DOI: 10.35218/ajm-2024-0005

Illusions of Auditory Reception and Paradoxes of Perception – Psychoacoustic Effects Generated by Sounds

ROSINA CATERINA FILIMON, Associate Prof. PhD
"George Enescu" National University of Arts Iași
ROMANIA*

Abstract: Auditory illusions and perception paradoxes were discovered a few centuries ago and have continued to be identified to this day through complex analyses. Whether intentionally or accidentally, some sound illusions are present in notable works by established musicians. These brain processes are caused by the paradoxes of musical perception, which are determined by the frequency of sounds and their spatial location. The auditory presence of illusions confirms the existence of cerebral mechanisms that alter the reception and perception of sound during the decoding process. The spatial component of music and the overlapping of sound planes promote the creation of musical chimeras. Studying auditory illusions and paradoxes contributes to understanding the perceptive and cognitive processes of decoding sound impulses, techniques for analysing and synthesizing sound, and the development of electroacoustic instruments. The present research outlines three auditory illusions: *Il Terzo suono di Tartini* (*Tartini's Third Sound*), the *Shepard Scale*, and the *Mysterious Melody*. The auditory illusion named *Il Terzo suono di Tartini* represents the discovery of Giuseppe Tartini, the Italian violinist, composer, educator, theorist, and philosopher. The illusion of an infinite musical scale, the *Shepard Scale*, is named after American psychologist and cognitive researcher Roger Shepard. The psychoacoustic illusion named the *Mysterious Melody* was discovered and studied by one of the best-known researchers in music psychology Diana Deutsch.

Keywords: auditory illusions and paradoxes, *Il Terzo suono di Tartini*, *Shepard Scale*, *Mysterious Melody*, Johann Sebastian Bach, György Sándor Ligeti, Anton Webern.

1. Introduction

The anatomical and physiological capacity of the auditory analyser, cerebral activity, and the physical characteristics of the sounds received interact in the complex process of musical reception and perception. The brain doesn't just record sounds; it decodes and interprets the perceived sound material. The auditory presence of illusions confirms the existence of cerebral mechanisms that, during the decoding process, alter the reception and perception of sound waves. Thus, just as there are well-known optical illusions,

* rosinafilimon@yahoo.com

there are also auditory illusions, but these are less known. They are caused by the paradoxes of musical perception determined by the frequency of sounds and their spatial location. The spatial component of music and the overlapping of sound planes promote the creation of musical chimeras.

Auditory illusions were discovered a few centuries ago and new ones have continued to be identified to this day through complex analyses. Whether intentionally or accidentally, some of them are present in notable works by established musicians, including Bach (1685-1750), Beethoven (1770-1827), Webern (1883-1945), Berg (1885-1935), Honegger (1892-1955), Krenek (1900-1991), Ligeti (1923-2006), and Stahnke (born 1951). Recent research on auditory illusions has been done by Diana Deutsch[1], who discovered numerous auditory illusions and paradoxes, including the *Octave Illusion, Chromatic Illusion, Tritone Paradox,* and *Mysterious Melody.*

2. Illusions of Auditory Reception and Paradoxes of Perception

The present study showcases three auditory illusions discovered over time: *Il Terzo suono di Tartini* (*Tartini's Third Sound*), the *Shepard scale,* and the *Mysterious Melody*.

2.1. *Il Terzo suono di Tartini*

Fig. 1
Giuseppe Tartini
(painting, anonymous painter, XVIII century)

The auditory illusion known as *Il Terzo suono di Tartini* (*Tartini's Third Sound*) is named after Giuseppe Tartini (1692, Pirano, Slovenia – 1770, Padua, Republic of Venice) (Fig. 1) (Milan, Castello Sforzesco Museum, public domain) – an Italian violinist, composer, educator, theorist, and philosopher (Durante, 2023, p. 219).

Giuseppe Tartini suddenly suffered from an unknown illness in his time, which resulted in the paralysis of his right arm (1740) (Petrobelli, 1968, pp. 150-151), impacting his activity as a virtuoso violinist. From that point, he devoted his attention to composition, theorising, and teaching.

