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'False Relations': Hermann von Helmholtz's Study of Music and the Delineation of Nineteenth-Century Physiology

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This article discusses the delineation between physiology and music theory in Hermann von Helmholtz's On the Sensations of Tone as a Physiological Basis for the Theory of Music *(1863). It takes the phenomenon of 'false relations' as a point of departure to question the methodology Helmholtz devised to study music and hearing. The key to understanding this experimental method is the concept of 'controlled deviation', which is substantiated in two main sections. After providing some background information on the history of music theory, the first section explores 'false relations' within the context of physiological experimentation and hydrodynamics, the two most important areas of Helmholtz's scientific research. The second section of the article is centred on the experimental methods of Helmholtz as used in his investigation of vision and hearing. More specifically, it introduces notions of distortion, defamiliarization and deviation to distinguish levels of physiology that relate to the body and to cognition. As it turns out, music posed specific problems for the researcher. Beyond the ephemerality of sound, the malleability of hearing and of musical aesthetics proved even more of an obstacle for controlled experimentation. The article concludes with a discussion of Hugo Riemann, who continued to explore the central finding of Helmholtz, namely that the rules of music change due to the habits of the listener.*

Introduction

Hermann von Helmholtz concludes his book *On the Sensations of Tone as a Physiological Basis for the Theory of Music* (1863) with the following remark: 'It appears to me that I have carried [my work] as far as the physiological properties of the sensation of hearing exercise a direct influence on the construction of a musical system, that is, as far as the work especially belongs to natural philosophy'.[1]

I wish to thank the editor of this collection of articles, Mark A. Pottinger, for his immense support as well as the anonymous reviewers for their helpful comments.

[1] Hermann L.F. Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music*, trans. by Alexander J. Ellis (London: Longmans, Green, 1875): 577. For the German

Others after him would have to answer how music can arouse emotions and feelings of aesthetic pleasure in the listener. Declaring himself 'too much of an amateur', he preferred the 'safe ground'[2] of the natural sciences.

When this passage was written, there had been a major change in the relationship between physiology and medicine. Physiology, defined in the *Oxford English Dictionary* as 'the branch of science that deals with the normal functioning of living organisms and their systems and organs', now took the lead in a process of 'scientification' of the life sciences, including medicine. French historical epistemologists Michel Foucault and Georges Canguilhem have delineated this shift. According to Foucault, it manifested itself in the 'effort to define a physiology of the morbid phenomenon'.[3] Disease began to be understood as traceable and measurable, and physiology became the frame of reference to carry out this investigation. Physiology, in turn, adopted experimentation as the main methodological tool. As Canguilhem argues, this paved the way for the formation of 'authentically biological concepts'.[4] Thus, rather than speculating about the various functions of the organs that anatomists detected through post-mortem dissection, physiologists now were able to reproduce and manipulate genuine physiological phenomena through laboratory experimentation. Physiology eventually obtained the status of a laboratory-based science, which provided a model for other life sciences.

Although Helmholtz received training as a military surgeon, his contributions to the 'scientification' of medicine took place in experimental physiology rather than in actual medical care. Unable to do much for his patients, he escaped into the laboratory whenever he could. During his service as army medical doctor, which he had to complete in order to pay back the full cost of his education, he joined a group of young scholars who pushed the development of physiology towards experimentation, seeking to bring it as close as possible to the standards and methods of the natural sciences. This 'bunch of twenty-somethings without position or recognition'[5] were the founders of the Berlin Physical Society (*Physikalische Gesellschaft zu Berlin*). They attempted to explain nature, including bodily functions, through physics and chemistry, and not through notions of a specific life force.[6]

In 1848, thanks to the intervention of Alexander von Humboldt, Helmholtz was freed from his military service and accepted a position as a teacher of anatomy at the Berlin Academy of the Arts. Further positions as professor of physiology were soon to follow. Helmholtz's invention in 1851 of the ophthalmoscope, a device

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original, see H. Helmholtz, *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* (Braunschweig: F. Vieweg, 1863): 560: 'Ich schliesse hiermit meine Arbeit. So viel ich übersehe, habe ich sie so weit fortgeführt, als die physiologischen Eigenthümlichkeiten der Gehörempfindung einen directen Einfluss auf die Construction des musikalischen Systems ausüben, so weit als die Arbeit hauptsächlich einem Naturforscher zufallen musste.'

2 Helmholtz, *On the Sensations of Tone*, 578.

3 Michel Foucault, *The Birth of the Clinic: An Archeology of Medical Perception* (London: Routledge, 1973): 188.

4 Georges Canguilhem, 'Experimentation in Animal Biology', in *Knowledge of Life*, ed. Paola Marrati and Todd Meyers, trans. Stefanos Geroulanos and Daniela Ginsburg (New York: Fordham University Press, 2008): 6.

5 M. Norton Wise, *Aesthetics, Industry, and Science: Hermann von Helmholtz and the Berlin Physical Society* (Chicago: University of Chicago Press, 2018): ix.

6 For a general biography of Helmholtz's life and career see David Cahan, *Helmholtz: A Life in Science* (Chicago: University of Chicago Press, 2018); on Helmholtz's medical studies and his rejection of vitalism, see, in particular, 39–53.

used to examine the interior surface of the eye, distinguished him as a competent sensory physiologist, whereupon he was entrusted with the authorship of a volume on 'physiological optics' for a handbook series on physics by the Leipzig-based publisher Voss.

From Königsberg, where Helmholtz was appointed professor of physiology in 1849, he moved on to Bonn in 1855 to become professor of physiology and anatomy. Unhappy with the research conditions and the inferior state of his laboratory, he turned to a new topic and delved into the study of hearing. After leaving Bonn, he arrived at Heidelberg University (1858–71), where he finalized two lengthy treatises: one on vision and one on hearing. *On the Sensations of Tone* came out in 1863, while the *Treatise on Physiological Optics* (*Handbuch der physiologischen Optik*) was published in 1867. He was eventually called back to Berlin in 1871 to the chair of physics at the University of Berlin. There he became president of the *Physikalische Gesellschaft* in 1878 – one year after his final revision of *On the Sensations of Tone* – and initiator and first president of the *Physikalisch-Technische Reichsanstalt* (State Institute of Physics and Technology) in 1888. He died in 1894. In his posthumously published lectures while at the University of Berlin, physiology is never mentioned.

The shift in the life sciences towards experimentation also put the supposed relationship between the arts and the sciences up for discussion, as Helmholtz's opening remark in the preface to *On the Sensations of Tone* demonstrates:

> In the present work an attempt will be made to form a connection between the boundaries of two sciences which, although drawn together by many natural relations, have hitherto remained sufficiently distinct – the boundaries of physical and physiological acoustics on the one side, and of musical science and esthetics on the other.[7]

The claim in fact anticipated a division that was not yet so securely defined. Neither 'physical and physiological acoustics', nor 'musical science and esthetics' were as rigidly delineated as Helmholtz suggested. Helmholtz in fact contributed to the separation of these fields as we know them today.[8] He systematized the knowledge on acoustics with unprecedented rigor, using the term 'Musikwissenschaft' for the first time in the same sense that it would acquire through the foundation of the journal *Vierteljahrsschrift für Musikwissenschaft* by Guido Adler, Friedrich Chrysander and Philipp Spitta in 1885. Most importantly, Helmholtz criticized the fact that prior to his work the role of the human body was not explored in relation to understanding sound. Sound is what we hear, he argued. As such, it is a product of the body, not a specific kind of vibration that the body only channels to the mind. As a consequence, music depended on the body as well. Helmholtz therefore considered sensory physiology the one field

[7] Helmholtz, *On the Sensations of Tone*, 1. Unable to draw upon a university discipline that dealt with music, Alexander Ellis translated '*Musikwissenschaft*' aptly as 'musical science'.

[8] In a similar way, he re-defined and then distributed the terms in the debate about nativism and empiricism, as historian of science Richard L. Kremer has shown, see his 'Innovation through Synthesis: Helmholtz and Color Research', in *Hermann von Helmholtz and the Foundations of Nineteenth-Century Science*, ed. David Cahan (Berkeley: University of California Press, 1993): 205–58.

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that could successfully grasp the body's role in defining sound and thus, to a certain extent, music.

