

From Atoms to Waves: Rhythmic Stylometry for Authorship Studies of Early Modern Spanish Theatre *

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Resumen

Cada comedia del Siglo de Oro puede descomponerse en cientos de patrones rítmicos —uno por cada verso— cuya superposición conforma una huella autorial característica. Podemos emplear técnicas estilométricas para comparar estos patrones formados por la concatenación de sílabas tónicas y átonas con el objetivo de establecer inferencias autoriales. En este trabajo conformamos un experimento en el que reunimos un conjunto de cien obras de autoría segura de nueve autores diferentes y realizamos una batería de pruebas para comprobar si estos patrones rítmicos pueden discriminar la autoría de una pieza teatral. Los resultados, aunque inferiores a los alcanzados con la estilometría léxica tradicional, se demuestran prometedores al conformar un camino alternativo para la indagación autorial, en especial con ciertos dramaturgos que responden de forma muy satisfactoria a las pruebas.

Palabras clave

Humanidades digitales; identificación autorial; aprendizaje automático; inteligencia artificial; Lope de Vega; escansión automática

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Título

De los átomos a las ondas: estilometría rítmica para los estudios de autoría en el teatro español del Siglo de Oro

Abstract

Each comedy from the Spanish Early Modern period can be decomposed into hundreds of rhythmic patterns—one for each verse—whose overlapping creates a characteristic authorial fingerprint. Stylometric techniques can be employed to compare these patterns, formed by the concatenation of stressed and unstressed syllables, in order to establish authorial inferences. In this exploratory work, we designed an experiment comprising a corpus of one hundred securely attributed plays by nine different authors, conducting a series of tests to determine whether these rhythmic patterns can discriminate the authorship of a theatrical piece. The results, although inferior to those obtained through traditional lexical stylometry, show promise as an alternative path for authorial investigation.

Keywords

Digital Humanities; Author Identification; Machine Learning; Artificial Intelligence; Lope de Vega; Automatic Scansion



To Simon Kroll, father of rhythmic stylometry

1. FROM ATOMS TO WAVES

Lexical stylometry has proven to be a productive and widely tested tool for determining the authorship of Early Modern Spanish plays (Calvo Tello and Cerezo Soler, 2018; Vega García-Luengos, 2021 and 2023; Martínez Carro, 2022; Hernández-Lorenzo and Byszuk, 2023; Cuéllar, 2024; Lara Ramírez, 2025, etc.). Over the past decades, a variety of approaches have consistently demonstrated that the statistical analysis of word frequencies can successfully discriminate between playwrights, even in cases where traditional philological criteria remain inconclusive. This methodological strength makes stylometry particularly valuable in the context of Golden Age theatre, where questions of attribution, collaboration, and textual transmission are especially pressing. The theatrical corpus of the Spanish Golden Age is indeed exceptionally well-suited

to this type of analysis, as it amply fulfills all the necessary requirements for computational processes to operate effectively and reliably. Unlike other corpora, it combines both quantity and homogeneity in ways that maximize the robustness of statistical methods. Four key factors, in particular, account for the effectiveness of stylometric methods in this domain:

1. We have access to a remarkably large collection of texts, comprising around 3,000 major works, including both comedias and autos. This scale is extraordinary within a single literary tradition and provides the sheer volume of data required for stylometry to operate effectively. The abundance of texts ensures that statistical inferences are based on massive accumulations of word frequencies rather than on isolated cases, thereby increasing the reliability of patterns detected across the corpus. In other words, the very size of the dataset guarantees that observed regularities rest on broad numerical evidence, a fundamental condition for any computational approach that depends on the law of large numbers.
2. The length of the texts is particularly well-suited for stylometric purposes, since plays typically range between 10,000 and 20,000 words. This provides ample textual mass to yield statistically reliable results while avoiding the distortions that arise in shorter works, where the limited amount of data often produces unstable or inconclusive outcomes. At the same time, the relatively uniform length of the plays ensures comparability across the corpus, since each text contributes a sufficiently rich and balanced sample of an author's style.
3. The corpus displays a high degree of formal and generic consistency, since all the plays are written in verse and share common metrical structures. This homogeneity greatly facilitates stylometric comparison, as it minimizes the interference of extraneous variables such as prose passages, irregular formats, or divergent literary conventions. By operating within a shared poetic framework—predominantly octosyllabic and hendecasyllabic lines with recognizable stanzaic patterns—the analysis is able to focus more directly on subtle stylistic and authorial signals rather than being distorted by formal disparities. Such consistency is rare in other literary corpora, making the Golden Age theatrical tradition especially favorable for stylometric inquiry.
4. Each playwright produced a considerable number of works, with some being exceptionally prolific, composing dozens or even hundreds of

plays (Lope de Vega, Calderón de la Barca, Tirso de Molina, etc.). This abundance of material by individual authors enables the construction of robust intra-author corpora, which are essential for identifying stable stylistic markers and minimizing the risk of basing conclusions on isolated or atypical texts. The large-scale output of figures such as Lope de Vega—who alone is credited with several hundred plays—offers a particularly rich testing ground for computational methods, allowing for both fine-grained analyses of a single author’s stylistic evolution and reliable cross-author comparisons within the broader Golden Age production.

These elements create ideal conditions for computational analysis. As a result, it is far easier to apply such methods to Golden Age theatre than to other domains, even within the same historical and cultural context, where the number of available works is considerably smaller. Golden Age prose, for instance, also presents urgent authorship problems, yet it encompasses texts of such diverse typologies as Avellaneda’s *Quixote* or the anonymous *Lazarillo de Tormes*, which are far less amenable to stylometric approaches. The diversity of genres, combined with the scarcity of comparable corpora, makes it genuinely difficult to establish reliable authorial inferences—let alone ones with sufficient validity and scholarly consensus. Lyric poetry of the Golden Age—comprising shorter forms such as sonnets, liras, romances, décimas, canciones, etc.—would also be of great interest for authorship studies, yet these texts do not lend themselves well to stylometric analysis because of their brevity. The small size of each poem yields too little textual mass to provide statistically reliable results, often producing unstable or inconclusive attributions. One possible workaround is to cluster several compositions together to create larger textual units, thereby reaching the volume required for computation. However, this solution introduces its own problems, as the resulting clusters are artificial groupings that blur the individuality of the texts and may distort the statistical signal. Such methodological challenges explain why stylometric inquiry has been most fruitful in longer dramatic works, where each play already offers sufficient material for robust analysis.

Lexical stylometry operates by atomizing works into their minimal constituents—the words—whose frequencies are then computed in order to establish authorial relationships or classifications. The accumulation of these words produces a distinctive authorial fingerprint that allows texts to be connected and compared. All words are taken into account, from functional words (or stopwords) to semantically charged terms. Typically, the analysis does not rely on just a handful of items, but rather on hundreds or even thousands of

words. To illustrate, the following list presents the 100 most frequent words in Spanish Golden Age theatre: *que, de, y, el, a, la, en, no, es, mi, me, con, por, si, se, los, lo, yo, su, pues, un, qué, al, las, te, le, ya, del, ha, tu, más, para, tan, como, porque, os, bien, quien, esta, amor, he, señor, sin, una, este, ser, mas, dios, aquí, mis, o, mí, sus, cuando, está, pero, aunque, dos, hay, soy, vida, él, esto, rey, don, vos, ni, así, todo, son, cielo, quién, tú, quiero, mal, alma, ella, ay, tus, fue, has, ver, tanto, estoy, hombre, solo, ahora, tiene, padre, vuestra, muerte, tal, donde, cómo, muy, tengo, hoy, eso, señora, mujer*. As immediately becomes clear, the highest-frequency words are common to virtually any Spanish text. As the list progresses toward less frequent items, more distinctive lexical choices begin to emerge, until we reach the hapax legomena—words that occur only once within the corpus, sometimes unique to a single author. Although this line of analysis has proven to be highly productive for authorship studies of Golden Age theatre, yielding excellent validation results, it nonetheless presents certain limitations. Some of these shortcomings may potentially be overcome through a parallel approach, such as the one proposed in this article. It is therefore worth outlining the main difficulties (Eder and Rybicki, 2012; Eder, 2013, 2015, and 2017a) that arise in analyses based on lexical stylometry.

