

## **Entrainment by Simon Heather**

Entrainment is defined in many different ways depending to which area of science we are looking at.

1. Entrainment (biomusicology) - the synchronisation of organisms to an external rhythm
2. Entrainment (chronobiology) - the alignment of a circadian rhythm to an external rhythm
3. Entrainment (engineering) - the entrapment of one substance by another substance
4. Entrainment (hydrodynamics) - the movement of one fluid by another
5. Entrainment (physics) - the process whereby two interacting oscillating systems assume the same period
6. Entrainment (brainwave) - the practice of entraining brainwaves to a desired frequency

In 1666 the Dutch physicist Christian Huygens, the inventor of the pendulum clock discovered the principal of 'entrainment' when he noticed that two pendulum clocks mounted on a board had begun to swing with the same rhythm.

The explanation for this phenomenon is that very small amounts of energy are transferred between the two objects when their vibrations or frequencies are not the same. The energy transfer forces the two objects to start vibrating at the same speed. The weaker system is entrained by the stronger system.

There is less energy used when two objects are entrained with each other. In other words, we expend less energy when we are in harmony with our surroundings.

Entrainment, is an accepted law that affects the natural world. It has been scientifically validated in a vast number of areas of study – astronomy, chemistry, pharmacology, biology, medicine, neurology, psychology, sociology.

### **Entrainment in Nature**

Entrainment can be observed in all animal and plant species. For instance crickets will chirp in unison, fireflies will flash at the same time and mosquitoes flap their wings together.

Each mosquito alters its wing-beat frequency in response to the flight tone of the other, so that within seconds their flight-tone frequencies are closely matched, if not completely synchronised.

The fireflies live on trees found on riverbanks throughout Southeast Asia. The insects gained scientific prominence in 1935, when Hugh M. Smith, a biologist from Washington USA, described them in the journal Science. [1]

"Imagine a tree 35 to 40 feet high thickly covered with small ovate leaves, apparently with a firefly on every leaf, and all the fireflies flashing in perfect unison at the rate of about three times in two seconds." Between flashes the tree was in complete darkness, he said. [1]

"Imagine a tenth of a mile of river front with an unbroken line of Sonnerati trees with fireflies on every leaf flashing in synchronism, the trees at the ends of the line acting in perfect union with those between." [1]

The highly synchronised movements of fish and flocks of birds have frequently been explained as an attempt to reduce energy expenditure. However Matz Larsson believes that synchronisation of group movements may improve hearing perception. This enables birds to hear predators more easily and to co-ordinate their flight behaviour.[2]

Sounds produced due to movement seem to be used by schooling fish as an aid to staying in formation and avoiding collisions. Bird and bat flocks seem to display the same behaviour. [2]

A huge amount of research has been done into entrainment in living things. Some researchers have stated that entrainment appears to be essential to life itself.

### **Musical Entrainment**

Entrainment in the biomusicological sense refers to the synchronisation of organisms to an external rhythm. People clap, dance and tap their feet to music.

Beat induction is the process in which a regular pulse is activated when one listens to music (i.e. the beat to which one would tap one's foot).

The cognitive mechanism that allows us to infer a beat from a sound pattern, and to synchronise or dance to it was thought to be uniquely human. No primate tested so far with exception of the human species can dance or clap to the beat of the music. Humans know when to start, when to stop, when to speed up or to slow down, in synchronising with their fellow dancers or musicians.

Hence, beat induction can be seen as a fundamental cognitive skill that allows for music (Patel, 2008). We can hear a pulse in a rhythmic pattern while it might not even be explicitly in there: The pulse is being induced while listening like a perspective can be induced by looking at an arrangement of objects in a picture. [3]

Neuroscientist Ani Patel says that "beat-based rhythm processing" is a key area in music language research, suggesting that beat induction is "a fundamental aspect of music cognition that is not a byproduct of cognitive mechanisms that also serve other, more clearly adaptive, domains (e.g. auditory scene analysis or language)." [3]

The hypothesis that beat induction is a solely human phenomenon was recently challenged by research with an Eleonora Cockatoo named Snowball, the subject of a popular YouTube video depicting him dancing to the beat of the Backstreet Boys' song, 'Everybody Backstreet's Back' and other songs. [4][5]

