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Computational analysis of musical elements across twenty-two European countries

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Abstract
This work examines the similarities and differences between twenty-two European countries by using the computational model Information Dynamics of Music (IDyOM) to analyze various musical elements in folk songs, children's folk songs, and children's songs. The examination of the (dis)similarities between 22 European countries tests two hypotheses. First, it examines whether there are significant differences in the use of musical elements between European countries that are considered to have a common musical style. Secondly, it explores whether the musical elements used in the representative music of a particular country are more similar in countries with similar cultural, political, historical and economic backgrounds and geographical proximity. The results of the research, which compared the three genres across 22 European countries, revealed significant differences that highlight the unique ways in which these genres manifest themselves and how musical elements are integrated into the musical structure, suggesting that European countries do not possess a single musical style. Furthermore, some geographically distant countries have exhibited similarities, while other geographically close countries showed dissimilarities. This implies that either there is no shared musical foundation across different countries, or that the unique variations in musical expression within certain countries have had a significant influence on the overall population.

Keywords Musical features · Musical structure · Computational analysis · IDyOM · Representative music

1 Introduction

Henry Wadsworth Longfellow once said, that "Music is the universal language of all mankind." (Longfellow 1835) Whether or not music is a universal language depends on how the terms "universal" and "language" are defined. As a tool for communication, language has meaningful symbols (words) that, when joined in a more complicated structure (following particular rules for combining—syntax),

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facilitate communication. Similarly, music as a specific "language" has its own symbols (notes) that may be combined into lower-order structures, (e.g. motifs, phrases, sentences/periods, etc.), and lower-order into higher-order structures (e.g. two-part, three-part songs…), using musical syntax which can differ in Western and Eastern music tradition. As opposed to language, none of the lower/higher-order musical elements has a meaning on its own, but acquires one in the context of complex musical structures, e.g., melody (Ludden 2015), which may (or may not) be understood in the same manner across cultures and even within cultures. Given this, it is difficult to claim that music is a "language" and "universal."

What is *universal* is the fact that music is widespread and may be found even in cultures where music is not referred to as "music" but rather as a musical activity (Mehr et al. 2019). However, even if music is viewed as a universality from this perspective, it differs between musical cultures. Cross-cultural studies reveal that despite more than a century of intensive research into the reasons why music differs between cultures, there is (still) no consensus (e.g., Brown and Jordania 2011; Harwood 1976; Henry 1976; Higgins 2012; List 1971; Lomax 1976; Savage et al. 2012, 2015; Steinruecken et al. 2015). Is it the comprehension and processing of music in an individual and/or society, how music has been passed over time, the social and cultural milieu that influences music production, or a combination of these factors? In addition, there are continuous discussions regarding what to seek in music to examine the diversity between cultures, which genre (style of music), and which approach to use (manual, semi-automatic, automatic).

This paper seeks to determine which *musical elements* contribute to the (dis)similarity between 22 European countries[1] by analyzing a sample of 2184 homophonic folk songs, children's folk songs, and children's songs. Some of the selected countries share a common cultural, historical, political, musicological, and sociological background; therefore, we could agree to define European (folk) music as a "single corpus of musical style" (Nettl and Béhague 1980, p. 37). However, even though each culture shares some elements of its music with another, particularly with neighboring countries, each country possesses important and specific musical qualities such as pitch, interval, contour patterns, etc. (Savage et al. 2012).

Emphasizing Western (folk) musical tradition could be interpreted as limiting the potential to answer broader or more specific issues concerning the diversity and scope of human music. However, to date, there are no cross-cultural research studies that compare folk songs, children's folk songs, and children's songs from the Western musical tradition. A thorough comparison of countries using these three genres could illuminate the impact of variability on the (dis)similarity of countries and reveal how children's folk songs and children's songs as musical genres contribute to the cultural identity of a country.

The present paper utilizes a comprehensive methodology to examine the musical elements in 22 European countries. It combines the analysis of music structure with the examination of the cultural, political, and historical influences on music within each country. To simulate listeners' perception of music and their enculturation, the

[1] Although culture is not synonymous with country or continent, and most people do not belong to a particular culture, the terms "culture" and "country" will be used interchangeably in this paper.

computational model Information Dynamics of Music (referred to as IDyOM) is utilized.

By comparing three musical genres (folk songs, children's folk songs, and children's songs) across 22 European countries, this paper brings the following contributions:

- We show that musical elements can reveal significant (dis)similarities in the way how musical elements are used in representative musical genres in a particular country.
- We highlight significant differences in how these genres manifest and integrate musical elements, suggesting that European countries lack a unified musical style.
- We find that geographically distant countries sometimes exhibit musical similarities, whereas geographically close countries can show notable dissimilarities, indicating either the absence of a common musical foundation or a greater influence of individuals on the musical expression at the population-level.

The organization of this paper is as follows. Section 2 provides an exposition of the relevant literature and theoretical foundations for the present investigation. The computational model IDyOM, which is employed for studying the similarities and differences across 22 European countries, is introduced in Sect. 3. A brief description of folk songs, children's folk songs, and children's songs is provided in Sect. 4. Data and statistical methodology is outlined in Sect. 5. The results are presented in Sect. 6, while the final remarks and future work are discussed in Sect. 7.

2 Scientific background and related literature

Despite the absence of archaeological evidence that could shed light on the origins of music, the truth remains that it has not developed in a single culture, but simultaneously in numerous cultures around the world (Mehr et al. 2019; Peretz 2006). Throughout human history and cultures, music has been discovered in every society (Mehr et al. 2019), making it a global *art form*. Consequently, if music is universal, why is there musical diversity between cultures throughout the world? Several plausible explanations have been proposed, with the *cultural* and *biological* explanations appearing to be the most prevalent in recent decades.

Music can be regarded as a *biological production* (Peretz 2006) since people are biological entities and everything generated by the human mind can be considered as biological. Various studies demonstrate the existence of similar universals in the creation and processing of music by humans (e.g., Tzanetakis et al. 2007, Drake and Bertrand 2001, Zatorre 2001), while also highlighting the existence of biases and limitations in music processing and production (Gingras et al. 2015). From this perspective, considering the differences in human perception, production, and appreciation, it is expected to find cultural diversity, as it is extremely unlikely to find the same processing, appreciation, or creation of music between cultures.

As a *social construct*, music varies not only between cultures (Blacking 1990; Higgins 2012; Lomax 1977), but even within a specific culture (Henry 1976; Rzeszutek et al. 2012). Each culture interacts (more or less) with the outside world and experiences various external and internal pressures (e.g., with tastes and preferences of different subgroups). The function and presentation of music (between or within cultures) can be identical to various degrees, yet the *ideas* of musical sounds and *forms* are different (Friedmann 1980). Since the fundamental components of music, such as timbre, pitch, and rhythm, vary in frequency, and form, and how they are perceived across and within cultures, it is important to also consider the behavior that is connected to music when examining the diversity in music that can be found in different cultures around the world.