1. A strongly marked thematic focus can often obscure the results of lexical stylometry. Plays devoted to saints' lives, military exploits, or mythological subjects, for example, tend to cluster together in stylometric analyses on the basis of their subject matter rather than according to the authorial attribution that concerns us. In such cases, the lexical signal of thematic vocabulary may override the subtler stylistic markers of individual playwrights, producing misleading affinities. This problem is particularly acute in corpora like Golden Age drama, where thematic cycles and subgenres abound, and where playwrights often drew on a common stock of motifs, settings, and rhetorical conventions.
2. Collaborative works also pose significant challenges for stylometric analysis. In such cases, although the overall plot is shared across the different sections of the play, each part was in fact composed by a different playwright. This circumstance often results in the recurrence of certain thematic or structural keywords throughout the entire work, irrespective of the hand that authored a given passage. As a consequence, lexical stylometry may mistakenly interpret these repeated elements as authorial markers, when in fact they simply reflect the unity of the narrative design. Given the prominence of

collaboration in Golden Age theatre, this limitation becomes a recurrent obstacle for computational attribution.

3. The dating of the *comedias* may also influence the analyses, since the lexicon naturally evolves over the course of decades. Words and expressions fall into or out of use, orthographic conventions shift, and stylistic fashions change in ways that may affect frequency counts. As a result, plays composed at different moments in a playwright's career—or belonging to different generational strata within the Golden Age—may appear stylistically distant not because of divergent authorship, but because of diachronic linguistic change. This temporal dimension introduces noise into the results, complicating the attribution of works whose chronology is uncertain or disputed.
4. Some playwrights do not respond well to lexical stylometry for intrinsic reasons. In such instances, the overlap in lexical choices dilutes the discriminative power of stylometric methods, making it difficult to distinguish one author from another with confidence. This limitation highlights a broader issue: when an author's linguistic habits fall within the dominant stylistic norms of the period, the statistical signal of individual authorship becomes blurred. As a result, stylometric classification may yield ambiguous or unstable results for these playwrights, despite the otherwise robust performance of the method.
5. A special case is that of works composed in an archaizing style, such as *Los jueces de Castilla* by Agustín de Moreto or *Las famosas asturianas* by Lope de Vega, where the writing deliberately seeks to imitate older linguistic forms. This conscious adoption of archaism disrupts lexical stylometry, since the vocabulary no longer reflects the habitual usage of the playwright but rather an intentional stylistic disguise. In such instances, the signal detected by computational analysis may point not to the author's own lexical fingerprint but to the conventions of an earlier period being artificially reproduced. This introduces a layer of noise that complicates attribution, blurring the distinction between genuine authorial markers and deliberate stylistic imitation.
6. The orthographic criteria adopted in different editions of Golden Age plays—such as the modernization of archaic forms, the regularization of variant spellings, or the editorial treatment of toponyms—can also negatively affect lexical stylometric studies of authorship. Because stylometry depends on the statistical distribution of word forms, even minor editorial interventions may distort the lexical profile of a text, either by

erasing distinctive spellings or by introducing artificial uniformity across the corpus. These inconsistencies are especially problematic when works prepared according to divergent editorial principles are compared side by side, as the signal attributed to authorial style may in fact reflect nothing more than the intervention of modern editors.

While lexical stylometry is based on atomizing Golden Age works into their basic constituents—the words—we can move beyond this level and apply similar processes to a wide range of parameters, whose productivity will vary depending on the objective of the study. The corpus, for instance, can be transformed into grammatical categories, lemmas, or even representations of sentiment or thematic domains, all of which can be exploited within the framework of computational stylistics. Looking ahead, it is also possible to envisage transforming the corpus into embeddings—that is, vector representations of the relationships among the words in a text—an especially promising avenue that merits systematic investigation in the future. In the present study, however, our focus is on exploring one of these alternative paths: the transformation of verses into their prosodic waves, which constitute rhythmic patterns that can be quantified and analyzed. Although this approach has been addressed in traditional research, it remains at an embryonic stage within the field of Digital Humanities.

When delivering a verse, the actor naturally produces an alternating rhythmic sequence of sounds that can be represented as a wave, with peaks (stressed syllables) and valleys (unstressed syllables). It is precisely this prosodic wave that we exploit here stylometrically, shifting the analysis from the lexical dimension—where words function as discrete units or atoms—to the rhythmic or prosodic dimension, conceived as intonational patterns or waves. In recent years, thanks to the work of the *Sound and Meaning* project (University of Vienna), directed by Professor Simon Kroll and further developed in the dissertation and research of Fernando Sanz Lázaro, a promising alternative avenue of inquiry has emerged: the computational study of the rhythmic patterns that structure these texts (Kroll and Sanz-Lázaro, 2022 and 2023; Sanz-Lázaro, 2023a, 2023b, and 2023c). Comparable explorations in other literary traditions have already shown that versification features can serve as effective stylometric markers, sometimes approaching the discriminative power of lexical ones (Plecháč, 2018 and 2021). In following this approach, we no longer atomize plays into their minimal constituents, the words, but instead extract the rhythmic waves that shape their verses through the alternation of stressed and unstressed syllables. This procedure, known as scansion, has engaged studies of poetry since antiquity. Traditional studies of metrics and orthology have proven

highly productive, especially in relation to Lope de Vega and Calderón de la Barca (Morley, 1927; Poesse, 1949; Fernández Rodríguez, 2021; Sánchez Jiménez, 2017 and 2020). These works have demonstrated that certain combinations and phonological features can be identified as distinctive of an author's dramatic production, thus helping to delimit his authentic corpus.

As an example, we can transform the opening octosyllabic verses (vv. 1–4) of *La doncella Teodor* by Lope de Vega (ed. González-Barrera, 2007) into their prosodic waves—the alternation of stressed and unstressed syllables—and, from these, derive the corresponding rhythmic patterns that can be encoded and processed computationally (Table 1).

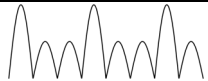
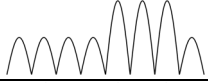
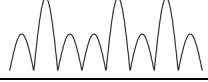
Verse	Prosodic Wave	Rhythmic Pattern
dame herruelo y sombrero		+--+--+
con esta media sotana		-+--+--
aunque mi ignorancia es llana		-----+
cogerte a las manos quiero		-+--+--

Table 1. Examples of octosyllabic verses from Golden Age drama, with their corresponding prosodic waves and rhythmic patterns.

Similarly, the opening hendecasyllables (vv. 1–4) of *Los templarios* by Juan Pérez de Montalbán (ed. Rodríguez del Cerro, 2014) can be rendered into the following rhythmic patterns (Table 2):

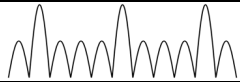
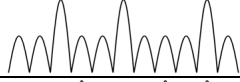
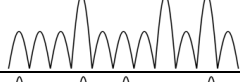
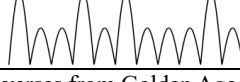
Verse	Prosodic Wave	Rhythmic Pattern
ahora que descansan los aceros		-+---+---+
de mis nunca olvidados compañeros		--+--+---+
y el enemigo de furor armado		---+---+--
huye vencido o duerme fatigado		+--+--+---

Table 2. Examples of hendecasyllabic verses from Golden Age drama, with their corresponding prosodic waves and rhythmic patterns.

