journal of interdisciplinary music studies
fall 2010, volume 4, issue 2, art. #10040205, pp. 85-97

Instrument in Interaction with Pitch Content of Selected Works by Brahms, Saint-Saëns, Hindemith, and Shostakovich

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Background in music theory and analysis. In traditional music analysis, the instrument is often overlooked while its effect on the formation of structurally relevant aspects of harmony and counterpoint is regarded as inconsiderable. The principles of harmony and counterpoint are believed to have a key influence on the formation of the pitch (class) content of a classical work. It does not follow that the instrument would have no effect on it. However, these aspects of work's pitch content have not yet been systematically studied, partly due to the lack of the adequate methodology.
Background in statistics. Currently we do have a range of new developments in the theory and practice of multivariate statistical data analysis. This essentially models reality where each situation, product, or decision involves more than a single variable. However, it was not just until recently that a new powerful multivariate tool was developed for taking apart separate and interactive effects of multiple factors. In music, it enables for the first time to take apart the separate and interactive effects that musical instrument, style, etc. may have on work's pitch content.
Aims. The aim of the paper is to highlight the characteristic features of pitch content of soloist parts of selected violin and cello compositions of Brahms, Saint-Saëns, Hindemith, and Shostakovich which are caused by the use of the selected instrument.
Main contribution. The MIDI files were converted into dataset. The multivariate effects of the studied factors on the pitch content were analyzed by statistical program PRIMER 6 & PERMANOVA. The Euclidean similarity measure was used to construct the similarity matrices. The statistical differences between the factor levels were assessed by three-way PERMANOVA with "century", "composer" (nested in century) and "instrument" as factors. When a factor and/or interaction was identified as significant ($P < 0.05$), post-hoc PERMANOVA pair-wise tests were conducted to detect which levels were responsible for significant differences. The contribution of different structural elements to the differences was calculated by SIMPER procedure.
Implications. The analyses showed that the effect of an instrument on pitch content primarily lies in the extent of the variability of selected elements. Secondly, the historical style seems to have a slight effect on the use of the instrument. Thirdly, composers take the aspect of an instrument into account but this does not affect their style.

Keywords: musical instrument, musical style, pitch content, multivariate analyses & PERMANOVA

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• *Received:* 8 February 2010; *Revised*: 1 September 2010; *Accepted:* 22 September 2010
• *Available online:* 30 November 2010
• doi: 10.4407/jims.2010.11.005

Introduction

In traditional music analysis, the instrument is often overlooked while its effect on the formation of structurally relevant aspects of harmony and counterpoint is regarded as inconsiderable.[1] Notwithstanding the instrumentation, the tonal structure of any classical work is based primarily on common principles of harmony and voice-leading. These principles, in their turn, are therefore believed to have a key influence on the formation of the pitch (class) content[2] of a classical work. However, it does not follow that the instrument would have no effect on it. For example, the pitch content of a work written for a particular instrument may stand out in terms of its register, characteristic use of intervals, etc.[3] However, these and also other similar aspects of pitch content have not been systematically studied, partly due to the lack of the adequate methodology.

Currently we do have a range of new developments in the theory and practice of multivariate statistical data analysis. Several contributions illustrate the use of multivariate methods in application fields such as economics, medicine, environment, and biology (e.g. Kotta et al. 2008) but rarely as music. Multivariate data analysis refers to any statistical technique used to analyze data that arises from more than one variable. This essentially models reality where each situation, product, or decision involves more than a single variable. However, it was not just until recently that a new powerful multivariate tool was developed for taking apart separate and interactive effects of multiple factors (Anderson 2001). In music, it enables for the first time to take apart the separate and interactive effects that musical instrument, style, etc. may have on work's pitch content. This is undoubtedly a major achievement as in many systems interaction effects are more important than separate effects of same variables. This is quite easy to perceive. According to the definition interaction is a kind of action that occurs as two or more objects have an effect upon one another opposing to a one-way causal effect. As all systems are related and interdependent then every action has a consequence of interactive nature.