Joseph Jordania recently suggested that the human ability to be entrained was developed by the forces of natural selection as an important part of achieving the specific altered state of consciousness, battle trance. In this state humans lose their individuality, do not feel fear and pain, are united in a shared collective identity, and act in the best interests of the group. [6]

Jordania suggests that achieving this state was crucial for the physical survival of our ancestors against the big African predators, after early humans descended from the trees to live more on the ground. [6]

### **Entrainment in Chronobiology**

One of the first experiments with entrainment in the field of living things was done by the French physicist de Mairan, who in 1729 first recognised the principal of 'photoc entrainment.' He noticed that plants responded to the cycle of light and dark.

Scientists have discovered that even simple bacteria have a 'circadian rhythm' (a 24hr cycle apparent in all living things).

Entrainment, within the study of chronobiology, occurs when rhythmic physiological or behavioural events match their period and phase to that of an environmental oscillation. A common example is the entrainment of circadian rhythms to the daily light–dark cycle, which ultimately is determined by the Earth's rotation. The term entrainment is justified because the biological rhythms are endogenous: they persist when the organism is isolated from periodic environmental cues.

Of the several possible causes of entrainment, bright light is by far the strongest. Many sea creatures behaviour is influenced by lunar cycles.

The activity/rest (sleep) cycle in animals is only one set of circadian rhythms that normally are entrained by environmental cues. In mammals, such endogenous rhythms are generated by the anterior hypothalamus. [7]

Circadian oscillations occur even in isolated organs, and it is believed that the master pacemaker in the mammalian brain is the suprachiasmatic nucleus or nuclei (SCN) which is a tiny region on the brain's midline, situated directly above the optic chiasm.

If our body clock is disturbed this can have serious health consequences. People who work shifts have more health problems than other workers. Shift work has been linked to obesity and depression. In fact, "every physiological system has been noted to have increased problem with shift work in general," says Elizabeth Klerman, a physician in the division of sleep medicine at Brigham and Women's Hospital and an associate professor at Harvard Medical School. [8]

### **Entrainment in Physics**

Entrainment has been used to refer to the process of mode locking of coupled driven oscillators, which is the process whereby two interacting oscillating systems, which have different periods when they function independently, assume a common period. The two oscillators may fall into synchrony, but other phase relationships are also possible. The system with the greater frequency slows down, and the slower system speeds up.

Dutch physicist Christian Huygens, the inventor of the pendulum clock, discovered the principal of entrainment after he noticed, in 1666, that the pendulums of two clocks mounted on a common board had synchronised, and subsequent experiments duplicated this phenomenon. He described this effect as "odd sympathy". The two pendulum clocks synchronised with their pendulums swinging in opposite directions, 180° out of phase, but in phase states can also result.

Entrainment occurs because small amounts of energy are transferred between the two systems when they are out of phase in such a way as to produce negative feedback. As they assume a more stable phase relationship, the amount of energy gradually reduces to zero. In the realm of physics, Huygens observations are related to resonance and the resonant coupling of harmonic oscillators, which also gives rise to sympathetic vibrations.

A 2002 study of Huygen's observations show that an antiphase stable oscillation was somewhat fortuitous, and that there are other possible stable solutions, including a "death state" where a clock stops running, depending on the strength of the coupling between the clocks. [9]

Mode locking between driven oscillators can be easily demonstrated using mechanical metronomes on a common, easily movable surface. [10] Such mode locking is important for many biological systems including the proper operation of pacemakers. [11]

We see the principal of entrainment in action when we tune a radio or TV. When we tune in a radio we are adjusting the frequency of our set's oscillator to match the frequency of the station's oscillators. When the frequencies come close to one another, they suddenly lock and we hear our radio programme.

There is a tendency for two oscillating bodies to lock into phase so that they vibrate in harmony. The weaker of the two oscillating bodies will have a tendency to adjust to the stronger one's vibration.

The powerful rhythmic vibrations of one object will cause the less powerful vibrations of another object to lock in step and oscillate at the first object's rate. This phenomenon of nature has to do with the conservation of energy.