Rhythmic stylometry thus offers a promising way of addressing several of the limitations inherent to lexical analysis. (1) In plays with strongly marked themes—such as hagiographic, military, or mythological subjects—it may help disentangle thematic convergence from genuine authorial signal, since by removing the lexical component it minimizes the influence of specialized terminology and highlights instead the underlying rhythmic habits of individual playwrights. (2) In collaborative works, where lexical stylometry often struggles due to the recurrence of shared vocabulary and plot elements, rhythmic stylometry could provide a more stable indicator of authorship, as metrical and prosodic preferences tend to be deeply ingrained and less easily homogenized by collective composition. (3) It may also prove advantageous in diachronic terms, given that vocabulary naturally evolves while rhythmic tendencies may remain comparatively stable over time, allowing plays written at different stages of a career—or even across generations—to be compared without the distortions introduced by lexical change. (4) Certain playwrights might respond better to rhythmic than to lexical stylometry, especially when their vocabulary overlaps extensively with that of their contemporaries but their metrical preferences—distribution of stresses, use of enjambment, or recurrence of particular rhythmic patterns—constitute distinctive stylistic fingerprints. (5) In works employing archaizing vocabulary, lexical stylometry may be misled by deliberate imitation of earlier linguistic forms, whereas rhythmic stylometry should preserve the underlying prosodic patterns that reflect the author's genuine habits, which are harder to disguise consistently across an entire play. (6) Finally, because it operates at a deeper structural level, rhythmic stylometry is largely unaffected by orthographic modernization or editorial intervention, factors that often distort lexical profiles; as it depends solely on the alternation of stressed and unstressed syllables, it can bypass the noise introduced by divergent transcription or normalization practices.

These observations must remain tentative, since it is possible, as Kroll (2022) has suggested, that rhythmic patterns are themselves closely bound to thematic choices and theatrical contexts. Indeed, in the *Comedia Nueva*, certain metrical forms—particularly those involving hendecasyllables, such as octavas reales, tercetos encadenados, or silvas—tend to be associated with specific tonal or generic registers, appearing more frequently in dramas than in comedias. This correlation suggests that rhythm, like lexis, may at times reflect the dominant theme or emotional tenor of a scene, rather than the author's individual signature, thus warranting a cautious approach when interpreting rhythmic stylometric signals. In that case, even if the semantic component is removed, such correlations may still surface. Rhythmic usage may also be conditioned by the chronological moment of composition, reflecting diachronic

shifts in versification practices, or by the dynamics of collaboration, where a playwright adjusts to the metrical habits of a co-author. Thus, although lexical–semantic noise is effectively reduced, other signals may persist, and even new ones may emerge. Further experimentation is therefore necessary in order to confirm or to refute these possibilities with greater certainty.

2. AUTOMATIC SCANSION

While scansion can certainly be performed manually on a verse-by-verse basis, such a method is only realistic for a very limited number of texts. When we turn to the full corpus of approximately three thousand plays from the Spanish Golden Age—the ultimate target of this research agenda—we are confronted with an estimated nine million verses. Even if each individual line were scanned by hand in just thirty seconds, the task would still require more than 3,000 consecutive days of uninterrupted work. The sheer scale of the undertaking makes manual scansion wholly impractical. Fortunately, recent advances in computational methods allow us to automate this process with levels of accuracy sufficient for large-scale experiments. While no automatic system is entirely error-free, the margins of error observed in current tools fall within acceptable thresholds for stylometric research. In fact, automation not only reduces the prohibitive time cost but also ensures consistency in the application of scansion rules—an advantage over purely manual approaches, where human annotators may disagree on ambiguous cases. The use of computational scansion thus enables us to envisage, for the first time, the systematic analysis of the entire Golden Age theatrical corpus from a rhythmic perspective. Automatic scansion—that is, the extraction of patterns of stressed and unstressed syllables—has attracted growing scholarly attention in recent years, with researchers proposing a variety of strategies to address this task (Navarro-Colorado, 2016 and 2017).

Yet the evaluation of these tools remains far from straightforward. Classical metrical theory itself offers no unified consensus, and even experienced human annotators frequently arrive at divergent conclusions regarding the stress of a given syllable or word. The problem is further complicated by linguistic variation: stress placement may shift according to diatopic, diachronic, diaphasic, or even idiolectal factors, and in performance may also depend on the interpretive choices of a particular actor at a given moment. To address these tasks, we can draw on several tools and processes that have been developed in recent years. First, *Rantanplán* (De la Rosa *et al.*, 2020) is a rule-based system that performs scansion through a full NLP pipeline including syllabification, stress assignment, and metrical adjustment, providing

rich linguistic information such as rhyme, stanza type, and phonological groups. *Jumper* (Marco *et al.*, 2021; Marco and Gonzalo, 2021), approaches the problem differently: it performs scansion without explicit syllabification, which minimizes error propagation and makes it considerably faster and more efficient while still achieving high accuracy. Most recently, the *libEscansión* tool¹ (Sanz-Lázaro, 2024) created within the Sound and Meaning Project has been designed specifically for Golden Age theatre, adapting the scansion process to the complexities of dramatic verse and offering detailed prosodic annotation: verses are decomposed into their phonetic components, rules governing diphthongs, hiatuses, and triphthongs are applied, together with the synalephas characteristic of poetic language. The result is a line segmented into syllables and annotated as stressed or unstressed.

It should be emphasized that excessive effort devoted to interpreting the meaning of an author's characteristic rhythms is rarely productive. While such an attempt may seem an appealing way to reduce the opacity of computational processes—which so often operate as black boxes where inputs and outputs are visible but the internal mechanisms remain obscure—in practice it yields limited scholarly value. A parallel may be drawn with lexical stylometry: one might conclude that Lope de Vega is characterized by his frequent use of words such as *con*, *árbol*, or *ninfa*, but such observations are of little significance to literary specialists. The strength of stylometry does not lie in these isolated markers, but in the cumulative effect of subtle differences across hundreds or even thousands of variables. It is precisely this statistical aggregation—whether of words or, in our case, rhythmic patterns—that generates an authorial fingerprint, one that may not be readily perceptible to the human mind yet proves robust in computational terms. Automatic scansion makes this possible by producing machine-readable outputs that allow these patterns to be compared systematically. Caution is nevertheless required: broken lines, irregular meters, or textual corruption can introduce noise into the results, and even a single error may compromise the rhythm of an entire verse. What is under consideration here is the simple concatenation of stressed and unstressed syllables, deliberately setting aside more intricate theories of primary, secondary, or tertiary stress. Particular attention must be given to the octosyllable, the dominant meter of Golden Age theatre. Here a key methodological question arises: if we measure rhythmic patterns and combine octosyllables with hendecasyllables, are we in fact analyzing rhythms, or are we conflating them with metrical structures? In practice, several other factors are also at play—text

¹ See <https://github.com/fsanzl/libEscansion>.

length, metrical form, or dramatic genre—all of which may influence the results without being explicitly controlled.

3. PREPARATION OF MATERIALS

We now move from the lexical experiments to rhythmic patterns. For this purpose, we employed *libEscansión*—developed by Fernando Sanz Lázaro within the Sound and Meaning project—and complemented its output with a brief manual review. As is well known, automatic scansion is never flawless: even among expert humanists, no two scholars would agree on every syllabic decision, and discrepancies are inevitable in matters such as stress placement, synalephas, or the treatment of metrical irregularities. We must therefore acknowledge that errors may occur in the scansion of these rhythms. Nonetheless, our working assumption is that the majority of rhythmic patterns are either accurate or, at the very least, internally consistent enough to permit meaningful comparison across the corpus. The statistics aggregated from these rhythmic patterns serve as the basis for constructing what we may call an *authorial fingerprint*. This logic mirrors the principles of lexical stylometry: in the case of words, a margin of error of 10–20% does not significantly compromise the outcome, since the model continues to capture stable relationships between plays. By analogy, we trust that in the case of rhythmic stylometry, a limited number of problematic verses will not invalidate the overall experiment. Yet big data here pushes us to the limit: whereas lexical stylometry typically works with 15,000–20,000 tokens per play (words), rhythmic stylometry is constrained to 2,000–3,000 units (verses). Each verse therefore carries proportionally more weight, making the accuracy of scansion a critical issue.