The findings of the study by Lumaca et al. (2018) demonstrate that the cultural and biological explanations for the diversity of music are insufficient when viewed independently, as music is neither a purely cultural nor biological product. Music (as language) can be defined as a system with structured symbols and syntax, as well as a collection of behaviors that are transmitted from one generation to the next (Bomin et al. 2016; Morley 2013), horizontally or vertically (Savage 2018). Which cultural properties are transmitted to the next generation depends on the "memory bottleneck" (Deacon 1997), i.e., the "human neurobiological filter" (Lumaca et al. 2018, p. 3), a collection of all the limitations (e.g., motoric, motoric-expressive, physiological, cross-modal, and semantic) that may affect musical structures. Information is more likely to be transmitted to the next generation when (i) it is easier to encode, understand, process, and memorize, and when (ii) it is useful and attachable (Gladwell 2002). As each individual is unique, a "neuronal niche" (Dehaene and Cohen 2007, p. 384), it follows that there is a high possibility of inter-individual variances in the processing of music within a group. Eventually, the neurobiological heterogeneity of individuals should show at the population level, as variances in musical behavior can have substantial effects on musical systems, especially if magnified by cultural transmission (Lumaca et al. 2018).

Multiple studies have demonstrated that music, culture, and society are intricately intertwined and that cultural context influences (to a greater or lesser extent) music created within cultural boundaries (Brenna 1992; Lomax 1976; Lundquiest and Szego 1998; Merriam 1960; Nettl 1992). From this perspective, the best way to analyze (dis)similarities between cultures is through the use of music, which best reflects, i.e. *represents* a culture. However, a song produced lately in a "traditional manner" (folk revival) might be considered to "represent" a culture, as can a song whose roots date back more than 300 years. Art music, children's folk songs, and children's songs, of which the latter two are generally neglected as a genre (Jožef-Beg and Mihelač 2019; Mihelač 2021; Mihelač and Panić Grazio 2021), also represent a particular culture, since many composers have included traditional folk components into their works.

The review of cross-cultural studies reveals that (folk) songs are predominantly used. In the study by Mehr et al. (2019), songs are used (with lyrics) to examine (non)universality in societies around the globe. The research demonstrates that songs (as musical forms) are a "human universal," as songs can be found all over the world, that songs are associated with similar behavior in different societies, and that songs from different societies share certain musical characteristics, such as tone, pitch, and rhythm. Songs are also utilized by Lomax (1976) to demonstrate that songs identify and depict the fundamental social systems. Due to the wide variety of instruments, acoustic peculiarities, tuning systems, and production techniques, songs are also used by Savage et al. (2012) since they are simpler to compare cross-culturally than instrumental music (Ellis 1885).

Unlike instruments, there are no examples of songs that have been fossilized. The hypothesis, however, is that even before the advent of musical instruments, a song-like communication mechanism, a “protolanguage” (Fitch and Gazzaniga 2004), preceded human language (e.g., Darwin 1871; Marler 1976; Mithen 2005), and that modern music is a sort of “behavioral fossil” of this communication system. The use of a song to analyze (dis)similarity between cultures is logical and acceptable when seen from this perspective because songs are a universal human trait prevalent in all cultures.

In cross-cultural studies, corpora consisting of folk (traditional) music are mostly used, while “non-representative” and “weird” corpora are often avoided. However, Heinrich et al. (2010) show strong evidence that “weird societies” (compared to other societies) are not just outliers, but “may represent the worst population on which to base our understanding of Homo sapiens” (Heinrich et al. 2010, p. 80), i.e., that even (supposedly) non-representative societies contribute to the study of human music (Savage 2018), which may also be true for (apparently) “non-representative” corpora consisting of music from subcultures (such as the children’s society).

According to a vast number of studies, the search for musical universals to explain cultural diversity has been and continues to be a topic of the utmost interest for decades (e.g., Harwood 1976; Lomax 1976; Brown and Jordania 2011; Savage et al. 2012, …). Lomax’s search for a “typical” song, a “modal profile” for each culture by employing musical universals has induced countless discussions about the (non)existence of musical universals (Harwood 1976; Meyer 1998), as well as similar studies from Brown and Jordania (2011), proposing a detailed list of 70 putative musical universals, and later by Savage et al. (2012, 2015), revealing that there are no absolute music universals between cultures, but only *statistical* ones.

These results are consistent with Steven’s study, in which he explains that the same musical components, assumed to be musical universals and found in musical structures around the world, imply “static features of static environments” and neglect “informative differences” (Sutton-Smith 1999, p. 654). Rather than searching for generalities, a more logical approach could be to search for particular instances of *diversity* at different levels, i.e. to search for “anti-patterns,” patterns that are rare or absent in a dataset compared to patterns to be found as frequent (Conklin 2013), or to recognize the musical *processing* over musical features and content (Harwood 1976), a complementary approach.

Depending on the task, e.g., if the task is computational modelling of melodic similarity, processing of musical features, or simply a classification problem, where only a few melodic features may be sufficient, the (dis)similarity in music between cultures is examined using audio recordings or/and notation, a manual approach (e.g., (Bomin et al. 2016; Lomax 1976; Rzeszutek et al. 2012; Savage et al. 2015; Ward 1963), a semi-computational approach (e.g., (Bronson 1949; Rhodes 1965), and, beginning around 1960, a computational approach (e.g., (Gómez E, Haro M, Herrera P 2009; Juhász Z, 2006, 2009; Pearce 2018; Steinruecken et al. 2015; Volk 2016).

3 Computational model

3.1 IDyOM

When examining the musical surface with artificial intelligence, it is necessary to establish proper "communication" between music and computers, i.e., the sound must be "captured," which can be accomplished through the use of symbolic representations of notes or other musical events, or audio representations of acoustic sound waves.

In this paper, the musical surface (musical input) is captured using the Information Dynamics of Music (IDyOM), a computational cognitive model[2] of music perception (Pearce 2005). Because the model cannot process dynamic, timbral, or textual changes, the musical input is represented symbolically in IDyOM. IDyOM learns progressively about musical syntactic structure and its sequential regularities after being exposed to a corpus of music after importing musical examples in MIDI format.[3]

The computational perceptual model IDyOM has proven to be an accurate predictor of melodic expectancy (Pearce and Wiggins 2006; Sauvé SA, Pearce MT 2019), of behavior and neural measures (EEG) of melodic expectedness (Agres et al. 2018; Pearce et al. 2010), of phrase boundaries (Pearce and Müllensiefen D, Wiggins GA 2010). It has been manifested that it provides a good quantitative model of cultural distance (Pearce 2018).