The use of the word entrainment in the modern physics literature most often refers to the movement of one fluid or collection of particulates by another. One fluid moving in another can push or pull the other along with it. Eductors or eductor-jet pumps are an excellent example. They are used onboard many ships to pump flooded out compartments in the event of an accident.

Seawater is pumped to the eductor and forced through a jet. Any fluid at the inlet of the eductor is carried along to the outlet and up and out of the compartment. Eductors can pump out whatever can flow through them, including water, oil, and small pieces of wood.

### **Entrainment in Humans**

In human beings, the human body has a variation in temperature that changes over a 24hr period. This is caused by changes in sunlight. The way entrainment affects health can be seen in situations where stable rhythms are connected to good health. For instance a healthy body has a healthy heart beat.

If we look at two individual muscle cells from the heart through a microscope each is pulsing with its own separate rhythm. When they move closer together even before they touch, there is a sudden shift in the rhythm, and they are pulsing together. The synchronous firing of cells in the human heart's are our natural "pacemaker."

An unhealthy body is often associated with an irregular heart beat. When this happens the person can be fitted with a pacemaker which entrains the heartbeat.

Dr. Mirollo and Dr. Strogatz "show that synchrony is the rule for mathematical models in which every firefly interacts with every other," said Dr. Ian Stewart of the Mathematics Institute at the University of Warwick in England. [1]

He said they had proved to their satisfaction a 1975 conjecture of Dr. C. S. Peskin, professor of mathematics at New York University, that was derived from his attempt to explain why pacemaker cells of the heart function synchronously. He concluded that it was a form of "self-synchronization." [1]

A recent study of pancreas cells has shown that they produce co-ordinated signals only when working in a group of 50 or more. [1]

We entrain to the rhythms around us all the time, although most of the time we are not aware of it. The relationship between external rhythms and our inner rhythms is inseparable. In fact, our internal rhythms will speed up or slow down to match a stronger external rhythm.

Try counting your heart beat or breathing rate when you're stuck in traffic, around noisy machinery, or listening to loud rock music. Then count your heart rate or breathing rate when you're sitting quietly on a beach or listening to peaceful music in a quiet surrounding.

Our heart rate, respiration and brain waves all entrain to each other. Slow down your breath and you slow down your heartbeat and your brain waves. Conversely, if you are able to slow down your brain waves, you can affect your heart rate and respiration. This is one of the principles of biofeedback.

It has been found that the frequencies of pulse, breathing and blood circulation, as well as their combined activities, all function harmonically. That is, their rhythms are strictly co-ordinated in whole number ratios-two to one, three to two.

When women spend a lot of time together their menstrual cycles synchronise. It also occurs in social groups who dress and think similarly. Entrainment is working when you walk into a room full of people who are laughing and light-hearted and your mood magically lifts to match theirs.

When a person follows a guided imagery meditation programme on a daily basis they are entraining themselves to the calmer happier mental state.

Entrainment also takes place when two people have a good conversation. Their brain waves oscillate synchronously. Such entrainment is seen in the relationship between students and their professors. Therapists/healers and clients entrain with each other, as do preachers and their congregation.

Other examples of entrainment include, when we meditate in a group we feel the increased "strength" of the experience and when participating in an exercise class to up tempo music.

It is OK to speed up during the day if we have a fast-paced career, but we need to slow down when you return home. We need to teach the body to slow down, to relax, to recover, to stimulate the parasympathetic system (your natural relaxation response). When we come home we need to find external rhythms that are slow (nature, quiet surroundings, certain music) to entrain to.

We know that our heart rate slows or speeds up in response to tempo. In a Swiss study published in May 2007, music with a fast, accentuated, staccato beat induced faster breathing and heart rates than did slower music did. [12]

Normally, our heart rate at rest should be about 70 beats per minute for men and about 75 for women. Music pulsed at about 60 beats per minute is ideal for helping to induce alpha states, the same relaxed state induced by meditation. A lot of reggae music is around 60 beats per minute and is relaxing for some people. Pacabel's 'Cannon' at 64 beats per minute is also very calming.

