Euclidean Rhythms Found in English Poetry and Lyrics

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Abstract

This paper introduces a computational framework that uses geometry to visualize and analyze the rhythmic structures found in English poetry and song lyrics. Drawing on previous research on musical rhythms, we propose new methods for studying rhythmic patterns in language at both the syllable and phoneme levels. Our approach highlights similar geometric features shared between English rhythmic texts and traditional music. An automatic analysis across diverse datasets demonstrates that rhythmic texts exhibit a higher occurrence of Euclidean patterns. Furthermore, a human evaluation study suggests that prominent Euclidean rhythms at the phoneme level are perceived as aesthetically pleasing, performing on par with traditional poetic rhythms. These findings suggest promising applications in algorithmic composition and cognitive studies of rhythmic English texts.

Introduction

The relationship between language and music has long been recognized. However, limited comparative studies have been conducted on the rhythms of music and language, mainly because it requires expertise in both fields [15]. Toussaint [17] introduced a way to geometrically visualize and analyze musical rhythms by arranging beats and rests at equally spaced vertices around a circle. Starting from an initial note, the pulses are placed in a clockwise order, and by connecting only the vertices corresponding to beats, a convex polygon is formed. In a later work, Toussaint [18] observed that many traditional musical rhythms follow a Euclidean structure, meaning that n beats are being distributed as evenly as possible over k pulses. These rhythms can be generated using Bjorklund algorithm [2]: Given a binary sequence consisting of n ones and $k - n$ zeros, the algorithm $E(n, k)$ constructs a k-bit sequence with exactly n ones arranged so that the ones are as evenly distributed as possible among the zeros. A formal description of the algorithm is provided in Algorithm 1 of the supplementary material. Euclidean rhythms have since been integrated into various algorithmic composition tools and music sequencers [14]. Toussaint [19] identified many geometric properties that seem to correlate with what make a rhythm "good".

In a previous work [4] we showed that these geometric properties also extend to language rhythms, particularly in classical Arabic poetry. Revealing that the rhythmic patterns in Arabic poetry are also predominantly Euclidean, symmetric, palindromic, and deep. Arabic poetry rhythms depend on a sequence of vocalized and non-vocalized consonants that can be mapped directly to beats and rests, respectively, creating a clear, one-to-one rhythmic correspondence. English poetry, on the other hand, relies on recurring patterns of syllables that differ in emphasis. These patterns typically form a binary sequence, with stressed syllables denoted by (ˊ) and unstressed syllables by (ˇ). The arrangement and relative length of these syllables forms the meter of a poem, which is organized into units known as feet. The challenge is to represent the stress patterns in English poetry using a geometric framework similar to that applied to musical and Arabic rhythms. In this paper, we address this gap by introducing a framework that represents the rhythmic patterns of English texts as geometric visualizations. Our method operates on two levels. At the *syllable-level*, we interpret stress patterns as beat notes and rests, which allows us to represent common metrical units as convex polygons arranged on a circle similar to how musical rhythms are analyzed. At the *phoneme-level*, we refine this representation by examining the consonant-vowel structure within syllables and aligning beats with vowel onsets. This reveals interesting features that English rhythmic texts exhibit and qualities often associated with aesthetically

pleasing musical rhythms. We believe that these observations are especially valuable for advancing research in the song composition and lyrics writing fields.

Geometric Properties of Syllable-Level Rhythms

In the poetry scansion process, it is common to use sound mnemonics such as "da" or "di" to represent unstressed syllables and "DUM" or "DĀ" for stressed syllables to break down complex syllabic sounds into more abstract components. They mimic the sound of drum taps where an unstressed syllable corresponds to a short tap and a stressed syllable to a longer tap. Early studies [1][16] have shown that when English listeners tap along to spoken English words, the perceived beat locations often align with transitions from consonants to vowels (*vowel onsets*). Interestingly, "da" and "di" are pure vowel onsets, while "DUM" and "DĀ" consist of a vowel onset followed by either a consonant or a vowel extension, respectively. Our framework is motivated by this abstraction. Accordingly, we match a beat note (denoted by 1) with each vowel onset and a rest (denoted by 0) otherwise. Under this scheme, a stressed syllable is encoded as 10, while an unstressed syllable is encoded as 1. We then use this encoding to transform metrical feet into sequences of notes and rests, which we represent visually in a circular format similar to Toussaint's rhythmic circles for musical rhythms.

