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## Increment/Decrement Asymmetries in Polyphonic Sonorities

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Existing research has shown that single-voice entries in polyphonic music are more easily perceived than single-voice exits. A study of 195 assorted musical works reveals a marked asymmetry between voice entries and exits. Specifically, voices tend to be added one at a time, while voice exits tend to occur several at a time. This practice is consistent with the hypothesis that voice entries and exits are perceptually important points in musical works and that composers avoid single-voice exits because they are less likely to be perceived.

A stereotypic feature of multivoiced music is the frequent introduction and retirement of voices or parts throughout the course of a work. In a study of the perceptibility of concurrent voices, Huron (1989) found that voice exits are significantly more difficult to perceive than voice entries. Specifically, expert listeners frequently fail to identify when a single voice is retired from the texture—although they are adept at identifying single-voice entries. Moreover, when reductions of texture are recognized by subjects, they are more prone to mistakenly judge the number of concurrent voices after the exit of a voice than in the comparable voice-entry condition.

These results suggest that there is a significant asymmetry between the perception of increasing and decreasing textural densities. In a subsequent paper, an explanation for this asymmetry that is based on research concerning auditory attention will be offered. However, before such a discussion can take place, it is necessary to demonstrate that the effect uncovered in an experimental setting is actually reflected in the construction or organization of works in an extensive musical repertoire.

In this paper, we propose to examine what might be dubbed the “ramp hypothesis”—namely, that textural densities are increased by the successive addition of one voice at a time, whereas textural densities are reduced by retiring groups of concurrent voices. Two methods of measurement will be used. Method 1 relies on the identification of voice entries and exits,

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while Method 2 examines changes of sonorities independent of assumptions of voicing. Both methods are applied to an analysis of a selection of multivoiced scores. The sample of works includes 14 vocal duets by Guillaume de Machaut, six vocal motets by Thomas Morley; assorted fugues by Claudio Merulo, Andrea Gabrieli, Giovanni Gabrieli, Jan Pieterszoon Sweelinck, Samuel Scheidt, Girolamo Frescobaldi, Johann Jakob Froberger, Johann Pachelbel, Johann Caspar Ferdinand Fischer, Dietrich Buxtehude, Georg Friedrich Handel, Johann Mattheson, Johann Ernst Eberlin, Wilhelm Friedemann Bach, Franz Schubert, Felix Mendelssohn-Bartholdy, Robert Schumann, Max Reger, Johann Nepomuk David, Julius Weismann, Dimitri Shostakovich; Johann Sebastian Bach's 48 fugues from the two volumes of the *Well-tempered Clavier* (WTC), 15 two-part inventions, 15 three-part sinfonias, 15 fugues from the *Art of Fugue* (AOF), two ricercari from the *Musical Offering*, a random sample of 10 organ works of varying textural densities (BWVs 532, 534, 538, 540, 547, 549, 552, 574, 578, and 677); two string quartets by Joseph Haydn; the first movement of String Quartet No. 1 by Arnold Schoenberg; 12 fugues from Paul Hindemith's *Ludus Tonalis*, and 33 assorted close-harmony works (barbershop quartets). In total, the analytic sample includes some 195 works.

### Defining Entry and Exit Sites

To a listener, the entry of a musical voice seems obvious enough. However, establishing a formal identification procedure suitable for empirical score-based analysis is a nontrivial task. In a study of inner- and outer-voice entries, Huron and Fantini (1990) defined the occurrence of a voice entry on the basis of a minimum period of preceding rest. Specifically, in Huron and Fantini a voice entry was operationally defined as the onset of any voice that previously had not been present in the texture or that had been inactive for 10 or more vertical sonorities before its reentry. A vertical sonority, in turn, was defined as a particular "slice" in the musical score: any change of pitch, introduction of a rest, or rearticulation of a note was deemed to constitute a new vertical sonority. With this method, it was found that a threshold of 10 vertical sonorities produced a selection of voice-entry sites similar in both number and position to entries selected manually by an experienced music theorist.

For the present study it is also necessary to operationally define voice-exit sites. For consistency, one might consider a definition reciprocal to that of the above definition of a voice entry: namely, a voice exit may be operationally defined as the occurrence of a rest in a voice that had been active for 10 or more vertical sonorities before the occurrence of the rest. However, it is at once evident that such a definition is inadequate. Although the onset of

a single eighth note may be sufficient to signal the introduction of a new voice, a single eighth-note rest is not sufficient cause to consider a voice as being absent from the texture.

Intuitively, we would suppose that a bona fide exit must also entail a substantial period of rest after a period of activity. In order to accommodate this intuition, it is appropriate to add a second condition to the identification of voice-exit sites:

A voice exit can be operationally defined as occurring with the onset of a rest period whose duration extends 10 or more vertical sonorities after a period of activity in which the voice has been active for 10 or more vertical sonorities.

