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Comparison of Solo and Ensemble Performances with Reference to Pythagorean, Just, and Equi-Tempered Intonations

JAMES A. MASON

I. INTRODUCTION AND PROBLEM

MANY METHODS of intervallic division of the octave for purposes of melodic and harmonic treatments have been developed. From these methods have come three theoretical and practical standards of intonation for use in contemporary Western music, (1) Pythagorean, (2) just, and (3) equi-tempered.

Pythagorean intonation.—This system of intonation derives all notes from the interval of the perfect fifth. For example, the major third is the fourth fifth above a predetermined tone reduced to the proper octave.¹

Just intonation.—This system of tuning in effect undertakes to make use of all perfect intervals of the harmonic series. It is a system of tuning based on true ratios of intervals, as opposed to equi-tempered tunings. Unlike the Pythagorean temperament, intervals are derived not only from the perfect fifth, but also from the "pure" third. An occurrence of a new key requires the notes to be transformed to a new tonality. "This requires some fifty separate tones within a single octave for satisfactory accommodations to all keys."²

Equi-tempered intonation.—The equi-tempered scale is a division of the octave interval into twelve equal semitones. In justification of the resulting distortion of every interval except that of the octave, the following arguments have been advanced:

(1) Any group of human beings using imperfect means (instruments) for tone production must have a common point of understanding in the realm of scale pitches, so that artistic unity may be better achieved in an environment of complex key relationships and modulations.

(2) The very act of building, tuning, and playing a musical instrument requires that there be one fixed pitch for every chromatic tone to avoid impossible complexities.

(3) In order to bring together in ensemble the various unavoidable and at times opposing differences of the interval tuning of various instruments, a single common standard of pitch should be understood by each player so that he may more intelligently direct his effort of humoring the pitch, especially when the ear is confused by other circumstances.³

Review of Pertinent Investigations

In spite of the reasons cited and the extant cultural conditioning for equal temperament, there are musicians who feel it to be objectionable, and they

¹John Redfield, *Music a Science and an Art* (New York: Tudor, 1937), p. 184.

²Donald W. Stauffer, *Intonation Deficiencies of Wind Instruments in Ensemble* (Washington D. C.: The Catholic University of America Press, 1954), p. 10.

³Stauffer, pp. 19-20.

prefer using an unequal temperament in their playing.⁴

Revesz has reported that players of certain instruments, primarily those of the string choir and the human voice, use untempered intonation when they are not confined to performing with keyboard instruments.⁵

The performance of six professional violinists was investigated by Green. Striking deviations from tempered intervals were found, as well as considerable agreement with the intervals of the Pythagorean scale in unaccompanied performance.⁶

Nickerson conducted an experiment using twenty-four well-trained string quartet players. He analyzed their solo and ensemble performances, as related to the three systems of intonation described above, and found the Pythagorean system in use typically for unaccompanied melodies and ensemble playing.⁷

Helmholtz, in conducting studies with choirs in England, found that those trained in solfeggio sang "pure" intervals (just intonation) when they were unaccompanied.⁸ Williamson, on the other hand, expressed the idea that, while just intonation appeals to physicists because of its relationship to the

harmonic series, few musicians have ever heard it and even fewer have ever practiced it.⁹

Furthermore, Barbour points out that brass instruments make use of extended portions of the harmonic series. Therefore, performers have a natural inclination to use just intonation in certain keys.¹⁰

In reviewing the contemporary literature on tonality, Nickerson found most of the information highly speculative. The few pertinent experiments reported had not employed satisfactory analytical methods.¹¹ Therefore, further experimentation is needed to determine the extent to which Pythagorean, just, and equi-tempered systems are used in musical instruments' intonation anomalies.

Statement of Problem

The purpose of this study was to determine: (1) if there is any consistent pattern of differences between the intonation of unaccompanied solo wind instrument performances and wind ensemble performances; (2) if unaccompanied solo performances tend to produce Pythagorean, just, or equi-tempered intonation; (3) if ensemble performances tend to produce Pythagorean, just, or equi-tempered intonation.

⁴Stauffer, p. 7.

⁵Geza Revesz, *The Psychology of Music*, trans. G. De Courcy (Norman: University of Oklahoma Press, 1954), pp. 30-31.

⁶Paul C. Green, "Violin Intonation," *Journal of the Acoustical Society of America*, IX (1937), 43-44.

⁷James F. Nickerson, "Intonation of Solo and Ensemble Performance," *Journal of the Acoustical Society of America*, XXI (1949), 593.

⁸Herman L. Helmholtz, *Sensations of Tone*, trans. A. J. Ellis (London: Longman, Green and Co., 1912), p. 427.

