temperament. The change between G major and G minor, then, would not be as striking as a modulation containing a large semitone.
- B major and A♭ major pieces spend more time in ♭VI than do other major keys. Perhaps the shift from the tempered B major to the purer G major created an effect Chopin particularly enjoyed. Depending on the temperament either A♭ or E major can be more tempered than the other, but they are generally closer in character

than B major and G major. The A♭ to E modulation, however, creates an opposition between a flat key and a sharp key. When modulating to ♭VI, we expect a shift towards F♭ major. The arrival of a sharper, brighter key such as E major is consequently surprising. Since they are enharmonically equivalent, both F♭ and E major sound the same, but the visual difference between a flat and a sharp key would be obvious to the pianist. Chopin often accompanies this modulation with a change in texture and character.[18]

- 9.1% of the bars in E♭ major pieces are in ♭VII, or D♭ major. This again represents a modulation to a bright key with a wider major third.

In minor keys, pieces in 7 out of 12 keys move to their parallel major for more than 10% of the analyzed bars. Motion to other keys such as V, v, VI, vi, #VI, #vi, etc. are also frequent, but they seem to be distributed at random as no particular patterns emerge. This might be because the minor scale has flexible scale degrees $\hat{6}$ and $\hat{7}$, creating more easily accessible keys. Similarly to the major keys, particular keys stand out as they are treated differently than others.

- In keys such as G, G♯, B♭, and F minor, the music spends more time in the relative major, III, than in any of the other home keys. The respective major keys are B♭, B, D♭ and A♭ major: the last three seem to be favourites of Chopin because of the sheer amount of pieces he wrote in those tonalities. Perhaps he chose to explore them

[18] See for instance the Polonaise Op. 53 in A♭ major, the Scherzo No. 4 in E major Op. 54, or the Etude B.130 No. 3 in A♭ major.

more frequently because of how they felt at the keyboard or because of their more brilliant, tempered sound.

- Unlike other keys, B♭ minor has a high incidence of music in ♯IV, E major.

The data presented in Figures 2.6 and 2.7 shows which keys are explored in relation to the home key, but it does not take into account which keys modulate directly to others. For instance, it shows that pieces in D major often have sections in the dominant A major, but we do not know if there are any modulations directly from I to V. Since directly modulating from one key to the other would showcase differences in temperament, it is likely that Chopin thought about that while composing.

Figures 2.8 and 2.9 show where each tonality is more likely to directly go. I obtained these results by considering how many times a particular key moved to another, without taking the home key into account. As an example, whenever Chopin writes in C major, there is a 17.2% probability the music will modulate to G major, 15.5% to A minor, 12.1% to A♭ major, 10.3% to E minor, 6.9% to F minor and B minor. The probability of modulating to keys such as A major, C minor, and F♯ minor is below 5%. These roman numerals in Figures 2.8 and 2.9 represent the relationship to the particular key under observation, not to the home key of a piece. For instance, modulating to iv (C minor) from G major might be a V-i modulation in the context of a C minor piece. Looking at where each tonality is more likely to go again gives us some insight on how Chopin might have treated keys differently. These results suggest that in some cases, instead of modulating to a closely related key, Chopin preferred to modulate to a foreign key that would present a significant change in character due to tuning.

- A few major keys move to their parallel minor at higher rates than others: A major moves to A minor 12.5% of the time, E♭ major moves to E♭ minor 11.8% of the time, and A♭ major moves to G♯ minor 8.9% of the time.
- E major frequently goes to A♭ major. In fact, it modulates to this key more often that it modulates to the dominant or subdominant.
- The bright D♭ major is more likely to move to the relatively purer C minor than to any other key.
- F major, which is traditionally close to pure, is as likely to move to ♭vi or ♭VI (more heavily tempered keys) than to its dominant C major.
- In A♭ major, a modulation to E major is more frequent than a modulation to the dominant E♭.
- G minor is more likely to modulate to ♭II, the heavily used A♭ major, than to D minor or G major.
- In C♯ minor, v is not as likely to follow as ♭VII (B major, another key often used by Chopin) or I (D♭ major)

Figure 2.6 Percentage of bars spent away from the home key – major tonalities

	i	♭II	♭ii	II	ii	III	iii	♯III	♯iii	IV	iv
C	0.0%	2.20%	0.0%	0.0%	0.30%	0.0%	2%	0.40%	0.30%	4.70%	0.0%
G	9.1%	2.4%	0.0%	2.1%	0.0%	2.4%	0.9%	0.0%	2.4%	12.5%	0.0%
D	0.0%	0.0%	0.0%	2.5%	0.0%	0.0%	0.0%	0.0%	3.8%	6.8%	0.0%
A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.1%	6.8%	47.5%	0.0%
E	0.2%	0.8%	1.2%	1.2%	3.1%	0.0%	0.1%	4.3%	1.8%	2.9%	0.1%
B	0.9%	1.6%	0.0%	1.3%	1.1%	2.9%	0.0%	4.0%	0.0%	0.3%	2.0%
G♭	2.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.1%	0.0%
D♭	9.1%	0.0%	0.0%	0.0%	1.5%	1.3%	0.0%	0.0%	3.3%	0.0%	0.0%
A♭	0.4%	1.0%	0.0%	1.8%	2.7%	2.5%	0.7%	3.2%	2.4%	8.5%	1.4%
E♭	1.5%	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%	0.0%	0.0%	12.1%	0.0%
B♭	1.7%	2.3%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	8.0%	0.0%
F	2.8%	1.9%	0.6%	0.0%	1.9%	0.2%	3.1%	0.0%	5.6%	13.0%	0.3%

	♯IV	♯iv	V	v	VI	vi	♯VI	♯vi	♭VII	♭vii	VII	vii
C	0.0%	0.0%	17.30%	0.0%	2.30%	0.0%	0.0%	3.60%	0.0%	0.0%	0.0%	0.0%
G	1.5%	0.9%	2.4%	0.0%	0.9%	0.0%	0.0%	2.4%	0.0%	1.5%	3.0%	0.0%
D	0.0%	0.0%	20.3%	0.0%	0.0%	0.0%	4.7%	4.2%	0.0%	0.0%	2.1%	0.0%
A	0.0%	0.0%	3.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
E	0.0%	0.0%	6.1%	0.9%	1.9%	0.0%	0.0%	15.1%	0.5%	0.0%	1.2%	0.0%
B	0.6%	0.4%	9.7%	2.0%	7.3%	0.0%	5.6%	3.2%	1.7%	0.0%	0.0%	0.6%
G♭	0.0%	0.0%	17.8%	0.7%	0.9%	0.0%	0.0%	11.9%	1.3%	0.0%	0.0%	0.0%
D♭	0.0%	0.0%	12.2%	0.7%	0.0%	0.0%	2.3%	5.8%	5.1%	0.0%	0.0%	0.0%
A♭	0.6%	0.0%	5.8%	0.7%	5.7%	0.0%	0.0%	8.5%	1.7%	1.4%	0.4%	0.3%
E♭	0.0%	0.0%	3.7%	2.6%	1.3%	0.0%	0.0%	5.0%	9.1%	0.0%	0.0%	0.0%
B♭	0.0%	0.0%	7.7%	2.3%	2.3%	0.0%	0.0%	14.2%	0.0%	0.0%	1.1%	0.0%
F	1.2%	0.6%	3.6%	0.6%	3.0%	0.0%	0.0%	5.4%	0.0%	0.2%	0.5%	0.0%

Figure 2.7 Percentage of bars spent away from the home key – minor tonalities

	I	♭II	♭ii	II	ii	III	iii	♯III	♯iii	IV	iv
C	14.9%	0.6%	0.3%	0.3%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	5.0%
G	1.4%	1.7%	0.0%	0.0%	1.8%	14.6%	0.0%	0.6%	0.0%	0.0%	0.0%
D	14.8%	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%	8.1%	2.0%	0.0%	0.0%
A	17.3%	0.0%	0.0%	0.5%	1.9%	5.4%	0.0%	0.2%	0.3%	1.2%	0.0%
E	10.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
B	16.2%	3.3%	0.0%	0.0%	0.0%	2.3%	0.0%	0.5%	0.0%	0.0%	2.6%
F♯	11.2%	0.0%	0.1%	1.6%	0.0%	3.3%	0.0%	7.2%	3.1%	4.9%	1.2%
C♯	18.6%	0.0%	0.0%	0.1%	0.0%	5.9%	0.9%	0.5%	0.0%	0.0%	2.7%
G♯	6.3%	0.0%	1.3%	0.0%	0.0%	29.6%	0.0%	1.3%	0.0%	0.0%	0.0%
E♭	0.4%	3.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
B♭	2.5%	0.3%	0.1%	0.0%	1.0%	12.6%	6.4%	1.9%	0.0%	0.0%	0.0%
F	0.3%	1.0%	0.0%	0.0%	1.0%	14.6%	0.0%	4.2%	0.6%	2.1%	7.0%

	♯IV	♯iv	V	v	VI	vi	♯VI	♯vi	♭VII	♭vii	VII	vii
C	0.1%	0.0%	5.3%	1.0%	4.9%	0.0%	0.9%	0.0%	6.9%	4.1%	1.4%	0.0%
G	0.0%	0.6%	0.0%	4.1%	13.5%	0.0%	2.0%	0.0%	6.1%	0.0%	4.6%	0.0%
D	0.0%	0.0%	8.1%	8.1%	0.0%	0.0%	0.0%	3.4%	4.0%	2.7%	4.0%	0.0%
A	0.5%	0.0%	0.9%	2.4%	0.5%	0.3%	0.0%	0.5%	0.7%	0.3%	0.2%	1.0%
E	0.0%	0.0%	12.0%	1.9%	6.7%	0.0%	0.0%	1.9%	0.0%	0.2%	0.0%	0.0%
B	0.0%	0.0%	0.0%	6.0%	0.0%	0.0%	0.0%	0.0%	0.3%	2.2%	1.8%	0.0%
G♭	0.0%	0.1%	5.3%	7.5%	0.0%	0.1%	0.0%	0.0%	7.2%	0.0%	2.2%	0.0%
D♭	0.0%	0.0%	3.6%	0.3%	1.1%	0.0%	0.0%	0.9%	3.4%	0.0%	1.8%	0.0%
A♭	1.3%	0.0%	0.0%	0.0%	2.5%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
E♭	1.9%	0.0%	0.0%	10.4%	9.6%	0.0%	0.0%	1.1%	3.7%	1.5%	0.0%	0.0%
B♭	16.5%	0.0%	0.0%	2.7%	4.7%	6.0%	0.0%	0.8%	0.0%	5.3%	7.7%	0.0%
F	0.0%	0.0%	0.7%	2.0%	4.0%	0.4%	0.0%	0.0%	6.0%	0.9%	0.4%	0.0%

