8.4 Consonance und dissonance

Although every musician thinks he/she knows what a **dissonant chord** is, a scientific description proves to be difficult. The Pythagoreans considered the octave, the fifth, and the fourth to be consonant (symphonical), and all other intervals as dissonant (diophonic). There is one peculiarity: *to the astonishment of the westerner, now and then the major second is also designated as being consonant. This has its basis in the totally different concept of melodic consonance: consonant is that which is easy to pitch* (*Simbriger/Zehelein*). Another explanation would be: the major second must not stand too far apart since it is the fruit of the "holy matrimony" (Fig. 8.6), and thus sanctioned via the insights of a "advanced civilization".

Apparently there is more than one type of consonance. As a synonym, we often find euphony, coalescence, serenity, relaxation. Playing in the middle range on the piano two notes at a distance of a fifth, both melt into one harmonic sound. The two notes "like each other", they sound well together, and that is exactly what con-sono means. Very different are two notes at a distance of a half-step: the esthete downright hears the fight they slug out, while the signal-theoretician detects beats, the psychoacoustician notices roughness – and the musician perceives dissonance.

Already early on, the nominal attribute became a ordinal attribute: for dyads, not only a statement was sought that they harmonize well, but also an assertion about how well they harmonize (concord) – in the sense of a ranking. **Franco von Köln** put together a five-step scale in the 13th century (C. = consonance, D. = dissonance):

Complete C.	Medium C.	Incomplete C.	Incomplete D.	Complete D.
Prime Octave	Fifth Fourth	Major third Minor sixth	Minor third Major sixth	Second Seventh

The high consonance of the fifth is already evident from Fig. 8.2: in the spectrum of the partials there is a close relationship. The 3rd, 6th, 9th, etc. partials of the lower note have the same frequency as the 2nd, 4th, 6th, etc. partial of the higher note – given perfect tuning and dispersion-free wave propagation. What could be closer than to derive, from the similarity of two notes, rules for the generation of consonance and dissonance? For example:

- The more shared partials, the higher the consonance. Or:
- The simpler the frequency ration, the higher the consonance.

However, there were also cautious rearguard actions: "essential are only the odd-numbered partials". Or: "the 7th, 11th, 13th, 14th, and 17th partials are excluded". Or: "the fourth is a perceptional dissonance". Or: "there are dissonant chords of highly consonant sound". Or "In context, a consonant chord very often is bestowed a dissonant purpose". And rather recent from Haunschild's 'New Theory of Harmony' (1998): "In general we can note that the human understanding of consonance and dissonance more and more shifts away from consonance, in favor of dissonance. This means that more and more intervals and chords that were surely classified as dissonant back in the day, are today rated as consonant. It is only the intervals with a so-called semi-tone-friction (minor second and augmented seventh) that are truly assessed as dissonant."

Let us give the philosophers some space, as well: "corresponding to the relations of the natural degrees of consonance it is possible to say that every entity, every form of being is the more complete, and thus the more in harmony with its physical and social environment, the closer it is positioned to its origin. The principle of consonance is the connecting within the differing – it therefore corresponds to the harmony, the organic integrated-ness in higher unity, in other words: love" (found in Simbriger/Zehelein). So then **Schönberg** possibly was a love-less person? He opined: "today we have already gone so far as to not make a difference anymore between consonance and dissonance." Rossi similarly (but not quite as radically) says: "consonance and dissonance greatly depend on each individual's musical experience, and, more broadly speaking, musical culture".

It shall not be disputed that beats, roughness, fluctuations, frictions, or anything else you would want to call the **envelope variations** of the partials, represent a cause for the perception of dissonance or consonance. However, perception psychology increasingly distances itself form the so-called *unbiased scaling*, i.e. an absolute, purely signal-dependent scaling. At the 8th Oldenburg Symposium, Viktor Sarris elaborates: "Whereas classical sensory psychophysics relies mainly on the (illusory) assumption of absolute, i.e. invariant stimulus-response laws, the relation-theory in psychophysics is based on the general premise that, on principle, one and the same stimulus may be perceived and judged very differently as a function of the variables implied by the total 'contextual' situation at hand. … Contextual effects in psychophysics are of major importance since virtually all kinds of sensory-perceptual-cognitive judgments, whether in direct or indirect scaling resp. in discrimination and postdiscrimination-testing, are **contextual**." The insight that evaluations happen in relation to the given situation also concerns judgments of consonance – in particular if these are delivered by persons with musical experience or education.