Helmholtz's introduction of the body into musical discourse needs to be accompanied with some cautioning remarks. First, the body, of course, figured prominently in earlier notions of music and auditory sensation. Eighteenth-century concepts of the continuous chain of unique bodies that touch one another – for example, from the string to the key to the body of the player – placed emphasis on bodily aspects within music. Vibration was also seen as part of that continuity, and it extended to the nerves that were equally conceived of as vibrating in this older physiology of musical sound and hearing.[9] Auditory physiology, however, stagnated for almost half a century after anatomists abolished the concept of vibrating nerves, without developing a new hypothesis for the process of hearing.[10] Parallel to this insecurity in auditory physiology, musical aesthetics rejected the idea that listening could be explained through medical knowledge of the body.[11]

A second cautionary remark needs to be made on the fact that Helmholtz did not investigate 'music for music's sake'. Music theory, although figuring prominently in the title of his book, was incompatible with the epistemic structure of physiology as a natural science. As Carl Dahlhaus has argued, music theory is a system only in the sense that it imposes a set of rules. Rather than appealing to reason or natural laws, music theory then resorts to conventional (or, in the words of Dahlhaus, 'dogmatic') rules.[12] Although Helmholtz took it upon himself to investigate how music is heard – as opposed to his treatise on optics, *On the Sensations of Tone* was not commissioned – it was not his main goal to explain music through knowledge of the body. Instead, the book is part of a larger enterprise in sensory physiology. That enterprise stretches from his first investigations in nerve physiology, which showed that nerve impulse propagation is too slow to match with the fine-grained differences in frequency that hearing is able to perform, up to the paper on 'Facts in Perception' from 1878, in which he argued that the perception of the outside world consisted in processing the data that the body produces on the basis of a structural analogy.[13] Music, for its part, helped Helmholtz investigate

[9] On this see the excellent summaries in Wolfgang Scherer, *Klavier-Spiele. Die Psychotechnik der Klaviere im 18. und 19. Jahrhundert* (Munich: Fink, 1989); Caroline Welsh, 'Die "Stimmung" im Spannungsfeld zwischen Natur- und Geisteswissenschaften: Ein Blick auf deren Trennungsgeschichte aus der Perspektive einer Denkfigur', *NTM. Zeitschrift für Geschichte der Wissenschaften, Technik und Medizin* 17 (2009): 135–69; ead., 'Nerven – Saiten – Stimmung; Zur Karriere einer Denkfigur zwischen Musik und Wissenschaft 1750–1850', *Berichte zur Wissenschaftsgeschichte* 31/2 (2008): 113–29.

[10] For a historical overview of physiological concepts of hearing from early modernity up to Helmholtz and on the stagnation in hypothesis formation in relation to, for instance, Xavier Bichat's theory of continuous tissues and Antonio Scarpa's anatomical description of the organ of hearing, see Julia Kursell, *Epistemologie des Hörens: Helmholtz' physiologische Grundlegung der Musiktheorie* (Paderborn: Fink, 2018): especially 212–19.

[11] See on this James Kennaway, 'Music and the Body in the History of Medicine', in *The Oxford Handbook of Music and the Body*, ed. Youn Kim and Sander L. Gilman (New York: Oxford University Press, 2019): 333–48.

[12] Carl Dahlhaus, 'Hermann von Helmholtz und der Wissenschaftscharakter der Musiktheorie', in *Über Musiktheorie. Referate der Arbeitstagung 1970 in Berlin*, ed. Frieder Zaminer (Köln: Arno Volk, 1970): 49–58.

[13] On the latter concept see, for instance, Michael Friedman, 'Helmholtz's Zeichentheorie and Schlick's Allgemeine Erkenntnislehre: Early Logical Empiricism and Its Nineteenth-Century Background', *Philosophical Topics* 25/2 (1997): 19–50; for a critical review

how the body functions, even though his readers found his work to enrich their understanding of music.[14]

The third and final cautionary remark is that, although the presence of music in the book in many places pushed the argument beyond the scope of the physiologist, this does not necessarily make Helmholtz a precursor of twentieth-century psychoacoustics. The historical account of Edwin G. Boring, in which Helmholtz figured as a psychologist, established for too long the emergence of psychoacoustics in the nineteenth century with the rise of experimental physiology.[15] Although part of the same trend towards experimentation as physiology, psychophysics treated the body as a 'black box', using physical stimuli to measure psychological sensations. So, in this sense, psychoacoustics studied everything *but* the actual body.

How, then, did Helmholtz's book reconcile music theory's dogmatic character with the systematic nature of physiology? To address this question, we can look at one of the last topics that Helmholtz tackled in the realm of hearing: 'false relations'. The term seems to stand for the ambiguity that was inherent in the physiological inquiry of music: it points us to the parting of ways between the exploration of biological concepts in the sense of Canguilhem, that is to say concepts that can be based on experimental knowledge, and the study of tonal relations in music. Yet, as a term it also seems awkward. For Helmholtz, physiology was able to explain why some sensations were unpleasant, yet it could not explain how one could declare something to be 'false', let alone a mistake. The notion that Helmholtz used in the original German, *unharmonischer Querstand*, which literally translates to 'non-harmonic cross position', points to no less a problem when considering the reconfiguration of bodily knowledge that Helmholtz is suggesting. His pursuit to understand the sensation of hearing and the role of the body in music stands between two periods that frame nineteenth-century music theory: on the one hand, the shift during the eighteenth century from individual parts to chords in order to conceive polyphonic harmony and, on the other, what some have termed a breakdown of tonality, or better yet, a shift from harmony to sound after 1900.

This article takes the phenomenon of 'false relations' as a point of departure to question the methodology Helmholtz devised in his study of sensory perception. As I will demonstrate, by introducing a new experimental method for the study of the senses, Helmholtz's physiological knowledge helped to reconfigure musical knowledge. The key to understanding this experimental method consists in controlled deviation, which will be substantiated in two main sections below.

of the theory see Lorraine Daston and Peter Galison *Objectivity* (New York: Zone Books, 2007): chapter "Objectivity without Images", 253–62. On Helmholtz's nerve physiology see Henning Schmidgen, *The Helmholtz Curves. Tracing Lost Time*, trans. Nils F. Scott (New York: Fordham University Press, 2014); id., *Hirn und Zeit: Die Geschichte eines Experiments, 1800–1950* (Berlin: Matthes und Seitz, 2014); for a comparison between vision and hearing in Helmholtz's sensory physiology see Timothy Lenoir, 'Helmholtz and the Materialities of Communication', *Osiris* 9 (1994): 184–207 and Kursell, *Epistemologie des Hörens*, chapter 'Experimentalisierung der Wahrnehmung', 257–81.

[14] I agree with Céline Vautrin in this respect, see her preface to *Helmholtz, du son à la musique*, ed. Céline Vautrin, Patrice Bailhache and Antonia Soulez (Paris: J. Vrin, 2011).

[15] Edwin G[arrigues] Boring, *A History of Experimental Psychology*, 2nd ed. (New York: Appleton-Century-Crofts, 1950) and *Sensation and Perception in the History of Experimental Psychology* (New York: Appleton-Century-Crofts, 1942). For an opposing narrative, see Erwin Hiebert, *The Helmholtz Legacy in Physiological Acoustics* (Cham: Springer, 2014).

The first section explains how Helmholtz tweaks the discourse on 'false relations'. To show this, I introduce historical examples from music encyclopaedias that preceded his work. I will then analyse certain contradictions in his explanation of 'false relations' and show how he imposed a completely new vocabulary in his descriptions of music that take inspiration from the rise of the natural sciences and industrialization in nineteenth century society. This section mainly relies on a close reading of the primary texts rather than any new source material.

The second section discusses the experimental method Helmholtz used when integrating music into his auditory physiology. Starting from his search for subjective phenomena in hearing, this section explains in more detail the methodological function of sonic distortion for Helmholtz. 'False relations' are the point of departure for this, insofar as they can be related to the role of deception and illusion in the study of perception. This section will also provide some background information on mid-nineteenth-century experimental physiology. Finally, Helmholtz's method for studying hearing is compared to the method he used in his study of vision.

The final section of the article briefly discusses Hugo Riemann's definition of false relations. Although Riemann explicitly turned away from what he thought to be Helmholtz's physiological foundation for music theory, he confirmed a new attitude towards 'rule breaking' in music composition that Helmholtz's physiology of hearing prepared.