For the preparation of the dataset, it was necessary to correct certain metrical misclassifications identified by the system, ensuring that octosyllables and hendecasyllables—the two predominant meters of Golden Age drama—were reliably recognized. However, a complete verse-by-verse verification proved impossible given the sheer scale of the undertaking: in total, the dataset comprises approximately 300,000 rhythmic patterns extracted from these 100 works. A ranked list of the 100 most frequent rhythmic patterns across the corpus shows a clear tendency (Fig. 1): the distribution is dominated by a handful of patterns that occur with exceptional frequency, while the tail consists of patterns that appear only rarely or even just once. This observation accords closely with the statistical principle known as Zipf's law. A further point, however, deserves emphasis. If scansion could be carried out with perfect accuracy, patterns that occur exclusively in a single author would provide

extremely valuable information for attribution. In reality, though, such unique instances are more likely to reflect transcriptional errors, scansion inconsistencies, or corrupted verses that obscure genuine authorial tendencies. Stylometry, by its very nature, rests on the principles of big data and the law of large numbers: it does not rely on isolated anomalies but on the cumulative repetition of features across thousands of units. For this reason, verses containing errors or aberrant scansions exert no significant influence on the overall results and are effectively disregarded by computational processes operating at scale. Zipf's law, originally formulated in relation to lexical frequency, states that the frequency of a given element in a corpus is inversely proportional to its rank in an ordered frequency list. While traditionally applied to written words, this law can also be extended to the domain of metrical and rhythmic structures in poetry or verse drama. Our analysis of Golden Age metrical sequences reveals precisely this pattern: a small number of rhythmic configurations appear with extraordinary regularity, while many others are markedly rare.

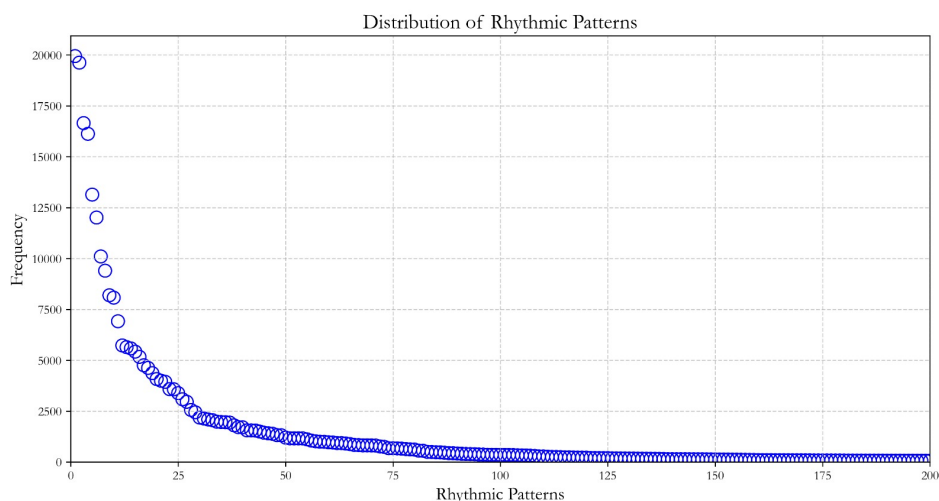


Figure 1. Distribution of rhythmic patterns in the set of 100 plays by nine playwrights.

The following table lists the 50 most frequent rhythmic patterns identified across the corpus of 100 securely attributed Golden Age plays (Table 3). For each pattern we report its rank and total number of occurrences within the dataset. This overview offers a first quantitative glimpse into the distribution of rhythmic structures in the corpus and provides the empirical foundation for the classification experiments that follow.

Rank	Rhythmic Pattern	No. of Occurrences	Rank	Rhythmic Pattern	No. of Occurrences
1°	--+---+-	19940	26°	+--+--+-	3081
2°	-+-+--+-	19618	27°	+--+--+	2959
3°	---+--+-	16648	28°	---+++-	2557
4°	-+-+--+	16121	29°	+--+--+	2442
5°	+--+--+-	13135	30°	--+--+--+-	2183
6°	--+--+--	12009	31°	++--+--	2139
7°	+--+--+-	10098	32°	+---+-+	2089
8°	-+----+-	9397	33°	--++--+	2054
9°	+--+--+	8191	34°	++----+-	1981
10°	-+-+--+	8073	35°	-+--+--+-	1964
11°	--+---+	6914	36°	--+---+	1956
12°	----+--+	5725	37°	-+-+--+	1936
13°	---+--+	5644	38°	-+++--+	1803
14°	-+--+++	5580	39°	-++---+	1713
15°	+---+--+	5422	40°	----+--+	1705
16°	+--+--+	5166	41°	-+-+--+++	1555
17°	--++--+	4753	42°	---+--+	1553
18°	++--+--	4621	43°	+--+--+	1546
19°	-++---+-	4366	44°	++--+--	1495
20°	--+--++	4076	45°	+--+--+	1438
21°	+-----	3993	46°	-++--+	1409
22°	-+----+	3938	47°	-+-+---+-	1385
23°	++--+--	3580	48°	+--+--+	1320
24°	-++--+	3573	49°	-+--++	1314
25°	-+--+--	3384	50°	---+--+--	1200

Table 3. 50 most common rhythmic patterns in the corpus of 100 plays by nine playwrights, with the total number of occurrences in the corpus.

4. EXPERIMENTS THROUGH RHYTHMIC STYLOMETRY

Building on a previous study (Cuéllar, 2024), in which a lexical stylometric evaluation was carried out on a sample of 100 securely attributed plays by canonical authors such as Miguel de Cervantes, Tirso de Molina, Lope de Vega, Calderón de la Barca, Ruiz de Alarcón, Agustín Moreto, Guillén de Castro, Rojas Zorrilla and Pérez de Montalbán, we take as our starting point the insights gained from that controlled experiment. In that study, each play was individually extracted from the corpus and classified into its corresponding authorial group. With most methods and parameter combinations, the system achieved over 85% accuracy, with some results approaching 100%. Such results underscored the robustness of stylometric methodologies and their extraordinary effectiveness when applied to a corpus that is both well defined and philologically secure. The analyses in the previous study were grounded on the

most common words found across Golden Age theatre. Each lexical item was treated as an independent entity: no lemmatization was applied, nor were words normalized or otherwise transformed. This decision reflected a methodological principle widely accepted in the field—namely, that stylometry does not rely on the semantic or morphological interpretation of words but rather on their sheer frequency of occurrence. It was precisely this statistical regularity, the cumulative patterning of words across thousands of lines, that allowed the formation of what could be called an authorial fingerprint. By focusing on the raw frequency of these common words, the study avoided the interpretive bias that might have been introduced by linguistic preprocessing. Instead, the computational process operated at a level inaccessible to human intuition, aggregating hundreds or even thousands of minute differences across the corpus. The result was a robust stylometric signal capable of distinguishing one author from another with remarkable accuracy.

Although the bibliography offered extensive discussion on the distances or methods to be employed, the results were, in fact, quite similar. As for the number of words, performance reached its maximum between 100 and 500 words and then remained stable thereafter. It was important to note that the use of only a few keywords did not yield satisfactory results; rather, it was always the accumulation of words that proved effective. Experiments carried out with functional and non-functional words likewise did not reveal significant differences in this regard. To conduct those experiments, the study began with a corpus of securely attributed plays and extracted one play at each step, in a process known as leave-one-out. The play was then classified according to a set of parameters—for example, 350 MFW with the SVM method. If the classification was correct, it was recorded as a success; if not, it was recorded as an error. This procedure was repeated for each of the one hundred plays, producing the result for a given data point—for instance, 87% accuracy if 87 plays were classified correctly, or 23% if only 23 were.

