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# The Effects of Sounds and Music on Cells and Organisms: A Promising and Developing Area of Research

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*This review is based on recent publications about the effects of sound, and more particularly of music, on several aspects of physiology. It has been known for a long time that music has effects on the brain and on the functioning of different organs. In recent years, several publications also described specific effects of music on the physicochemical mechanisms in the other organisms, bacteria, plants and animals. These researches being rather disparate in the methodologies used and the results obtained, they need to be classified. In this review, we summarize the studies and attempt to explain the cellular mechanisms involved, by considering the properties of the plasma membrane and its links with the extracellular and intracellular medium. This field of research is currently in full expansion, but still requires further studies to understand and go further in the possible applications, the precise molecular mechanisms of effects of music still remain to be clarified.*

**Keywords:** *sound, music, plant, animal, unicellular organism*

## Introduction

Music is a complex acoustic and temporal structure, whose effects on biology are a hot topic. It has long been known that music influences mood and arouses strong emotions. Today, we are discovering the numerous effects it has on the brain and on organic functions. It is used in a care approach (music therapy) (Behzadmehr et al. 2020, Billar et al. 2020, Buglione et al. 2020, Bulut et al. 2020, Martin et al. 2020, Çelebi et al. 2020, Chai et al. 2020a, b, Cimen et al. 2020, Chan et al. 2020, Dai et al. 2020, Ernberg et al. 2020, Gamboa et al. 2020, Garcia Guerra et al. 2020, Giordano et al. 2020, Gogoularadja and Bakshi 2020, Guo et al. 2020, Howlin and Rooney 2020, Johnson and Elkins 2020, Köhler et al. 2020, Pérez-Eizaguirre and Vergara-Moragues 2020, Polascik et al. 2021, Saraogi et al. 2020, Usui et al. 2020, Wang et al. 2020, Zhang et al. 2020, Dunbar et al. 2021, Yang et al. 2021), but its influence on well-being goes beyond the human being (Sambraus and Hecker 1985, Hurnik and Johnson 1997, Kenison 2016, Bowman et al. 2017, González-Grajales et al. 2019, Kemp 2020). In fact, many studies have described the various effects of music on different organisms (Lemarquis 2009, 2021, Dhungana et al. 2018, Exbrayat and Brun 2019, Mayoud and Lemarquis 2019, Pulcrano and di Porzio 2021).

Music is a fundamental mean of communication, which developed and diversified over the millennia as human beings migrated around the planet (Wallin et al. 2000, Mehr et al. 2020, Savage et al. 2020). It allows people to share intentions

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and emotions. Power of music pass through the capture of musical sounds by auditory cells which record sounds, transform them into electrical signals which in turn reach the brain where they are translated into emotions. The neurophysiological mechanisms are better known thanks to the development of innovated methods (Zimmermann and Fermin 1996, Fettiplace and Hackney 2006, Ashmore 2008, Müller 2008, Rabbitt et al. 2010). Scientific evidences thus confirmed the long-praised medicinal virtues of music, such as neurostimulation and neuroprotection (Lemarquis 2009, 2021, Jones et al. 2020). But for a few years now, more and more publications have addressed the direct effects on non-auditory cells, a less obvious aspect of the effects of music (Lestard et al. 2013, Lestard and Capella 2016). The experiences performed by researchers present very disparate results. Whatever this great disparity, the study of the effects of sound and music on cells reveals the available possibilities to modulate cell physiology.

## Evolution and Adaptation of Communication in the Animal Kingdom

So that on organism could live, it is necessary that it communicates with other organisms and, in a broader sense, with the elements of the environment. Throughout its life, every organism is subject to many stimuli. In unicellular organisms, the single cell is equipped with receptors that register different types of stimuli acting directly on it. Some unicellular, prokaryotes or eukaryotes, are sensitive to molecules emitted by other individuals and react by synthesizing substances. They may also be sensitive to vibrations produced by sound and respond by producing molecules. For example, among unicellular organisms, volvox algae live in colonies of thousands of flagellated cells, able to move toward the same direction. All the cells contain a light-sensitive pigment that directs each cell towards it, and the perception of light allows a set of juxtaposed cells to move towards the same goal (Hallmann 2003, Ikushima and Maruyama 2007).