Figure 2.8 Probability of modulating to a particular key – major tonalities

	i	♭II	♭ii	II	ii	III	iii	♯III	♯iii	IV	iv
C	4.0%	2.0%	0.0%	0.0%	2.0%	0.0%	12.0%	4.0%	0.0%	0.0%	8.0%
G	5.9%	2.9%	0.0%	0.0%	0.0%	2.9%	0.0%	11.8%	2.9%	29.4%	14.7%
D	0.0%	0.0%	0.0%	7.7%	3.8%	0.0%	0.0%	0.0%	11.5%	0.0%	0.0%
A	12.5%	4.7%	1.6%	1.6%	0.0%	0.0%	10.9%	7.8%	0.0%	4.7%	1.6%
E	4.0%	0.0%	1.3%	1.3%	5.3%	2.7%	1.3%	13.3%	13.3%	6.7%	1.3%
B	2.8%	1.4%	1.4%	4.2%	8.3%	4.2%	0.0%	5.6%	8.3%	9.7%	2.8%
G♭	9.5%	0.0%	2.4%	0.0%	0.0%	0.0%	0.0%	4.8%	0.0%	0.0%	16.7%
D♭	12.2%	4.4%	1.1%	3.3%	4.4%	1.1%	0.0%	3.3%	6.7%	0.0%	17.8%
A♭	0.0%	5.2%	0.0%	4.3%	12.2%	4.3%	0.9%	7.0%	6.1%	0.0%	13.9%
E♭	1.9%	3.7%	0.0%	0.0%	5.6%	0.0%	5.6%	0.0%	0.0%	27.8%	0.0%
B♭	4.3%	6.5%	0.0%	0.0%	2.2%	4.3%	0.0%	0.0%	0.0%	0.0%	19.6%
F	2.9%	0.0%	0.0%	0.0%	2.9%	2.9%	0.0%	2.9%	17.1%	17.1%	8.6%

	♯IV	♯iv	V	v	VI	vi	♯VI	♯vi	♭VII	♭vii	VII	vii
C	0.0%	2.0%	20.0%	4.0%	14.0%	18.0%	4.0%	0.0%	4.0%	2.0%	0.0%	0.0%
G	2.9%	0.0%	5.9%	2.9%	5.9%	0.0%	0.0%	5.9%	0.0%	2.9%	2.9%	0.0%
D	3.8%	0.0%	15.4%	11.5%	3.8%	0.0%	7.7%	15.4%	3.8%	0.0%	15.4%	0.0%
A	0.0%	0.0%	14.1%	0.0%	9.4%	4.7%	1.6%	7.8%	3.1%	1.6%	12.5%	0.0%
E	0.0%	1.3%	8.0%	4.0%	0.0%	1.3%	4.0%	21.3%	1.3%	0.0%	6.7%	1.3%
B	1.4%	0.0%	12.5%	5.6%	8.3%	0.0%	4.2%	0.0%	2.8%	15.3%	0.0%	1.4%
G♭	0.0%	0.0%	33.3%	2.4%	0.0%	0.0%	7.1%	7.1%	9.5%	2.4%	2.4%	2.4%
D♭	0.0%	0.0%	8.9%	1.1%	10.0%	18.9%	0.0%	0.0%	3.3%	1.1%	1.1%	1.1%
A♭	1.7%	0.0%	8.7%	0.0%	11.3%	18.3%	0.0%	0.0%	0.9%	2.6%	0.0%	2.6%
E♭	3.7%	1.9%	13.0%	0.0%	9.3%	1.9%	0.0%	18.5%	3.7%	0.0%	3.7%	0.0%
B♭	0.0%	15.2%	13.0%	4.3%	6.5%	0.0%	0.0%	0.0%	10.9%	2.2%	6.5%	4.3%
F	0.0%	2.9%	11.4%	0.0%	11.4%	11.4%	0.0%	8.6%	0.0%	0.0%	0.0%	0.0%

Figure 2.9 Probability of modulating to a particular key – Minor tonalities

	I	♭II	♭ii	II	ii	III	iii	♯III	♯iii	IV	iv
C	15.2%	8.7%	0.0%	0.0%	2.2%	19.6%	0.0%	2.2%	0.0%	0.0%	6.5%
G	10.7%	14.3%	0.0%	0.0%	0.0%	32.1%	3.6%	0.0%	3.6%	0.0%	7.1%
D	6.7%	0.0%	0.0%	0.0%	6.7%	20.0%	6.7%	0.0%	0.0%	6.7%	26.7%
A	22.0%	0.0%	2.4%	0.0%	0.0%	0.0%	2.4%	24.4%	2.4%	0.0%	4.9%
E	17.9%	7.1%	0.0%	0.0%	7.1%	10.7%	0.0%	0.0%	0.0%	0.0%	0.0%
B	21.2%	0.0%	0.0%	0.0%	3.0%	15.2%	12.1%	0.0%	0.0%	0.0%	12.1%
F♯	10.0%	0.0%	0.0%	4.0%	4.0%	8.0%	0.0%	2.0%	6.0%	2.0%	14.0%
C♯	11.8%	0.0%	0.0%	1.3%	1.3%	25.0%	0.0%	2.6%	2.6%	0.0%	18.4%
G♯	6.5%	0.0%	0.0%	0.0%	9.7%	45.2%	0.0%	3.2%	3.2%	0.0%	12.9%
E♭	13.0%	4.3%	0.0%	0.0%	0.0%	8.7%	4.3%	4.3%	0.0%	4.3%	0.0%
B♭	5.1%	3.4%	0.0%	0.0%	1.7%	0.0%	32.2%	1.7%	3.4%	3.4%	6.8%
F	1.7%	1.7%	0.0%	0.0%	3.4%	54.2%	1.7%	5.1%	0.0%	1.7%	1.7%

	♯IV	♯iv	V	v	VI	vi	♯VI	♯vi	♭VII	♭vii	VII	vii
C	0.0%	2.2%	6.5%	8.7%	13.0%	2.2%	2.2%	2.2%	4.3%	2.2%	0.0%	2.2%
G	0.0%	3.6%	3.6%	10.7%	3.6%	0.0%	3.6%	0.0%	3.6%	0.0%	0.0%	0.0%
D	0.0%	0.0%	6.7%	6.7%	6.7%	0.0%	0.0%	0.0%	6.7%	0.0%	0.0%	0.0%
A	0.0%	0.0%	4.9%	2.4%	12.2%	2.4%	12.2%	0.0%	2.4%	0.0%	4.9%	0.0%
E	0.0%	0.0%	10.7%	14.3%	25.0%	3.6%	0.0%	0.0%	3.6%	0.0%	0.0%	0.0%
B	0.0%	0.0%	3.0%	18.2%	3.0%	0.0%	0.0%	0.0%	6.1%	6.1%	0.0%	0.0%
G♭	2.0%	2.0%	4.0%	30.0%	2.0%	0.0%	0.0%	0.0%	4.0%	4.0%	2.0%	0.0%
D♭	0.0%	0.0%	6.6%	2.6%	11.8%	0.0%	0.0%	2.6%	11.8%	0.0%	1.3%	0.0%
A♭	0.0%	0.0%	0.0%	0.0%	12.9%	0.0%	3.2%	0.0%	0.0%	3.2%	0.0%	0.0%
E♭	0.0%	8.7%	0.0%	8.7%	13.0%	4.3%	0.0%	4.3%	21.7%	0.0%	0.0%	0.0%
B♭	3.4%	0.0%	3.4%	10.2%	6.8%	0.0%	0.0%	0.0%	13.6%	3.4%	1.7%	0.0%
F	0.0%	0.0%	3.4%	11.9%	5.1%	0.0%	0.0%	0.0%	5.1%	1.7%	1.7%	0.0%

2.3 Unequal temperament and key characteristics

In the first part of this chapter, I have discussed the impact of unequal temperament on melody and harmony. This final section addresses the possible links between unequal tuning systems and the characteristics that have been historically ascribed to keys.

Traditionally, different keys have been associated with different characteristics. In *A History of Key Characteristics in the Eighteenth and Early Nineteenth Centuries*, Rita Steblin addresses the issue in depth.[19] She explains that there are at least two conflicting explanations at work to account for key characteristics. The first maintains that pitch height is responsible for the affect of tonalities, while the second maintains that unequal temperament causes these differences, making different keys more suited for different musical topoi.

In the late 17th century, several French musicians (Rousseau, Charpentier, Masson, Rameau) published lists of keys and of their specific properties. For instance, Figure 2.10 reproduces the way in which Charpentier describes the characteristics of different keys. In later publications, musicians appear to abandon subjective characterisation in favour of grouping keys into categories when referring to their affect. In the article "Ton" from the *Encyclopédie,* for instance, Rousseau describes key characteristics as shown in Figure 2.11.

[19] Rita Steblin, *A History of Key Characteristics in the Eighteenth and Early Nineteenth Centuries* (Rochester, NY: University of Rochester Press, 2002).

Figure 2.10 Marc-Antoine Charpentier's Key Characteristics (1682)
Reproduced from Steblin, Table 3.1

	The Character of Keys
C major	Gay and militant
C minor	Gloomy and sad
D minor	Serious and pious
D major	Joyful and very militant
E major	Effeminate, amorous, and plaintive
E minor	Quarrelsome and clamorous
E♭ major	Cruel and hard
E♭ minor	Horrible, frightful
F major	Furious and quick-tempered
F minor	Gloomy and plaintive
G major	Sweetly joyful
G minor	Serious and magnificent
A minor	Tender and plaintive
A major	Joyful and pastoral
B♭ major	Magnificent and joyful
B♭ minor	Gloomy and terrible
B minor	Lonely and melancholic
B major	Harsh and plaintive

Figure 2.11 Jean-Jacques Rousseau's Key Characteristics (1765)
Reproduced from Steblin, Table 3.4

	The Character of Keys
F and the flat major keys	Majesty, gravity
A, D, the sharp major keys	Gaiety or brilliance
The flat minor keys	Touching or tender
C minor	Tenderness
F minor	Lugubriousness and sadness

Similar descriptions of keys have been published afterwards, by Castil-Blaze, Gianelli, etc., all based on Rousseau's *Encyclopédie* entry. Despite some minor differences (all explained in detail by Steblin in her book), terms like 'Gay, brilliant, spirited, and martial, vivacity' are used to describe the effect of major keys with sharps, while 'majesty, gravity' refer to the flat major keys, and F major. Different terms are used to describe minor keys; they vary from 'touching, tender' to 'religious, lugubrious, sad, biting, dry, and savage'. In general, a trend emerges: keys on the sharp side are often described as brilliant and bright, while keys on the flat side are characterized as softer and nobler.