IDyOM is based on *n*-gram models, which are used effectively in the biological domain, in natural language processing, statistical machine learning, and artificial intelligence, from 1950 on in music research-related tasks (e.g., in machine improvisation, music information retrieval, cognitive modeling). An *n*-gram model is a collection of sequences, s, consisting of n symbols (characters/events), each of which is associated with a frequency count. The model calculates the probability of a symbol s_n based on a history $h = s_1 \ldots s_{n-1}$, $P(s_n|h)$. Where $n = 1$, a monogram model, a zeroth–order model determine the predictions, meaning that a symbol s_n is independent from the previous context (symbols). In a bigram model, $n = 2$, the probability of a symbol depends just on the previous one, and so on.

When using fixed-order *n*-gram models, low orders may fail to provide a good model of the global structure of the distributions, while high orders may not capture enough of the statistical regularity in a sequence. This trade-off may be addressed by using hierarchical forms of *n*-gram model (Zatorre 2001), and this is arguably

[2] The word "model" has been used in this paper as a term for the IDyOM 'theory-and-system', and also for some of its components (models of data). IDyOM may be downloaded from https://github.com/mtpearce/idyom/wiki.

[3] Another possibility is to import musical examples in ** kern format: more in Huron (Huron 1997).

a necessary feature if a model is to describe the structure of sequences that include long-term dependencies (Wiggins et al. 2009). However, IDyOM has been shown to capture the structure of melody extremely well, suggesting that such long-term dependencies are not significant in this context.

A special case occurs when in a sequence of symbols an unseen symbol is encountered, providing an estimated probability of zero (Pearce and Wiggins 2006; Wiggins and Sanjekdar 2019). These issues are addressed in IDyOM by implementing different strategies, among others, by extending the basic n-gram modeling to a Variable-Order Markov Model (VMM) over a finite alphabet Σ, where the conditional probability distributions are combined in a way that reflects the statistics obtained from the training data (Begleiter et al. 2004). VMMs, in contrast to basic n-gram models, can capture contexts of different lengths in a single probabilistic model.

IDyOM uses a complex methodology in estimating probabilities of an event e given a history h. The central component in IDyOM is a sequence prediction model, the adaptive[4] lossless data compression algorithm PPM*, an improved version of PPM (Prediction by Partial Match). In the classic PPM algorithm, originally introduced by Cleary & Witten (Cleary and Witten 1984), the maximum context length is a fixed constant k, where k denotes the number of preceding events used in the prediction task. A "suite" of fixedorder context models is used, with different values of k, from 0 up to pre-determined maximum. The learning about context-dependent conditional probability distributions is gradual (Stevens 2012). The process of prediction starts by default with the model with the largest k, followed by orders with a smaller value of k in case an event is novel, and is terminated when all the events are encoded.

A separate probability distribution in each model is calculated from counts of all the events that have followed every subsequence of length k in that particular model. If there are models with different values of k, it means that different probability distributions are obtained from these models, which are in the end effectively combined in a single model. This is achieved with blending, using an escape method, where artificial escape symbols are put in a transition from higher to lower-order context models in case a model does not contain the input symbol (Drinic et al. 2003). In IDyOM, PPM* algorithm has been used in combination with interpolated smoothing, a technique used in generating non-zero probabilities to unseen events, as it has manifested to outperform the backoff smoothing (Pearce 2005).

IDyOM uses statistical learning and probabilistic prediction to acquire and process the internal representations of a musical piece/style. IDyOM learns about syntactic structure simply by being exposed to it while observing and analyzing content in a corpus of musical pieces. From the perspective of the feature that is analyzed with a viewpoint or viewpoints,[5] the likelihood of a forthcoming event is determined using sequential regularities (Pearce 2018).

IDyOM simulates a listener's expectations in music (which is based on the knowledge acquired during the entire lifetime) with a *long-term model* (LTM), which

[4] In the information-theoretic literature the term "adaptive" is understood as "sequential".

[5] More about viewpoints in Sect. 3.2

accumulates statistical information about musical structure from a large corpus. As listeners are sensitive to repeated patterns in an ongoing listening experience, a second, *short-term model* (STM) is also used, in which the information about the musical structure of the current piece is learned dynamically and incrementally (Pearce 2005, 2018). LTM and STM predictions are then combined, and it has been shown that better prediction performance is achieved by combining LTM and STM dynamically (Conklin 1990; Pearce and Wiggins 2004, 2006; Pearce 2005).

3.2 Viewpoints

When a sequence of events (notes) is given, we can define viewpoints, which are functions (variables, features) that accept initial sub-sequences of the sequence and measure a particular feature inside it, such as pitch, duration, or the relationship between two tones. Pitch (cpitch), and time (dur) are the two fundamental viewpoints from which IDyOM describes events in a sequence.

Additionally, we can compute with IDyOM so-called *derived* viewpoints (derived from basic viewpoints), *linked* viewpoints (when two or more viewpoints are linked), *threated* viewpoints (types of viewpoints defined at specific points in a piece of music, for example, the first event in each bar), and *test* viewpoints (which return a Boolean value indicating whether or not a particular condition is satisfied). An innovative alternative is to use *viewpoint selection*, a hill-climbing procedure that integrates multiple viewpoints in order to minimize the information content of a dataset.

This paper employs a variety of viewpoints, depending on the (dis)similarity in the way musical features and/or musical dimensions are utilized. The used viewpoints are: cpitch, cpitch $\otimes$ dur, dur-ratio, inscale, cpint, cpint-size, cpitch-class, cpcint, cpcint-size, contour, newcontour, cpintfref, cpintfip, tessitura, ioi $\otimes$ ratio, cpitch $\otimes$ ioi-ratio.

Their selection is based on research showing their usefulness in investigating musical structure, simulating the listener's cognition and perception of music, as well as enculturation (e.g., Gingras et al. 2016; Mihelač and Povh 2020; Pearce 2005, 2018; Pearce and Müllensiefen, Wiggins 2010).

The basic viewpoint cpitch specifies the chromatic pitch of each event (chromatic notes are counted from middle C = 60 up and down). Dur is another basic viewpoint that quantifies duration in basic time units. There is currently no consensus about how listeners' pitch and temporal structure are processed, i.e. whether these dimensions are managed independently or interactively (see more in Krumhansl 1990; Justus et al. 2003; Volk et al. 2008; Pearce 2018; Mihelač et al. 2023). IDyOM supports the processing of pitch and duration independently (using two separate models) or in combination (using a single model that combines these two dimensions). Cpitch and dur are employed interactively in this paper as a linked viewpoint cpitch $\otimes$ dur. The derived viewpoint dur-ratio represents the duration of last/duration of previous events in a sequence.

The derived viewpoint cpitch-class denotes a pitch class (or chroma) where note E2 is identical to notes E3, E4, and E5. The viewpoint reflects the significance in the perception of equivalence relations between two pitches, the most influential of which, according to various studies, is octave equivalence (Hoeschele et al. 2012; Patel 2003; Peter et al. 2008).