Aims

The aim of the paper is to highlight the characteristic features of pitch content of soloist parts of selected violin and cello compositions of Brahms, Saint-Saëns, Hindemith, and Shostakovich which are caused by the use of the selected instrument. More specifically, we try to distinguish the characteristics of pitch content caused by the use of particular instruments from those caused by the style or harmonic and contrapuntal principles. Unlike the instrument, the musical style and its effect on pitch content has been discussed in terms of statistics quite many times, but never analyzed using a rigorous hypothesis-testing framework. If some complex statistics were computed then the used analyses were likely too stringent in their assumptions for most multivariate data sets (Bigand 1997).
Usually the authors, having, in comparison with our study, similar purposes, tend to concentrate on the range or dispersion of pitch classes (Knopoff and Hutchinson 1983) or scale degrees (Snyder 1990) intentionally discarding the other aspects of

pitch content (e.g. intervals, timbre, etc.). Using dispersion analysis of pitch classes or scale degrees, they actually describe the musical style above all as a certain treatment of the resources of the (classical) tonality. Considering this, Snyder spends much time working out the method of tabulating data, in which all relevant features of tonality would have been taken into account.

Our approach is somewhat different. As our study proceeds from instrument, we are not only interested in the aspects of the tonal organization of pitch content (i.e. the dispersion of pitches or pitch classes generated within a tonal framework) for it seems reasonable to assume that the aspects associated with the functional relations of the scale degrees are relatively independent from those possibly caused by instrument. Secondly, as our study also comprises the post-tonal (neo-modal) repertoire of the 20th century (Hindemith and Shostakovich), the working out of a general analytical framework based solely on a heptatonic scale would be rather problematic. In looking for a common ground for 19th and 20th century music, we propose that the work's pitch content can likewise be described in terms of melodic intervals (dyads), i.e. characteristic sequences of pitches.[4] We believe that such approach is also suitable for describing musical instrument. All types of musical instruments have their own technical constraints (e.g. playing of some interval is more "handy" than another) and it seems reasonable to think that composers take this aspect of instrument into account. We also hypothesize that the interactive effects of the use of a specific musical instrument are somewhat different for the music of 19th and 20th century composers. Since the aim of the paper is to examine how the writing for a concrete instrument affects the pitch content of the work (i.e. the choice of notes written in the score), the different tuning systems, which have effect on performance rather than composition, here remain unexplored.

Main contribution

The soloist parts of sixteen works for solo instrument (violin or cello) and piano/orchestra by Johannes Brahms, Camille Saint-Saëns, Paul Hindemith, and Dmitri Shostakovich form the basis for this research. Every composer is represented by two works for violin and two works for cello. Such a choice was due to several reasons. First, in order to reveal how the writing for a concrete instrument affects the pitch content of the work, we needed at least two groups of works representing different instruments: thus the first group includes the works written for violin and the second group the works written for cello. Secondly, in order to bring out the influence of musical style, the selected works had to represent at least two different stylistic periods of music history (in our case the 19th and 20th century respectively). For best results, it would have been necessary to test additionally the works of 17th and 18th century, but most of the "cello" works of this era were originally written for *viola da gamba* or some other similar historic instrument and cannot be therefore taken as true or valid representatives of modern cello. Third, to distinguish between the traits of the style of the composer and historic period each period had to be represented at least by two composers. And finally, to distinguish the occasional manifestations of the pitch content from those which are supposedly related to the composer's personal style, each composer had to be represented at least by two works.

