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Open Peer Commentary

Commentary on 'Effects of learning on dissonance judgments'

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The authors present an overview of research on the perception of consonance and dissonance. They focus on sensory aspects like roughness of isolated chords, being aware of the fact that musical consonance/dissonance is also related to the function of intervals in a musical context. This aspect is discussed in chapter 4 of the paper. However, the main point of the paper is to show that sensory consonance/dissonance is coupled with positive and negative emotional valence and that the emotional response can be changed by exposure especially to dissonant chords.

In the introduction, the authors discuss several theories of sensory consonance /dissonance starting with the ancient theory of simple proportions of consonant intervals. Hermann von Helmholtz is mentioned as the first author who stressed the role of beatings between harmonics of the tones of an interval. It is correct that Helmholtz presented the first elaborated theory of the role of hearing mechanism in consonance/dissonance perception. However, as early as in 1747 Georg Andreas Sorge shifted the argumentation from interval proportions to interactions between harmonics of the sounds, thus recommending not to use e.g. the interval of a fifth (seen as a perfect consonance) in low registers of a composition (Sorge, 1747, 334-335). Other theories mentioned in this chapter are Carl Stumpf's theory of "Verschmelzung" which is related to the newer theory of harmonicity which means the fit of a complex sound to a single harmonic series.

In the first chapter, the authors discuss theories that postulate an inborn preference for consonant intervals with humans. They argue that even if young infants already show a preference for consonant sounds it cannot be concluded that this is based on an inborn preference since even short time exposure to music may have an influence on preference judgments. Indeed, the nature/nurture question with music listening cannot be answered satisfactorily as long as we know little about the listening experience of embryos.

The second chapter deals with the influence of learning on perception of consonance and dissonance. A report of several experimental studies is given. However, there is a paradox not discussed by the authors. On the one hand, experimental studies showed that repeated exposure to special sounds (e.g. to quarter tone intervals) has an

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influence on the emotional response in a way that sounds with an initial negative response are evaluated more positively after having become more familiar. On the other hand, expert listeners like musicians who are acquainted with different styles of music are more sensitive to dissonant sounds than non-musicians. This is corroborated by research on the so-called clash of keys, which means that a piece of music is played simultaneously in two keys, e.g. C-major and C#-major. Experts are more sensitive to clashes of keys than non-experts. In addition, sensitivity is different for different musical styles (Kopiez & Platz, 2009). Obviously musical training which leads to a better perceptual discrimination of sounds interacts with mere exposure to a certain kind of sounds resulting in more familiarity. So, the term "learning" should be used more carefully. When it comes to music, sensory dissonance may be less prominent than in isolated sounds because of contextual effects.

In chapter 3, the authors give a report of some research of neural correlates of consonance/dissonance perception, in chapter 4 they deal with the functional aspects of musical intervals and chords. It should be mentioned that already Carl Stumpf differentiated between sensory and functional aspects of consonance and dissonance. For the latter ones he coined the terms "Konkordanz" and "Diskordanz" (Stumpf, 1911).

Commentary on ‘Effects of learning on dissonance judgments’

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Omigie, Dellacherie, and Samson provide a thoughtful and welcome review of the empirical literature on consonance and dissonance. Over the decades, dissonance research has reached an intimidating level of complexity that discourages many interested scholars from pursuing pertinent research. Their article offers a spirited proposal for dissonance as primarily a learned phenomenon. I agree with much in this review, but a commentary should necessarily focus on problems.

All biological processes involve some interaction with an environment, so the concept of “innate” behaviors has appropriately fallen by the wayside. Nevertheless, there are compelling reasons to suggest that some auditory behaviors are biologically prepared.

Consider, for a moment, the case of visual annoyance. If a person obscures your vision by placing a hand in front of your face, you are likely to become annoyed. Similarly, an out-of-focus film will evoke irritation. Driving in the direction of the setting sun is unpleasant, and entering a dark cave will evoke mild fear. There are excellent reasons why we should experience irritation when we encounter obstruction, unfocus, glare, or darkness. In each case, the sensory capacity is compromised. The negative feelings motivate us to take actions that restore full or partial vision.