In his dissertation, Miller addresses the topic of key characteristics and their possible link to temperament. He explains that a lot of theorists have pointed out that C major is a key that is appropriate for pure, simple, naïve music, characteristic that coincide with the fact that traditional unequal temperaments usually privilege C major as the key closest to just intonation. Miller then explains that the descriptions given to A major, such as more energetic, have to do with the larger size of the A-C♯ major third. When reaching keys even further along the circle of fifths, such as B major, traditional key characteristics reach an extreme in character. For minor keys, Miller believes that the less pure a chord is, the more mournful a key sounds.

What I have discussed so far are mostly 18th-century debates on key characteristics that took place in France. Were these characteristic still relevant in Chopin's time or had they been relegated to tradition? Writers after Chopin's death noted how some keys were more appropriate for certain types of pieces because of the tuning system. Like Bellman points out, Mathis Lussy writes that "the result of this system of tuning is that the scales of A♭, D♭, and G♭ are sweet, almost effeminate, whilst those of E and B are hard and harsh. We shall, therefore, generally find that *genre* pieces, such as Nocturnes, Reveries, &c., are written in flats."[20] Ernst Pauer also discussed how certain keys were appropriate to certain pieces, writing that "D flat major […] is remarkable for its fullness of tone, and its sonorousness and euphony. It is the favorite key for Notturnos."[21] These authors show

[20] Mathis Lussy, *Musical Expression,* translated by M. E. von Glehn (London: Novello, 1892), 7.
[21] Ernst Pauer, *The Elelments of Beautiful Music* (London: Novello and Company, 1877), 25.

that in the late 18th century, traditional ideas on key characteristic still held despite the progressive shift to equal temperament.

Chapter 3 – An Intervallic Study of Chopin's Piano Works

This chapter consists of an intervallic analysis of a corpus of 99 Chopin pieces. By locating and weighing all the harmonic major thirds, I aim to determine how Chopin might have responded to the sound of an unequal temperament by privileging some major thirds while avoiding others. I chose to focus on major thirds because, as I have shown in the first chapter, they are significantly affected by temperament. Moreover, potential tuning errors seem to be more noticeable in major thirds than in minor thirds. Steven Cannon writes that while the minor third exists in the harmonic series, neither of its notes share a pitch class with the fundamental note, which potentially allows for a higher tolerance in tuning error. Compared to the major third (5:4), the minor third (6:5) is higher in the harmonic series, granting it a more dissonant status.[1] Finally, focusing on a specific interval type keeps the size of the study manageable.

In the first section, I describe a similar experiment conducted by John Barnes and Steven Cannon on Bach's *Well-Tempered Clavier,* and explain how I adapt it to Chopin's music. The remainder of the chapter is dedicated to explaining my hypothesis, describing my analytical method, presenting the results, and analysing them in a discussion.

3.1 Barnes's and Cannon's analysis of *Das Wohltemperierte Klavier*

In a 1979 article, "Bach's Keyboard Temperament," John Barnes analyses the musical content of *Das Wohltemperierte Klavier*, books I and II, to determine which kind of

[1] Steven Cannon, "Deducing Temperament from Analysis of the Well-Tempered Clavier: Contradictory or Complementary Evidence?" McGill University (2007): 2.

unequal temperament Bach might have adopted. Barnes's method consists in identifying, rating and compiling all of the harmonic major thirds found in the major-key preludes. He explains that "the avoidance of bad major thirds [...] appears to be the principal constraint in the use of a circular temperament. This should be an influence on the composer which, in favourable circumstances, might be recognizable as confirmation of the use of a circular temperament."[2] *Das Wohltemperierte Klavier* is the ideal work for this type of analysis since Bach explores all 24 tonalities in pieces that are all of comparable length. As the purity of major thirds varies depending on the temperament, the idea is that finding the most common ones in a work that explores all major and minor keys could conceivably give an indication of Bach's tuning preferences.

Barnes identifies all the harmonic major thirds in the major-key preludes and evaluates their prominence using a points system. He deducts points from a third if it does not sound for a significant amount of time, if its two notes are unequal in strength, if it is not in the middle or lower register of the keyboard, or if it sounds at the same time as other notes. Based on these criteria, he gives each third a ranking from A (most prominent) to E (least prominent). Any tuning error would be very obvious in a third labelled A and virtually imperceptible in a third labelled D or E. To give more statistical weight to higher-ranked thirds, Barnes multiplies the results in the following way: Ax8, Bx4, Cx2, Dx1 and Ex0.

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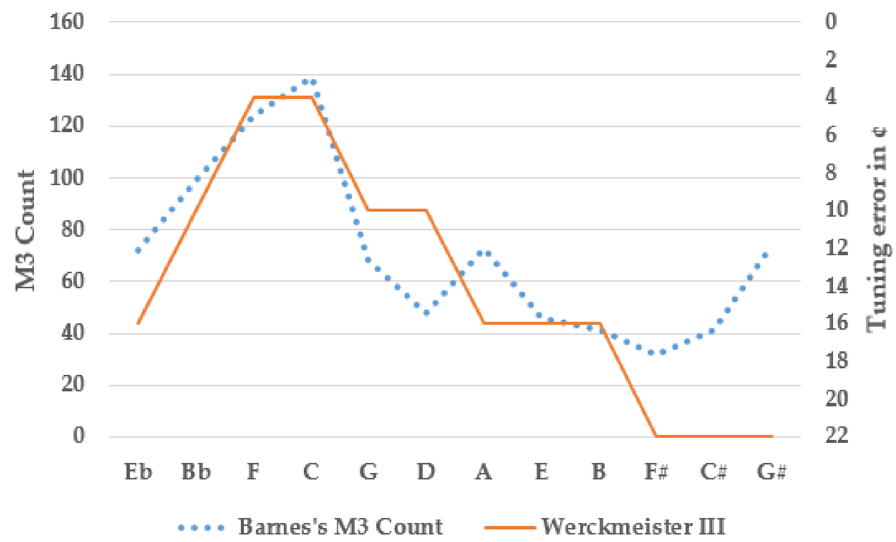
[2] John Barnes, "Bach's Keyboard Temperament: Interval Evidence from the Well-Tempered Clavier," Early Music 7/2 (1979): 241.

Barnes deduces that if Bach were to have responded to purer thirds by using them more prominently or more often, then we could infer his temperament of choice by examining the relative prominence of major thirds. As shown in Figure 3.1, the final count of major thirds expressed as a curve has a similar contour to the curve displaying the error in cents of the major thirds in Werckmeister III, a popular temperament in Bach's time. In other words, the thirds used more often by Bach correspond to the purer thirds of this unequal temperament. The resemblance of the major third curve to a historically appropriate temperament, hard to dismiss as coincidental, gives credence to Barnes's notion that a temperament might be reflected in the music itself. The two curves do not match exactly and Barnes suggests three causes for these deviations. First, the creative process of composition is influenced by other factors than temperament. Second, the 24 major-key preludes are a rather small sample; had Bach written more than two books of preludes, the data might correspond more precisely to the suggested temperament. Finally, Barnes suggests that the deviations exist because Bach might have used a temperament slightly different from Werckmeister III. The remainder of the article is spent describing Barnes's "invented" temperament, which corresponds more closely to the curve of major thirds resulting from his analysis.

Figure 3.1 Barnes's major third count evaluated against Werckmeister III



Barnes's study only addresses the major-key preludes. He does not analyse the fugues because they present more compositional constraints that may distort the data. In a 2007 paper, Steven Cannon analyses the minor-key preludes using a modified version of Barnes's method. Cannon devises his own way of weighting the thirds by applying "strict criteria to Barnes's vague descriptions."[3] He reduces the prominence rating of a major third if:

- It sounds along with a dissonance;
- The two notes are not struck simultaneously;
- The major third sounds for only a sixteenth note (two points are removed for thirds lasting less than a sixteenth-note);

[3] Cannon, "Deducing Temperament," 7.

- The major third is located above the treble staff. (Barnes and Cannon omit these major thirds ter because variations in tuning would be less evident in a higher register)

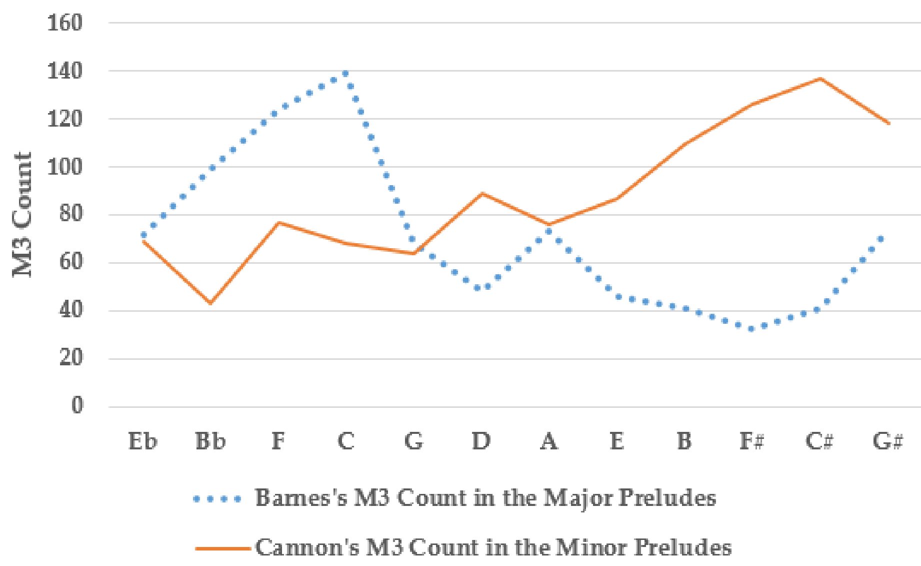
These criteria allow Cannon to classify thirds by prominence: the more points are allotted to a major third, the more it is audible in the musical texture, therefore having possibly been influenced more by temperament. Like Barnes, Cannon obtains thirds ranked from A to E. He only includes the thirds labelled A, B and C in his analysis, multiplying them in the following way: Ax4, Bx2, Cx1.

As shown in Figure 3.2, the curve for the minor-key preludes is nearly opposite to Barnes's curve for the major preludes. Major thirds that are traditionally closer to just intonation, such as F–A and C–E, are more prevalent in major keys than in minor ones. Conversely, major thirds that are generally more tempered in an unequal temperament, such as B-D♯, F♯-A♯, and other major thirds belonging to keys distant from C major, are more frequently used by Bach in the minor-key preludes. Major keys would consequently privilege purer sounds, while minor keys would tend to feature more heavily tempered and brighter sonorities. Cannon concludes that Bach might have conceived the sounds of the major and minor modes in different ways, hinting at "a relationship between temperament and mode […] at work in Bach's music."[4] For the remainder of the article, Cannon evaluates the data against a series of modern and historical temperaments,

[4] Ibid, 14.

concluding that Francesco Antonio Vallotti's 1780 temperament would fit his results more accurately.