English meters mostly use disyllabic (2-syllable) and trisyllabic (3-syllable) feet with one stressed syllable and one or two unstressed syllables [7]. The iamb (˘ ´) and the trochee (´ ˘) are common examples of disyllabic feet. The anapest (˘ ˘ ´), the dactyl (´ ˘ ˘) and the amphibrach (˘ ´ ˘) are examples of trisyllabic feet. The spondee (´ ´) and the pyrrhic (˘ ˘), often found in a sequence of closed-class words such as "and the" or "of a" do not define a meter in English poetry but they are frequently used as substitutions within verses.

To counteract excessively regular blank verse that lacks rhythmic variations, poets often introduce substitutions (variations in the standard metrical pattern) to create a more engaging rhythm. Although these substitutions are mostly influenced by instinct or taste rather than strict rules [7], common examples include the replacement of an iamb with a trochee and vice versa. It is also common to use the spondee and pyrrhic as substitutions of the iamb and trochee.

When we plot these common metrical feet using the circular format, we observe the formation of unique geometric patterns:

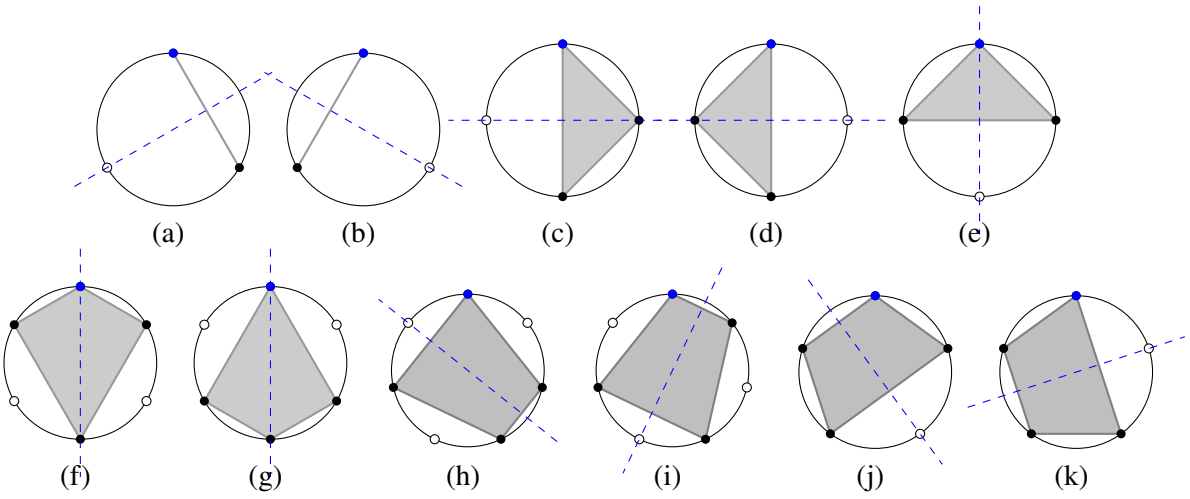

Figure 1: *Group 1: (a) iamb and (b) trochee. Group 2: (c) anapest, (d) dactyl, and (e) amphibrach. Group 3: (f) trochaic, and (g) iambic substitutions. Group 4: (h) spondaic substitution after a trochee and (i) after an iamb. Group 5: (j) pyrrhic substitution after a trochee and (k) after an iamb.*