We therefore moved on to the experiments based on rhythmic patterns, making use of the *Stylo* library (Eder, Rybicki and Kestemont, 2016) for R, which has become one of the standard tools for stylometric analysis in the humanities². On this basis, we implemented a script for cross-validation that iteratively extracts each play from the corpus and attempts to classify it according to various parameters, such as the number of rhythmic patterns included in the analysis and the statistical method applied. This procedure

² Many of the libraries and programs used for stylometric analysis do not properly recognize non-alphabetic symbol strings. By encoding them as alphabetic tokens, we ensure compatibility with existing classification systems

allows us to test the robustness of the method across a range of configurations and to evaluate how sensitive rhythmic stylometry is to corpus size, feature selection, and choice of algorithm. To present the accuracy results of the systems under varying parameters, we rely on the F1 score. This metric is preferred over alternatives such as overall accuracy or precision alone because it provides a more balanced and informative evaluation of model performance. Specifically, F1 combines two complementary aspects of classification: precision, or the model's ability to avoid false positives, and recall, or its capacity to identify correctly all positive instances. By taking the harmonic mean of these two measures, F1 avoids the pitfalls of metrics that might appear satisfactory in isolation but mask underlying imbalances in performance.

As explained earlier, in lexical stylometry the results were exceptionally strong (Fig. 2), with accuracy scores approaching 1.0 under the methods employed, particularly when using Support Vector Machines (SVM). Once the analysis included around 500 of the most frequent words, the system stabilized and this level remained consistent as the number of MFW was extended into the several thousands. By contrast, when only a small set of MFW was considered, performance was poor and unstable; however, once the threshold of roughly 100 words was reached, the results began to stabilize and produced nearly perfect classifications of the plays.

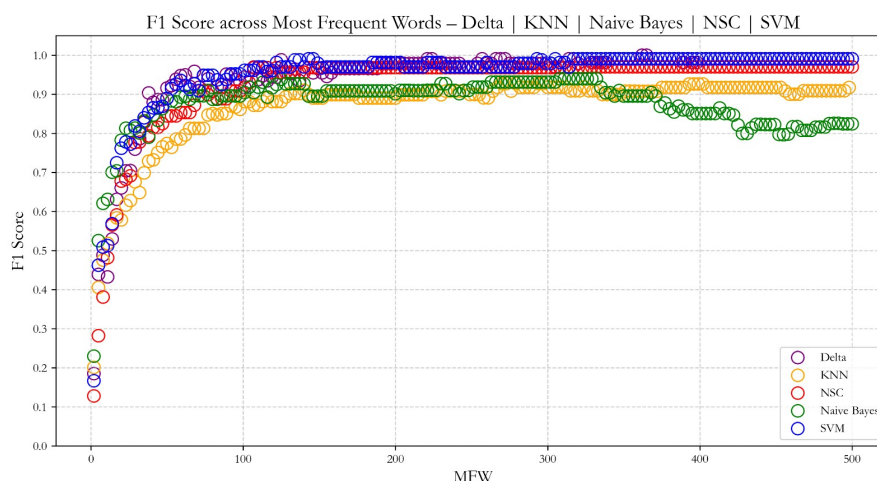


Figure 2. F1 score variation with most frequent words across five classification methods for the dataset of one hundred plays by nine playwrights.

Let us now turn to the same set of plays, but this time replacing the most frequent words with the most common rhythmic patterns as the basis of

analysis. The contrast is immediate and significant: the overall performance deteriorates considerably, with accuracy scores peaking at around 0.7 at best. Unlike the lexical experiments, where additional words tended to stabilize or reinforce the results, here the incorporation of more patterns does not necessarily lead to improvement. On the contrary, beyond a certain threshold, performance begins to decline for several of the statistical methods tested. This suggests that the system may be overfitting or becoming distracted by noise once less frequent or less stable patterns are introduced into the analysis. In other words, while the most frequent rhythmic structures provide a certain level of discriminatory power, adding more does not strengthen but rather weakens the signal. A detailed breakdown of performance across the different methods employed can be observed in the graph below (Fig. 3), which make clear both the potential and the limitations of this rhythmic approach in comparison to the lexical baseline.

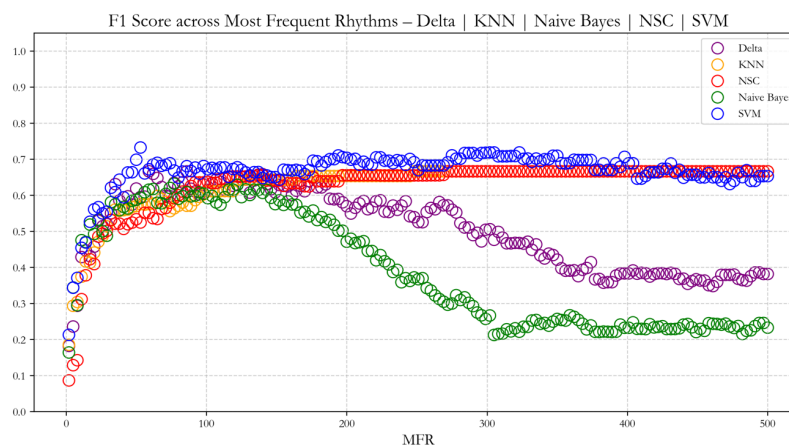


Figure 3. F1 score variation with most frequent rhythms across five classification methods for the dataset of one hundred plays by nine playwrights.

The results obtained with rhythmic stylometry are clearly inferior to those achieved with lexical stylometry. Whereas lexical analyses reached near-perfect accuracy—often approaching 100% with methods such as SVM and NSC once a threshold of the most frequent words was surpassed—the rhythmic experiments performed less impressively, with overall accuracy peaking at around 70%. This gap underscores the robustness of lexical frequencies as markers of authorial style and the relative fragility of rhythmic features when subjected to large-scale statistical testing. It also suggests that while lexical signals accumulate rapidly and stabilize with only a few hundred words, rhythmic signals are both scarcer and more sensitive to noise introduced by

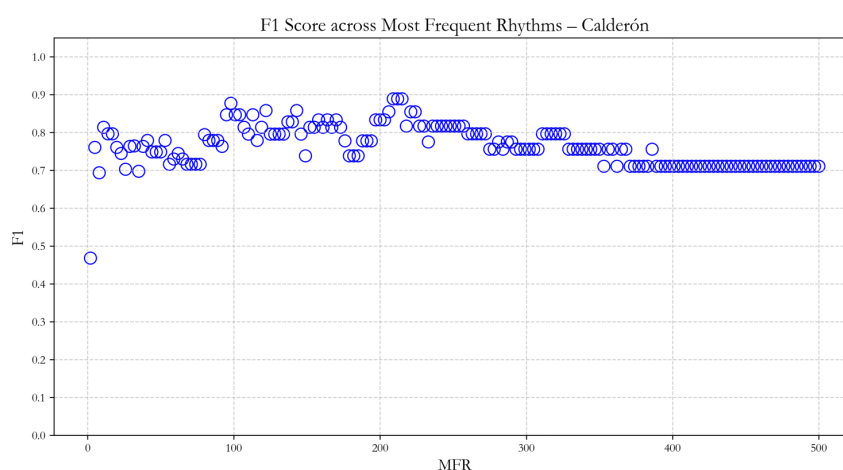
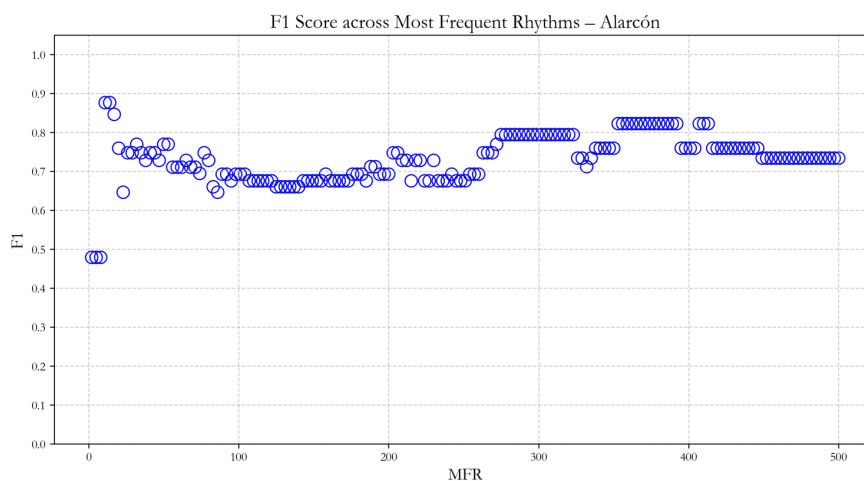
scansion errors, editorial variation, or metrical flexibility. In practice, this means that rhythmic stylometry cannot yet match the reliability of lexical approaches for broad corpus-level classification, although it may still provide valuable supplementary evidence in specific cases where lexical results are ambiguous or contested.

