academicJournals

Vol. 8(1), pp. 1-12, January 2018
DOI: 10.5897/JMD11.003
Article Number: 050A98255768
ISSN 2360-8579

http://www.academicjournals.org/JMD

Journal of Music and Dance

*Full Length Research Paper*

# Perceiving patterns of ratios when they are converted from relative durations to melody and from cross rhythms to harmony

**Aggelos Bousmpouras**

Media Technology Program, Computer Science Institute, Faculty of Creative and Performing Arts Leiden University, Netherlands.

Received 15 April, 2011: Accepted 9 June, 2017

**This research aims to study the perception of relative durational and cross-rhythm patterns when they are converted into melodic or harmonic patterns. Twenty-four international students from Groningen conservatoire were given twenty- four trials; twelve deals with their melodic/harmonic perception ability and the other twelve deals with the ability to perceive the converted rhythmical patterns. The purpose of the twelve first trials was to see if the perception ability patterns within a single property (part A) are done in the rational perception ability patterns of relative durations to melody or cross rhythms to harmony (part B). This was not the case, although there were some notable exceptions. The results in PART B had a great variety ranging from 4 to 87.5% accuracy rate, pointing that the relative difficulty of the trials was of great importance. If the comparison patterns are complex and have common elements with the standard pattern, then the accuracy of the subjects decreases. This contrasts the significant accuracy scores if the comparison patterns differ much in complexity and have no common elements with the standard pattern.**

**Key words:** Ratios, rhythmical patterns, Gestalt, perceptual invariance, intramodal transfer, rational scales, cross-properties matching.

## INTRODUCTION

The recognition of patterns and similarities among them is a common human attribute. Also, some patterns with specific ratios are apparently important and used in diverse human endeavors, ranging from geometry, painting and architecture to sculpture, music and even literature.

Music, in particular, a field that this research embraced has had from the ancient Greek Pythagoras to the modern avant-garde composer Henry Cowell, its pioneers of assimilating specific ratio patterns. By realizing the importance of using ratios for structuring melodies, harmonies, rhythms and also themes, one would wonder if humans are able to perceive similar, equivalent rational patterns, not from a single sound property as it has usually been the case, but now, from different properties.

As melody/harmony and rhythm constitute the most vital and basic elements of a musical piece, these will be the best candidates of opening this-maybe extended-

E-mail: a.bousmpouras@gmail.com.

research field. Cowell (1930), being one of the most novel composers of the 20th century, suggested that one could make rhythmical and durational relations from the ratios of the harmonic series. He also composed pieces with that in mind.

Other authors have also done research on this field like Yilmaz (1967) who came with the principle of perceptual invariance, assuming that perceiving ratios of sensations remain invariant when the environment changes systematically. Giving emphasis on relations, ratios between constructive units rather than absolute sensation values, Krantz (1972) argued in his theory of magnitude estimation and cross-modality matching that: “what really matters are relations, or ratios among sensory intensities, not the absolute values of individual sensations”. Marks (1978) theorized that an underlying neural code could link sensory intensity with brightness in vision, loudness in hearing and so forth.

Also, Intramodal transfer (transfer within the same sense modality) of form discrimination was often found superior to cross-modal transfer (Abravanel, 1971; Cashdan, 1968). The modality matching functions supported the so- called S.S. Stevens’ law, stating that “equal stimuli ratios give rise to equal sensory ratios” (Marks, 1978).

If, indeed, skilled musicians were to perceive a similarity between rhythmical patterns and melodic/harmonic patterns that share the same ratio structure, this would add trust to turning focus on researching more specific intramodal and intermodal sense properties constructed with exact rational relationships. This gives an explanation of people’s capacity to recognize patterns on a mathematical-based, rational sense.

Moreover, an ever-expanding vocabulary of scales constructed out of ratios offers a united systematic approach to the composer. This also helps to enhance the field of cross-properties matching associations, structured in a rational way. Instead of abstract analogies , the use of patterns of ratios (rational scales) establishes a common formula of translating patterns from one property of a single sense modality to another or intermodally. Future results evaluate the degree of agreement or deviation in the cross-matching perceptions of the constructed patterns.

**Operational definitions**

Some underlying terms of this research have to be introduced in order to make the reader familiar with them. So firstly, rational patterns are patterns constructed out of specific ratios.

As melodic scales in the traditional music theory have been constructed by specific ratios among their constructive units, or musical tones, re-initiated on the octave and repeated ever since to unlimited octaves, the same applies for durational and cross rhythm patterns. As the rhythmical ratio of 2:1, like the octave in pitch ratios, appears to be a musical universal (Levitin, 2006), the rhythmical scales like the melodic scales are repeated on an octave. This means that a ratio of 2:1 is considered equivalent to 1:1 because when the frequency is doubled it is perceived as the same with the half, as would be a C note with a C on a higher or lower octave register.

Durational patterns are made of relative durations. For example a (10:12:15) rational pattern that corresponds to a minor arpeggio in the western scale, would be a pattern of durations consisting of 10n duration units, 12n duration units and 15n duration units (with n being any number). In the case of cross rhythms 10n beats over 12n beats over 15n beats would form a cross rhythm rational pattern. And as octave is considered the same with the root, 20n would be considered equal to 10n beats, 24n beats with 12n beats, and so forth.

