Commentary on "An Exploratory Study of Western Orchestration: Patterns through History" by S.H. Chon, D. Huron, & D. DeVlieger

CHRISTOPH REUTER [1]
Musicological Institute of the University of Vienna, Austria

ABSTRACT: This commentary discusses the exploratory study by Chon, Huron and DeVlieger about the usage and combinations of musical instruments in orchestral works between 1700 and 2000 under the perspective of the evolution of the musical instruments in that time, their acoustical and social aspects as well as recommendations in orchestration treatises of the last 300 years.

Submitted 2017 August 1; accepted 2017 September 1.

KEYWORDS: *orchestration, instrumentation, instrument combination, music history*

ORCHESTRATION and its history is a very complex issue. Based on 1800 score excerpts sampled from 180 orchestral works from the time between 1701 and 2000 (separated into 50-year periods) Chon, Huron and DeVlieger draw a big picture of 300 years of western orchestration. Of course, the authors know about the many possible drawbacks and shortcomings of such an endeavor (and discuss them on several places in their work very closely and prudently). The results of their exploratory study are enlightening and inspiring in many aspects (see below); and possibly a few further points can be taken into consideration:

METHOD: SAMPLED COMPOSERS, WORKS AND SONORITIES

It is difficult to estimate the importance, the typicality or the value of a composer or a musical work, and it is understandable that the authors found orientation in two modern classical music guides (Jolly, 2012 and Dubal, 2002) as well as in the Wikipedia list of classical composers. Of course, one has to start somewhere. However, when looking at a period of 300 years consisting of different and changing epochs, styles, preferences etc. one has to keep in mind that the importance and value of a certain composer is not stable over time. Looking for example into the Leipziger Allgemeine Musikalische Zeitung of October 1799 one can find a copper engraving made by A.F.C. Kollmann on column 104 (see Figure 1), which gives a clear picture of the importance of certain composers as perceived in the second half of the 18th century. Here J.S. Bach is symbolized as a sun in the middle, surrounded by Haydn, Händel and Graun, while e.g. Mozart is seen more in the edge at a lower category same as Kozeluch, Pleyel or Reichard.

It is imaginable that the selection of composers (and works) would be different when choosing them by the appraisal of contemporary authors instead of from a somehow anachronistic perspective. Similar considerations could be taken into account regarding the selection of the musical works (by reference to the number of performances in a certain time period one could estimate the importance of a musical piece at that time).

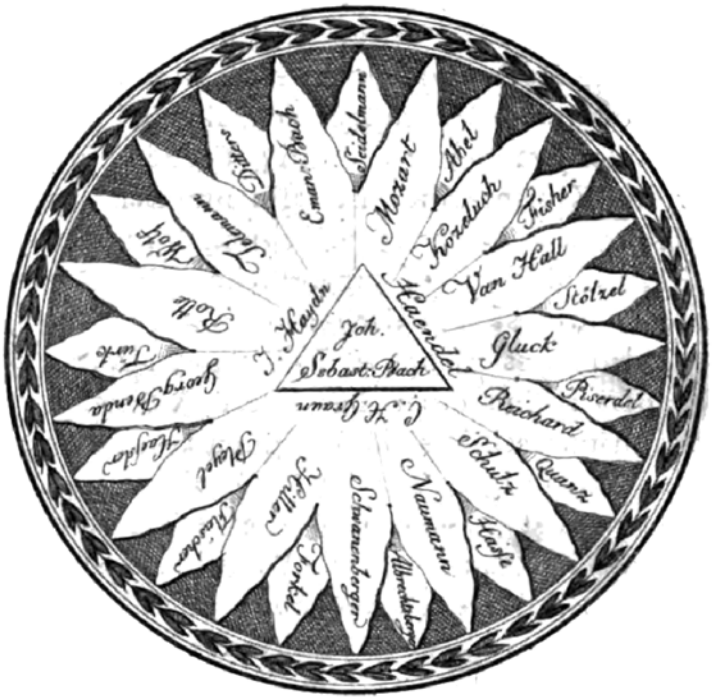

Fig. 1. Kollmann's composers diagram. From Forkel (1799, c. 104).

The question about the typicality and general validity applies also in the case of the score excerpts ("sonorities", 10 excerpts randomly chosen from each of the 180 orchestral works respectively): Mostly the use of instruments, tempo, dynamics, etc. change with the functional part of a musical work. One should keep in mind that there are formative and characteristic parts in classical sonata form (like the main theme in the exposition or recapitulation) and non-typical and negligible parts (like transition to the development). So when searching for characteristic sonorities perhaps it would also make sense to start with the search in the more typical and characteristic parts of the musical piece.

Coding

Of course, the coding of the used instruments with a priori equivalents is necessary. However, the evolution of the musical instruments in the years between 1700 and 2000 was substantial and complex. Therefore, in some cases one can discuss the equivalence between certain historical and modern instruments. Looking at the chalumeau for example (the keyless instrument, not the register; range F3–A4, Majer, 1732, p. 32) one has to consider that in the 18th century the word "chalumeau" was also used for the "Schalmey" (a double reed instrument which is a precursor of the oboe) or for the "Chalemie" (a bagpipe-like instrument) (cf. Trichet, 1640, p. 92–93; Majer, 1732, p. 32; Walther, 1732, p. 153–154; Gutknecht, 1993, p. 19). And the timbre of the early clarinet was described as rather trumpet-like (Majer, l732, p. 39; Walther, 1732, p. 168; Eisel, 1738, p. 76), not to forget that the instrument was often used in its high register as a surrogate for the clarine trumpet at that time ("clarinetto" means "small clarine trumpet"). Another case is the corno da cacchia which has more in common with a natural trumpet than with a French horn. Being played with a cup-shaped mouthpiece (instead of a funnel-shaped mouthpiece) and having a small bell it was more or less a curved little trumpet and it was also used accordingly (Fitzpatrick, 1963, p. 42; Kunitz, 1957, Vol. 6, p. 450), so perhaps it should rather be considered an equivalent to a trumpet than to a French horn.

