

The Effect of Musical Experience on the Conception of Accurate Tuning

FRANZ LOOSEN

University of Leuven

The present study investigates the relationship between musical experience and subjects' conception of accurate tuning. In a paired comparisons experiment, 7 violinists, 7 pianists, and 10 nonmusicians evaluated the tuning of computer-generated, ascending and descending eight-tone diatonic scales of C major. Subjects were required to indicate which member of the pair was "most accurately tuned." The subjects were unaware that all scales were perfectly tuned in the Pythagorean, just, or equal-tempered intonation, respectively. Results showed that (1) violinists, as a group, preferred Pythagorean to equal-tempered scales more frequently than vice versa ($p < .01$), (2) pianists preferred equal-tempered to Pythagorean scales more frequently than vice versa ($p < .01$), (3) violinists and pianists judged just intoned scales to be less accurately tuned than either Pythagorean or equal-tempered scales ($p < .01$), and (4) nonmusicians did not show any preference for any of the three intonation models. These findings confirm the claim that subjects' conception of accurate tuning is determined by musical experience rather than by characteristics of the auditory system. Relevance of the results to assessment of tonal perception is discussed.

Numerous intonation models have been proposed for centuries by musicologists, and dozens of pages are still being printed on the relative "beauty" and merits of various tuning systems (e.g., Barbour, 1951; Devie, 1990; Lloyd & Boyle, 1963; Rasch, 1985). Moreover, empirical research on musical scales has been stimulated recently by the renewed interest in performing baroque music on authentic instruments and according to tuning systems that were in vogue in that period.

Musicians frequently contend that the choice of the tuning system that must be used in a musical performance is not determined completely by the instrument or the music played. They claim that there also exist personal preferences. The present study is focused on these personal preferences. More specifically, the hypothesis that playing a particular musical

Requests for reprints may be sent to Franz Loosen, Department of Psychology, University of Leuven, Tienestraat 102, B-3000 Leuven, Belgium.

1386
LOOSEN, F.
1995

122

instrument (such as a violin or a piano) creates an associated mental model of in-tuneness that determines tuning preferences after a number of years is tested.

So far, attention has been focused on (1) intonation in *actual performances* of Western classical music on variable pitch instruments such as string and wind instruments (e.g., Cornu & Mercadier, 1872; Corso, 1954; Geringer, 1978; Greene, 1937; Loosen, 1993; Nickerson, 1949; Shackford, 1961, 1962; Small, 1937) and (2) intonation in *isolated musical intervals* as major seconds, major thirds, perfect fifths, octaves, etc. For example, Allen (1967), Ellis (1954), Partch (1949), Platt and Racine (1985), Rakowski (1976), Roberts and Mathews (1984), Ward (1970), Ward and Martin (1961) have explored the manner in which subjects adjust tonal intervals; Mathews and Sims (1981), Vos (1982, 1984), and Vos and van Vianen (1985) have studied the discrimination of tonal intervals in different intonations, and Small (1939) has investigated preferences for tonal intervals in various intonations. The general trend of the results of all those studies is to "compress" smaller intervals and to "stretch" wider intervals relative to equal-tempered intonation (the present standard in Western music¹).

To the best of my knowledge, only Van Esbroeck and Monfort (1946), and Ward and Martin (1961) focused on intonation in larger *melodic tonal sequences* (i.e., sequences consisting of successive tones).

Van Esbroeck and Monfort (1946) presented (in a paired comparison experiment) musical scales and the *Frère Jacques* melody in the Pythagorean, the equal tempered, and the just intonations on a purposely built wind organ. The subjects were required to select the "more acceptable" performance from each pair. Unfortunately, the study was not carried out

1. The *equal-tempered scale* is unequivocally defined by 12 equal logarithmic steps (semitones), each representing a frequency that is $2^{1/12}$ greater than the one below. The inclusive set of 12 adjacent semitones within an octave (i.e., the interval between two frequencies having a ratio of 2:1) is referred to as the *chromatic scale*. Most compositions in Western music do not use all of the intervals of the chromatic scale, but are based on seven-interval subsets of the chromatic scale. A *diatonic scale* consists of seven tones separated by an invariant sequence of 2, 2, 1, 2, 2, 2, 1 semitone intervals. Each diatonic scale is identified by the note that acts as tonal center. That note is called the *keynote* (or tonic). For the *major mode*, the keynote is the first note. Hence in the *diatonic scale of C major* the first note is C [see Piston (1978) for more details]. There exist model scales in which the 12 adjacent intervals of the octave are not all of equal size. Two important representatives of those are the *Pythagorean scale* and the *just intonation scale*. In this paper, the labels "Pythagorean" and "just intonation" stand for Ptolemy's diatonic ditoniaion and Ptolemy's diatonic syntonon, respectively. The major mode of the former is defined as one in which the ratios of the frequencies of adjacent notes beginning with the tonic are 9/8, 9/8, 256/243, 9/8, 9/8, 9/8, and 256/243. Analogously, the major mode of the just intonation scale is defined by the ratios 9/8, 10/9, 16/15, 9/8, 10/9, 9/8 and 16/15 (for a detailed description of these tunings, see Barbour, 1951, Chap. II).

under controlled conditions and the results were not precisely presented, making it difficult to draw clear conclusions.