The difference between different parts of dataset (works of 19th vs. works of 20th century, works for violin vs. works for cello, works for Hindemith vs. works for Brahms, etc.) were quantified using pair-wise tests. Such tests permitted to discriminate between the effects of century (historical style), composer (individual style), and instrument on pitch content of studied works. The selected works include:

1. Violin Concerto in D Major, Op. 77, Violin Sonata No. 2 in A Major, Op. 100, Cello Sonata No. 1 in E minor, Op. 38, and Cello Sonata No. 2 in F Major, Op. 99 by Brahms;
2. Violin Concerto No. 3 in B minor, Op. 61, Violin Sonata No. 1 in D minor, Op. 75, Cello Sonata No. 1 in C minor, Op. 32, and Cello Concerto No. 1 in A minor, Op. 33 by Saint-Saëns;
3. Violin Concerto, Violin Sonata in E, Cello Concerto, and Cello Sonata by Paul Hindemith;
4. Violin Concerto No. 1 in A minor, Op. 77, Violin Sonata in G Major, Op. 134, Cello Concerto No. 2 in G minor, Op. 126, and Cello Sonata in D minor, Op. 40 by Shostakovich.

For our analysis, we had to convert the soloist parts of the aforementioned works into dataset. Using Adobe Photoshop we first scanned the soloist parts of the works. The received TIFF files were then imported to Finale 2007 and converted into MUS (MIDI) files. Due to the poor quality of some scores, the converted files included occasional errors. Therefore the MUS (MIDI) files were proofread by comparing them with the original scores. Corrected MUS (MIDI) files, in their turn, have been converted into music xml files and imported into PRIMER software data files. The data of columns which display the pitch class of the diatonic pitch collection[5] and its (possible) alteration (/part/measure/note/ pitch/step, /part/measure/note/pitch/alter) as well as its register (/part/measure/note/pitch/octave) of the received PRIMER files has been used as a basis for the statistical analysis.

The earlier studies that have aimed to identify patterns often focused on the means and neglected the variances about the means. Such studies have analyzed the response of systems to trends in mean values, offering little insight into the relative roles of mean as compared with its variance and into their interactions. Moreover, recent statistical experiments have indicated that means and variability can have opposite effects on the structure of a given system and therefore both should be incorporated into the analytical framework (Benedetti-Cecchi et al. 2006). In order to avoid such limitation we generated a set of variables describing the mean and variability of certain factors and levels of pitch (class) content for each work. The factors of studied works were "instrument" (violin or cello), "century" (referring to the historical style, i.e. 19th or 20th century), and "composer" (Brahms, Saint-Saëns, Hindemith, and Shostakovich). The generated variables were "pitch" and "pitch class of the diatonic pitch collection" (which we referred as elements), interval between the first and second element (i.e. interval between two adjacent pitches or pitch classes of the diatonic pitch collection), interval between the first and third element and so on up to the interval between the first and tenth element. The generated variables also included "register" (octave) and the degree of variability of all abovementioned variables.

The variables related to the element of pitch class of the diatonic pitch collection need a commentary. Here, the justified question of what aspects of pitch content would such variables actually display might arise. From the point of stylistic aspect, the answer to that question may depend on the musical context of a studied work. In the context of the 19th century tonal composition they obviously refer to the diatonic activity, a degree of readiness to abandon (or keep) once established scale degree or diatonic interval.[6] However, in the context of 20th century neo-modal composition they, beside diatonic activity, can also display the use of different non-traditional scales (e.g. octatonic) in which the different scale degrees are represented by the same letter name of the pitch.

As the characteristics of an instrument, they apparently display additional information about the relative simplicity or complexity of the studied parts. For example, if a part includes a relatively large number of augmented primes, i.e. intervals, which are usually "handy" to play, then these intervals, projected against the diatonic background (diatonic pitch collection), appear as repetitions of the same pitch (same letter name). The latter, in its turn, refers to the smaller variability of pitch content and a relative simplicity of the studied part accordingly. The calculation of letter names also brings out the preferred diatonic intervals, which, supposedly, are more likely to be used in composing for a particular instrument.

