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Pitch salience in chords of harmonic complex tones

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ABSTRACT

Parncutt (1993) estimated the salience of the 12 chroma in chords of octave-complex tones (OCTs, Shepard tones). In each trial, listeners rated how well an OCT went with a preceding chord. The conventional root tended to go better than other chord tones. Non-chord pitches tended to go better if they corresponded to steps of associated scales; tones following the major triad went well if they belonged to the major scale (perfect fourth, major sixth, major seventh), following the minor if in (a) minor scale (major second, perfect fourth, minor sixth, minor seventh). The non-chord tones that went well tended to be missing fundamentals of incomplete harmonic series whose salience can be predicted by spectral or temporal models of pitch perception. Thus, it is unclear whether the data were determined by pitch perception, musical familiarity or both.

We repeated the experiment using chords of harmonic complex tones - closer to real music. 20 Western musicians (students at the University of Graz) participated (the task was too difficult for non-musicians). 5 triads (major, minor, diminished, major third plus tritone, suspended fourth) were each presented in root position and two inversions. Each chord was followed by 12 probe tones. 180 trials were presented in a random order that differed for each listener. Chords were built from piano tones. Probe tones were OCTs and were slightly quieter than the chords. Each trial was randomly transposed. Listeners rated how well the tone went with the preceding chord on a 7-point scale.

When averaged over inversions, results are similar to those of Parncutt (1993) for chords of OCTs. They are consistent with, but often do not confirm, the following assumptions: roots are more salient than other chord tones, non-chord pitches corresponding to missing fundamentals of incomplete harmonic series are more salient than other non-chord tones, and outer voices are more salient (as predicted by models of masking).

The nature-nurture question remains unresolved. A possible interpretation is that pitches at missing fundamentals influenced the historical development of tonal-harmonic syntax, which in turn influenced preferences for specific chord progressions and, via frequent exposure, the perception of relationships between individual triads and preceding and following passages.

I. INTRODUCTION

Parncutt (1993) investigated pitch salience in chords of octave-complex tones. An octave-complex tone comprises pure tones in different octave registers. Each pure tone is tuned to the same chroma or pitch class, corresponding to the tone's perceived chroma. The octave register is highly ambiguous and depends to some extent on spectral envelope (e.g. Deutsch, 1987; Parncutt, 1989; Terhardt et al., 1982a). A bell-shaped spectral envelope was used by Shepard (1984) and by Krumhansl (1979, and subsequent studies). Terhardt et al. (1982a) and Parncutt (1989, 1993) used a flat spectral envelope.

Results of Parncutt (1993) were consistent with predictions of Parncutt (1988) for the root of a musical chord, when the algorithm was extended to account for masking. The resultant hybrid algorithm was essentially an octave-generalized version of Terhardt et al. (1982b). In each trial of Parncutt (1993), simultaneity of octave-complex tones was presented to a listener, followed by a single octave-complex tone. The listener was asked how well the single tone went with the preceding chord. Results could be explained as a result of either experience of Western music (tones that often follow a given chord are heard to go well with it) or principles of pitch perception (a virtual pitch is heard near the fundamental of an approximately harmonic series of spectral pitches). Krumhansl and Kessler (1982) obtained similar results in the special case where the key context was represented by a single chord, the tonic triad (rather than a progression of three chords). In their data, the peak of the *tone profile* of a major or minor triad corresponded to the root.

Typical musical tones are of course not octave-complex but harmonic-complex tones. In chords of harmonic-complex tones, masking theory predicts that, other things being equal, the outer voices of a chord will be more salient than the inner voices, because the outer voices are masked from one side, the inner voices from both sides. This argument is valid for chords of either pure tones or complex tones whose fundamentals are relatively strong by comparison to the higher partials. We therefore expect that the pitch-salience profiles of chords of harmonic complex tones will depend on their voicing: the outer voices should be more salient.

II. METHOD

A. Listeners

46 people participated in the experiment. They were divided into three groups on the basis of their musical experience.