RESULTS

The results of this study are remarkable, especially when it comes to the hierarchical clustering of instruments (*Strings*, *Core Winds* and *Effects*). This model is very convincing and in accordance with the observations in the history of orchestration, the evolution of musical instruments and their combinations described in the

orchestration treatises and similar books about the use of musical instruments in the time between the 16th and 20th century (see below). It is also to be emphasized that the authors showed – by reference to the calculated entropy for pair-wise instrument combinations – that in the course of the 20th century the orchestration got more and more characterized by "a form of predictable uniqueness or standardized novelty". A further study on this observation would be very promising. Many further eye-opening insights into orchestration history are presented in their study, as well as many impulses for further discussions:

Instrumentation Presence and Instrument Usage

The figures and description about the occurrence of the musical instruments are very much in agreement with the big picture one has so far concerning orchestration history. A particular positive aspect is that the authors differentiate between the presence and the usage of a musical instrument, and their figures might get even more revealing, when adding some historical data. For example in 1800–1850 the presence of the flute increases a lot (its usage only a little) which could be ascribed also to the influence of the Prussian King Friedrich II ("The Great"). As a great admirer of the flute (it was a symbol for Enlightenment to him) he ensured that there are four or more flute players in his court orchestra (Reinecke, 1988; Reuter, 2002, p. 32–33). In the course of the 19th century other courts like Munich, Copenhagen, Dresden, Stuttgart, Mannheim etc. followed (a synoptic view about the numbers of instrumentalists in orchestras and similar ensembles in Europe between 1610 and 1886 is given in Reuter, 2002, p. 523–544). It is a little bit confusing that in case of the continuo instruments the presence and usage of bass instruments like double-bass, bassoon and cello in the time between 1700 and 1800 remains unclear. Adding the data of the continuo instruments to those of double-bass, bassoon and cello the graph for the use and presence of double-bass, bassoon and cello should more or less have a similar course like that of violin/viola and oboe. The same applies to the presence and use of trumpet and horn in the 18th century. Because of the fluent transition between these two instruments in the time between 1700 and 1800 it is not so easy to estimate the presence and usage of the historic natural horn and trumpet only by the names in the score parts (cf. Kunitz, 1957, Vol. 6, p. 346, 438, 441–443, 449 and 451; Dullat, 1989, p. 66).

When looking at the total number of parts specified in orchestral scores and their increase in the years between 1700 and 1950 (and their stagnation in the years from 1950 to 2000) it could be enlightening to take a glance at a similar phenomenon, which can be seen in the growing number of musical instrument players in 415 European orchestra-like ensembles in the time between 1610 and 1877 (see Figure 2, calculated on the basis of ensemble members lists in Reuter, 2002, p. 523–544). One can say that not only the number of parts in orchestral scores was increasing over time, but also the number of instrumentalists playing in an orchestra:

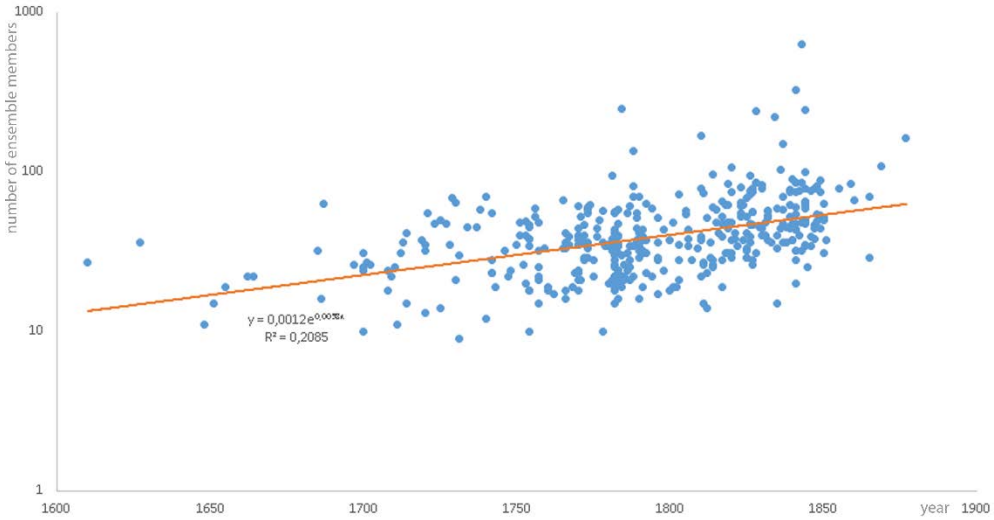

Fig. 2. Number of musical instrument players in orchestra-like ensembles (Y axis) plotted against the year of European orchestral performances (X axis) showing a general growth in ensemble size.

Most Common Instruments Combinations

Looking at the most common instrument combinations, it is striking that nearly all of the common combinations are contingent on string instruments combined with – very occasionally – a bassoon or oboes here and there. These results correspond very well with the basic definition of an orchestra (multiplied bowed string instruments, doubled or complemented with wind instruments sometimes; cf. Zaslaw, 1988). Furthermore, the hierarchical clustering (over the individual centuries as well as over the whole time period of 300 years) with the result of a *String* section, a *Core Wind* section and an *Effect* section as main clusters mirrors the description of the usage of orchestral instruments in a large number of orchestration treatises as well as in gestalt-theoretical aspects and in formant-based orchestration (see below).