Ward and Martin (1961) investigated *discriminability* of ascending diatonic scales in just intonation and equal temperament. Two different timbres were used, one flutelike and the other spectrally complex. Results showed that only three subjects (out of 20 amateur musicians and music students) gave responses significantly different from chance. Subjects who were certain of a discrimination unequivocally preferred equal temperament.

More recently, Vos (1988) studied the *acceptability* of various tuning systems in two-part musical fragments based on the first 6–10 tones of choral settings from the *Musae Sioniae* by Michael Praetorius. Computer-generated complex tones of varying spectral content were used. By means of a multiple linear regression analysis, it was found that overall acceptability of the performance could be predicted from a linear combination of the purity rating of isolated harmonic fifths and major thirds. However, the study concentrated on *harmonic* intervals (i.e., intervals between simultaneous tones), and no explicit attention was given to *melodic* intervals. Hence, the presence of beats (caused by interference of nearly coinciding harmonics when complex tones are presented simultaneously) could provide a sensation of mistuning.

In the present paper, intonation preferences were studied in a well-known sequence of successive tones: the diatonic scale of C major. This scale was chosen because of its pervasive character [see Burns & Ward (1982) for a thorough discussion of arguments].

Psychological literature indicates that experience plays a major part in establishing musical expertise. For example, acquiring the ability to appraise well-formed tonal phrases and the development of delicately graded templates of relative pitch relations requires many years of musical experience (Dowling, 1991; House, 1977; Krumhansl, 1979, 1990; Sloboda, 1985; Watkins & Dyson, 1985). Following these findings and analogously to Loosen (1994), it can be expected that after many years of intense music practice, violinists and pianists have acquired different intonational preferences. More specifically, it can be expected that (1) violinists would prefer Pythagorean intonation because both the tone-generating mechanism of their instrument and the Pythagorean intonation rely on perfect fifths (the open strings of a violin are tuned in perfect fifths and the Pythagorean intonation is derived from a circle of perfect fifths), (2) pianists would prefer equal temperament because they are used to an instrument that is tuned approximately in that manner,² and nonmusicians

2. Pianos are tuned in a "stretched" scale (i.e., upper tones higher and lower tones lower than the equal-tempered scale). However, departures from the equal tempered intonation can be neglected in the middle range of the piano scale (Martin & Ward, 1961).

would not show any preference for some intonation model, because they were not conditioned by musical experience in one way or another.

In the present study, these hypotheses were tested via a paired comparisons experiment in which pairs of musical scales in various intonations were presented. In addition, whether the accuracy with which subjects detected stimulus pairs composed of *identical* scales was dependent on musical experience was also investigated. In this way, it was tested if (1) violinists would detect more accurately identical scales when the scales are tuned in Pythagorean intonation than if the scales were tuned in a different intonation, (2) pianists would detect more accurately identical scales when the scales are tuned in equal-tempered intonation than if the scales are tuned in another intonation, and (3) nonmusicians, with no particular musical experience, would make the same number of errors for all types of tuning.

Method

SUBJECTS

Seven professional violinists (four men and three women), seven professional pianists (four men and three women), and ten musically inexperienced subjects (five men and five women) referred to as nonmusicians participated in the experiment. The musicians were 25–31 years old, and the nonmusicians were 20–23 years old. All musicians were members of an orchestra and were teachers in an academy of music. None of the violinists or pianists played any other instrument professionally. Nonmusicians were graduate students who had never practiced a musical instrument or studied music formally. Subjects were screened using a Békésy-type audiometer (Bruel & Kjaer, model 1800). All subjects showed "normal" hearing in that they tested at 20 dB HL or better in both ears at all test frequencies. All subjects were unaware of the objective of the experiment and participated voluntarily without monetary compensation.

STIMULI AND APPARATUS

The tones were band-limited pseudo-sawtooth waves generated by additive synthesis of the fundamental and the first eight harmonics with amplitudes according to:

$$p(t) = \sum_{n=1}^9 \frac{1}{n} \sin(2n\pi ft - \varphi_n).$$

This resulted in a tone with a spectral-envelope slope of -6 dB/octave. The phases (φ_n) of the individual harmonics were randomly set according to a uniform distribution in the interval $[0, \pi/36]$. As a result, the waveform of repeated generations of the same note, although having the same spectral envelope, varied (as in actual performance) slightly. The tones had amplitude envelopes of 800-ms duration, including a linear rise and fall time of 30 ms and 20 ms, respectively. Transients were not audible, and adjacent tones were separated by a 20-ms silent interval. The acoustical parameters resulted in a musical sound with a timbre that could be described as that of a bland clarinet.