In sponges, jellyfish and polyps, a reduced number of cell types is observed and the nervous system is limited to a few neurons, or it is almost absent (Arai 1997, Moore 2006, Barnes et al. 2009). The perception of external signals exists however and allows oriented movements and responses adapted to the environment. As organisms become more complex, various sensory organs appear, in connection with the development of an increasingly efficient nervous system. The latter will allow a better adaptation of the organisms in their environment. Stimuli are then received by receptors of sense organs, and the nerve impulses are transmitted and interpreted by the nervous system.

For Humans, the five specific senses commonly known and already listed by Aristotle (384-322 BC), are touch, sight, hearing, smell and taste. In addition, there is a general sensitivity including mecanoreception, thermoception, nociception and proprioception.

There are also other types of senses in the animal kingdom directly related to the evolutionary level and the way of life of organisms. For example, fish and certain amphibian larvae have a lateral line which allows perception of water movements and hydrostatic pressure (Bleckmann and Zelick 2009). They also have an ampullary organ (consisting of the ampullae described by Lorenzini in 1678) which is sensitive to low frequency electric fields and allows electrolocation (Roth and Tscharntke 1976, Gibbs and Northcutt 2004, King et al. 2018). In lizards, snakes and caecilian amphibians, particularly well-developed vomeronasal organs are added to the classic olfactory organ (Badenhorst 1978, Billo 1986, Billo and Wake 1987, Døving and Trotier 1998). Finally, in some migratory birds, magnetoreceptors make the individual sensitive to the earth's magnetic field (Wiltschko and Wiltschko 2012).

## Sounds and Music as a Communication Signal

In the course of evolution, different mechanisms have been selected to allow animals to emit sounds and communicate.

Aristotle already indicated that fish could emit “vocalizations”. A significant number of studies confirm that some fish emit sounds and that their repertoire is surprisingly vast. So, sound is involved in a large number of behaviors related to reproduction, feeding or defense of the territory. The means of producing sounds are variable; they range from the air bubble released by the posterior part of digestive tube (in herrings) to chirping produced by the friction of two hard parts of the body: striated joint of the pectoral fins in catfish, pharyngeal teeth located at the level of the gills which squeak in *Haemulon plumierii*; some species can also use the swim bladder to emit sounds (Parmentier et al. 2016, Raick et al. 2018, Di Iorio et al. 2019, Huby et al. 2019, Bolgan et al. 2020). About 100 families of bony fish have been shown to be able to communicate acoustically. The same species can even produce several different sounds. Currently, the "vocalizations" of more than 200 species of fish were described in the Northwest Atlantic (Fish and Mowbray 1970).

Aquatic mammals such as Cetaceans also emit all kinds of sounds, vocally or not, allowing communication between animals of the same species (Payne 1984). Sonar is used by dolphins (Whitlow 1993). These animals emit sounds of varying frequencies to communicate or find their way in space. They use air sacs (Helmholtz cavities) to emit sounds at various resonant frequencies. When diving, dolphins store air in the lungs. They use their larynx to produce ultrasounds (Whitlow 1993).

Bats use echolocation to navigate and locate prey. They modulate calls of different frequencies according to the species, which allow them to perceive the distance of the prey or the obstacle by measuring the delay between emission of the call and echo. The perception of sound is carried out by a classical hearing system (Suga and O'Neill 1979, Moss and Sinha 2003).

In many species of birds, at the time of reproduction, the male utters a characteristic song using the syrinx, an organ made up of cartilaginous parts located below the trachea, unlike the vocal cords which are located above the trachea (Warner 2009).

These few examples show that the senses of organisms represent adaptations to living environment. Any response to the environment implies that stimuli such as molecules, vibrations, low frequencies, electric fields or light waves, are captured at a membrane receptor, before a cascade of intracellular reactions leads to a response (Lim et al. 2015, Syrovatkina et al. 2016). The complexity of the sense organs observed in multicellular organisms is closely related to the development of the nervous system: from a simple network of nerve fibers in the mesoglea (mesohyle) of porifers and cnidarians, this system becomes more complex and centralized, allowing more elaborate behavioral responses. Table 1 summarizes the diversity of sound production mechanisms in animals.