Similar phenomena should be expected in audition. Masking is just one example of how one sound can interfere with our ability to perceive other sounds. As in vision, there are compelling reasons why certain circumstances might evoke irritation, since these feelings motivate actions that restore the sensory capacity. Moreover, like obstruction, focus, glare, and darkness, we might expect several different forms of sensory-engendered degradation of the auditory system, each capable of evoking mild annoyance. (Of course, like spicy food, we might also expect subsequent learning to lead sometimes to enjoyment.)

The overarching question is "Why would any sound ever evoke a limbic response?" As chronicled in Huron (2006), there are excellent biological reasons why animals should prefer predictable sounds. Consequently, we ought to expect familiarity (and hence learning) to play a major role in valenced assessments of sounds. But familiarity is not the only pertinent mechanism.

One major claim by the authors supporting learning is the comparative sensitivity of musicians to consonance and dissonance compared with non-musicians. However, the causality here may be reversed. It is reasonable to suppose that people tend to become musicians (or music lovers) because they are more reactive to musical stimuli. Learning is not the slam-dunk argument it might appear to be.

The nub of the issue is evident in the authors' concluding appeal to *parsimony* in arguing for the primacy of learning. In general, the principle of parsimony (the idea that the simplest explanation is probably right) has served science well. The outstanding exception is biology, where Nature has no difficulty with excessive complication. In biology, the simplest explanation is rarely correct.

If I could offer one piece of advice to future researchers addressing consonance and dissonance: don't assume that dissonance is one phenomenon. For more than half a century we have possessed very good empirical evidence that there are several distinct phenomena involved (e.g., Van de Geer *et al.,* 1962). There are plenty of both biological and cultural reasons why some sounds might be preferred over others.

Commentary on 'Effects of learning on dissonance judgments'

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The paper by Omigie, Dellacherie and Sampson provides a good and well-written overview of the different models and empirical evidence relating to the perception of sensory consonance and dissonance and the question whether these perceptions and the corresponding pleasantness/unpleasantness judgements are innate or learned. The authors define sensory dissonance as 'an unpleasant sensation induced by the simultaneous presentation of two sounds' and at the same time distinguish sensory dissonance from musical dissonance which they describe as pleasantness judgments of sounds given their musical contexts and which is only covered to a lesser degree in the review. This review will be a valuable text for university-level teaching as well as a reference source for further research in this area. I would have liked to see the psychoacoustic strand of research presented in a slightly more detailed way, for example including the equations and functions (by Greenwood, 1961; Plomp & Levelt, 1965; Glasberg & Moore, 1990; Greenwood, 1991) that describe a precise relationship between critical bandwidth (and the mechanics of the cochlear) and dissonance perception. Equations and mathematical functions allow the specification of very precise hypotheses in future experiments and can be of enormous help to decide between competing models. Building on this, one very interesting avenue of future research might be to re-parametrize psychoacoustic models of dissonance perception (e.g. Greenwood, 1961; Plomp & Levelt, 1965) by introducing parameters that reflect individual differences, e.g. musical training, pure tone discrimination thresholds, age or the degree of listening engagement for particular musical styles. It then becomes an empirical question (that could be answered with standard model statistical comparison techniques) whether and which individual differences parameters are necessary to describe human dissonance perception more accurately than standard models that just rely on simple averages across all participants. Extending the existing psychoacoustic models by introducing continuous parameters can lead to a more comprehensive understanding of dissonance perception than evidence just derived from simple group comparisons (think: the standard musician vs non-musician distinction) that do not allow to generalize findings for all levels of an individual differences factor. However, combining psychoacoustic models with individual differences research requires the recruitment and testing of large samples of participants; and to make it worse, testing over the internet might not be feasible for psychoacoustic experiments where testing conditions for all participants usually need to be highly controlled. Thus, this means that it might be necessary to bundle efforts across different research groups and run much larger lab studies than is common in this area which, of course, bears the danger that it affects the publication output (i.e. #papers / year) of the involved researchers negatively – a prospect that might not be overly popular with everyone. But in the long run, bundling efforts and testing (and replicating) more comprehensive models on larger samples might have benefits for this research area as a whole (for a similar argument see Frieler et al., 2013).