Group I: Active musicians. This group comprised 20 people, 10 male and 10 female, mean age 24 years (sd = 3.4). The following data were obtained from a questionnaire following the experiment. All participants had completed high school and three had a university degree. 18 played at least one musical instrument and had been practising or performing regularly for an average of 15 years (sd = 5.5); the other two had considerable singing experience. 16 were able to demonstrate their understanding of the concept of chord root in Western music theory. 12 claimed to have recognized individual chords during the experiment, and 6 correctly named examples such as major, minor and diminished.

Group II: Passive musicians. This group comprised 15 people, 9 male and 6 female, mean age 32 years (sd = 11). Participants within this group had stopped practising or performing a musical instrument an average of 11 years ago (sd = 11). Before that they had practised and performed regularly for 7 years (sd = 4.4). Six participants indicated that they understood the root concept, 4 claimed to have recognized individual chords during the experiment, and 2 correctly named examples. The data of this group are not presented here because they did not correlate with the presence or absence of tones in the chords. In spite of their extensive music performance experience, these listeners appeared to be incapable of distinguishing between a probe tone that was physically present in a previous chord and one that was not.

Group III: Non-musicians. This group comprised 11 persons, 5 male and 6 female, mean age 37 years (sd = 13.4). No one in this group reported any experience in performing or practising music and no one recognized individual chords or could name them. Again, the data for this group did not correlate with the presence or absence of tones in chords, and so are not presented here.

B. Design and stimuli

The design was symmetrical. Five triads (major [in semitones above the root: [047], minor [037], diminished [036], major third plus tritone [046], and suspended fourth [057]) were each presented in 3 inversions (root position, 1st inversion and 2nd inversion). Each chord was followed by 12 probe tones. Triads were built from harmonic complex tones. The sound files were 44 kHz and 16bit, and taken from the database “Grand Piano” provided with the sampler AKAI 1100. The MIDI key velocity was 100 and the pitch range was Bb3 to A5 (MIDI pitches 58 to 81, or fundamental frequencies from 230 and 880 Hz). The perceived loudness was assumed to be constant over this range. The tones were cut to a constant duration of 300 ms with a short decay time using ProTools software. Comparison tones were octave-spaced tones tuned to an equally tempered chromatic scale with A=440 Hz. Partials had constant amplitude before amplification across the entire audible range. They were calculated in Matlab 2006a software, which was also used to run the tests. Their amplitude was adjusted by five listeners in a preliminary experiment such that their loudness was slightly lower than that of the chords.

C. Equipment

The experiment was run on a Laptop (Compaq Evo N800C) running Matlab 2006a. Stimuli were presented monophonically over headphones (Bayerdynamic DT 990) via an internal soundcard (Intel® 82809C/CAM AC’97). Participants were tested individually in a quiet room at the University of Graz.

D. Procedure

Participants first read a short introduction on the computer screen. In an initial training phase they became familiar with the sounds, the task and the mouse interface. They were asked to set the volume to a comfortable level.

Each listener was presented with 180 different trials. The order of trials was random and different for each listener. In addition (and independently of that randomisation), each trial was randomly transposed through an interval between 0 and 11 semitones. Listeners were invited to take a break after trial no. 90, but most continued without a break.

Every trial comprised a chord followed by a comparison tone, then the same chord-tone pair repeated. Chords and tones had duration of 0.3s. The three silent time intervals (chord-tone, tone-chord, chord-tone) were all set to 0.2s.

Listeners were asked to rate how well the tone went with the chord in a musical sense (*Wie gut passt der Einzelton zum Akkord?*) on a seven-point scale from “very poorly” to “very well”. There was no time limit for responding, but participants were asked to respond as quickly and spontaneously as possible. They were encouraged to use the whole scale (*Versuchen Sie bitte die ganze Skala zu verwenden*) and only to choose point seven if they thought that the tone was physically present in the chord (*In diesem Fall sind Sie sicher, dass der Ton im Akkord enthalten ist*).

III. RESULTS

Results are shown only for the group of 20 active musicians. They are presented in Figure 1 for each of the 5x3=15 chordal inversions separately (20 data per point). In Figure 2 data for each chord are averaged over three inversions (60 data per point). The vertical axis is the mean goodness-of-fit rating, interpreted here as pitch salience.