We may use as an **example** a dyad with the two tones forming a **major sixth** – i.e. for example B-G#. Let us imagine two guitar players: one of them continuously plays an E-major chord, the other frets the B on the G-string, and alternatingly (e.g. with a 6/8th rhythm) the G# on the high E string. Both B and G# are included in the E-major triad; the two guitars play in harmony and the result is a tension-free sound. Now the "man of the 6th" shifts his fretting hand upwards by 3 semi-tones, i.e. he frets the D on the G-string and the B on the E-string. After one bar he shifts upwards by another 3 semi-tones and plays F-D (**Fig. 8.25**). All the while the accompanying guitarist continues playing the E-major chord. The second sixth is – with D-B – still close to E-major; the D (representing the minor seventh) does already build some slight tension, though (E^7-chord). However, only the third sixth brings some serious dramatics to the game: the D can again be taken as the minor seventh, but the F – representing the minor ninth – is dissonant to a high degree ($E^{7/b9}$-chord). Every player of the electric guitar with some classical education (i.e. Beatles-Beck-Blackmore) knows this skewed chord from Lennon/McCartney's *I want you*. The interesting thing in this example is: even if no accompanying guitar is playing along, the experienced payer of sixths still hears these mounting dramatics! The latter may be relaxed (resolved) e.g. via a concluding augmented sixth to E-C#. Again: a guitarist plays (now without accompaniment) the augmented sixths: B-G#, D-B, F-D, E-C#, and he/she hears an arc of suspense – although always an equal (not one and the same!) interval is being played.

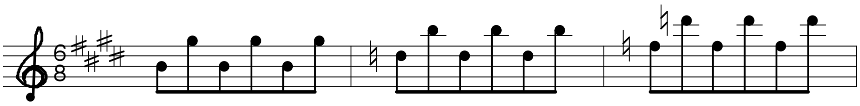

Fig. 8.25: Augmented Sixths.

Requirement for the changing musical tension is a **reference** carried along in memory – which needs to be available to every musician. Otherwise there would be no way to play an improvisation that is guided by accompanying chords. Now, the well-versed musician will (in contrast to the beginner) not need any audible accompaniment at all – he/she will generate it "within", using the "internal ear". The whole thing is less esoteric that one might fear. The reader could, as an example, begin to speak but stop at the last moment – intending to say "*a*" but keep the vocal chords shut. Dutifully, the tongue will already have moved into position, and a well-formed notion of how the vowel will sound (had only been allowed to do so) has emerged. The "internal ear" has already heard the "*a*" although the latter has physically not manifested itself at all. A vocalist could in addition also already set the vocal chords to the appropriate tension in order to produce a targeted pitch; however, already this will not work as well anymore without vocal training. The reason is that the internal ear requires connections between the motor-control areas and the sensory areas in the brain. Strangely, when it comes to hearing, the sensors not only comprise the 8th brain-nerve (N. acusticus). If a layperson-singer (i.e. in this case a person that wants to sing but lacks any skill) is played a note and then asked to sing it, a more or less horrible control process[♣] starts: the vocal chords generate a tone but only as the latter is physically existent can the hearing recognize the pitch and make the vocal chords change their tension. An expert singer, however, is expected to immediately produce the correct pitch without any interfering control processes. This he/she can do, too, because he/she has learned to pre-tension the vocal chords correctly already before the tone sounds ("muscular tone-memory").