**Table 1.** *Examples Illustrating the Diversity of Sound Production Mechanisms in Animals*

| Structures used in sound production | Mechanisms | Animals |
|---|---|---|
| Use of resonant external substrate | Hitting a substrate | **Beavers**: slapping the tail on the surface of water<br>**Spiders**: drumming during courtship sequences |
| Use of body structures | Clicking, snapping, vibrating | **Some insects**: wing vibrating<br>**Cicadas**: vibrating a drum-like membrane (modified membrane localted on the abdomen)<br>**Fish (Sciaenidae)**: swimbladder snapping<br>**Birds**: beak clicking/grinding<br>**Bats**: tongue clicking |
| | Rubbing body parts together | **Orthopterans**: stridulation by dragging the body part equipped with a scraper across an adjacent body part with a file-like structure<br>**Fish (catfish)**: stridulation by using the pectoral fins |
| | Vibrating a membrane in an air flow | **Birds**: tympaniform membranes vibrating (presence of a syrinx)<br>**Amphibians, reptiles and mammals**: presence of a larynx containing vocal cords |

## Effects of Vibrations, Sounds and Music on Cells and Organisms

In recent years, research has focused on the effects of music on various organisms in an attempt to understand how sound vibrations act at the cell level. Experiments have been carried out on cell cultures, in cancer cells, microorganisms, and on complete organisms, by testing different biological parameters (Lemarquis 2009, 2021, Dhungana, et al. 2018, Exbrayat and Brun 2019, Mayoud and Lemarquis 2019, Pulcrano and di Porzio 2021). Tables 2 and 3 summarize the state of the art about the positive effects of music in different organisms and non-auditory cells.

**Table 2.** *State of the Art About Some Effects of Music on Non-auditory Animal Cultured Cells*

| Cultured cells | Effects of music |
|---|---|
| ST2 stromal cells<br>C2C12 myoblasts | Suppression of mechanosensitive genes by audible sound stimulation |
| NIH3T3 fibroblasts<br>NB2a neuroblastoma cells | No observation of suppression of mechanosensitive genes by audible sound stimulation, showing a cell type-specific response to sound |
| Human embryo | Improvement of fertilization rates |
| Cancer cell lines | Alteration of cell cycle and decrease in viability, but differences in response depending on cell line |
| Buffalo granulosa cell speroids | Up-regulation of steroidogenic gene expression |

Note: The key references are mentioned in the text.

**Table 3.** *State of the Art About Positive Effects of Music (Soft Rhythmic Music) in Different Uni- and Pluricellular Organisms*

| Organisms | | | Positive effects of music |
|---|---|---|---|
| Animal species | Domestic animals | Dogs | Increase in sleep duration |
| | | Cats | Increase in approach behaviour |
| | Farm animals | Cows | Increase in milk production |
| | | Buffaloes | Change in behaviour |
| | Race horses | | Influence of emotional state |
| | Birds | Chickens | Increase in number of neurons and mean neuronal nuclear area |
| | | Songbirds | Improvement in learning to sing |
| | Rodents | | Improvement in spatial learning and reduction of anxiety-related behavior; increase in the body weight of pups |
| | Monkeys | Chimpanzees | Reduction in aggression |
| | | Baboons | Decrease in heartrate |
| | Elephants | | Reduction of stereotyped behaviour |
| Vegetal species | Herbaceous plants | | Increase in germination, growth and development, disease resistance |
| Unicellular organisms | Bacteria and yeast | | Improvement in growth and antibiotic sensitivity |

Note: Choice of music, depending of the acoustic communication system of the species, is decisive to observe behavorial effect. In general, loud and inharmonious music tends to have a negative effect. The key references are mentioned in the text.

