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Potential Note Degree of Khong Wong Yai Based on Rhyme Structure and Pillar Tone as a Novel Approach for Musical Analysis Using Multivariate Statistics: A Case Study of the Composition Sadhukarn from Thailand, Laos, and Cambodia

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Abstract: Diverse multivariate statistics are powerful tools for musical analysis. A recent study identified relationships among different versions of the composition Sadhukarn from Thailand, Laos, and Cambodia using non-metric multidimensional scaling (NMDS) and cluster analysis. However, the datasets used for NMDS and cluster analysis require musical knowledge and complicated manual conversion of notations. This work aims to (i) evaluate a novel approach based on multivariate statistics of potential note degree of rhyme structure and pillar tone (Look Tok) for musical analysis of the 26 versions of the composition Sadhukarn from Thailand, Laos, and Cambodia; (ii) compare the multivariate results obtained by this novel approach and with the datasets from the published method using manual conversion; and (iii) investigate the impact of normalization on the results obtained by this new method. The result shows that the novel approach established in this study successfully identifies the 26 Sadhukarn versions according to their countries of origin. The results obtained by the novel approach of the full version were comparable to those obtained by the manual conversion approach. The normalization process causes the loss of identity and uniqueness. In conclusion, the novel approach based on the full version can be considered as a useful alternative approach for musical analysis based on multivariate statistics. In addition, it can be applied for other music genres, forms, and styles, as well as other musical instruments.

Keywords: Sadhukarn; multivariate statistics; pillar tone; Look Tok; rhyme structure; musical analysis; music composition; Na phat music

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1. Introduction

Multivariate statistics are branches of statistics that involve the simultaneous observation and analysis of more than one outcome variables. They encompass a range of techniques and models for understanding the relationships and structures among multiple variables within a dataset [1]. Multivariate analysis is a powerful approach used to explore and examine the simultaneous effect of multiple variables [2]. It has been used across various disciplines [2–5]. Diverse multivariate statistics approaches have been recently used for musical analysis [6,7], e.g., principal component analysis (PCA) paired with K-means clustering for dimensional reduction in Korean pop music audio features [8], goodness-of-fit test and subgroup analysis [9], logistic regression and discriminant analysis [7], non-metric multidimensional scaling (NMDS) and cluster analysis based on the unweighted pair-group average (UPGMA) [6].

In the cultural areas of the Mekong–Chao Phraya river basins, there is one famous traditional music piece, Sadhukarn, which is performed in many important ceremonies. The origin of Sadhukarn is still unclear, and there are diverse Sadhukarn versions distributed across different areas of Thailand, Laos, and Cambodia. Due to its importance, unknown origin, and unclear relationships among different versions, Sadhukarn was selected for this current study. Multivariate statistical approaches may help to shed some light on the origin of Sadhukarn and on relationships among different versions in the same/different countries of origin. A recent study successfully identified relationships among different versions of the composition Sadhukarn from Thailand, Laos, and Cambodia using NMDS and cluster analysis based on rhyme structure, pillar tone, rhythmic and melodic patterns, intervals, pitches, and combinations of these parameters [6]. This study was also able to separate the composition Sadhukarn according to its countries of origin and identify the relationships among different versions [6,10]. Briefly, Sadhukarn is one of the most important traditional music compositions particularly in Thailand, Laos, and Cambodia. It has been played as a prelude to worship and invite the power of the triple gem in Buddhism, deities, and holy spirits of an ancestor music master, which implies opening ceremonies and feasts with success and fortune [10–14]. Originally, the piece was composed and performed by Wong Phi Phat, the traditional wind and percussion ensemble, including oboe, gong circle, xylophone, barrel drums, and cymbals, notably located in the Chao Phraya and Mekong river basins of Thailand, Laos, and Cambodia nowadays [12]. In Thai music tradition, the Sadhukarn main melody played on the large gong circle "Khong Wong Yai" is the first study taught to music students following *wai kru ritual* [15]. The previous study also showed that rhyme structure was among the best parameters for musical analysis using multivariate statistics as it correctly identified the composition Sadhukarn according to its countries of origin [6]. The result derived from rhyme structure was consistent when either the full version or normalized version (shorter versions with similar bar and key and 32 phrases and in G as a tonic key) was used in multivariate statistics [6]. Pillar tone (Look Tok) was also another important parameter that informed us about the identity of the composition Sadhukarn, especially when full versions were used [6]. Although rhyme structure and pillar tone are very useful parameters, methods for transcribing them into datasets for multivariate statistical analysis are very difficult, complex, and time-consuming [10]. In addition, such transcriptions also require expertise and deep knowledge in Southeast Asian music [10].

In this study, I established a novel approach to transcribe the rhyme structure and pillar tone into multivariate datasets based on the potential note degree of Khong Wong Yai, Supplementary Materials, Table S1. Note degree is defined as the possibility of note and interval ratios appearing particularly in a large gong circle (Khong Wong Yai), which consists of 16 tuned bossed gongs played with two beaters [6]. The approach is standardized and requires only little knowledge of Southeast Asian music and time.

This work aims to (i) evaluate a novel approach based on multivariate statistics of potential note degree of rhyme structure and pillar tone (Look Tok) for musical analysis of the 26 versions of the composition Sadhukarn from Thailand, Laos, and Cambodia; (ii) compare the multivariate results obtained by this novel approach and with the datasets from the published method using manual conversion [6,10]; and (iii) investigate impact of normalization on the results obtained by the novel approach based on potential note degree of Khong Wong Yai. The multivariate statistics in this study were performed using NMDS and cluster analysis. While NMDS provides better visualization of the holistic understanding of the overall relationships, cluster analysis shows clear distances. Thus, a combination of these two multivariate statistical approaches leads to a better understanding of overall and specific relationships between/among different versions of Sadhukarn in Thailand, Laos, and Cambodia.