Tartini was one of the most renowned musicians of his time and composed over 450 works (Durante, 2023, p. 219), most of which were for violin. He was known as *Maestro delle*

[1] Diana Deutsch (b. 1938, London), Emeritus Professor in the *Psychology Department* at the University of California, San Diego, Adjunct Professor at *The Center for Computer Research in Music and Acoustics*, Music Department, Stanford University. Deutsch is one of the best-known researchers in music psychology, also known for the discovery of auditory illusions described in her paper *Musical Illusions and Phantom Words: How Music and Speech Unlock Mysteries of the Brain* (2019).

nazioni (*Master of Nations*) due to his success as a pedagogue at his cosmopolitan school, founded in 1728, where young people from across Europe studied and became notable artistic personalities. Francesco Salieri studied at Tartini's school and later taught Antonio Salieri, the well-known composer and conductor, who was his brother.

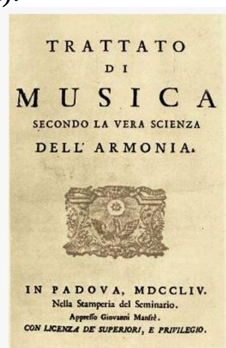
Among his theoretical works are *Trattato di musica secondo la vera scienza dell'armonia* (*Treatise on music according to the True Science of Harmony*) (1754, Padua: Stamperia del Seminario), *Regole per arrivare a saper ben suonare il Violino* (*Rules for playing the violin well*)[2] (1760) – a violin treatise published posthumously with the title *Traité des agrémens de la musique* (*Treatise on music accreditation*) (1770, Paris: Pierre Denis), *De' principi dell'armonia musicale contenuta nel diatonico genere* (*Principles of Musical Harmony Contained in the Diatonic Genus*) (1767, Padua: Stamperia del Seminario). The violin treatise contains a synthesis of Tartini's principles and circulated in the educational circles in manuscript form. This teaching material was a source of inspiration for Leopold Mozart in conceiving a treatise for violin intended for publication – *Versuch einer gründlichen Violinschule* (*A treatise on the fundamental principles of violin playing*) (1756, Augsburg: Johann Jacob Lotter), incorporating some Tartinian passages entirely without citing their source (Gatti, 2001, p. 10).

He devised a musical and philosophical theory based on observing an acoustic phenomenon that he described in his work *Trattato di musica secondo la vera scienza dell'armonia* (Assayag, Feichtinger, Rodrigues, 2002, p. 54) (Fig. 2 – Fig. 4, public domain).


14 TRATTATO DI MUSICA.

te intuonati. Si ſentirà un terzo ſuono affatto diſtinguibile, e ſarà il ſottopoſto ſegnato in note chiuſe muſicali.

Lo ſteſſo ſuccederà, ſe ſaranno ſuonati gli eſpoſti intervalli da due ſuonatori di Violino diſtanti tra loro cinque, o ſei paſſi, ſuonando ciaſcuno la ſua nota nello ſteſſo tempo, e ſempre con arcata forte, e ſoſtenuta. L' uditore poſto nel mezzo riſpettivo de' due ſuonatori ſentirà molto più queſto terzo ſuono, che vicino a ciaſcuno de' due ſuonatori: ſegno fiſico evidente della cagione del terzo ſuono, ch' è l' urto de' due riſpettivi volumi d' aria moſſi dalle vibrazioni delle due corde ſuonate. Si avrà lo


TRATTATO
DI
MUSICA
SECONDO LA VERA SCIENZA
DELL' ARMONIA.

IN PADOVA, MDCCLIV.
Nella Stamperia del Seminario.
Appreſſo Giovanni Manfrè.
CON LICENZA DE' SUPERIORI, E PRIVILEGIO.