⁹Charles Williamson, "Intonation in Musical Performance," *American Journal of Physics*, X (August, 1942), 172.

¹⁰J. Murray Barbour, *Tuning and Temperament* (East Lansing: Michigan State College Press, 1951), p. 200.

¹¹James F. Nickerson, "A Comparison of Performances of the Same Melody Played in Solo and in Ensemble with Reference to Equi-Tempered, Just, and Pythagorean Intonations" (unpublished Ph.D. dissertation, University of Minnesota, 1948), p. 49.

II. EXPERIMENTAL DESIGN

An experiment was designed to seek further data concerning the nature of intonations used by performers on the instruments of the woodwind quintet. The investigation involved the members of two woodwind quintets. Recordings of their unaccompanied solo and ensemble performances were made.

Description of Subjects

Members of the woodwind quintets served as subjects. Each quintet was comprised of a flute, oboe, clarinet, horn, and bassoon. Both ensembles were associated with a university music department, one a faculty quintet and the other a student quintet. The faculty group consisted of well-trained performers, most of whom had had both professional and teaching experience on their respective instruments. The student group was comprised of schooled and experienced performers. However, the professional experience of the student group was limited.

Selection of Music

The music employed in this study was Ravel's "Pavane pour une infante défunte" transcribed for woodwind quintet by Lawrence Intravaia. This composition was selected because: (1) it presented a typical playing situation; (2) it offered a satisfactory musical experience; (3) seven significant diatonic pitches were presented in the melodic solo for each instrument; (4) the music was written in a harmonic rather than a polyphonic style; (5) it had a slow tempo (quarter note = 66); (6) modulation was kept at a minimum.¹²

¹²Authorities maintain that a new tonality changes the dimension of the notes in unequal temperament. Stauffer, p. 10.

Apparatus

Apparatus utilized in this experiment included (1) a chromatic stroboscope (Stroboconn), an electronic device for rapid and accurate visual measurements of sound frequencies to within one hundredth part of one equitempered semitone; (2) a Strobotuner, a simple stroboscope for analyzing visually one tone at a time (calibrated to A-440 and used in this experiment for tuning the woodwind quintet instruments); (3) two Ampex tape recorders (Models 600 and 600Y), an Ampex amplifier and speaker (Model A692) and an Altec (No. 21 "Lip-stick") microphone for recording master tapes and for editing and preparing tape loops.

Other miscellaneous equipment included a metronome to establish tempo, a thermometer to check recording room temperature, an A-440 tape loop¹³ for periodically checking accuracy of analyzing apparatus, and tape splicing supplies.

Procedures

Subjects were prepared for the experiment by playing a series of warm-up experiences and individually practicing the experimental music. Care was taken to tune each instrument (A-440) as determined by the Strobotuner. The performers were instructed to play as accurately and musically as possible. Tempo was established by a metronome prior to each recording.

Lighting, ventilation, temperature, and room acoustics were satisfactory. A standard woodwind quintet seating arrangement was used.

¹³The A-440 tape loop was prepared from the U. S. Bureau of Standards signal.

Individual recordings of unaccompanied solo performances were made previous to recordings of the complete ensembles. Each quintet rehearsed the music in ensemble and performed it five times. During each of the five ensemble performances the microphone was placed immediately adjacent to a different instrument so that each instrument could be easily distinguished from the rest when stroboscopic analyses were made.

Significant pitches were selected representing intervals of the G major scale. The same pitches were used for both solo and ensemble analyses. These pitches were taken from melodic sections of the composition.

Tape loops were prepared from master tapes. These loops represented sections of solo and ensemble performances chosen for analyses. Each loop was played until all selected pitches were analyzed in plus or minus cents.¹⁴

TABLE 1
QUINTET X: INTERVALLIC COMPARISONS OF SOLO AND ENSEMBLE PERFORMANCES

<i>Instrument</i>		<i>Root</i>	<i>Maj. 2nd</i>	<i>Maj. 3rd</i>	<i>Per. 4th</i>	<i>Aug. 4th</i>	<i>Per. 5th</i>	<i>Maj. 6th</i>	<i>Maj. 7th</i>
Frequency cents from the tonic		0	200	400	500	600	700	900	1100
Flute	S	-2	175	378		575	679	901	1096
	E	10	202	404		605	707	920	1108
Oboe	S	10	214	425	512		710	912	1115
	E	6	202	399	506		705	904	1102
Clarinet	S	5	207	403	500		702	900	1100
	E	9	207	405	502		705	903	1101
Horn	S	0	196	396	500		700	900	1100
	E	9	192	405	501		706	900	1094
Bassoon	S	15	202	418		601	711	900	1107
	E	9	195	399		591	705	895	1107

III. RESULTS AND INTERPRETATIONS

The data concerning the obtained frequencies of the experimental pitches for both solo and ensemble performances are presented in the tables and are expressed in cents, as follows: (1) solo versus ensemble pitch levels, Tables 1 and 2; (2) solo versus Pythagorean, just, and equi-tempered pitch lev-

els, Table 3; and (3) ensemble versus Pythagorean, just, and equi-tempered pitch levels, Table 4.