Listeners evidently responded to the sound of chord itself and not on the basis of expected continuations, that is, whether the probe tone represented a good music continuation or not. For example, for the diminished triad [036] in second inversion, the mean rating for the perfect fifth (7) was not higher as would be expected if 6 was heard as a leading tone an 7 as its resolution, but instead was significantly lower than the mean rating for the chord tones 0, 3 and 6, as well as the implied root at 8 (Tukey HSD, $p <= 0.05$).

The ratings of 14 listeners correlated significantly with the physical presence or absence of tones in the chords. Between the profiles of the three inversions of each chord there were no significant differences (Table 1.).

Table 1. Homogenous subgroups for the 5 triads show no significant differences between the inversions.

	[036]	[037]	[046]	[047]	[057]
root vs. 1st					
Z	-1,233	-,485	-,592	-,641	-,477
Sig. (2-way)	,217	,628	,554	,522	,634
root vs. 2nd					
Z	-,057	-,085	-1,230	-1,185	-,831
Sig. (2-way)	,954	,933	,219	,236	,406
1st vs. 2nd					
Z	-1,369	-,634	-,617	-,477	-,269
Sig. (2-way)	,171	,526	,537	,633	,788

A main effect of salience was observable in 13 of the 15 chordal inversions treated separately (exception: [046] in first and second inversion). 14 profiles correlated positively with the presence or absence of tones (exception: [046] in second inversion). A comparison of all mean ratings with all other mean ratings within each profile (Tukey HSD, $p <= 0.05$) yielded isolated significant effects, such as for example: For [036] in 2nd inversion, the rating for 7 was significantly lower than the rating for each chord tone 0, 3 and 6 as well as the implied root at 8; the rating for the major third (4) was significantly lower, for [036] in 2nd inversion, than the rating for the chord tones 3 and 6. For [037] in root position, the rating for the root (0) and the fifth (7) differed from the ratings for all non-chord tones, but the rating for the minor third (3) did not differ from any other rating. For [046] in root position the root (0) differed only from 3, 5 and 9 and the major third (4) only from the perfect fourth (5). For the major triad [047] in root position, the rating for the root (0) differed from the ratings for all non-chord tones; the rating for the major third (4) differed from all non-chord tones except the 10. In second inversion the root (0) and the fifth (7) differed from all non-chord tones; the rating for the major third (4) differed from the root (0), the fifth (7) but not from the 10. For the chord suspended fourth [057] in root position the root (0) and the perfect fourth (5) differed only from the tritone (6).

In summary the mean salience for the three tones that were physically present in the chord was significantly higher than the mean salience of the other 9 tones for the triads [037] in root position and for [047] in root position and 2nd inversion. All other triads had single significant higher ratings for the physically present tones except of [036] in root position and 1st inversion.

On averaging data for root position, 1st and 2nd inversion a main effect of salience was observable. Chords correlated significantly with the presence or absence of tones.

IV. DISCUSSION

The data are consistent with the model but the predicted differences between inversions are not significant. The reason is presumably that the task was (even) more difficult than that of Parncutt (1993) due to the timbral difference between test chord and probe tone. To empirically investigate the effect of inversion, we will have to recruit more listeners.

The model of Parncutt 1988 predicts a virtual pitch at the perfect fourth and the major sixte in the major triad, and perfect fourth and minor sixth in the minor triad. On that basis we predict that: for the major triad [047] the salience of the perfect fourth (5) is greater than that for the tritone (6) and the salience of the major sixth above the root (9 semitones) is greater than that of the minor sixth (8) in all three inversions. As for the major triad for the minor triad [037] the salience of the perfect fourth (5) is greater that the salience for the tritone (6) but the ratings for the minor sixth (8) are greater than the ratings for the major sixth (9). The results of Parncutt 1993 and this study are consistent with the prediction but the differences in the data are not significant (exception: major chord [047] minor sixth (8) and major sixth (9); Wilcoxon-Test, $p_{(\text{one sided})} < 0.1$).