The tones were generated by an electronic system consisting of nine digital oscillators. Each oscillator was an eight-bit digital-to-analog converter controlled by a 256-byte wave-

TABLE 1
Fundamental Frequencies (in Hertz) of Notes in Stimulus Scales

Note	Type 1 Scales			Type 2 Scales		
	Pythagorean	Just Intonation	Equal Temperament	Pythagorean	Just Intonation	Equal Temperament
C ₄	260.7	264.0	261.6	262.4	262.4	262.4
D ₄	293.3	297.0	293.7	295.2	295.2	294.5
E ₄	330.0	330.0	329.6	332.1	328.0	330.6
F ₄	347.7	352.0	349.2	349.8	349.8	350.2
G ₄	391.1	396.0	392.0	393.6	393.6	393.1
A ₄	440.0	440.0	440.0	442.7	437.3	441.2
B ₄	495.0	495.0	493.0	498.1	491.9	495.3
C ₅	521.5	528.0	523.3	524.7	524.7	524.7

form table at a sample rate of 31.25 kHz with one-byte amplitude and two-byte frequency specifications. The outputs of the oscillators were summed and low-pass filtered by a Krohn-Hite filter (Model 330N) for smoothing. The cutoff frequency of the filter was approximately 5 kHz. The resulting signal passed through a buffer amplifier to a high-fidelity audio preamplifier Klein & Hummel, model SSV, and was subsequently played through a high-quality studio-loudspeaker system (Klein & Hummel, model OY) with incorporated amplifier. The loudspeaker system had an almost perfectly flat frequency response between 100 Hz and 14 kHz (± 2 dB SPL). The loudness of the tones was not controlled because scaling data were not available for the tones used in the present study. The sound-pressure level in the test room was not measured, but was set at a comfortable listening level, estimated to be about 70 dB at the subjects' ears. Experimental control and data acquisition were performed by a Rockwell AIM-65 computer.

Stimulus Scales

Stimulus scales were ascending and descending diatonic scales of C major (C₄-C₅) tuned in either Pythagorean, just, or equal-tempered intonations. Two types of stimulus scales were used (Type 1 and Type 2). The fundamental frequencies (in hertz) of the notes in both types of scales are shown in Table 1. In the Type 1 scales, A₄ was always set at 440.0 Hz. In the Type 2 scales, C₄ was always set at 262.4 Hz, that is the geometric mean of the lowest (260.7 Hz) and the highest (264.0 Hz) frequency for C₄ in the Type 1 scales. Both types of stimulus scales were used because of the contention that subjects may use the tone of A₄ (the diapason in Western music) or the tone of C₄ (the keynote in the scale of C major) as reference tones for appraising the tuning of the whole scale.

In Tables 2 and 3, the difference in interval sizes between the three intonations is given in terms of cents³ difference between *adjacent* notes in the scale, and *from the keynote*. It should be noticed that some differences are irrelevant from a perceptual point of view. For example, the difference between just and equal-tempered fifths is only 1.96 cents, which is less than any of the just noticeable differences for single tones. Hence, it is quite certain that no subject will be able to distinguish equally tempered fifths from their just counterparts. Notice also that differences between interval sizes in the Pythagorean and the equal tem-

3. A *cent* is a unit of interval measure equalling the 1200th part of an octave. Therefore, if f_1 and f_2 are the frequencies of, respectively, the lower and upper limit of an interval, then the interval size in cents is defined as $1200 \log_2(f_2/f_1)$.

TABLE 2
Differences in Interval Sizes (in Cents) Between Adjacent Notes in
Pythagorean, Just, and Equally Tempered Intonations in the Diatonic
Scale of C Major

Difference	Interval						
	C-D	D-E	E-F	F-G	G-A	A-B	B-C
Pythagorean - equal temperament	3.91	3.91	-9.09	3.91	3.91	3.91	-9.09
Equal temperament - just intonation	-3.91	17.60	-11.73	-3.91	17.60	-3.91	-11.73
Pythagorean - just intonation	0.00	21.51	-21.51	0.00	21.51	0.00	-21.51

TABLE 3
Differences in Interval Sizes (in Cents) from Keynote in Pythagorean,
Just, and Equally Tempered Intonations in the Diatonic Scale of C Major

Difference	Interval					
	C-D	C-E	C-F	C-G	C-A	C-B
Pythagorean - equal temperament	3.91	7.82	-1.96	1.96	5.86	9.77
Equal temperament - just intonation	-3.91	13.69	1.96	-1.96	15.64	11.73
Pythagorean - just intonation	0.00	21.51	0.00	0.00	-21.51	-21.51

perament are always less than 10 cents, which is small considering that in actual performances of professional musicians playing on variable pitch instruments, the total range for the same musical interval can easily reach 10 cents (Loosen, 1993; Ward, 1954).

PROCEDURE

The experiment was run in a sound-attenuating room of about 4 × 4 m. Each subject was tested individually. All apparatus was set up outside the test room. The subject was seated comfortably, about 2 m in front of the loudspeaker, which presented both the tape-recorded instructions and the computer-generated tonal stimuli.

