Corpus Study of Voice-Leading

LANEY LIGHT

Georgia Institute of Technology

CLAIRE ARTHUR

Georgia Institute of Technology

# INTRODUCTION

VOICE leading, an integral aspect of Western music, refers to the way individual voices, or musical parts, move together in a multi-part texture. This movement must consider each voice’s melodic motion (horizontal intervals) as well as the harmony created between voices active at the same time (vertical intervals). Voice leading is commonly associated with part-writing in a homophonic style (i.e., choral music), but aspects of voice leading, though stylistically constrained, are relevant to all forms of classical music and, in fact, to almost all Western styles of music, including popular and jazz styles.

Voice leading in Western music originated in early forms of polyphonic singing during the Middle Ages as described in early compositional treatises dating back to the ninth century (Fuller, 2002). As polyphonic music evolved during the Medieval to Renaissance period, theorists expanded these guidelines to account for more complex counterpoint with more voices. The term “counterpoint” first appeared in the 14th century to describe the combination of simultaneously sounding musical lines according to a system of rules (cite new Grove xxx). Historical treatises often present examples of what, in modern terms, we would refer to as voice leading, although a formal set of *general* rules (as one might find in modern textbooks on counterpoint or part writing) had not yet been codified at that point. However, modern textbooks (e.g. Aldwell et al, 2019) do contain a set of general rules for teaching voice leading principles, which can find their origins in compositional treatises of the Medieval and Renaissance periods. In addition, twentieth century texts on writing in the Renaissance style do contain general rules and guidelines (e.g., Gauldin, 1985). These guidelines, written by Renaissance music scholars, arise from the synthesis of a lifetime of observation of both early musical treatises and a vast body of early contrapuntal composition, and thus, while obviously simplified (since they are for pedagogical purposes) would be expected to conform to the stylistic norms of Renaissance polyphony. However, given the vast body of musical material from this period, it would be impossible for a human being to examine voice-leading practices in a systematic manner.

Computational methods have been used to analyze scores since the 1970s (Volk et al, 2011), but until relatively recently, we have not had the ability to study large volumes of scores computationally in an efficient manner. Using modern methods, we can now analyze scores to identify patterns and comprehensively examine how often, and under what conditions, composers “followed the rules” within a given style. Even though voice leading is a central component of the undergraduate music theory curriculum, it has received relatively little attention as the object of scholarly study. In this paper we comprehensively examine the voice-leading practices in a large body of Renaissance polyphony in order to clarify certain ambiguities (or inconsistencies) in both ancient and modern texts.

Examining voice leading patterns in Renaissance music using computational methods has implications for Renaissance voice leading pedagogy because it can highlight subtle variations or differences arising between Renaissance theory and practice, clarify the context under which certain rules appear to operate, and potentially identify a set of more general principles guiding certain compositional behaviors. Since Renaissance polyphony formed the basis for voice leading practices through the Baroque, Classical, and into the modern era, any insights gained from this research will also have implications for voice leading in later musical styles. There are, additionally, implications for other forms of computational analysis that focus on note-to-note or unit-to-unit transitions, when the principles guiding those transitions may differ at different "hierarchical" levels.

Although modern computational methods provide powerful tools for analyzing scores, defining compositional rules algorithmically requires careful consideration. For example, it is often unclear how the “rules” of voice leading should be applied regarding meter (or, an implicit pattern of strong and weak note positions). Isolated musical examples—especially in Renaissance treatises—are often presented as prototypical notation that is agnostic to the “beat,” specific note durations, or relative onset positions, or are demonstrated with a very specific selection of musical material. One question that arises, then, when trying to interpret these examples is whether they represent a rule to be followed at *any* “hierarchical level,” or whether there are separate rules that would apply to the “note-to-note" (or “interval-to-interval") transition level, and to the “beat to beat” levels? That is, are voice-leading rules to be applied differently at different hierarchical levels?

In this study, we took a systematic computational approach to investigate whether composers employ voice-leading differently in terms of the treatment of intervals on a note-to-note basis versus a "pulse to pulse" basis. To answer this question, we used a digitally encoded corpus of Palestrina’s masses. This corpus is ideal for this analysis since Palestrina is well known as an exemplar of Renaissance vocal polyphony (Benjamin, 2005), and therefore should be representative of voice leading practices during the Renaissance. Moreover, since Palestrina’s influence on the development of counterpoint is well established (Marvin, 2002;), we would expect to find evidence of at least some of these voice-leading practices in later polyphonic music.