Figure 3.2 Cannon's and Barnes's results



3.2 Analysing chopin's piano works

My intervallic analysis of Chopin's piano works builds on Barnes' and Cannon's experiment on Bach. By examining this corpus, I hope to shed light on how Chopin might have treated major and minor keys differently by emphasizing different major thirds depending on the mode.[5]

To analyse the corpus, I use criteria very similar to Cannon's. I assign a label from A to D to each major third, removing a point if:

[5] The harmonic major third is especially interesting to study in a Chopin corpus because as Rothstein has pointed out, "Chopin often centered his melodies on the third degree of the major scale." Rothstein, "Chopin and the B-major Complex," 4.

- **The third is played at the same time as a dissonance;**

I consider any sonority that is not a major third, a major triad, or a minor triad as a dissonance. Moreover, I only remove a point if the dissonance is struck simultaneously with the major third.

- **Both notes are not struck simultaneously;**

I deduct one point if both notes are not struck at the same time. I consider grace notes and rolled chords as simultaneous.

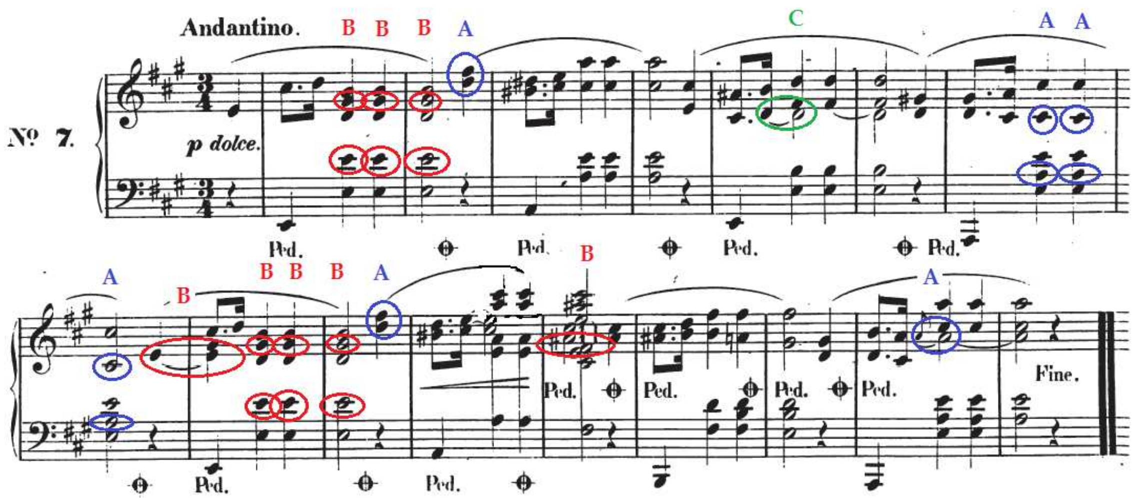
- **The third lasts for a sixteenth note or less.**

I deduct one point if a third lasts for a sixteenth note or less.

Unlike Barnes and Cannon, I ignore thirds below and above the grand staff in my analysis. When a major third is played in an extreme register, I feel that a tuning error would be less audible than in the middle register, which is used by piano tuners to set the bearings of a temperament. By only accounting for major thirds located between G2 and B♭5, I hope to obtain a more precise picture of the intervals Chopin used to prioritize because of tuning.

A score of the A-major prelude is shown in Example 3.1, illustrating my weighting by hand of all of its major thirds according to the above criteria. The first three E-G# major thirds are rated *B* because of the chordal seventh, D. The D-F# in bar 2 is rated *A* as no points need to be removed: the third is not played at the same time as a dissonance, the two notes are struck together, the third lasts for a whole beat, and is within the treble staff. The D-F# third in bar 5 is rated *C*. The D is struck earlier than the F#, and the third resonates at the same time as the dissonant E in the left hand. I ignore the two A-C# thirds in bar 11 since they are above the treble staff. Finally, the A-C# third in the penultimate bar receives the highest rating because I consider the grace note as simultaneous with the rest of the chord.

Example 3.1 Chopin, Prelude in A major, Op. 28 No. 7

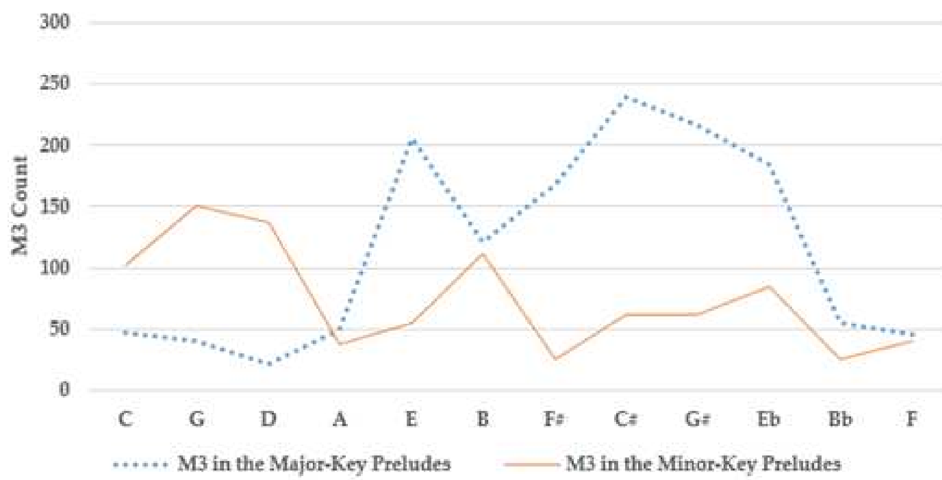


A preliminary study conducted by hand on the *24 Preludes*, Op. 28, indeed shows a difference in treatment of major thirds depending on the mode. In Figure 3.3, the dotted curve indicates the prominence of major thirds in the major-key preludes, while the solid curve represents major thirds in the minor-key preludes. The two curves are, to a first approximation, in an inverse relationship, suggesting that Chopin, like Bach in Cannon's account, understood the affect of the two modes as opposite in nature. Comparing these results to the general shape of 19th-century temperaments indicates that Chopin might have preferred the sound of bright major thirds (such as those found on roots distant from C major) when writing in major tonalities. Conversely, he might have aimed for the sweeter sound of thirds, noticeably closer to pure, when writing minor-key music. Analysing a larger corpus allows me to provide a more accurate depiction of Chopin's treatment of thirds in both modes; it also allows to pursue statistical validation of my results using a larger corpus.

A potential criticism that could be raised about analyzing the Chopin corpus is that the differentiation between keys in the temperaments he used were less pronounced than the ones in Bach's lifetime. As figure 3.1 shows, the major thirds in a temperament like Werckmeister varied from 4¢ to 22¢ wider than just intonation. Indeed, a tuning system like Hummel's, that approximates equal temperament, has significantly less differentiation between keys. However, what we find in tuning manuals does not necessarily reflect the practical temperaments that were attained, and it is possible that the differentiation between keys was larger than what theorists intended. Moreover, temperaments such as Jousse's feature thirds that vary from 9 to 21¢ wider than just intonation - a range fully two-thirds as wide as the range in Werckmeister - and so there would definitely be an audible difference since most scholars agree that the threshold for recognizing tuning discrepancies is around 5 or 6 ¢.[6]

[6] Loeffler, "Instrument Timbres and Pitch Estimation," 6.

Figure 3.3 Intervallic analysis of the *24 Préludes*, Op. 28



3.3 Hypothesis

Based on the preliminary study conducted on the 24 Préludes Op. 28, it is likely that analyzing the larger corpus will result in similar data at a larger-scale level. If Chopin privileges major thirds that are traditionally purer when composing in minor keys, and brighter, more tempered major thirds in major keys, we will probably see this reflected in the data given by the larger corpus. Since Chopin also prefers composing in keys further away from C major, containing more black keys, there might be a higher incidence of major thirds using at least one black key on the piano. Knowing this, we can formulate the following hypotheses:

- **There will be a higher incidence of major thirds that use at least one black key of the keyboard.**
- **There will be substantial discrepancies between the use of major thirds in major and minor keys.** Following the results obtained by analyzing the 24 Preludes Op. 28, we can expect pure major thirds to be more prevalent in minor keys, and

brighter, more tempered major thirds to be more frequently used in major tonalities.

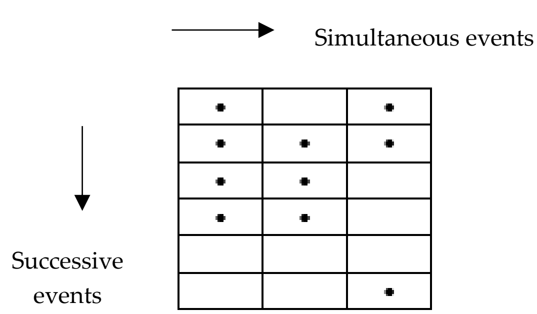
3.4 Method

Analyzing the corpus by hand would be too time consuming, but the Humdrum toolkit offers a handy solution. Developed by David Huron in the 1980s, it is a set of command-line tools that can be used in computational musicology. The various utilities can be applied on different types of musical data that is encoded using a particular syntax. In this section, I will provide a brief explanation of the Humdrum syntax and of some of the tools, then describe the process I used for analyzing the Chopin corpus.

a) The Humdrum Syntax

The Humdrum syntax provides a manner in which different types of musical data can be encoded. The tokens are organized in vertical spines on a two-dimensional plane, as shown in Figure 3.4. Successive events unfold from top to bottom on the vertical axis, while concurrent events are represented as being horizontal. In other words, the data is organized much like a music staff that was rotated 90°: time unfolds from top to bottom rather than from left to right, and simultaneous events are presented side-by-side rather than being one above the other.

Figure 3.4 Simultaneous and successive events in the Humdrum syntax



Several pre-defined Humdrum representations are available for encoding musical data. The **kern format, for instance, is defined by Huron as a "core pitch/duration representation for common practice music notation."[7] Example 3.2 shows the opening four bars of Chopin's E minor prelude Op. 28 No. 4 in **kern format. The two spines (the parallel vertical lines of data) respectively show the two hands of the pianist. Note how the complete chords of the left hand are shown in the first spine. Individual spines do not need to be restricted to a single note; they can account for chords, double stops, or voice splitting.