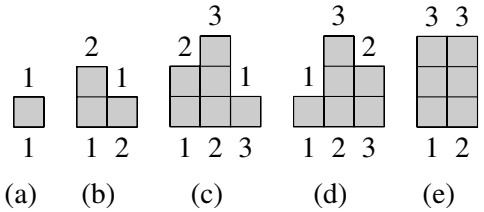

Figure 2: *The interval histograms for: (a) Group 1, (b) Group 2, (c) Group 3, (d) Group 4 and (e) Group 5.*

Isomorphism

We observe the formation of isomorphic groups, where the shape of one rhythm can be transformed into another through rotation. These isomorphic groups are as follows: (1) the iambic and trochaic feet, (2) the anapestic, dactylic and amphibrachic feet, (3) the iambic and trochaic substitutions, (4) the spondaic substitutions in an iambic or trochaic meter, and (5) the pyrrhic substitutions in an iambic or trochaic meter (see Figure 1).

Symmetry and Palindromicity

All the rhythmic patterns in our study exhibit symmetry, as each pattern can be divided into two identical halves along a line of symmetry (the dashed blue line in Figure 1). However, their palindromicity, meaning that the sequence of notes and rests is the same when played anti-clockwise, differ across the groups. The amphibrachic foot is strictly palindromic, as well as the iambic and trochaic substitutions. The anapestic and dactylic feet have *weak* palindromicity, meaning that the sequence can be played backwards at some beat other than the starting beat. Conversely, the standard iambic and trochaic feet, as well as the spondaic and pyrrhic substitutions, do not possess palindromicity.

Euclidean Property

The Euclidean property holds for the majority of these isomorphic groups. Most can be generated using the Bjorklund algorithm (for example, $E(2,3)$ for group 1, $E(3,4)$ for group 2, $E(4,7)$ for group 4, and $E(4,5)$ for group 5). However, the iambic and trochaic substitutions are non-Euclidean as they are not isomorphic to $E(4,6) = 110110$, which represents two periods of the maximally even $E(2,3) = 110$. Reflections, rotations, and complements of Euclidean rhythms remain Euclidean [19].

Rhythmic Depth

The interval histogram shows the number of occurrences (on the y-axis) for each possible distance between beat notes (on the x-axis). Analyzing the interval histograms in Figure 2 reveals that with the exception of the pyrrhic substitutions all groups can be classified as Winograd and Erdős deep rhythms, meaning that every possible distance between beats (from 1 to $\lfloor \frac{N}{2} \rfloor$) occurs with a unique multiplicity [3].

Geometric Properties of Phoneme-Level Rhythms

Let's revisit the moment we abstracted the sounds of stressed and unstressed syllables with the percussion mnemonics. Stressed syllables receive a slight extension in duration either by ending with a consonant sound in "DUM" or by elongating the vowel in "DĀ". But what if we could directly align the natural flow of consonant-vowel patterns within the syllables with the beats without imposing such abstractions?

Our motivation comes from the studies that have investigated how listeners perceive rhythmic beats within the syllable structure of English speech [1][16] indicating that beats are often placed on the vowel onsets in a syllable. On what makes "good" rhythms, Toussaint [19] has hinted that some rhythmic patterns common in music may also be found within the syllables of English words. Although the author offers

illustrative examples, the author does not detail a systematic process by which these patterns emerge. For example, the author assigns the words “engineer” and “kangaroo” the rhythm [x . x x] and “spaghetti” and “potato” the rhythm [x x . x], using the box notation where “x” represents a beat and “.” represents a rest. In these cases, beats are placed on the vowel onsets and rests otherwise, with the exception of ignoring the final rest probably because the author has assumed the default state is to have a rest after a final beat.

A syllable in English consists of three components: an *onset*, a *nucleus*, and a *coda*. The nucleus, which is always present, is a vowel sound, whether short, long, or a diphthong. The onset and coda, when present, consist of consonant sounds and may comprise multiple consonants. A syllable that lacks a coda is known as *open syllable*, whereas one without an onset is referred to as *null onset*. Every English syllable consists of at least a nucleus, which ensures that it can be aligned with a beat perceived at the vowel following a consonant in the onset. In syllables with a null onset, where no consonant precedes the vowel, the syllable may adopt an onset by borrowing a consonant from the previous syllable’s coda or by employing a glottal stop, which is a consonant sound that naturally occurs before isolated or initial null onsets [9]. Since consonant sounds that do not precede a vowel, and vowel elements that are not vowel onsets, such as elongated vowels or the second element in a diphthong, do not align with perceived beats, we classify them as non-beat pulses (rests).