Complexity is a relevant term to consonance level which is commonly used by music theorists and tells us how complicated a relationship between constructive units is. In order not to confuse subjective notions of what is considered consonant and what is not, the term complexity is preferred. Partch (1974) defined the complexity of a just intonation interval (an interval tuned in integer ratios), as proportional to the size of the numbers in its ratio, when the ratio is in lowest terms and named odd limit. Erlich (2001) confirmed the soundness of this theory. Odd limit alone is not enough to define complexity.

**For a positive odd number n, the n-odd-limit contains all rational numbers such that the largest odd number that divides either the numerator or denominator is not greater than n.*

As the ear analyzes small-integer ratios both in pitch (Boomslitter and Creel, 1961; Partch, 1974) and durations (Levitin, 2006) more efficiently, these can be considered as less complex.

Complexity thus can be viewed also in terms of the relative period of the wave that results when two or more tones of a different frequency are sounded. The shorter the period of the combined waves, the less complex (or more consonant) the interval is. In this research, for example, the less complex interval in matters of wave periodicity was the rational pattern of 2:3 (The interval of a perfect fifth).

The combined wave repeats every six periods. In contrast, the most complex rational pattern in wave periodicity was 32:45 and 30:32:45, having a period of 1440. Theories have been developed on why the ear prefers small ratios with shorter waves, even from infants (Weinberger, 2004), hypothesizing that the ear might contain a kind of detector responding stronger to short repeating waveforms. Periodicity theories of pitch perception suppose the existence of this time-based detector (Cariani,1999; Pierce, 1991).

One thing that has to be added here is that a period of 12√128 for example (a perfect fifth of the 12 TET most common tuning), which has a very long or infinite wave periodicity would be perceived as consonant because of the just noticeable perception in pitch difference which compromise the ratio to a 3/2. This means that the sensory organ due to limitations is not able to perceive in detail every ratio aspect, but it compromises it to the closest ratio that is able to analyze and perceive (Levitin, 2006, Sethares, 2005), so the intervals in this research were chosen carefully to avoid this compromise.

Lastly, the term difficulty level has to be discussed. Every listening pattern in the test has a standard, an example pattern that has to be matched with one of the three comparison patterns following. Only one of the three patterns shared the same ratio relationships with the standard. The other two were made of different ratios. The amount of difficulty for one trial proved to depend on the relative complexities of the comparison patterns.

Thus, when a pattern was closer in waves periodicity, odd number or sharing of ratios (having 1 or 2 shared interval ratios with the standard), the trial had an increased difficulty level. The calculation for an exact formula would require further analysis and can be taken up by later research. The contribution of these factors is evident as shown in the tables in this work.

## Research question

The research question breaks down into two parts: Firstly, do listeners perceive as aesthetically equivalent melodic and harmonic patterns with their rationally converted relative durational and cross-rhythm patterns? And if yes, is the perceiving ability within single property pattern recognition (harmony to harmony or melody to melody) analogous to that of relative durations to melody or cross rhythms to harmony?

## METHODOLOGY

### Subjects

24 international students from Groningen conservatoire (22 males and 2 females) participated in this research. The nationalities of the subjects were Bulgarian (3), German (3), Italian (2), S.Corean (5), Chinese (2), Uruguayan, Spanish, Swiss, Tunisian, Greek, Cameroonese, Slovenian and Dutch (2). The purpose of choosing musical experienced people was to elaborate better results based on musical skill, something that a random population sample could not provide.

### Listening environment

The students were gathered in their classroom substituting a regular hour class. The sounds were produced by monitor speakers used for class instruction lessons.

### Instrumentation/Recording

The patterns were recorded with the aid of a sequencer, exported by an external sound card, into wav format. The melodies and harmonies were produced by a sampled piano instrument, tuned in a just intonation tuning. For the rhythmical patterns a drum-machine was used (drum samples).

### Randomization and clues removal

The order of patterns played was randomized in order to exclude experimenter bias. Also, the contour (the relative change in pitch over time of a primary sequence of played notes) was randomized to exclude clues or biases from listeners based on the contour.

The number of comparison patterns sharing the same number of intervals or tones with the standard was also randomized to 2 to 3 being equivalent to the standard pattern (omitting the 3rd common note or interval by having two times one of the same notes in a higher or lower octave register, thus maintaining the ratio pattern), to 0 to 2 being non-equivalent to the standard pattern.

Lastly, durational times were randomized to exclude time-based clues. The duration between the standard patterns and the comparison patterns remained unaltered (1:1). Other Influential factors such as individual and overall dynamic level, reverberation, remained unaltered(1:1) .Complexity based on wave periodicity was scaled from 6 to 1440 waves maximum and then randomized in order of appearance in questions.

### Procedure

#### *1st part*

To test if a certain musical ability affected the results, the following method was followed: Firstly, to test the accuracy in detecting a pattern that shared the same ratio structure with the standard and being from the same property as well, six trials of melodic rational patterns and six of harmonic rational patterns were given.