### *Effects of Vibration, Sound and Music on the Animal Cells*

The effects of electromagnetic waves on living beings have been studied for much longer than those of sound waves (National Research Council (US) Committee on Assessment of the Possible Health Effects of Ground Wave Emergency Network (GWEN) 1993, Cardinale and Pope 2003). Nevertheless, a number of studies suggest that emotions triggered by music can be particularly useful in relieving stress. Recent experiments show that different non-hearing cells respond to sound, the fluids contained in the cells being sensitive to pressure variations induced by sound waves. The mechanisms of cell growth or cell death affected by acoustic vibrations appear to be similar for all cell types, whether they are auditory or not. The basic mechanisms could thus be common and universal (Zimmermann and Fermin 1996, Chan and Hudspeth 2005, Fettiplace and Hackney 2006, Ashmore 2008, Müller 2008, Rabbitt and Boyle 2010, Lestard et al. 2013, Lestard and Capella 2016). Thus, research has been carried out on the effects of music on the biology of different cell types. Study of effects of music on human chondrocytes has shown that use of music help to identify biomarkers and provide a new approach to the treatment of osteoarthritis (Vannoni 2012, Corallo et al. 2013, 2014, Dhungana et al, 2018, Exbrayat and Brun, 2019). On the other hand, it has been observed that the size and the granularity of tumoral MCF7 cells cultivated in vitro was altered by music (Lestard et al. 2013, Lestard and Capella 2016). In the lab Sprague-Dawley rats, music also decreased the enhancing effects of stress on the development of lung metastases provoked by previously injected carcinosarcoma cells (Nuñez et al. 2002).

Music has an effect on the deformability and aggregation of red blood cells and can therefore have an influence on some pathologies. In particular, effects on the surface properties of plasmic membrane have been observed. Membrane molecules such as adenylate kinase, show sensibility to the exposure to low frequency fields (Erken et al. 2008, Albanese et al. 2009). Acoustic vibrations affect fibroblast migration and cell morphology with formation of filopodia and lamellipodia (Mohammed et al. 2016).

*Specific Effects on the Immune System*

Several studies have shown the effects of music on the immune system of people under stress, or suffering from Alzheimer's disease, Parkinson’s disease, or after a stroke (Hasegawa et al. 2001). The effects are visible on the activity of the natural killers (NK) cells and on the hormone norepinephrine level. Other researches have shown that rhythmic percussions can increase NKs cells and the amount of the hormone dehydroepiandrosterone relative to cortisol, indicating stress regulation (Lu et al. 2013). A variety of neuroendocrine ways also contribute to immune system changes (Bittman et al 2001, Hirokawa and Ohira 2003, Wachi et al, 2007).

Several experiments have also been carried out in rodents with pathologies and have shown a role for music on the immune system. In young and adult rats suffering from asthma, music modulates the number of leukocytes and the level of IL-4 (Lu et al. 2010). In lab BALB/c mice subjected either to noise or to music, thymus and spleen cell density, T cell population, splenocyte proliferation and NKs activity were enhanced by music (Nuñez et al. 2002). The survival of allografts in an experimental model of murine heart transplantation was significantly prolonged in animals exposed to occidental opera and classical music. Cell proliferation, IL-2 and interferon-γ were suppressed in mice exposed to opera, while IL-4 and IL-10 were upregulated and CD4 +, CD25 +, Foxp3 + increased after exposure to certain types of music (Uchiyama et al. 2012a, b).

*Other Effects on Animal Organisms*

Several effects on animal behavior in different Vertebrates have been reviewed (Dhungana et al. 2018). Studies in chicken have shown that music reduces stress measured by various parameters (duration of tonic immobility, white blood cells/ lymphocyte ratio and fluctuating asymmetry of the organism) (Bonzom 1999, Dávila et al. 2011). It is interesting to observe that the effects described according to the type of music and the animal species can be positive, negative or inexistent. In birds, it is known that the young learn the characteristic melodies of their species by listening to the adults. Young birds deprived of sound, either because they are deaf or because they are raised in isolation, away from the song of adults, are unable to sing. The learning of birdsong in relation to the intrinsic plasticity of neurons has been studied recently in zebra finch (Daou and Margoliash 2021).