# BACKGROUND

Historical and Theoretical Context

During the Renaissance, new developments in music and other art forms created the foundation for the arts in centuries to come (Blume, 1967). During this period, counterpoint saw a transition from early polyphonic forms, which were extensions of the monophonic plainsong style of Gregorian chants, to more complex polyphony with larger numbers of voices. By the time of Palestrina in the late Renaissance, both horizontal (melodic) and vertical (harmonic) intervals were carefully attended to when composing “good” counterpoint (Schubert, 2002).

Guidelines emerged during the Renaissance about what was generally considered “good” and “bad” polyphonic writing. The following quotes from Renaissance theorists Vicentino and Zarlino illustrate some of these guidelines about writing successions of the same type of interval.

“*...[one] must not make two similar consonances, such as two octaves, two fifths, two fourths, or two similar thirds, either major or minor, because of the way these intervals are generated by number [i.e. ratio]. Although custom permits two or more similar imperfect consonances...”*

- Vicentino (p.111, Maniates)

*“Since for this reason it is forbidden to place two perfect consonances of the same species consecutively, it is the more forbidden to write two imperfect ones of the same proportion, because these are not so consonant as the perfect....two consecutive major sixths [ascending or descending one step] are tolerable.''*

-Zarlino

*“Although...two consonances of similar proportion should not be written ascending or descending together, it is possible to write consecutive perfect or imperfect consonances of the same ratio, namely two octaves, two fifths... This can be done when the two voices involved exchange pitches, moving in contrary motion [example 50].”*

-Zarlino

As the number of voices increased in choral works, this presented challenges as it became increasingly more difficult to avoid breaking the rules. Even in a composition with five or more voices, all voices were typically in the texture less than one-third of the time (Gauldin, 1985, p. 179). However, in sections where the texture does contain five or more voices, some of the rules may have been less stringent. When writing for five or six voices, “the restrictions regarding the approach to octaves and even unisons are more relaxed than in writing for four voices” (Gauldin, 1985, p. 179). This indicates that the number of voices in the texture may be an important factor in the prevalence of breaking the voice leading rules.

Renaissance music presents challenges when defining rhythmic levels or hierarchies for computational voice leading analysis. While modern notation includes bar lines that (typically) define the beat hierarchy clearly, this notational practice was not yet used during the Renaissance. DeFord (2015) presents a nuanced discussion of the tactus in Renaissance music. For the purpose of this analysis, we will use DeFord’s definition of the compositional tactus (“the time unit that serves as a standard of reference for various aspects of rhythm.” The tactus in Renaissance music is typically the semibreve, or whole note (De Ford, 2015). Gauldin (1985) states that we can think of the meter in Palestrina’s music as 4/2, with one beat per minim or half note and two semibreves per “measure.” The semibreves can be subdivided into minims, where the minim receives one beat and the semibreve receives two beats (Benjamin (2005). Although Renaissance composers did not use measures in the modern sense, they did use a hierarchical framework of subdivided mensural notation which may indicate a hierarchy of mensural accents. We defined the “pulse beats” as the beats in each measure marked by the tactus (beats two and four in a 4/2 time signature). Notes falling on these beats are treated differently from a compositional perspective, for example they are more likely to be consonant (deFord, 2015).

It is unclear whether voice leading rules should be applied from one pulse beat to the next, or from any note to the next note. Modern voice leading texts often present examples of note-to-note transitions that are agnostic to the beat or time signature. Aldwell et al (2019) indicates that parallels on the “surface layer” created by passing or neighboring tones may be less important than the “more stable elements of the underlying voice leading. This suggests a hierarchy of beat importance from a voice leading perspective, where transitions from one strong beat to the next may be more important than other note-to-note transitions. Andrews (1958) states that “the interval combinations on the harmonic pulse beats of the measure are the vertical landmarks of the texture,” where the pulse beats normally land on a consonance (p. 62). These texts, along with the quotes below, suggests that intervals from one pulse beat to the next are the most pertinent for voice leading in Palestrina’s works. However, it is unclear how the implied importance of certain beats relates to actual compositional practice.

*“Direct consecutives perfect fifths and octaves or unisons between any two voices were rigidly prohibited in sixteenth-century polyphony. It does not matter on what pulses or factions of pulses of the measure they occur, nor how many voices may make up the tale of the parts, nor will consecutives be saved by the fact that one of the notes making the progression may be an unessential note.”*

* Andrews, 1958, p. 64

*“The rules prohibiting parallel perfect consonances apply in some cases to the intervals on consecutive semibreves even if there is another consonance on the second half of the first semibreve, because an intervening minim may not have enough structural weight to counteract the sense of progression from one semibreve to the next.”*

* DeFord, 2015, p. 89

Andrews gives explicit examples of “incorrect” technique in Palestrina’s works, where direct consecutives at the pulse level are interrupted by a passing tone. However, we do find evidence of this pattern used occasionally in Palestrina’s masses, as illustrated in **Fig. 1**. Using modern computational techniques, we can analyze millions of individual intervals to quantify how often these types of patterns occur in compositional practice, and under what circumstances.