The instructor before every sound example was going to be produced would inform the subjects that a prime pattern will play (The standard). He repeated it twice or three times on demand. Then the instructor said that three comparison patterns would follow and only one of them would share equivalent ratios with the standard. Before each of the comparison patterns would start, the instructor said it was an ‘a’, ‘b’ or ‘c’, setting the signal for the next pattern.

The first part served to indicate if recognition of a pattern within the same property – something related with the traditional solfeggio- would also account for cross-property recognition ability. High scores in the latter correlated with the first to see if indeed there was a significant relationship.

#### *2nd part*

Subjects again listened firstly to the standard pattern, and then were informed that three comparison patterns would follow in a process identical to that of the first part. The difference here though, was that the musical property listened in the prime pattern was not reproduced in the three comparison patterns. Thus, the first six prime patterns of the second part were relative durations recorded with a drum-machine, while their corresponding comparison patterns were melodies, with only one for every trial, sharing the same ratio relationships with the standard. The last six standard patterns of the second part were cross-rhythm patterns, while their comparison patterns were harmonies, again, with one pattern only sharing the exact same ratios.

**Table 1.** Part A, sum results.

| Melodic patterns trial # | Sum melodic patterns accuracy | Percentage (%) | Harmonic patterns trial # | Sum harmonic patterns accuracy | Percentage (%) |
|---|---|---|---|---|---|
| 1 | 13/24 | 54.1 | 1 | 14/24 | 58.3 |
| 2 | 12/24 | 50 | 2 | 19/24 | 79.1 |
| 3 | 21/24 | 87.5 | 3 | 21/24 | 87.5 |
| 4 | 12/24 | 50 | 4 | 14/24 | 58.3 |
| 5 | 12/24 | 50 | 5 | 9/24 | 37.5 |
| 6 | 12/24 | 50 | 6 | 8/24 | 33.3 |
| All | 82/144 | 56.9 | All | 85/144 | 59 |

Sum of melodic plus harmonic patterns accuracy: 167/288: 57.9%.

**Rational patterns used**

Starting with the less complex to the most complex: 2:3, known as power chord, 6 periods (for the combined wave to repeat), odd limit 3, 3:4:5 (major arpeggio) 60 periods, odd limit 5, 10:12:15 (minor arpeggio) 60 periods, odd limit 15, 10:12:15:18 (minor seventh), 180 periods, odd limit 15, 32:45, the tritone interval,1440 periods, odd limit 45, 30:32:45, (semitone, plus tritone, plus fourth), 1440 periods, odd limit 45. For the stimuli in detail, Appendix Tables 1 to 6.

## RESULTS

Regarding the individual results for part A (Appendix 2), only one subject managed to get all trials in melodic patterns accuracy correct (#5), and four succeeded in five out of six trials.

On the harmonic patterns accuracy part, one subject again succeeded in all trials (#3) and five completed correctly five out of six trials. ‘Percent’ indicates the percentage of answering accurately to each trial. Thus, in melodic and harmonic patterns combined, the best results came from subjects #5 and #3 having eleven out of twelve trials correct (91.6%) , two followed with ten correct trials (83.3%), four with eight (66.6%).

In Table 1, the sum of the subjects completed with accuracy 56.9% of the melodic pattern trials and 59% of the harmonic pattern trials, bringing a 57.9% accuracy score for both of them, a score that indicates a rather medium level in this particular musical skill for the average student of this conservatoire.

In part B, cross-properties matching accuracy was tested (procedure, 2nd part). The task here was much more difficult. The subjects had to use not any known rules of solfeggio and had not any specific practice before matching relative durations with melodies and cross rhythms with harmonies. Despite that, some did correct the half of the trials and a few did above 65%.

Specifically, for relative durations to melodic patterns, cross-properties accuracy, a subject scored an impressive four out of six (66.6%), and five subjects got correct the half of the trials (Appendix 2). For cross rhythms to harmonic patterns, two had a 66.6% accuracy score and thirteen got 50%. In other words, fifteen out of twenty-four people scored at least half of the trials correct, making a percentage of 62.5%.

In Table 2, the subjects in total got 32.6% correct for relative durations to melodic patterns (under ‘Sum durational patterns accuracy’) and 42.3% in total, correct for cross rhythms to harmonic patterns accuracy (under sum cross rhythm patterns accuracy), despite the fact that 62.5% answered half and above of the trials correctly. In total, this brought a 37.5% accuracy scores for both duration-melody and cross rhythm-harmony, trials.

Also, the sum results for each trial, presented in Table 2, show a great diversity in accuracy range, something that is reflected on the difficulty level of each trial. For example trial one of cross rhythms to harmony had only 8.3% accurate answers while trial two had a very high of 87.5%, which would be considered high even for part A’s questions.

Table 3 indicates factors that all together form the relative difficulty level of each trial. It shows a comparison between factors that contributed to the difficulty level of a trial on the relative duration to melodic patterns matching. Shortest wave periodicity difference shows the shortest number of periods that two rational patterns differed in a given trial. For example, in trial 1, the shortest wave periodicity difference was 60 because the standard pattern had a period of 60, while the rational pattern with the closest number to that had a period of 120. So their difference was 60 periods.