Magnetic resonance imaging has enabled us to "watch the brain thinking", and we have started to understand how the individual brain regions cooperate. Or rather: we have a certain conjecture, because an actual comprehensive grasp has yet to be established. Some interesting connections have been observed in pianists: if a **pianist** listens to piano music, regions in his/her brain that are assigned to the fingers become also active. Presumably, the brain already practices how the fingers would have to be moved in order to play what is heard – even though the pianist merely listens and does not actually play. This works the other way round, as well: playing on a keyboard that does not sound any audible notes still activates brain regions related to auditory perception – that is the "internal ear". With beginners of the piano, these senso-motoric connections have, by the way, not been observed. Rookies need to first configure the hardware by practicing.

But back to our topic of **consonance**: at least the well-versed musician supplements the sounds aurally recorded by fundamental and accompanying notes that exist only in his/her imagination. The supplement may be more or less consonant, and therefore consonance is describable by physical signal parameters alone. The major sixths mentioned in the above example will generate an increasing tension only if the E, or the E-major chord, are retained. If the listener thinks of a concurrently changing fundamental note (in the example i.e. E – G – Bb), then the tension is not changed. Setting the respective current reference is an individual process that will follow some roughly predefined rules, but it will not run a predetermined course in the individual case. Rather, musical training as a general criterion, and musical context in particular, are significant. It is easily imaginable that probabilities related to the given choice of the fundamental are set up and evaluated, and that relations within the partials, as well as chord relationships, play an important role. After all, the brain is most powerful in supplementing missing sections in visual impressions – there should be similarities in the auditory system.

[♣] We are familiar with this from casting shows that have spawned frog-like superstars (Kermit on dope), the skillfulness of which with regard to intonation have called for critical voices to speak up even within Lower Bavaria (!).

The third sixth-dyad (F-D) described in the above example may be seen as part of a tetrad in a third relationship. Two tetrads are **third-related** if three of the four notes in the two chords correspond, and if moreover the root notes are located a third apart. In the example, the first two sixth-dyads form – with B-G# and D-B – the basis for an E^7-chord. The third sixth-dyad is part of a diminished seventh-chord ($G\#^{07}$). Third-related to E^7, it forms an $E^{7/\flat 9}$-chord with the latter. This rule of formation is not compulsory; alternative reference systems may be imagined. Indeed it is specifically the possibility of multiple reference systems that renders the degree of consonance not unambiguously definable.

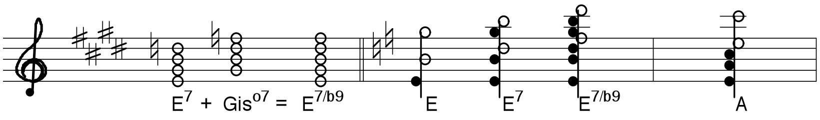

Fig. 8.26: Left: third-related tetrads; right: arc of suspense with resolution in A-major. “Gis” = G#

Fig. 8.26 clearly shows the third-relation mentioned above: E-G#-B-D forms an E^7-chord that has three notes in common with G#-B-D-F ($G\#^{o7}$). The latter supplement the E^7 to an $E^{7/\flat 9}$-chord. The right-hand section of the figure depicts the first sixth-dyad (open note-symbols), and the mentally supplied root note E (filled symbol). This pattern is stored in memory, and the next sixth-dyad is added, resulting in the E^7-chord. The latter is memorized as well (filled symbols) and supplemented by the third sixth-dyad … and there we have our dissonance. Actually played are merely the notes given by the open symbols; all other notes exist only in memory. In case the guitarist plays, in conclusion, also the major sixth E-C#, a nice resolution (relaxation) in A happens; this works in particular if he/she imagines E-A-C# in addition.