**Fig 1.** Excerpt from Palestrina’s *Missa Sine nomine (Mantuan),* *Agnus.* The orange notes break the “rule” prohibiting direct consecutive perfect intervals if the interval is measured from one pulse beat to the next. Because of the passing tone in the bass in blue, the rule is not broken at the note-to-note level.

Literature Review

There have been many studies on Renaissance counterpoint and Palestrina in particular, but most have used traditional musicology approaches. (e.g. Jeppesen, 1927; These studies have covered a wide range of historical and music theory topics, for example dissonance (Jeppesen, 1927), paraphrase (Marshall, 1963), imitation (Whang, 2004), and modular analysis (Hanson, 1983; Schubert et al, 2013. Using computational methods, we can build on these theoretical works to examine scores systematically and identify patterns from large datasets in ways that are not possible with traditional musicology approaches.

*Computational papers on Renaissance voice leading*

Huron and Collins (1999) investigated the degree to which voice leading rule sets by theorists such as Zarlino and Berardi agreed with compositional practice. This study focused on a specific type of composition type (the cantus firmus canon in Renaissance and Baroque music), which has exactly three voices and follows a strict canonic form. It was unclear whether melodic intervals rules should apply to all intervals or only those on the principle beats, or strong beats. To address this, Huron and Collins created two separate “inventories” of melodic intervals, one containing note-to-note intervals and the other containing intervals between notes on the strong beats. Each of these two inventories was combined with a third inventory containing all harmonic intervals and used to identify voice leading patterns. Although this study focused on a specific compositional form with many structural constraints, the approach of comparing several “inventories” of interval definitions to test agreement with voice leading rules can be extended to non-canonic Renaissance compositions with varying numbers of voices.

Wall et al (2020) conducted a perception study of the effects of voice leading and harmony on expectancy, using timbre discrimination as a cover task. Although this study did not analyze voice leading patterns from symbolic score data, they did use a systematic, empirical approach to study the effects of voice leading patterns on human perception. The stimuli included piano chord progressions classified as “good” or “poor” voice leading, using a series of voice leading rules (e.g. a preference for small steps as opposed to leaps, avoidance of parallel perfect intervals, and a preference for contrary motion). Participants were asked to respond as quickly as possible as to whether the chord timbre changed in the last chord. Faster reaction times were observed with “good” voice leading patterns than with “bad” patterns, lending support to the perceptual importance of voice leading.

*Other computational studies of Palestrina’s compositions*

Palestrina’s compositions provide a rich data source for computational analysis because of the large number of works that have been encoded as symbolic score data. Several studies have leveraged this data source for computational analyses, but to date none have focused specifically on corpus studies of voice leading patterns. For example, Knopke et al (2009) focused on melody, using a computational approach to identify melodic phrases that repeat in Palestrina’s masses. Farbood & Schoner (2001) did focus on counterpoint, but from a generative music perspective. They used Markov chains to generate a single harmonic counterpoint line from an existing melodic line in the style of Palestrina. They imposed rules for writing 16th century counterpoint and created probability tables to determine optimal note-to-note transitions. “Illegal” transitions, such as approaching a perfect interval by direct motion, were assigned a weight of zero, thus ensuring they would never occur in the generated results. For a generative task, imposing these rules ensures a prototypical solution. However, a full corpus analysis could reveal how often these scenarios occur in Palestrina’s compositions, and under what circumstances.

Sigler, 2015 conducted a corpus study of dissonances in the masses of Palestrina and Victoria. They identified a set of features for each dissonance, including metric weight and duration, and used the feature set to create a set of schemas, or common patterns. Mavromatis (2012) used a hidden Markov model (HMM) to analyze rhythmic structure in Palestrina’s compositions. They used set of “hard” rules and “soft” preferences related to metric placement. For example, a hard rule is “Any duration longer than a whole note must be placed on a strong beat (1 or 3).” The HMM confirmed the majority of “hard” rules and provided a quantitative prevalence of the “soft” preferences. However, the rules analyzed in this study were not related to harmonic intervals.