2. Material and Method

2.1. The 26 Versions of the Composition Sadhukarn from Thailand, Laos, and Cambodia

This study consists of 26 versions of Sadhukarn main melodies collected from Thailand, Laos, Cambodia, and their border areas (Table 1). All details about data collection, conversion of music notions, and Thai and Western music notations have been published in my earlier studies [6,10]. Data on rhyme structure and pillar tone are also freely available in the Supplementary Materials of those publications [6,10] and in Supplementary Materials, Table S2.

Table 1. Information on the 26 versions of the Sadhukarn used in this study (modified from Eambangyung et al. 2022; 2024 [6,10]).

Number	Name of Version [Abbreviation]	Location
1	Thai Fine Arts Department [TF]	Bangkok, Thailand
2	Luang Bamrung Chit Chareon [TB]	Bangkok, Thailand
3	Samran Kerdphol I [TS1]	Ayutthaya, Thailand
4	Pinij Chaisuwan I [TP1]	Ayutthaya, Thailand
5	Thai music ensemble of Bangkok [TK]	Bangkok, Thailand
6	Chub Sowat [TC]	Ayutthaya, Thailand
7	Chue Dontrirod [TD]	Ayutthaya, Thailand
8	Tuen Phatayakul [TP]	Phetchaburi, Thailand
9	Thawin Attakisna [TT]	Ayutthaya, Thailand
10	Pinij Chaisuwan II [TP2]	Ayutthaya, Thailand
11	Rasi Phumthongsuk [TR]	Bangkok, Thailand
12	Siri Nakdontri [TN]	Samut Songkhram, Thailand
13	Sangobsuek Thamviharn [TW]	Bangkok, Thailand
14	Samran Kerdphol II [TS2]	Ayutthaya, Thailand
15	Subin Chankeaw [TJ]	Sing Buri, Thailand
16	Sadhukarn Chan Dio [TTP]	Ayutthaya, Thailand
17	Keo Sonankavai I [KS1]	Phnom Penh, Cambodia
18	Keo Sonankavai II [KS2]	Phnom Penh, Cambodia
19	Royal University of Fine Arts [KR]	Phnom Penh, Cambodia
20	Ban Pang Lang [IP]	Sa Kaeo, Thai–Cambodian border areas
21	Ban Nong Sai [IN]	Buriram, Thai–Cambodian border areas
22	Boonthieng Sisackda I [LB1]	Vientiane, Laos
23	Boonthieng Sisackda II [LB2]	Vientiane, Laos
24	Boonthieng Sisackda III [LB3]	Vientiane, Laos
25	Boonyadech Meunsanit [LY]	Luang Prabang, Laos
26	Wat Reach Bo Pinpeat ensemble [KW]	Siem Reap, Cambodian–Thai border areas

2.2. Potential Note Degrees of Khong Wong Yai

In this study, potential note degree (previously called "degree of note and interval ratio in Khong Wong Yai") is defined as the possibility of note and interval ratios appearing particularly in a large gong circle (Khong Wong Yai), which consists of 16 tuned bossed gongs (i.e., D_3, E_3, F_3, G_3, A_3, B_3, C_4, D_4, . . . , B_4, C_5, D_5, and E_5 sequentially, according to Scientific Pitch Notation Method or SPN [16] with modifications according to Eambangyung et al. [10]) played with two beaters (single and interval) [6]. The potential note degree, thus, refers to the numbers from 1 to 136, which represent the combination of single and interval notes [6]. A detailed explanation of the potential note degree is presented in Table S1. The datasets of rhyme structure and pillar tone have been published in my previous study [6] and are presented in Table S2. The datasets of potential note degrees based on rhyme structure, pillar tone, and their combination of 26 different versions of the Sadhukarn main melody collected from Thailand, Laos, Cambodia, and their border areas are included in

Tables S3–S5. Normalized datasets of potential note degree of rhyme structure, pillar tone, and their combination are presented in Tables S6–S8.

2.3. Statistics

In this study, cluster analysis and NMDS based on Euclidean distance were used as multivariate statistical techniques for music composition analysis. The concept of analysis is that similar versions of the Sadhukarn main melody are located closer together in the NMDS ordination space and/or cluster together in the cluster analysis diagram. Euclidean distance can be calculated using the following formula [17]:

$$d_{jk} = \sqrt{\sum_{i=1}^{n} (X_{ji} - X_{ki})^2} \quad (1)$$

where the following definitions hold:

d_{jk} = the dissimilarity measure between a pair of Sadhukarn versions j and k;
j, k = two points in Euclidean n-space;
X_{ji}, X_{ki} = Euclidean vectors (scores), starting from the origin of the space (initial unit);
n = n-space (unit).

The NMDS plots and cluster analysis were conducted with PAST software (Paleontological Statistics, version 4.11) [17,18]. The quality of NMDS ordination was tested using the goodness of fit of the regression and presented as a stress value. The goodness of fit is based on the novel algorithm developed by Taguchi and Oono [19]. Stress values between 0 and 0.20 are considered acceptable. The cluster analysis was based on the unweighted pair-group average (UPGMA) clustering algorithm. Due to the difference in the number of phrases and keys in the Sadhukarn main melody version, my recent study suggests that a normalization process should be used to avoid bias. There are 5, 19, 30, 32, and 55 phrases, but 32 phrases are played most often, which could be the so-called "32 shared phrases" [6,10]. For the normalization process, therefore, I chose only the 32 shared phrases and the G note as the tonic of the pieces [6,10].