The two quintets are referred to as

¹⁴A cent is the interval between two tones having as a basic frequency ratio the twelve-hundredth root of two. (One one-hundredth of an equi-tempered semitone.)

TABLE 2
 QUINTET Y: INTERVALLIC COMPARISONS OF SOLO AND ENSEMBLE
 PERFORMANCES

<i>Instrument</i>		<i>Root</i>	<i>Maj. 2nd</i>	<i>Maj. 3rd</i>	<i>Per. 4th</i>	<i>Aug. 4th</i>	<i>Per. 5th</i>	<i>Maj. 6th</i>	<i>Maj. 7th</i>
Frequency cents from the tonic		0	200	400	500	600	700	900	1100
Flute	S	15	204	417		620	719	918	1120
	E	16	212	416		618	713	917	1120
Oboe	S	5	205	410	505		707	913	1118
	E	8	203	408	501		708	911	1106
Clarinet	S	12	203	397	495		699	899	1103
	E	12	206	415	511		705	905	1104
Horn	S	0	202	400	500		712	903	1101
	E	15	206	410	507		715	910	1104
Bassoon	S	25	222	418		615	719	905	1112
	E	42	224	426		617	729	910	1118

X and *Y*; quintet *X* representing the faculty ensemble and quintet *Y* the student ensemble. In Table 1 and 2, *S* and *E* are used to represent solo and ensemble performances respectively.

Solo Versus Ensemble Performances

Tables 1 and 2 present the frequency data obtained from stroboscopic analyses of certain pitches as produced in both the solo and ensemble performances of quintets *X* and *Y*.

In spite of the ample warm-up periods allowed and the care taken by the performers in tuning to A-440, there was a general tendency on the part of all performers to play sharper than the established pitch. Particularly noticeable deviations were evidenced in the solo performances of flute *X*, and horns *X* and *Y*. As a general rule, contemporary wind instrumentalists use in-

struments constructed to conform with the international standard tuning frequency. However, these instrumentalists often tune to an *A* of significantly higher frequency to attain brilliancy. A few performers have been known to have had their instruments built to a higher frequency than A-440.¹⁵ Such practices have possibly conditioned woodwind quintet instrumentalists to a higher pitch standard.

Data in Tables 1 and 2 reveal that there are few if any consistent patterns of differences between unaccompanied solo and ensemble performances. However, the finding that differences do exist, even if random in nature, contradicts what Nickerson found with re-

¹⁵Robert W. Young, "Why an International Standard Tuning Frequency?" *Journal of the Acoustical Society of America*; XXVII (1955), 380.

TABLE 3
SOLO VERSUS PYTHAGOREAN, JUST, AND EQUI-TEMPERED INTONATIONS

<i>Intervals</i>	<i>Instruments</i>	<i>Pythagorean</i>		<i>Just</i>		<i>Equi-Tempered</i>	
		<i>X</i>	<i>Y</i>	<i>X</i>	<i>Y</i>	<i>X</i>	<i>Y</i>
Root	Fl.	—2	15	—2	15	—2	15
	Ob.	10	5	10	5	10	5
	Cl.	5	12	5	12	5	12
	Hn.	0	0	0	0	0	0
	Bsn.	15	25	15	25	15	25
Maj. 2nd	Fl.	—29	0	—29	0	—25	4
	Ob.	10	1	10	1	14	5
	Cl.	3	—1	3	—1	7	3
	Hn.	—8	—2	—8	—2	—4	2
	Bsn.	—2	18	—2	18	2	22
Maj. 3rd	Fl.	—30	9	—8	31	—22	17
	Ob.	17	2	39	24	25	10
	Cl.	—5	—11	17	11	3	—3
	Hn.	—12	—8	10	14	—4	0
	Bsn.	10	10	32	32	18	18
Per. 4th	Ob.	14	7	14	7	12	5
	Cl.	2	—3	2	—3	0	—5
	Hn.	2	2	2	2	0	0
Aug. 4th	Fl.	—37	8	—15	30	—25	20
	Bsn.	—11	3	11	25	1	15
Per. 5th	Fl.	—23	—17	—23	—17	—21	19
	Ob.	8	5	8	5	10	7
	Cl.	0	—3	0	—3	2	—1
	Hn.	—2	10	—2	10	0	12
	Bsn.	9	17	9	17	11	19
Maj. 6th	Fl.	—5	12	17	34	1	18
	Ob.	6	7	28	29	12	13
	Cl.	—6	—7	16	15	0	—1
	Hn.	—6	—3	16	19	0	3
	Bsn.	—6	—1	16	21	0	5
Maj. 7th	Fl.	—14	10	8	32	—4	20
	Ob.	5	8	27	30	15	18
	Cl.	—10	—7	12	15	0	3
	Hn.	—10	—9	12	13	0	1
	Bsn.	—3	2	19	24	7	12