*Models for voice leading representation*

Because voice leading involves both horizontal (melodic) movement and vertical (harmonic) movement, there are multiple ways in which these patterns can be represented symbolically. Conklin (2002) presents a representation based on sequences of relationships between notes, considering both the vertical and horizontal structure. Each piece was encoded as simultaneous sequence of notes, which were then grouped into “viewpoint sequences” describing the relationships between those notes. Because a voice can remain stationary as others move, each piece was fully expanded to duplicate held pitches at each unique onset, creating a new vertical “slice” at each new onset. This full expansion can then be “sampled” at regular intervals (every quarter note, for example, in this corpus of Bach chorales). This enables searching for matches to specific viewpoint patterns (or voice leading patterns). While this approach is well-suited to computational analysis of voice leading patterns, the criteria for choosing an appropriate “sampling unit” is unclear.

As an alternative to the viewpoint representation model, Sears et al (2002) presented a “skip-gram” representation. It does not assume that each note depends only on the notes immediately before or after it. Instead, it employs skip-grams, defined as sequences occurring within a given number of events (for example, bigrams are defined as sequences within 2 events). As with Conklin’s method, Sears also conducted a full expansion defined by unique onsets before identifying patterns. An advantage of this method is its ability to uncover higher-level structural patterns that may be “hidden” by other passing tones. However, the skip-grams model does not account for the length of the notes or the beats on which the tones occur. Consequently, equal length bigrams could have different levels of structural importance. This model was tested on several corpora including Haydn string quartets and piano works by Mozart, Beethoven and Chopin. However, it was not evaluated on any music from the Renaissance era and focused more on tonal harmony (for example, identifying a specific chord progression) than specifically on voice leading.

Finkensiep et al (2018) extended the skip-gram model and applied it to identify common patterns within polyphonic streams. This model used a maximum distance measure based on the inter-onset interval, in contrast to Sears’ maximum distance measure based on a set number of skips. This approach seeks to address the problem unequal note durations being treated as skips of equal importance. Rather than slicing the score vertically at each new onset, this model allowed for overlapping notes (a new onset occurs in one part while the other part is held). However, it does not account for the specific beat on which a pattern starts or ends, uses a sliding window instead to define the intervals. It was also tested only on a corpus of Mozart piano sonatas with a maximum of three voices.

In this analysis, we employed aspects of several of these representation models. We performed a full expansion of the score, slicing at each new onset to obtain an inventory of all vertical intervals. We sampled from this inventory at regular intervals to obtain a separate inventory of pulse beat-to-pulse beat intervals, as described in detail in the Methodology section.

# METHODOLOGY

We used a systematic computational approach to analyze voice leading patterns. Our primary aim was to determine whether voice leading patterns differ based on the unit of analysis. Specifically, we compared the distribution of voice leading pattern types between notes positioned at the pulse beats, compared to the patterns between every note-to-note succession. We examined patterns that break the traditional rules of voice leading, testing whether the rules are broken more often from one pulse beat to the next, compared to all note-to-note successions. We also investigated factors associated with breaking the rules. In the following sections, we describe our data source and the methodology used to calculate intervals, identify voice leading patterns, and analyze the results.

**Corpus**

To address our research question, we identified a data source containing choral music from the Renaissance era. We used the corpus of 104 masses by Palestrina, encoded in music21 format. This corpus contains 1318 individual files (6 to 26 files per mass, with each file representing a movement or portion of a movement). The number of parts per file ranges from 3 to 8, with 90% written for 4 to 6 voices.

Voice leading patterns

We identified voice leading patterns by calculating all vertical (harmonic) intervals between voices and all harmonic (melodic) intervals within each voice. For each pair of voices in the texture at a given point in time, we used the horizontal and vertical intervals to categorizing the type of motion between those two voices.

First, we performed a full expansion of each score, replicating held tones at each new onset. We identified vertical intervals by “slicing” the score vertically each time a new event occurred in any of the voices. For each pair of voices in the texture at a given slice, we calculated the vertical bigram, or harmonic interval (e.g. m2 or M3 [1]). We reduced compound intervals greater than an octave to their simple interval equivalents (for example, a M9 was represented as a M2). Next, we calculated all horizontal bigrams, or melodic intervals, for each voice. This included both the interval and the direction of movement to the next slice (for example, descending P5 or ascending M3). Using the combination of vertical and horizonal intervals, we categorized the types of contrapuntal motion leading to each vertical interval, as described below.