The multivariate effects of the studied factors on the pitch content of works were analyzed by statistical program PRIMER 6 & PERMANOVA (Clarke and Gorley 2006). PERMANOVA is a new non-parametric method for multivariate analysis of variance. It is an improvement on previous non-parametric methods because it allows a direct additive partitioning of variation for complex models. It does this while maintaining the flexibility and lack of formal assumptions of other non-parametric methods (which is not the case with the classical methods). The test-statistic is a multivariate analogue to Fisher's F-ratio and is calculated directly from any symmetric distance or dissimilarity matrix. P-values are then obtained using permutations. In the current study the Euclidean similarity measure was used to construct the similarity matrices. The statistical differences between the factor levels were assessed by three-way PERMANOVA with "century", "composer" (nested in century) and "instrument" (as factors). Due to relatively small sample sizes the permutation of raw data was used as this method does not need large sample sizes to work well (Gonzalez and Manly 1998) and this option tends to be more conservative than the tests that permute residuals[7] (Anderson and ter Braak 2003). When a factor and/or interaction was identified as significant ($P < 0.05$), post-hoc PERMANOVA pair-wise tests were conducted to detect which levels were responsible for significant differences. The contribution of different variables to the differences was calculated by SIMPER procedure. SIMPER computes the percentage contribution that each studied variable makes to the overall variability and identifies which variables are responsible for the observed difference among factor levels. A nonmetric MDS analysis was performed to better visualize the results of multivariate analyses.

Results

The statistical significance of the factors and their interactions are presented in Table 1. Factors and levels of the fixed effects making up the column referred as “Source” are as follows: Century = 19th and 20th century, Instrument = violin, cello, Composer = Brahms, Saint-Saëns, Hindemith, and Shostakovich, “Century × Instrument” = century in interaction with instrument, and “Instrument × Composer” = instrument in interaction with personal style of the composer (nested in century). The column of P(MC) refers to the statistical significance of the factors and the factor is considered significant if $P < 0.05$.

Table 1. The Monte Carlo asymptotic p-values of three-way PERMANOVA analyses with “century”, “composer” (nested in century) and “instrument” as factors.

Source	**P(MC)**
Century	0.839
Instrument	0.008
Composer	0.001
Century × Instrument	0.099
Instrument × Composer	0.900

As shown in the table, the PERMANOVA analyses of abovementioned variables indicated strong separate effects of instrument and composer on the pitch content of the studied works. The effect of century (i.e. the historical style), however, was not statistically significant. The latter may seem quite surprising as the works based on functional harmony are believed to represent fundamentally different type of tonality compared to those (types) of 20th century works. Still, we do not think that the results presented here contrast the findings of Snyder and others. Since our analysis was not conducted within a certain tonal framework, the reasons of which were mentioned above, it basically points that, at least in the case of studied works, the difference between (highly chromatic) tonality of late 19th century (Brahms and Saint-Saëns) and the free tonality (neo-modality or even atonality) of the first half of 20th century (Hindemith and Shostakovich) do not lie primarily in different frequencies of occurrence of pitches or pitch classes of the diatonic pitch collection, intervals, and the degree of their variability.

Although the works did not distinguish in terms of historical style, they did so in terms of composers and instruments. Besides, composers did not distinguish in structural elements that were characteristic to certain instruments and vice versa i.e. instruments did not interactively affect the choice of structural elements by a composer. This, in its turn, seems to reinforce, albeit indirectly, one of the central principles of the traditional music theory and analysis that the tonal (i.e. harmonic or contrapuntal) structure of a classical composition has to be regarded as superior to other aspects of musical structure and be therefore analyzed independently, as “thingin-itself" without paying much attention to the timbre, instrumentation etc. It was also surprising that, technically, none of the interactions were statistically significant. Still, the century in interaction with instrument (Century × Instrument) can be regarded as nearly significant (P = 0.099), i.e. in the case of studied works, the historical style seems to have a slight effect on the use of the instrument.

The following tables represent the PERMANOVA pair-wise tests. Table 2 represents the pair-wise tests of the instruments. As shown in the table, the works written for violin and works written for cello differ statistically in their pitch content.

