Ear as Instrument

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Sometimes called difference or combination tones, Distortion Product Oto-Acoustic Emissions (DPOAEs) are non-linear distortions that occur in the cochlea in response to simultaneously presented pairs of pure tones with a ratio between 1:1 and 1:3 and that activate the cochlea in the same region of the basilar membrane [1]. It is possible to hear up to three of these tones: the quadratic difference tone (QDT), which occurs at frequency $f_2-f_1$ (when $f_2 > f_1$); the cubic difference tone (CDT), at $2f_1-f_2$; and the lower-order sideband, at $3f_1-2f_2$ [2]. While the DPOAE is not present in the acoustic signal, it would be wrong to call it an auditory illusion. It is a physical phenomenon that can be recorded using an ear-probe microphone. Nevertheless, it does have an illusory quality: Careful control of the stimulus frequencies can produce a ghostly, ethereal timbre reminiscent of the glass harmonica. And because the sound is not audible to anyone but the individual hearer, she is drawn inward, into considering herself both as agent and recipient of the sound. The active mechanism responsible for DPOAEs has been called the “cochlear amplifier,” and in Correlation Number One (CNO) (2010), this physiological description becomes aesthetic. The “tiny loudspeaker inside the ear” [3] is rendered audible to the listener.

In work with DPOAEs, the acoustic tones attain an ontological status similar to that of the breath that excites a woodwind instrument. They are stimulus tones—sound waves that “perform” the ear—and as with the woodwind, technique is required. The primary considerations are (1) listening comfort and (2) good stream segregation of the acoustic tones and the DPOAE; these two considerations do not necessarily coincide. Consider a 100Hz QDT. (This, incidentally, is the most audible of the three tones, and the one I have focused on in my work.) The smaller the $f_1:f_2$ ratio, the more the resulting DPOAE will be distinguishable from the pure tones; but since this results in combinations of higher frequencies, greater intensity is required for it to sound. There is thus a trade-off between frequency and amplitude that I find resolves most pleasingly around the area where the cochlea is most sensitive (3kHz–5kHz), since the lesser the amplitude required for the effect to work, the more comfortable it will be for the listener. Despite this, a sound pressure level (SPL) of >80dB is necessary for the DPOAE to be suitably audible. To attenuate this, a method of summing a series of sinusoidal components with constant difference frequencies was devised whereby each of eight channels contained a different signal that reinforced the requested QDT. Spreading the frequencies out over different critical bands so that the intensity is no longer concentrated in the same region of the basilar membrane means that listening fatigue is considerably reduced. Nevertheless, 9 minutes seemed to be the upper limit to how long a listener should listen to pure tones of moderate intensity in this frequency range. So, far from being “limitless,” we find ourselves in a very narrow corner of computer music: Amplitude, duration, frequency range and timbre each have been restricted to within a narrow degree: imposed from outside by the capacities of the cochlea.

Based on the research described above, I developed a method of “composing with absent sound” [4]. This description makes it clear that the DPOAE is not being created accidentally or arbitrarily, as can happen in quite a lot of loud drone music. Fine-grained control of the DPOAE is possible, but in order to achieve it, I found it necessary for the work to be realized inside out, so to speak, so that direct control was being applied to the “absent” sound rather than the acoustic tones. The QDT function is simply inverted, with the acoustic tones generated mathematically within a specified range.

$f_1 = CDT + QDT$

$f_2 = CDT + 2QDT$

Once this inverted system was in place, it was possible to treat the DPOAE just as though it were any signal. Keeping the CDT value constant (approx 3.5kHz in CNO) and manipulating the pitch and amplitude of the “virtual” QDT, one discovers a noise-to-noise continuum of sorts. Classic time-domain electronic music techniques such as vibrato and tremolo work especially well, resulting in sonorities reminiscent of the tuned guitar feedback tones of Manuel Gottsching or Robert Fripp [5].

I have described how the absent tones were afforded priority during the compositional process, with the acoustic tones being generated as secondary stimulus tones. This purely technical conceit spilled over into the aesthetics of CNO, because although the acoustic tones are by no means arbi-

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there is tension on a perceptual level, the performer, in this space, with the combination of breath on the instrument, the noise of the bow/planes, as though tensions exist between them and they compete for priority. This multidimensional quality (which Xenakis called the “transparent sandwich” [6]) is particularly tangible in long-form, slow-moving or static drone works. Consider a very famous example: La Monte Young’s Composition 1960 #7, which is composed of a B and F#, with the direction, “to be held for a long time.” Now, at a primary level, one hears precisely that: When I saw it performed, a cellist repeatedly bowed the two fixed pitches. But between the physical impossibility of the instrumentist producing the exact same gesture twice and the psychological impossibility of our hearing the same gesture as identical is a universe of continual difference: micro-fluctuations in pitch and intensity, slight variations in the partial weightings of the notes corresponding to one’s own position in space, the noise of the bow/breath on the instrument, combination tones. What is composed can only ever frame what is heard: on that instrument, the two fixed pitches. But between the physical impossibility of the instrumentist producing the exact same gesture twice and the psychological impossibility of our hearing the same gesture as identical is a universe of continual difference: micro-fluctuations in pitch and intensity, slight variations in the partial weightings of the notes corresponding to one’s own position in space, the noise of the bow/breath on the instrument, combination tones. What is composed can only ever frame what is heard: on that instrument, by that performer, in this space, with these ears and so on. Therefore, where there is tension on a perceptual level, as the listener tries to understand what, precisely, she is supposed to be listening to (Is it the same? Is it different?), the same tension spreads to analysis: What is the musical work? And can it be said to be composed?

Composition 1960 #7 illuminates the inherent instability of authorship and its susceptibility to variability. But this illusory quality of musical listening, whereby details can emerge that may not exist on a second listen, is to a certain extent orchestrated in CNO. Manipulation of the chimerical quality of listening is possible due the intimacy of the DPOAE. Listeners often remark upon an experience akin to headphone listening, and some can find this unsettling. (One listener described it as being like “voices in my head.”) The experience feels entirely subjective because it is: Age, gender and lifestyle all affect the individual quality of the DPOAE, again marking its instrumental quality. Yet, at the same time, I have shown that most of its dimensions are entirely predictable. The listener-directed quality, wherein one becomes a creative agent, able to direct one’s attentional focus and so on, is thus manufactured—made into a tangible parameter—by careful control of the DPOAE. The aforementioned tension between objective and subjective planes of sound becomes a straightforward question of psychoacoustics, as the acoustic tones and the DPOAE are segregated by timbre and by space to produce two separate streams, competing for attention.

References and Notes

2. However, it is the cubic and quadratic tones that are usually cited in the literature.
6. “Music is like a multiple sandwich, but a transparent one: Whilst in the middle of it, one can see at the same time lower or higher layers everywhere.” I. Xenakis, “Determinacy and Indeterminacy,” Organised Sound, No. 1, 143–155 (1996).

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