* Parallel motion: both voices move in the same direction by the same exact intervals
* Similar motion: both voices move in the same direction by different intervals
* Contrary motion: voices move in opposite directions
* Oblique motion: one voice does not change from the previous note while the other voice moves in any direction
* Stasis: no movement between voices (i.e., one or both voices was resting on the previous vertical interval, or both voices repeat the same notes)

We created two inventories of intervals, categorizing the contrapuntal motion types in two ways. The first inventory (“note-to-note”) was based on all note-to-note successions (one vertical slice to the next). The second inventory (“pulse-to-pulse”) defined intervals from one pulse beat to the next, ignoring any notes in between. We defined the pulse as the whole note, or semibreve. The majority of the movements (n=1203) had a 4/2 time signature when translated into modern notation. For these movements, we defined beats 1 and 3 as the pulse beats. For the small number of 3/2 and 2/2 movements (n=114 and n=1, respectively), we defined beat 1 of each measure as the pulse beat. Within each inventory, we identified the following set of features associated with each vertical interval:

* Antecedent and consequent vertical intervals
* Antecedent and consequent beat positions
* Total number of voices in the texture at the consequent interval
* Position of each voice within the texture at the consequent interval (inner vs. outer voice)
* Whether each voice moved by a leap or a step
* Horizontal (melodic) bigram for each voice in the interval
* Motion type from the current interval to the next interval (parallel, similar, contrary, oblique, or stasis)

After creating the two inventories of intervals, we searched each inventory for specific patterns that violate two voice-leading “rules.” We focused on the following two rules governing harmonic intervals.

* R1: perfect harmonic interval (P5, P8, or P1) should not be approached by parallel motion
* R2: perfect harmonic interval (P5, P8, or P1) should not be approached by similar motion

Statistical Analysis

We conducted several statistical tests to assess the associations between metric position, hierarchical levels, and voice leading patterns. All statistical tests were conducted using JMP® software, and *p*-values less than .05 were considered statistically significant.

First, we tested whether the types of harmonic intervals (consonances and dissonances) differed for onsets on the pulse beats, compared to other metric positions. We categorized the harmonic intervals into perfect consonances (P1, P5, and P8), imperfect consonances (m3, M3, m6, and M6), and dissonances (all other intervals). Using a chi-square test, we compared the distributions of the interval categories for harmonic intervals landing on a pulse beat, compared to all other metric positions.

Next, we evaluated whether Palestrina used different voice leading patterns at different hierarchical levels. To do this, we compared the distribution of motion types (stasis, similar, parallel, oblique, and contrary) in the note-to-note inventory vs. the pulse-to-pulse inventory, using a chi-square test to determine if the two distributions were significantly different. We also calculated the percentage of intervals that violate each of the rules within each inventory. Using a chi-square test, we tested whether rule adherence differed using all note-to-note intervals compared to intervals between strong beats.

After we assessed the general differences in motion type patterns, we compared the prevalence of breaking specific voice leading rules. We calculated the percentage of all intervals that broke R1 (approaching a perfect harmonic interval by parallel motion) and the percentage that broke R2 (approaching a perfect harmonic interval by similar motion). We used a chi-square test to assess whether the rules were broken more often at the pulse-to-pulse level than the note-to-note level.

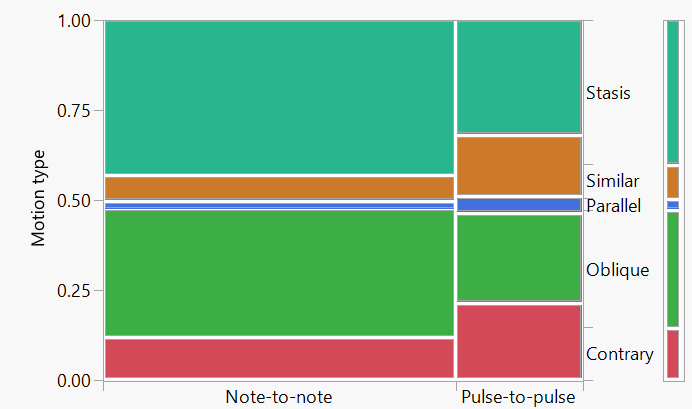
Once we identified whether there were significant differences in breaking the rules, we investigated the specific conditions under which the rules were broken. For example, was Palestrina more likely to break the rules in a texture with many voices, or when the upper voice moved by a leap as opposed to a step? Are there different factors associated with breaking rules at different hierarchical levels? To answer these questions, we used logistic regression, with separate models for each voice leading rule and separate models for the note-to-note and pulse-to-pulse inventories (4 total models). The dependent variable for each model was whether the rule was broken (0=no, 1=yes). The independent variables were: positions of the voice pair within the texture at the consequent interval (inner/inner, outer/outer, or inner/outer); total number of voices in the texture at the consequent interval (categorized as 2 to 3, 4 to 5, or 6+ voices); whether the upper voice moved by a leap; and whether the lower voice moved by a leap.