Part One: Non-harmonic Cross Relations

Historical Context

In the penultimate chapter of Helmholtz's *On the Sensations of Tone* we read: 'What the singer finds a difficulty in hitting, must naturally also appear an unusual and forced skip to the hearer'.[16] What Helmholtz is referring to here is a phenomenon known in his time as '*unharmonischer Querstand*' or 'non-harmonic cross position'. The term refers to certain sequences of notes that were forbidden according to the rules of musical composition, namely those in which 'two tones in consecutive chords, which belong to different voices, form false Octaves or false Fifths'.[17] This definition (and especially the designation of the intervals as 'false') has its roots in medieval music theory. It stems from the time up to the Renaissance when chromatic steps could occur, but not be notated, at least not without implying additional rules. The rules that clarified how to read the written notes with chromatic steps were known as *musica ficta* or *musica falsa* (fictitious or false music).[18]

'False relations' – the correct English term used in the translation of Helmholtz's book – resulted from a breach of one of those rules: *mi contra fa est diabolus in musica*. That is to say, music that contains two consecutive notes that read as the *fa* and *mi*

[16] Helmholtz, *On the Sensations of Tone*, 562.

[17] Helmholtz, *On the Sensations of Tone*, 562.

[18] The designations of such instances as 'fictitious' or 'false' were sometimes used interchangeably in the medieval sources, see, for example, the explanation of *musica ficta* in the codex of St Emmeram: 'variatio vocum necessaria de tono in semitonium vel e converso per falsam mutationem sive fictam', quoted after *Lexicon musicum latinum medii aevi*, entry 'fingo' (www.woerterbuchnetz.de/LmL?lemma=fingo), cf. also ibid., entry 'falsa', (www.woerterbuchnetz.de/LmL?lemma=falsa) (accessed 19 Sept 2018).

from two different scales in the Guidonian hexachord system constitute an unruly jump between hexachords, resulting in such awkward intervals as the altered octave or the tritone. Neither of these intervals was supposed to occur between two different voices and especially the outer two voices in a polyphonic setting.

The designation of these intervals as 'false' had come down to Helmholtz's own time, as can be seen from the continuation of his text:

> For example, if one voice in the first chord sings *b* and another voice in the next chord sings *b*♭, or the first has c and the second *c*♯, there are false Octave relations. False Fifth relations are forbidden for the extreme voices only. Thus in the first chord the bass has *b*, in the second the soprano has *f*, or conversely, where *b–f* is a false Fifth.[19]

Starting in the eighteenth century, it struck music theorists as inadequate to call such voice relations 'false' or unharmonious. In his *Musikalisches Lexikon* of 1802, Heinrich Christoph Koch stated under the heading '*Unharmonischer Querstand*' that 'no definite rules could be given as to which of the cases of note progression would be objectionable and which admissible'.[20] If one strictly applied the old rules, then a simple progression of thirds had to be considered a mistake. But as this case showed, many instances of false relations could not be avoided in a harmonic setting, nor did they strike anyone as false or ugly. Some instances, Koch conceded, were indeed unpleasant, but 'good composers' (*gute Tonsetzer*) avoided them.[21] He spent most of the entry, though, on specific cases in which the rule was to be abolished.

Koch's article closely resembles the entry in Johann Georg Sulzer's *Allgemeine Theorie der Schönen Künste* (1771–74; General Theory of Fine Arts), authored by Johann Philipp Kirnberger and his pupil Johann Abraham Peter Schulz.[22] Comparing the entries, one notices how graphic markers of performance, such as the treble clef and different-facing note stems, begin to vanish from the music examples, which adumbrates the allegedly neutral piano-inspired setting that later became the standard for music examples in music theory. This indicates a change in the performance medium that was already well under way in the eighteenth century.

More importantly, for the purposes of this discussion, however, we find that listening had gained a new-found status. Both entries prominently emphasize the effect contrapuntal cross relations have on the listener, yet they do so from two different perspectives. The heading for Sulzer's entry presented the qualifier '*Unharmonisch*', which means both non-harmonic and unharmonious, while the term '*Querstand*' (cross relation, false relation) remains unexplained in the body of the text. In Sulzer's *General Theory of Fine Arts*, the clarification of such terminology was not the pressing issue. What was more important was the explanation of

19 Helmholtz, *On the Sensations of Tone*, 562.

20 Heinrich Christoph Koch, *Musikalisches Lexikon* (Frankfurt/M.: August Hermann jr,1802): 1623–25, at 1624. Where not indicated otherwise, translations are my own.

21 Koch, *Musikalisches Lexikon*, 1623.

22 Johann Georg Sulzer, *Allgemeine Theorie der Schönen Künste*, 2 vols (Leipzig: M.G. Weidmanns Erben und Reich, 1771–1774): vol. 2: K–Z, 1202–3. On the question of Kirnberger's and Schulz's authorship see Beverly Jerold, 'Johann Philipp Kirnberger and Authorship', *Notes* 69 (2013): 688–705. Koch's dependence on Sulzer with regard to his aesthetic views is discussed in Nancy Kovaleff Baker, 'The Aesthetic Theories of Heinrich Christoph Koch', *International Review of the Aesthetics and Sociology of Music* 8 (1977): 183–209.

what counted as unruly within the confines of good harmony. Readers were instructed that music had its own system of rules, which sometimes clashed with the common sense or the 'feel' of listeners. Remarkably, for Kirnberger and Schulz cross relations were the only unharmonious phenomena in music worthy of an entry. The fact that he did not find this unharmonious phenomenon unpleasant makes the entry even more remarkable.

Whereas Sulzer addressed an erudite public without musical expertise, Koch in his lexicon addressed the musical expertise of his readers. His lemma '*Unharmonischer Querstand*' refers to terminology in the first instance. In addition, Koch discussed a subset of cross relations that he assumed to be known to the reader as non-harmonic from the outset. The fact that Koch, like Sulzer, spent most of his entry on 'unharmonious cross relations' by listing examples that did not merit disqualification became more of a reason to change the rules rather than to keep them. Koch's book was thus meant to empower his readers to use correct terminology, and, at the same time, he invited them to redefine the rules that governed composition.

If these eighteenth-century music theorists insisted that most of the cross relations called 'false' were in fact tolerable, a reference work from the first half of the nineteenth century does the exact opposite. Ignaz Jeitteles's *Aesthetisches Lexikon* (1837) has an entry '*Unharmonischer Querstand*' as does Koch, but he called the phenomenon straightforwardly 'incorrect'. Notwithstanding its elegant brevity, the explanation he provided rather obscured the matter, for it demonstrated the opacity of musical correctness to the erudite layman.[23] The amateur listener, now the one being addressed, should just trust that the rules of composition would be properly executed in the hands and ears of the experts.

As we come to the time of Helmholtz, we see that his explanation of false relations introduced a new perspective that differs from others of the past. Believing that the chromatic step that implied two different tonal contexts was difficult to sing, Helmholtz concluded:

> The meaning of this rule is, probably, that the singer would find it difficult to hit the new tone which is not in the scale, if he had just heard the next nearest tone of the scale given by another singer. Similarly, when he has to take the false Fifth of a tone which is prominent in present harmony as lowest or highest.[24]

The earlier writers on false relations highlighted the unruliness in strict counterpoint from the medieval writers of theory without any explanation. Their mentioning of any effects on the listener mainly served the discussion of whether the strict rules of counterpoint needed to be updated. Helmholtz, in contrast, did not take the validity of such rules for granted. He looked for an explanation by examining

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23 Ignaz Jeitteles, *Aesthetisches Lexikon. Ein alphabetisches Handbuch zur Theorie der Philosophie des Schönen und der schönen Künste nebst Erklärung der Kunstausdrücke aller ästhetischen Zweige*, vol. 2: L–Z (Vienna: Gerold, 1837): 404: 'unrichtiger Fortgang der Tonstufen, die unter sich in der Tonleiter einen halben Ton ausmachen. Er entsteht, wenn in den beiden Tetrachorden, aus welchen die Octave besteht, diese von den ältern Tonlehrern mit *mi fa* bezeichneten halben Töne nicht correspondiren, getrennt werden, oder ein in der Unterstimme erhöhtes Intervall in der Oberstimme gleich darauf erniedert [!] wird und umgekehrt, wodurch auch erklärt wird, warum eine Fortschreitung mehrer [!] großen Terzen widrig klingt.'