**Table 2.** Part B sum results.

| Durational pattern trial # | Sum durational patterns accuracy | Percentage (%) | Cross rhythm pattern trial # | Sum cross rhythm patterns accuracy | Percentage (%) |
|---|---|---|---|---|---|
| 1 | 7/24 | 29.1 | 1 | 2/24 | 8.3 |
| 2 | 14/24 | 58.3 | 2 | 21/24 | 87.5 |
| 3 | 9/24 | 37.5 | 3 | 9/24 | 37.5 |
| 4 | 4/24 | 16.6 | 4 | 12/24 | 50 |
| 5 | 5/24 | 20.8 | 5 | 7/24 | 29.1 |
| 6 | 8/24 | 33.3 | 6 | 10/24 | 41.6 |
| All | 47/144 | 32.6 | ALL | 61/144 | 42.3 |

Sum of duration/melody plus cross rhythm/harmony patterns accuracy: 108/288: 37.5%.

**Table 3.** Duration to melody, difficulty factors. Comparison.

| Trial # | Shortest wave periodicity difference | Sum accuracy (%) | Most popular answer percentage (%) | Periods difference with most popular answer | Largest number of common ratios | Shortest odd limit difference |
|---|---|---|---|---|---|---|
| 1 | 60 | 29.1 | 50 | 60 | 0 | 10 |
| 2 | 1380 | 58.3 | 58.3 | 0 | 2 | 40 |
| 3 | 540 | 37.5 | 37.5 | 0/540 | 2 | 10 |
| 4 | 1434 | 16.6 | 45.8 | 1434 | 2 | 42 |
| 5 | 240 | 20.8 | 54.1 | 240 | 0 | 20 |
| 6 | 420 | 33.3 | 33.3 | 0/420 | 1 | 10 |

Sum accuracy shows the percentage of the accurate answers and most popular answer percent shows the most popular answers percentage that would be equal with the sum accuracy if most of the subjects got the correct answer. Period difference with the most popular answers shows the difference between the correct answer and the most popular answer in number of periods. If the number is 0, this means that the most popular answer was also the correct one. If two numbers are shown, this means that two answers had the same percentage being both the most popular ones. Number of common ratios shows how many rational intervals are shared between the standard and the comparison patters.

As the results show, a higher number of common ratios might have confused the subjects on which pattern corresponded with the standard. Lastly, shortest odd limit difference shows the difference between the odd limit of the standard and the comparison pattern with the closest number to that. For example, if a standard had an odd limit of 10, and the two comparison patterns had a 15 and 25, the closest one was the 15, making a ‘5’ shortest odd limit difference. The wave periodicity difference and odd limit difference numbers came out by the chosen rational patterns used.

These numbers are easy to get by applying the fact that a wave periodicity number is the result of the combined wave, for example for the ratio 2:3 the wave periodicity is 2*3=6. And odd limit as discussed before is equal to the odd number of the numerator or the denominator when the ratio is in its lowest terms. The Pearson correlation coefficient between shortest wave periodicity difference and sum accuracy was only 0.286, but excluding question four came it as high to 0.942. This may have been caused by the factor of common ratios as it will be discussed in the discussion section. Correlation between odd limit and sum accuracy was 0.125 but with excluding question four it came to 0.718.

Finally, Table 4 shows a comparison between factors that contributed to the difficulty level of a

**Table 4.** Cross rhythm to harmony, difficulty factors and comparison.

| Trial # | Shortest wave periodicity difference | Sum accuracy (%) | Most popular answer percentage | Periods difference with most popular answer | Largest number of common ratios | Shortest odd limit difference |
|---|---|---|---|---|---|---|
| 1 | 24 | 8.3 | 79.1 | 24 | 0 | 2 |
| 2 | 1368 | 87.5 | 87.5 | 0 | 0 | 36 |
| 3 | 30 | 37.5 | 41.6 | 30 | 2 | 0 |
| 4 | 150 | 50 | 50 | 0 | 0 | 10 |
| 5 | 540 | 29.1 | 37.5 | 540 | 2 | 20 |
| 6 | 30 | 41.6 | 41.6 | 0 | 2 | 6 |

trial on the cross rhythm to harmonic patterns matching. As the individual factors that add to a difficulty level have been explained, the question here is how shortest wave periodicity difference and shortest odd limit difference contribute to the sum accuracy scores.

Trial 2 with the very high accuracy rate of 87.5% had the largest number in the shortest wave periodicity difference (1368), and also the largest number in the odd limit difference (36). On the other hand, trial 1 with the lowest sum accuracy rate of 8.3% had the shortest number in wave periodicity difference (24), and the second shortest odd limit difference (2). This indicates that as the trials were closer in relative complexity, they were perceived as more difficult, while when they were much further in relative complexity they were perceived easier and the subjects had better accuracy scores***.***

This is shown by the correlation coefficient between sum accuracy and shortest wave periodicity difference, being 0.804 and between sum accuracy and shortest odd limit difference, being 0.764. In this case, none of the trials would alter the results as with the case of durational to melodic patterns.