The derived viewpoint cpint denotes an interval, a relationship between two consecutive pitches. Additionally, a derived viewpoint, cpint-size, captures the size of intervals and can be used to explore intervals that are larger than the largest interval in the data. Intervals have been demonstrated to be significant in a variety of studies, including recognition of melodies, orienting the listener in the scale, and facilitating musical tonality (McDermott et al. 2008). The viewpoint cpcint denotes the octave equivalent pitch class interval, and is derived from cpint, in the same manner as cpitch-class is derived from cpitch. Cpcint-size is the absolute value for cpcint.

Tessitura is a viewpoint derived from cpitch. It examines a melody's pitch range. While certain melodies have a broad range, the range of pitches is limited, and the center of that range appears to be favored. Thus, this viewpoint captures pitches that are extremely high or extremely low in relation to the pitch range's center.

Different intervals are used to produce the shape of a melody, the contour, which can be rising or falling. It is represented by the viewpoint contour. Numerous studies examining contour from a variety of perspectives, including psychological, music-theoretical, and computational, confirm that contour is a vital part of musical perception (e.g., Kranenburg 2010; Marvin 1991; Morris 1993; Narmour 1990). The viewpoint newcontour, derived from cpitch, focuses on contour changes and their relationship to the preceding contour (value 1 is given if contour is unchanged from the preceding contour, and 0 if it is different).

Cpintfref denotes the pitch interval between two events. This viewpoint, which has been used in numerous studies (e.g., Gingras et al. 2016; Graves and Oxenham 2017; Marmel and Tillmann 2008), has demonstrated that listeners' perceptions of melodic structure are influenced by the tonal hierarchical relationships within a scale, in which the tonal function (the first scale degree) is the most stable and serves as the anchor point for a key (Krumhansl 1990). The pitch interval of an event from the first event in the piece is represented by the viewpoint cpintfip. This viewpoint was chosen to illustrate the impact of primacy on perceptual and structural salience. The derived viewpoint ioi, which represents the Inter Onset Interval ratio, is utilized separately and in combination with cpitch, resulting in cpitch $\otimes$ ioi, which shows to be effective in determining cultural distance (Pearce 2018). Inscale reflects both "in-key" and "out-key" tones. Tonality is expressed in musical compositions through the use of tones that occur frequently together (in-key tones) rather than tones that are considered out of key (Cancino-Chacón, Grachten, Agres 2017).

4 Defining folk songs, children's folk songs, and children's songs

Folk song is defined in this paper as a song made by an unknown, gifted member of a non-literate, rural part of a society (Bohlman 1988), where the song is kept, transferred, and altered through an oral tradition. It is simultaneously a product of the individual *and* the society, as many people are continually making changes. This process can be termed as "communal re-creation" (Nettl and Béhague 1980) owing to the song's constant refinement to sound like previously heard music or due to the fact that certain parts of the song have been forgotten.

As folk song (sung or played) is traditionally transmitted orally, thus not in a written form as the newly created folk songs (Kumer 1988), and as notation is not the traditional "medium" of folk songs, we can expect variations of the same folk song, depending on all the changes the song may be exposed to, as well as the communal re-creation (e.g., transformations in a society, wars, compulsory schooling, cultural migrations, …). Depending on the isolation of a particular culture, some songs may have been unaffected by these changes and passed in their original form (from the perspective of structure and performance) from one generation to the next, by individuals with "good memory" (Ling 1997), to the present day, and then finally archived as recordings and/or transcriptions.

The collections of *children's folk songs* from around the world demonstrate that these collections contain songs written by adults specifically for children, folk songs, and songs that children have produced and passed down to one another (Mihelač 2021; Mihelač and Panić Grazio 2021). Summarizing all of these songs, it can be very challenging to identify their original creators because children's folk songs frequently undergo changes and adaptations over the course of generations, or are even published by adults due to children's lack of musical training and inability to correctly notate songs.

Regardless of who composed these songs, a number of them share many characteristics with folk songs and are passed down orally from generation to generation, much as folk songs are. These songs, which could be defined as "children's folk songs" for which there is no clear definition (Trask 2010), are tonal and structurally simple, even more so than folk songs, syllabic, free of ornamentation, and full of repetition, with a content close to the children's world, likely to make them as adaptable as possible for children (Pond 1981; Romet 1980).

According to Kartomi (Kartomi 1999), *children's songs* written by children are worlds apart from those developed by adults for children, since the songs created by children follow different rules and have a unique approach to rhythm, structure, text, and substance, possessing a childlike aspect. Nonetheless, authors who have devoted themselves to composing entirely or primarily children's songs use the aforementioned traits, writing the children's songs in a way that children would comprehend and that is contentand ability-appropriate.

These songs are based on words that come from the child's world, which is full of toys, plays, games, imagination, and activities that primarily occupy adults (e.g., cleaning, sawing, building…). From the standpoint of the musical construction, they have a strong rhyme, a multiverse text, a simple structure, syncopated rhythms, and unusual rhythm and pitch patterns (Jožef-Beg and Mihelač 2019).

Children's songs are frequently influenced by folk elements and folk music of the composer's native country (e.g., use of intervals, motifs, melodic figure, and ancient tonal patterns), while globalization, a dynamic force in contemporary societies (Trehub et al. 2000), influences (among other things) the creation of new children's

Table 1 Number of folk songs (FS), children's folk songs (CFS), and children's songs (CS) from 22 European countries

Country	FS	FS (Sc)	CFS	CS	Country	FS	FS (Sc)	CFS	CS
Bulgaria	23	0	18	18	Croatia	58	0	16	16
Denmark	22	9	15	11	France	133	131	71	22
Germany	139	139	124	21	UK	41	0	38	17
Greece	23	0	26	19	Hungary	34	34	27	16
Italy	23	7	22	12	Latvia	46	0	23	20
Netherlands	53	53	58	23	Norway	30	0	23	20
Poland	24	20	22	21	Portugal	15	0	27	15
Romania	23	23	18	18	Russia	28	28	21	21
Serbia	24	0	13	23	Slovenia	71	0	44	111
Spain	19	0	54	15	Sweden	30	11	29	17
Switzerland	75	75	23	16	Turkey	25	0	24	17

The column FS (Sc) indicates the detailed number of 530 songs used from the Shaffrath Collection

songs (e.g., using contemporary cultural and social values, integrating folk elements with popular music).

5 Data and statistical methodology

5.1 Data

To discover the (dis)similarities between 22 European countries, we have used a corpus of songs that includes 2,184 songs from 22 European countries and three genres: 959 folk songs, 736 children's folk songs, and 489 children's songs (see Table 1).[6]

The compilation of 959 folk songs was assembled by combining the first author's collection of 429 folk songs (using songbooks, books, and textbooks from various national and school libraries in 22 countries) with 530 folk songs from the Shaffrath Essen Collection (Schaffrath 1995). In determining the final selection of folk songs, musical, cultural, historical, political, and other aspects of music traditions were examined where necessary.