24 Helmholtz, *On the Sensations of Tone*, 562.

the listening effect that a rule produced during a performance. He assumed that the rule originally had responded to the needs of singers and that, as a consequence of the difficulties in singing cross relations, listeners also felt awkward as they sensed the difficulties of the performers, whereby he insinuated that an empathetic bond now developed between listener and singer.

The speculative mode in which he argued, on the one hand, suggests that Helmholtz did not feel entitled to comment on the rules of counterpoint. The question of what was correct or incorrect, on the other hand, did not matter much for his argument. He observed the situation of performance from an outsider's perspective. The authority for both speculation and observation was no longer granted by the system of rules itself. On the contrary, Helmholtz offered up for discussion the entire system of rules and established a new way of examining them. As a result, speculation of a rule system governed by the effects of a performance on the listener appealed to a thought experiment rather than to an actual performance. Singing became part of an experimental setting: it turned into an activity that had to comply with rules different than those of harmony, namely those of scientific observation in the service of controlled experimentation.

Helmholtz's thought experiment implied a number of new aspects that had been absent in the earlier discussions of false relations. Most strikingly, the earlier authors did not invoke sound in their discussion of the rules that governed false relations. They discussed whether certain instances were objectionable or acceptable, and even when they directly addressed the effects of them, they did so only in a double negation. Thus, Sulzer's entry, for instance, reports that a harmonic progression of major thirds was 'rarely considered obnoxious'.[25]

Helmholtz, in contrast, considered the acoustic effects of the note. The fact that the outer voice parts were considered more audible was not mentioned by the earlier authors. The rule seemed to be valid for them without such additional explanation to its sonic effect. From his outsider position as a non-music theorist, however, Helmholtz made this a prominent aspect of his explanation of compositional rules. What is more, the depiction of a hypothetical performance highlighted the immediate effects of sound on performers and listeners. If it was difficult for the imagined performer to hit the right note, then this was owing to the fact that another disturbingly resembling note was present in the chord that the singer heard while heading towards the new note. For the composer and the music theorist this may have seemed self-evident, for the observing experimenter, however, this was crucial. Such a reaction would have to occur every time that this conflict between the notes heard and the notes to be sung occurred to make the situation fit into the rules of his thought experiment. In that case the problem caused by false relations could be said to be a repeatable and independent experience.

On the other hand, the discussion of cross relations placed an emphasis on sequences of notes. It is indeed part of the chapter on voice leading in his book, where it figures as the concluding topic. The entire chapter is characterized by a discussion of harmony that reaches far beyond an empirical investigation of the physical activity of hearing. Nevertheless, this discussion is made to fit with the mainstream physics of Helmholtz's time. He subjected musical harmony to a guiding metaphor that he took from fluid mechanics. Thus, music appeared in his text as 'sound mass' (*Klangmasse*), where a stream of liquid matter was to be kept in

25 Sulzer, *Allgemeine Theorie*, 1203: 'selten als übler Querstand betrachtet'.

equilibrium. Harmony was what could, in the end, grant the equilibrium within the liquid, but it could also be used to express 'stress' or 'pressure' (*Kraftanstrengung*).[26]

Such terms found in the text betray the scientific disciplines that would come to define Helmholtz as the leading expert of the mid-nineteenth century, namely hydrodynamics and thermodynamics. Helmholtz's contribution to these areas began with his proposal for a law of conservation of energy in 1847, which would eventually lead to his appointment as chair of physics at the University of Berlin in 1871. One notes in his descriptions of music this expertise lurking in the background, especially when he describes, for instance, voice-leading relations to the tonic at the beginning of that same chapter:

> On these relations depends the connection of the parts of a mass of tone into a coherent whole. But besides this the succession of the tones and chords must be regulated by natural relations. The mass of tone thus becomes more intimately bound up together, and, as a general rule, we must aim at producing such a connection, although, exceptionally, peculiar expression may necessitate the selection of a more violent and less obvious plan of progression.[27]

The industrial overtones that are presented in this description in the original German are slightly mitigated in the English text, where the translation of 'a mass of tone' shifts Helmholtz's neologism '*Klangmasse*' back into the realm of music and the first-person plural integrates the reader into the organization of sound, which the German reader was confronted with in the passive voice. The grandeur and potential violence, elicited by the motion of sound in music's 'connected vessels', comes across despite such mitigation in the translation. In the nineteenth century, new energy supplies increasingly dominated the industrialized world. In order to conduct and exploit the flows of energy, it was essential to remain in control of steam engines, gas systems, and the growing scale of production they enabled. Loss and danger through leakage or turbulence, friction, and uncontrolled change in temperature had to be prevented, and this required the smooth equilibrium that is ascribed here to music.[28]

A related feature in the chapter on voice leading is the striving for the efficiency of expression. Together with notions of effort and equilibrium, Helmholtz was able to cover a wide range of phenomena under this notion of efficiency. The focus was on the effect that they made on a listener without specific training in music theory. He alluded, for instance, to the imitation of speaking, howling or crying. At other times, he commented on the contrapuntal rules for resolving dissonance as a process to overcome resistance, or on the effort voices make for reaching high notes, or even on suspensions pushing each other forward and the best ways of performing such nuances of expression:

[26] See Helmholtz, *On the Sensations of Tone*, chap. XVIII, 544–62.

[27] Helmholtz, *On the Sensations of Tone*, 544.

[28] On the history of fluid mechanics in the nineteenth century and on Helmholtz's specific role in it, see Olivier Darrigol, 'From Organ Pipes to Atmospheric Motions: Helmholtz on Fluid Mechanics', *Historical Studies in the Physical and Biological Sciences* 29 (1998): 1–51 and his more recent *Worlds of Flow: A History of Hydrodynamics from the Bernoullis to Prandtl* (New York: Oxford University Press, 2005). On this and further hydrodynamic metaphors in Helmholz's writings, such as turbulence, see Kursell, *Epistemologie des Hörens*, 89–141.

> Nothing sounds worse than dissonances played or sung in a dragging or uncertain manner. In that case they appear to be simply mistakes ['missklingend']. They are, as a rule, only justified by expressing energy and vigorous progress.[29]

In all these statements, Helmholtz's fluid mechanics of sonic expression never embraced music's system of rules. The forces of equilibrium in a moving sound mass were presented as essentially self-sustaining. The sound mass flows where it finds a convincing continuation of its original path; the composer only controls the flow for the sake of expression. Helmholtz thus avoided judging chord progressions as correct or incorrect. To this point, the English translation of Helmholtz is often misleading as it presumes that he is judging the correctness of a chord when he states 'they appear to be simply mistakes', when in fact it should be translated as 'they are simply sounding badly'. The translator thus often inserted cognition, where Helmholtz always spoke of the physicality of the tone.

Deviation

'False relations' epitomizes Helmholtz's foray into the realm of sound succession as well as musical aesthetics. As we have seen, for Helmholtz, the thought experiment of false relations consisted of the fact that one singer had to produce a note that did not fit with what he heard in the context of other singers. The auditory sensation felt by the singer hindered his ability to produce the note. The distracting note trapped the singer's mind. The role of sensing the present harmony in a cross relation as described by Helmholtz thus receded to a single moment of exposure where the flow was disrupted. It was as if the fictitious singer faced a gap between physical hearing and musical cognition, between tones and notes. The flow of the music got stuck and only a cognitive effort would make it continue.

The above speculation of Helmholtz is primarily supported by his description of an economy of expression. In the chapter on voice leading, he generalized the relationship between the listener and the flow of music as moments of stasis and expressivity:

> It is clearly an entirely false position which teachers of harmony have assumed, in declaring this or that to be 'forbidden'. In point of fact nothing musical is absolutely forbidden, and all rules for the progression of parts are actually violated in the most effective pieces of the greatest composers. It would have been much better to proceed from the principle that certain transitions, which are disallowed, produce striking and unusual effects upon the hearer, and consequently are unsuitable except for the expression of what is unusual. Generally speaking, the object of the rules laid down by theorists is to keep up a well-connected flow of melody and harmony, and make its course readily intelligible. If that is what we aim at, we had best observe their restrictions. But it cannot be denied that too anxious avoidance of what is unusual places us in danger of becoming trivial and dull, while, on the other hand, inconsiderate and frequent infringement of rules makes compositions eccentric and unconnected.[30]

Here we see that the infringements of harmony take on a peculiar role. They appear to the listener as *deviations* from the usual flow of music. Such deviations serve the

[29] Helmholtz, *On the Sensations of Tone*, 549.
[30] Helmholtz, *On the Sensations of Tone*, 554.