Interference, harmonicity, and well-formedness: A Response to 'Effects of learning on dissonance judgments'

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Within critical bands, various musical idioms have employed interference between fundamental frequencies as an expressive resource. On one hand, Balinese metallophones have featured *penjorog*, i.e., beating at rates <~15 Hz (comparable to vibrato rates in such non-fixed-frequency sources as the human voice and violin). On the other hand, roughness at rates >~15 Hz has been prominent in vocal polyphonic idioms in such regions as eastern Europe.

Studies cited by Omigie et al. have identified gradations of harmonicity, which appears greatest in interference-free perfect primes and perfect octaves. Around its peak value, which generally corresponds to a small-whole-number fundamental-frequency ratio, each harmonicity gradation comprises a dispersion of harmonicity.

Between such peak values are the following well-documented intervals:

- ~720+ cents in ‘equipentatonic’ (e.g., *sléndro*) ‘5ths’ of Bali, Central Java, and the Ganda of Uganda,
- ~533+ cents in *pélog* 5ths of Bali and Central Java,
- ~343+ cents in ‘equiheptatonic’ 3rds of Thailand, Myanmar, and the ’Are’Are in the Solomon Islands.

Do such intervals, whose magnitudes are between harmonicity peaks, have low probabilities of resulting in harmonicity responses? Or is there another way of accounting for their use?

Common to each of the scales that comprise the between-peak intervals just mentioned is an intervallic structure Norman Carey and David Clampitt (1989) have termed ‘well-formed’. Carey and Clampitt employed a single real-number fundamental-frequency ratio for each of the intervals in each scale that illustrates their formulation of well-formedness. Nonetheless, one can generalize their formulation by identifying each ‘generic-specific’ interval-class with all the intervals that a) span a particular number of steps and b) have as their fundamental-frequency ratios values that are smaller than the fundamental-frequency ratios of all the intervals in certain other interval-classes.

Such well-formed structures maximize the total number of interval-pairs within particular interval-classes. In abstract, mathematical terms, if d is the number of steps in a register, the number of such interval-pairs is $d^2(d-1)/2$ in ‘degenerate well-formed’ equipentatonic and equiheptatonic scales, and $(d+1)(d)(d-1)/3$ in the remaining, ‘non-degenerate well-formed’ scales considered above.

Of consequence for the studies Omigie et al., the diatonic scale is non-degenerate well-formed, as is the ‘usual’ pentatonic (e.g., CDEGA). Since these scales comprise intervals that also maximize harmonicity, well-formedness can be considered consistent with harmonicity. Further, since well-formedness characterizes more scales and is applicable to both polyphonic/multisonant and monophonic textures, its empirical scope is much greater than harmonicity’s.

Accordingly, one can regard harmonicity as a special feature of certain non-degenerate well-formed scales. Moreover, just as various kinds and degrees of interference can combine in musical practice with various degrees of harmonicity, so too can particular scales realize various multiplicities of interval-pairs within interval-classes. E.g., ascending melodic-minor (or the 'acoustic' scale in jazz theory) comprises fewer interval-pairs within particular interval-classes than diatonic, whereas harmonic-minor and harmonic-major scales comprise fewer than ascending melodic-minor. Finally, one can conclude that multiplicity of interval-pairs within particular interval-classes constitutes a parsimonious formulation of interval usage and provides a framework for considering the use of intervals in music over the centuries and *around the globe*.

Commentary on 'Effects of learning on dissonance judgments'

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This review, well researched and convincingly presented, documents research evidence that learning and memory processes play roles in emotional judgments of dissonance. Citing many methodologies, the authors contend that exposure, familiarity, and explicit training affect such judgments. Literature ranges from Helmholtz (1870) to the present, covering animal, infant, child, and adult studies, and making cogent connections between studies. This connectedness supports a concluding statement about "the relevance of complementary methodologies … in addressing" an age-old question—the origins of listeners' aversion to dissonance.

As a teaching musician, and psychology of music researcher, this commentator's concern is with valid connections to musical practice. Music perception researchers' collaborations with musicians have led, among other benefits, to more accurate terminology, which improves communication of findings. Shared terminology is fruitful; faulty terminology is confusing.