### **Brainwave Entrainment**

Brainwave entrainment or "brainwave synchronisation," is any practice that causes brainwave frequencies to fall into step with an external stimulus. It depends upon a "frequency following" response in the human brain which has a tendency to change its EEG frequency towards the frequency of a dominant external stimulus.

In July 1875 Richard Caton reported to the British Medical Association in Edinburgh that he had used a galvanometer to observe electrical impulses from the surfaces of living brains.

Hans Berger developed the EEG (electroencephalography) in the 1920's. Berger observed and categorised five different ranges of brain wave frequencies.

**Delta Range - 0.5 to 4 HZ** - Delta brain rhythms occur in the state of deep sleep

**Theta Range - 4 HZ to 8 HZ** - Theta brain rhythms occur in dreaming sleep, and other mental states where the mind is wandering, like daydreaming and imagining. Meditators are in this state while meditating. Theta is the state that occurs when we first fall asleep. It is also associated with trance states and the dream states and can be used for hypnosis.

A person driving on a motorway who discovers that they can't recall the last five miles, is often in a theta state induced by the process of motorway driving. It is a state where tasks become so automatic you can mentally disengage from them.

**Alpha Range - 8 to 13 HZ** – Alpha brain rhythms occur in a state of relaxation and meditation. There is more alpha wave functioning when we listen.

**Beta Range - 13 HZ to 30 HZ** - Beta brain rhythms occur in our normal active aware state. There is an abundance of betawave functioning when we speak.

**Gamma Range - 30 HZ to 100 HZ** - Gamma brain rhythms occur appear to be involved in higher mental activity, including perception and consciousness.

Synchronous activity at about 40Hz appears to be involved in binding sensory inputs into the single, unitary object we perceive.

Different EEG's correspond to different mental states. In the early days of EEG research it was also discovered that some alpha and beta waves could be entrained to the frequency of an external, bright strobe light stimulus. In due course scientists realised that not only strobe lights but also rhythmic tones could create such states.

By the help of external stimuli it is possible to alter brainwave frequency. By doing so we can experience desired mental states like relaxation, meditative, creative, stress relief etc. Usually the stimuli used to achieve these states are sounds but visionary stimuli can be used too.

There are three ways main of manipulating sound for entrainment purposes. Binaural beats, monaural beats and isochronic tones.

When binaural beats are used two tones close to each other in frequency are played separately to each ear through headphones. For instance if one is 200hz and the other is 210hz through the entrainment process 10hz brainwaves are created. This method requires headphones.

Monaural beats are derived from the convergence of two frequencies within a single speaker to create a perceivable pulse or beat. For example, if a 400Hz tone and a 410Hz tone are played through a speaker, one would hear a 10Hz beat amidst the original tones.

Second, binaural beats seem to be “created” or perceived by cortical areas of the brain combining the two different frequencies, whereas monaural beats stimulate the basilar membrane of the brain.

Isochronic tones are evenly spaced tone pulses. Unlike binaural and monaural beats, isochronic tones do not rely on the combination of two tones - the "beat" is created manually by turning a tone on and off. Isochronic beats produce very strong cortical responses in the brain.

There are two main programmes for brainwave entrainment, these programmes are called Neuroprogrammer and Brainwave Generator.

There are about 100 sessions in Neuroprogrammer targeting anxiety, stress relief, creativity, relaxation and meditation. There is even a session that puts your brain in a state of healing and recovery. Brainwave Generator is a simpler programme that can also be used for relaxation.

Brainwave entrainment is not widely accepted in medical. It is a helpful tool for relaxation and meditation.

## **Sound Healing**

At football matches the crowd chants to encourage their team. As a result most teams win more matches at home than away. Players will often comment that the support of the crowd was like having an extra team member. This may be an example of entrainment as is the mother who sings soothing songs to get her baby off to sleep.