## DISCUSSION

The results do not negate the ability of recognizing a rational pattern when it is converted from relative durations to melody or from cross rhythms to harmony point to the possibility that several factors limit their accuracy.

Firstly, the hypothesis that the musical skill of perceiving a rational pattern from melody to melody or from harmony to harmony is kept to a certain extent in perceiving a rational pattern from relative durations to melody and from cross rhythms to harmony did not give a high correlation.

In fact, as an outcome of the aforementioned results, the correlation between the first parts of melody to melody accuracy rate to duration to melody gave a correlation coefficient of 0.261 only. And for harmony to harmony, accuracy rate to cross rhythms to harmony is 0.277.

Some subjects were very inconsistent in their scoring and the majority had controversial results, negating a significant correlation between these variables. Despite that, the results in thorough look could show us something different. The first six subjects in total accuracy in all twenty-four answers scored relatively well in part b, giving a correlation coefficient between all questions accuracy to part b's accuracy of 0.634.

Also, the six subjects with most errors in all questions scored altogether relatively low in part b, giving a correlation coefficient of 0.788. This shows that although in the whole population controversy was there, the most skilled and the less skilled in general in part a would keep this trend in part b. Most notably subject #5 who had a 91.6% success rate in part a, had a 50% success rate in part b, to be the first in total correct answers (part a, plus part b), having 17 out of 24 correct, a success rate of 70.8%. While subject #23 who had a 25% success rate in part a, had a 33.3% success rate in part b, to be the last in total correct answers, having 7 out of 24 correct (29.1%).

Thus, it can be said that the ones that scored the highest and lowest in part a, were relatively good or bad in part b while in the medium levels there was not such an indication.

### Complexity factors/ difficulty level

As the success rates for part b varied greatly, some explanation behind this has to be found. In durational to melodic patterns cross-matching the highest score was 58.3% in trial 2, with the second largest wave difference (1380) and the second largest odd limit difference (40).

On the other hand, the trial with the lowest score was problematic in providing that these two factors alone counted for the difficulty level of a trial. Trial 4 with a sum success rate of 16.6% had the largest wave difference (1434) and the largest odd limit difference (42).

Thus, one would expect a very high scoring from the subjects. The reason that this did not happen may be due to the number of common ratios shared by the standard and the most popular answer. Thus, the most popular answer with a percentage of 45.8% was the rational pattern 90:96:135:160, a semitone followed by a tritone a minor third and a tone

The standard was the ratio 2:3, the common power chord. Having two intervals shared (135:90 equals 3:2 and (180:135, equals 4:3), might contribute to the confusion of the subjects. As the 2:3 pattern was the shortest in number of ratios, it could be derived by the most popular pattern. If this factor contributed to that inconsistency, later research will show.

Despite that, and excluding this trial, the correlation coefficient for shortest waves periodicity difference in sum accuracy came to the very significant 0.942 and for shortest odd limit difference of 0.718. So, when keeping common ratios to 0, one would expect a much higher score in accuracy ratings. This is emphasized by the cross rhythms to harmonies cross matching, with no inconsistencies between trials with a correlation coefficient for shortest waves periodicity difference to sum accuracy being 0.804 and between sum accuracy and shortest odd limit difference, being 0.764.

Moreover, for cross rhythms to harmony, the correlation coefficient for the second most popular answer in waves periodicity difference in standard pattern accuracy was 0.779 when common ratios were shared, but up to the significant 0.922 when no common ratios were shared Also, for durations to melody, the correlation coefficient for the second most popular answer in waves periodicity difference to standard pattern accuracy excluding common ratios (trial four) was as high as 0.944, something that emphasizes the importance of this difficulty factor.

## Conclusion

The results indicate that emphasis must be on how the patterns are constructed in order to provide a higher percent accuracy.

This, of course, means that the questions are facilitated to provide a good score, but nevertheless, it would not negate the ability to perceive rational patterns when converted from rhythmical properties to melodic/harmonic ones. It shows rather that it is an area that has not been established for studying and with things being the way they are, a certain skill could be retained from the most crafted subjects or a certain distinct skill could be acquired.

The overall, rather average level of the particular conservatoire could be a factor that did not permit all subjects to have equally good results. A significant number of people , especially for cross rhythms to harmonies, had the half of the questions correct and a subject ( #21) had eight of twelve questions correct for all part b, a significant score of 66.6%, scoring even better than from part a ( seven out of twelve).

To conclude, it would be interesting to get results from a more successful group in part a, with as high scores as the first subjects of this sample group and it would not be erroneous to expect an overall success rate of more than 50% in part b, when the comparison patterns would have a wave difference of over 1300 waves and no common ratios, or an odd limit difference of more than 35 and no common ratios. This would at least emphasize the fact that even if the ability of accurately perceiving from rhythm to melodies/harmonies is lower than from melodies to melodies or harmonies to harmonies, it can be facilitated and it is open for practice.

## CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

## REFERENCES


Abravanel E (1971). Active detection of solid-shape information by touch and vision. Perception and psychophysics.10:358-360.