Only children's folk songs contained in formal music curricula or songbooks used as supplementary instructional material in kindergartens and primary schools were selected. Additionally, whenever possible, children's folk songs with a specific country of origin were included, although the same song can frequently be found in another country, even in geographically distant European countries (for example, "wanderer melody" found in the Czech song *Kočka leze d´ırou, pes oknem*, and in the Slovenian song *Čuk se je oženil*).

[6] All songs are freely available at https://github.com/LMihel/LMihelac.

Children's songs from European countries were selected and compiled from the songbooks of renowned children's song authors and the official websites of these European children's music authors.

The decision to include Russia is based on geography (approximately 23 percent of western Russia can be considered a European part) and shared history between former and present Russia and Europe. Turkey's songs have been added to this data set because a small portion of the country is regarded to be in Europe (about 3 percent) and because the Ottoman Empire shared a historical, political, and cultural background with many European countries (Hurewitz 1961; Kostopoulou 2016). Some European countries, such as Austria and the Czech Republic, were omitted from this corpus due to insufficient data for a particular genre, and the decision to include a proportional number of countries from West, East, North, and South Europe.

5.2 Statistical methodology

In this paper, two hypotheses are tested: (i) There are substantial variances in the use of musical elements between European countries that are regarded to share a single musical style, and (ii) The musical elements used in the representative music of a certain country are more similar in countries that share a similar cultural, political, historical, economic background, and are geographically close.

To explain the (dis)similarities between the countries and genres using musical elements, IDyOM was utilized to simulate the listener's processing and perception of songs. Because empirical findings from numerous studies have shown that the information content is effective in capturing stylistic statistical patterns and psychological processes in listeners' music perception (Hansen and Pearce 2014; Omigie et al. 2013; Pearce 2005, 2018), the average information content (IC), as estimated by the model for each target viewpoint, was used.

The musical features and dimensions were observed using 16 viewpoints (see Table 3) at two different levels of granularity: low (song-based) and high (genre- and countrybased).[7] Precisely, the following was computed for each of the 22 countries and each of the three genres:

- The mean values of all viewpoints for each song in order to simulate the listener's perception of each song and collect as much information as possible on the events in a particular song (the song based granularity).
- The mean values for all viewpoints for a group of chosen songs from a given genre (the genre based granularity).
- The mean values for all three genres combined from a particular country (the country based granularity).

Multivariate Analysis of Variance (MANOVA) was complemented with a series of independent univariate Analysis of Variance (ANOVA) models to study how

[7] For a comprehensive list and description of each viewpoint, see the Sect. 3.2.

viewpoints vary across genres and countries. Agglomerative hierarchical algorithms, Euclidean distance as a similarity measure, and the Ward agglomeration method (Wesch 2018) were utilized to find clusters in the multidimensional data.

6 Results

First, the hypothesis that there are substantial differences in the use of musical features and dimensions among European countries considered to have a single musical style was tested with Wilks' Λ statistic.[8] When 16 viewpoints were utilized to examine the musical features and dimensions, the following was found:

- There are significant differences between vectors of mean values of viewpoints computed across the countries (Wilk's $\Lambda = 0.223$, $F(336{,}27{,}473) = 10.18$, $p < 2.2\text{e-}16$).
- There are significant differences between vectors of mean values of viewpoints computed across the genres FS, CFS, CS (Wilk's $\Lambda = 0.502$, $F(32{,}4332) = 55.63$, $p < 2.2\text{e-}16$).

Next, a one-way Multivariate Analysis of Variance (MANOVA) was performed to determine if there are statistically significant differences in the vectors of mean values of viewpoints across genres for each country. As a result, 22 MANOVAs were conducted, and the findings, which are presented in Table 2, indicate that there are significant differences between the mean values of viewpoints used to observe the musical features and dimensions in songs belonging to the FS, CFS, and CS song groups, for each country.

ANOVAs were performed for each viewpoint to see which viewpoints have significantly different mean values across countries and genres. Table 3 contains the results. There are significant differences between the mean values of all viewpoints when the groups are defined by the countries and the genres, respectively, except for the tessitura viewpoint, for which significant differences between genres cannot be confirmed.

Figure 1 illustrates how the mean values of viewpoints in different countries differ from the overall mean values. The boxplots display the mean values for each viewpoint across 22 countries as well as the lowest and highest mean values for each country. The fact that each viewpoint's intervals of values vary widely across the countries further proves that the differences are indeed significant. The countries that differ most from the mean value, for each viewpoint, are also identified by the whiskers of each boxplot.

The hypothesis that musical features and dimensions used in a country's national representative music are more similar in countries with similar cultural, political, historical, and economic backgrounds and that are geographically close

[8] Only the results for the Wilks' Λ statistic are reported. The other standard statistics (Hotelling-Lawley, Roy, Pillai) imply the same conclusions.

Table 2 Results of the series of MANOVA, conducted within each of the countries separately

Country	Wilks Λ	F-value	df_1	df_2	p-value
Bulgaria	0.074	6.843	32	82	0.000000
Croatia	0.043	17.170	32	144	0.000000
Denmark	0.076	4.925	32	60	0.000000
France	0.053	43.211	32	416	0.000000
Germany	0.045	61.988	32	532	0.000000
Great Britain	0.047	17.545	32	156	0.000000
Greece	0.331	2.307	32	100	0.000873
Hungary	0.028	18.283	32	118	0.000000
Italy	0.050	8.428	32	78	0.000000
Latvia	0.367	2.889	32	142	0.000009
Netherlands	0.071	19.991	32	232	0.000000
Norway	0.020	20.965	32	110	0.000000
Poland	0.075	8.136	32	98	0.000000
Portugal	0.073	6.581	32	78	0.000000
Romania	0.015	18.617	32	82	0.000000
Russia	0.042	12.550	32	104	0.000000
Serbia	0.071	7.208	32	84	0.000000
Slovenia	0.069	36.560	32	416	0.000000
Spain	0.056	14.166	32	140	0.000000
Sweden	0.124	6.688	32	116	0.000000
Switzerland	0.052	20.296	32	192	0.000000
Turkey	0.066	8.645	32	96	0.000000

to one another is tested in the continuation using clustering analysis. For each country is used:

(1) A vector of length 16, containing mean values of each viewpoint computed across the songs belonging to the set of FS, CFS, and CS songs
(2) A vector of length 48, obtained by stacking the three vectors of length 16, which are described in the previous item

The results of clusters are summarized in Table 4, and visualized in Figs. 6, 7, 8 and 9.[9] Only a basic hierarchical clustering was performed, in which point-to-point dissimilarity is estimated using Euclidean distance and agglomeration is performed using the Ward method (Wesch 2018). Dendrograms were utilized to determine the optimal number of groups based on the results of this procedure.