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aim of expression, and they can be perceived against the background of a stable equilibrium in the musical flow that is granted by the rules.

A second factor in Helmholtz's speculation on false relations can also be contributed to the interplay of rules and infringements. Given the listeners' changing habits, the context of the rule itself was flexible. Listeners constantly readjusted their hearing and expectations to what at a given moment counted as 'usual' and what as an 'effective violation'. As Helmholtz explains, this also held for false relations:

> [N]umerous exceptions have arisen as the ear of modern musicians, singers and hearers, have become accustomed to bolder combinations and livelier progressions. All these rules were essentially intended for old ecclesiastical music, where a quiet, gentle, well-contrived, and well-adjusted stream of sound was aimed at, without any intentional effort or disturbance of the smoothest equilibrium.[31]

The metaphor of fluid mechanics comes full circle in this passage. We see that the 'old ecclesiastical music' imposed rules that modern composers could twist and bend, thereby shaping new listening habits and rules. As a physiologist wrenches a complex theory of hearing from the laws of fluid mechanics, a composer can be said to impose an original, expressive modification on the system of harmony. Undeniably, a strong notion of progress governs much of Helmholtz's thinking here, one that was quite common in his time.[32]

However, for the experimenter, progress in music comes with a specific problem: the aesthetic endeavour imposed by composers provided no stopping rule. By admitting that nothing determined whether an infringement would be considered progressive or harmful, Helmholtz deprived himself of a fixed frame. As a consequence, it became impossible to query which physiological phenomena would play into this notion of bending the rules. The repetition of an experiment *ceteris paribus*, that is, keeping all factors stable except the one of interest, was illusory, since the repetition of an expressive infringement in music would not necessarily produce the same effect twice, but instead lead to a habitual effect. The habit, for instance, of considering something a dissonance or consonance as such did not give access to a physiological experiment. In that particular case, Helmholtz found a way to deal with the shifting expressive aspects of dissonance and consonance in various intervals. His own theory, namely that the roughness resulting from acoustic beats in various intervals, was flexible enough to explain changing tastes and definitions across centuries.

However, if false relations pointed to a rule that could be infringed upon by the composer at any time, this meant that there was nothing to hold onto for the experimenter. Expression therefore could not only justify infringements, but it could even turn upside down the entire system of rules:

> Where music has to express effort and excitement, these rules become meaningless. Hidden Fifth and Octaves and even false relations of Fifths are found in abundance in the chorales of Sebastian Bach, who is otherwise so strict in his harmonies, but it must

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[31] Helmholtz, *On the Sensations of Tone*, 562.

[32] The notion of progress in Helmholtz's work is thoroughly discussed against the background of historicism in Benjamin Steege, *Helmholtz and the Modern Listener* (Cambridge: Cambridge University Press, 2012).

> be admitted that the motion of his voices is much more powerfully expressed than in the old Italian ecclesiastical music.[33]

So, when music expressed effort or excitement, physicality overruled harmony. To say that the rules of music become meaningless is after all a surprising statement. By the same token, this eliminated the option to have to investigate the misstep. Without a reference point for the infringement, there was no longer any deviation to be explored and measured in the experimental investigation. As will be shown in part two below, for Helmholtz's experimental research into hearing to occur, a deviation was necessary between two states: one undistorted and the other a deviation from it.

Part Two: Experimentation in Sensory Physiology

Objects and Devices of Auditory Physiology

The English term 'false relations' and the German '*Querstand*' are fully equivalent in the sense that they refer to the same infringement of a rule in voice leading. Whereas the German term perhaps fits more easily into a physiologist's account of the rules of music, the English term more explicitly addresses the purpose of the present argument. Physiology can comment on phenomena in organic life, but it cannot possibly explain why something is considered 'false'. Yet, the study of the senses has always had an interest in 'the oddities or departures from the common and commonplace accuracies of perception'.[34] Eighteenth-century studies in perception adhered to the notion that perception relates to the perceived object as being either veridical or illusory. The moon illusion, a traditional example that goes back to Aristotle and was discussed by Kant in his *Critique of Pure Reason*, illustrates this quite well. The size of the moon as we perceive it may change, depending on the position of the moon and our own position in relation to the moon, but this does not entail that the actual size of the moon changes as well.[35]

Perceptual phenomena changed their status in early nineteenth-century physiology. If sensory perception is produced by the body in one way or the other, then to call such phenomena illusions is not justified. What the body produces is what we must accept. Johann Wolfgang von Goethe was among the first to carry out extensive experimentation on the physiology of vision – as opposed to a physics of light or a philosophy of visual perception. He spoke of a 'subjective experiment' (*subjektiver Versuch*) in which the experimenter's body was involved as the site of experimentation, as opposed to an 'objective experiment' (*objektiver Versuch*), in which the experimenter took on the role of an observer of phenomena occurring outside of their own body. In his *Farbenlehre*, he reported extensively on his studies of subjective phenomena in optics.[36]

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33 Helmholtz, *On the Sensations of Tone*, 562. On the problem Helmholtz saw in the fact that parallel fifths and octaves were present in any periodic sound, but forbidden by the rules of counterpoint see Julia Kursell, 'Helmholtzquinten', in *Dilettantismus als Beruf*, ed. Safia Azzouni and Uwe Wirth (Berlin: Kadmos, 2010): 131–42.

34 Nicholas J. Wade, *Perception and Illusion: Historical Perspectives* (Dordrecht: Springer, 2005): vii.

35 On the moon illusion, see Thomas Sturm and Mitchell Ash, 'Roles of Instruments in Psychological Research', *History of Psychology* 8/1 (2005): 3–34, at 10–11.

36 See, on Goethe, for instance, Friedrich Steinle, 'Das Nächste ans Nächste reihen' – Goethe, Newton und das Experiment', *Philosophia naturalis* 39 (2001): 141–72; Armin

Following Goethe, physiologists such as Jan Evangelista Purkyňe and Johannes Müller claimed that subjective phenomena in perception occurred just as regularly as any physical phenomena outside of the human body and therefore merited scientific investigation. The point of departure for nineteenth-century physiology was thus the study of these 'subjective phenomena', like the after-images one sees when closing the eyes after just looking into a source of light. After-images clearly demonstrated that the body itself produced phenomena. These phenomena disrupted the discourse on perception that had considered them either as physically demonstrable or as figments of the imagination.

In exactly these terms, the author of an 1805 article on the Tartini tone described the third tone that appears when two strong notes with constant pitch resound. Ulrich Vieth, translator of Thomas Young into German, doubted that the combination tone, as he called the third tone, could be explained as either purely physical or purely imaginative. On the contrary, both explanations seemed valid. Any tone thus would be called a figment of the imagination if the criterion for this was that regular motion results in the perception of a tone.[37] Vieth did not consider sensory physiology suitable to find the answers to his questions – recall that his text was published five years before the first publication of Goethe's *Farbenlehre*. And in fact, for the study of hearing it proved difficult to claim any heard phenomenon as being subjective, yet verifiable at the same time. Johannes Müller, for instance, argued that the rattle of a stagecoach that remains in one's ears for days after travelling could serve as an example. He could not give any advice, though, on how to investigate this phenomenon in a systematic way.

Helmholtz instead scrutinized the wealth of knowledge on sound gathered through the ages in music composition. His preference for periodic sound, that is to say sounds with a clear pitch, privileged Western music for this purpose. Periodic sound was easier to reproduce and to research, and it provoked all kinds of distortions. According to Helmholtz, distortions, in particular, offered insight into the body's production of the sensation of sound and more specifically the limitations of such production. For his research into hearing, he took combination tones as his point of departure. He was able to demonstrate that the third tone occurred in the body as a distortion, which results when two vibrations are superimposed in a small-sized medium, such as in the middle ear.[38]

The article on combination tones perfectly presented his method of auditory physiology. It demonstrated that the body produced sound rather than just channelling vibrations to the mind. For understanding this bodily production of sound, distortion was a privileged measurable object.[39] As long as the coming into being

Schäfer, 'Goethes naturwissenschaftliche Kunstauffassung', in *Goethe-Handbuch. Supplemente*, ed. Andreas Beyer and Ernst Osterkamp, vol. 3: *Kunst* (Stuttgart: Metzler, 2011): 183–96; on nineteenth-century sensory physiology, see Jonathan Crary, *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century* (Cambridge, MA: MIT Press, 1990).