Consonant clusters, which are groups of adjacent consonants, are a common feature in English. Note how the duration of syllables in words like “play,” “pay,” and “lay” is roughly equivalent despite differences in their consonant structures. A study by Haggard [8] on a 70-word sample found that consonants within clusters tend to have a shorter duration than those in isolation. Consequently, we treat consonant clusters within the same onset or coda as equivalent to a single non-beat pulse unit. This reduction is applied only when the consonants do not affect the pronunciation of adjacent syllables through resyllabification in connected speech. For example, in the phrase “the play,” the coda of the first syllable will borrow the “p” sound from the consonant cluster, while the “l” sound functions as the onset of the second syllable. In such instances, the consonant cluster should not be combined.

English poets typically focus systematically on the stress patterns rather than on the arrangement of phoneme-level patterns. Nonetheless, a manual phoneme-level analysis of the Beatles’ song “Yesterday” reveals familiar patterns. The rhythm of “Yesterday” first caught our attention after reading the study of Lerdahl [13] where the author employed it as a key example to illustrate the connections between the sounds of English poetry and music from the stress-pitch perspective. If we shift our attention to the phoneme-level patterns, we can observe that they mostly are Euclidean rhythms, symmetric, palindromic, Winograd and Erdős deep and can be put in isomorphic pairs. Figure 3 shows the phoneme-level analysis of the first line of

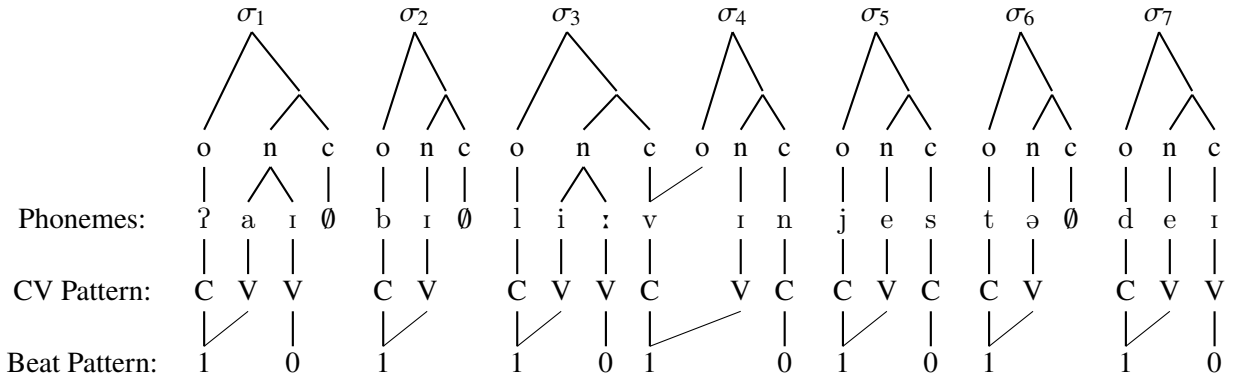

Figure 3: *Converting the seven-syllable “I believe in yesterday” from phonemes to beat pattern. σ_1 is a null onset employing a glottal stop, and σ_4 is a null onset that borrows the consonant from the previous syllable. σ_1, σ_2, and σ_6 are open syllables.*