Figure 2 is a dendrogram illustrating the bottom-up clustering procedure, where merging levels correspond to the measure of dissimilarity between two groups of countries. This dendrogram was obtained by representing the 22 countries with stacked FS, CFS, and CS vectors of viewpoints. The vertical dashed lines represent

[9] The countries in grey are those that were excluded from the corpus.

Table 3 Results of ANOVAs for each viewpoint

Viewpoint	F	df_1	df_2	p-value	F	df_1	df_2	p-value
cpitch	10.197	21	2162	0.000000	38.761	2	2181	0.000000
cpitch-class	34.802	21	2162	0.000000	181.110	2	2181	0.000000
tessitura	17.799	21	2162	0.000000	1.083	2	2181	**0.338810**
cpint	9.349	21	2162	0.000000	40.472	2	2181	0.000000
cpint-size	15.324	21	2162	0.000000	144.053	2	2181	0.000000
cpcint	26.319	21	2162	0.000000	122.552	2	2181	0.000000
cpcint-size	42.263	21	2162	0.000000	257.634	2	2181	0.000000
contour	18.666	21	2162	0.000000	353.957	2	2181	0.000000
newcontour	33.296	21	2162	0.000000	357.952	2	2181	0.000000
cpintfip	7.141	21	2162	0.000000	21.314	2	2181	0.000000
cpintfref	38.978	21	2162	0.000000	197.064	2	2181	0.000000
inscale	77.834	21	2162	0.000000	372.920	2	2181	0.000000
cpitch⊗dur	8.917	21	2162	0.000000	58.367	2	2181	0.000000
dur-ratio	13.226	21	2162	0.000000	40.492	2	2181	0.000000
ioi ratio	7.736	21	2162	0.000000	55.663	2	2181	0.000000
cpitch⊗ioi- ratio	7.117	21	2162	0.000000	54.191	2	2181	0.000000

The columns 2–5 correspond to ANOVA tests across the countries and the four rightmost columns to the ANOVA tests across the genres. The first columns in both groups report the values of F statistic, the second and the third columns report the corresponding degrees of freedom and the fourth column in both groups reports the p-values

the most significant clusters in this dendrogram, which are comprised of the most related countries. Figures 3, 4 and 5 depict the dendrograms for each genre (FS, CFS, CS) independently.

When employing the FS, CFS, and CS genres separately and together, significant differences between groupings of countries can be observed. Additionally, some geographically distant countries without a common political, cultural, economic, or historical background (such as the UK, Switzerland, and the Netherlands or Latvia and Slovenia) use musical features and dimensions similarly, while other geographically close countries with a common past use them differently.

7 Discussion and conclusions

This paper utilized the computational model IDyOM and 16 viewpoints to investigate similarities and differences among 22 European countries. In contrast to other crosscultural research that focused just on one genre, namely folk songs, this study utilized three different genres: folk songs (FS), children's folk songs (CFS), and children's songs (CS). The rationale behind incorporating not only folk songs but also children's folk songs and children's songs was that these genres serve as representative music of a specific country, as they embody the cultural values and views of that country, just like folk songs do.

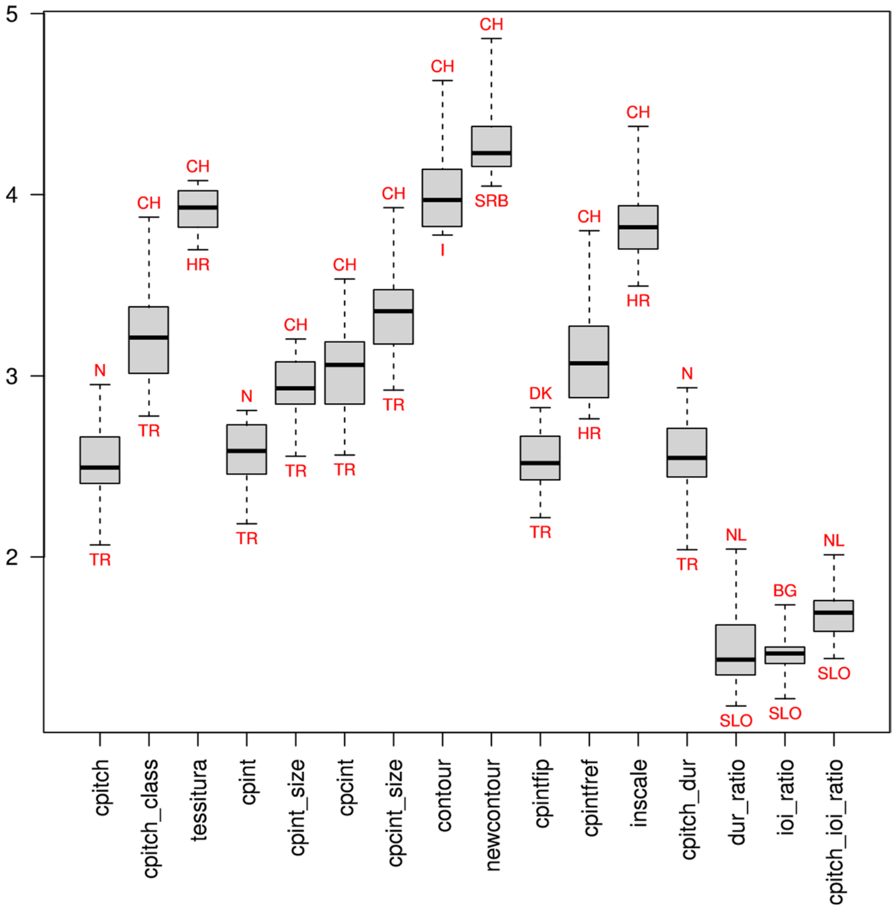


Fig. 1 Boxplots for the countries' means values of viewpoints

According to Nettl & Behague (Nettl and Béhague 1980), music from different cultures should be analyzed from two perspectives: its style and structure, and its cultural context. The structure of a piece of music reveals how musical elements are utilized within a culture (Mihelač and Povh 2021), and thus reflects (as a "material artefact") a specific culture. Nonetheless, *the society*, whether on a micro (as a person) or macro (as a population) level within a territory or region, processes music. By structuring and processing musical elements in musical artifacts *dynamically* across time, society influences the dynamic and ongoing transformation of a culture based on shared or individual beliefs (Widmer 2016).