# RESULTS

The inventory of all note-to-note intervals contained 1,705,371 harmonic intervals with their associated features, which was approximately 2.8 times the size of the pulse-to-pulse inventory (615,730 intervals).

We found that the distribution of interval types and motion types was different at the pulse-to-pulse level than at the note-to-note level. The distribution of perfect, imperfect, and dissonant intervals on the pulse beats differed significantly from the distribution at other metric positions (p<.01 for the chi-square test). As shown in **Fig. 2**, consonances were more common on the pulse beats compared to other metric positions, consistent with trends described by Andrews (1958; p. 63).

**Fig. 2.** The distribution of harmonic interval types varies by metric position. Intervals landing on pulse beats are more likely to be consonant than intervals at other metric positions.



**Fig. 3.** The distribution of voice leading motion types differs by hierarchical level. Similar, parallel, and contrary motion are more prevalent at the pulse-to-pulse level than the note-to-note level. The width of the columns is proportional to the total number of intervals in each inventory.

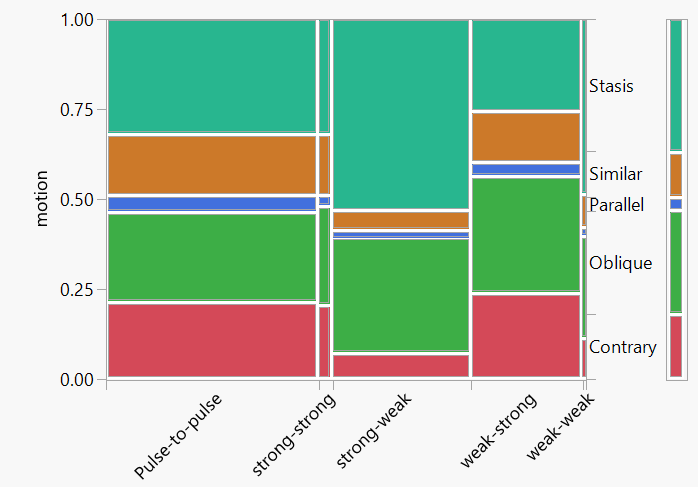
We observed different voice leading patterns at the note-to-note level compared to the pulse-to-pulse level (see **Fig. 3)**. Similar, parallel, and contrary motion are more prevalent at the pulse-to-pulse level than the note-to-note level, while stasis and oblique motion are more prevalent at the note-to-note level (p<.01 for the chi-square test). However, the reasons for these differences were not immediately apparent. Did Palestrina use different voice leading patterns at different hierarchical levels, or are the differences driven by the fact that the pulse-to-pulse patterns land on “strong” beats? To further investigate reasons for the observed differences in voice leading patterns, we examined patterns within four subgroups of the “note-to-note” inventory, based on the beat strength of the antecedent and consequent intervals, as described in **Table 1**. We expected the motion type distribution to be similar between the pulse-to-pulse inventory and subgroup 1 (strong to strong), because subgroup 1 represents horizontal intervals between one pulse beat and the next that have no intervening notes to skip over in the pulse-to-pulse inventory. If the observed differences in **Fig. 2** are driven by the hierarchical level (different patterns used at the semibreve level than the note-to-note level), we would expect subgroup 4 (semibreve level) to have voice leading patterns similar to those seen in the pulse-to-pulse inventory. On the other hand, if the differences are driven by the fact that the pulse-to-pulse intervals all *land* on a strong beat, regardless of the prior beat position or duration of the melodic interval, we would expect subgroup 3 (weak to strong) to be similar to the pulse-to-pulse inventory.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Subgroup** | **Antecedent and consequent beats\*** | **N** | **Percent of total note-to-note intervals** | **Unit of movement** |
| 1. 1. Strong to strong | (1,3) or (3,1) | 38,381 | 2% | Semibreve  (2 beats) |
| 1. 2. Strong to weak | (1,2) or (3,4) | 402,627 | 24% | Minim  (1 beat) |
| 1. 3. Weak to strong | (2,3) or (4,1) | 324,834 | 19% | Minim  (1 beat) |
| 1. 4. Weak to weak | (2,4) or (4,2) | 9,216 | 1% | Semibreve  (2 beats) |

**Table 1.** Description of four subgroups of the note-to-note inventory.

\*Beats are for movements in 4/2. In 3/2 time, beat 1 is considered strong and beats 2 and 3 are considered weak.