The addition of a second condition to the definition of an exit site produces an asymmetry between the definition of exits and entries. As we intend to compare exits and entries, such an asymmetry is undesirable because it may generate differences between exits and entries that are artifacts of the different definitions. This asymmetry can be avoided by adding a complementary condition to the operational definition of an entry. Where Xs and 0s are used to indicate sonorities containing notes and rests, respectively, the definition of entry and exit sites can be schematically represented as follows:

|        |       |                     |   |   |   |   |   |   |   |   |   |   |       |
|--------|-------|---------------------|---|---|---|---|---|---|---|---|---|---|-------|
| entry: | . . . | 0 0 0 0 0 0 0 0 0 0 | 0 | X | X | X | X | X | X | X | X | X | . . . |
| exit:  | . . . | X X X X X X X X X X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | . . . |
|        |       |                     | ↓ |   |   |   |   |   |   |   |   |   |       |
|        |       |                     | ↑ |   |   |   |   |   |   |   |   |   |       |

In many musical settings, this criterion for identifying entries and exits is apt to be too stringent. For example, the presence of a single eighth-note rest penultimate to the withdrawal of a voice is sufficient to invalidate the site as an operationally defined exit. An active voice can disappear from the texture without generating an “exit”:

. . . X X X X X X X X 0 X 0 0 0 0 0 0 0 0 . . .

Unfortunately, attempts to accommodate such cases with more flexible rules run into further difficulties. In particular, the use of more flexible rules tends to lessen the security with which one can point to a particular moment or “edge” between voice activity and inactivity. As we intend to examine *simultaneous* entries and exits for multiple voices, it is important that entry/exit sites be established with some certainty and precision. Thus our strict definitions are preferable, even at the expense of omitting certain “entries” or “exits” from the analysis.

A related unusual consequence of these definitions is that it is possible for a voice to officially “enter” a texture without “exiting” or vice versa. This presents the possibility that our method for identifying entry and exit sites might skew the data in favor of entries or exits and that this may confound

or invalidate the analysis in some unspecified way. According to the above criterion, 1189 unambiguous entry sites and 1218 exit sites were identified in the 195 works. The difference between the number of entry and exit sites amounts to only 2.4%. Thus we may proceed with some assurance that our method for identifying entry and exit sites is not skewed in favor of the identification of one over the other.

### **Increment/Decrement Measures: Method 1**

Having identified the exit and entry sites in the sample of works, it was possible to determine whether individual exits or entries coincided with other exits or entries in other voices. Four conditions can be distinguished: the onset of a single voice, the concurrent onset of two or more voices, the exit of a single voice, and the concurrent exit of two or more voices. Table 1 tabulates the results according to the different repertoires examined. In order to test the ‘ramp hypothesis,’ we would look in a contingency table for an association between the direction of change (increment versus decrement) and the type of change (single versus multiple). Specifically, we would predict that voice entries would tend to be singular whereas voice exits would be multiple. The strength of dependency between the direction of change and the type of change is expressed by the phi coefficient. Positive phi values indicate that the data are consistent with the ramp hypothesis, whereas negative values indicate a reverse tendency. Significances have been determined from the corresponding chi-square values. In 15 out of 18 repertoires, the ramp hypothesis is indeed confirmed. In 14 repertoires, the effect is statistically robust at better than the 0.001 confidence level. Only the Haydn and Schoenberg string quarters and the Machaut vocal duets fail to display the predicted asymmetry. These latter three repertoires aside, the overall results confirm the existence of a marked asymmetry between adding and retiring voices.

### **Increment/Decrement Measures: Method 2**

The above tests notwithstanding, we may still retain some skepticism regarding the demonstration of the ramp hypothesis. As outlined earlier, there are several problems with the definitions of entry and exit sites. Specifically, the operational definitions for entries and exits may be too stringent—requiring that all entries and exits have well-defined or “hard” edges. This criterion may eliminate data that might, in the end, invalidate the increment/decrement asymmetry found by using Method 1.

