What is a pure tone?

Most of us can recognize when music is out of tune. Why can we hear this, and what exactly is a pure tone?

You're sitting in a concert hall. The crowd tenses in anticipation as the vocalist approaches the song’s high note. Abruptly, the excitement changes to wrinkled noses and disgruntlement when the singer misses it.

What happened? Why can most of us hear when someone sings off key? We went to the Department of Musicology at the University of Oslo (UiO) to find out.

Easier to hear than to sing

Most of us can hear when music is out of tune. So why can’t all musicians hear it?

“We’re used to hearing music that isn’t live. The music is recorded in the studio and edited with advanced applications. Studio recordings have been going on for a long time, but in the past we didn’t have tools that could adjust the music perfectly. Because we’re so used to hearing studio recorded and edited music, I think we’re getting pretty strict reference points for what is and isn’t pure,” says Associate professor Åshild Watne at UiO’s Department of Musicology.

“It may be easier to hear off-key notes in others than in oneself. Singing is more difficult than listening and requires more motor control. The vocal cords have to create tones that leave your mouth. These sounds come back in through your ears, get analysed and then corrected if necessary. That can be challenging,” says Professor Hallgjerd Aksnes.

Both Aksnes and Watne believe that most people can get better at singing and hearing tones.

“Very few people are unable to perceive and distinguish tones from each other at all. You could compare that condition with being colour-blind. You have the sense of sight, but the brain can’t understand the colours it’s seeing,” says Watne.

Many definitions

But what exactly is a pure tone?

“The standard answer is that a completely pure tone is a sine wave tone,” says Aksnes, “that is, an even Hertz frequency that forms an s-shaped sine wave.”

However, she says, “a sine tone can only be produced using technology. But even pure sine tones will sound ‘off’ – with a vibration or harshness in the sound – if they have a small difference in frequency. In the same way, you can hear “beats” when two piano strings or two singers aren’t perfectly in tune.”

Natural overtones always occur when someone sings or plays an instrument. That is why pure sine waves, which don’t have any overtones, can only be produced technologically.
Overtones are an infinite number of tones over the fundamental tone that we don’t necessarily notice. An overtone series is a series of natural overtones that occur over a fundamental.

Musicians on instruments like the jaw harp and flute consciously use overtones by changing the shape of their mouth or varying the airflow to accentuate different overtones.

“Since overtones occur naturally, you could call them completely pure tones,” says Watne.

In this video you can hear the first overtones in the series. First they are played separately, as sine wave tones. Then the tones sound together, as when someone plays an instrument or sings.

Influence of genre

Sometimes notes may be sung accurately, but may still be perceived as being out of tune – and vice versa.

“Genre has a lot to do with it. Ole Paus and Bob Dylan can sing as pure tones as a classical singer, but the genre requirements for how to sing the tone are completely different.

Likewise, we can easily tolerate an “out of tune” note in a blues tune, because it’s part of the genre’s expression. But the last note you play or sing in a song should be pure. Otherwise, I think we perceive it as sour, regardless of genre,” says Watne.

Often we think music sounds out of tune if musicians fail to hit exactly the same note. If the vocalist doesn’t stay in the same key as the band, or the flute plays the note slightly higher or lower than the rest of the orchestra, our ears notice that something is amiss.

The note’s relationship to its neighbouring tones is an important element for our ears in determining whether the note is in tune or not.

We’re used to hearing sour notes

In Western music we are actually used to hearing impure music, according to the researchers.

A piano has seven octaves. An octave extends from the note C to the next C, for example, and contains twelve half-steps, or semitones.

On modern pianos that use equal temperament tuning, the distance between each semitone is 100 cents. This is not completely pure according to the natural overtones, or what is known as just-intonation (pure tuning). In just scale tuning, the distance between each semitone is not exactly 100 cents.

Pianos are tempered so that notes played together will sound pure, regardless of the key they’re played in. That’s why we don’t perceive tempered tuning as impure, although technically it is.

You can press the keys to hear the notes. The keys at the top are from a tempered scale, while the keys at the bottom are from a just scale. As individual notes sound, the just and tempered tones are very similar, but when playing multiple notes simultaneously as chords in a piece of music, the differences in sound increase.

In the video below, Watne and freshmen musicology students attempt to find and sing natural overtones. They sing a triad with a fundamental, a fifth and a major-third. “Third” and “fifth” describe the note’s step on the scale. In the piano illustration above, the fundamental would be C, the major–third E and the fifth G.

The singers’ fundamental corresponds with the piano’s. The fifth also correlates fairly well, but the singers’ third doesn’t exactly match the piano’s. This happens because the distance from the fundamental to the
major-third is 400 cents on a tempered piano, but only 386 cents in the natural overtone series.

*(English subtitles are available in the videoplayer settings.)*

Watne believes the student chorus sings the most purely a capella, that is, without piano accompaniment.

“You can choose to play or sing in the direction of just intonation, like the notes in the overtone series, rather than in tempered tuning. Doing this will make the notes and chords technically more pure than a piano. But you always have to compromise so that it sounds good,” says Watne.

Tempered tuning has been the standard for pianos for many centuries. But in other musical cultures, different scales are more common.

**But are there only twelve notes?**

The answer is no. Between each semitone there are infinitely many other tones, which might be perceived as impure by current western music ideals.

Norwegian folk music and Arabic music, for example, use these microtones exactly the same way as the twelve "pure" tones.

You can hear an example of the use of microtones in Norwegian folk music below.

**Singing in tune can be learned**

The researchers emphasize that most individuals can learn to sing in tune with practice.

“Many children sing with relatively pure tone, but they tend to be a little flat when they come to the song’s high notes. But you can practice raising your pitch at the high notes,” says Aksnes.

“Concentration is sometimes also a factor with children. Their tone is pure, but then it goes flat a bit, and suddenly they’ve changed key. Their singing is pure in the new key, but off in the original one. In choral work I also notice that often the fifth is too low, and this causes the intonation of the whole chorus to drop. If you go a little light on this note, it’s easier for the chorus to maintain a pitch,” says Watne.

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*Read the Norwegian version of this article at forskning.no [5]*

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Assistant professor Åshild Watne and undergraduate students in the University of Oslo’s Department of Musicology practice singing with as pure a tone as possible. But a pure tone can be defined in many different ways. (Photo: Anna Camilla Kjensmo / forskning.no) [6]

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