The above example was intended to show how the consonance of a major sixth can turn dissonant – if the imagination (the internal ear) plays along. Of course, not only the imagined, but also the notes existing in reality influence the perceived dissonance. In general, the **major seventh** (e.g. E-D#) is considered to be dissonant. However, if it is generated using two sine-tones, “actual” beats do not happen (in contrast to the minor second E-F), but octave beating (so-called 2nd-order beats) results. Experiments tapping the electrical potentials of the cortical nerve give rise to the assumption that our hearing system performs some sort of half-wave rectification within the analysis of the vibration of the basilar membrane[♣]. The patterns seen in the action-potentials on the nerve fibers change their shape in the same rhythm as the difference frequency (in this example defined by $T = 1 / (f_2 - 2f_1)$). **Fig. 8.27** depicts such a signal; the shown section corresponds to just this beating-periodicity. To compare: in Fig. 8.5, a 1st-order beating was shown. 2nd-order beats act in a more subdued fashion compared to 1st-order beats [Plomp, JASA 1967].

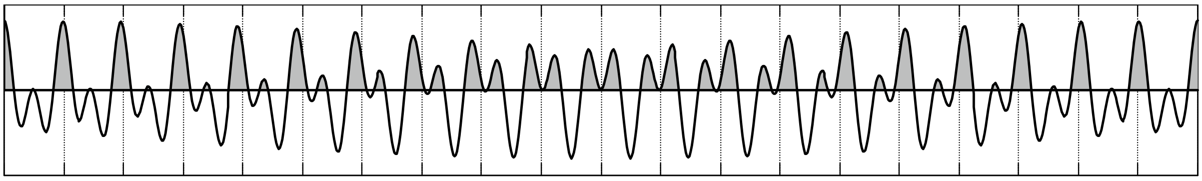

Fig. 8.27: Octave beating. Sum of two primary tones of the same level. The frequency of the higher tone is larger by 2,5% than twice the frequency of the lower tone: $f_2 = 2{,}05 \cdot f_1$.

[♣] At least in the frequency range below 1,5 kHz.

Tones from instruments are almost never composed of only one single partial, though. In the guitar, we will normally have to deal with several partials – and in this case 1st-order beats do determine the sound, as the following example will show. Playing the just mentioned major seventh on the guitar (e.g. the E on the D-string and the D# on the B-string) indeed yields a sound that most would call dissonant. However, as soon as we supplement additional tones to these two tones to form a complete **E^{maj7}-chord** E-B-E-G#-D#-G#, the dissonance is gone[♣]. Causes may be found in the many consonant intervals that this chord features, or in the destruction of the strong envelope fluctuations by the additional partials. What is interesting in this context: in the chord sheets of e.g. the book "Rock Gitarre" (Bechtermünz publishers), a different E^{maj7}-chord appears: E-B-D#-G#-B-E. These are the same note-designations as above, but the root position has changed. The chord rumbles a bit and does not ring with the same beautiful melancholy as the chord mentioned first above. But again this is a subjective assessment. In fact, there can be no wrong chords – only wrong expectations.

Fig. 8.28 shows both E^{maj7}-chords in comparison. The spectra are based on equal-temperament tuning; all partials have (arbitrarily) the same amplitude. In the second chord, two partials with only 9 Hz distance appear at 160 Hz – they generate a fast beating that sounds rather unpleasant. The neighboring partials at 415 Hz have a distance of 3 Hz: they beat, as well, but slowly and more in the sense of a vibrato i.e. less annoying. What's happening at 311 Hz / 330 Hz? Here we have the intended dissonance of the major seventh that showed up already in the first chord – given by the E- and D#-partials.

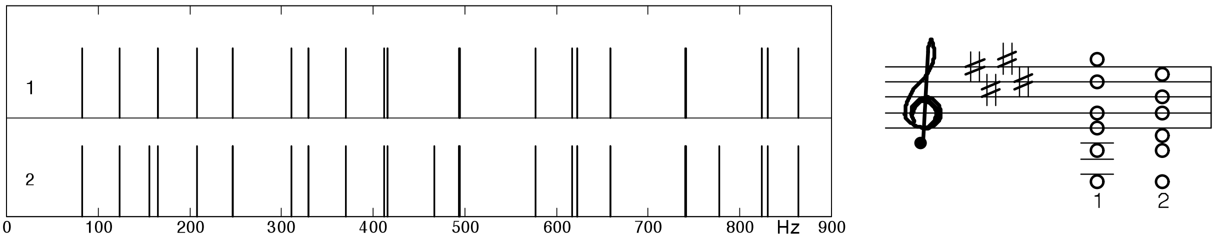

Fig. 8.28: Amplitude spectra and musical score of the E^{maj7}-chords elaborated in the text.