Subjects were required to indicate the "more accurately tuned" member from each pair of stimulus scales. Nothing was mentioned about musical tuning systems, and subjects were invited to listen more than once to a stimulus pair before answering. A hand-held unit, containing six pushbuttons (Start, Play, Clear, and three Response buttons) was used by the subject. The Start button served to call up a pair of stimulus scales. The Play button allowed the generation of the actual pair of stimulus scales as often as desired before keying in one of the three Response buttons, "1" (the first scale is tuned most accurately), "2" (the second scale is tuned most accurately), and "=" (both scales are identical). Finally, the Clear button was provided to delete the last response in cases in which the subject pressed the wrong button.

Subjects were instructed that scales within pairs were either identical or different. On hearing a difference between the scales, the scale that was tuned "most accurately" had to be selected. If no difference was heard, then the "=" button had to be pushed. Thus, "=" responses may not be interpreted as cases in which the two scales were perceived as different, but equally well-tuned.

Each subject judged all possible combinations of intonations. Half of the stimulus pairs were composed of two identical members. As there were three intonation models, two types of scales (Type 1 and Type 2), and two directions of scales (ascending or descending), the order of scales within pairs was counterbalanced, and each stimulus pair was presented twice, each subject made a total of 96 comparisons.

Presentation order of stimulus pairs was randomized between and within subjects. Within pairs, both scales were either Type 1 or Type 2 scales and both scales were either ascending or descending. (The first pair of stimulus scales was always ascending.) Scales within pairs had either identical A_4 frequencies or identical C_4 frequencies. The two members of the stimulus pairs were separated by a silent interval of 700 ms.

Data recording was limited to response category. No knowledge of results was provided. There was no time pressure, and subjects were able to insert breaks when they desired. An experimental session lasted approximately 1.5 hr.

Results

Within each subject group, data were pooled over subjects, types of stimulus scales, and scale directions. Pooling was legitimized because subject groups could be considered as homogeneous and choice proportions were never significantly different for data divided according to the type of stimulus scale or the scale direction (hypergeometric tests for differences between proportions yielded p values always greater than .10).

In Table 4, preference matrices are shown for the three groups of subjects. Entries are the conditional proportions with which scales tuned as indicated in row headings were judged "more accurately tuned" than scales tuned as indicated in column headings. For example, the entry .55 in the upper right corner of the matrix for violinists means that violinists

TABLE 4
Proportion of Choices in Which Row Alternative was Judged as "More Accurately Tuned" than Column Alternative

	Violinists			Pianists			Nonmusicians		
	P	J	T	P	J	T	P	J	T
P	.23	.93	.55	.52	.86	.18	.54	.39	.34
J	.07	.45	.04	.07	.64	.07	.31	.58	.33
T	.30	.96	.41	.50	.75	.34	.30	.35	.51

NOTE. P = Pythagorean intonation, J = just intonation, T = equally tempered intonation. Entries for violinists, pianists, and nonmusicians are based on 56, 56, and 80 comparisons, respectively.

judged Pythagorean scales more accurately tuned than equal-tempered scales in 55% of the stimulus pairs composed of a Pythagorean and an equal-tempered scale. Conversely, violinists judged equal-tempered scales more accurately tuned than Pythagorean scales in only 30% of comparisons (see the lowest row of the matrix). Notice that the sum of 55% and 30% is not equal to 100% because ties were permitted. For clarity's sake, (redundant) complementary proportions of ties are tabulated explicitly in Table 5. Thus, Table 5 shows that violinists did not perceive any difference between equal-tempered and Pythagorean scales in 14% of comparisons (see the lowest row of the matrix). The difference between 55% + 30% + 14% and 100% is due to rounding errors. Notice that the entries on the principal diagonals of the matrices in Table 4 refer to identical scales judged as being *different*. On the other hand, nondiagonal entries in the matrices of Table 5 refer to different scales perceived as being *identical*.

A three-dimensional log likelihood-ratio test (Woolf, 1957) of the data in Table 4 indicated that the pattern of preferences for the three subject groups is significantly different ($G = 41.4, p < .0001$). Traditional techniques of scaling (i.e., Thurstone's case V model in Torgerson, 1965) were not applicable in this case because equality judgments were allowed, and scalings techniques make little sense when only three "stimuli" are compared. Hence, the data analysis focused on testing hypotheses directly related to the main issue of the study.

Table 6 shows the expected proportions of choices for three hypothetical cases. Model 1 assumes that subjects push the response buttons randomly. Models 2 and 3 assume that subjects first decide whether two members of a stimulus pair are identical or not, and then select the most accurately tuned one, in the case when both scales are perceived as being different. More specifically, Model 2 assumes that both stages of the decision process occur randomly. Model 3 assumes that identical tonal se-

TABLE 5
Proportion in Which the Two Members of Paired Presented Scales Were Judged as "Equal"

	Violinists			Pianists			Nonmusicians		
	P	J	T	P	J	T	P	J	T
P	.77			.48			.46		
J	.00	.55		.07	.36		.30	.43	
T	.14	.00	.59	.32	.18	.66	.36	.33	.49

NOTE. P = Pythagorean intonation, J = just intonation, T = equally tempered intonation. Entries for violinists, pianists, and nonmusicians are based on 56, 56, and 80 comparisons, respectively.