The introduction speaks of dissonant "chords", but text reveals that these stimuli comprised only two sounds, i.e., "intervals", or dyads. For musicians, it takes three notes to make a chord. To translate this review for colleagues, one would say "interval" for all two-sound stimuli. (The authors themselves avoid the word "chord" towards the end of the text.)

The authors cite the distinction between *sensory* dissonance, and *musical* dissonance in context; but use the same terms-- pleasant/unpleasant—for both. Musical dissonance might better have been termed "stable/unstable", the effect understood by most euro-classical musicians to be the core of dissonance: not whether a vertical simultaneity is unpleasant, but whether it needs to resolve to a more stable structure. Perhaps this is one reason why musicians are more sensitive to dissonances than non-musicians; we're trained to spot them in order to resolve them. Note that this argument echoes Cazden (p 16), concurs with the report that judgment of dissonance in context is particularly susceptible to acculturation, and supports the authors' view that training impacts judgments of dissonance.

There are surprisingly few suggestions as to future research. A survey of increased use of dissonance by composers, over time, is one. Other ideas could include: A study of modification of listeners' tolerance of dissonance via iPod; a study of the impact of music appreciation courses on listener's understanding of and tolerance for dissonance; etc. Perhaps, given the importance of emotional valence in the article, one could study the emotional tone of learning experiences themselves. Does learning with a positive, enthusiastic teacher who adores dissonances (and whom one adores) make one less averse to dissonance?

Karpinski (2000, pp 115 – 116) explains *why* it is important for musicians to perceive dissonance. Perhaps listeners would have a richer experience of music if they better understood what dissonance contributes to music. This is meant as a vote of support for the authors' statement that "a parsimonious theory of dissonance should incorporate learning and memory processes". Might this expand to "learning, enculturation, memory processes, and emotional associations"?

Authors' Response

Deconstructing dissonance: The multifaceted role of learning

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We thank the authors of the commentaries for not only drawing our attention to details overlooked but also for considerably broadening the discussion to include several new players, notably music pedagogics, ethnomusicologists and ethologists. Perhaps most importantly, the contributions clearly and explicitly suggest a range of new empirical investigations that are extremely feasible and potentially very fruitful for a deeper understanding of the current issue.

Our aim with the original article was to provide a synthesis of recent research showing an influence on dissonance judgments of what we termed 'learning' - this, via a quick look at the main working hypotheses, through history, as to how and why the experience of dissonance arises. Amongst other things, our commentators introduce us to less known historical details about the evolution of these hypotheses (Aufhagen), suggest alternative accounts of the experience of dissonance (Rahn), and further, remind us that just as dissonance may be considered 'more than one phenomenon' (Huron), so also can the notion of learning, while seemingly easily circumscribable, be taken to encompass a plethora of different phenomena. As always, it becomes clear that only through the process of deconstructing the terms used in describing a problem (and identifying their many different facets) can we reach our ultimate aim of better understanding a given phenomenon.

In Music Cognition research, and specifically when considering emotional responses to music, it is typical to draw a distinction between 'intra-musical' and 'extra-musical' factors. Beckett calls attention to at least one aspect of learning that we do not refer to which is 'learning to like' based on positive associations - the '*emotional tone during learning*'. She suggests that the enthusiasm of a teacher that is passionate about dissonance may be contagious and open up an unrivaled degree of interest in, as well as tolerance and openness to, sensory dissonance - a type of learning that is possibly even quicker to take effect than passive exposure. Influences such as an especially influential mentor are extra-musical in that they do not arise from the normal interaction of the physical properties of the sound and the organ of hearing. They may also be considered top down or knowledge-based factors. Importantly, such factors are generally held to influence aesthetic appreciation and their role in moulding responses to dissonance is very plausible.