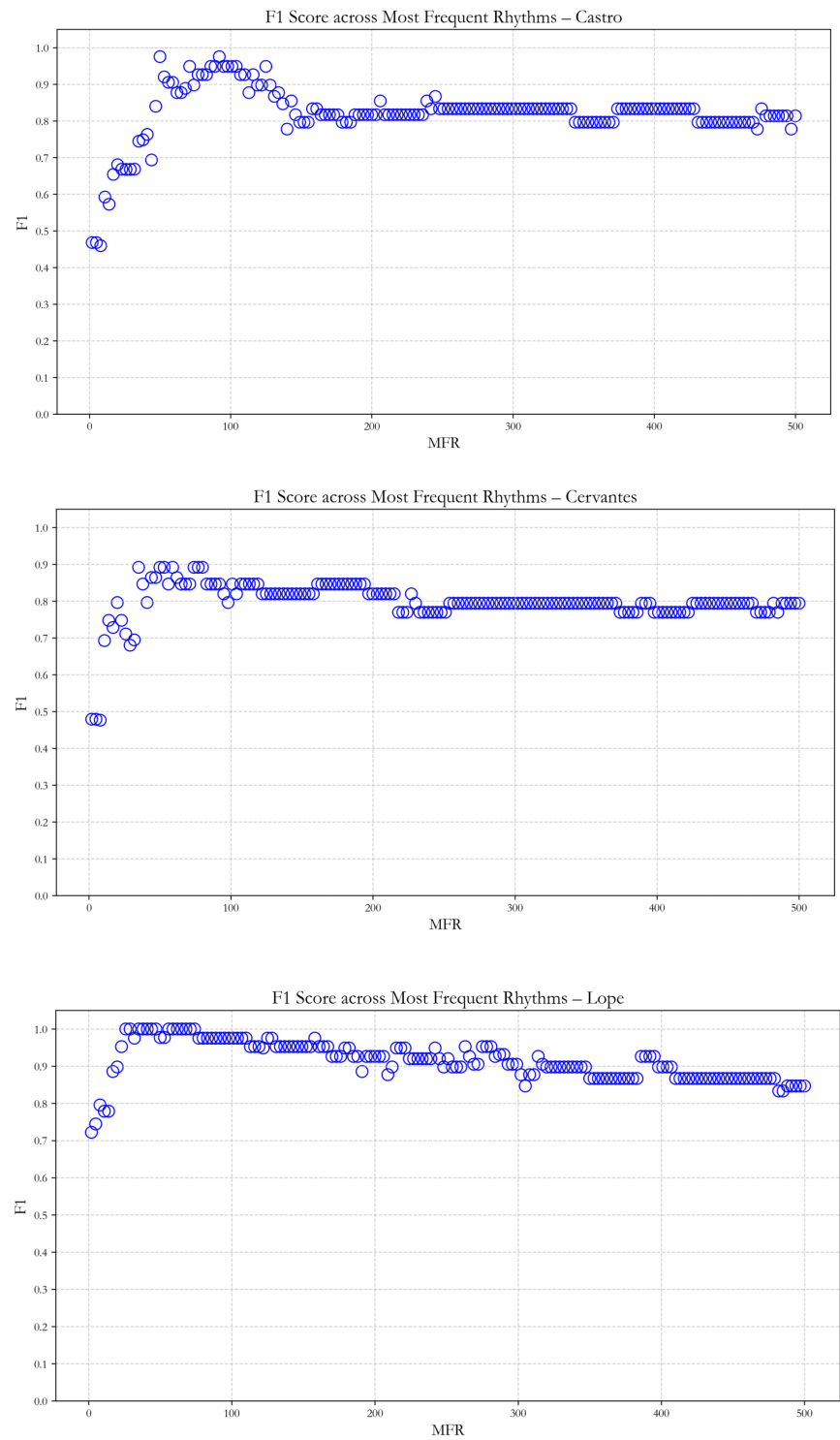
4.1. Binarization

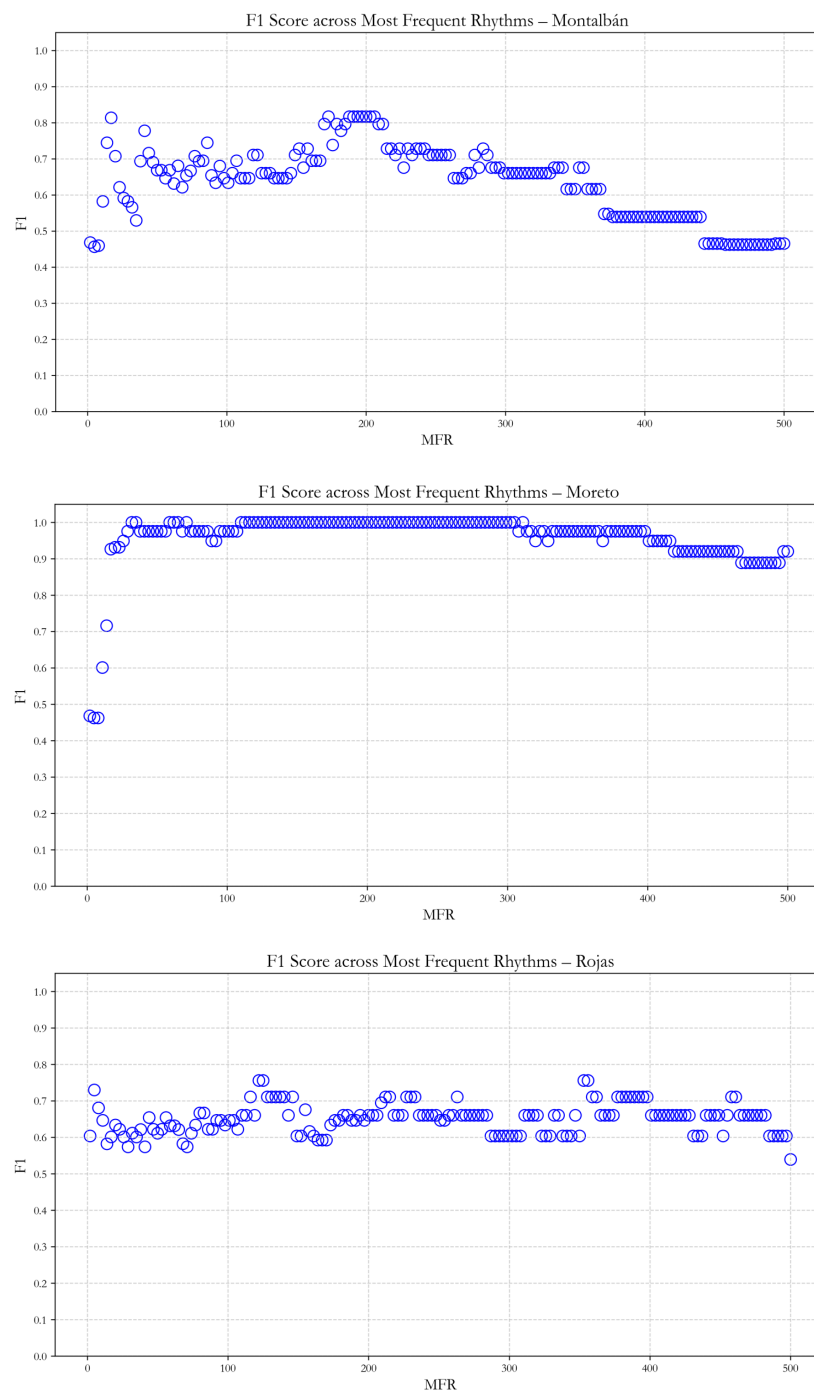
One promising way to address this limitation is through *binarization*. Instead of asking the system to classify a play among nine authorial groups simultaneously—a task that requires the algorithm to identify multiple precise decision boundaries—we can pose a simpler question: does this play belong to a given author, or does it not? Framed in this way, as for example Lope versus not-Lope or Calderón versus not-Calderón, results improve substantially (Fig. 4), in some cases reaching perfect accuracy. For Lope de Vega, in particular, we obtain 100% classification accuracy under controlled conditions, suggesting that rhythmic stylometry may indeed provide a viable parallel pathway for addressing long-standing attribution problems. The improvement is not surprising when considered from a computational perspective. Multi-class classification with LOOCV forces the SVM to carve out several hyperplanes simultaneously, balancing delicate boundaries among all nine groups. Any partial overlap or blurred frontier between authors significantly reduces performance. By contrast, binary classification simplifies the task to a single boundary: deciding whether a play belongs to one author or to the rest.