3. Results

3.1. Successful Identification of the Countries of Origins and Their Relations of Composition Sadhukarn Using Full Versions of Datasets Derived from Potential Note Degree of Khong Wong Yai

In this study, NMDS and cluster analyses based on potential note degree using the Euclidean distance were successfully applied with rhyme structure, pillar tone, and their combination to analyze the 26 different versions of Sadhukarn main melodies from Thailand, Laos, and Cambodia. In general, different music elemental parameters including rhyme structure and pillar tone as well as their combination showed consistent results for NMDS and cluster analyses that almost all full Sadhukarn versions from Thailand (except TTD) were clustered closely and strongly separated from other Sadhukarn versions from Laos, Cambodia, and the border areas of Thailand–Cambodia (Figures 1–3). TTD was clearly separated from other Sadhukarn versions. Sadhukarn versions from Laos (LB1, LB2, LB3, and LY), border areas (IP, IN, and KW), and KR from Cambodia were grouped together and/or located nearby in the NMDS ordination plots and were clearly separated from the Sadhukarn version from Cambodia (KS1 and KS2) (Figures 1–3).

Considering the specific cluster of Sadhukarn versions from Thailand, three closely related groups were identified (Figures 1–3). Group I consisted of TP1, TP2, and TK (all versions belong to Pinij Chaisuwan, Ayutthaya, and Bangkok, Thailand) with distances approximately lower than 170, 550, and 500 Euclidean units when pillar tone, rhyme structure, and the combination between rhyme structure and pillar tone were considered. Group II consisted of TS1 and TS2 (all versions belong to Samran Kerdphol, Ayutthaya, Thailand) with distances approximately lower than 50 (pillar tone) and 200 (rhyme structure and the combination) Euclidean units. Group III consisted of TB and TW (all versions belong to Luang Bamrung Chit Chareon, Bangkok, Thailand) with distances approximately lower than 10 (pillar tone) and 130 (rhyme structure and the combination between rhyme structure and pillar tone) Euclidean units (Figures 1–3).

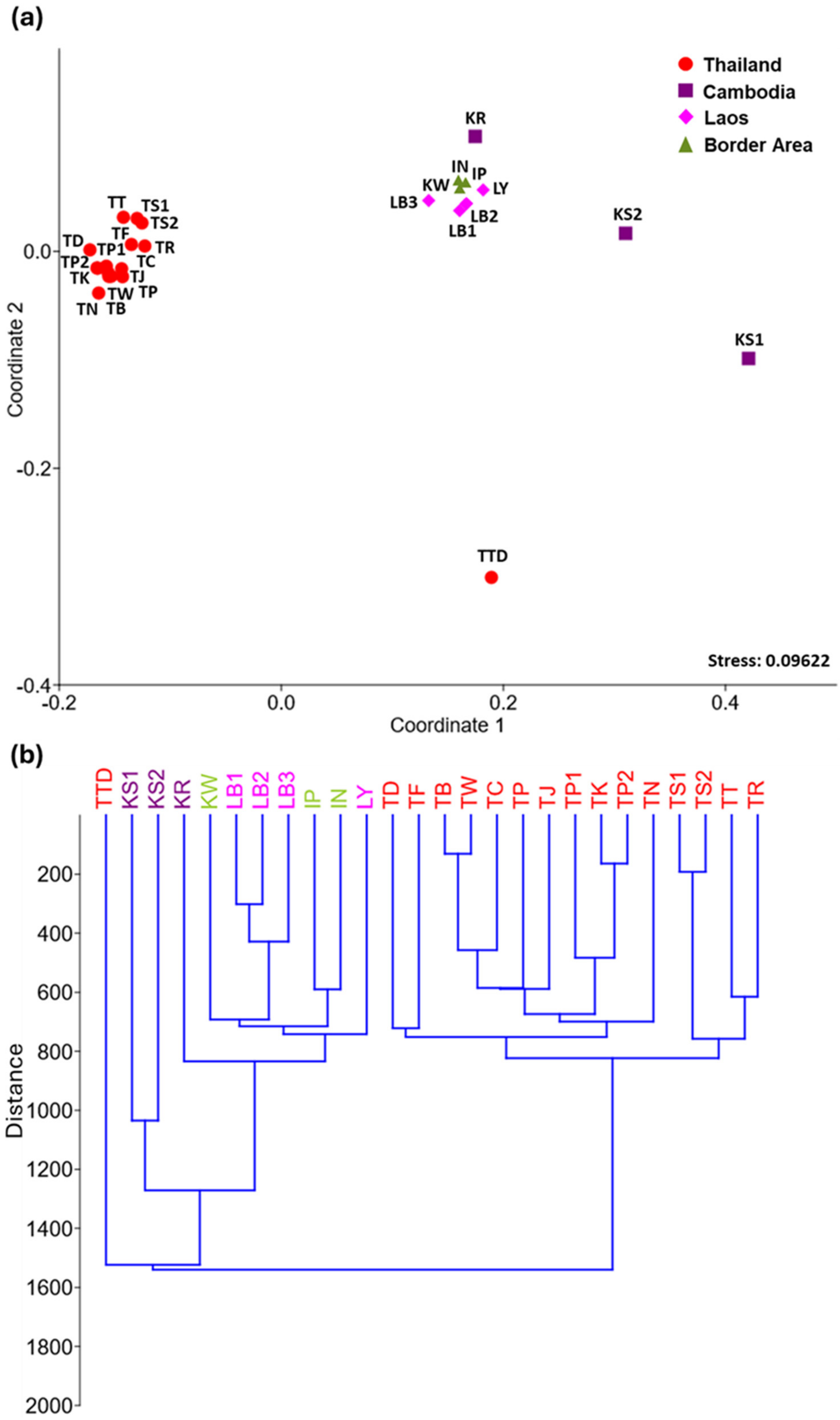

Figure 1. Non−metric multidimensional scaling (NMDS) ordination plot (**a**) and hierarchical cluster analysis diagram (**b**) of 26 different versions of Sadhukarn's main melody [full version] generated by rhyme structure. The full names of all versions of Sadhukarn's main melody are provided in Table 1.