Looking at these three instrument clusters – *Strings*, *Core Winds* (flute, oboe, clarinet, bassoon and French horn) and *Effects* (other instruments) – the question arises whether *Strings* and *Core Winds* have not also been used as effect instruments. One can name many examples in orchestra literature like e.g. the use of "col legno" by the strings in Saint-Saëns "Danse Macabre" (1874), the use of the clarinet's chalumeau register to cause eerie stage effects in Weber's "Freischütz" (1821) (cf. also the orchestration treatises of Bussler, 1879, p. 259; Schubert, 1885, p. 37 and 41; Gevaert, 1887, p. 180; Hofmann, 1893, p. 17 etc.), the use of the bassoon in its high register for getting ludicrous or grotesque effects (Höfer, 1913, p. 45 and 46 (bassoon as the "comedian of the orchestra"; similar in Kling, 1882, p. 32; Prout, 1888, p. 38; Strauß & Berlioz, 1904, p. 205; Kennan, 1962, p. 85; Delmar, 1983, p. 176 etc.). On the other hand the instruments of the *Effects* cluster are often not used for effects but for normal accompaniment, like – for example – the English horn: In classical orchestra pieces it is mostly used to musically describe grief, melancholy situations or countryside idylls, until Richard Strauß used it as a normal inner voice of the woodwind parts in his symphonic poem "Ein Heldenleben" (1899)(cf. Kunitz, 1956, Vol. 3, p. 91). In other words: Nearly each instrument of the orchestra can be used as an effect instrument, but only string instruments can be located in the *String* cluster and only the most common wind instruments (flute, oboe, clarinet, bassoon and French horn) can be found in the *Core Wind* cluster. So perhaps it would be a good alternative to speak of an "*Additional Instruments*" cluster instead of "*Effects*".

The observation of the authors that the double-bass reached a certain autonomy in the course of 19th century is a phenomenon that can also be found in the case of the bassoon (it becomes independent from the lower strings group in the middle of 18th century (Gevaert, 1887, p. 162; Carse, 1949, p. 22; Kunitz, 1957, Vol. 5, p. 312–313; Becker, 1964, p. 23) or the clarinet in the end of the 18th century (it is released from its role as an alternative for the oboe, Bussler, 1879, p. 257; Jadassohn, 1889).

With the focus on the *Core Wind* section, the authors found out, that inside this cluster the instruments of the higher and middle pitch range (flute, oboe and clarinet) are used to play in the foreground, while the instruments of the lower pitch range (bassoon and French horn) are more located in the background. This sheds a light on some deeper insights into the function and combination of musical instruments, and perhaps this light gets a little bit brighter when adding some historical and acoustical information. Looking into the earliest instrumentation treatises (Roeser, 1764 or Francoeur, 1772) only the *Core Winds* section is represented there (and Roeser, 1764 even deals only with a small part of it: the composition for bassoon, clarinet and French horn). The succeeding orchestration treatises also mostly focus on the *Core Winds* section and its use in ensemble play. So, if one sees an orchestra as an ensemble, where multiplied strings are playing most of the time in order to give a consistent timbral background (like a canvas), the purpose of the wind instruments (especially when not doubling the string parts) is more or less to draw or enrich melodic/harmonic lines in their different colors on this canvas. This also makes sense from a (psycho)acoustic perspective: the timbre of string instruments, especially when playing multiplied, is pre-eminently characterized by fluctuations and modulations, while the timbres of wind instruments (especially that of double-reed and brass instruments) are spectrally shaped by typical, stable and timbre-determining frequency maxima (so-called "formants", see below). Considering the aural benefit of binaural masking level difference and comodulation masking release when listening to and/or detecting binaurally more or less constant spectral structures in a fluctuating/modulating environment (cf. Gelfand, 2004, p. 416ff.; Yost, 2007, p. 184ff. and 212ff.) the usefulness of the combination of the *Core Wind* section (and also of the *Effects* section) acoustically embedded into the *String* section becomes clear. Because of the different timbre structure of *Strings* vs. *Core Wind* instruments (fluctuations vs. formants) the signal-to-noise ratio or separability of the involved instruments is highest in this constellation. But why speak of formants in this context?

Digression: The role of formant areas in instrument detection and orchestration

When the authors state in the introduction of their paper, that the results of timbre research so far "have offered little insight into issues related to conventional orchestration" (p. 116), they perhaps were not aware of a long tradition of European timbre research, where a lot of issues of conventional orchestration turned out to be better understandable with the help of the paradigm of fixed, pitch-independent and timbre-decisive formant areas, which can be found in the spectra of wind and brass instruments.

Formants have been used for instrument timbre description e.g. by acousticians like David Luce and Melville Clark, when they searched for the physical correlates of brass instrument tones in 1967. Later formants turned out to be a useful predictor for acoustical blending or separation of the timbres of wind instruments playing together (Lembke, 2014; Lembke & McAdams, 2015; Reuter, 1996; Reuter & Siddiq, 2017). But how is it even possible that one can find formant areas in the spectrum of musical instrument timbres? Wind instrument timbres often have a vowel-like character (e.g. a bassoon sounds similar to an "oh", while the sound of an oboe rather resembles an "ah" etc., see for example Figure 3).