**kern files show three types of data: notes, rests, and bar lines.

- **Notes** are represented with upper and lower-case letters. Middle C becomes c; higher octaves are designated by repetition: C5 = cc, C7 = cccc, etc. Notes below middle C are designated with capital letters: C3 = C, C2 = CC. For instance, the first two melodic notes of the prelude are respectively encoded as b and cc. The B belongs to the '4' octave, and the C to '5'. Other elements, such as accidentals, can be attributed to a note. A sharp is indicated by an octothorpe (#) and a flat by a minus sign (-). A natural is a lower-case n. Rhythmical values are placed before the pitch name, represented by numbers that corresponds with the English name of the duration: 4 is a quarter note, 8 is an eighth note, and so on. For instance, each

[7] David Huron, "The Humdrum User Guide," accessed on July 3, 2016, http://www.humdrum.org.

of the pitches in the left-hand spine of Figure 3.5 is preceded by the value 8, indicating that they are eighth notes.[8]

- **Rests** are identified by a lower-case r and are accompanied by a number representing duration. For instance, the first token in the left-hand spine is 4r, which indicates that a whole-note rest occurs in the score.
- **Bar lines** are represented via an equal sign (=) followed by a measure number. While bar line indications occupy a line in the document, they are not considered as having a duration since no number precedes them.

The **kern format is only one of the several representations made possible by the Humdrum syntax. Other formats allow for encoding lyrics, piano fingerings, solfege syllables, frequencies, and so on. For this project, I use the **kern and **pitch representations. Both are analogous, the sole difference being that under the **pitch representation, notes are represented in ISO format (a pitch letter followed by an accidental if necessary, then by an octave number). Figure 3.6 shows the same Chopin excerpt, this time encoded using the **pitch representation. Notice how upper- and lower-case letters are replaced by ISO pitch notation.

[8] Other symbols can be used to encode articulation, phrasing, and ornamentation, among others. Since my study only addresses pitch and rhythmic data, I will not discuss these representations. A thorough explanation of the different signifiers is available at http://www.humdrum.org/guide/ch02/.

Example 3.2 Chopin, Prelude in E minor, Op. 28 No. 4, mm. 1-4

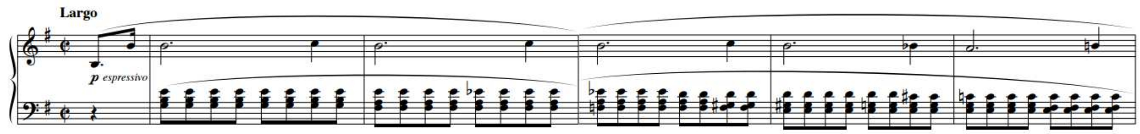


Figure 3.5 Chopin, Prelude in E minor, Op. 28 No. 4, mm. 1-4 in **kern representation

```
*Ipiano     *Ipiano
*lh   *rh
*clefF4     *clefG2
*k[f#]      *k[f#]
*e:   *e:
*met(C|)    *met(C|)
*M2/2 *M2/2
*MM72 *MM72
4r    8.B
.     16b
=1    =1
8G 8B 8e   2.b
8G 8B 8e   .
8G 8B 8e   .
8G 8B 8e   .
8G 8B 8e   .
8G 8B 8e   .
8G 8B 8e   4cc
8G 8B 8e   .
=2    =2
8F# 8A 8e  2.b
8F# 8A 8e  .
8F# 8A 8e  .
8F# 8A 8e  .
8F# 8A 8e- .
8F# 8A 8e- .
8F# 8A 8e- 4cc
8F# 8A 8e- .
=3    =3
8Fn 8A 8e- 2.b
8F 8A 8e-  .
8F 8A 8e-  .
8F 8A 8e-  .
8F 8A 8d   .
8F 8A 8d   .
8F 8G# 8d  4cc
8F 8G# 8d  .
=4    =4
8E 8G# 8d  2.b
8E 8G# 8d  .
8E 8G# 8d  .
8E 8G# 8d  .
8E 8Gn 8d  .
8E 8G 8d   .
8E 8G 8c#  4b-
8E 8G 8c#  .
```

Figure 3.6 Chopin, Prelude in E minor, Op. 28 No. 4, mm. 1-4 in **pitch representation

```
*Ipiano     *Ipiano
*lh   *rh
*clefF4     *clefG2
*k[f#]      *k[f#]
*e:   *e:
*met(C|)    *met(C|)
*M2/2 *M2/2
*MM72 *MM72
4r    8.B
.        16B
=1       =1
8G3 8B3 8E4     2.B4
8G3 8B3 8E4     .
8G3 8B3 8E4     .
8G3 8B3 8E4     .
8G3 8B3 8E4     .
8G3 8B3 8E4     .
8G3 8B3 8E4     4C5
8G3 8B3 8E4     .
=2       =2
8F#3 8A3 8E4    2.B4
8F#3 8A3 8E4    .
8F#3 8A3 8E4    .
8F#3 8A3 8E4    .
8F#3 8A3 8Eb4   .
8F#3 8A3 8Eb4   .
8F#3 8A3 8Eb4   4C5
8F#3 8A3 8Eb4   .
=3       =3
8F3 8A3 8Eb4    2.B4
8F3 8A3 8Eb4    .
8F3 8A3 8Eb4    .
8F3 8A3 8Eb4    .
8F3 8A3 8D4     .
8F3 8A3 8D4     .
8F3 8G#3 8D4    4C5
8F3 8G#3 8D4    .
=4       =4
8E3 8G#3 8D4    2.B4
8E3 8G#3 8D4    .
8E3 8G#3 8D4    .
8E3 8G#3 8D4    .
8E3 8G3 8D4     .
8E3 8G3 8D4     .
8E3 8G3 8C#4    4Bb4
8E3 8G3 8C#4    .
```

b) The Humdrum toolkit

The Humdrum toolkit provides a set of tools that can be used in conjunction with other command-line tools. When using the toolkit to manipulate encoded music, one quickly realizes that the challenge lays not so much in understanding the capabilities of individual tools, but in associating them with others to obtain the desired output. For my study of the Chopin corpus, two humdrum tools and three (UNIX) tools are relevant:

- The ****pitch** command, when followed by a filename, outputs data encoded in the **pitch format. It can translate files encoded in formats such as **kern or **midi. For instance, the following command would translate the .krn file in pitch notation, and create a new file named prelude28-04.pit.

```
pitch prelude28-04.krn > prelude28-04.pit
```

- The ****ditto** command replaces null tokens, designated by a period (.), by the previous token in the spine. This is particularly useful in calculating harmonic intervals whose two pitches are not struck simultaneously. For instance, applying the **ditto command to the Op.28 No. 4 Prelude would replace the null tokens that appear in the right-hand spine when a note is held over (see Figure 3.5) by another instance of the previous pitch token. Notice how in measure 1, the 2.b token is repeated on every line until the pitch changes to 4cc. This explicitly indicates that the half-note B in the score creates harmonic intervals with every left-hand chord, even the ones who are not struck simultaneously with the melodic line.

```
        Ditto prelude28-04.krn

    **kern  **kern
    *Ipiano *Ipiano
    *lh     *rh
    *clefF4 *clefG2
    *k[f#]  *k[f#]
    *e:     *e:
    *met(C|)        *met(C|)
    *M2/2   *M2/2
    *MM72   *MM72
    4r      8.B
    4r      16b
    =1      =1
    8G 8B 8e        2.b
    8G 8B 8e        2.b
    8G 8B 8e        2.b
    8G 8B 8e        2.b
    8G 8B 8e        2.b
    8G 8B 8e        2.b
    8G 8B 8e        4cc
    8G 8B 8e        4cc
```

- The **grep** command is a utility that allows for searching lines that match a regular expression (a sequence of characters). It does a global search for the expression and prints the lines containing it. If we wanted to identify all lines containing an F#4 in the Op.28 No. 4 Prelude, we could obtain them with the following command:

```
grep F#4 prelude28-04.pit
```

Adding the option –v to the command prints the line that *do not* contain the regular expression.

```
grep -v F#4 prelude28-04.pit
```

- The **egrep** command is analogous to grep, but it allows for searching extended regular expressions that contains features such as the logical OR (|). The following command would search for all lines containing either F#4, F#5, or both.

```
egrep 'F#4|F#5' prelude28-04.pit
```

  The –v option can also be applied to the egrep command to identify all lines that *do not* contain an expression

```
egrep -v 'F#4|F#5' prelude28-04.pit
```

- The **wc** command (short for word count), when combined with the –l option, prints the line count of the output. For instance, the following command would indicate how many lines (in **kern format, simultaneous sonorities), contain a B♭ in any octave:

```
grep Bb prelude28-04.krn | wc -l
```

  The vertical line (|) separates the two commands in a pipeline. The output of the first command becomes the input of the second.

c) Analyzing the corpus

The corpus studied in this chapter contains 99 Chopin pieces—a combination of Etudes, Mazurkas, Preludes, and Waltzes—that are available in *kern format. As stated earlier, I want to find all harmonic major thirds that occur within the grand staff and remove a point if the two pitches are not struck simultaneously, if they sound along a dissonance, or if at least one of them lasts for a sixteenth note or less. Figure 3.7 lists the eight possible combinations of these features, along with the rating they would obtain. Since I do not take into account thirds rated D in my analysis, we can ignore the last option.

Figure 3.7 Eight possible sets of features for a harmonic major third

Features of the major third	Rating
1) Simultaneous pitches, consonances only, longer than a 𝅘𝅥𝅯	**A**
2) Simultaneous pitches, dissonant, longer than a 𝅘𝅥𝅯	**B**
3) Simultaneous pitches, consonances only, 𝅘𝅥𝅯 or shorter	**B**
4) Simultaneous pitches, dissonant, 𝅘𝅥𝅯 or shorter	**C**
5) Non-simultaneous pitches, consonances only, longer than a 𝅘𝅥𝅯	**B**
6) Non-simultaneous pitches, dissonant, longer than 𝅘𝅥𝅯	**C**
7) Non-simultaneous pitches, consonances only, 𝅘𝅥𝅯 or shorter	**C**
8) Non-simultaneous pitches, dissonant, 𝅘𝅥𝅯 or shorter	**D**

Part 1. Finding major thirds with simultaneous pitches

We can begin by identifying all harmonic thirds that occur on simultaneous pitches. Let's take the third C4-E4 as an example. The following command gives us the number of simultaneous sonorities containing the major third C4-E4, that are longer than a sixteenth note.

```
Pitch * | grep C4 | grep E4 | egrep '1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4|12E4' | wc -l
# find lines containing C4-E4 major thirds that are longer than a sixteenth note
```

In this pipeline:

- **Pitch *** translates the corpus in pitch notation (pitch *).