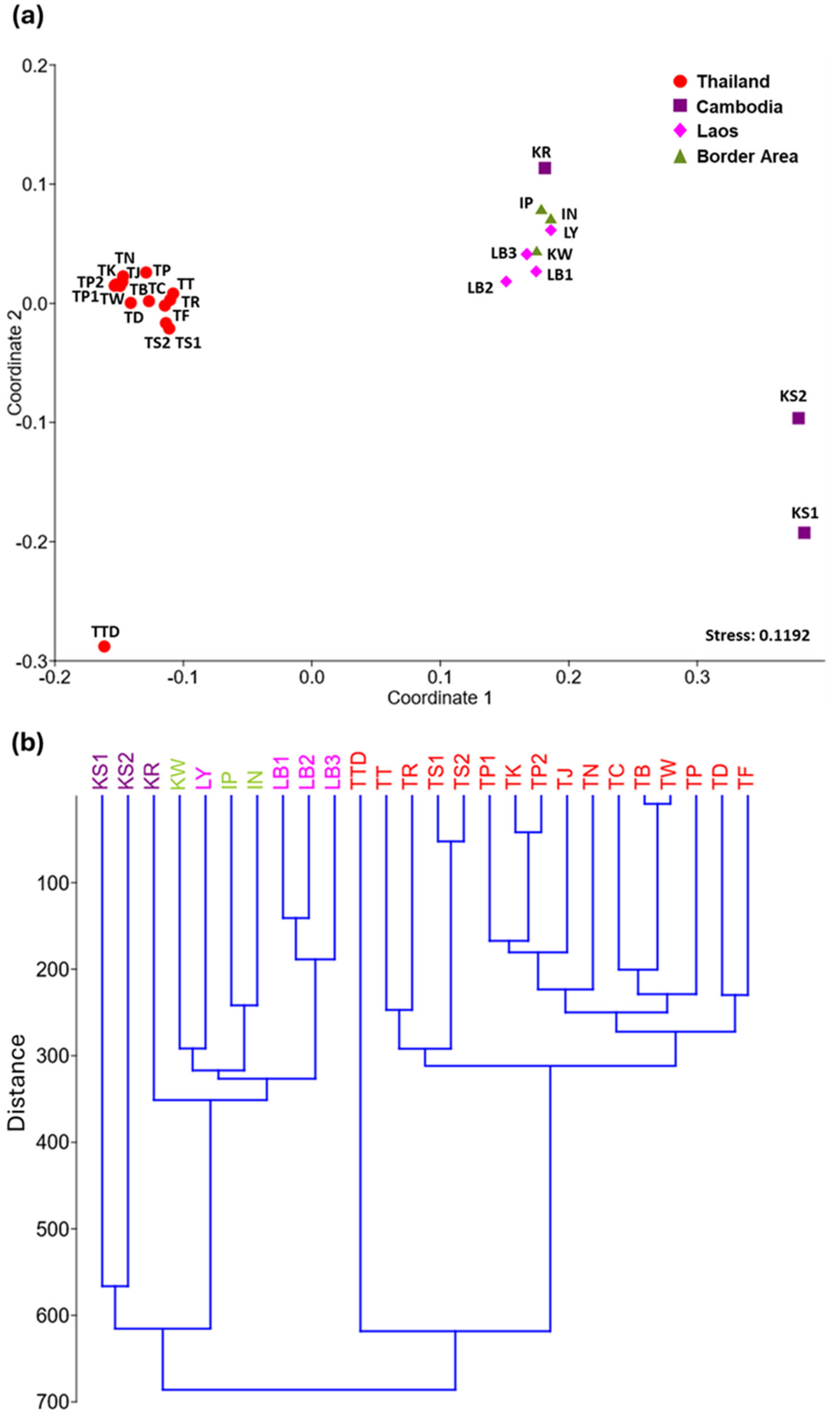

Figure 2. Non−metric multidimensional scaling (NMDS) ordination plot (**a**) and hierarchical cluster analysis diagram (**b**) of 26 different versions of Sadhukarn's main melody [full version] generated by pillar tone. The full names of all versions of Sadhukarn's main melody are provided in Table 1.