TABLE 1  
Voice Entries and Exits According to Repertoire (Method 1)

| Repertoire                         | N   | Voice Entries |          | Voice Exits |          | Phi    | Significance  |
|------------------------------------|-----|---------------|----------|-------------|----------|--------|---------------|
|                                    |     | Single        | Multiple | Single      | Multiple |        |               |
| Machaut duets                      | 39  | 8             | 16       | 3           | 12       | -0.144 | $p = .368005$ |
| Morley motets<br>(four-part)       | 36  | 14            | 2        | 2           | 18       | +0.775 | $p = .000003$ |
| Morley motets<br>(five-part)       | 146 | 73            | 0        | 50          | 23       | +0.432 | $p = .000000$ |
| Morley motets<br>(six-part)        | 105 | 47            | 8        | 27          | 23       | +0.344 | $p = .000417$ |
| Bach invention<br>(two-part)       | 56  | 20            | 6        | 4           | 26       | +0.641 | $p = .000002$ |
| Bach sinfonia<br>(three-part)      | 130 | 57            | 10       | 27          | 36       | +0.441 | $p = .000000$ |
| Bach WTC<br>(three-part)           | 171 | 86            | 0        | 47          | 38       | +0.538 | $p = .000000$ |
| Bach WTC<br>(four-part)            | 164 | 87            | 2        | 36          | 39       | +0.572 | $p = .000000$ |
| Bach AOF<br>(four-part)            | 182 | 85            | 4        | 46          | 47       | +0.512 | $p = .000000$ |
| Bach WTC<br>(five-part)            | 67  | 28            | 0        | 20          | 19       | +0.533 | $p = .000013$ |
| Bach organ fugues<br>(three-part)  | 42  | 20            | 0        | 13          | 9        | +0.498 | $p = .001251$ |
| Bach organ fugues<br>(four-part)   | 181 | 73            | 12       | 61          | 35       | +0.254 | $p = .000623$ |
| Bach organ fugues<br>(five-part)   | 134 | 73            | 0        | 26          | 35       | +0.650 | $p = .000000$ |
| Hindemith <i>Ludus<br/>Tonalis</i> | 73  | 41            | 0        | 18          | 14       | +0.551 | $p = .000002$ |
| Other fugues                       | 572 | 268           | 4        | 173         | 127      | +0.486 | $p = .000000$ |
| Haydn string<br>quartets           | 39  | 4             | 18       | 3           | 14       | -0.007 | $p = .965580$ |
| Schoenberg string<br>quartet       | 37  | 16            | 4        | 11          | 6        | +0.172 | $p = .296505$ |
| Barbershop quar-<br>tets           | 233 | 10            | 93       | 0           | 130      | +0.238 | $p = .000282$ |

An alternative method for investigating asymmetric changes of textural density is to examine changes in successive vertical sonorities in works. As noted earlier, a vertical sonority is defined as a particular “slice” in the musical score: any change of pitch, introduction of a rest, or rearticulation of a note is deemed to constitute a new vertical sonority. For each vertical sonority, it is possible to measure the number of concurrent sounding pitches.

This method is illustrated in Figure 1. The lower row of numbers given in Figure 1 indicates changes in the number of concurrent pitches from sonority to sonority. The aggregate results of such changes can then be tabulated as in Table 2. Table 2 shows the results for four-, five-, and six-part vocal motets by Thomas Morley. Once again, in order to test the ramp hypothesis we would look in a contingency table for an association between the direction of change (increment versus decrement) and the type of change (single versus multiple). Table 3 tabulates the results according to the different repertoires examined.

In general terms, the results are highly consistent with the ramp hypothesis. Sixteen of the 18 repertoires examined are consistent with the ramp hypothesis. Only one repertoire fails to disprove the null hypothesis (Machaut), and one repertoire shows a significant reverse trend (Haydn). The case of the duets by Guillaume de Machaut can be easily accounted for. If

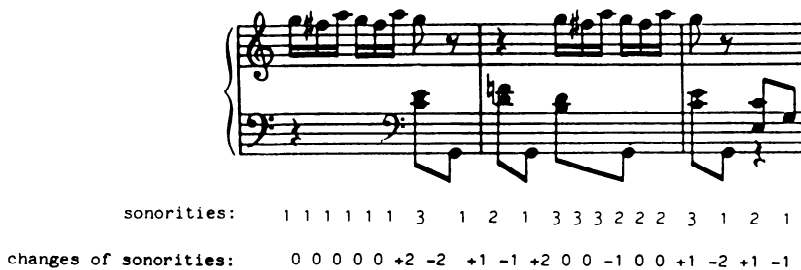


Fig. 1. Changes of number of concurrent sounding pitches.