Table 2. The Monte Carlo asymptotic p-values of pairwise test of PERMANOVA analyses showing the statistical differences among the studied instruments.

Groups	**P(MC)**
Cello vs. Violin	0.004

Table 3 represents the pair-wise test of the composers. Here, the pairs of "Brahms – Shostakovich", "Saint-Saëns – Shostakovich", and "Hindemith – Shostakovich" statistically distinguished from each other. Other differences were not statistically different. Again, it is rather surprising that all abovementioned pairs involve Shostakovich which denotes him as a composer in some way different from others. Since Brahms and Saint-Saëns represent the tradition of 19^{th} and Hindemith and Shostakovich the tradition of 20^{th} century, one might expect the difference arising rather between 19^{th} and 20^{th} century composers than between Shostakovich and others. Possible reasons of such difference are going to be discussed hereinafter.

Table 3. The Monte Carlo asymptotic p-values of pairwise test of PERMANOVA analyses showing the statistical differences among the studied composers.

Groups	**P(MC)**
Brahms vs. Saint-Saëns	0.545
Brahms vs. Hindemith	0.193
Brahms vs. Shostakovich	0.017
Saint-Saëns vs. Hindemith	0.637
Saint-Saëns vs. Shostakovich	0.001
Hindemith vs. Shostakovich	0.001

The next tables display the studied variables (structural elements) that had the strongest effect on the statistical difference between different factor levels. The column designated as "Variable" refers to structural elements. In this column, "Step" refers to the pitch class of the diatonic pitch collection, "Octave" to register, "StepOctave" to pitch, "Step1" to the interval between each adjacent elements of the work if the element is understood as pitch class of the diatonic pitch collection, and "Step1Octave" to the interval between each adjacent elements of the work if the element is understood as (absolute) pitch. "VarStep", "VarOctave", "VarStepOctave", "VarStep1", and "VarStep1Octave" refer to the variability of abovementioned factor levels, respectively. All other variables are labeled similarly. The last column of

“Cont” refers to the contribution of certain variable to the overall effect given in percentage.

Table 4 presents the first fifteen variables which had the strongest effect on the statistical difference between the use of violin and cello. “Violin” and “Cello” denote means of the normalized structural element for the respective instrument.

Table 4. The results of SIMPER test showing the contribution of different variables to the overall differences among instruments.

Variable	Cello	Violin	Contribution
Octave	-0.899	0.899	3.63
StepOctave	-0.897	0.897	3.62
VarStep2	-0.342	0.342	2.22
VarStep6	-0.315	0.315	2.19
VarStep10	-0.298	0.298	2.17
VarStep1	-0.239	0.239	2.10
VarStep	-0.163	0.163	2.04
VarStepOctave	0.160	-0.16	2.04
Step	-0.151	0.151	2.03
VarStep5	-0.150	0.150	2.03
VarStep4	-0.144	0.144	2.03
StepOctave2	-0.142	0.142	2.03
VarStepOctave3	-0.133	0.133	2.02
VarStepOctave5	-0.114	0.114	2.01
VarStepOctave6	-0.108	0.108	2.01

According to Table 4 the main difference between the use of violin and cello primarily lies in their effect on the variability of different structural elements (majority of listed factor levels (variables) include Var- as prefix). It is also notable that almost all numeric values making up the cello column are negative, which refers to pointed variables’[8] greater stability (if the variability of a specific structural element is discussed) or lesser frequencies of occurrence (if the mean of a specific structural element is discussed). Thus, as compared to violin parts, cello parts differ in their more modest usage of different registers and pitches (see first two structural elements; the only elements which statistical difference exceed 3 %), and, consequently, lower variability of intervals (next six variables). The results presented here are not as self-evident as they might appear at first sight. Although the violin is believed to have a greater range than any other (bowed) string instrument, the cello, similarly, has a range of more than four octaves, and, especially in soloist parts, the upper limit of its range is, analogically to violin, often determined by the skill of the player. As the majorities of studied parts of the cello were technically demanding and encompassed the full range of cello register we did not expect so big difference between the parts of the violin and cello might arise.

