An Illustration of Binaural Beats

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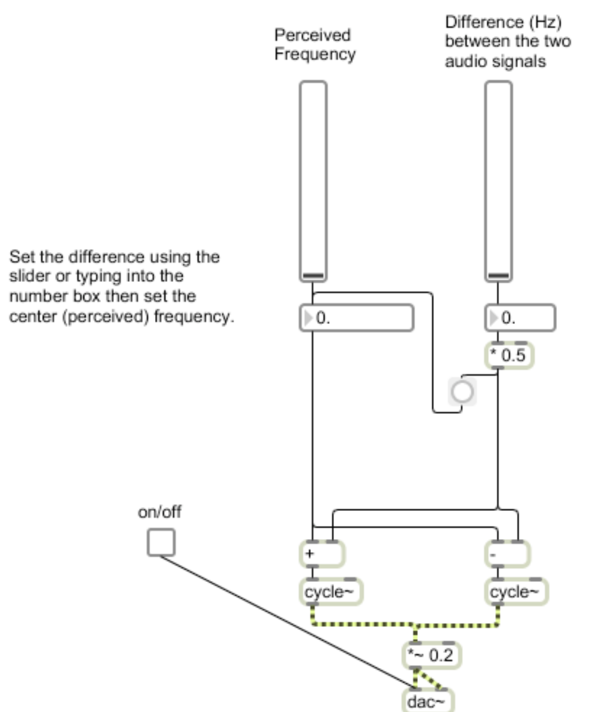
Binaural beats are a phenomena that has been described by David First as "auditory responses originating in each hemisphere of the brain that are caused by the interaction between two slightly detuned sine waves, divided between the left and right ears" (2003, p. 31). This perceptual phenomenon differs from the beating caused by phase interference that can be heard when two audio signals with closely related frequencies are combined in a monaural setting. The auditory beating that is heard in this case is created by amplitude modulations that beat at the rate of the difference between the two audio signals. Furthermore, the frequency that the listener perceives in this case is half way between the two frequencies that are causing the auditory beats. (Lane, Kasian, Owens, & Marsh, 1997, p. 249). For example, two signals sounding together with a difference of 10 Hz between them will beat at a rate of 10 beats per second and the listener will perceive this pitch to be 5 Hz below the upper frequency and 5 Hz above the lower frequency. This auditory beating is what can be heard when a guitar player tunes his or her instrument by matching pitches between two strings (see Example 1). Binaural beats can produce a similar sounding effect. However, binaural beats must occur under much more specific circumstances. First, the signals must be presented to the ears dichotically. This means that one signal must be sent to the left ear and only the left ear while a separate signal of a different frequency is sent to only the right ear. Therefore, it is absolutely necessary to use headphones to truly experience the phenomenon. When the two signals of varying frequency are each being sent individually, it is impossible for the signals to superpose to create any effects of amplitude modulation. This simple fact proves that the beats caused by the interaction of the two signals that are sounding dichotically are actually originating from within the brain (McFadden & Pasanen,