TABLE 6
Expected Proportions in Three Response Models for Paired Comparisons of
Musical Scales in Three Intonations

	Model 1						Model 2						Model 3					
	Preferences ^a			Equality ^b			Preferences			Equality			Preferences			Equality		
	P	J	T	P	J	T	P	J	T	P	J	T	P	J	T	P	J	T
P	2/3	1/3	1/3	1/3			1/2	1/4	1/4	1/2			0	1/2	1/2	1		
J	1/3	2/3	1/3	1/3	1/3		1/4	1/2	1/4	1/2	1/2		1/2	0	1/2	0	1	
T	1/3	1/3	2/3	1/3	1/3	1/3	1/4	1/4	1/2	1/2	1/2	1/2	1/2	1/2	0	0	0	1

NOTE. P = Pythagorean intonation, J = just intonation, T = equally tempered intonation. Entries for violinists, pianists, and nonmusicians are based on 56, 56, and 80 comparisons, respectively.

^aRow alternative is judged "more accurately tuned" than column alternative.

^bRow and column alternatives are judged "equal."

quences can be detected perfectly (because that implies a merely sensory process), but subjects answer randomly when they must choose which of two different scales is most accurately tuned.

VIOLINISTS

Proportions in Table 4 deviate significantly from expected values for Models 1, 2, and 3. [Chi-square statistics on underlying frequencies yielded a χ^2 (8, $N = 221$) = 189.0, $p < .0001$ for Model 1 and Model 2, and a χ^2 (5, $N = 160$) = 98.4, $p < .0001$ for Model 3.⁴] Hence, violinists do not answer randomly. As was expected, they more frequently judged Pythagorean scales as more accurately tuned (.93) than just intoned scales (binomial test, $p < .0001$). Contrary to expectation, Pythagorean scales were not more frequently (.55) judged more accurately tuned than equal-tempered scales (binomial test, $p > .17$). This result, however, needs to be put into perspective: Table 4 shows that, in pairs that consist of a Pythagorean and an equal-tempered scale, violinists preferred Pythagorean to equal-tempered scales (.55) more frequently than vice versa, equal-tempered scales to Pythagorean scales (.30) (hypergeometric test, $p < .007$).

Paired comparisons of the proportions on the main diagonal of Table 5 showed that identical scales were more frequently detected (.77) in the case of Pythagorean scales than in the case of just intoned (.55) or equal-tempered scales (.59) (hypergeometric tests, $p < .02$ and $p < .04$, respec-

4. Notice that Model 1 and Model 2 yielded identical chi-square statistics because proportionality in expected proportions is identical in both models. Notice also that the data on the principal diagonal were excluded in the test for Model 3 because expected values are equal to zero.

tively). Hence the accuracy with which identical scales were detected depended on intonation.

PIANISTS

As for violinists, data of pianists deviate significantly from the three response models [χ^2 (8, $N = 220$) = 119.5, $p < .0001$ for Model 1 and 2, and χ^2 (5, $N = 136$) = 83.9, $p < .0001$ for Model 3]. As was expected, pianists judged equal-tempered scales more frequently (.75) as better "in-tune" than just intoned scales (binomial test, $p < .0001$). Contrary to expectation, equal-tempered scales were not preferred (.50) to Pythagorean scales. However, in pairs that consist of an equal-tempered and a Pythagorean scale, pianists selected the equal-tempered scale more frequently (.50) than the Pythagorean scale (.18) as the best tuned one (hypergeometric test, $p < .001$). Paired comparisons of the proportions on the principal diagonal of Table 5 show that identical tempered scales were more frequently detected (.66) than Pythagorean (.48) or just intoned (.36) scales (hypergeometric test, $p < .05$ and $p < .002$, respectively).

It should be noticed that pianists (as opposed to violinists) more than once perceived strongly contrasting stimulus pairs as identical [i.e., stimulus pairs composed of a Pythagorean and a just intoned scale (.07) and stimulus pairs composed of an equal-tempered and a just intoned scale (.18)]. Analogously, slightly contrasting stimulus pairs (composed of a Pythagorean and an equal-tempered scale) were also more frequently perceived as being identical by pianists (.32) than by violinists (.14) (hypergeometric test, $p < .025$).

NONMUSICIANS

Overall chi-square goodness of fit tests showed that responses of *nonmusicians do not deviate significantly from the expected proportions* for Model 1 and Model 2. Moreover, the accuracy with which nonmusicians detected identical scales does not depend on intonation. Nonmusicians also fail to detect the difference between different scales more frequently than musicians do. The overall proportions of "missers" for violinists, pianists, and nonmusicians are equal to .05, .19, and .33, respectively. Paired comparisons of these three proportions yield p values always less than .001 (hypergeometric tests).