Next tables present first fifteen variables which had the strongest effect on the statistical difference between the pitch contents of Brahms and Shostakovich, Saint-Saëns and Shostakovich, and Hindemith and Shostakovich.

Table 5. The results of SIMPER test showing the contribution of different variables to the overall differences among instruments.

Variable	Brahms	Shostakovich	Contribution
VarStep	0.208	-0.549	3.37
VarOctave	-0.259	1.200	3.32
VarStepOctave	-0.239	1.170	3.30
VarStep7	0.382	-0.828	3.23
VarStep5	0.304	-1.010	3.01
VarStepOctave2	0.061	0.890	2.97
VarStep1	0.868	-0.323	2.93
VarStep8	0.019	-0.718	2.91
Step	-0.376	0.312	2.89
VarStep2	-0.032	-0.758	2.79
VarStep6	0.034	-0.593	2.75
VarStep9	0.077	-0.448	2.64
VarStepOctave4	0.151	0.475	2.50
VarStepOctave1	0.210	1.080	2.48
VarStep3	0.047	-0.532	2.42

Table 6. The results of SIMPER test showing the contribution of different variables to the overall differences among the named composers.

Variable	Saint-Saëns	Shostakovich	Contribution
VarStepOctave1	-0.616	1.080	4.57
VarStepOctave2	-0.439	0.890	4.11
VarStepOctave3	-0.501	1.030	3.89
VarStepOctave5	-0.441	0.820	3.77
VarOctave	-0.334	1.200	3.72
VarStepOctave4	-0.342	0.475	3.59
VarStepOctave	-0.32	1.170	3.54
VarStepOctave7	-0.34	0.756	3.47
VarStepOctave8	-0.162	0.294	3.40
VarStepOctave10	-0.085	0.445	3.29
VarStepOctave9	-0.171	0.618	3.05
VarStepOctave6	-0.323	0.439	2.99
VarStep2	0.449	-0.758	2.60
VarStep5	0.233	-1.010	2.58
VarStep9	0.146	-0.448	2.55

Table 7. The results of SIMPER test showing the contribution of different variables to the overall differences among the named composers.

Variable	Hindemith	Shostakovich	Contribution
VarStepOctave1	-0.670	1.080	3.79
VarOctave	-0.606	1.200	3.75
VarStepOctave	-0.612	1.170	3.68
VarStepOctave2	-0.512	0.890	3.43
VarStepOctave3	-0.671	1.030	3.34
VarStep5	0.468	-1.010	2.89
VarStepOctave5	-0.479	0.820	2.68
VarStepOctave7	-0.481	0.756	2.46
VarStep8	0.713	-0.718	2.37
VarStepOctave4	-0.284	0.475	2.35
Step1	0.152	-0.432	2.30
VarStep9	0.224	-0.448	2.28
Step4	0.167	-0.231	2.24
VarStep10	0.500	-0.730	2.19
VarStep7	0.345	-0.828	2.16

According to tables 5–7, the main difference between Shostakovich and other composers is based on the variability of intervallic structure and the use of different registers. This is particularly clear in tables 6 and 7, in which a considerable number of listed variables refer to the variability of certain aspects of intervallic structure. The tables also demonstrate that the aforementioned variables are usually represented through negative numeric values in Saint-Saëns and Hindemith columns (tables 6 and 7) or, comparing Shostakovich, lesser numeric values in Brahms column (table 5). Thus, as paralleled with the rest of the composers, Shostakovich tends to abandon once established interval or register more frequently as the work progresses. This, in its turn, can likely be coupled with his rather eclectic style which encompasses a wide range of different compositional techniques often employed in a single work.

