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PREFERENCE FOR MUSICAL TUNING SYSTEMS: HOW COGNITIVE ANATOMY INTERACTS WITH CULTURAL SHAPING

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ABSTRACT

Previous studies testing the production and evaluation of musical scales revealed a preference for Pythagorean intonation among violinists whereas pianists preferred equal temperament, with non-musicians showing no clear preferences. This study investigates preferences for four musical tuning systems using chord sequences and excerpts from musical compositions performed in different instrumental timbres. Forty participants (string players, pianists, non-musicians) made forced-choice preference judgments between pairs of tunings, as well as judgments of purity and sound brilliance. Results show that when using real music and instrumental sounds, the preferences for tuning systems vary not only between groups of participants but also between types of music and timbres. A general preference for a single tuning system therefore seems to be an over-simplified assumption.

1. BACKGROUND

Musical tuning systems define the relative and absolute pitches of musical instruments, usually by means of a theoretical framework. Since it is mathematically impossible to realize only "pure" intervals (with simple frequency ratios) in a tuning system – a series of 12 perfect fifths above the note C ends in B# leading to a discrepancy of 23.5 cents, the "Pythagorean comma" –, different tuning systems have been proposed, each of which has put an emphasis on certain intervals considered to be most important. The psychologically interesting question is whether there exists a natural preference for consonant intervals or scales in terms of small-integer frequency ratios. The higher number of identical partials in pure intervals is thought to be the cause of such a hypothesized preference.

Empirical evidence shows that participants can detect slightly mistuned intervals based on the sensation of beating (Levelt et al., 1966; Terhardt, 1978; Vos, 1986; Hall & Hess, 1984). Studies analyzing the intervals in musicians' performances revealed a large variability in intonation (summary by Ward, 1970). Loosen (1993) showed that solo violinists' performances of C major scales can best be described by a combination of Pythagorean and equal-tempered intonation. Experiments with infants could not find clear preferences for purely tuned intervals (Schellenberger & Trehub, 1996). Together, this evidence suggests that although pure intervals can be identified in a laboratory setting they are neither widely used in actual musical practice nor consistently preferred. A study by Loosen (1995), who found expertise- and main-instrument-specific intonation preferences, suggests that learned interval categories may be more important than natural intervals. Beyond "physical purity", ontogenetic adaptation and familiarity can have strong influences on tuning preferences: Culture shapes cognitive anatomy.

2. AIMS

Our study is an extension of Loosen's (1995) experiment, using excerpts from musical compositions in different instrumental timbres instead of C major scales. Two natural and two tempered tuning systems were used: Just intonation (pure intervals relative to the tonic), Pythagorean intonation (scale is built on perfect fifths, differs from just intonation mainly in the thirds and sixths), mean-tone intonation (with smaller fifths leading to pure thirds and sixths), and equal temperament (all semitones have the same size of 100 cents). The aim was to test whether the use of "real music" in different tuning systems leads to similar preference effects as found for sequential scales.

It has to be kept in mind that every tuning system implemented on a keyboard (i.e., with fixed key-pitch allocations) entails certain problems. For instance, "just" intonation is defined relative to the tonic, but simultaneously causes mistuned intervals built on other steps (e.g., the II-VI fifth is too small by 20 cents). We therefore restricted our selection of musical stimuli (see 4.1.) to "favorable" excerpts for the respective intonation (e.g., I/IV/V cadences for just intonation), avoiding gross mistunings and presenting all systems in good shape.

3. HYPOTHESES

In accordance with Loosen's (1995) results, we proposed a familiarization effect: Musicians who play instruments with fixed pitches (pianists) should prefer equal-tempered intonation, which has been the tuning standard for more than a century now, while musicians who play instruments with variable pitches (string players) should prefer systems based on pure intervals. For instance, pure major thirds may sound "too small" to pianists relative to a potentially internalized equal-tempered standard. Although non-musicians are expected to show no systematic preferences, both familiarization effects (preference for equal temperament) and preferences for "natural" tunings might occur. Beyond expertise-dependent preferences we also expected piece-specific effects: Musical sequences containing harmonic intervals (in which beatings are well perceivable) should lead to stronger preferences for pure intervals than sequences containing mostly melodic intervals. Finally, tuning preferences may also depend on the immediate context of adjacent sequences (temporary "tuning in" effects).