[37] [Gerhard Ulrich Anton] Vieth, 'Ueber Combinationstöne, in Beziehung auf einige Streitschriften über sie zweier englischer Physiker, Th. Young und Jo. Gough', *Annalen der Physik* 21 (1805): 265–314.

[38] H[ermann von] Helmholtz, 'Ueber Combinationstöne', *Annalen der Physik und Chemie* 175 (1856): 497–540.

[39] German media studies have pointed to this role of distortion in knowledge production and the rise of auditory media, starting from Friedrich Kittler, *Aufschreibesysteme 1800–1900*

of tones themselves was difficult to determine, distortions demonstrated the limits within which tones can be heard. Distortions such as the third tone proved that the ear itself is a site where sound emerges. Distortions, as defined in this way, made hearing perceptible.

Another important aspect of Helmholtz's methodology on combination tones is that the conditions needed for third tone to emerge were dependent on the two initial tones. Not just any sound produced the third note, but a musical tone that was in line with an aesthetics of a beautiful note that was not so far away from Helmholtz's idea of the hydrodynamic equilibrium in musical harmony. So, all the phenomena involved were musical notes, including the distortion itself. As a consequence, the constellation of a third note joining two notes played simultaneously could be easily observed with regard to the resulting intervals. The third tone would either fit, or be in contradiction with, the rules of counterpoint or distort them like a note that was out of tune. In the history of music theory, this third tone even served as a starting point for constructing entire systems of harmony before and after Helmholtz; the treatises by Giuseppe Tartini and Paul Hindemith are prominent examples.[40]

Distortion in this context acquires a second meaning. The combination tones not only witness the limitations of sound emerging in the body, they also function as a potentially disturbing occurrence within the system of musical harmony. This made Helmholtz ask whether the system of rules governing music composition also had taken these occurrences into account. He designed an extended series of experiments in which he scrutinized compositions with respect to the traces of distortion within them. In so doing, he tried to confirm that the 'best' composers had avoided distortion by combination tones. In fact, he found a lack of distortions in Mozart's *Ave verum corpus* and Palestrina's *Stabat mater*.[41] In Palestrina, for instance, Helmholtz analysed the chords one by one, and then arranged them on a scale of 'harmoniousness'. The resulting statistics demonstrated that Palestrina's choice of chords avoided the registers in which distortion through difference tones would have been audible. How this particular finding related to voice leading was of no concern to Helmholtz at this point in his research, though.

It is important to note that Helmholtz's work on auditory physiology stood somewhat apart from physiological experimentation more generally. As noted previously, physiology developed rapidly during the nineteenth century. A major factor in this had been the call for a new mode of experimentation. French physiologist François Magendie was among the first to urge his colleagues to adopt experimental methods in his *Précis élémentaire de physiologie* (1817).[42] According to him, physiologists had to renounce the strict coupling between physiology and post-mortem anatomy. Neither the gaze into a corpse, nor a fixed notion of what they should be looking for in it would help physicians to understand the living body. Magendie's

(Munich: Fink, 1985) and Bernhard Siegert, *Passage des Digitalen. Zeichenpraktiken der neuzeitlichen Wissenschaften, 1500–1900* (Berlin: Brinkmann und Bose, 2003).

[40] Giuseppe Tartini, *Trattato di Musica, secondo la vera scienza dell'armonia* (Padua: Stamperia del seminario Giovanni Manfrè, 1754); Paul Hindemith, *Unterweisung im Tonsatz*, vol. 1: *Theoretischer Teil* (Mainz: Schott, 1937).

[41] On this see Julia Kursell, 'A Third Note: Helmholtz, Palestrina, and the Early History of Musicology', *Isis* 106 (2015): 353–66.

[42] François Magendie, *Précis élémentaire de physiologie*, 2 vols (Paris: Méquignon-Marvis, 1816–1817): vol. 1, 6.

own handbook for medical students instead dealt with experimentation extensively.[43]

As explained earlier in this article, physiology eventually succeeded in subjecting living organisms to experimentation, although an understanding of life itself still remained out of reach. For this, experimentation was set on a new footing. Earlier models of experimentation in physics had proposed to test a pre-formulated hypothesis under the conditions of a controlled experience in order to either confirm or contest it. Such an *experimentum crucis* was not feasible on living objects, however, since most factors of their functioning were unknown. Physiological experimentation instead turned towards an exploratory mode of inquiry.[44] Physiologists provoked the emergence of new phenomena, even though no hypotheses for their explanation were available. The scrutiny of after-images mentioned earlier is an example for this. Physiologists produced extended series of such visual impressions in order to understand the patterns and laws potentially inherent in them. In modern terms, one could say that the physiologists were gathering data, before subjecting the data to a hypothesis.

For the study of hearing, the exploratory mode was problematic. Controlled experimentation imposed additional constraints. Stable reproduction of sounds was by no means easy. More importantly, it dawned to nineteenth-century researchers working in the domain of acoustics that they did not know enough about sound to tell what they heard. Even when it seemed that the same sound was reproduced, this did not guarantee that the auditory experience was the same. Helmholtz's use of music was peculiar in this respect. At first glance, he seems to continue a tradition of using music for identifying, consistently reproducing, and denoting sound. Upon a closer look, though, music appears to have a different function. A comparison with the study of vision can help to clarify this peculiarity.

Vision and Hearing

The role of music in Helmholtz's auditory physiology is different in important ways from that of the art of painting in his treatise on physiological optics. In the foreword to the book *On the Sensations of Tone* he states that music has a different status than the other arts, because musical harmony deals with 'the natural power of immediate sensation':

> Music stands in a much closer connection with pure sensation than any of the other arts. The latter rather deal with what the senses apprehend, that is with the images of outward objects, collected by psychical processes from immediate sensation. … It is only in painting that we find colour as an element which is directly appreciated by sensation, without any intervening act of the intellect. On the contrary, in music, the sensations of tone are the material of the art. So far as these sensations are excited in music, we do not create out of them any images of external objects or actions.[45]

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[43] On this see Julia Kursell, 'Hearing in the Music of Hector Berlioz', in *Nineteenth-Century Opera and the Scientific Imagination*, ed. David Trippett and Benjamin Walton (Cambridge: Cambridge University Press, 2019): 109–33.

[44] On exploratory experimentation see Friedrich Steinle, *Exploratory Experiments: Ampère, Faraday and the Origins of Electrodynamics*, trans. Alex Levine (Pittsburgh: University of Pittsburgh Press, 2016).

[45] Helmholtz, *On the Sensations of Tone*, 3. Helmholtz, *Die Lehre von den Tonempfindungen*, 3: 'Die Musik steht in einem viel näheren Verhältniss zu den reinen Sinnesempfindungen, als

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Painters eagerly embraced this idea of an immediacy of colour. They looked for new ways to see and depict the world and found them in what Helmholtz explained about *vision*, not *painting*.