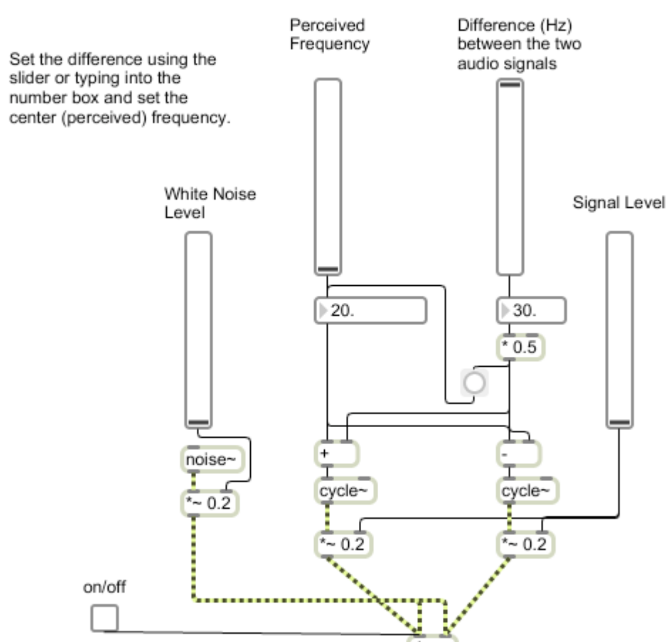


Example 1 shows a patch created with Max/MSP that can be used to test the ability to hear auditory beating under monaural conditions. The two signals are sent to both the left and right inlets of the digital audio converter simultaneously. This is necessary for a monaural presentation of the effect. This effect can be heard with or without the use of headphones.

1975).

A German experimenter named H. W. Dove originally discovered binaural beats almost 200 years ago. Due to limitations in the technology needed to accurately test Dove's findings, however, the discovery was not recognized for what it was until the early 1900s. Before then, Dove's binaural beats were somewhat disregarded as "a trivial special case of monaural beats" (Oster, 1973). Studies dealing with the function of binaural beats have since shown that not only does this phenomenon exist, but also binaural beats can be heard over a wide range of frequencies and can also have a very important psychophysical impact on the human body.

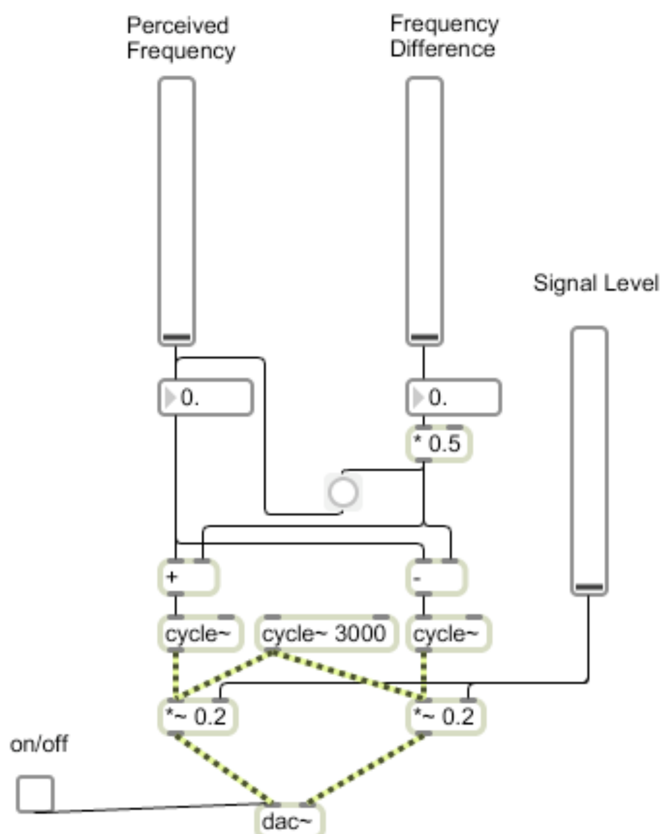
Past research has proven that binaural beats can be heard between two simple sinusoidal waveforms presented to a listener dichotically below frequencies of about 15 kHz. This cutoff frequency zone is about the same as the range between the ways the human ear localizes simple sinusoidal wave projections according to the duplex theory of sound localization (McFadden & Pasanen, 1975). This theory provides two explanations for the human ability to localize sound: one being the ability to perceive interaural level difference (ILD) cues, which generally help to localize tones at higher frequencies, and the other being interaural time difference (ITD) cues, which are used to localize sounds at lower frequencies (Blanks, Buss, Grose, Fitzptrick, & Hall, 2008). Simple, low-frequency tones that are capable of generating binaural beats are processed by the brain using these interaural time difference cues. Early on in testing human ability to perceive low-frequency binaural beats, it was discovered that these beats are not masked as easily as signals of equal frequency being projected to the ears. White noise, for example, can be used to mask equal-frequency sinusoidal tones being projected monaurally into one's headphones. As soon as the frequency of a tone is changed to a difference that is capable of generating binaural beats, however, the beating can often be heard through the masker. Oster explains that this phenomenon is caused by an interaural modulation occurring from the binaural beats' effect on the white noise (1973).