4. METHOD

4.1. Stimuli

The following musical sequences were used as stimuli (short characterization of the compositions in brackets):

- Two thirds (e/g and c/e, producing a C major triad) played as chords one after the other (THIRDS),

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- C major four-part cadences I/IV/V/I (CADENCES),
- J.S. Bach: Organ Toccata in D minor BWV 565, bars 1-3 (introduction of the piece: D minor scales with closing cadence; INTRO),
- J.S. Bach: Organ Toccata in D minor BWV 565, bars 12-15 (latent two-part sequence in D minor in which all intervals appear above the same repeating note in the left-hand voice; POLY),
- J.H. Schein: Madrigal „Unser Leben währet siebnzig Jahr“, bars 1-5 (four-part polyphonic passage in A minor, ending with a half cadence; SCHEIN),
- H. Schütz: Motet „Wie lieblich sind Deine Wohnungen“, bars 1-3 (three four-part chords: C major, F major, A major; SCHÜTZ),
- H. Purcell: Duet from „Dido and Aeneas“: „Fear no danger“, 8 bars (series of major and minor thirds in C major; PURCELL)
- Medieval organum (alla mente style: series of perfect fourths and fifths; ORGANUM).

The musical sequences were realized on a Yamaha Clavinova CLP-950 digital piano. Each sequence was played and thereby recorded on the memory system of the Clavinova. The sequence was played back in two different intonations. The Clavinova was connected to a DAT-Recorder (Sony TCD-D100) via a Sony Super Bit Mapping Adaptor SBM-1. The two versions of each musical sequence were recorded on DAT (sampling frequency 44.1 kHz, stereo, 16 bit). By this procedure, both versions of each musical sequence were identical in terms of every musical feature (e.g. loudness, tempo, and phrasing) except for their intonation.

Three timbres were used in the experiment, and some sequences were realized in two different timbres. An organ timbre was used for THIRDS, CADENCES, INTRO, POLY, SCHEIN, and SCHÜTZ. Since the organ timbre has a very straight sound, beatings are well perceivable. A piano timbre was used for THIRDS and CADENCES, so that comparisons between piano and organ timbres were possible for these two sequences. In contrast to the organ timbre, the piano sound has a more rapid decay, making beatings less well perceivable. A choir timbre was used for SCHEIN, PURCELL and ORGANUM. This made comparisons between choir and organ timbre possible for SCHEIN. Since the choir timbre has more vibrato than the other timbres, differences between intonations are smaller here. As a consequence, some sequences (e.g. in SCHEIN) which sound quite unfamiliar in the organ timbre do sound more acceptable in the choir timbre.

Every piece was only presented in two of the four tuning systems. All pieces were presented once in equal temperament and once in either just, mean-tone, or Pythagorean intonation. The alternative was *just* intonation for THIRDS, CADENCES, INTRO and POLY. Thus a preference for just vs. equal-tempered intonation was tested with both very simple and more complex musical material. The alternative was *mean-tone* intonation for SCHEIN, SCHÜTZ and PURCELL, three pieces from the 17th century when different versions of mean-tone intonation were the standard for the tuning of musical instruments. The alternative was *Pythagorean* intonation for ORGANUM, which was composed in the middle ages when the Pythagorean scale was supposedly used in musical practice. This means that for the pieces presented in either mean-tone or Pythagorean vs. equal-tempered intonation, the aspect of preference for “historically correct” scales was also considered.

(*Sample pairs of musical sequences in different intonations:* [CADENCE_organ_equal.wav], [CADENCE_organ_just.wav], [CADENCE_piano_equal.wav], [CADENCE_piano_just.wav], [SCHUETZ_equal.wav], [SCHUETZ_meantone.wav])

4.2. Procedure

Participants were tested individually in quiet rooms of the Max Planck Institute. Stimuli were presented via headphones (Sennheiser HD 200) connected to the DAT-Recorder. Participants were asked to make forced-choice preference judgments after each pair (one piece in two different intonations). Each pair was presented five times, with varying order of intonations. The pieces recorded in two different timbres were presented five times in each timbre, so that there were five preference judgments for every piece-timbre-combination. After the five preference judgments, the respective pair was presented again and participants were asked to rate each version on two five-point Likert scales, namely “brilliance of sound” (1 = not brilliant to 5 = very brilliant) and “purity of tuning” (1 = impure to 5 = very pure).

The experimental session started with THIRDS (organ and piano timbre) as the simplest musical material. Subsequently, we tested for *context-dependent* judgments by presenting a series of six C major cadences (I/IV/V/I), organ timbre, in just intonation to half of the participants, and in equal temperament to the other half. All participants were asked to listen to the respective cadences and then judge another five pairs of THIRDS (just vs. equal-tempered). After this “set effect” task, the experiment continued with INTRO, CADENCE organ timbre, POLY, CADENCE piano timbre, SCHEIN organ and choir timbre, ORGANUM, SCHÜTZ, and PURCELL. The average session took about 1 h.