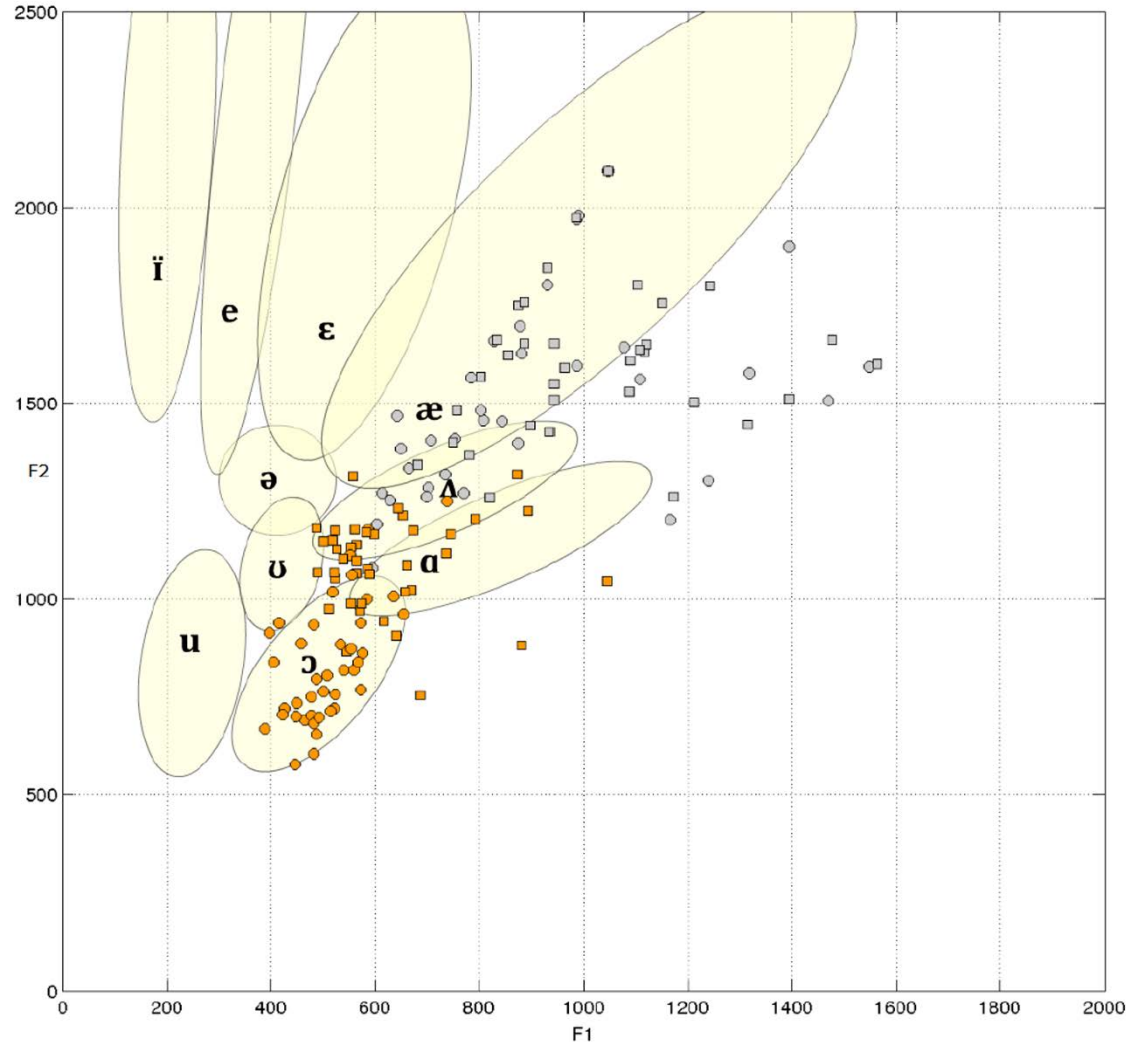

Fig. 3. First formant (F1, X axis) and second formant (F2, Y axis) of bassoon timbres (orange) and oboe timbres (grey) in all reachable pitches and in *ff* as well as in *pp* projected on vowel formant areas. From Reuter et al. (2017, p. 191).

The instrument's tube cannot be the reason for such a vowel-likeness, because its resonance changes with every opened or closed key, hole or valve, so accordingly the timbre (or the spectral envelope with its gaps and maxima) would change with every pitch. Instead, the reason for the typical wind

instruments' formants can be found in the structure of the excitation pulses (first noticed by Fransson in 1966 and 1967 as well as Fricke, 1975 and Voigt, 1975). When looking at the opening and closing times of a double-reed or (in case of brass instruments) of the lips in a mouthpiece with the help of a high speed camera one can observe that the duration of closed lips or reeds (as excitation pulses) stays more or less constant independent of the pitch. These constant closing times lead to fixed areas in the spectrum, where no partials can occur (spectral gaps) and between them those fixed areas with a constant formant-like structure independent of the pitch emerge (a detailed English description and digital simulation of this so-called "pulse forming principle" is given in Oehler & Reuter, 2009).

Carl Stumpf in 1926 was the first one who discovered fixed formant areas in the spectra of musical instrument sounds (Stumpf, 1926, p. 382). Before this time, the word "formant" in its sense of a fixed and pitch-independent spectral maximum was in use for the description of vowel timbres only (as proposed for the first time by Ludimar Hermann in 1896).

Because of their pitch-independency, formants represent a good choice when it comes to the description of musical instrument timbres as a whole instead of the timbre of a single sound. The authors are right with their introductory complaint that "most of the extant timbre research has focused on perceptual properties of isolated tones": Single isolated tones do not reveal much about the global timbre of a musical instrument. While dealing with timbres and their characteristic spectral maxima, Carl Stumpf emphasized the same point more than 90 years ago when he wrote: "they [timbral modifications occurring during instrument play] show us again the difference between the concept of "sound" and that of "musical instrument" (translation of the passage in Stumpf, 1926, p. 393). With other words: one has to observe a lot of pitches and dynamics of one instrument to be able to tell something useful about its typical, characteristic, pitch-independent timbre.