Both we and Parncutt (1993) failed to distinguish between the root and fifth of the minor triad. One possible reason is a ceiling effect produced by the additional instruction to select the highest rating (7) only when the probe tone was heard to be physically present in the chord. Another possible explanation is that the fifth of the minor triad is, on average, masked less than the root, because it lies further away from neighbouring tones (5 semitones from the root and 4 semitones from the third).

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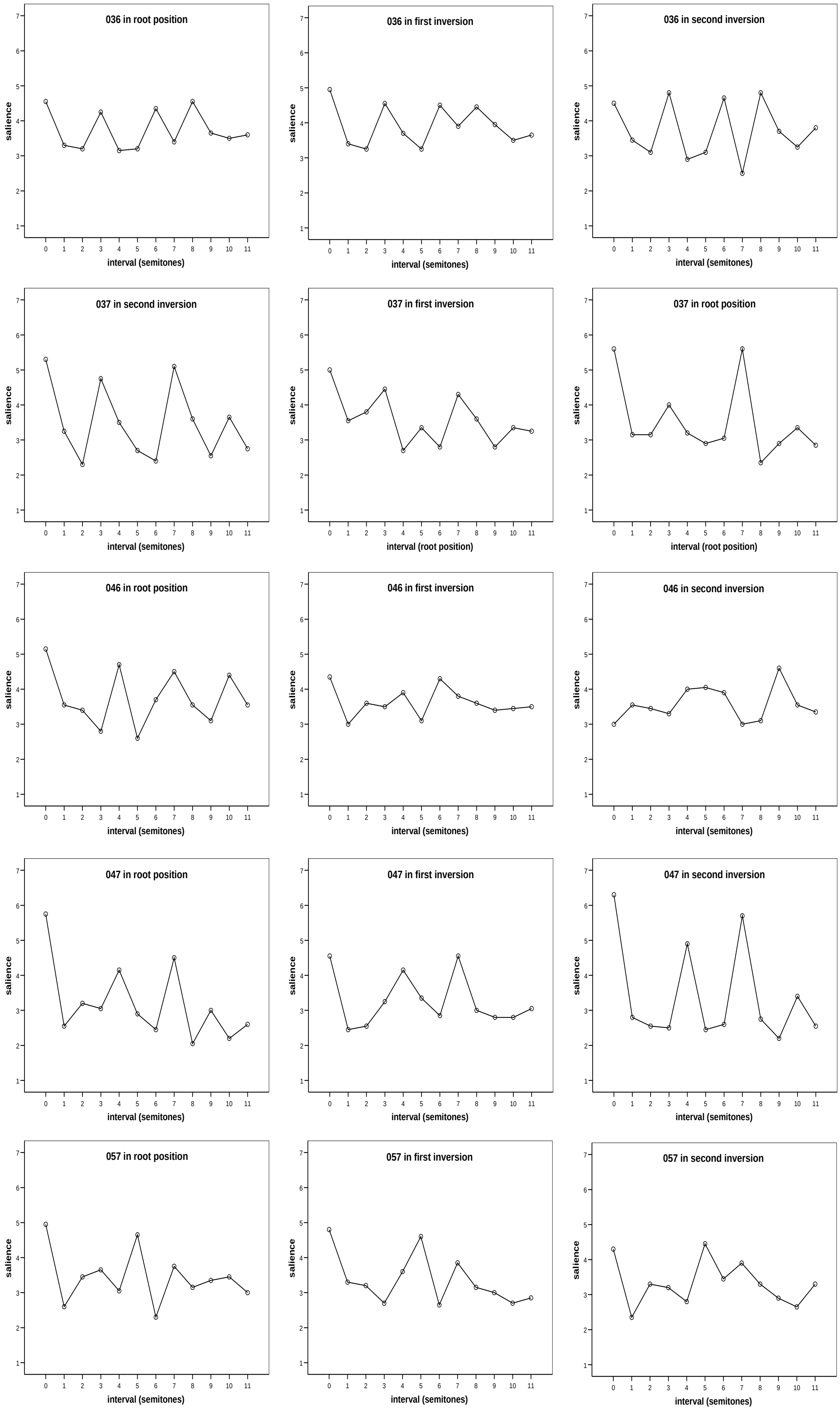

Figure 1. Mean responses for each of 180 trials. Each point is a mean of 20 salience ratings.