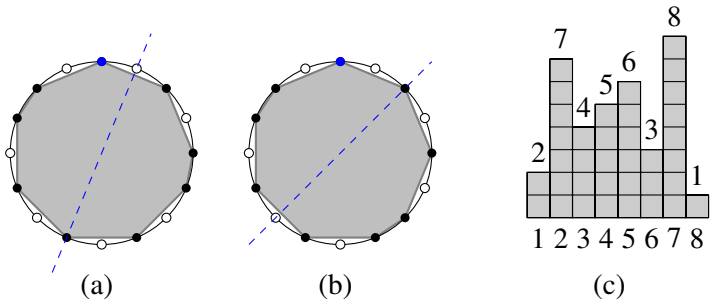

Figure 4: *The circles for (a) "All my troubles seemed so far away" from the first stanza and (b) "I'm not half the man I used to be" from the second stanza, with (c) their interval histogram.*

the song, and Figure 4 shows the plot of a pair of lines isomorphic to $E(9,16)$ with their interval histogram showing unique multiplicities for each distance between beats.

This observation raised several questions in our minds: Are the geometric properties observed at the phoneme-level in "Yesterday" lyrics also present in other song lyrics or poems? Do the phoneme-level rhythms in lyrics and poetry generally exhibit Euclidean properties? Moreover, are these rhythmic patterns also found in non-rhythmic texts? To address these questions, we will present an automatic analysis of the geometric patterns found in English lyrics and poetry at the phoneme-level. Our study will include lyrics from both famous and amateur songs and poems and famous rap lyrics. For comparison, we will also analyze news headlines and sentences from random Wikipedia articles to determine whether the phoneme-level rhythmic patterns in lyrics and poetry are unique or if they commonly occur in general English texts.

Data Collection and Preprocessing

To test our hypothesis, we used seven datasets spanning lyrics, poetry, and non-rhythmic texts. Our lyrics corpus includes (*AL*): lyrics from amateur writers collected from AllPoetry [20] website at */poems/about/Lyric*, and (*FL*): lyrics from famous songs covering 21 artists [10], (*FRL*): rap lyrics from approximately $21,000$ songs [11]. For poetry, we sourced (*AP*): $1,000$ random amateur poems from AllPoetry at */poem/id* where *id* is a random number between 1 and $17e6$, and (*FP*): the collection of poems from famous poets on AllPoetry at */famous-poems*. Finally, we established non-rhythmic baselines using (*NH*) $210,000$ news headlines [12] and (*WL*) $1,000$ random Wikipedia articles [21] at */wiki/Special:Random* which were segmented into sentences based on punctuation.

We processed the lines from all datasets by removing special characters, numbers, and punctuations. Next, we encoded the lines into beat patterns using a grapheme-to-beat model we developed [5] which converts graphemes into phonemes, then the phonemes are mapped into consonant-vowel patterns, and finally translates these patterns into beat sequences as described in the previous section. Given the variability in dataset sizes and line lengths, we randomly sampled 5 subsets matching the size and line length distribution of all other datasets to that of the smallest dataset (4750 lines) to control for any effects due to line length.

Experiments and Results

For each line, we counted the number of beat notes (b) and rests (r) of the shortest repeating pattern. We then applied the Bjorklund algorithm $E(b, b+r)$ to generate the corresponding Euclidean rhythms and tested whether the rhythm of the lines is isomorphic to the Euclidean pattern. Our experiments show that at least 55% of each rhythmic text group (song lyrics, rap lyrics, and poems) exhibit Euclidean rhythms, rising to over 61% for famous lyrics (see Figure 5a). In contrast, no more than 45% of non-rhythmic texts (news headlines