Several results were also been obtained in monkeys: music can have effects in decreasing the heartrate of baboons, increasing the social behaviour in chimpanzees, or inducing an abnormal behaviour in rhesus macaques (Dhungana et al. 2018). In rats, music might improve spatial learning and memory ability (Xiong et al. 2018).

Effects of music have also been observed in domestic animals. In dogs, classical music can decrease vocalization and body shaking and increase sleep duration. Cats are sensitive to music and suitable musical pieces have been created (Dhungana et al. 2018). On the other hand, various effects have been observed in cattle. It has been observed that dairy breeds are more sensitive to sound, and especially music, than beef breeds (Dhungana et al. 2018). Increase or decrease in milk production depends on the noise levels. Loud noise or excessive sounds cause a stress of cattle and therefore a decrease in the amount of milk produced (Hemsworth 2003). In contrast, slow music can increase milk production contrarily to fast music (Algers et al. 1978, Algers and Jensen 1991). In buffalo, animal behaviour and reproduction are affected by music (Abuzead and Khalil 2007).

On the other hand, music seems to have effects on embryonic development, facilitating neurogenesis, and also regeneration and repair of neurons in Human (Kim et al. 2006, Fukui and Toyoshima 2008), and modulating expression of apoptosis in the development of auditory nuclei in chicks (Alladi et al. 2005). In a study devoted to the effects of music on the development, pairs of Wistar rats were exposed to classic music. Before parturition, the fetuses were extracted and brains prepared for electron microscopy. The results showed that prenatal music had an effect on neuroplasticity of fetal brain. As rat fetuses cannot hear until birth, these neuroplasticity changes of fetal brain could be related to a reduction in the mothers' blood corticosterone level (Sheikhi and Saboory 2015). In chicks, prenatal music stimulation leads to morphological changes in hippocampus and brainstem auditory nuclei. In contrast, unpatterned noise and loud music (110 dB) induce altered volume and neuronal number in these regions, indicating that the characteristic of the sound was mediating effects on brain development (Sanyal et al. 2013). Furthermore, it has been shown that *in ovo* sound stimulation (music or noise: 110 dB) affects the regulation of brain-derived neurotrophic factor (BDNF) in the developing auditory system of chicks; it was regulated at the transcriptional and post-translational level in the auditory cortex and at the post-translational level in the hippocampus (Kathpalia et al. 2019).

According to some authors, music would also improve the success of fertilization rates of *in vitro* cultured human embryos (Lopez-Teijón et al. 2015).

At last, some studies have shown the effects of sounds and music on stem cells (Choi et al. 2016, Wei et al. 2016, Ventura et al. 2017).

*Some Adverse Effects on Animal Cells*

The effects of music cannot be equated with the effects of all types of sound. Research shows that not all types of sound have beneficial effects on the cells. There are sounds with harmful effects (Clark 1991). When the choroidal plexus of rats is submitted to noise, the number of normal cells decreased and the number of apoptotic cells increased (McCarthy et al. 1992, Aydin et al. 2011). In experiments conducted to analyze the effects of anxiolytics in rats, both noise and music suppressed the sexual behavior of females. In another experiment, noise suppressed the sexual impulses of ovariectomized females treated with high dose of estradiol and induced avoidance of the area where males were located (Le Moëne and Ågmo 2018a, b, Le Moëne et al. 2019). These studies show that in some cases, music can negatively affect animal behavior.

*Effects on Unicellular Organisms*

Like multicellular organisms, unicellular organisms, eukaryotes or prokaryotes, seem to be sensitive to music. Several works have shown the effects of single-frequency sound on the biology of various bacteria (Mortazavian 2012). Experiments using indian music have shown that it has a positive effect on the growth of bacteria and yeasts. Beneficial effects have thus been shown on cellular growth, metabolism and antibiotic sensitivity (Norris and Hyland 1997, Matsuhashi et al. 1998, Ayan et al. 2008, Shaobin et al. 2010, Sarvaiya and Kothari 2015, Shah et al. 2016). Growth, pigment production and antibiotic sensibility are affected by the intensity of sound in several bacteria (Kothari and Sarvaiya 2017, Khotari et al. 2018).