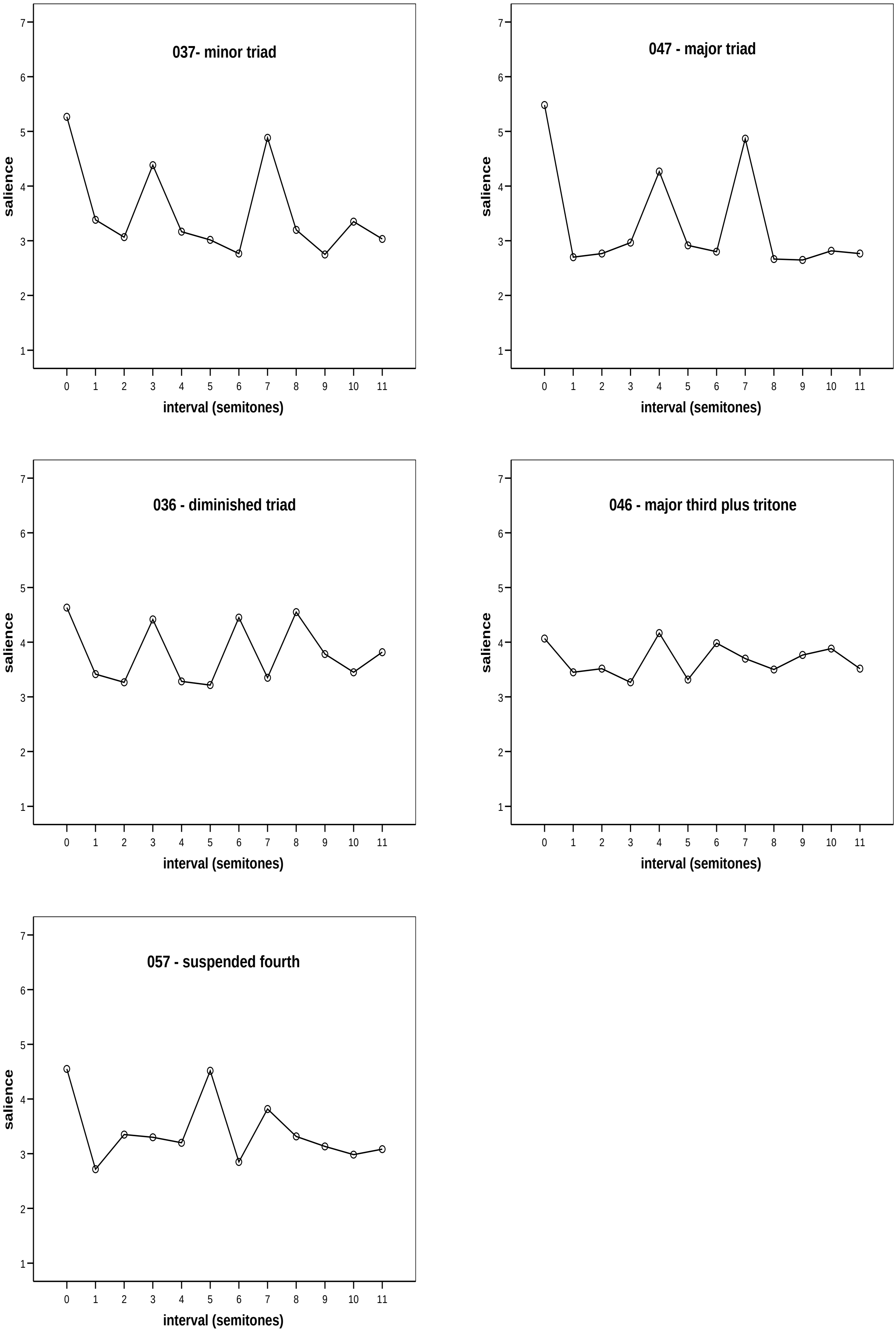

Figure 2. Data for each chord averaged over three inversions, 60 data per point.