The closer two partials are spectrally located, the slower the resulting beats. Very small distances of partials (e.g. 1 Hz) happen in single notes, as well – due to slight detuning of the circular string-polarization, due to progressive spreading of partials, or because the instrument is polychoral (e.g. the piano). Somewhat faster beats (e.g. 4 Hz) may also appear for single notes, for example if the tone is generated using vibrato or tremolo. Even faster beats that are in part perceived as **fluctuation strength** [12] and in part as **roughness**, are typically only generated as several tones are played simultaneously. The borderline between fluctuation strength and roughness lies at a modulation frequency of about 20 Hz. Tones modulated that way – whether rough or fluctuating – can diminish the euphony and sound dissonant. As the modulation frequency further grows, the impression of dissonance decreases again – otherwise already the (harmonically complex) 100-Hz-tone would be dissonant (which it isn't). It may be deemed rough, but not dissonant. It cannot be specified by a single number at which distance between the partials a maximum dissonance occurs; the terms consonance and dissonance are too complex, and the sounds are too diverse.

[♣] Again, this is naturally a matter of the approach taken, and may be subjectively judged differently in the individual case.

Psychoacousticians like the sensory to separate consonance and the musical consonance, or similar (often historically established) terms. Sensory consonance is represented in the absolute scaling, the "unbiased Scaling" that psychologists will readily put into question. So: put on the headphones, don't think of anything bad (and of course not of anything good, either), and evaluate the consonance of the two sine-tones presented. Just to avoid any misunderstanding: that is not pointless – from this we obtain elementary basic knowledge that may at some point form the fundamentals for a comprehensive theory on dissonance. However, it is still a long way from the dissonance of two sine-tones to the dissonance of a E^{maj7}-chord. That is true not only because here musical context, musical experience, and culture need to be involved (all elements of the musical consonance, also termed tonality), but also because already the purely psychoacoustical analytic poses considerable problems. Issues easily dealt with given an AM- or FM-tone turn voyage-into-the-unknown for a chord. As nice as the formulas about frequency- and level-dependencies of roughness and fluctuation strength are – they are of no help when dealing with signals containing complicated, time-variant partials. That E^{maj7}-chord has neither a modulation frequency nor a modulation index – just like the car engine the roughness of which has kept generations of acousticians busy. The synthesis of specific roughnesses proposed by Aures [Acustica, 58, 1985] shows a way but also reveals problems: we need to know not only the level of every partial (this could be measured) but also determine the phases of the partials because a cross-correlation is required across the specific roughnesses of neighboring frequency bands. That implies the time-functions, and therefore the phase is of importance. Your customary analyzer will, however, model only the damping function of the hearing-specific critical-band filters with reasonable accuracy. Not much is known yet about the (level-dependent!) phase response of these filters; and even if we would have that information, we would still have only captured one single dimension. Because: *One and the same stimulus may be perceived and judged very differently as a function of the variables implied by the total 'contextual' situation at hand* [Sarris].