Unlike lexical stylometry, where most playwrights respond similarly to statistical probing, the rhythmic approach seems to reveal more individual variation. In certain cases, such as Agustín de Moreto, results are consistently perfect across a wide range of rhythmic features, suggesting that his metrical habits form a distinctive and stable fingerprint. Lope de Vega also yields excellent results, particularly when analyses are restricted to the 60–100 most frequent rhythmic patterns—largely octosyllabic structures—where proportions appear decisive. Interestingly, this suggests that the key to effective rhythmic attribution lies not in expanding the set of patterns indefinitely, but rather in focusing on a limited cluster of recurring forms. Other playwrights, however, present more difficulty. In the cases of Juan Pérez de Montalbán or Rojas Zorrilla, accuracy struggles to exceed 80%, even under favorable conditions. These mixed results remind us that while rhythmic stylometry is a promising supplement, it cannot yet compete with lexical stylometry in consistency and reliability. Still, it would be a mistake to dismiss 80–90% accuracy as unsatisfactory; such figures remain strong in absolute terms, particularly given

the novelty and complexity of the method. The results are heterogeneous, but therein lies their potential: rhythms may help to distinguish some authors more sharply than others, complementing the lexical fingerprint rather than replacing it. In short, rhythmic stylometry produces results that are both encouraging and uneven. It demonstrates promise for certain playwrights, such as Lope and Moreto, while exposing challenges for others. As with any experimental approach, applying these methods to large, noisy, and heterogeneous real-world corpora will be more demanding. Yet the gains achieved through binarization, and the stability observed in a subset of authors, suggest that rhythmic stylometry deserves further exploration—not as a replacement for lexical methods, but as a parallel and potentially corroborative line of inquiry.







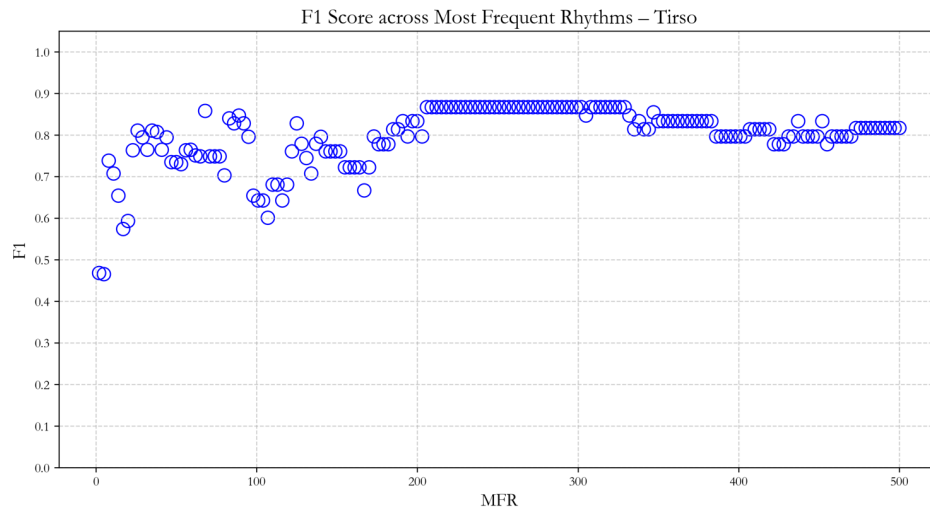


Figure 4. F1 score as most frequent rhythms vary across the nine playwrights in the control experiment.

4.2. Stylometric networks

One of the most effective ways of presenting stylometric results is through automatic networks (Eder, 2017b) that map plays onto a plane according to their degrees of similarity. Unlike distance matrices or dendrograms, which either require laborious interpretation or prove unstable when small variations occur in the data, networks provide an immediate and intuitive visualization of how texts gravitate toward one another. Lexical stylometry, based on the 500 most frequent words, yields a particularly clear and stable network (Fig. 5): the plays cluster almost perfectly by author, with only a few minor interferences, such as certain works by Calderón. This outcome confirms the extraordinary reliability of lexical stylometry for authorship attribution in Golden Age theatre.

When we apply the same procedure using rhythmic stylometry (Fig. 6), however, the picture becomes more complex. Constructed from the 80 most frequent rhythmic patterns in our corpus, the network reveals both strengths and limitations. Some authors, such as Lope de Vega and Agustín de Moreto, produce relatively coherent clusters, suggesting the presence of distinctive rhythmic fingerprints. Yet other playwrights appear far more dispersed, and the clusters that do emerge are weaker and less stable than in the lexical case. A striking example is *La dama boba*, which detaches from the main Lope cluster and occupies a distant position in the network, perhaps due to its “elevadísima

cantidad de cambios métricos” (Antonucci, 2020: 111), although this remains difficult to determine with certainty without further study. The contrast between the two networks highlights the complementary role of rhythmic stylometry. While lexical stylometry provides stronger and more robust results overall, rhythmic analysis captures additional nuances that may prove valuable for specific authors or for exploring dimensions of style less visible at the lexical level. The method is thus promising, though still fragile: it requires further refinement before it can approach the clarity and reliability already achieved in lexical stylometry.