In 1929, Carl Erich Schumann (a pupil of Carl Stumpf) found some generalizable principles in the behavior of musical instruments' formants. In his habilitation thesis, Schumann could confirm the observations of Carl Stumpf that musical wind instruments show pitch-independent typical and stable spectral maxima and he consolidated his findings in his *Principle of formant areas* ("Formantstreckengesetz"): As explained above, formants of musical instruments are fixed and pitch-independent areas of the spectrum, wherein partials have exceptionally strong amplitudes, so that the timbre impression is influenced mainly by partials located in these areas (Schumann, 1929, p. 89).

Schumann summarized further observations about the dynamic-dependent behavior of timbre in the *Principle of formant shifting* ('Formantverschiebungsgesetz'): With increasing musical dynamics, the strongest amplitude of the partial in the formant area shifts to a partial of higher order in the same formant area (Schumann, 1929, p. 15–18, 98 and 100). The *Principle of spectral gap skipping* ('Sprunggesetz') is an extreme case of the *Principle of formant shifting*: With very intense musical dynamics, the strongest amplitude of the first (or lowest) formant area shifts to a partial in the second (higher) formant area, skipping over the partials between these areas (Schumann, 1929, p. 98 and 100).

Like the works of Carl Stumpf the habilitation thesis of Carl Erich Schumann has never been translated into English, but in German literature formants became one of the common tools for the description of musical wind instrument timbres (e.g. Meyer, 2015; Weinzierl, 2014, etc.).

In 1986, Jobst Fricke set up a theory about fragmentary masking of musical instrument timbres with non-overlapping formants. He assumed that musical instrument timbres can be distinguished very well from a total sound mixture, because of the fact that the formants of one instrument are located in the spectral gaps of the other instrument and vice versa.

Testing this hypothesis with scale segments of unison playing instruments in all reachable pitches this theory could be confirmed in most parts (Reuter, 1996), especially in the case of woodwind and brass instruments with a strong distinctive first formant area, playing in the low and middle register (e.g. bassoon & trumpet or oboe & French horn playing in unison are very well separable).

During this study, also the opposite of the principle of fragmentary masking could be observed (Reuter, 1996). Timbral blending is caused by the overlapping of corresponding formant areas: This means, when two instruments with corresponding first formants are playing together in unison it is not easy if possible at all to distinguish a single instrument from the total sound mixture (e.g. bassoon & French horn or oboe & trumpet playing in unison blend very well).

The next step was to search for comments and advises about timbre blending and separation in orchestration treatises. Most of these comments and remarks turned out to be very consistent with the formant-based theory of timbre blending and fragmentary masking. With these results, a formant-based orchestration treatise for wind instruments was possible, which is in conformity with preceding orchestration

treatises, and where all remarks about timbre, registers etc. of the different authors are listed systematically in tables (Reuter, 2002).

Formants are not only a helpful tool in the research of timbre blending of simultaneously playing musical instruments, but they are also very suitable for predicting the auditory grouping of successively playing alternating instrument timbres (Reuter, 2003). Alternating timbres with corresponding main formant areas lead up to one sole, continuous melody in perception (e.g. a single melodic stream is perceived when alternating bassoon & French horn timbres). Analogically, alternating timbres with non-matching formant areas are perceived as two distinct interwoven melodies (e.g. two melodic streams occur when alternating oboe & French horn timbres). The consideration of the authors after hierarchical clustering of the sonorities that high-pitch *Core Wind* instruments (like flute and oboe) are playing a foreground role while low-pitch *Core Wind* instruments (like bassoon and French horn) are having more a background function, could be confirmed in listening tests, even when the instruments are playing in alternation within the same loudness and pitch range: The instrument with the higher main formant (oboe or trumpet) always sounds brighter than the instrument with a lower main formant (bassoon or French horn), so most of the test subjects perceived the oboe or the trumpet as playing in the foreground and the bassoon or French horn in the background, even independently of their pitch (Reuter, 2003).

Dynamics, Tempo and Pitch

Also in the case of dynamics, the authors could observe that the French horn is closely related to the *Core Wind* section, while the other brass instruments (trumpet, trombone, and tuba) built their own group in the *Effects* cluster. One can be sure that this is not only because of the enormous blending capabilities of the French horn but there are also some historical reasons for this, which are mirrored in the history of orchestration (see the early orchestration treatises by Roeser, 1764 and Francoeur, 1772 as mentioned above) as well as in the special use of the brass instruments in the early times of orchestra:

Trumpeters of the 17th and 18th century belonged to a special guild with representative and military tasks (so-called “Reichszunft der Trompeter und Pauker” since 1623, cf. Altenburg, 1795), so the usage of the trumpet as an instrument in the early orchestra-like ensemble was very rare in the 18th century. It was similar with the trombone, which was more or less exclusively used in church music for the accompaniment of the choir in the 18th Century, and it was rarely used outside the church in that time (Mattheson, 1713, p. 267; Carse, 1964, p. 112). And finally, the tuba as a successor of the (valve-)ophiclëide was built at the earliest in 1835, so during the whole 18th century the French horn was the only brass instrument, which was permanently available and could be used without any social difficulties. Therefore, it is hardly surprising that the French horn is a member of the *Core Wind* section, being the only permanently available brass instrument in the first approximately one hundred years of orchestra development, and the 17th and 18th century was a time, where these *Core Wind* instruments had been optimized for ensemble play by musicians and instrument makers.