- **grep C4** finds all lines (simultaneous sonorities) containing C4. Here, the **pitch notation is convenient: searching for the character 'c' in a corpus encoded in **kern format would also print lines including 'cc', 'ccc,' and so on.
- **grep E4** searches in all the lines containing C4 for lines that also contain E4.
- **egrep '1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4|12E4'** finds all lines containing C4 and E4 that last for a whole, half, quarter, or sixteenth note, or a triplet. Lines containing either of these notes in a shorter value will be ignored.
- The **wc –l** command counts the number of lines that satisfy the above criteria.

The command seizes all major thirds, whether or not they sound along with a dissonance. There are only three types of consonant sonorities containing a major third: the major third on its own, a major triad, and a minor triad. To find the C4-E4 major thirds that belong to these three sonorities we can run the following commands.

```
Pitch * | grep C4 | grep E4 | egrep  '1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4|12E4'
| egrep –v 'D|F|G|A|B|C#|Cb|E#|Eb' | wc -l
# find lines containing only Cs and Es

Pitch * | grep C4 | grep E4 | egrep  '1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4 |
grep G | egrep –v 'D|F|A|B|C#|Cb|E#|Eb' | wc -l
# find lines containing C4-E4 as part of a major triad

Pitch * | grep C4 | grep E4 | egrep  '1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4 |
grep A | egrep –v 'D|F|G|B|C#|Cb|E#|Eb' | wc -l
# find lines containing C4-E4 as part of a minor triad
```

The first command only counts lines containing Cs and Es, as any other pitch is eliminated through the egrep –v command. The second command counts all lines containing a C4-E4 major third along with a G in any register, creating a major triad, while the last command counts all lines containing a C4-E4 major third along with an A in any octave, creating a minor triad.

Adding the results of the last three commands gives the amount of major thirds C4-E4 that are part of a consonant sonority. Subtracting this result from the total number of C4-E4 major thirds gives the amount of thirds that are part of a dissonant sonority. After running the above four commands, therefore, we know the number of C4-E4 major thirds that satisfy the first two sets of features.

To identify major thirds that last a sixteenth note or shorter, we can use the same pipelines with a slightly modified command:

```
Pitch * | grep C4 | grep E4 | wc -l
# find lines containing C4-E4 in any duration

Pitch * | grep C4 | grep E4 | egrep -v ‘D|F|G|A|B|C#|Cb|E#|Eb’ | wc -l
# find lines containing only Cs and Es

Pitch * | grep C4 | grep E4 | grep G | egrep -v ‘D|F|A|B|C#|Cb|E#|Eb’ | wc -l
# find lines containing C4-E4 as part of a major triad

Pitch * | grep C4 | grep E4 | grep A | egrep -v ‘D|F|G|B|C#|Cb|E#|Eb’ | wc -l
# find lines containing C4-E4 as part of a minor triad
```

Running these commands gives us all simultaneous major thirds in any duration. Since we know the number of major thirds lasting longer than a sixteenth note, we can subtract them from these results to obtain the number of C4-E4 major thirds that last a sixteenth note or shorter, corresponding with options 3) and 4).

Part 2. Finding major thirds with non-simultaneous pitches

To find non-simultaneous major thirds, we can use the ditto command. The following commands can be used for finding thirds belonging to options 5) and 6)

```
Pitch * | ditto | grep C4 | grep E4 | egrep
‘1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4|12E4’ |  wc -l
# find lines containing C4-E4 thirds that are longer than a sixteenth note
```

Followed by

```
Pitch * | ditto | grep C4 | grep E4 | egrep
‘1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4|12E4’ | egrep -v
‘D|F|G|A|B|C#|Cb|E#|Eb’ | wc -l
# find lines containing only Cs and Es


Pitch * | ditto | grep C4 | grep E4 | egrep
‘1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4 | grep G | egrep -v
‘D|F|A|B|C#|Cb|E#|Eb’ | wc -l
# find lines containing C4-E4 as part of a major triad

Pitch * | ditto | grep C4 | grep E4 | egrep
‘1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4 | grep A | egrep -v
‘D|F|G|B|C#|Cb|E#|Eb’ | wc -l
# find lines containing C4-E4 as part of a minor triad
```

Again, we subtract the sum of the last three commands from the first to obtain the number of dissonant and consonant thirds.

Major thirds a sixteenth note or shorter can be found as previously, with the following commands:

```
Pitch * | ditto | grep C4 | grep E4 | egrep -v
‘1C4|1E4|2C4|2E4|4C4|4E4|8C4|8E4|12C4|12E4’ |  wc -l
# find lines containing C4-E4 thirds that are longer than a sixteenth note
```

Followed by:

```
Pitch * | ditto | grep C4 | grep E4 | egrep -v ‘D|F|G|A|B|C#|Cb|E#|Eb’ | wc -l
# find lines containing only Cs and Es

Pitch * | ditto | grep C4 | grep E4 | grep G | egrep -v ‘D|F|A|B|C#|Cb|E#|Eb’
| wc -l
# find lines containing C4-E4 as part of a major triad

Pitch * | ditto | grep C4 | grep E4 | grep A | egrep -v ‘D|F|G|B|C#|Cb|E#|Eb’
| wc -l
# find lines containing C4-E4 as part of a minor triad
```

Applying the ditto command to the whole corpus finds the non-simultaneous thirds, but also the simultaneous thirds we had already found in part 1. To obtain the number of non-simultaneous thirds only, we can subtract the results from Part 1 from the results obtained here.

3.5 Results

I ran the described humdrum commands on a corpus of 99 Chopin pieces, which are listed in Figure 3.8. The amounts listed represent the numbers of major thirds that occur on any note between G2 and B♭5; for instance, the following row represents the sum of all G♭3/B♭3, G♭4/B♭4, G♭5/B♭5, F♯3/A♯3, F♯4/A♯4, and F♯5/A♯5 major thirds rated A,B, and C present in the corpus.

Gb/B♭	137	280	192

The number of major thirds, sorted by prominence, is shown in Figure 3.9. To increase the statistical importance of the more prominent thirds, I weighted them in the following manner: Ax3, Bx2 and Cx1. Figure 3.10 shows the weighted results, which are represented in graph form in Figure 3.11.

Figure 3.8

a) Piano works contained in the corpus

Etudes (4 pieces)	Op. 10 Nos. 2, 4, 5, and 9
Mazurkas (52 pieces)	Op. 6, 7, 17, 24, 30, 33, 41, 50, 56, 59, 63, 67, 68, B. 82, 134, 140
Nocturnes (1 piece)	Op. 72 No. 1
Préludes (24 pieces)	Op. 28
Waltzes (18 piecse)	Op. 18, 34, 42, 64, 69, 70, B. 21, 44, 56, 133, 150

b) Breakdown by key

Major keys		Minor keys	
C	7	**C**	5
G	3	**G**	3
D	2	**D**	1
A	1	**A**	12
E	2	**E**	5
B	4	**B**	4
G♭/F♯	2	**F♯**	4
D♭	4	**C♯**	7
A♭	12	**G♯**	2
E♭	3	**E♭**	2
B♭	3	**B♭**	2
F	2	**F**	6

Figure 3.9 Major thirds from G♭2 to B♭5, grouped by prominence

Major Pieces

	A	B	C
C/E	251	190	146
G/B	165	138	98
D/F♯	101	201	154
A/C♯	68	73	196
E/G♯	159	226	57
B/D♯	173	196	80
Gb/B♭	137	280	192
D♭/F	276	402	303
A♭/C	525	719	239
E♭/G	76	508	140
B♭/D	100	110	136
F/A	61	140	217

Minor Pieces

	A	B	C
C/E	231	215	92
G/B	129	285	595
D/F♯	85	225	140
A/C♯	225	192	103
E/G♯	184	354	213
B/D♯	185	276	152
G♭/B♭	103	210	129
D♭/F	118	197	79
A♭/C	156	265	270
E♭/G	69	119	66
B♭/D	84	103	49
F/A	122	198	105

Figure 3.10 Weighted major thirds from G♭2 to B♭5, grouped by prominence

Major Pieces

	A	B	C
C/E	753	380	146
G/B	495	276	98
D/F♯	303	402	154
A/C♯	204	146	196
E/G♯	477	452	57
B/D♯	519	392	80
Gb/B♭	411	560	192
D♭/F	828	804	303
A♭/C	1575	1438	239
E♭/G	228	1016	140
B♭/D	300	220	136
F/A	183	280	217

Minor Pieces

	A	B	C
C/E	693	430	92
G/B	387	570	595
D/F♯	255	450	140
A/C♯	675	384	103
E/G♯	552	708	213
B/D♯	555	552	152
G♭/B♭	309	420	129
D♭/F	354	394	79
A♭/C	468	530	270
E♭/G	207	238	66
B♭/D	252	206	49
F/A	366	396	105

Figure 3.11 Major thirds in 99 Chopin pieces, major and minor keys separated

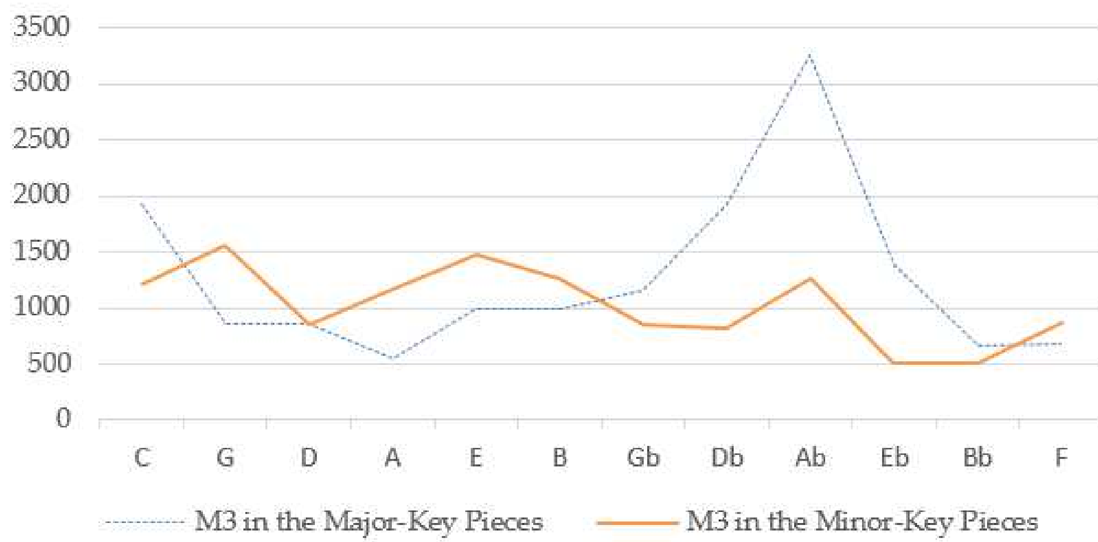
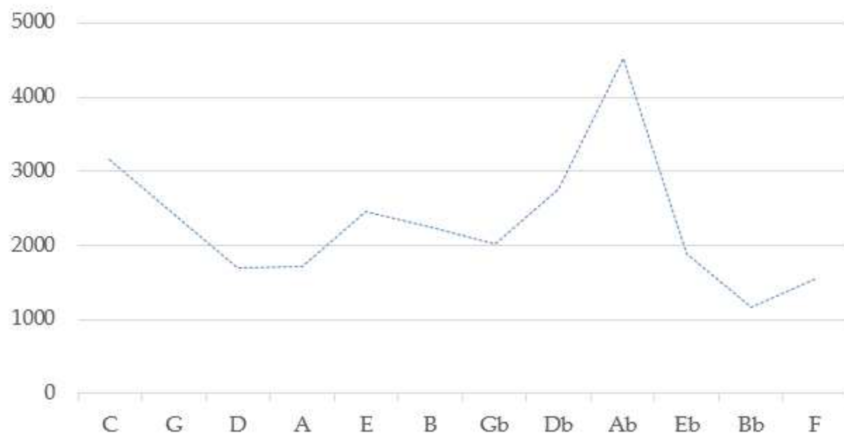


Figure 3.12 Major thirds in 99 Chopin pieces, major and minor keys combined



3.6 Discussion

The results shown in the previous section summarize Chopin's treatment of different major thirds in the corpus. While this data can provide information related to temperament, several other factors influence the results.