Discussion

All results not directly related to the main issue of the present study are in line with expectations and previous findings. For example, the fact that

Type 1 and Type 2 stimulus scales (i.e., scales that were slid slightly from each other) yielded virtually identical results was to be expected: music concerns the ratio between frequencies rather than the frequencies themselves. This view not only constitutes the fundamentals of traditional music theory (Attneave & Olson, 1971; Dowling & Harwood, 1986), it is also supported by a great number of empirical studies (Burns & Ward, 1978; Siegel & Siegel, 1977a,b). The finding that choices were not affected by scale direction is in line with studies of actual musical perception (Duke, 1985; Greene, 1937; Loosen, 1993; Mason, 1960) and with studies in which mistuned scales were adjusted (Loosen, 1994).

Turning to the major purpose of the present study, results of overall tests are consistent with the general claim that choices of violinists, pianists, and nonmusicians differ significantly. So one can argue that the data show the effect of different experience. However, at first sight, the data do not provide evidence for the more specific hypothesis that violinists prefer the Pythagorean intonation and pianists, the equal temperament: in merely 55% of the comparisons, violinists judged Pythagorean scales more accurately tuned than equal-tempered scales, and pianists perceived equal-tempered scales more accurately tuned than Pythagorean scales in merely 50% of the comparisons.

On closer examination, these results also provide evidence for the specific hypothesis: (1) violinists preferred Pythagorean to the equal-tempered scales more frequently (55%) than vice versa, equal-tempered to Pythagorean scales (30%), whereas pianists preferred equal-tempered to Pythagorean scales more frequently (50%) than vice versa, Pythagorean (18%) to equal-tempered scales. This finding is supported by the results of Loosen (1994), who studied subjects adjusting mistuned scales. (2) Violinists most frequently (77%) detect scale identity in the case of Pythagorean intonation, whereas pianists detect scale identity most frequently (66%) in the case of equal temperament. (3) Violinists and pianists perceived just intoned scales less accurately tuned than scales in Pythagorean or equal-tempered intonations. Just intoned scales were judged to have tones that were "too flat." This result is in line with studies that showed that performances always deviate more from just intonation than from Pythagorean or equal-tempered intonations (Cornu & Mercadier, 1872; Loosen, 1993; Mason, 1960; Moran & Pratt, 1926). Ward and Martin's (1961) conflicting conclusion that even most musicians cannot distinguish melodic sequences in just intonation from those in equal temperament is probably due to differences in the subjects tested. Ward and Martin studied amateur musicians and music students, whereas in the present study, highly trained professional violinists and pianists were used.

The fact that violinists frequently prefer (.30) equal-tempered scales to Pythagorean scales is not surprising when one bears in mind that profes-

sional violinists also have intensive experience with equal-tempered intonation because they are often accompanied by piano. In studies on unaccompanied violin playing, it was found that performances were sometimes best approximated by Pythagorean intonation (Greene, 1937; Nickerson, 1949), and at other times best approximated by equal-tempered intonation (Ward, 1970). Recently, Loosen (1993) also showed that solo performances of professional violinists playing diatonic scales of C major fit Pythagorean intonation as well as equal-tempered intonation.

It should be noticed that violinists rarely failed to detect differences between scales, whereas pianists frequently failed, and nonmusicians even more. It is hardly plausible to assume that musicians have better pitch discrimination abilities than nonmusicians (Parker, 1983), the greater "sensitivity" of musicians should be attributed to the fact that they have been trained more thoroughly than nonmusicians to appraise tonal intervals. These findings are in line with studies that showed that nonmusicians are incapable of identifying intervals reliably (Mathews & Sims, 1981; Siegel & Siegel, 1977a), and nonmusicians are more variable in frequency settings than musicians (Elliot, Platt, & Racine, 1987; Platt & Racine, 1985).

The present study offers no evidence for the hypothesis that intonation preferences have a natural basis on either mathematical or acoustic grounds (see, Benade, 1976; Meyer, 1956). If innate constraints have brought subjects to prefer musical intervals with small-integer ratios (with reference to the tonic or the preceding note), then analogously, choices should have reflected a preference for just intonation because the tones of that model can be obtained by dividing a string exactly into two, three, four, or more equal sections (and bringing them back to the proper octave). However, just as in Mason's (1960) investigation on performances of woodwind quintets, subjects reject just intonation. Hence, it would appear that a person's conception of accurate tuning is determined more by his musical experience than by a priori views of temperament.

It should be noticed that the present study does not imply that every violinist prefers Pythagorean tuning and every pianist equal temperament. The study reveals only group tendencies. Hence, the result that subjects within groups could be considered as homogeneous from a statistical viewpoint when individual data sets were analyzed as a whole should not be interpreted as if every subject closely fits all aspects of the trend in Tables 4 and 5. Substantial individual differences among subjects within a group can easily be revealed. For example, for specific pairs of intonations, the probability of getting a choice frequency distribution (i.e., a distribution specifying the number of times a subject prefers the different response

TABLE 7

Number of Times Violinists and Pianists Judged the Pythagorean (P), and the Equally Tempered (T) Tuned Member of Eight Pairs of Diatonic Scales of C Major as "the Most Accurately Tuned" Member of the Pair