When looking at the instruments’ dynamics it is surprising that the instruments seem to play mostly in *f* or *p*. These results are somewhat unexpected; by experience, one would expect that the instruments would mostly play in *mf* while the other dynamic labels would be used less commonly. One (possible but not yet discussed) reason for such a low appearance of *mf* signs could be, that it is mostly self-evident for musicians to play in *mf*, when no dynamic label is given (but even this assumption does not explain the strong and singular preference for *mf* in the case of the harp). Similar open questions remain when mapping the instruments with the tempo, and perhaps the fuzzy impression of both mappings (instruments with dynamics and with tempo) is partly due to the uneven distribution of the data, as the authors also pointed out. The frequent appearance of the English horn in very slow tempo can very well be explained by its nearly exclusive usage in melancholic, sorrowful or rural musical contexts (see above), while the even more striking occurrence of the piccolo flute in moderate tempo is not so easy to explain by the instrument’s character or its history.

The comparison of the pitch ranges and mean pitches of the instruments used in the last 300 years with the pitch ranges and mean pitches of a modern orchestration treatise (Adler, 2002) seems to be a little bit anachronistic. Keeping in mind that the pitch range of the instruments of the 18th century usually has been smaller (which could be a reason for the lower mean pitches found for most instruments) and some pitches inside the ranges could not be played easily (or could not be played at all) because of missing keys or other constructional reasons, it is surprising that the mean pitches found in the sampled data are so close to the median pitch of the modern instruments, especially in case of the trumpet (which had been used as a

natural trumpet without valves until the middle of 19th century in different tunings). The same holds for the French horn, which is (beside the timpani) the only instrument whose mean pitch of the sampled data is higher than the actual median pitch. This result is perhaps not so surprising when taking into account that the authors have also coded the (smaller and higher pitched) *corno da caccia* as a French horn (see above). In the case of the timpani, one has to think of the fact that these instruments are always tuned in one sole pitch each (of course except in the case of the pedal timpani), so the mean pitch found out for the timpani is strongly dependent on the respective key of the evaluated orchestral work.

Doubling and Chord Factors

Discussing the combination of instruments in pitch classes, unison, octaves and chords based on the evaluated data merits a paper or rather book on its own, especially when thinking of the different composition styles and recommendations in composition and orchestration treatises in the last 300 years. Here the authors found a very good and pragmatic way to paint a big picture using a table of the most commonly doubled instrument pairs, showing that there are two broad trends of instrument combinations: within-family doubling and doubling of low pitched instruments, which is very much in agreement with orchestration history and – in the case of the bass instruments doubling – comprehensibly discussed under psychoacoustic aspects by the authors as well as their enlightening observation that bass instruments are more or less forced to play doubled in pitch (class), because they do not have so many other chord options.

The emphasized observation that the timpani is mostly doubled by trumpets or French horns when playing, could also be explained by looking at the history of these instruments: In the 18th century and before timpani players belonged to the trumpeters' guild with similar representative and military tasks (see above), the timpani where the bass instruments of the trumpeter ensemble, where the lowest trumpets could also be played on one or two pitches only (Majer, 1732, p. 73; Altenburg, 1795, p. 71). The common practice to double the timpani with the low trumpeter parts in military pieces ("Feldstücke") has been adopted as normal usage in orchestration in the course of the 18th century (and because of the fluent transition between trumpets and horns at that time the combination of the timpani with the horn instruments also followed these rules). More surprising (and not yet explainable by the sources) is the observation the authors found in the combination of the piccolo with the trombone, whose pitch doubling probability is 73,9%, but only in a pitch-class, where the pitches have a distance of two or more octaves (with 0% octave or unison doubling probability). This is strange; the combination of trombone and piccolo is extremely unusual (and can hardly be found in any orchestration treatise of the last 300 years). Perhaps it has something to do with the usage of these instruments playing often together in the louder parts of an orchestral work. Because of the enormous masking capability of the loud trombone group, the piccolo has to play in a very high pitch to be heard in such a context at all (or to add a brighter timbre to the total sound mixture).

Concerning the use of the instruments in chord combinations the authors admit that it is difficult to draw reliable or generalizable conclusions. They can show that the low string instruments (and also other bass instruments like timpani, bass trombone, tuba etc.) are mostly located in the root position of the chords and that violins are often heard in the third and seventh position. It is noticeable here that the oboe is comparatively often heard in the third position in major chords as well as in the third and seventh position in major/minor 7th chords. The use of the oboe (with the brightest timbre and the highest formant position of the instruments in the *Core Wind* section) in the most characterizing position of a chord (third and seventh) to tighten the chord or dissonance impression is a stylistic device often used in orchestration history (for example: "Leur [the oboe] timbre incisif augmente singulièrement l'apreté des dissonances de seconde et de septieme", Gevaert, 1885, p. 145–146; see also Voigt, 1985, p. 99–124 with lots of similar examples in orchestration treatises which deal with the usage of the oboe in chords and (dissonant) intervals).

Pitch, Loudness and Tempo Interactions

The question if there are significant interactions in the scores between pitch, loudness and tempo bears some difficulties. Of course, when listening to a music performance, one often gets the impression that a musician increases tempo with stronger dynamics or that higher pitches seem to be louder as well etc. and the authors convincingly cite the corresponding papers describing these effects. However, the individual interpretation of a musical piece with subtle context-driven changes in dynamics and tempo is not so easily comparable to the written score. This might explain why it was hard to find generalizable tendencies for an interaction between higher pitches and louder dynamics or faster tempo in the data.