Although Brahms and Shostakovich differ in the variability of intervallic structure and the use of different registers (see variables 2–3, 6, 9, and 13–14 of table 5), they can also be distinguished by treatment of the pitch classes of diatonic pitch collection (see variables 1, 4–5, 7–8, 10–12, and 15 of table 5). As already told, if the “Octave” (i.e. the register) is not involved in the name of a variable it represents the pitch class of diatonic pitch collection or interval arising between the pitch classes of diatonic pitch collection. By such variables the Shostakovich column, compared to that of Brahms’s, usually displays lesser numeric values. As already said, the smaller variability of the pitch classes of diatonic pitch collection may refer to the (extensive) use of different non-traditional scales in the context of 20th century composition. If so, then this again denotes the musical style of Shostakovich as rather diverse. Such differentiation can be also made by comparing Hindemith and Shostakovich where it is not as evident (see variables 6, 9, 12, and 14–15 of table 7). Consequently, this property links the tonal structures of the works of Brahms and Hindemith.

Figure 1 displays the non-metric MDS analysis on the variability of the studied works in terms of their pitch content and intervallic structure. The analysis showed that the works composed by Shostakovich and Saint-Saëns varied at smaller extent compared to those of Brahms and Hindemith. This links Brahms and Hindemith on the one hand and Saint-Saëns and Shostakovich on the other. Whereas the smaller variability in heptatonic context can be related to relatively more modest use of structural devices in the compositions of Saint-Saëns (compared to Brahms and Hindemith), it, in the non-heptatonic context, obviously refers to the greater modal diversity of works of Shostakovich.

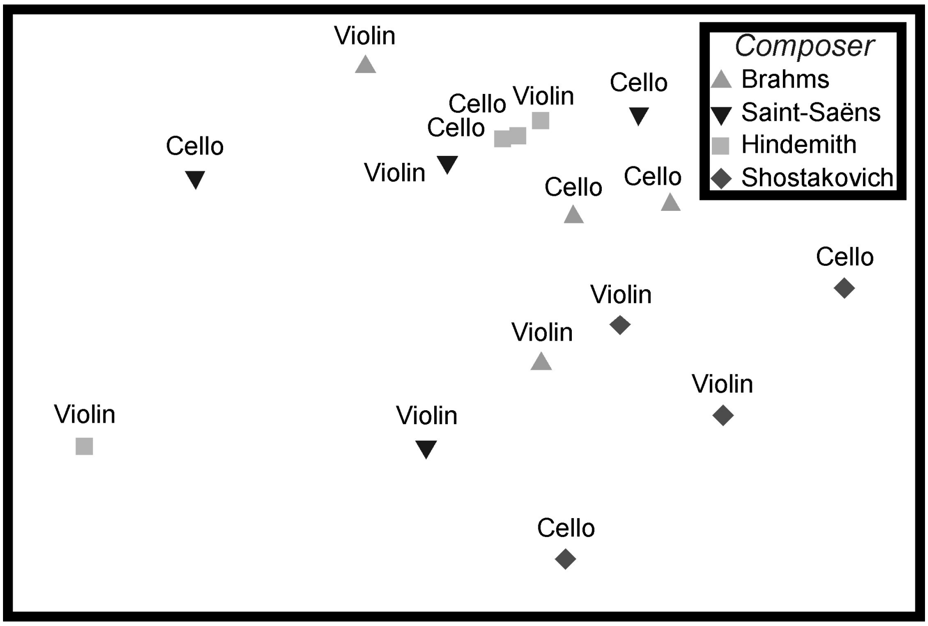

Figure 1. A nonmetric MDS analysis to visualize the multivariate distance between the works of the studied composers and instruments. The distance between points indicates the dissimilarity of the respective works.