Example 2 shows a patch created with Max/MSP that can be used to test the ability to perceive binaural beats. In this example, the two signals are isolated from each other between the two channels of the digital audio converter. Headphones must be worn to experience this effect.

In Example 2, a frequency difference between 0 – 30 Hz is applied to two low-frequency generating oscillators whose frequency values are set by the frequency selected by the user +/- the selected frequency difference. Low-frequency binaural beats can be heard in most cases if the frequency of the two tones is below about 1,200 – 1,600 Hz and the difference between the two tones is less than 30 Hz. The number 30 is generally accepted as the “maximum number of separate events the ear can discern per second” (Puckett, 2007, p. 34). For this reason, the human ear is unable to pick out any amplitude modulations that are happening either interaurally or externally, and the tone is perceived as one “solid” signal. White noise can also be added to the signal monaurally as a masker to cover signals when there is a zero frequency difference between them. Under the right circumstances, changing the frequency difference of the two signals to a value greater than zero that is capable of generating a beat will cause the signals to dominate over the white noise.

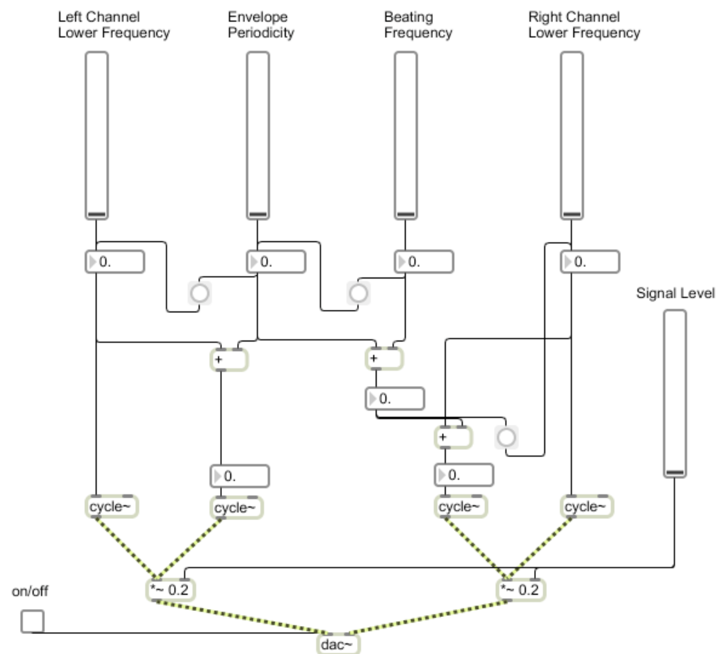
In 1975, studies were done to show that the auditory system could process high-frequency signals using interaural time difference (ITD) cues if the signals presented are more complex than two separate sinusoidal signals. These studies also demonstrated the ability to perceive binaural beats at much higher frequencies than previously believed. The study involved mixing the signals that are capable of creating binaural beats with other sinusoidal signals to create complex signals (McFadden & Pasanen, 1975). For example, if one high frequency sinusoidal signal is presented to both the left and right ear as well as two sinusoidal signals that are separated by a small difference in frequency and presented dichotically, the listener is often capable of perceiving binaural beats similar to the low-frequency binaural beats discussed earlier. This setup can be seen in Example 3. A sinusoidal signal of 3,000 Hz is presented both the left and right ears equally. Also, two sinusoidal signals are generated based on a selected “perceived frequency” that is divided into two separate frequency values that have a difference of the selected “frequency difference”. This creates two complex tones with envelope periodicities differing by the selected frequency. Under these circumstances, the brain is often capable of perceiving binaural beats using ITD cues.