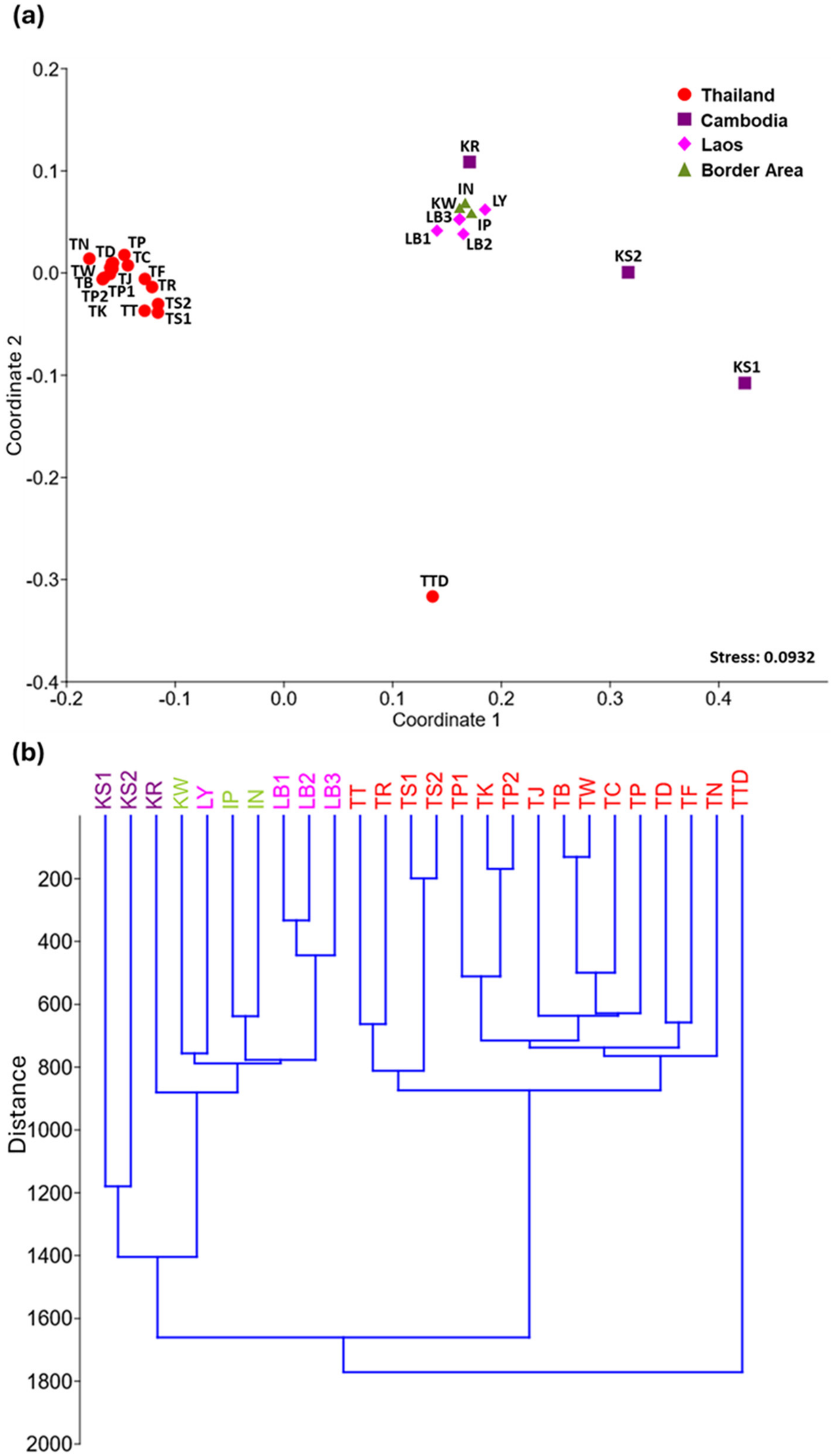

Figure 3. Non−metric multidimensional scaling (NMDS) ordination plot (**a**) and hierarchical cluster analysis diagram (**b**) of 26 different versions of Sadhukarn's main melody [full version] generated by the combination of rhyme structure and pillar tone. The full names of all versions of Sadhukarn's main melody are provided in Table 1.

Considering the specific cluster of Laos, Cambodia, and the border areas of Thailand–Cambodia, two groups were identified: group I consisted of Sadhukarn versions from Laos (LB1, LB2, LB3, and LY), Cambodia (KR), and border areas (IP, IN, and KW); group II joined Cambodian Sadhukarn versions of KS1 and KS2 (Figures 1–3). In group 1, three versions of Boonthieng Sisackda from Vientiane (LB1, LB2, and LB3), Laos, grouped very tightly together with 190, 420, and 450 Euclidean units when pillar tone, rhyme structure, and the combination between rhyme structure and pillar tone were considered.

3.2. Impact of Normalization on the Results Obtained by This New Method Based on Potential Note Degree of Khong Wong Yai

After normalization for the number of music phrases and keys, 20 versions of Sadhukarn with 32 shared phrases with comparable keys remained for further analysis, Tables S6–S8. Six versions were removed, including TTD (16 phrases), KS1 (5 phrases), KS2 (19 phrases), LB1 (different key), LB2 (33 phrases), and LY (27 phrases). Different music elemental parameters including rhyme structure, pillar tone, and their combination showed consistent results for NMDS and cluster analyses that all normalized Sadhukarn versions from Thailand were clustered closely together and separated from other Sadhukarn versions from Cambodia and the border areas of Thailand–Cambodia (Figures 4–6). Importantly, a Sadhukarn version from Laos (LB3) was clustered together with Sadhukarn versions from Thailand (Figures 4–6).

Considering the specific cluster of Sadhukarn versions from Thailand, three closely related groups were also identified, similar to the full version (Tables S3–S8). Group I consisted of TP1, TP2, and TK, with distances approximately lower than 170, 550, and 500 Euclidean units when pillar tone, rhyme structure, and the combination between rhyme structure and pillar tone were considered (Figures 4–6). TJ (belongs to Subin Chankeaw, Sing Buri) also grouped together with the Sadhukarn version of Pinij Chaisuwan (TP1) when pillar tone was considered (Figure 5). Group II also consisted of TS1 and TS2 with distances approximately lower than 50 (pillar tone) and 200 Euclidean units (rhyme structure and the combination) (Figures 4 and 6). Group III also consisted of TB and TW with distances approximately lower than 10 (pillar tone) and 32 Euclidean units (rhyme structure and the combination between rhyme structure and pillar tone) (Figures 4–6). Two Sadhukarn versions from Thai–Cambodian border areas (IP and IN) were grouped together, and they were separated from the KW version. Sadhukarn version from Cambodia (KR) was clearly separated from other Sadhukarn versions. Overall, although the results of full and normalized versions were relatively similar, there were some important differences, including the mix of Sadhukarn versions from Thailand and Lao, and also the separation of KW from other Sadhukarn versions located in the border areas of Thailand–Cambodia (Figures 4–6).