Especially in case of the loudness, one has to scrutinize the sentence of Sundberg et al. (1983) that "the amplitude increases somewhat with the fundamental frequency" in almost every musical instrument. Actually, it is the case that most instruments are not able to radiate their lower frequencies adequately, because the wavelengths of these low frequencies are much larger than the instrument's body. In other words: In case of low pitches, the amplitude of the fundamental frequency is in most cases very weak. However, that does not mean that the amplitude of the whole sound is weak when the instrument is played on a low pitch. Especially when looking at string instruments, their sound amplitude decreases with increasing pitch, while when looking at wind instruments their amplitude increases with pitch in some cases (e.g. flute or French Horn) or it remains more or less independent of pitch (e.g. clarinet or trumpet) (Pierce, 1983, p.114). Additionally, one has to keep in mind that musical dynamics are less connected with loudness or amplitudes then with timbre or brightness of the sound (see Schumann's formant principles above), and from the perspective of loudness or amplitude the dynamic ranges of musical instruments are in most cases not very large (e.g. Rossing et al., 2002, S. 113; an overview of the measurements of dynamic ranges of musical instruments on different pitches since 1931 is listed in tabular form in Reuter, 1996, p. 323–339).

For the interaction between tempo and dynamics the authors found a negative correlation between tempo and dynamics (increasing tempo is connected with lower dynamics), but this result is difficult to explain. Looking at the tempo/dynamic correlations it can be seen that the authors differentiate between "French horn" and "Ventilhorn" here. This is a little bit strange because a "Ventilhorn" (horn with valves) is a French horn. One can assume that the authors coded the different types of horn instruments (from historical natural horn over the classical Inventionshorn up to the modern valve horn) as French horn, so the Ventilhorn should also be coded in this category.

CONCLUSION

With their exploratory study Chon, Huron, and DeVlieger examined western orchestration from different perspectives with a lot of enlightening results that also provide starting points for further discussions and studies. Especially when combining their results with the advices and recommendations in orchestration treatises of the last 300 years, with the evolution of the musical instruments during that time as well as the paradigm of formants and their role in instrument combination, the applicability of the authors' concept of *Strings*, *Core Wind* and *Effects* can be strongly confirmed in many aspects.

ACKNOWLEDGEMENTS

Many thanks to Kelly Jakubowski for the article layout.

NOTES

[1] Correspondence can be addressed to: Prof. Dr. Christoph Reuter, Musicological Institute, University of Vienna, Spitalgasse 2–4, AAKH Campus Court 9, 1090 Vienna, Austria, christoph.reuter@univie.ac.at

REFERENCES

Adler, S. (2002). *The study of orchestration*. New York: W.W. Norton.

Altenburg, J. E. (1795). *Versuch einer anleitung zur heroisch-musikalischen trompeter- und paukerkunst*. Halle: J.C. Hendel.

Becker, H. (1964). *Geschichte der instrumentation*. Cologne: A. Volk.

Bussler, L. (1879). *Instrumentation und orchestersatz.* Berlin: C. Habel.

Carse, A. (1949). *The orchestra*. London: M. Parrish & Co.

Carse, A. (1964). *The history of orchestration*. New York: Dover.

Del Mar, N. (1983). *Anatomy of the orchestra*. Berkely, Los Angeles: University of Califomia Press.

Dubal, D. (2001). *The essential canon of classical music*. New York: North Point Press.

Dullat, G. (1989). *Metallblasinstrumentenbau*. Frankfurt: Bochinsky.

Eisel, J.P. (1738). *Musicus autodidaktos*. Erfurt: J. M. Funck.

Fitzpatrick, H. (1963). Some historical notes on the horn in Germany and Austria. *The Galpin Society Journal, 16*, 33–48. https://doi.org/10.2307/841093

Forkel, J.N. (1799). Anekdoten. *Leipziger Allgemeine Musikalische Zeitung 2*(5), October 1799, c. 103–104.

Francoeur, L.-J. (1772). *Diapason general de tous les instruments a vent*. Paris: Des Laurlers.

Fransson, F.V. (1966). The source spectrum of double-reed wood-wind instruments. Part I. The bassoon. *STL-QPSR, 7*(4), 35–37.

Fransson, F.V. (1967). The source spectrum of double-reed wood-wind instruments. Part II. The oboe and the cor anglais. *STL-QPSR 8*(1), 25–27.

Fricke, J.P. (1975). Formantbildende impulsfolgen bei blasinstrumenten. In Deutsche Arbeitsgemeinschaft für Akustik (Eds.), *Proceedings of the 4. Conference of Acoustic (DAGA'75)* (pp. 407–411). Braunschweig, Germany.

Fricke, J.P. (1986). Zur anwendung digitaler klangfarbenfilter bei aufnahme und wiedergabe. In Bildungswerk des VDT (Eds.), *Bericht über die 14. Tonmeistertagung* (pp. 135–148). Munich.

Gelfand, S.A. (2004). *Hearing*. New York: M. Dekker. https://doi.org/10.1201/b14858

Gevaert, F.-A. (1885). *Nouveau traité d'instrumentation*, Paris, Bruxelles: Lemoine & fils.

Gevaert, F.-A. (1887). *Neue instrumenten-lehre*. Leipzig: O. Junne.

Gutknecht, D. (1993). *Studien zur geschichte der aufführungspraxis alter musik*. Cologne: Concerto.

Hermann, L. (1894). Phonophotographische Untersuchungen VI. Nachtrag zur Untersuchung der Vocalcurven. In E.F.W. Pflüger (Ed.), *Archiv für die gesammte Physiologie des Menschen und der Thiere, 58*, 264–279.

Höfer, F. (1913). *Instrumentationslehre mit besonderer berücksichtigung der kirchenmusik*. Regensburg, Rome: F. Pustet.