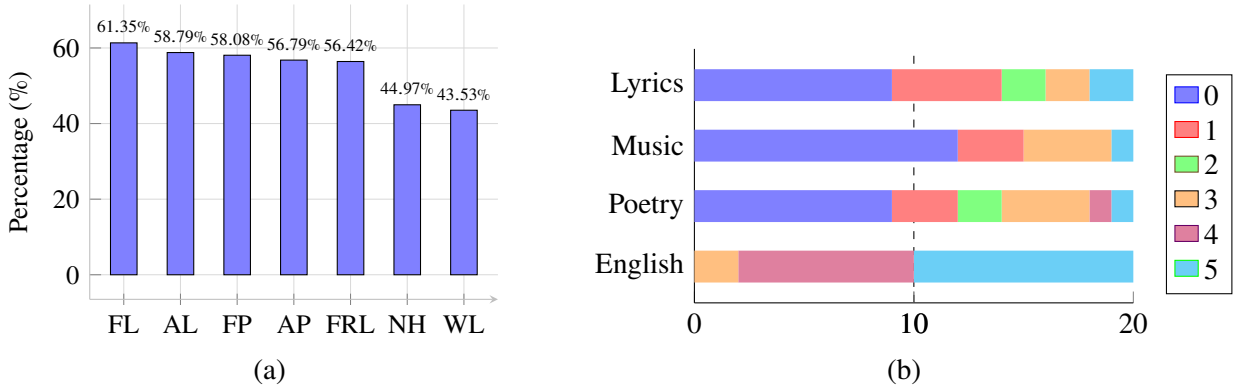

Figure 5: *(a) Distribution of Euclidean rhythms across text sources. (b) Demographics of the participants.*

and Wikipedia lines) exhibit Euclidean rhythms, all with confidence intervals below ±1%, indicating a clear distinction between rhythmic and non-rhythmic texts. This supports our hypothesis that rhythmic texts are more likely to exhibit Euclidean rhythms, especially song lyrics which are accompanied by music.

Our analysis revealed that patterns occur most frequently when n is a divisor of k in $E(n,k)$. This suggests that the dominant rhythmic structure is a periodic pattern of 10, in which beats are uniformly distributed across the pulses. This regular pattern appeared in over 40% of the lyrics datasets. One possible explanation for the prevalence of such uniformly spaced beat patterns in lyrics is that they are easily adaptable to various musical styles, effectively aligning with the consistent background uniform pulse common to many songs.

Human Perception of Rhythmic Aesthetics

In this section, we examine whether English speaking participants find phoneme-level Euclidean patterns aesthetically pleasing in poetry and song lyrics. In particular, we focus on the pattern $E(7,12)$, which has been noted for its prevalence in traditional music worldwide [19]. Our goal is to assess whether this rhythmic pattern, when applied to English lyrics at the phoneme-level, is perceived as appealing in its own right.

To generate examples for evaluation, we utilize the ParaPoetry dataset [6] which includes human-written poetry lines with five automatically generated rephrases each. First, we automatically extract the beat pattern for all the lines and their rephrases in the dataset using the grapheme-to-beat model. Second, we selected the cases where at least one rephrased line matched a period of 2 of the pattern 110101101010, the most common pattern in classical Arabic poetry [4] isomorphic to $E(7,12)$, ensuring sufficient context to be presented for evaluation. We then manually verified that the selected lines adhered to the target pattern, did not exhibit a traditional identifiable stress pattern, and that at least one rephrase lacked either a Euclidean or a traditional stress pattern to eliminate potential bias. This process resulted in a final set of 12 triplets, each comprising the original line (*Original*), a line exhibiting the target Euclidean phoneme-level rhythmic pattern (*Euclidean*), and a line with a random rhythm that is neither Euclidean nor traditional (*Random*).

Twenty participants were recruited for this study via convenience sampling, drawing on graduate students at the University of Calgary from the Department of Computer Science and acquaintances with a background in poetry or lyrics composition. Each participant self-assessed their English proficiency on a 0 (no understanding) to 5 (native speaker) scale and their familiarity with writing poetry, lyrics, and music composition on a 0 (no experience) to 5 (published-level expertise) scale. Figure 5b illustrates our sample, which comprised an approximately equal mix of native and non-native English speakers as well as individuals with and without prior experience in poetry, lyrics writing, or music composition. Participants were asked to rate the rhythmic appeal of these 12 triplets to choose the line they found most rhythmically appealing and best suited for lyrics intended to be sung, based solely on a natural reading without the need for poetic scansion. All

experiments received ethics approval from the Conjoint Faculties Research Ethics Board (CFREB) at the University of Calgary under protocol number REB24-0877.