From this point of view, the prevalence of particular musical characteristics within the structures of songs from a variety of European countries could be attributed, for instance, to local folk music traditions and expressions (such as the use of pentatonic scales and modal harmonies, peculiar use of rhythm, intervals)

Table 4 22 European countries grouped by genres

All genres	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
	Latvia	Greece	Romania	Norway	Switzerland
	Portugal	Bulgaria	Russia	Sweden	Germany
	Italy	Serbia	Poland	Netherlands	France
	Slovenia	Turkey	Hungary	Denmark	UK
		Croatia		Spain	
Only FS	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
	Germany	Great Britain	Portugal	Turkey	Serbia
	France	Netherlands	Sweden	Bulgaria	Croatia
	Switzerland	Poland	Latvia	Greece	Spain
		Hungary	Slovenia		
		Romania	Norway		
		Russia	Denmark Italy		
Only CFS	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
	Switzerland	Croatia	Spain	Portugal	Slovenia
	Denmark	Turkey	Netherlands	Romania	Bulgaria
	Great Britain	Hungary	France	Italy	Poland
	Norway	Serbia	Germany	Russia	
	Sweden			Greece Latvia	
Only CS	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
	Norway	Italy	Croatia	Latvia	Greece
	Denmark	Turkey	Bulgaria	Switzerland	Portugal
	Netherlands	Hungary	Great Britain	Slovenia	Serbia
		Poland	Russia	Spain	Romania
				Sweden	France Germany

that have been cultivated and emphasized more or less depending on the degree of isolation that a particular country has experienced. Some other plausible key factors could be the structure of a country's language that influences the melodic and rhythmic contours of its music, or strong vocal music traditions that place an emphasis on pitch and melodic contour.

In this paper, folk songs, children's folk songs, and children's songs were used to study the diversity of musical elements across 22 European countries. The results of the study of these three genres between 22 countries have revealed substantial differences, highlighting the distinctive manifestations of these genres and how musical features are incorporated into the musical structure, confirming the first hypothesis, that European countries cannot be considered as a single musical style.

The fundamental question that arises is why similar relationships have been discovered between countries compared to other cross-cultural research

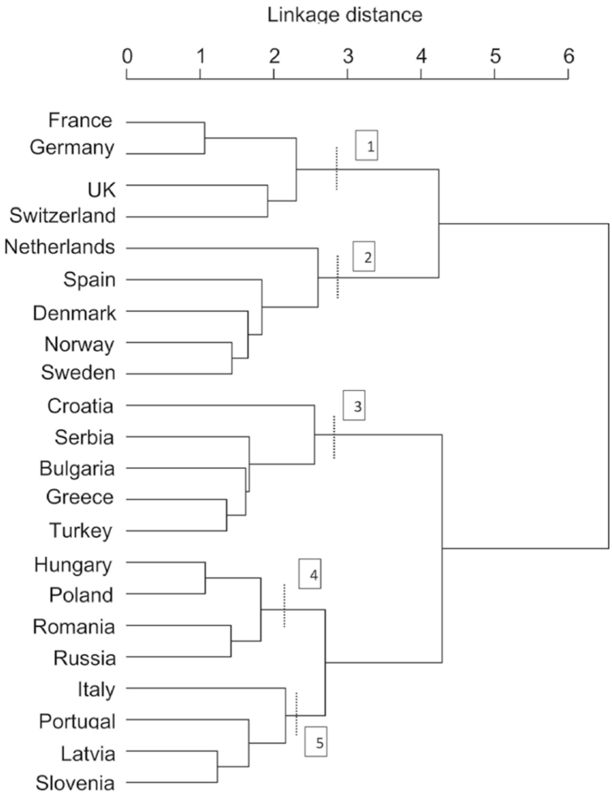
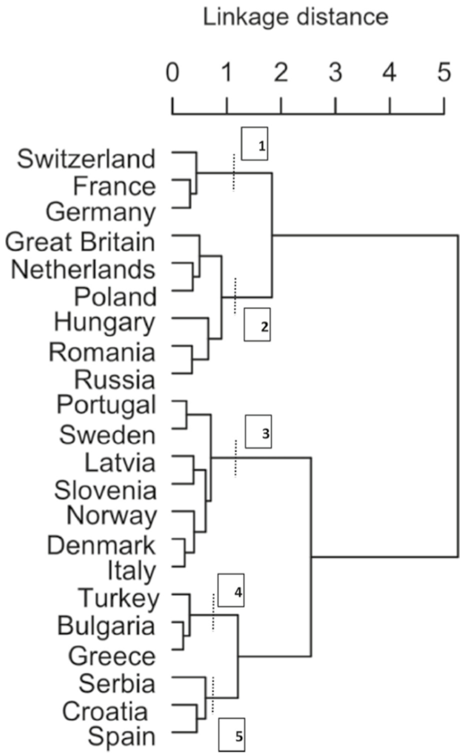


Fig. 2 Dendrogram, based on stacked vectors of view- points

studies that deal with only one genre, namely folk songs (e.g., Juhász 2006; Panteli 2018)? There is always the chance of genres "assimilating" or "merging," much as (sub)cultures adapt to a culture that exerts strong dominance over other cultures, and after a given period, behaviors/cultural variances within a subculture are driven towards fixity (Foley and Mirazón Larh 2011; Newson et al. 2007). For instance, what is considered a folk song representative of a particular country may be a children's folk song or even a children's song that was labeled a folk song after a certain period, perhaps due to insufficient attention to the origins and circumstances under which a song was created. This could explain the same outcomes in several cross-cultural research, regardless of whether only one genre (folk music) or multiple genres were employed.

From a historical, geographical, cultural, social, and musical perspective better results of hierarchical clustering were achieved by combining the three genres (FS, CFS, CS) than utilizing them independently. This should be interpreted similarly to the contribution of various (sub)cultures to the national identity of a multi-national country, without losing their primary identity (Huntington and Dunn 2004). There is the possibility that specific songs belonging to a particular genre that are transmitted

Fig. 3 Dendrogram, based on the mean view points computed over FSgenre

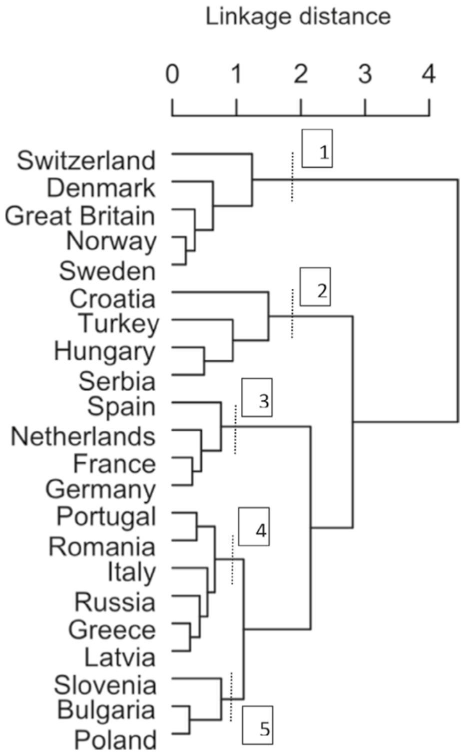


from generation to generation in a certain group of people with shared cultural norms and beliefs contribute to the final formation of a distinctive musical identity at the "top-level"—the population level of a country, while retaining some of their original characteristics and expressions.