Subject	Violinists				Pianists			
	P	T	=	<i>p</i>	P	T	=	<i>p</i>
1	4	3	1	.11	0	4	4	.05
2	5	3	0	.08	0	2	6	.01
3	4	2	2	.07	2	5	1	.05
4	5	2	1	.11	2	5	1	.05
5	5	2	1	.11	4	4	0	.004
6	4	3	1	.11	0	4	4	.05
7	4	2	2	.07	2	4	2	.09

NOTE. The probability of getting a frequency distribution that deviates at least as much from the group frequency distribution as the tabulated individual distributions is listed in the column *p*. The "=" column gives the number of times no difference was heard between the two members of the stimulus pair.

alternatives) that deviates at least as much from the overall distribution as the distributions of the individual subjects can be computed. Following this procedure, it can, for example, be shown that in the case of pairs composed of a Pythagorean and an equal-tempered scale, two pianists gave results significantly different from the overall performance of violinists (multinomial test, $p < .05$). One pianist preferred the equal-tempered scale to the Pythagorean scale twice (out of the eight pairs that were presented) and six times heard no difference between the two tunings. The other pianist, however, did not give any equal judgment and chose the equal-tempered scale four times and the Pythagorean scale four times as the most accurately tuned of the pair. On the other hand, for the same pair of intonations, none of the violinists deviated significantly from the violinists' overall trend (see Table 7 for the distribution of choices of the other subjects).

In this study, only scales in C major were used. The stimulus tones had particular timbre characteristics and were presented at a particular rate. Consequently, until further investigations are undertaken, it remains an open question whether the present conclusions can be generalized to situations in which longer and less prototypical musical sequences are investigated.⁵

5. The author is indebted to Noel Bovens, Rik Delabastita, Gabriel Forrez, Donald Leenknecht, and Jan Wouters for technical support. The author also wishes to thank Monique Lioen and John Drewery for their assistance with the article's preparation. Thanks are also due to the subjects, who gave their full cooperation in the experiment.

References

- Allen, D. Octave discriminability of musical and non-musical subjects. *Psychonomic Science*, 1967, 7, 421-422.
- Attneave, F., & Olson, R. K. Pitch as a medium: A new approach to psychological scaling. *American Journal of Psychology*, 1971, 84, 147-165.
- Barbour, J. M. *Tuning and temperament: A historical survey*. East Lansing: Michigan State College, 1951. (Reprinted 1972, New York: Da Capo.)
- Benade, A. H. *Fundamentals of musical acoustics*. New York: Oxford University Press, 1976.
- Burns, E. M., & Ward, W. D. Categorical perception: Phenomenon or epiphenomenon. Evidence from experiments in the perception of melodic musical intervals. *Journal of the Acoustical Society of America*, 1978, 63, 456-468.
- Burns, E. M., & Ward, W. D. Intervals, scales, and tuning. In D. Deutsch (Ed.), *The psychology of music*. New York: Academic Press, 1982, pp. 241-269.
- Cornu, A., & Mercadier, E. Sur les intervalles musicaux mélodiques. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, 1872, 74, 321-323.
- Corso, J. F. (1954). Scale position and performed melodic octaves. *Journal of Psychology*, 1954, 37, 297-305.
- Devie, D. *Le tempérament musical: Philosophie, histoire, théorie et pratique* [The musical temperament: Philosophy, history, theory and practice]. Béziers: Société de Musicologie du Languedoc, 1990.
- Dowling, W. J. Pitch structure. In P. Howell, R. West, & I. Cross (Eds.), *Representing musical structure*. London: Academic Press, 1991, pp. 33-57.
- Dowling, W. J., & Harwood, D. L. *Music cognition*. Orlando, FL: Academic Press, 1986.
- Duke, R. A. Wind instrumentalist's intonational performance of selected musical intervals. *Journal of Research in Music Education*, 1985, 33, 101-111.
- Ellis, A. J. *Additions to the translation of the book on the sensations of tone by Helmholtz 1885*. New York: Dover, 1954.
- Elliot, J., Platt, J. R., & Racine, R. J. Adjustments of successive and simultaneous intervals by musically experienced and inexperienced subjects. *Perception & Psychophysics*, 1987, 42, 594-598.
- Geringer, J. M. Intonational performance and perception of ascending scales. *Journal of Research in Music Education*, 1978, 26, 32-40.
- Greene, P. C. Violin intonation. *Journal of the Acoustical Society of America*, 1937, 9, 43-44.
- House, W. J. Octave generalisation and the identification of distorted melodies. *Perception & Psychophysics*, 1977, 21, 586-589.
- Krumhansl, C. L. The psychological representation of musical pitch in a tonal context. *Cognitive Psychology*, 1979, 11, 346-374.
- Krumhansl, C. L. *Cognitive foundations of musical pitch*. Oxford: Oxford University Press, 1990.
- Lloyd, L. S., & Boyle, H. *Intervals, scales and temperaments*. London: Macdonald & Jane's, 1963.
- Loosen, F. Intonation of solo violin performance with reference to equally tempered, Pythagorean, and just intonations. *Journal of the Acoustical Society of America*, 1993, 93, 525-539.
- Loosen, F. Tuning of diatonic scales by violinists, pianists, and nonmusicians. *Perception & Psychophysics* 1994, 56, 221-226.
- Martin D. W., & Ward W. D. Subjective evaluation of musical scale temperament in pianos. *Journal of the Acoustical Society of America*, 1961, 33, 582-585.
- Mason, J. A. Comparison of solo and ensemble performances with reference to Pythagorean, just, and equi-tempered intonations. *Journal of Research in Music Education*, 1960, 8, 31-38.