Boomslitter P, Creel W (1961).The long pattern hypothesis in harmony and hearing. J. Music Theory (2):2-30.

Cariani P (1999). Temporal coding of periodicity pitch in the auditory system: an overview, Neural Plasticity 6(4):147-172.

Cashdan S (1968). Visual and haptic form discrimination under conditions of successive stimulation. J. Experimental Psychol.,76: 215-218.

Cowell H (1930). New musical resources. Edited by David Nicholls. New York: Alfred Knopf. Reprint, Cambridge University Press (1996 edition).

Erlich P (2001) The forms of tonality. http://lumma.org/tuning/erlich/erlich-tFoT.pdf

Krantz DH (1972). A theory of magnitude estimation and cross-modality matching. J. Mathematical Psychol. 9:168-199.

Levitin D.J (2006). This Is Your Brain on Music: The Science of a Human Obsession. New York: Plume.

Marks L.E (1978). The unity of the senses (interrelations among the modalities), Academic Press. New York, San Francisco London.

Partch H (1974). Genesis of music, Da capo Press, New York.

Pierce JR (1991). Periodicity and pitch perception, J. Acoust. Soc. Am. 90(4):1889-1993.

Sethares W (2005). Tuning, Timbre, Spectrum, Scale, second edition, Springer.

Weinberger N.M (2004). Music and the brain, *Scientific American* (November): pp.89-95.

Yilmaz H (1967). Perceptual invariance and the psychophysical law. Perception and psychophysics. 2:533-538.

**Appendix 1.** Stimuli description and details durations to melody.

Here follows a detailed explanation of the stimuli regarding the 'durations to melody' trials. First, presented, is the standard durations pattern. Its ratio structure, its total duration and successive duration units based on its ratio structure. Then, the comparison melodic patterns are presented in detail. With 1st being the one that was presented first, 3rd the one that was presented last, in the listening section for each trial. After the rational pattern structure, its wave period is presented along with its odd limit. The standard pattern (the correct answer) is shown in brackets. 'Notes in succession ', shows the notes of the melody of each pattern, with the numbers indicating their respective position in the octave register. For every pattern, the amount of notes was the same (4), in a 4/4 meter to exclude any listener bias. The pairing of the standard pattern with the comparison pattern was randomized with the aid of a random number generator.

**Trial 1.** Standard durations pattern: 4:5:6, total duration: 1500 ms; durational units in succession: 400, 600 and 500 ms.

| Comparison melodic pattern | Rational pattern | Period | Odd limit | Notes in succession |
|---|---|---|---|---|
| 1st | 32:45:48 | 1440 | 45 | C6,F#6,G6,C7 |
| 2nd | 15:16 | 120 | 15 | B7,B6,C7,C6 |
| 3rd | 4:5:6 (Standard) | 60 | 5 | C7,G7,E7,G8 |

**Trial 2.** Standard durations pattern: 32:45, total duration: 1925 ms, durational units in succession: 1125 and 800 ms.

| Comparison melodic pattern | Rational pattern | Period | Odd limit | Notes in succession |
|---|---|---|---|---|
| 1st | 160:192:225:256 | 57600 | 225 | C6,G#6,D#7,F#7 |
| 2nd | 32:45(Standard) | 1440 | 45 | C5,F#7,C5,F#6 |
| 3rd | 3:4:5 | 60 | 5 | C7,F7,C8,A7 |

**Trial 3.** Standard durations pattern: 10:12:15, TOTAL DURATION 1110 ms, duration units in succession: 300, 360 and 450 ms

| Comparison melodic pattern | Rational pattern | Period | Odd limit | Notes in succession |
|---|---|---|---|---|
| 1st | 32:45:48 | 1440 | 45 | C6,C7,F#6,G6 |
| 2nd | 20:24:25 | 600 | 25 | F6,F#6,F7,D7 |
| 3rd | 10:12:15 (Standard) | 60 | 15 | D#7,G6,C6,D#6 |

**Trial 4.** Standard durations pattern: 2:3, total duration: 880 ms duration units in succession: 240, 320 and 320 ms.

| Comparison melodic pattern | Rational pattern | Period | Odd limit | Notes in succession |
|---|---|---|---|---|
| 1st | 2:3 (Standard) | 6 | 3 | C6, G5, G6, C5 |
| 2nd | 90:96:135:160 | 4320 | 135 | C#7,C#6,C6,G6 |
| 3rd | 32:40:45 | 1440 | 45 | C5,E5,C6,F#5 |

**Trial 5.** Standard durations pattern: 30:32:45, total duration: 1620 ms duration units in succession: 240, 225 and 240 ms, 240 ms, 675 ms.

| Comparison melodic pattern | Rational pattern | Period | Odd limit | Notes in succession |
|---|---|---|---|---|
| 1st | 25:30:48 | 1200 | 25 | C5, B5, C6, D#5 |
| 2nd | 15:16:20:24 | 240 | 15 | G#7,C8,D#7,G7 |
| 3rd | 30:32:45(Standard) | 1440 | 45 | C6,G6,C7,C#7 |