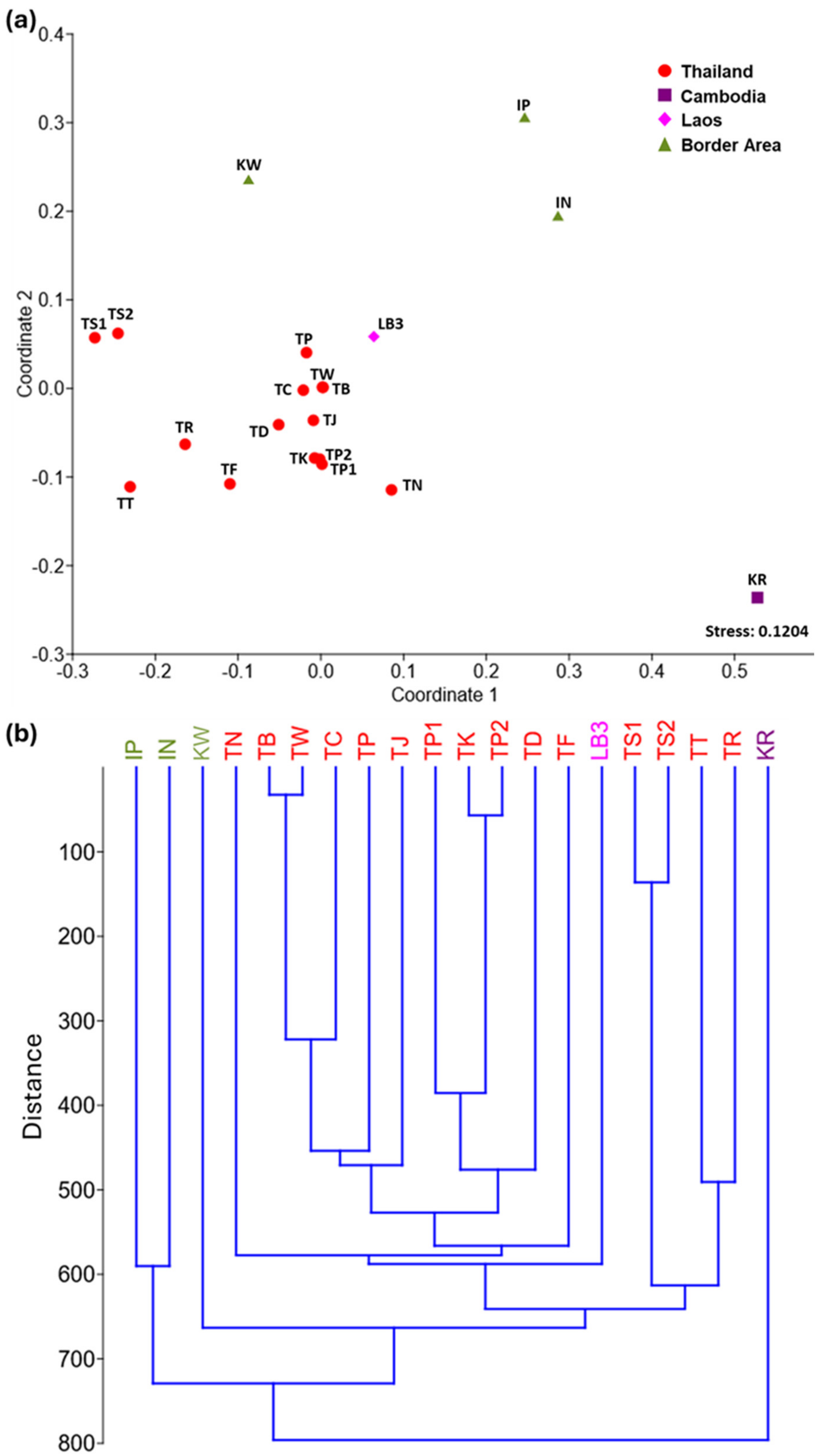

Figure 4. Non−metric multidimensional scaling (NMDS) ordination plots (**a**) and hierarchical cluster analysis diagrams (**b**) of 20 different versions of Sadhukarn's main melody [normalized version] generated by rhyme structure. The full names of all versions of Sadhukarn's main melody are provided in Table 1.