Conclusions

The results of the analyses conducted in this study confirm some generally accepted notions and provide some new insights. The analyses showed that the effect of an instrument on pitch content primarily lies in the characteristic variability of selected elements (as shown in Table 4). Secondly, the historical style seems to have a slight effect on the use of the instrument. Thirdly, composers take the aspect of an instrument into account (the works written for violin and cello differ in their pitch content) but this does not affect their style (notwithstanding the selected instrument, the works of Shostakovich could be clearly distinguished from others in their characteristic pitch content). Moreover, lacking interactions between different factors (century × instrument, instrument × composer) in general seems to be the "intrinsic nature" of the musical work. This in its turn distinguishes it as a system from other systems, e.g. ecosystem, which is often described, first of all, through the interactive effects of its factors (Kotta and Witman 2009), and defines the musical work as an artificial phenomenon, as artwork *par excellence*.

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[1] In classical harmony, we usually speak about the elements of tonal structure, i.e. chords, chord progression, voice leading etc individually, not taking the aspect of instrument into consideration. According to David Gagné (1999) "…in dealing both with individual works and with general categories […] analysts tend to focus primarily on thematic, harmonic, and (more recently) voice leading factors with the medium regarded only as a means of realization. Analytical essays seldom consider how the structure

[…] might have been shaped and, to some extent, even determined by the nature of the medium [i.e. the choice of the instrument, performance etc].”

2 Since the term “tonal structure” primarily refers to the harmonic and contrapuntal structure, we use the term “pitch content” instead. Unlike the former, the term “pitch content” has no rigid stylistic or historical connotations.

3 It is a generally accepted notion that some aspects of work’s pitch content, namely the selection of a key and the persistent use of a concrete register, may be affected by the use of a concrete instrument. For example, a rather considerable number of famous violin concertos are written in D major, a “convenient” key for the violin player.

4 In our analysis, we calculate the entropy of pitches (or pitch classes) too, but this aspect is mostly discussed in interaction with intervallic aspects of pitch content.

5 The term “pitch class of the diatonic pitch collection” needs to be explained. “Diatonic pitch collection” indicates to the musical tones represented by the first seven letters of the alphabet (i.e. white keys of the keyboard). The term “pitch class”, in its turn, refers to the note that is identified by its letter name but not by its position in a particular octave or register (Gauldin 1997: 7, 10). Thus, the pitch class of the diatonic pitch collection refers to the letter name of a pitch and not necessarily to the diatonic pitch class, i.e. the pitch class of some diatonic scale.

6 In order to determine the number of diatonic steps between the tones of an interval in the traditional heptatonic context (i.e. the size but not quality of diatonic interval) one simply has to count the letter names of the pitches between the tones making up the interval. For example, the dyads C–D, C♯–D, C–D♭, and C♯–D♯ etc. all make up the seconds notwithstanding the scale within which they may arise.

7 Residuals are obtained by subtracting from each replicate the mean corresponding to its particular cell (where a “cell” means a particular combination of factor levels). These residuals are estimating the errors associated with each replicate. These are then permuted and the statistic is recalculated for the errors alone under permutation. Although permutation of residuals empirically gives the best power and the most accurate type I error for complex designs in the widest circumstances, in practice, these two approaches will give very similar results.

8 It is also notable, that the variables 3–7 (i.e. the most important variables except register and variance of pitches) refer to the intervals between the pitch classes of the diatonic pitch collection. One can therefore speculate that, in comparing different instruments, the „diatonic“ dataset can be more „sensitive“ in displaying the main difference of instruments on pitch structure.

Biographies

Kerri Kotta (PhD) is the assistant professor and the coordinator of Music Theory at the Estonian Academy of Music and Theatre. His main research interests are harmonic and contrapuntal structure and their relations to the musical form. He has published on Mozart, Shostakovich, and Estonian music (including contemporary Estonian composers Erkki-Sven Tüür and Helena Tulve) in different volumes (e.g. *Schwarze Milch und bunte Steine. Der Komponist Erkki-Sven Tüür*) as well as journals such as *Composition as a Problem* and *Mūzikas akadēmijas raksti*.

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