**Trial 6.** Standard durations pattern: 10:12:15:18, total duration: 1540 ms duration units in succession: 252, 280, 336, 420 and 252 ms.

| Comparison melodic pattern | Rational pattern | Period | Odd limit | Notes in succession |
|---|---|---|---|---|
| 1st | 10:12:15:18 (Standard) | 180 | 15 | E6,G7,B7,D7 |
| 2nd | 20:24:25 | 600 | 25 | F6,F#6,D7,F7 |
| 3rd | 20:25:30:36 | 900 | 25 | E7,G7,A#7,C7 |

**Cross-rhythms to harmony**

Here follows a detailed explanation of the stimuli regarding the 'cross rhythm to harmony' trials. First, presented, is the standard cross-rhythm pattern. Its ratio structure, its total duration and its simultaneous beats total duration was based on the complexity of the period of the pattern. The more complex it was, the more likely to be extended as otherwise it would be too rapid to be perceived by the listeners. Then, the comparison harmonic patterns are presented in detail. With 1st being the one that was presented first, 3rd the one that was presented last in the listening section for each trial. After the rational pattern structure, its wave period is presented along with its odd limit. The standard pattern (the correct answer) is shown in brackets. Harmonic structure shows the notes contained in the harmony of each pattern, with the numbers indicating their respective position in the octave register. For every pattern, the amount of notes was the same (3), as a simple triad, to exclude any listener bias. * The pairing of the standard pattern with the comparison pattern was randomized with the aid of a random number generator (*An exception was trial 4, as the standard rational pattern had four digits (10:12:15:18).Thus the amount of notes had to be also four).

**Trial 1.** Standard cross rhythm pattern: 2:3, total duration: 1350 ms simultaneous beats: Six-over-two.

| Comparison harmonic pattern | Rational pattern | Period | Odd limit | Harmonic structure |
|---|---|---|---|---|
| 1st | 8:12:!5 | 120 | 15 | (A#5,B6,F#7) |
| 2nd | 2:3 (Standard) | 6 | 3 | (C5,G5,C6) |
| 3rd | 5:6:10 | 30 | 5 | (C5,D#5,C6) |

**Trial 2.** standard cross rhythm pattern: 32:45, TOTAL DURATION:9050, ms simultaneous beats: Forty-five-over-sixteen.

| Comparison harmonic pattern | Rational pattern | Period | Odd limit | Harmonic structure |
|---|---|---|---|---|
| 1st | 6:8:9 | 72 | 9 | (E6,A6,B6) |
| 2nd | 5:6:8 | 60 | 5 | (C7,D#7,G#7) |
| 3rd | 32:45 (Standard) | 1440 | 45 | (F#5,C6,C7) |

**Trial 3.** Standard cross rthythm pattern: 3:4:5, total duration: 2160 ms, simultaneous beats: Five-over-four-over-three

| Comparison harmonic pattern | Rational pattern | Period | Odd limit | Harmonic structure |
|---|---|---|---|---|
| 1st | 3:5:6 | 30 | 5 | (C7,A7,C7) |
| 2nd | 3:4:5 (Standard) | 60 | 5 | (G6,C6,E6) |
| 3rd | 32:45 | 1440 | 45 | (F#5, F#6,C7) |

**Trial 4.** Standard cross rhythm pattern: 10:12:15:18, total duration: 5000ms, simultaneous beats: Eighteen-over-fifteen-over-twelve-over-ten.

| Comparison harmonic pattern | Rational pattern | Period | Odd limit | Harmonic structure |
|---|---|---|---|---|
| 1st | 3:5:6 | 30 | 5 | (G6,E7,G7,E8) |
| 2nd | 10:12:15:18 (Standard) | 180 | 15 | (E6,G6,B6,D7) |
| 3rd | 32:45 | 1440 | 45 | (C6,F6,C7,F#7) |

**Trial 5.** Standard cross rhythm pattern: 30:32:45, total duration: 8850 ms, Simultaneous beats: Forty-five-over-thirty-two-over-thirty.

| Comparison harmonic pattern | Rational pattern | Period | Odd limit | Harmonic structure |
|---|---|---|---|---|
| 1st | 30:32:45 (Standard) | 1440 | 45 | (C6, C#6, G6) |
| 2nd | 25:30:36 | 900 | 25 | (A6,C7,D#7) |
| 3rd | 2:3 | 6 | 3 | (C4,G4,C6) |

**Trial 6.** Standard cross rhythm pattern: 10:12:15, total duration: 6730 ms, simultaneous beats: Fifteen-over-twelve-over-ten.

| Comparison harmonic pattern | Rational pattern | Period | Odd limit | Harmonic structure |
|---|---|---|---|---|
| 1st | 25:30:48 | 1200 | 25 | (C7,D#7,B8) |
| 2nd | 10:12:15 (Standard) | 60 | 15 | (C6,D#6,G6) |
| 3rd | 5:6:9 | 90 | 9 | (C7,D#7,A#8) |