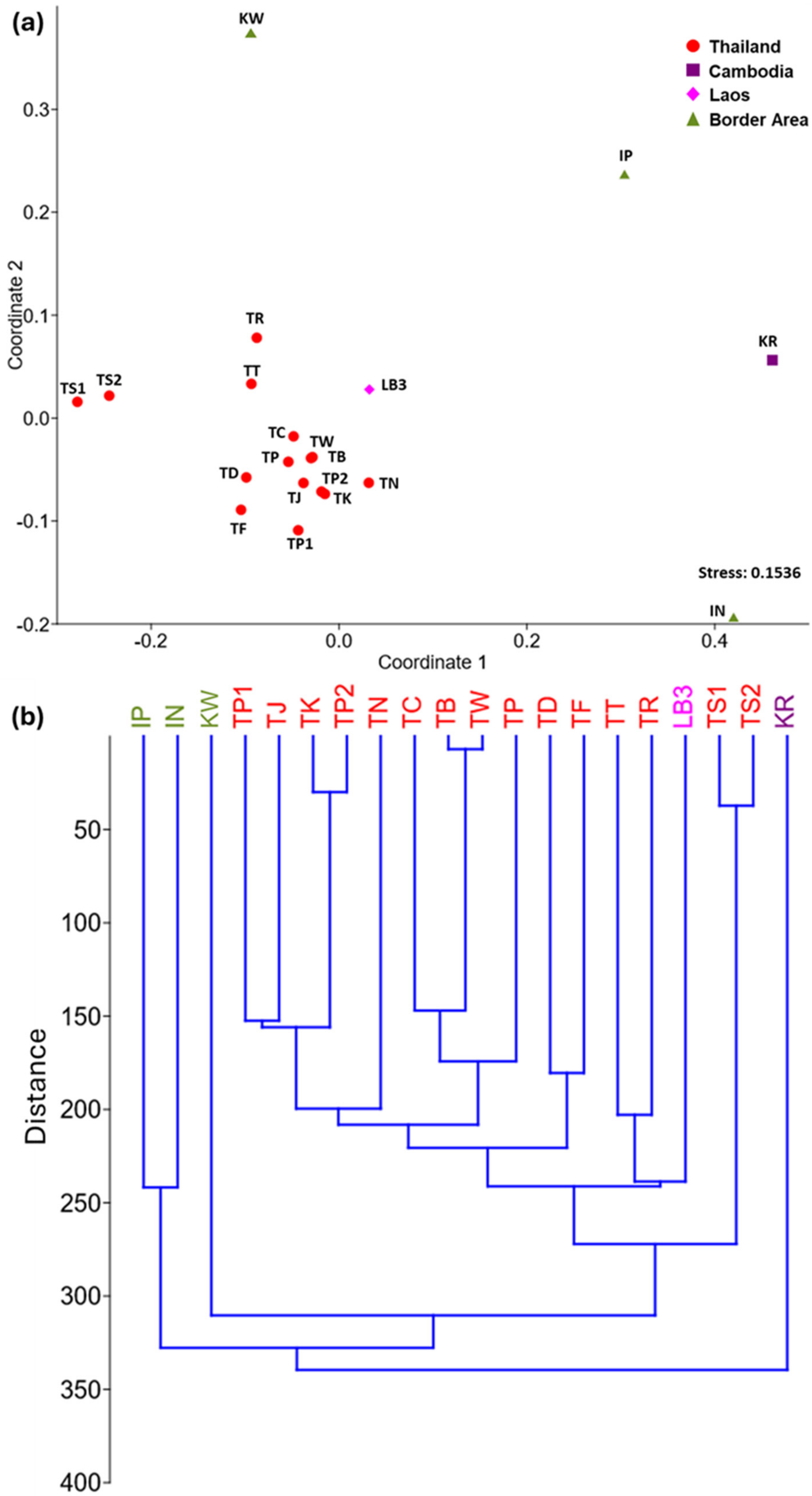

Figure 5. Non−metric multidimensional scaling (NMDS) ordination plots (**a**) and hierarchical cluster analysis diagrams (**b**) of 20 different versions of Sadhukarn's main melody [normalized version] generated by pillar tone. The full names of all versions of Sadhukarn's main melody are provided in Table 1.