Music, in contrast, pervades the argument of *On the Sensations of Tone*. Yet, the reactions of composers to his text only become noticeable in the early twentieth century.[46] Music and visual arts differ in the way they impact and relate to Helmholtz's sensory physiology in a number of ways. The first of these concerns the stability of the objects. Seeing the same thing twice is not the same as hearing the same sound repeated. Yet experimentation needs reiteration. Acoustic experimentation had to ensure that the phenomena under investigation could be stably reproduced. Part of Helmholtz's success in putting acoustics on a new footing was founded on keeping one sound stable until his query into this sound was done, rather than rely on identical reproduction of that sound. He used the siren for this purpose, as well as electro-magnetically produced vibration in tuning forks. Although he was well aware that this excluded transient features in sound perception from the scope of his investigation, he was at pains to demonstrate that there was still enough to be discriminated by the ear and thus to be scrutinized by the physiologist.[47]

A second aspect is that anatomical knowledge about the ear, and especially the neural structures of the organ of hearing, made a leap with technical improvements in microscopy in the mid-nineteenth century. To begin with, the enterprise of presenting a new physiological theory of hearing was triggered by the findings of neurological structures in the inner ear by Marquis Alfonso Corti, who was first to apply the new techniques of microscopy in the ears of mammals. He mentioned in passing that what he saw there resembled the action of a piano, and Helmholtz famously expanded on this idea.[48] Speculation reached its end, though, when it came to the connection between both ears. For the physiologist, it was not evident that the eyes and ears work together in any comparable manner. The optic nerves cross directly behind the eyes and before reaching the brain. Their chiastic juncture could be detected without microscopy and accordingly was known long

sämmtliche übrigen Künste welche es vielmehr mit den Sinneswahrnehmungen, das heisst mit den Vorstellungen von äusseren Objecten zu thun haben, die wir erst mittelst psychischer Processe aus den Sinnesempfindungen gewinnen. … Nur in der Malerei findet sich die Farbe als ein Element, welches unmittelbar von der sinnlichen Empfindung aufgenommen wird, ohne dass sich Acte des Verständnisses einzuschieben brauchen. In der Musik dagegen sind es wirklich geradezu die Tonempfindungen, welche das Material der Kunst bilden; wir bilden aus diesen Empfindungen, wenigstens so weit sie in der Musik zur Geltung kommen, nicht die Vorstellungen äusserlicher Gegenstände und Vorgänge.'

46 See Benjamin A. Steege, 'Varèse *in vitro*: On Attention, Aurality, and the Laboratory', *Current Musicology* 76 (2003): 25–51; for the context of the Russian avant-garde between ca. 1900 and 1920, see Julia Kursell, *Schallkunst: Eine Literaturgeschichte der Musik in der frühen russischen Avantgarde* (Munich: Sagner, 2003).

47 On this, see Julia Kursell, 'Experiments on Tone Color in Music and Acoustics', *Osiris* 28 (2013): 191–211.

48 On physiological speculation between Corti and Helmholtz, in particular by Emil Harleß and Otto Deiters, see Kursell, *Epistemologie des Hörens*, 206–10. A compelling overview of the history of research in otology is given in Adam Politzer, *Geschichte der Ohrenheilkunde*, 2 vols (Stuttgart: Ferdinand Enke, 1907–1911), notwithstanding the bias that stems from Helmholtz's theory of hearing then still being considered valid. For the cultural history of hearing see Veit Erlmann, *Reason and Resonance: A History of Modern Aurality* (New York: Zone Books, 2010).

before Helmholtz. Nothing of the same sort was known for the two ears. It took until the end of the century for microscopic neuroanatomists to discover the complex and tiny structures that connect the acoustic nerves before the brain.

Helmholtz therefore treated the ears like two independent organs. He considered the way in which auditory data from the two ears merged to be the same as the way in which we combine input from different senses. Not long before he started working on sensory physiology, astronomers had stumbled upon the phenomenon that sense data from different organs are synchronized differently in each individual. The consistent deviations among the personnel who notated the passing of stars in the telescope to the beat of a pendulum could only be explained based on each member's individual manner of relating auditory and visual perception. This individual footprint of correlating beat and vision was termed the 'personal equation'.[49] If the two ears had to be considered independent, then their combination was likely to result in equally individual manners of concatenating input. For Helmholtz, this was a reason to leave out binocular hearing in his auditory physiology, whereas in his physiological optics binocular vision provided an important share of the examples he discussed in the part that dealt with higher order physiological processes in vision.

This takes us to a third aspect in the comparison. Vision and hearing yield different ways of dealing with the cognitive aspects of perception. Both books follow roughly the same three-part structure, which in turn derives from Helmholtz's distinction of three levels in his concept of sensory physiology. He explains further in the preface to *On the Sensations of Tone*:

> First we have to discover how the agent reaches the nerves to be excited, as light for the eye and sound for the ear. This may be called the physical part of the corresponding physiological investigation. Secondly we have to investigate the various modes in which the nerves themselves are excited, giving rise to their various sensations, and finally the laws according to which these sensations result in mental images of determinate external objects, that is, in perceptions. Hence we have secondly a specially physiological investigation for sensations, and thirdly, a specially psychological investigation for perceptions'.[50]

The third part of Helmholtz's *Treatise on Physiological Optics* dealt with experimenting on the 'unconscious inferences' we make when dealing with two sources of optical input. A simple experiment could consist in closing one eye and then comparing the way in which the impression of a shiny surface is reduced to a stark contrast in the subsequent view of that surface. This experiment points to some unconscious operation that merges both visual impressions into a third quality, namely the perception of the shiny surface. This unconsciously occurring inference explains *why* we see the stark contrasts on both surfaces at slightly different locations merge. The contrast is due to a reflection on that surface; it is not a feature of that surface's colour.

49 See Simon Schaffer, 'Astronomers Mark Time: Discipline and the Personal Equation', *Science in Context* 2 (1988): 115–45.

50 Helmholtz, *On the Sensations of Tone*, 5. In his optics, Helmholtz explicitly uses the somewhat awkward terms 'physical physiology', 'physiological physiology' and 'psychological physiology', thereby emphasizing that the 'psychological part of the investigation' is nevertheless part of physiology.

The way in which the experimental physiologist reached this insight consisted of a simple change in the perceptual condition. Closing the eyes alternately revealed the different location of the contrast on the perceived surface. The inference thereby became a conscious one. On a higher level of abstraction, the change in the condition could be called a 'defamiliarization' of vision. Various instruments were used, and sometimes explicitly devised, for experiments that forced the subject into perceptual situations, in which such unconscious inference was interrupted. The stereoscope is one example, which used a combination of mirrors to swap the images between the left and right eyes.[51] Helmholtz also used very simple ways to achieve defamiliarization, like closing one eye or bending over so as to look between one's legs.

According to Helmholtz, timbre was the equivalent to such unconscious concatenation in hearing – not in the least because humans can distinguish timbre with one ear only. Concatenation had to be understood more literally in this case. As is well known, Helmholtz assumed that the ear operates like a mathematician using Fourier analysis. The theorem proposed by Jean Baptiste Joseph Fourier in 1822 postulated that any periodic function could be analysed into simple parts of sinusoidal shape in integer ratios. Fourier himself had suggested that his theorem might prove useful for understanding the motion of a vibrating string, but had not mentioned the sense of hearing. Georg Simon Ohm later postulated that the same theorem could be applied to the tones of music and more generally to any periodic sound. In his first article, a mistake in his calculus made him infer that we hear only one note where there are several frequencies (he obtained an infinite amplitude for the fundamental frequency). Another physicist, August Seebeck, detected the mistake and flatly denied the postulate altogether. In his last paper on acoustics from 1846, Seebeck nevertheless conceded that Fourier analysis was probably the means to analyse tones and went on to speculate that this might relate to timbre, but did not delve into the matter. Ohm by then had already given up on acoustics; Seebeck died prematurely in 1849.

Helmholtz did not credit Seebeck for this insight, nor the otherwise unknown school teacher from Königsberg named Eduard Brandt, whose posthumously published paper informs the reader that he had shown his ideas on Fourier analysis and timbre to Helmholtz in the summer of 1855, shortly before the latter left Königsberg for Bonn. These ideas concerned the following postulation: if the analysis of periodic waves yielded different results for different timbres, then the distinction of timbre by the ear could, inversely, be related to Fourier analysis. Helmholtz pursued this idea, crediting Ohm for naming the insight that periodic sound could be analysed in the terms of Fourier analysis, while keeping the decisive insight into how Fourier's theorem could be linked to hearing for himself. As opposed to Brandt, Helmholtz also provided a label for the distinction. Differentiating shades of timbre from now on would refer to 'Klangfarbe'.[52]

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[51] On the stereoscope see Thomas L. Hankins and Robert J. Silverman, *Instruments and the Imagination* (Princeton: Princeton University Press, 1995): 148–77; see also Steege, *Helmholtz and the Modern Listener*, 130–48.

[52] [Eduard] Brandt, 'Ueber Verschiedenheit des Klanges (Klangfarbe)', *Annalen der Physik und Chemie* 188 (1861): 324–36. See Kursell, *Epistemologie des Hörens*, 174–9; ead., 'Klangfarbe um 1850: Ein epistemischer Raum', in *Wissensgeschichte des Hörens in der Moderne*, ed. Netzwerk Hörwissen im Wandel (Berlin: De Gruyter, 2017): 21–39. To my knowledge, the notion of the acoustic spectrum is not used in the nineteenth century, see for example Kursell, 'Klangfarbe', in *Handbuch Sound: Geschichte, Begriffe, Ansätze*, ed.