If we don't pitch (sic!) our expectations that high and content ourselves with qualitative rules – then we can actually explain quite a few phenomena. Such as: if on a guitar the low E (open E-string) and the D# on the B-string (4th fret) are plucked with the fingernail, a dissonant dyad is sounded. The dissonance is significantly diminished if the fingertip is used for plucking. Explanation: dissonant beats may occur between the fundamental of the D# and the 4th harmonic of the low E. This will only happen, though, if this 4th harmonic is present with a sufficient level. Plucking with the fingernail or the plectrum will emphasize harmonics and generate a sufficiently strong 4th harmonic if the strings are not too old. Plucking with the fingertip, however, makes for a weaker excitation of the 4th harmonic – the dissonance thus is less pronounced. The markedness of the dissonance in this example is influenced by the playing technique (the interpretation) and cannot be determined merely on the basis of the interval. Of course, it is highly important how well the guitar radiates these neighboring partials, and how quickly they decay – and how the room transmits them … and whether further strings are plucked such that individual partials are masked. Roederer♣ describes a supplementary example: *if e.g. a clarinet and a violin play a major third with the clarinet playing the lower note, this interval sounds "smooth". If the clarinet plays the upper note, though, the interval sounds "rough".* The reasoning again lies in the instrument-specific structure of the harmonics which may not only be influenced by the mechanisms in the generator itself but also by the musician, the room and the setup in it, and of course by all other sources that may concurrently sound. In the end, a subjective assessment happens on the basis of the knowledge of the listener in relation to the musical context. The result is a highly subjective degree of dissonance the may certainly not merely be calculated just based on an interval relationship.

A tremendous range is covered from the older books on harmony[1] that attested to the major sixth a general dissonance, to more modern books[2] seeking to attribute this feature only to the minor second, from divine perfection and imperfect devil's notes via Helmholtz-ian tone-relations, all the way to multiple regressions[3]. They all share the search for rules, because: music is played according to rules … rather complicated ones at that, though. Auditory processing of acoustical signals also follows rules – and again the latter are all but simple … and they are subject to inter-individual as well as intra-individual scatter.

There are good reasons to assume that auditory perceptions emerge on the basis of audible partials. Audible are partials only if they surmount both the hearing threshold in quiet and masking thresholds caused by other tones. 'Audible' in this sense does not mean, though, that the partial would necessarily be *audible as individual tone*. To that effect, a partial is audible (i.e. it contributes to the overall hearing sensation) if the aural perception changes when the partial is filtered out. If the perception does not change, the corresponding partial is not audible. If we regard the interaction of individual partials as the source of the perception of dissonance, the (so defined) audibility of these partials is prerequisite. With this, however, dissonance becomes dependent on the individual sound spectrum and can by no means be calculated "from the score". If, conversely, the basis is the sound spectrum arriving at the ear, then orientating calculations are possible – albeit right now only with considerably reduced general validity. Daniel's[3] conclusion may serve to obtain three insights: roughness and sensory euphony are (negatively) correlated; roughness and unpleasantness are (positively) correlated, but: sensory euphony and unpleasantness are not correlated. Daniel moreover states: "this points to a significant difference between the opposite pairs *pleasant – unpleasant* and *euphonious – dissonant*". Daniel does not further delve into the subjects of pleasant dissonances or unpleasant consonances. It is now difficult, though, to repress the question of: what actually do subjects judge when asked about the consonance of a musical chord? Is it the pleasantness … or the euphony?

It is not a wonder that already 50 years ago Michael Dachs[4] arrived at this rationale: *in context, a consonating interval often gains a dissonant meaning*. Around the same time, Simbriger/Zehelein opine: *There is barely a second problem that would be as controversial in modern acoustics as that of consonance and dissonance*. While 50 years of supplemental research have considerably widened the body of knowledge available back then, an algorithm for calculating consonance that is at the same time manageable to the musician could still not be made available. Which is not necessarily a disadvantage: if you can feel it, you can play it. Oh yeah: those musicians, always having a solution at hand. And if you can't make it, fake it.

♣ Roederer J.: Physikalische und psychoakustische Grundlagen der Musik, Springer 1999.

[1] Z.B. H. Grabner, Handbuch der funktionellen Harmonielehre, Max Hesses, Berlin 1950.

[2] Z.B. F. Haunschild, Die neue Harmonielehre, AMA, Brühl 1998.

[3] Z.B. P. Daniel: Berechnung und kategoriale Beurteilung der Rauhigkeit und Unangenehmheit von synthetischen und natürlichen Schallen, Universität Oldenburg, 1995.

[4] M. Dachs: Harmonielehre, Kösel 1948.