*Effects on Plants*

In plants, sound waves can influence germination, development and growth (Qin et al. 2003, Mishra et al. 2016, Vicient 2017). It can also enhance the immunity increasing tolerance to drought (Chivukula and Ramaswamy 2014, Choi et al. 2017, Lopez-Ribera and Vicient 2017). A recent study looked at the response of *Oenothera drummondii* plants to sound. The main result obtained is that the flowers of this plant produce a sweeter nectar only three minutes after being exposed to the rustling of the wings of butterflies and bees which are its pollinators (De Luca and Vallejo-Marin 2013, Veits et al. 2019). Other examples are consistent with the existence of an acoustic communication during interactions between plants and pollinators (Ayan et al. 2008, Mishra et al. 2016, Schöner et al. 2016).

More broadly, some animals and other plants can use the sounds emitted by a plant to obtain information about its condition (Khait et al. 2019).

Some studies have shown that the roots of various plants orient themselves towards the noise generated for example by flowing water (Gagliano et al. 2012, Gagliano 2013) and that the corn roots tend to grow towards a sound source whose frequency is close to 200 Hz (Gagliano 2013). Those different examples confirm that plants can also use sound, but the ecological and evolutionary implications that this represents in the life of a plant are not yet well known (Hongbo et al. 2008, Gagliano et al. 2012, Gagliano 2013). Further studies on plant bioacoustics are still needed to understand the interactions of plants with their environment.

### *Effects on Genome*

Studies have looked at the roles of various forms of genomic changes and gene regulation related to music abilities. Some genes inherited with musical aptitude have been identified. In particular, the alpha-synuclein gene, involved in song perception in songbirds, has been shown to be also overexpressed in individuals listening or performing music. Its mutation is associated to several cognitive diseases in humans and perturbations of song production and perception in songbirds. These observations are in accordance with an evolutionary conservation in biological processes related to sound perception (Kanduri et al. 2015, Järvellä 2018). On the other hand, changes in the peripheral blood microRNA transcriptome after 2 hours of concert performance are identified in professional musicians, suggesting regulatory mechanisms underlying auditory perception. Based on the current knowledge about the microRNA function in blood and brain, the authors interpreted the regulation of these non-coding RNAs as consequence of a regular musical activity. In brain, the putative targets of these microRNAs were involved in neuronal activity, neuronal plasticity, myelination and cognitive functions (Nair et al. 2019, Nair et al. 2021).

It has been shown that Indian Vedic music can upregulate the expression of steroidogenic genes in 3D cultured buffalo granulosa cell spheroids (Pandey et al. 2021).

Proliferation of gastric cancer cells did not increase when cells were exposed to classical music contrarily to those exposed to metal music. The expression of several genes involved in proliferation seems to be modulated in different ways according to the music type (Ramírez-Rivera and Bernal 2019).

In order to give a molecular basis to effects of music on organisms, a metanalysis of 105 publications concerning humans and several animal models identified several candidate genes related to musical traits. The authors have shown that these genes are involved in biological functions underlying learning and memory, which are essential properties for music abilities (Oikkonen et al. 2016). A study of properties of audible sound as mechanical stimulus by cells has shown an effect of wave form and sound pressure level, more than frequency, on gene expression, with a cell type-specific response to sound (Kumeta et al. 2018).

**Reception of Vibrations and Intracellular Repercussions**

How vibrations can intervene on cellular physiology? The effects of vibrations are well known in hearing cells. These cells also called “hair cells” are sensory cells emitting cilia which are really cytoplasmic expansions, the stereocilia. These cells are arranged along the basilar membrane of the cochlea (still called “organ of Corti”). Depending on their position on the cochlea, cell membranes are sensitive to vibrations at well-defined frequencies. The vibrations cause a deformation of the membrane of these cells at the level of the cilia which amplifies the surface of reception of the vibrations. The deviation of the stereocilia causes the opening of ion channels creating an electrical receptor potential. $Ca^{++}$ ions enter the cell, releasing glutamate, a neurotransmitter at the level of the synapses in connection with axons of neurons. The signal is transmitted to the auditory areas of the brain. This type of interactions between cell membrane and vibrations can certainly be generalized to all cells.