4.3. Participants

The group of participants consisted of 20 musicians and 20 non-musicians (14 males, 26 females). Among the *musicians* were 10 string-players and 10 pianists, many of them being music students with violin or piano as main instrument. The musicians were on average 27 (range: 21-37) years old, had 19 (11-28) years of instrumental practice, and listened to music (other than playing themselves) for 13.5 h (0.5-70) per week. Among the *non-musicians* there were 11 participants who have had instrumental lessons in the past and 9 participants without instrumental experience. They were on average 30 (21-60) years old and listened to music for 14 h (1-60) per week. The musically experienced non-musicians had 8 (0.5-22) years of instrumental practice.

4.4. Data Analysis

The number of times the equal-tempered version had been preferred was counted separately for each musical example (i.e. how often one intonation had been preferred in the five trials of each piece-timbre combination). The null hypothesis is that participants made random judgments. If that were true, the average number of preference judgments for either intonation

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should be 2.5. One sample t-tests against 2.5 were performed for every piece-timbre combination, for every group of subjects as well as for pooled groups. Wilcoxon-tests were performed to test for significant differences in the "brilliance" and "purity" ratings of the two respective intonations. Chi-square tests were performed to test for context-dependent judgments in the "set effect" task.

5. RESULTS

5.1. Just Intonation vs. Equal Temperament

As can be seen in Tab. 1, string players overall preferred *just intonation* in 71 %, pianists in 54 % and non-musicians in 53 % (with musical experience) or 49 % (without musical experience) of trials. As preference rates varied considerably between different musical stimuli, statistical tests were performed separately for each musical sequence. Preference for just organ CADENCES was significant for all musicians whereas just piano CADENCES were preferred by string players only. Neither THIRDS (organ or piano) nor the two Bach excerpts (INTRO and POLY) provoked significant preference judgments among musicians. Non-musicians' preferences for just intonation did not differ from chance except in one piece (POLY). Tab. 2 shows the ratings of sound characteristics. The just versions of the organ CADENCES and the INTRO were perceived as significantly more brilliant and more pure than the respective equal-tempered version. No such differences were found for piano CADENCES and POLY.

	Preference for **equal-tempered** version in %				
musical sequence	**string players** (n = 10)	**pianists** (n = 10)	**non-musicians with musical experience** (n = 11)	**non-musicians without musical experience** (n = 9)	**All** (n = 40)
sequences with **just intonation** as alternative					
THIRDS (organ)	32	44	40	54	42
THIRDS (piano)	32	44	53	42	43
CADENCES (organ)	**18**	**16**	38	49	**30**
CADENCES (piano)	**22**	46	44	44	**39**
INTRO (organ)	30	68	55	53	52
POLY (organ)	42	58	49	**64**	53
ALL PIECES	**29**	46	47	51	**43**
sequences with **mean-tone intonation** as alternative					
SCHEIN (choir)	46	56	50	56	52
SCHEIN (organ)	66	72	56	**69**	**66**
SCHÜTZ (organ)	**12**	**16**	**26**	**31**	**21**
PURCELL (choir)	64	64	55	53	**59**
ALL PIECES	47	52	47	52	49
sequences with **Pythagorean intonation** as alternative					
ORGANUM (choir)	44	38	49	49	45

Table 1: Average preference rates for equal temperament among the 4 groups of subjects. Percentages < 50 indicate that the alternative intonation was preferred over equal temperament. Every piece-timbre-combination was judged five times. Significant preference rates (one-sample t-test against expected value under H_0 2.5, $p < .05$) are printed in bold.

musical sequence	**brilliance of sound:** median (mean)		**purity of tuning:** median (mean)	
	just intonation version	**equal-tempered** version	**just intonation** version	**equal-tempered** version
CADENCES (organ)	**4 (3.7)**	**3 (3.0)**	**4 (3.9)**	**3 (2.8)**
CADENCES (piano)	3.5 (3.2)	3 (3.4)	3.5 (3.4)	3.5 (3.3)
INTRO (organ)	**4 (3.6)**	**3 (3.2)**	**4 (3.8)**	**3 (3.3)**
POLY (organ)	4 (3.6)	4 (3.7)	4 (3.6)	4 (3.9)
	mean-tone version		**mean-tone** version	
SCHEIN (choir)	4 (3.4)	4 (3.7)	**3 (3.4)**	**4 (3.7)**
SCHEIN (organ)	3 (3.1)	3 (3.3)	3 (3.0)	3 (3.1)
SCHÜTZ (organ)	4 (3.8)	4 (3.5)	**4 (3.6)**	**2 (2.5)**
PURCELL (choir)	**3 (2.9)**	**4 (3.3)**	**3 (2.8)**	**3 (3.2)**
	Pythagorean version		**Pythagorean** version	
ORGANUM	**4 (3.5)**	**3 (3.1)**	4 (3.4)	3 (3.2)