TABLE 4
ENSEMBLE VERSUS PYTHAGOREAN, JUST, AND EQUI-TEMPERED INTONATIONS

<i>Intervals</i>	<i>Instruments</i>	<i>Pythagorean</i>		<i>Just</i>		<i>Equi-Tempered</i>	
		<i>X</i>	<i>Y</i>	<i>X</i>	<i>Y</i>	<i>X</i>	<i>Y</i>
Root	Fl.	10	16	10	16	10	16
	Ob.	6	8	6	8	6	8
	Cl.	9	12	9	12	9	12
	Hn.	9	15	9	15	9	15
	Bsn.	9	42	9	42	9	42
Maj. 2nd	Fl.	—2	8	—2	8	2	12
	Ob.	—2	—1	—2	—1	2	3
	Cl.	3	2	3	2	7	6
	Hn.	—12	2	—12	2	—8	6
	Bsn.	—9	20	—9	20	—5	24
Maj. 3rd	Fl.	—4	8	18	30	4	16
	Ob.	—9	0	13	22	—1	8
	Cl.	—3	7	19	29	5	15
	Hn.	—3	2	19	24	5	10
	Bsn.	—9	18	13	40	—1	26
Per. 4th	Ob.	8	3	8	3	6	1
	Cl.	4	13	4	13	2	11
	Hn.	3	9	3	9	1	7
Aug. 4th	Fl.	—7	6	15	28	5	18
	Bsn.	—21	5	1	27	—9	17
Per. 5th	Fl.	5	11	5	11	7	13
	Ob.	3	6	3	6	5	8
	Cl.	3	3	3	3	5	5
	Hn.	4	13	4	13	6	15
	Bsn.	3	27	3	27	5	29
Maj. 6th	Fl.	14	11	36	33	20	17
	Ob.	—2	5	20	27	4	11
	Cl.	—3	—1	19	21	3	5
	Hn.	—6	4	16	26	0	10
	Bsn.	—11	4	11	26	—5	10
Maj. 7th	Fl.	—2	10	20	32	8	20
	Ob.	—8	—4	14	18	2	6
	Cl.	—9	—6	13	16	1	4
	Hn.	—16	—6	6	16	—6	4
	Bsn.	—3	8	19	30	7	18

gard to string quartets. While results of the string quartet study evince no significant intonational changes to conform to harmonic demands,¹⁶ this study seems to indicate that woodwind quintet performances are significantly affected by the harmonic structure of music.

*Solo Versus Pythagorean,
Just, and Equi-Tempered Intonations*

Table 3 presents the frequency deviations of solo performances from Pythagorean, just, and equi-tempered intonations. The comparative data were obtained from stroboscopic analyses of the intervals. These intervals are identified in the column on the left side of the table. To the right of the interval column appear the instruments and their corresponding deviations from Pythagorean, just, and equi-tempered intonations. These comparative deviations are presented in plus and minus cents.

Data in Table 3 reveal a significant lack of conformity in woodwind solo performances either to Pythagorean, just, or equi-tempered intonations.

¹⁶Nickerson, "Intonation of Solo and Ensemble Performance," p. 594.

Quintet X deviated least from equi-tempered intonation, while quintet Y deviated least from Pythagorean intonation. In the solo performances, the greatest departure occurred from the just system of intonation.

*Ensemble Performances Versus
Pythagorean, Just and Equi-Tempered
Intonations*

Table 4 presents the frequency deviations of ensemble performances from Pythagorean, just, and equi-tempered intonations.

Data in Table 4, like those in Table 3, reveal a significant lack of conformity in woodwind ensemble performances either to Pythagorean, just, or equi-tempered intonations.

An average of the deviations from all systems of intonation in ensemble performances compares favorably with the findings for solo performances. Quintet X deviated least from equi-tempered intonation, while quintet Y deviated least from Pythagorean intonation. In the ensemble performances, the greatest departure occurred from the just system of intonation.

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