1. Not every key is equally represented, which affects the curve. For instance, the presence of 12 pieces in A♭ major is partly responsible for the peak at the A♭-C major third. The curves shown in Figure 3.11, however, are not only related to the number of pieces present in each key. For instance, the corpus contains four pieces each in B and D♭ major, but Chopin uses a significantly larger number of harmonic major thirds on D♭-F than on B-D♯. In C and E minor, which are each represented by five pieces, the major third contained in the C minor tonic chord, E♭-G, is used significantly less often than the G-B third contained in E minor.
2. While it might seem desirable to normalize the results to make each key equally significant - dividing each total of major thirds by the total number of measures in keys they could belong to - doing so would be problematic for a few reasons. First,

this method would imply that I, IV, vi, V, and so on, which all contain major thirds, are equally likely. Moreover, normalizing the data would deemphasize the significant fact that Chopin simply decided to use some major thirds more frequently than others.

3. While the presence of several pieces in a particular key can augment the number of major thirds that belong to its tonic chord, we must also keep in mind that a piece's tonality is only representative of its home key, and that several keys can be explored within a same piece. The large number of thirds on A♭ major can be partly caused by the large number of pieces analyzed in this key, but also because as seen in Chapter 2, Chopin often modulates to that key while writing in other tonalities. Consequently, even if the data presented in the last section is influenced by the unequal key-representation in the corpus, it is still representative of Chopin's taste and choice of frequent major thirds.
4. A large number of major thirds in one key can also indicate that Chopin preferred to use this sonority in a thicker texture. A preference for a thick, chordal texture in some tonalities as opposed to a scalar or arpeggiated texture in others might also be related to temperament.

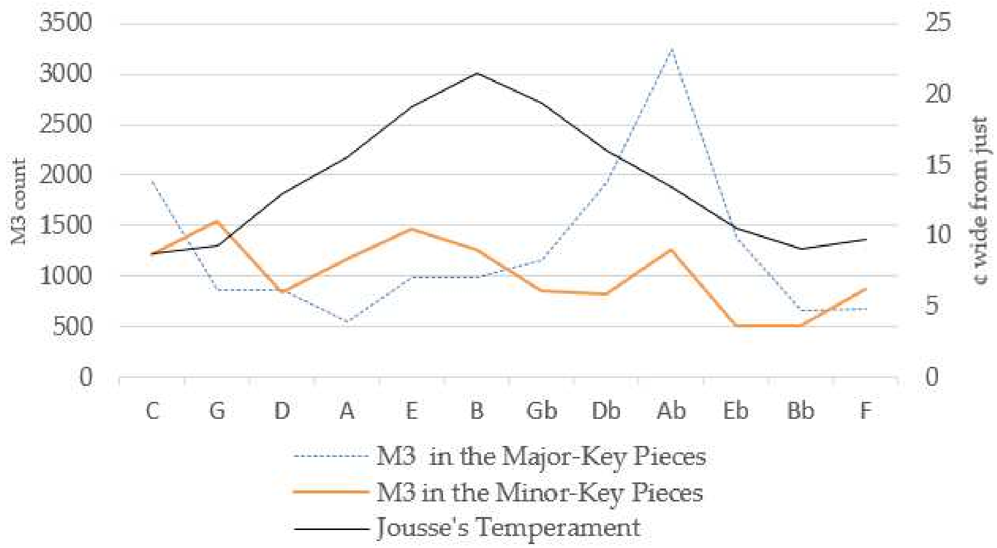
With these observations in mind, we can now revisit our previous hypotheses with the results obtained from the corpus.

- **There will be a higher incidence of major thirds that use at least one black key of the keyboard.**

In fact, the four harmonic major thirds that are more frequently used in major-key pieces are A♭-C, D♭-F, C-E, and E♭-G. C-E stands out among the other 'white-note' keys, as it is used significantly more often than the G and F major thirds. The A♭-D♭ and E♭ tonalities are all adjacent on a circle of fifths, and would therefore be tuned in similar ways in an unequal temperament. Figure 3.13 shows the results of the study compared with Jousse's well-temperament; the black curve shows the amount in cents by which each major third diverges from just intonation. The three major thirds fall somewhere in between both extremes of the temperament; they are more tempered than C major but not as extreme and bright as B or E major. In fact, the major thirds A♭, D♭ and E♭ vary between 396 and 402¢, which is close to today's equal tempered 400¢ major third – perhaps Chopin thought these particular sonorities were appropriate for more chordal textures. Of course, this might not be the only explanation for the popularity of these major thirds, as they are also similar in size to the rarely-used D-F# and A-C# major thirds.

There is yet another similarity between the E♭-G, A♭-C, and D♭-F major thirds: when played as part of a major triad (E♭, A♭ and D♭ major), they are laid out in the same way on a keyboard. The outer notes of the triad are on elevated on black keys, while the middle one is lower on a white key. Perhaps the particular hand position brought on by these chords felt especially comfortable for Chopin when writing in more chordal textures, and this may explain why we find these major thirds more frequently than others.

Figure 3.13 Results compared with Jousse's temperament



We can turn to Chopin's own writings to clarify his understanding of the piano keyboard. Chopin wrote some sketches for a piano pedagogy method, which was not published during his lifetime. The drafts have been assembled by Jean-Jacques Eigeldinger in a volume called *Esquisses pour une méthode de piano*. Chopin writes:

> *The position of the hand is found by placing the fingers on the keys E, F#, G#, A#, B: the long fingers will be placed on the elevated keys, and the short fingers on the low keys. Fingers on the elevated keys must be placed in a same line, like the ones placed on the white keys […] this will give the hand a curve which will provide a necessary suppleness that it could not attain with straight fingers. The supple hand; the forearm, the arm, everything will follow the hand in the natural order of things.* [9]

[9] Frédéric Chopin, *Esquisses pour une méthode de piano* (Paris: Flammarion, 1993), 64. My translation. Original text reads: "On trouve la position de la main en plaçant les doigts sur les touches mi, fa#, sol#, la#, si : les doigts longs occuperont les touches hautes, et les doigts courts les touches basses. Il faut placer les doigts qui occupent les touches hautes sur une même ligne et ceux qui occupent les blanches de même… ce qui donnera à la main une courbe qui donne une souplesse nécessaire qu'elle ne pourrait avoir avec les doigts étendus. La main souple; le poignet, l'avant-bras, le bras, tout suivra la main selon l'ordre."

This indicates that Chopin preferred using tonalities where the longer fingers would fall on the black key, because this particular setup provides more support for the hand. The following passage also supports this:

> *The tuning being done at the keyboard by the tuner, this difficulty not existing anymore for the pianist, it is useless to start by learning the C scale at the piano, the easier one to read, and the hardest for the hand, having no fulcrum. We start with a [scale] that places the hand more easily, placing the long fingers on the elevated keys, for instance B major.*[10]

Chopin encouraged his students to anchor their fingers on the black keys because he felt that this method was ergonomic and practical. The results of the study, however, show that he rarely used the harmonic major thirds belonging to keys following these schemes, like E or B major. Perhaps he felt that these tonalities were more appropriate for scalar or arpeggiated textures.

To sum up, the harmonic major thirds that are mostly used in major keys, when played in an unequal tuning, would correspond to a tempered sound that is similar to the thirds attained in today's equal temperament. Moreover, their layout on the keyboard may also be a factor in their frequent use. In minor tonalities, no particular patterns emerge; perhaps studying a larger corpus would yield more precise results.

[10] Ibid., 66."L'intonation étant faite au piano par l'accordeur, cette grande difficulté n'existant plus pour le pianiste, il est inutile de commencer à apprendre les gammes au piano par celle d'ut, la plus facile pour lire, et la plus difficile pour la main, comme n'ayant aucun point d'appui. On commence par une (gamme) qui place la main facilement, occupant les doigts longs avec les touches hautes, comme [p]ar ex[emple] si majeur."

The amount of major thirds located on white keys is generally lower, the C-E major third being the only exception. In minor keys, the pure-sounding G major third is the more frequently used, with C-E trailing not far behind. This may suggest that Chopin might have sought a bright, lively sound for some of his major pieces, while aiming for smoother sonorities in the minor preludes.

- **There will be some correlation between the use of major thirds in major and minor keys.**

The correlation coefficient between the major-key and minor-key curves is approximately 0.14, which shows a weak positive correlation (the thirds follow each other rather than being opposed). Given its weak strength, the direction of the correlation is indistinguishable from chance; it is not conclusive enough to suggest Chopin envisioned the sounds of major and minor keys in opposing or similar ways. Once again, perhaps the other factors affecting composition along with the unequal key representation in the corpus are affecting the results.

Finally, the curve for major thirds is significantly flatter in minor keys than in major keys. Even if the two curves are not significantly correlated, this difference suggests that Chopin may have preferred to use the major third sonority more in the major mode than in minor keys.