**Appendix 2.**

**Table Part A.** Individual results.

| Subject | Melodic patterns accuracy | Percentage | Harmonic patterns accuracy | Percentage | Melodic plus harmonic patterns accuracy | Percentage |
|---|---|---|---|---|---|---|
| #1 | 3/6 | 50 | 4/6 | 66.6 | 7/12 | 58.3 |
| #2 | 5/6 | 83.3 | 5/6 | 83.3 | 10/12 | 83.3 |
| #3 | 5/6 | 83.3 | 6/6 | 100 | 11/12 | 91.6 |
| #4 | 2/6 | 33.3 | 2/6 | 33.3 | 4/12 | 33.3 |
| #5 | 6/6 | 100 | 5/6 | 83.3 | 11/12 | 91.6 |
| #6 | 3/6 | 50 | 3/6 | 50 | 6/12 | 50 |
| #7 | 3/6 | 50 | 5/6 | 83.3 | 8/12 | 66.6 |
| #8 | 2/6 | 33.3 | 4/6 | 66.6 | 6/12 | 50 |
| #9 | 3/6 | 50 | 3/6 | 50 | 6/12 | 50 |
| #10 | 4/6 | 66.6 | 3/6 | 50 | 7/12 | 58.3 |
| #11 | 4/6 | 66.6 | 2/6 | 33.3 | 6/12 | 50 |
| #12 | 4/6 | 66.6 | 4/6 | 66.6 | 8/12 | 66.6 |
| #13 | 3/6 | 50 | 3/6 | 50 | 6/12 | 50 |
| #14 | 3/6 | 50 | 3/6 | 50 | 6/12 | 50 |
| #15 | 4/6 | 66.6 | 4/6 | 66.6 | 8/12 | 66.6 |
| #16 | 3/6 | 50 | 2/6 | 33.3 | 5/12 | 41.6 |
| #17 | 2/6 | 33.3 | 3/6 | 50 | 5/12 | 41.6 |
| #18 | 4/6 | 66.6 | 4/6 | 66.6 | 8/12 | 66.6 |
| #19 | 5/6 | 83.3 | 5/6 | 83.3 | 10/12 | 83.3 |
| #20 | 2/6 | 33.3 | 3/6 | 50 | 5/12 | 41.6 |
| #21 | 3/6 | 50 | 4/6 | 66.6 | 7/12 | 58.3 |
| #22 | 2/6 | 33.3 | 5/6 | 83.3 | 7/12 | 58.3 |
| #23 | 2/6 | 33.3 | 1/6 | 16.6 | 3/12 | 25 |
| #24 | 5/6 | 83.3 | 2/6 | 33.3 | 7/12 | 58.3 |

**Table Part B.** Individual results.

| Subject | Duration to melodic patterns accuracy | Percentage | Cross rhythm to harmonic patterns accuracy | Percentage | Duration/harmony plus cross rhythm /melody accuracy | Percentage |
|---|---|---|---|---|---|---|
| #1 | 2/6 | 33.3 | 1/6 | 16.6 | 3/12 | 25 |
| #2 | 2/6 | 33.3 | 2/6 | 33.3 | 4/12 | 33.3 |
| #3 | 3/6 | 50 | 2/6 | 33.3 | 5/12 | 41.6 |
| #4 | 1/6 | 16.6 | 3/6 | 50 | 4/12 | 33.3 |
| #5 | 3/6 | 50 | 3/6 | 50 | 6/12 | 50 |
| #6 | 1/6 | 16.6 | 3/6 | 50 | 4/12 | 33.3 |
| #7 | 0/6 | 0 | 2/6 | 33.3 | 2/12 | 16.6 |
| #8 | 2/6 | 33.3 | 3/6 | 50 | 5/12 | 41.6 |
| #9 | 1/6 | 16.6 | 3/6 | 50 | 4/12 | 33.3 |
| #10 | 2/6 | 33.3 | 2/6 | 33.3 | 4/12 | 33.3 |
| #11 | 2/6 | 33.3 | 4/6 | 66.6 | 6/12 | 50 |
| #12 | 1/6 | 16.6 | 3/6 | 50 | 4/12 | 33.3 |
| #13 | 2/6 | 33.3 | 1/6 | 16.6 | 3/12 | 25 |
| #14 | 2/6 | 33.3 | 3/6 | 50 | 5/12 | 41.6 |
| #15 | 3/6 | 50 | 3/6 | 50 | 6/12 | 50 |
| #16 | 2/6 | 33.3 | 1/6 | 16.6 | 3/12 | 25 |
| #17 | 2/6 | 33.3 | 3/6 | 50 | 5/12 | 41.6 |
| #18 | 2/6 | 33.3 | 3/6 | 50 | 5/12 | 41.6 |
| #19 | 1/6 | 16.6 | 1/6 | 16.6 | 2/12 | 16.6 |
| #20 | 3/6 | 50 | 3/6 | 50 | 6/12 | 50 |
| #21 | 4/6 | 66.6 | 4/6 | 66.6 | 8/12 | 66.6 |
| #22 | 2/6 | 33.3 | 2/6 | 33.3 | 4/12 | 33.3 |
| #23 | 1/6 | 16.6 | 3/6 | 50 | 4/12 | 33.3 |
| #24 | 3/6 | 50 | 3/6 | 50 | 6/12 | 50 |