The subgroup analysis results (**Fig. 3**) show that the strong-strong and weak-strong subgroups have distributions of motion types that are similar to the distribution at the pulse-to-pulse level. There is slightly more oblique motion and less stasis in the weak-strong subgroup compared to the pulse-to-pulse level, but the relative proportions of parallel, oblique, and contrary motion are similar. Subgroups 2 and 4 (those landing on weak beats) had distributions that were similar to each other but differed from the pulse-to-pulse distribution. This suggests that the differences observed between the pulse-to-pulse and note-to-note inventories may be driven by the consequent beat position (whether the motion ends on a strong or a weak beat), as opposed to the hierarchical level.



**Fig 2.** The motion type distribution for the strong-strong and weak-weak subgroups were similar to the distribution at the pulse-to-pulse level.

As shown in **Fig. 4**, both voice leading rules were broken more often at the pulse-to-pulse level than the note-to-note level. The differences for both rules were statistically significant (*p*<.01 for the chi-square test). We observed that R1 (parallel motion to perfect interval) was almost never broken from one note to the next (0.1% prevalence), but this voice leading pattern was used about 2% of the time at the pulse-to-pulse level. This indicates that Palestrina used this voice leading pattern with passing tones introduced between the pulse beats.

**Fig 4.** Both voice leading rules were broken more often at the pulse-to-pulse level than the note-to-note level

We investigated what factors were associated with breaking R1 and R2 (**Table 2**) using logistic regression. We found that at the note-to-note level and the pulse-to-pulse level outer/outer voice pairings and textures containing 6+ voices were more likely to break R1. At the note-to-note level, R1 was less likely to be broken if the upper or lower voice moved by a step, compared to a leap. In contrast, at the pulse-to-pulse level R1 was more likely to be broken if the upper or lower voice moved by a step, although the effect size was small. All effects were significant for both models, but the effect sizes were generally larger for the note-to-note level than the pulse-to-pulse level. One notable differences between the note-to-note and pulse-to-pulse level results was that moving by a step was associated with a *lower* probability of breaking R1 at the note-to-note level, but a *slightly higher* probability of breaking R1 at the pulse-to-pulse level.



**Table 2:** Parameter estimates from logistic regression. Dependent variable = breaking R1 (parallel motion to perfect harmonic interval) or R2 (similar motion to perfect interval). All effects were statistically significant (p<.05).

# DISCUSSION

We found that consonances were more prevalent on the pulse beats, consistent with Andrews’ (1958) statement that the harmonic pulses are usually consonant (p. 62). Our analysis of voice leading patterns showed that contrary, similar, and parallel motion types made up a larger proportion of the total intervals at the pulse-to-pulse level than at the note-to-note level. A subgroup analysis of different beat strength combinations in the note-to-note inventory (strong-strong, weak-strong, etc.) suggested that the note-to-note vs. pulse-to-pulse differences in voice leading patterns may be driven by the strength of the beat on which the interval lands.

Specific voice leading “rules” (approaching perfect intervals by parallel or similar motion) were broken more often at the pulse-to-pulse level. This indicates that Palestrina used these motion types on occasion but broke them up by introducing other passing tones between the strong beats. This is seemingly inconsistent with some theoretical texts indicating that passing tones do not break up the perceptual effect of using parallel motion to a perfect interval. However, Gauldin indicates that “perfect fifths between consecutive strong beats are possible, provided an imperfect consonance intervenes” (p. 29). An additional subgroup analysis could focus on intervals landing on P1, P5, and P8 separately, and the types of intervening intervals.

We also found that certain features were associated with a greater likelihood of breaking certain voice leading rules. Breaking R1 was more likely between inner/inner or outer/inner voices than between outer/outer voices, suggesting that the patterns may be “hidden” within the texture rather than placed in the outer voices where they would be more noticeable. However, R2 was more likely to be broken for an outer/inner pairing than an outer/outer pairing. Both rules were least likely to be broken for 2-3 voice movements than larger numbers of voices, supporting theoretical observations that it becomes more difficult to follow the rules as the number of voices increases.