TABLE 2  
Changes of Sonorous Density in Ten Morley Motets

|                  | Sonority<br>Increments | Sonority<br>Decrements |
|------------------|------------------------|------------------------|
| Single           | 582                    | 389                    |
| Double           | 32                     | 82                     |
| Triple           | 7                      | 18                     |
| Quadruple        | 0                      | 7                      |
| Quintuple        | 1                      | 5                      |
| Sextuple         | 0                      | 2                      |
| Total (multiple) | 40                     | 114                    |

TABLE 3  
Changes of Sonorities According to Repertoire (Method 2)

| Repertoire                         | N    | Increment |          | Decrement |          | Phi    | Significance    |
|------------------------------------|------|-----------|----------|-----------|----------|--------|-----------------|
|                                    |      | Single    | Multiple | Single    | Multiple |        |                 |
| Machaut duets                      | 296  | 137       | 12       | 133       | 14       | +0.026 | $p = .655043$   |
| Morley motets<br>(four-part)       | 195  | 94        | 14       | 61        | 26       | +0.208 | $p = .003626$   |
| Morley motets<br>(five-part)       | 621  | 329       | 13       | 224       | 55       | +0.253 | $p = .000000$   |
| Morley motets<br>(six-part)        | 309  | 159       | 13       | 104       | 33       | +0.231 | $p = .000050$   |
| Bach inventions<br>(two-part)      | 291  | 148       | 4        | 126       | 13       | +0.143 | $p = .014615$   |
| Bach sinfonia<br>(three-part)      | 675  | 342       | 16       | 275       | 42       | +0.156 | $p = .000049$   |
| Bach WTC<br>(three-part)           | 1666 | 850       | 32       | 698       | 86       | +0.143 | $p = .000000$   |
| Bach WTC<br>(four-part)            | 1775 | 833       | 130      | 605       | 207      | +0.152 | $p = .000000$   |
| Bach AOF<br>(four-part)            | 1409 | 721       | 47       | 508       | 133      | +0.218 | $p = .000000$   |
| Bach WTC<br>(five-part)            | 131  | 72        | 1        | 48        | 10       | +0.284 | $p = .001140$   |
| Bach organ fugues<br>(three-part)  | 45   | 26        | 0        | 14        | 5        | +0.414 | $p = .005530$   |
| Bach organ fugues<br>(four-part)   | 851  | 334       | 117      | 263       | 137      | +0.091 | $p = .008209$   |
| Bach organ fugues<br>(five-part)   | 379  | 181       | 35       | 95        | 68       | +0.284 | $p = .000000$   |
| Hindemith <i>Ludus<br/>Tonalis</i> | 1077 | 491       | 69       | 424       | 93       | +0.079 | $p = .009346$   |
| Other fugues                       | 2206 | 1051      | 149      | 750       | 256      | +0.168 | $p = .000000$   |
| Haydn string<br>quartets           | 373  | 113       | 139      | 91        | 30       | -0.286 | $p = .000000^a$ |
| Schoenberg string<br>quartet       | 950  | 348       | 146      | 293       | 163      | +0.066 | $p = .041854$   |
| Barbershop quar-<br>tets           | 409  | 48        | 173      | 16        | 172      | +0.181 | $p = .000248$   |

<sup>a</sup>Significant reverse trend.

there is an inclination to have at least one voice active throughout the course of a work, it is readily apparent that it is impossible to have multiple decrements in two-part works. This explanation also may account for the comparatively low level of significance found in the Bach Two-Part Inventions.



In general, the results derived from Methods 1 and 2 are in very close agreement. Together, the two methods provide strong evidence in support of the hypothesis for an increment/decrement asymmetry in the evolution of multivoiced sonorities. Moreover, the two methods provide complementary information. Method 1 applied strict criteria for the identification of voice entries/exits, with the possible danger of ignoring too much pertinent information. In contrast, Method 2 applied a lax criterion for the identification of changes of textural density, with the possible danger of including too much irrelevant information and so obscuring the effect. But whether the lax or strict methods are used, the conclusion is the same. Although the perceptual mechanisms for the identification of changes of auditory texture may be more sophisticated than suggested by either of the measures used in this paper, it is improbable that the true perceptual effect would contradict the prominent trends evident in both of the boundary condition measurements.

### Discussion

A possible objection might be raised that the single increment strategy is an obvious feature of polyphonic music—particularly in fugal construction. The most salient characteristic of fugue form is the successive accumulation of subjects and answers that forms the exposition. Three responses are appropriate to this objection. In the first instance, if it is assumed that each of the *WTC* and *AOF* fugues contains two fugal expositions, these expositions would still account for less than 40% of the excess of single-voice increments over single-voice decrements. The fugal expositions alone do not entirely account for the observed asymmetry in these works. Second, although traditional approaches dictate the incremental building of textural density, there is no comparable formal directive to retire several voices simultaneously rather than singly. Finally, and more importantly, we cannot discount a perceptual account of a traditional practice merely because the practice is traditional. It is possible that perceptual concomitants themselves account for or encourage the acceptance of a given formal practice.

### Conclusion

An analysis of 195 works shows an asymmetry between textural increments and decrements. Specifically, there is a marked tendency to augment the textural density one voice at a time, while reductions of textural density entail several voices at a time. These results are consistent with Huron

(1989), who found that single-voice entries are more easily perceived than single-voice exits.<sup>1</sup>

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