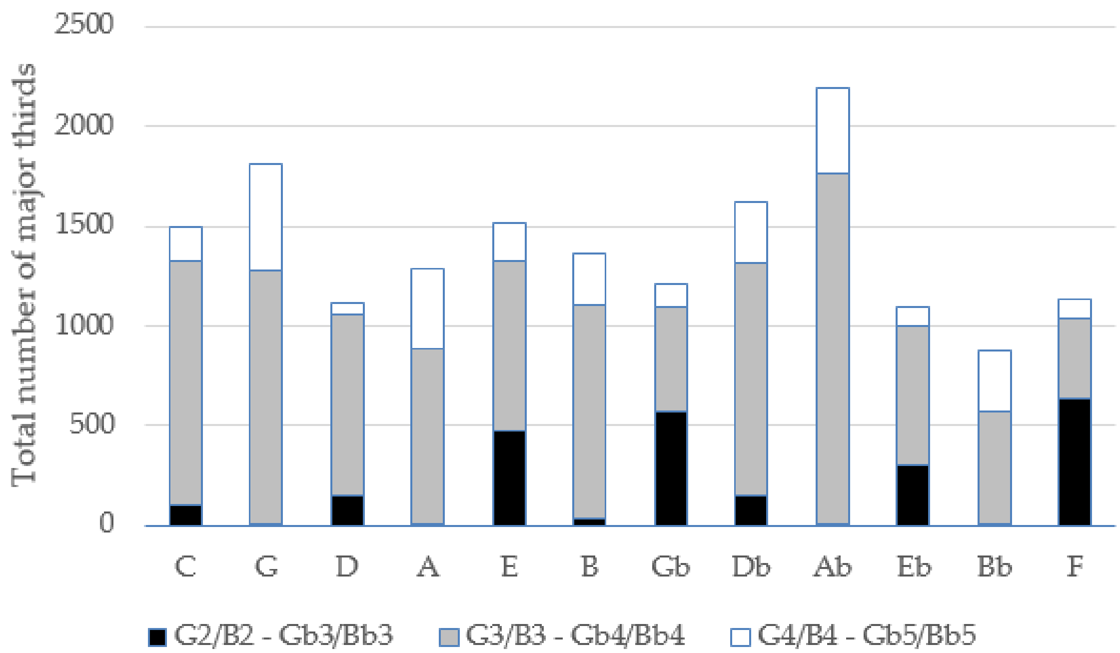
In addition to providing an answer to the hypotheses formulated, other interesting results arose from this study. To reiterate, when searching for major thirds in the corpus, I only analyzed the pitches ranging from G2 to B♭5. This decision was motivated by the fact that tuning error is less clear when an interval is played in extreme registers. When compiling the results, it became increasingly evident that Chopin tends to use harmonic major thirds more frequently when writing between G♭3 and B♭4, in the middle register of the piano. Figure 3.14 shows the distribution of major thirds in the different registers. The white area shows the major thirds in the higher part of the staff, the grey shows the thirds in the middle register and the black shows the lower major thirds. The grey area is significantly larger, showing how harmonic major thirds are more frequent in the middle register.

Two factors could explain this data. First, as shown in Example 3.3, in pieces like the mazurkas and waltzes, Chopin tends to writes using a bass-chord-melody texture. The block chords, which occur mostly in the middle register, often contain a major third, which could explain the high instance of this interval. The lower register is usually used for single notes or octaves, while the higher one is responsible for the melody, which may explain why harmonic major thirds are less common in these registers.

Not all pieces in the corpus, however, are written in this texture; the freer pieces, like the preludes and etudes, vary in texture, and Chopin may use a scalar or arpeggiated texture. Some pieces featuring block chords, like the preludes in E major or A♭ major, feature blocked chords that happen in the middle register.

Interestingly, the middle register is also the one where tuners set the bearings for a temperament before tuning the rest of the keyboard. Maybe chords in a middle register would sound better and clearer than in the extremes of the keyboard, where melodies and basslines can stand out because of their register. A study of all intervals in all registers of the corpus could shed light on whether or not chords are mostly used in the middle register, and whether particular intervals are more frequent than others in some registers.

Figure 3.14 Major thirds in different registers



Example 3.3 Bass-chord-melody texture in Chopin, Waltz in G♭ major Op. 70 No. 1, mm. 1-7

Conclusion

After presenting an overview of meantone, unequal, and equal temperaments, the first chapter of this research explained why modern tuning differs from the 19th-century tunings. In the second chapter, I focused on how temperament can affect certain musical parameters, and the third chapter examined how Chopin's choice of intervals can reflect his preference in terms of temperament. This last section will summarize my research's finding, and suggest some topics for future research.

4.1 Questions addressed in this research

- *What theoretical and practical challenges did 19th-century keyboard tuners face?*

In the first chapter, I showed what types of tuning instructions were available to 19th-century musicians, and what types of temperaments each would result in. Because of vague instructions, the same instructions could easily have different outcomes. Later in the 19th century, instructions intended to teach twelve-tone equal temperament would in fact only give approximate results, because of the lack of precise beat charts.

- *Which types of temperaments may have been available to Chopin, and what were their characteristics?*

At the end of the first chapter, I presented and described five unequal temperaments that were available during Chopin's lifetime. Pleyel & Dussek's, Jousse's, Hummel's and de Morgan's temperaments are all extracted from 19th-century tuning manuals, while the Representative Victorian is designed by Jorgensen as an average of temperaments available on Broadwood pianos – one of Chopin's favourite firms - in the mid-1880s. These five temperaments are by no means an exhaustive list, but provide an overview of the tuning landscape of 19th-century Europe. Since we have no explicit pronouncements by Chopin on the temperament he preferred, nor do we have evidence of how Pleyel pianos were tuned in the Paris Chopin knew, I am hesitant to single out one temperament as "the best" for playing Chopin. We can reasonably conclude, nonetheless, that the pianos Chopin had at his disposition featured enough discrepancies in interval size to create audible differentiation between keys.

- *What features of Chopin's music may have been affected by temperament?*

Temperament has an impact on both the vertical (harmonic) and horizontal (melodic) dimensions of music, and the two are often intertwined. In the second chapter, I explained how both the chromatic scale and chord colour can be affected by inequalities in temperament. Miller and Van Evera have addressed these issues from different angles, and I relied on their research to show how they take form in Chopin's piano repertoire. I showed examples of Chopin's music in which particular semitones were rhetorically emphasized, and explained how this would be linked to changes in colour. Moreover, I described how particular chords, which would be accompanied by striking colour changes in an unequal temperament, were emphasized by Chopin with shifts in musical parameters such as texture, dynamic, and register.

- *Does Chopin treat all keys in the same manner, or are some types of modulations more frequent in the context of certain keys? How might this relate to temperament?*

By analyzing and compiling all modulations in the mazurkas, waltzes, etudes, ballades, nocturnes, polonaises, and scherzos, I have shown that Chopin does not treat all tonalities the same way, and that a modulation that is prevalent in one key may not be as frequent in another. The modulations that recur more often in Chopin's piano works, apart from the regular diatonic moves to the dominant, subdominant, and relative, often feature two keys that would contrast in colour in an unequal temperament. (C♯ minor to D♭ major, B major to G major, etc.) Since Chopin treated different keys in different ways, it is likely that he understood them in different ways. If individual keys had their own aesthetic meaning for him, he probably did not consider them as interchangeable.

- *Did Chopin favour some major thirds – an interval significantly affected by temperament – over others? To what extent can this interval evidence from the music provide a consistent picture of the structure of a temperament?*

A study of a 99-piece corpus shows that when writing in major keys, Chopin tends to use the A♭-C, D♭-F and E♭-G major thirds more frequently. The C-E major third is also very common. The first three of these intervals are adjacent on the circle of fifths, and would therefore be tempered similarly in an unequal temperament. In a traditionally-shaped tuning system such as Jousse's, these intervals would fall between the highly tempered thirds such as B-D♯ and the purer sounding F-A. Chopin perhaps found this particular sound to be especially appropriate when writing in a texture with several chords; the popularity of these intervals may also be related to how they fall under the fingers at the keyboard.

4.2 New research paths

- *What other musical parameters can influence the prominence of an interval?*

I have classified and ranked intervals based on their range, duration, and level of consonance. In order to gain an even clearer image of the intervals preferred by Chopin, other issues, such as the harmonic and metric context of intervals, could be considered in further research. The prominence of an interval is likely to be influenced by the function of the chord it belongs to, or by its relationship to the downbeats and weak beats of a measure.

- *What is the relationship between textural changes and temperament?*

I have addressed the issue of musical texture in specific examples, showing for instance how Chopin might move to a thinner style while modulating to a purer key, or use thick chords when writing in a key that would be more tempered. Further research could take a broader, comprehensive approach to analyze Chopin's treatment of texture and its relationship with tonality. Are there any general trends in the textures Chopin uses for particular keys? Does he write differently (register, chord thickness) depending on the degree of purity of a tonality? Building on Rothstein's research on the B-major complex, other studies could be conducted on Chopin's association of musical topics with some keys.

- *Were other composers of the same era affected by temperament in a way similar to Chopin's when composing keyboard music?*

Van Evera's dissertation standing as the only exception, the sparse literature on 19th-century temperament and composition focuses mainly on Chopin. Further research could address the music of Liszt, Schubert, Schumann, etc. and its relationship to temperament. On top of potentially providing insight on these composers' treatment of tonality and of other musical aspects, such studies could shed light on the results I obtained from this research. Was Chopin influenced by temperament in similar ways as his contemporaries? Can we notice trends in their general treatment of modulation, tonality, etc.?

4.3 Final thoughts

While temperament can be studied from a theoretical perspective, its main interest lies in how it affects music as an aural phenomenon. In the case of unequal temperaments like the ones Chopin would have been used to, the differences between keys are subtle, but there are ways to enhance them during a performance. The use of the soft pedal, various dynamics, or changes in attacks can increase the effect of a change in purity between keys. As I have explained in the first chapter, a good number of pianists have recorded some of Chopin's compositions on an unequally tempered piano, using different temperaments; I believe that any traditionally shaped unequal temperament, that confers a purer sound to tonalities closer to C while becoming progressively wider as we move through the circle of fifths, has the potential to give a good result. Moreover, since it to be expected that he experienced a variety of temperaments himself while playing on different pianos, trying to pick one only as the ultimate answer might be a little too idealistic.

Nonetheless, I am confident that performances of Chopin's piano music on a retuned keyboard can help a performer wishing to play music in a way that may be closer to what Chopin's contemporaries would have heard. As I show in Chapter 2, both the melodic and harmonic dimensions of the music can be affected by temperament; it can be left to the performer's imagination to find a way to emphasize these discrepancies between intervals with performance techniques. In the meantime, I hope that this research has helped in showing that unequal tuning systems do not only affect the music during a performance, but that they can also have an impact on a composer's writing process, playing a role in musical factors such as texture, key organization within a piece, chord voicing, and the overall choice of a key for a piece.

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