The influence of environmental effects on our response to dissonance has been strongly emphasised in recent years. However, Huron reminds us not to downplay the likely very important role of biological predispositions. The notion that 'auditory behaviours' may be 'biologically prepared' is compellingly illustrated through his use of examples from the visual domain. By drawing parallels between the perception of rough sounds and the visual irritation that arises in cases of 'obstruction, lack of focus, glare and darkness', he reminds us that we tend not to welcome those experiences that prove a challenge to our sensory capacities. Extending the notion of preparedness (or a lack thereof) to the level of the individual, he raises the possibility that observed differences between musicians and non-musicians in terms of their responses to dissonance may have biological origins. However, with this suggestion that an innate sensitivity might be what drives musicians to become so Huron harks back to a well-known issue that is increasingly being addressed. It seems safe to say that the answer to this question (whether musicians show differences because of the training they have undergone or become musicians because of predispositions) will become clearer with the increasingly greater employment of longitudinal studies that examine musical perception and production abilities over time.

In his synthesis of our article, Auhagen draws attention to the paradox whereby what we generally refer to as 'learning' seems to lead to both a greater perceptual sensitivity to dissonance (as seen in musicians) as well as a greater acceptance of it (as seen in the early experiments demonstrating the mere exposure effect). What becomes clear here is that the nature of the interaction between increased perceptual ability and musical knowledge matters. It is perhaps understandable that those highly trained to detect sensory dissonance (musicians) will show a heightened response to it in an experimental context when compared to non-musicians. These same individuals, however, will also be expected to have a different response when listening to real music, where dissonance plays an aesthetic role. As we stated in the original article, the utility of studying responses to sensory dissonance when the main goal is to study real music has been questioned (Cazden, 1980). However, Beckett draws our attention to a possible relevance, namely that the hypersensitivity to sensory dissonance that musicians develop might also result in a greater sensitivity to musical dissonance. Thus the reductionist study of the unit may not be trivial. Indeed, the extent to which a greater sensitivity to sensory dissonance may lead to a ‘richer experience of music‘ (via a better appreciation of musical dissonance) is an empirical question that should be embarked on and for which, we have no scientific evidence as yet.

Consideration of the commentators’ contributions greatly expands our historical and geographical borders in thinking about dissonance. Auhagen, reminds us that the workers on this question have been numerous, with some being less acknowledged today than others. We are informed that precursors of the newer theory of harmonicity (or at least the tendency to emphasise harmonic interactions rather than interval proportions) go back even further than previously appreciated to Georg Andreas Sorge, a contemporary of J. S Bach. Similarly Rahn reminds us of the universal use of ‘interference between fundamental frequencies’ as an ‘expressive resource’ citing specific intervals prominent in music from Uganda, Bali and Myanmur to name a few. In so doing he also opens the floor to a consideration of the concept of ‘well-formedness’ (Carey and Clampitt, 1989) as an alternative to the theory of Harmonicity. Rahn points out that given that the property of well-formedness is characteristic of more scales than the property of harmonicity (which may be considered a ‘feature of certain non-degenerate well formed scales’), a theory based on the former may provide a better model of our responses to dissonance than the latter. Rahn’s proposition that the well-formedness account may facilitate understanding of the use of intervals in music ‘over the centuries and around the globe’ certainly appeals to our ultimate aim, however potentially misguided, of finding a degree of parsimony in our explanation of how dissonance is experienced.

How do we move forward? Several new experiment ideas spring to mind but always useful is a model-based approach that allows predictions to be made and competing ideas to be decided between. Here, we completely agree with Müllensiefen that the revisiting of classical formulas and functions armed with large amounts of empirical data that can be used to reparametrise them, would present a very useful and fruitful direction. Müllensiefen alludes to norms in research practices that would discourage the necessarily combined efforts required to collect such data. However the potential advantages of such an approach for the current research question are considerable and with reforms in publishing and an ever-increasing appreciation of the power of ‘big data’ such approaches may become more viable.

Finally, the amount that has been written on dissonance across different disciplines is considerable and it clearly poses a challenge to keep on top of the ever-swiftening speed of knowledge documentation. However we argue that engagement with a variety of sources will always be useful with a problem like the current one. One thing that can facilitate exchange across disciplines is a resolute emphasis on clarity of concept. Interdisciplinary approaches to a problem will only be fruitful when workers are able to establish a means of mapping a relationship between terms or jargon commonly used in the different disciplines (Poeppel, 2005). This will involve deconstructing terms often taken for granted in the respective disciplines. It will also involve weighing up what within each discipline constitutes useful content for consideration outside that discipline so that the level of complexity as seen by an outsider will be that much less intimidating.

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