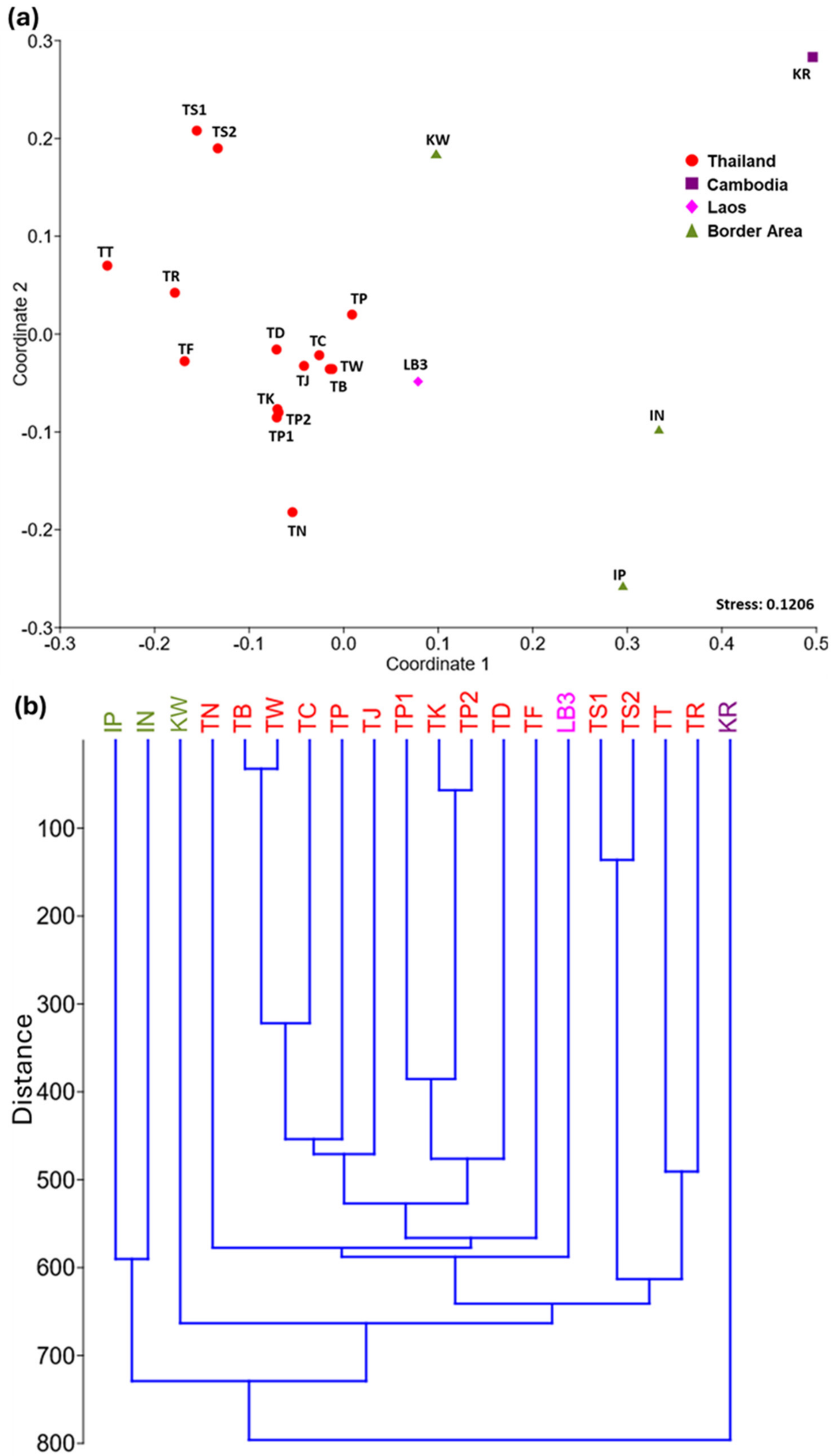

Figure 6. Non−metric multidimensional scaling (NMDS) ordination plots (**a**) and hierarchical cluster analysis diagrams (**b**) of 20 different versions of Sadhukarn's main melody [normalized version] generated by the combination of rhyme structure and pillar tone. The full names of all versions of Sadhukarn's main melody are provided in Table 1.

4. Discussion

4.1. Comparison of Multivariate Results Obtained by the New Method Developed in This Study and the Published Method Using Manual Conversion

The results of the novel approach employing the potential note degree of Khong Wong Yai based on rhyme structure, pillar tone, and their combination using the full versions of the composition Sadhukarn are accurate and consistent as compared with the complicated and time-consuming manual conversion [6]. All three closely related groups of Sadhukarn versions from Thailand and Laos are correctly identified. The results from pillar tone even show better performance; specifically, with the new approach, Sadhukarn versions from Laos, KR (Phnom Penh, Cambodia), and Thai–Cambodian border areas are all clustered together (Figure 2). Using the manual conversion approach, only rhyme structure (which is considered among the best parameters for music composition analysis of Sadhukarn based on multivariate analysis) can give similar results as compared with the novel approach based on potential note degree [6].

In this study, rhyme structure and pillar tone were used for developing the new approach because of their high performance as compared with other elemental music parameters. Furthermore, both rhyme structure and pillar tone are relatively easy to understand and transcode. Rhyme structure has been defined as "*a music aesthetic element based on poetic consonance. It determines a music composition in terms of structure, form, characteristic, melodic motion,* etc. *Similar to poetry and song, music rhyming is a presentation of the consonant pitches of notes existing both in the same and different music phrases*". [10]. Pillar tone has been defined as "*the smallest pitch-unit in Thai music composition*" that "*used to define the melodic structure as well as the melodic contour in reductive form, and also specifically used to shape a melodic outline*" [20,21]. Both rhyme structure and pillar tone can be feasibly transcoded using Thai and/or Western notations [6,10]. After the transcoding process, rhyme structure and pillar tone data can be conveniently transformed into datasets used for multivariate statistics based on a potential note degree conversion chart (Table S1).

4.2. Normalization: Losses of Identity and Uniqueness

Using this novel approach, the normalization of rhyme structure and pillar tone can cause a loss of identity and uniqueness. Furthermore, normalization in general resulted in a significant loss of Sadhukarn versions (6 out of 26 versions) due to their different numbers of phrases and keys. However, based on manual conversion, normalization of rhyme structure can separate Sadhukarn according to the country of origin [6,10]. Although the manual conversion is complicated, it contains much more detail and information. Due to the simplicity of the new method, it is feasible to lose information. Thus, I conclude that the new method should be used together with the full versions of the composition Sadhukarn for multivariate analysis.

4.3. Application and Future Perspectives

The potential note degree of rhyme structure and pillar tone developed in this study can be a useful alternative approach for music analysis based on multivariate statistics, which can be applied to other kinds of music compositions, as well as other musical instruments. The most important aspects to be considered are the number of notes appearing in a musical instrument, for example, gong chime, Ranad (Thai xylophone), recorder, etc., and the possible ways to play the note (single, intervals, or more). Moreover, this approach based on potential note degree can be applied to other kinds of music, including folk music, Thai traditional music, Western music, etc.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/stats7040089/s1: Table S1: Degree of note and interval ratio in Khong Wong Yai; Table S2: Dataset—rhyme structure and pillar tone of 26 versions of Sadhukarn main melody (reproduced from Eambangyung 2022; 2024 [6,10]); Table S3: Dataset—potential note degree of rhyme structure of 26 versions of Sadhukarn main melody in full version; Table S4: Dataset—

potential note degree of pillar tone of 26 versions of Sadhukarn main melody in full version; Table S5: Dataset—potential note degree of the combination of 26 versions of Sadhukarn main melody in full version; Table S6: Normalized dataset of potential note degree of rhyme structure of 20 versions of Sadhukarn main melody; Table S7: Normalized dataset of potential note degree of pillar tone of 20 versions of Sadhukarn main melody; Table S8: Normalized dataset of potential note degree of the combination of 20 versions of Sadhukarn main melody.

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Data Availability Statement: Data on rhyme structure, pillar tone, and combinations of 26 different versions of Sadhukarn main melodies from Thailand, Laos, and Cambodia can be derived from Western notation, Thai notation, and rhyme structure which were published and are freely available at https://www.mdpi.com/2306-5729/7/11/150 (accessed on 15 October 2024) and https://www.mdpi.com/2306-5729/9/4/50 (accessed on 15 October 2024).

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