- Mathews M. V., & Sims, G. Perceptual discrimination of just and equal tempered tunings. *Journal of the Acoustical Society of America*, Supplement 1, 1981, 69, S38.
- Meyer, L. B. *Emotion and meaning in music*. Chicago: University of Chicago Press, 1956.
- Moran, H., & Pratt, C. C. Variability in judgments on musical intervals. *Journal of Experimental Psychology*, 1926, 9, 492-500.
- Nickerson, J. F. Intonation of solo and ensemble performance of the same melody. *Journal of the Acoustical Society of America*, 1949, 21, 593-595.
- Parker, O. G. Quantitative differences in frequency perceptions by violinists, pianists, and trombonists. *Bulletin of the Council for Research in Music Education*, 1983, 76, 49-58.
- Partch, H. *Genesis of a new music*. Madison: Wisconsin University Press, 1949.
- Piston, W. *Harmony*, 4th ed. (revised and expanded by M. DeVoto). New York: Norton, 1978.
- Platt, J. R., & Racine, R. J. Effects of frequency, timbre, experience, and feedback on musical tuning skills. *Perception & Psychophysics*, 1985, 38, 543-553.
- Rakowski, A. Tuning of isolated musical intervals. *Journal of the Acoustical Society of America*, Supplement 1, 1976, 59, S50.
- Rasch, R. A. Does 'well-tempered' mean 'equal-tempered'? In P. Williams (Ed.), *Bach, Handel, Scarlatti tercentenary essays*. Cambridge: Cambridge University Press, 1985, pp. 293-310.
- Roberts, L. A., & Mathews, M. V. Intonation sensitivity for traditional and nontraditional chords. *Journal of the Acoustical Society of America*, 1984, 75, 952-959.
- Shackford, C. Some aspects of perception. Part I. *Journal of Musical Theory*, 1961, 5, 162-202.
- Shackford, C. Some aspects of perception. Part II. *Journal of Musical Theory*, 1962, 6, 66-90.
- Siegel, J. A., & Siegel, W. Absolute identification of notes and intervals by musicians. *Perception & Psychophysics*, 1977a, 21, 143-152.
- Siegel, J. A., & Siegel, W. Categorical perception of tonal intervals: Musicians can't tell sharp from flat. *Perception & Psychophysics*, 1977b, 21, 399-407.
- Sloboda, J. A. *The musical mind: The cognitive psychology of music*. Oxford: Clarendon Press, 1985.
- Small, A. M. Present-day preferences for certain melodic intervals in the natural, equal-tempered and Pythagorean scales. *Journal of the Acoustical Society of America*, 1939, 10, 256.
- Small, A. M. An objective analysis of artistic violin performance. *Studies in the Psychology of Music*, 1937, 4, 172-231.
- Torgerson, W. S. *Theory and methods of scaling*. New York: Wiley, 1965.
- Van Esbroeck, G., & Monfort, F. Qu'est-ce que jouer juste? [What is playing in tune?]. Brussels: Editions Lumière, 1946.
- Vos, J. The perception of pure and mistuned musical fifths and major thirds: Thresholds for discrimination, beats, and identification. *Perception & Psychophysics*, 1982, 32, 297-313.
- Vos, J. Spectral effects in the perception of pure and tempered intervals: Discrimination and beats. *Perception & Psychophysics*, 1984, 35, 173-185.
- Vos, J. Subjective acceptability of various regular twelve-tone tuning systems in two-part musical fragments. *Journal of the Acoustical Society of America*, 1988, 83, 2383-2392.
- Vos, J. & van Vianen, B. G. Thresholds for discrimination between pure and tempered intervals: The relevance of nearly coinciding harmonics. *Journal of the Acoustical Society of America*, 1985, 77, 176-187.
- Ward, W. D. Subjective musical pitch. *Journal of the Acoustical Society of America*, 1954, 26, 369-380.
- Ward, W. D. Musical perception. In J. V. Tobias (Ed.), *Foundations of modern auditory theory*, Vol. 1. New York: Academic Press, 1970, pp. 420-421.
- Ward, W., & Martin, W. Psychophysical comparison of just tuning and equal temperament in sequences of interval tones. *Journal of the Acoustical Society of America*, 1961, 33, 586-588.

- Watkins, A. J., & Dyson, M. C. On the perceptual organisation of tone sequences and melodies. In P. Howell, I. Cross, & R. West (Eds.), *Musical structure and cognition*. London: Academic Press, 1985, pp. 71-119.
- Woolf, B. The log likelihood ratio test (The G-test). *Annals of Human Genetics*, 1957, 21, 397-409.