Table 2: Medians (means) of "brilliance" and "purity" ratings for all participants (n = 40). Significant differences (Wilcoxon-test, $p < .05$) between the two intonations are printed in bold (both medians).

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5.2. Mean-Tone Intonation vs. Equal Temperament

The comparison of the SCHEIN organ and choir versions shows that only the organ version led to significant preference judgments. While in SCHEIN (organ) and PURCELL all participants significantly preferred the equal-tempered version, the mean-tone version was preferred in the SCHÜTZ. The Wilcoxon-test revealed that the SCHEIN (choir) equal-tempered version was perceived as purer than the mean-tone version. The same was true for PURCELL, where the equal-tempered version was additionally perceived as more brilliant, whereas for SCHÜTZ the mean-tone version received higher purity ratings.

5.3. Pythagorean Intonation vs. Equal Temperament

The ORGANUM did not lead to any significant preference judgments, although the Pythagorean version was judged to be significantly more brilliant than the equal-tempered version.

5.4. Context-Dependent Preference Judgments

As shown in Tab. 3, tuning contexts did not have significant effects on subsequent preference judgments (chi-square test, $p > .05$). Instead, just intonation was preferred independent of the THIRDS being preceded by just or equal-tempered intonation.

		pro **equal-tempered**	pro **just** intonation	∑
CADENCES in	equal-temp.	7	13	20
	just inton.	4	16	20
	∑	11	29	40

Table 3: Preference judgments for the first pair of THIRDS following CADENCES in either just intonation or equal temperament ("set effect" task).

6. DISCUSSION

As expected, string players generally preferred just intonation over equal temperament. Although only CADENCES led to significant preferences, there was a similar tendency also for THIRDS and the two Bach excerpts. A remarkable group effect emerged for INTRO (with its full closing chords), where string players and pianists showed reverse preference tendencies. Pianists had no significant preferences in THIRDS and piano CADENCES. While preferring just organ CADENCES, they tended to prefer equal-tempered Bach excerpts. Thus for pianists, preference judgments did depend more on the type of music presented than for string players, and it is obviously not possible to assume a general group preference for equal temperament. The fact that the musically most naïve group did not systematically prefer just intonation speaks against the assumption of a clear-cut natural preference for pure intervals. The results of the two Likert scales show that all participants perceived the just organ CADENCES and the INTRO as significantly more brilliant and pure. Together with the result of the set effect task (preference for just THIRDS no matter which set preceded them), this suggests that musical examples containing many harmonic intervals (making beatings well perceivable) lead to a stronger preference for pure intervals than musical examples with mostly melodic intervals (POLY) or timbres with rapid decay (piano CADENCES).

Especially for the mean-tone versions, the results from both the preference judgments and the Likert scales suggest that preferences depend on the musical material. The only piece that led to a significant preference for mean-tone intonation was SCHÜTZ, which consisted of only three chords. Seemingly, participants tend to prefer the tuning system that they are familiar with, namely equal temperament, over the historical mean-tone intonation. Contrary to our expectation pianists had a stronger tendency to prefer the Pythagorean ORGANUM than string players, but there were no significant preferences in any group, although all participants judged the Pythagorean version to be more brilliant. The ORGANUM might just have been too long (> 30 s), so that the lack of clear preferences could be caused by memory effects, as well as by the choir timbre reducing the differences between intonations.

7. CONCLUSION

In sum, tuning preferences – as observable in realistic musical contexts – are moderated by musical expertise, familiarity, timbre, and musical content of the piece (e.g., in terms of melodic plausibility and strength of beatings). Especially for non-expert listeners, preference patterns are often ambiguous due to the small differences between intonations and the auditory system's tolerance. Still, brilliance and purity ratings did typically match preference patterns. Altogether, the ideal of an optimal ("just") intonation is hard to achieve, and seems to be overly ambitious in most musical contexts and for most listeners.

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