In the hierarchical cluster analysis-derived dendrogram (Fig. 2), countries are grouped according to their similarities, confirming our second hypothesis. The partition of the dendrogram into two main clusters, the first relating to a group of countries merged into clusters no. 1 and no. 2, and the second relating to all the other countries merged into clusters no. 3–5, reveals the historical, political, cultural, economic, and social roots of the 22 countries, as well as their very specific and complex relationships, which can be traced over a long period. The two major clusters show the conceivable coexistence of two opposites from roughly the 15th to the twentieth centuries: the Habsburg Empire (later Austro-Hungarian) and the Ottoman Empire; Western and Eastern; Catholic and Muslim; which is consistent with the findings of Juhász (2006); Juhász 2009).

However, it is interesting that differences have been found in the way how musical elements are used in countries, which are more similar regarding their cultural, political, historical, and economic backgrounds and are geographically close to one another, and similarities between countries which do not have a common music foundation and are geographically distant. For example, similarities have been discovered between geographically distant countries (e.g., between

Fig. 4 Dendrogram, based on the mean

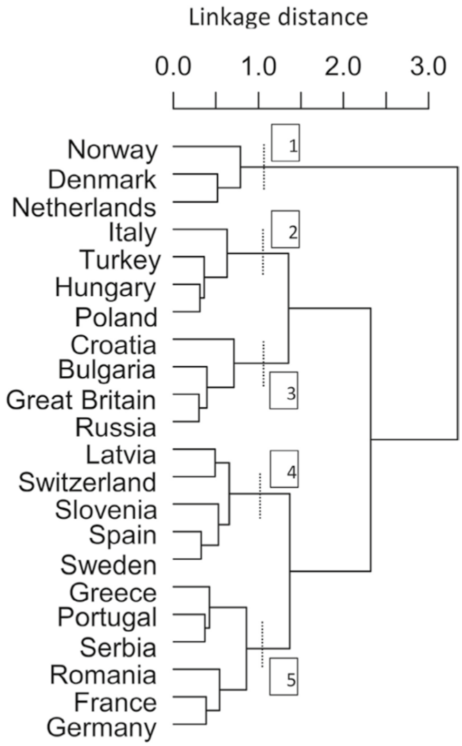


Slovenia and Latvia, between Sweden and Spain). Mehr et al. (2019, p. 1) suggest that a plausible explanation could be that "behavioral patterns once considered arbitrary cultural products may exhibit deeper, abstract similarities across societies". The existence of dissimilarity between geographically close countries (e.g., the Netherlands and Germany or Spain and Portugal) indicates either (i) The absence (or abundance) of a common musical core (Juhász 2006) or (ii) The fact that the variability of individuals has manifested itself more strongly at the population level, consistent with the findings of Lumaca et al. (2018).

Currently, it is unclear how exactly each genre (folk songs, children's folk songs, children's songs) influences a country's identity at the highest, 'top' level. Future research could explore how these genres interact with each other, their specific role in shaping the cultural identity of different countries, and to what degree and under what circumstances these genres impact the similarities or differences between countries.

Studying how musical genres are passed down through generations and their impact on maintaining or evolving national musical identities could be a potential future research topic. This could include an analysis of the influence of cultural norms, social structures, or educational systems on genre transmission.

Fig. 5 Dendrogram, based on the mean viewpoints computed over CFS genre. viewpoints computed over CS genre



A further examination could be exploring the role of globalization on the convergence or divergence of musical traditions across countries. This could examine how global trends (e.g., Western pop music, digitization, and streaming platforms) affect the preservation or transformation of traditional music genres, including folk and children's music. Especially valuable could be investigating how government policies and initiatives aimed at preserving cultural heritage either succeed or fail in maintaining distinctive musical identities, and how modern cultural forces (e.g., migration, tourism) influence the adaptability of a country's musical identity.

Extending the research beyond Europe to other regions (e.g., Africa, Asia, or to America) could offer more generalizable insights about how various music genres contribute to national or cultural identity. This could also involve examining how non-European musical traditions integrate or contrast with children's songs or folk songs.

Last but not least, given the discovery of similarities between geographically distant countries (e.g., Slovenia and Latvia, Sweden and Spain), future research could explore the possibility of cognitive or behavioral universals in how humans process and produce music. This could involve a more interdisciplinary approach, merging psychology, anthropology, and musicology.

Fig. 6 Clusters obtained by using all genres

Fig. 7 Clusters obtained by using FS only

Fig. 8 Clusters obtained by using CFS only

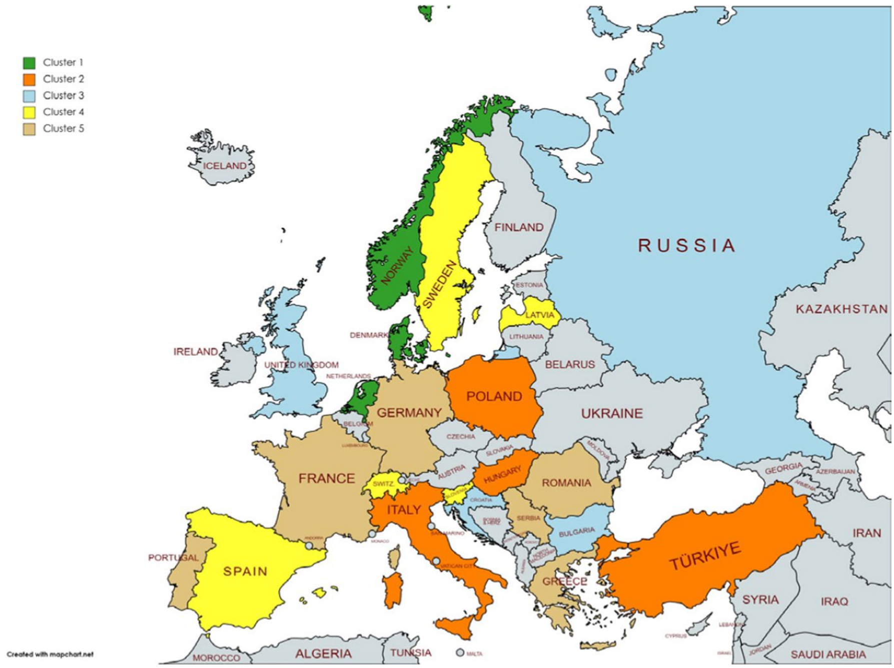


Fig. 9 Clusters obtained by using CS only

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Declarations

Conflict of Interest The authors have no conflicts of interest to declare.

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