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Starting from the Fall of 1855, Helmholtz worked on devising an *experimentum crucis* for this hypothesis: if the ear proved capable in distinguishing a minimal timbral difference between periodic sounds, then Fourier's theorem would become meaningful. Just as the analysis of different shapes of periodic waves resulted in different patterns of sinusoidal components according to Fourier's theorem, so these same patterns could be considered to designate a difference in timbre for the human ear.

Although timbre took on the role of binocular vision in the sense of showing how sensations merge into higher-level perceptions, it did not serve as the main example in the third part of the book. Instead, harmony and voice leading – or rather, the topography of periodic sound – provided the subject matter for the psychological physiology of hearing. Here, he questioned the extent to which musical systems can be reduced to Fourier analysis, providing a trigonometric space in which hearing detects affinities between the sounds of instruments.[53] Many musical instruments exhibit harmonic spectra and thereby suggest that humans had reacted to this feature in sound. Based on this observation, Helmholtz again and again questioned the systems of rules that had yielded musical systems, whether in other places of the world like China and Persia or in other times like Greek Antiquity or the Italian Renaissance.[54]

Deviation as a Research Device

The experimental setups for a psychological physiology of hearing used neither defamiliarization nor did they focus on distortion. Distortion shed light on the normal functioning of the body. For this, distortion (in the sense of Helmholtz) had to be seen as a physiological feature itself. Defamiliarization, in turn, relied on everyday understandings. Against the background of unquestioned features in perception, its functioning became accessible to the experimenter.

Unfamiliar modes of hearing were difficult to achieve and to deal with, as Helmholtz knew. He kept polemicizing against his contemporaries to whom it did not occur that a discussion of locally or historically distant ways of music-making could not be carried out by playing the music in question on a piano. Helmholtz himself exploited this very difference between listening habits in his work. Whether he discussed Greek and medieval music theory, Renaissance composition, or Chinese and Arabic scales, he always emphasized that in using other instruments, the musicians did not have the habit of hearing equal temperament. Such distant instances of listening habits, therefore, were the ideal space for setting up an experiment. For this he devised a harmonium in a system of (almost) just intonation. The harmonium was less an instrument

Daniel Morat and Hansjakob Ziemer (Stuttgart: Metzler, 2016): 57–62, and ead., 'Hearing in the Music of Hector Berlioz'.

[53] On the notion of affinity that Helmholtz uses also in the title of this third section, see Steege, *Helmholtz and the Modern Listener*; for an overview of theories of timbre as geometrical space, see Daniel Muzzulini, *Genealogie der Klangfarbe* (Bern: Peter Lang, 2006).

[54] For his work on Greek music theory see Julia Kursell, 'Musiktheorie hören: Hermann von Helmholtz und die griechische Antike', *MusikTheorie: Zeitschrift für Musikwissenschaft* 22 (2007): 337–48; on Persian music theory see ead., 'Fine-tuning Philology: Helmholtz's Investigation Into Ancient Greek and Persian Scales', *History of Humanities* 2 (2017): 345–59.

for re-enacting distant music than for producing a significant deviation from present habits.

Helmholtz's polemics against the piano as a tool for understanding distant instances of music was grounded in his empiricist stance towards perception. He argued that perception is not an innate human faculty, but it must be learned. Learning how to perceive always occurred under concrete historical and material conditions. Nineteenth-century music theorists, more often than not, had acquired their musical skills using a piano. One could not expect them on these grounds to intuit, for instance, the fine distinctions of melodic modes in Greek theory, not to speak of the latter's affective contents.

The effects of learning, though, were likely to be just as much individually determined as the concatenation of the perception from both ears. So, the problem remained just how to ask a valid question about them. The investigation of distant listening habits offered a solution. He read both music theory sources and composition as descriptions of different conditions for learning to hear. On the harmonium, he tested whether those conditions might indeed produce effects that went unnoticed on a piano, but would came to the fore when played with the stable and sharp sounds of the harmonium. These experimentally produced sounds were significantly different, yet valid cases of making sense from hearing periodic sound under conditions Helmholtz could not have invented himself. Music, in this way, became a reservoir of producing cases for creating significant deviation.

Conclusion and Outlook

Looking back from the top of a mountain, it is easy to recognize the straight way one might have gone, instead of the crooked path one actually took. Helmholtz himself once described his experimental endeavours in this way.[55] 'False relations' are one of the stumbling blocks that forced him to take a detour in his research. They demarcate the line between an experimental procedure in need of some kind of deviation and a musical practice that depended on the fluency of a given system of rules. The peculiar constellation of rules and expressive infringements that false relations entailed led beyond the confines of physiological research. In other words, they demarcated the line between physiology and aesthetics. Helmholtz steered towards this line, but he did not transgress it.

Helmholtz's comment that the rules of harmony become meaningless when expression dictates change reads today like a prediction of the changes that music underwent after 1900. By then, a new definition of cross relations had already been given in the new standard encyclopaedia, Hugo Riemann's *Musiklexicon* (1882). Without reference to the old rules of *mi contra fa*, Riemann defined false relation as 'the conspicuous appearance, and one the effect of which is unpleasant to the ear, of a chromatically changed note in a part other than the one in which it could have been reached by the step of a semitone'.[56]

Unlike previous authors, Riemann went on to attribute the unpleasant effect of the phenomenon to 'insufficient comprehension' of the harmonic relationship. Accordingly, the effect would change if one was confronted with false relations more frequently:

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[55] Cf. Helmholtz, *Vorträge und Reden*, vol. 1, 14.
[56] Hugo Riemann, *Dictionary of Music* (London: Augener, 1896): 229.

> Of this, one can easily become convinced, since by the frequent repetition of an harmonic progression involving a false relation, the unpleasantness almost entirely disappears. An effect of false relation will always happen when a progression of parts, not otherwise modulating, cannot possibly be explained as a case of impure intonation. Mozart and Schubert, in their pianoforte works, are extremely fond of playing with effects of false relation; the performer, however, need only make the note producing false relation a little more prominent than the rest in order to remove all unpleasantness.[57]

Whether or not Riemann was aware of how radical his statement was cannot be known. As Alexander Rehding has shown, Riemann had undergone a painful career of first enthusiastically embracing the new insights of auditory science as provided by Helmholtz and others, only to eventually turn his back on them.[58] Riemann eventually postulated that aesthetics was not in need of a science that could not explain the contemporary system of rules and that music theory should therefore return to its own explanatory powers. In his *Elements of Musical Aesthetics* (1900), he speaks of musical harmony as a 'cosmos that is closed in itself and detached from worldly matters',[59] denouncing as 'musical nonsense' any interpretive insight that went beyond the pitch relations within Western harmony.[60]

Riemann eventually took pains to express the importance of tonal relations for those who might otherwise be exposed to too much unruliness. His theory of tonal representations that he published after the turn of the century presents a full-fledged psycho-technique for listeners. He invited his readers to sit down at a piano and practice the imaginary presence of tonal relationships until they would come to them as second nature when sitting in a concert. Music listeners could then follow even a new composition at eye level with the composer. Not at ear level to be sure, especially if a composer intended anything else than pitch relations as atonal music was about to demonstrate.[61] Seen from today's perspective, Riemann was thus among the first to invite fellow music theorists on a journey into experiencing the historical features of music, features that had lost some meaning from when they existed under different historical conditions of learning.

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57 Riemann, *Dictionary of Music*, 229.

58 Alexander Rehding, *Hugo Riemann and the Birth of Modern Musical Thought* (Cambridge: Cambridge University Press, 2003)

59 Hugo Riemann, *Elemente der musikalischen Ästhetik* (Berlin: Spemann, 1900): 88. See Kursell, *Schallkunst*, 84–6.

60 Hugo Riemann, *Handbuch der Akustik (Musikwissenschaft)* (Berlin: Max Hesse, 1921): 104.

61 See Kursell, 'Notenlesen', in *Medienphilologie: Konturen eines Paradigmas*, ed. Friedrich Balke and Ruppert Gaderer (Göttingen: Wallstein, 2017): 172–95.