All cell membranes are made up of a bilayer of phospholipids in which proteins are incorporated. This membrane is bound outside the cell and can carry receptors; it is also linked directly to the cytoskeleton and to the enzyme systems located inside the cell. Even if studies specifically related to the mechanism of the effects of the sounds received by cell membranes are still lacking, the analysis of works on membrane receptors, the nature of the signals and the elastic capacities of the cell allow us to make assumptions as to these mechanisms.

At the cellular level, it is certainly in plants that work is the most advanced. Sound vibrations can affect microfilament rearrangements, increase the levels of polyamines and soluble sugars, alter the activity of various proteins, and regulate the transcription of some genes (Qin et al. 2003, Hongbo et al. 2008, Mishra et al. 2016). The reception of chemical signals by animal cells is well known. Various stimuli such as light, ions, pheromones, hormones or neurotransmitters, bind to G protein-coupled receptors located on cell membranes. Then, they transduce these extracellular signals inside the cells by engaging G proteins, that trigger a cascade of signaling events leading to an appropriate cellular response (Lim et al. 2015, Syrovatkina et al. 2016). Further studies on the modalities of acoustic signal capture will provide a better understanding of the intracellular repercussions of sound. Elasticity of biological tissues can be measured by elastography. This imaging method makes it possible to understand the variations in the hardness of tissues and their elasticity (Brum 2012, Grasland-Mongrain 2013) as a consequence of the links that membrane receptors establish with the elements of the cytoskeleton (Icard-Arcizet 2007).

Reading these works, we can assume that sound vibrations trigger the plasmatic membrane’s vibration, which could result in the activation of certain proteins of the G protein type and the transmission of a chemical signal in the cell. Several metabolic reactions governing the physiology of the cell could then be affected.

A controversial theory, the “proteody theory”, emitted by the French particle physicist Joël Sternheimer at the beginning of the 1990s, defended the idea of the existence of waves emitted in the body molecules. Unfortunately, no scientific publications are available for now (Doux 2019). According to this theory, waves whose frequencies can be transcribed into musical notes are associated with each group of amino acids. In the same vein, King and Angus (1996) published a computer program called PM (protein music) to analyze information about protein sequences by audification, i.e. using the hearing to analyze data (Kramer 1994).

Petrovski et al. (2021) found a correlation between yeast vacuolar proton-ATPase activity (involved in many life processes) and the intensity of several frequencies of an oscillating electric field generated by music. These observations led these authors to conclude that such an electric field from the music interfered with the periodic transmembrane movements of the enzyme. Based on the fact that organisms are subject in nature to several rhythmic oscillations, Muehsam and Ventura (2014) give a theoretical study in which they examine the effects of sound vibrations on gene expression.

## Conclusions

During biological evolution, organisms have acquired senses that allow them to interact with the environment. The sensory perception of living organisms is very diversified and is directly related to the lifestyle of the organism. Several of those senses will be put to good use by art in Human. Among the arts, music is directly related to the sensory system of hearing. While the effects of sound vibrations on auditory cells have long been known, the effects on other cell types are much less well understood. Currently, an increasing number of works is investigating the effects of music on the biochemistry of non-auditory cells and on various aspects of metabolism. Nevertheless, these works remain still quite disparate.

Music elicits reactions in humans that promote positive emotions, stress relief and immune function, by soliciting different cellular signaling molecules including hormones, neurotransmitters, cytokines, and peptides (Gangrade 2012). Music can restore some of the homeostasis and thus reduce pain (Nelson et al. 2008). It probably reduces alterations in the hypothalamic-pituitary hormonal axes (Russo et al. 2017). Music (432 Hz) can also influence growth, by increasing food intake and body weight; a significant increase of ghrelin expression was found in hypothalamic neurons in music-treated rat pups (Russo et al. 2021). A hypothesis involves quantum mechanics. But beware of the enthusiasm aroused by these exciting results. Studies are still necessary to understand and go further in the possible applications, the precise molecular mechanisms of its effects indeed yet to be clarified. But there is a field of research emerging here.

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