Our findings are relevant for voice leading pedagogy because it suggests that Palestrina used certain types of “forbidden” voice leading patterns more often than previously assumed, albeit at a higher metric level. Our findings also have implications for other types of computational analyses using note-to-note successions, because using higher-level hierarchical structures could uncover different patterns. However, selecting the best unit of analysis for voice leading is still unclear. The most perceptually salient beats should be used for the pulse-to-pulse level analysis, but determining which beats are the most salient depends on many factors, including the tempo at which a piece would have been performed, which we cannot determine with confidence for Renaissance music. Future analyses could explore differences in voice leading patterns between notes landing on beats 1, 2, 3, and 4, or from beat 1 of one “measure” to beat 1 of the next measure.

# NOTES

[1] “M” denotes major harmonic intervals, “m” denotes minor intervals, and “P” denotes perfect intervals.

# REFERENCES

Aldwell, E., Schachter, C., & Cadwallader A. (2019) *Harmony & Voice Leading* (Fifth ed.). Boston, MA: Cengage.

Andrews, H.K. 1958. An Introduction to the Technique of Palestrina. London: Novello and Company.

Benjamin, T. (2005). The Craft of Modal Counterpoint (2nd ed.). Routledge.

Blume, Friedrich. (1967). *Renaissance and Baroque Music: A Comprehensive Survey.* New York: W.W. Norton & Company, Inc.

Conklin, D. (2002). *Representation and Discovery of Vertical Patterns in Music.* In C. Anagnostopoulou, M. Ferrand, & A. Smaill (Eds.), *Music and Artificial Intelligence* (Vol. 2445, pp. 32–42). Springer Berlin Heidelberg. <https://doi.org/10.1007/3-540-45722-4_5>

Cuthbert, M. S., & Ariza, C. (2010). “music21: A Toolkit for Computer-Aided Musicology and Symbolic Music Data.” Michael Cuthbert. Retrieved from https://dspace.mit.edu/handle/1721.1/84963

DeFord, R. (2015). *Tactus, Mensuration, and Rhythm in Renaissance Music.* Cambridge, United Kingdom: Cambridge University Press.

Finkensiep, C., Neuwirth, M., & Rohrmeier, M. (2018). Generalized Skipgrams for Pattern Discover in Polyphonic Streams. Proceedings of the 19th International Society for Music Information Retrieval Conference, ISMIR, 547–553.

Fuller, S. (2002). Organum – Discantus – Contrapunctus in the Middle Ages. In T. Christensen (Ed.), The Cambridge History of Western Music Theory. Cambridge University Press.

Huron, D., Collins, D. (1999). *Voice leading in cantus firmus-based composition: a comparison between theory and practice in Renaissance and Baroque music using computer-assisted inferential measures.* Computers in Music Research, 6 (Spring), 53–95.

Gauldin, R. (1985). *A Practical Approach to Sixteenth-Century Counterpoint.* Englewood Cliffs, New Jersey: Prentice Hall, Inc.

Hanson, John R. (1983). *Enumeration of Dissonance in the Masses of Palestrina*. College Music Symposium 23 (1): 50–64.

Jeppesen, K. (1927). *The Style of Palestrina and the Dissonance*. Translated by Nargaret N. Hamerik. London: Oxford University Press; revised English edition, 1946; reprint of the 1946 edition, NY: Dover Publications, 1970.

JMP®, Version 15. SAS Institute Inc., Cary, NC, 1989-2020.

Marshall, R (1963). *The Paraphrase Technique of Palestrina in his Masses Based on Hymns.* Journal of the American Musicological Society, 16(3).

Marvin, C. (2002). Giovanni Pierluigi Da Palestrina: A Research Guide. Routledge Music Bibliographies Ser. (1st ed., Vol. 56). Routledge Publishing, Inc.

Schubert, P. (2002). Counterpoint pedagogy in the Renaissance. In T. Christensen (Ed.), The Cambridge History of Western Music Theory. Cambridge University Press.

Schubert, P., & Lessoil-Daelman, M. (2013). What Modular Analysis Can Tell Us About Musical Modeling in the Renaissance. Music Theory Online, 19(1). <https://doi.org/10.30535/mto.19.1.6>

Sears, D. R. W., Arzt, A., Frostel, H., Sonnleitner, R., & Widmer, G. (2017, July 18). Modeling Harmony with Skip-Grams. *Proceedings of the 18th International Society for Music Information Retrieval Conference (ISMIR)*. <http://arxiv.org/abs/1707.04457>

Volk, A., Wiering, F., & van Kranenburg, P. (2011). Unfolding the Potential of Computational Musicology. Proceedings of the Thirteenth International Conference on Informatics and Semiotics in Organisation.

Whang, C. (2004). *Re-defining relationships: Modeling in four imitation masses by Palestrina.* Dissertations available from ProQuest.