Our analysis shows that the original lines and the Euclidean lines were selected with very close rates, at 46.67% and 39.58% respectively with no significant statistical difference on a one-tailed t-test with a p-value = 0.27. This finding suggests that the Euclidean pattern 110101101010 is at least as aesthetically appealing to our participants as the traditional rhythm produced by real poets. Moreover, both the original and Euclidean lines were rated significantly more favorably than the random lines, which were chosen only 13.75% of the time with a small p-value < 0.01.

Figure 6 shows how often each type of line was picked by the participants, separated by whether participants were native English speakers and whether they had any experience in poetry, lyrics, or music. The graph shows that native and experienced participants tend to be more consistent in preferring the original lines directly followed by the Euclidean line and the random line least preferred.

These preliminary results indicate that considering the Euclidean rhythmic structure $E(7,12)$ has an aesthetic appeal in English lyrics, aligning them with patterns valued in other musical and poetic traditions. We acknowledge that a larger-scale study is necessary to confirm these findings and to further explore the relationship between the rhythmic patterns and the aesthetic appeal in various textual genres. However, this can be considered as a pilot study for the broader set that encapsulates Euclidean rhythms coupled with other geometric features.

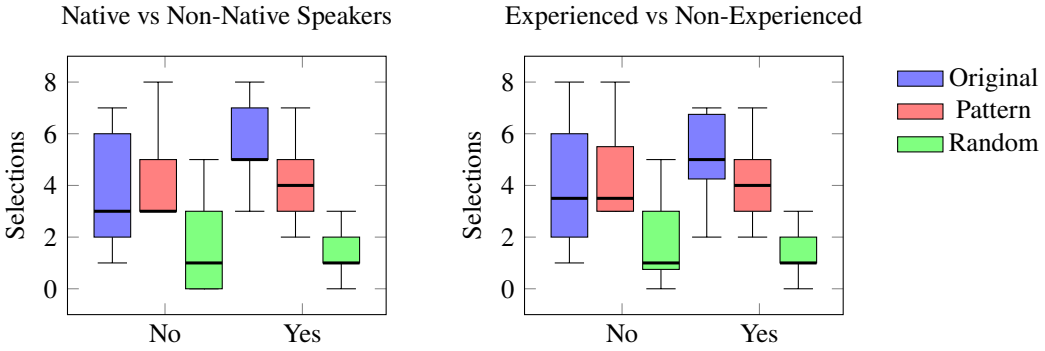

Figure 6: *Distribution of the participants' choices in the human study.*

Conclusion and Future Work

In this paper, we presented a framework that converts the rhythmic patterns in English poetry and song lyrics into visual representations. By combining traditional theories of rhythm with computational methods, our approach offers new insights into English rhythmic structures and provides practical tools for creative expression. We encoded patterns at both the syllable and phoneme levels and found that rhythmic patterns typically observed in traditional music also appear in English poetry and lyrics such as being Euclidean, symmetric, palindromic and deep. Our analysis reveals that rhythmic texts such as song lyrics, rap, and poetry contain these patterns more frequently than non-rhythmic texts. Moreover, our human evaluation study suggests that Euclidean rhythms, particularly the prominent $E(7,12)$ rhythm, are perceived as aesthetically appealing, aligning with rhythmic traditions found in other cultures. This can indicate that the Bjorklund algorithm has a potential to generate new rhythmic patterns that are not usually found in English poetry but still found to be appealing, offering lyricists and poets a tool to experiment with novel rhythmic structures.

Despite this, our work has several limitations. The automatic process for converting text to its phonetic form is not error-free, and even minor discrepancies can affect the geometric properties of the rhythmic patterns. Moreover, the sample sizes in our human evaluation is relatively small, which may limit the gen-

eralizability of our findings. Future research could improve on the automatic conversion process and extend this framework to additional languages and cultural contexts. We hope that our work will inspire further interdisciplinary studies in computational creativity and the algorithmic poetry and lyrics composition.

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