Example 3. Two complex signals are created and presented to the ears separately making it possible to perceive binaural beats at high frequencies. Headphones must be worn to experience this effect.

McFadden and Pasanen take this experiment one step further by testing the ability to hear high-frequency binaural beats when the complex signals do not share a carrier signal of the same frequency. Their findings show that binaural beats can still be heard when the two complex signals are made up of different frequencies as long as their envelope periodicities differ by an amount capable of producing binaural beats (1973). For example, this means that binaural beats can be heard in most cases when a complex signal in one ear is made up of a 3,400 Hz signal and a 3,000 Hz signal while the complex signal in the other ear is made up of a 2,600 Hz signal and a 2,2001 Hz signal. In this case, a one-per-second beating can be perceived (see Example 4).

In Example 4, a complex signal is generated and sent to the left channel by summing a signal with a selected frequency and a signal with a frequency of a higher value generated by adding the chosen envelope periodicity with the original signal frequency value. The complex signal in the right channel is generated the same way except that the chosen envelope periodicity value is first added to the chosen value of the beating frequency. In this case, the envelope periodicity of the complex signal sent to the left channel will be less than the envelope periodicity of the complex signal sent to the right channel by the value beating frequency that is selected by a user. Therefore, if the beating frequency is set to 1 Hz, the listener can often perceive a one-per-second beat.



Example 4. Two complex signals are created. The user has the ability to chose the envelope periodicities of the two signals. Headphones must be worn to experience the possible effects of binaural beats.

There have been several clinical studies over the years suggesting that binaural beats can have a direct affect on human brain-wave activity and in turn can affect one's mood (Atwater, 2009; First, 2003; Lane et al., 1998). This is often referred to as binaural beat brainwave entrainment (BBBE). This entrainment ability has been linked to changes in arousal in test subjects. Recently, F. Holmes Atwater compiled a list effects and uses for binaural beats that includes sensory integration, alpha biofeedback, relaxation, meditation, stress reduction, pain management, improved sleep, health care, enriched learning environments, enhanced memory, creativity, treatment of children with developmental disabilities, the facilitation of attention, peak and other exceptional experiences, enhancement of hypnotizability, treatment of alcoholic depression, and promotion of vigilance performance and mood (2009). Other observations have been made that include a potential link between the ability to perceive binaural beats in patients with Parkinson's disease, a potential relationship between the range of binaural beats that can be perceived in women and their menstrual cycles, and differences in perceivable binaural beats between men and women (Oster, 1973).

In a study done by Lane, Kasian, Owens, & March in 1998, subjects were presented with recordings of binaural beats within very specific frequency ranges and asked to perform a series of tasks while their performance and mood were closely monitored. In one test, they were presented with binaural beats that were in the EEG-beta frequency range, which is known to be consistent with anxious thinking and active concentration. In a second test, subjects were presented with binaural beats that were in the EEG-theta/delta frequency range, which is known be consistent with deep meditation and sleep. Their study showed that subjects performed given tasks with greater accuracy when presented with EEG-beta range binaural beats as opposed to the EEG-theta/delta range binaural beats. The moods of the subjects were also directly linked to the EEG frequency ranges they were presented with. The study also pointed out that these findings could have very positive applications for tasks that require high levels of performance and attention such as air traffic control or commercial highway driving (Lane et al., 1998).

More recently, binaural beats have been used in a more commercial realm. Just performing a simple search for "binaural beats" in a search engine (such as http://www.google.com) will yield approximately two commercial sites with the purpose of selling a product for every one informational website. Some websites will go so far as marketing purchasable recordings of binaural beats as "legal drugs" because of the potentially mood altering affect binaural beats can have on the human brain (http://web-us.com; http://healingbeats.com; http://www.binaural-beats.com). Hopefully, the growing interest in binaural beats over the last several decades along with major advancements in computer and music technology will pave the way for more surprising and exciting discoveries to come.

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