When we hear a drum beat we automatically entrain to its rhythm. Listening to drumming will change our brain wave pattern from the beta to alpha. The sound of the drum sedates the left hemisphere of the brain, which would ordinarily get distracted by ordinary events; this helps us to access the more intuitive side of the brain. [13]

Music educator Ed Mikenas finds that drumming provides “an authentic experience of unity and physiological synchronicity. If we put people together who are out of sync with themselves (i.e., diseased, addicted) and help them experience the phenomenon of entrainment, it is possible for them to feel with and through others what it is like to be synchronous in a state of preverbal connectedness.” [13]

In sound healing we are helping the client to move to a more balanced mental and physical state.

When a more balanced healer treats an out of balance client the client’s energy system is the weaker of the two oscillating bodies. The healer’s energy system is the stronger.

Was it the healing atmosphere of the treatment room, the soothing music, an hour lying on a massage table or the healer’s treatment that caused the shift in vibration?

The truth is, it was all these things. By the time the client leaves the treatment room their mental and emotional state is much closer to the healers. The client has entrained to the healer’s higher vibration.

## **References**

1. Sullivan, W, - Mystery of Nature: Mangroves Full of Fireflies Blinking in Unison - Published: August 13, 1991 <http://www.nytimes.com/1991/08/13/science/a-mystery-of-nature-mangroves-full-of-fireflies-blinking-in-unison.html?pagewanted=all&src=pm>
2. Matz Larsson - Incidental sounds of locomotion in animal cognition - Animal Cognition 2012 January; 15(1): 1–13. Published online 2011 July 12. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3249174/>
3. Patel, A. (2008) - "Beat-based rhythm processing as a key research area", In Music, Language and the Brain (pp. 402–415). Oxford: Oxford University Press.

4. YouTube video of Cockatoo dancing - [www.youtube.com/watch?v=cNAAZ5Nt6pk](http://www.youtube.com/watch?v=cNAAZ5Nt6pk)
5. Recent evidence for beat induction in vocal learners - [http://musiccognition.blogspot.com/2011/11/is-beat-induction-species-specific-part\\_30.html](http://musiccognition.blogspot.com/2011/11/is-beat-induction-species-specific-part_30.html)
6. Joseph Jordania - Why do People Sing? Music in Human Evolution. Logos, 2011.
7. Toh, Kong Leong (August 2008) - "Basic Science Review on Circadian Rhythm Biology and Circadian Sleep Disorders" (Review, Full Text, PDF). Annals Academy Med Singapore 37 (8): 662–8. Retrieved 2009-08-15.
8. Hobson, Katherine - A lack of sleep and disruption to your biological clock can have harmful effects. <http://health.usnews.com/health-news/family-health/sleep/articles/2009/12/04/6-ways-to-make-working-the-night-shift-less-hazardous-to-your-health>
9. M Bennett, M F Schatz, H Rockwood, and K Wiesenfeld - Proc. Roy. Soc. Lond. A 458 (2002) 563-579.
10. J. Pantaleone - "Synchronization of Metronomes," American Journal of Physics, vol 70 (2002) 992-1000.
11. G. B. Ermentrout and J. Rinzel - "Beyond a pacemaker's entrainment limit: phase walk-through," American Journal of Physiology - Regulatory, Integrative and Comparative Physiology, Vol 246 (1984) R102-R106.
12. Patrick Gomez, Brigitta Danuser Institut Universitaire Romand de Sante au Travail - Relationships between musical structure and psychophysiological measures of emotion - Lausanne, Switzerland. Journal Article: Emotion (impact factor: 3.73). 06/2007; 7(2):377-87. DOI:10.1037/1528-3542.7.2.377.
13. Michael Drake - Therapeutic Effects of Drumming - <http://healing.about.com/od/drums/a/drumtherapy.htm>

### **Entrainment Web Sites**

<http://en.wikipedia.org/wiki/Entrainment>

<http://www.affirmations-for-radical-success.com/entrainment-theory.html>

<http://www.energy-healing-info.com/science-of-energy-healing-and-entrainment.html>

### **Brainwave Entrainment**

[http://en.wikipedia.org/wiki/Brainwave\\_entrainment](http://en.wikipedia.org/wiki/Brainwave_entrainment)

<http://www.brainwave-sync.com/page.html?id=5>

<http://ofmelancholy.hubpages.com/hub/brainwave-entrainment-an-alternative-therapy>