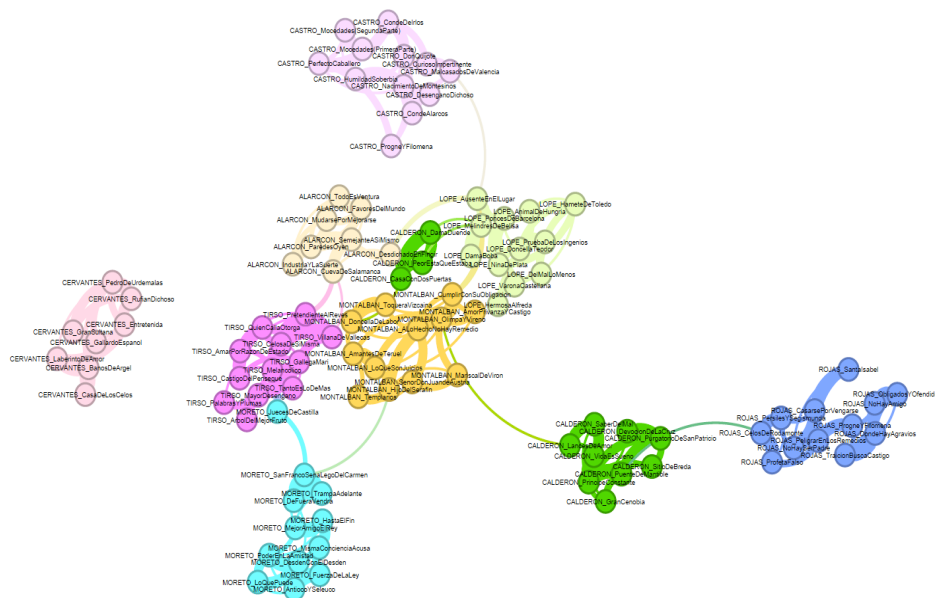


Figure 5. Stylometric network with 500 Most Frequent Words and Delta method for the corpus of 100 plays by nine playwrights

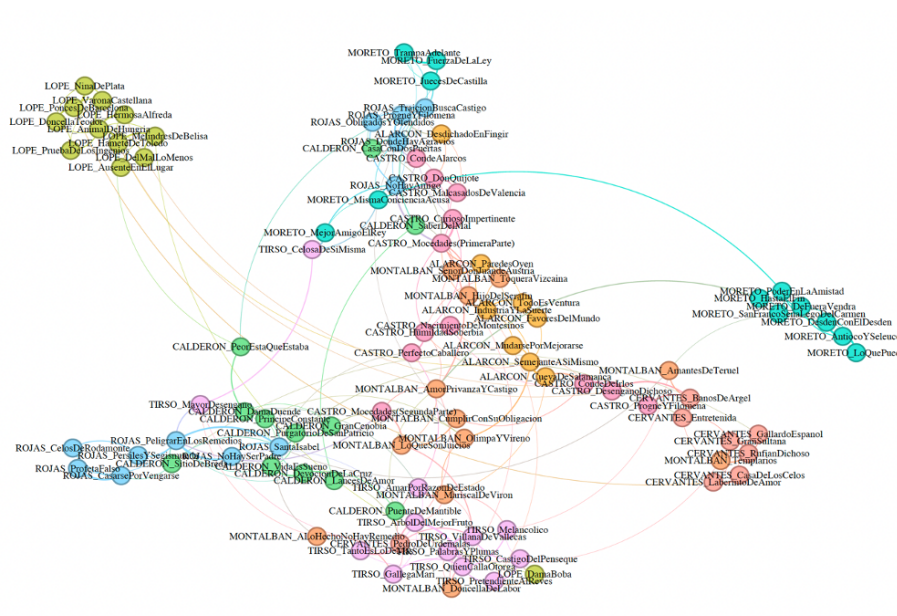


Figure 6. Stylometric network with 80 rhythmic patterns and Delta method for the corpus of 100 plays by nine playwrights.

5. CONCLUSIONS

Up to this point, most stylometric research on the theatrical corpus of the Spanish Golden Age has relied on lexical analysis, atomizing plays into their basic constituents: words. In this study, however, we have taken a further step by conceiving each play not only as a sequence of lexical units but also as a chain of some thousand waves, rhythmic pulses that reflect the prosodic habits of its author. By shifting the analytical focus from words to rhythms, we have explored the potential of rhythmic stylometry as a complementary approach to the lexical paradigm. Our experiments demonstrate that rhythmic stylometry, when applied to the same corpus used for lexical tests, operates at lower levels of accuracy: rarely above 80% when treated as a multi-class problem. Nevertheless, once the task is binarized—for example, distinguishing Lope from non-Lope or Calderón from non-Calderón—accuracy rises dramatically, in some cases reaching perfect scores. This improvement highlights both the inherent difficulty of multi-class classification and the promise of binary approaches for practical attribution tasks. A noteworthy tendency can be observed when the analysis focuses on a limited set of around 80–100 rhythmic

patterns. In certain cases this range yields stronger results, suggesting that a relatively small cluster of recurrent patterns may provide greater discriminative power. In other authors, however, such a peak is not always evident, and the behavior of the system remains more heterogeneous. By contrast, lexical stylometry tends to stabilize at near-perfect accuracy once a sufficient threshold of frequent words is reached, whereas rhythmic stylometry often displays local peaks of performance rather than a smooth path toward stability. This indicates that future work will need to identify the optimal peak individually for each playwright, since rhythmic stylometry may operate at different thresholds depending on the particular metrical habits of the author under study.

This exploratory work opens the door to a series of new questions. Might rhythmic stylometry, beyond attribution, also serve for the automatic dating of texts, or for classification by genre, gender, or geographical origin? Could wave theory be applied to these materials—through summation, superposition, or the simplification of signals via Fourier transforms—to yield even more powerful analytical tools? At the same time, certain limitations must be acknowledged. The preparation of materials may not have been equally rigorous for all authors, and discrepancies in scansion quality could affect outcomes. Lope de Vega's corpus, for example, may have benefited from greater editorial care, leading to more reliable rhythmic extraction. Such imbalances remind us that the method must be tested further before its results can be generalized. Yet it should also be noted that stylometry as a whole is robust to error: just as lexical stylometry tolerates error rates of 20–30% without collapsing, rhythmic stylometry too should be able to absorb modest levels of noise without compromising its overall validity. Equally important is the role of traditional expertise. Specialists in Golden Age metrics and in the individual playwrights under consideration must be invited to reflect on the significance of these findings. Only through dialogue with philologists and literary historians will it be possible to interpret the computational signal in a way that enriches, rather than replaces, established scholarship. Rhythmic stylometry should not be seen as an endpoint but as a new instrument that can be integrated into the broader toolkit of Early Modern literary studies.

Lexical and rhythmic stylometry need not remain isolated approaches. A promising direction for future work lies in their combination: lexico-rhythmic models that incorporate both sets of features simultaneously, or even alongside other dimensions (morphological, syntactic, semantic, or thematic). Such hybrid approaches, though still unexplored, could yield more nuanced authorial fingerprints and push the boundaries of stylometric research. In sum, rhythmic stylometry is not yet as powerful or consistent as lexical stylometry, but its promise is evident. For some playwrights—most notably Lope de Vega, Agustín

de Moreto and Guillén de Castro—it already delivers results that rival or complement lexical tests. For others, it highlights the need for more refined methods and cleaner corpora. Either way, it opens a new path forward. We believe that this avenue deserves to be pursued with much greater depth, through both computational refinement and philological engagement, as it holds the potential to enrich our understanding of authorship, style, and the poetic fabric of the Golden Age stage.

Ultimately, the horizon of this line of inquiry must be the full-scale transformation of the Golden Age corpus—some three thousand plays and nearly nine million verses—into rhythmic waves, in order to investigate what new insights might emerge at such breadth. This is, of course, an ambitious goal that requires sustained philological, computational, and methodological refinement: automatic scansion must be further improved, metrical irregularities must be systematically addressed, and textual corpora must continue to be normalized. Yet the potential reward is considerable. By expanding rhythmic stylometry to its natural scale, we may uncover large-scale regularities in prosodic usage that remain invisible in smaller samples, and in so doing, open an entirely new dimension of authorship studies in Early Modern theatre.



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