Hofmann, R. (1893). *Praktische instrumentationslehre*. Leipzig: Dorfling & Franke.

Jadassohn, S. (1889). *Lehrbuch der instrumentation*. Leipzig: Breitkopf & Härtel.

Jolly, J. (2010). *The Gramophone classical music guide*. Haymarket Consumer Media.

Kennan, K.W. (1962). *The technique of orchestration*. New York: Prentice-Hall.

Kling, H. (1882). *Populäre instrumentationslehre*. Hanover: Oertel.

Kunitz, H. (1956–1961). *Die instrumentation*. Vol. 1–13, Leipzig: Breitkopf & Härtel.

Lembke, S.A. (2014). *When timbre blends musically: Perception and acoustics underlying orchestration and performance*. Ph.D. dissertation, McGill University, Canada.

Lembke, S.A. & McAdams, S. (2015). The role of spectral-envelope characteristics in perceptual blending of wind-instrument sounds. *Acta Acustica united with Acustica, 101,* 1039–1051. https://doi.org/10.3813/AAA.918898

Luce, D. & Clark, M. (1967). Physical correlates of brass-instrument tones. *Journal of the Acoustical Society of America, 42,* 1232–1243. https://doi.org/10.1121/1.1910710

Majer, J.F.B.C. (1732). *Museum Musicum Theoretico Practicum*. Schwäbisch Hall: G.M. Majer.

Mattheson, J. (1713). *Das neu-eröffnete orchestre*. Hamburg: B. Schiller.

Meyer, J. (2009). *Acoustics and the performance of music*. Berlin: Springer. https://doi.org/10.1007/978-0-387-09517-2

Oehler, M. & Reuter, C. (2009). Dynamic excitation impulse modification as foundation of a synthesis and analysis system for wind instrument sounds. In T. Klouche & T. Noll (Eds.), *MCM2007 – Communications in Computer and Information Science* (pp. 189–197). Berlin: Springer. https://doi.org/10.1007/978-3-642-04579-0_17

Pierce, J.R. (1983). *The science of musical sound*. New York: Freeman.

Prout, E. (1888). *Elementar-lehrbuch der instrumentation*. Leipzig: Breitkopf & Härtel.

Reinecke, H.-P. (1988). Mutmassungen über das flötenspiel Friedrichs des Grossen. In H. Danuser (Ed.), *Das Musikalische Kunstwerk* (pp. 395–401). Laaber: Laaber.

Reuter, C. (1996). *Die auditive diskrimination von orchesterinstrumenten*. Frankfurt: Lang.

Reuter, C. (2002). *Klangfarbe und instrumentation*. Frankfurt: Lang.

Reuter, C. (2003): Stream segregation and formant areas. In R. Kopiez, A. Lehmann, I. Wolther & C. Wolf (Eds.), *Proceedings of the 5th International Conference of the European Society for the Cognitive Sciences of Music (ESCOM)* (pp. 213–217). Hanover [CD-ROM].

Reuter, C., Czedik-Eysenberg, I., Siddiq, S. & Oehler, M. (2017). Formanten als hilfreiche timbre-deskriptoren für die darstellung von blasinstrumentenklängen. In Deutsche Arbeitsgemeinschaft für Akustik (Eds.), *Proceedings of the 43. Conference of Acoustic (DAGA 2017)* (pp. 190–193). Kiel, Germany.

Reuter, C. & Siddiq, S. (2017). The colourful life of timbre spaces – Timbre concepts from early ideas to meta-timbre space and beyond. In C. Wöllner (Ed.), *Body, Sound and Space in Music and Beyond – Multimodal Explorations* (pp. 150–167). London, New York: Routledge.

Roeser, V. (1764). *Essai d'instruction A l'usage de ceux, qui Composent pour la Clarinette et le Cor*. Paris: Mercier.

Rossing, T.D.; Moore, F.R. & Wheeler, P.A. (2002). *The Science of Sound*. San Francisco: Addison Wesley.

Schubert, F.L. (1885). *Instrumentationslehre nach den bedürfnissen der gegenwart*. Leipzig: C. Merseburger.

Schumann, K.E. (1929). *Physik der klangfarben*. Habilitation dissertation. Berlin: University of Berlin.

Strauß, R. & Berlioz, H. (1904). *Instrumentationslehre, ergänzt und revidiert von Richard Strauß*. Leipzig: C.F. Peters.

Stumpf, C. (1926). *Die sprachlaute*. Berlin: Springer. https://doi.org/10.1007/978-3-662-33112-5

Sundberg, J., Askenfelt, A., & Frydén, L. (1983). Musical performance: A synthesis-by-rule approach. *Computer Music Journal*, *7*(1), 37–43. https://doi.org/10.2307/3679917

Trichet, P. (1640). *Traite des instruments de musique*. Paris: Bibliothèque Sainte-Geneviève.

Voigt, W. (1975). *Untersuchungen zur formantbildung in klängen von fagott und dulzianen*. Regensburg: Bosse.

Voigt, W. (1985). *Dissonanz und klangfarbe*. Bonn: Systematische Musikwissenschaft.

Walther, J.G. (1732). *Musicalisches lexicon oder musicalische bibliothec*. Leipzig: W. Deer.

Weinzierl, S. (2014). *Akustische grundlagen der musik.* Laaber: Laaber.

Yost, W.A. (2007). *Fundamentals of hearing*. Oxford: Elsevier.

Zaslaw, N. (1988). When is an orchestra not an orchestra? *Early Music*, *16*(4), 483–495. https://doi.org/10.1093/earlyj/XVI.4.483