Mi domanderà poi ella in ſecondo luogo in qual relazione ſi trovi queſto terzo ſuono agl' intervalli riſpettivi, da' quali riſulta. Le riſpondo, che dati i ſeguenti intervalli, de' quali è riſpettivo terzo ſuono il ſottopoſto, queſto ſarà dimoſtrativamente il Baſſo armonico de' dati intervalli, e ſarà paralogiſmo qualunque altro Baſſo vi ſi ſottoponga. Solamente ſi avverta, che i tre intervalli ſegnati, ſeſto, ottavo, e decimo, ſono in ragione diverſa da quello appare. Il ſeſto, e l' ottavo non ſono terze minori, ma ſeſquiſeſte; cioè il Gſolreut b molle è la nota, che divide ar-

Fig. 2
Il Terzo suono di Tartini – graphic representation (Tartini, 1714, p. 14)

Fig. 3
Tartini – *Trattato di musica secondo la vera scienza dell'armonia* (the cover)

Fig. 4
Il Terzo suono di Tartini – graphic representation (Tartini, 1714, p. 17)

[2] Treatise also known as *Lezioni pratiche*.

Tartini observed that when playing a perfect fifth interval on the violin with high intensity, perfectly tuned, a third sound was heard in the bass, resonating (1714) (Padula, 2008, p. 77). Essentially, when two sounds are played simultaneously, the ear perceives a third sound with a frequency equal to the difference in frequency between the two emitted sounds. These sounds are called combination tones, more precisely differential tones, as opposed to summation tones obtained from summing the frequencies of the emitted sounds. The differential tone phenomenon, known for over half a century, is used in applied electronics in telecommunications, where it is known as intermodulation products (Broadhouse, 2009, p. 31). Tartini explains, among other hypotheses detailed in his work, that the acoustic phenomenon that bears his name may be due to the harmonics inherent to the sounds, or could be an illusion of the missing fundamental. Currently, this phantom frequency, the Third Sound, besides being considered a physical phenomenon, is also interpreted as evidence of the ear's nonlinear behaviour caused by the high sound intensity which determines the amplitude distortion of the sound signal.

This acoustic phenomenon has its applicability in the construction of musical instruments, such as the organ: this effect is employed by playing two sounds simultaneously at a fifth interval, in order to produce a deeper (lower) sound through *Tartini's Third Sound*, without constructing long tubes that would otherwise be required to produce such sounds.

2.2. The Illusion of the Infinite Musical Scale

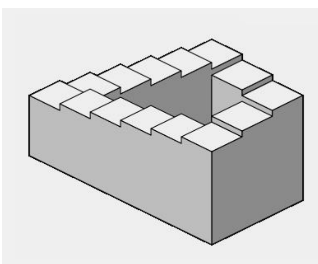


Fig. 5
Penrose Staircase

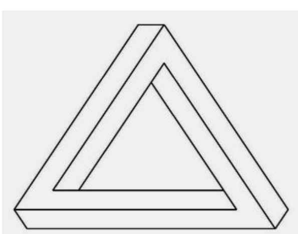


Fig. 6
Penrose Triangle

The illusion of an infinite musical scale, known as the *Shepard Scale,* is named after the American psychologist and researcher specialising in cognitive psychology, Roger Newland Shepard (b. 1929, Palo Alto, California – 2022, Tucson, Arizona).

The *Shepard Scale* represents an infinitely ascending or descending canon, with the auditory illusion generated through the superposition of chromatic musical scales at an octave interval. This has a visual equivalent in the infinite staircase known as the *Penrose Staircase* (Fig. 5), conceived by the Englishmen Lionel Sharples Penrose (1898-1972) – a physician, geneticist, mathematician, and chess player – and his son Roger Penrose (1931) – a physicist and mathematician.

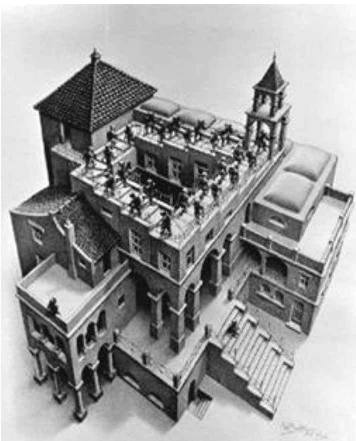


Fig. 7
M. Escher, *Ascending and Descending* (lithography)

Penrose Staircase, considered a variation of the Penrose Triangle[3] (Fig. 6), is graphically represented by Maurits Cornelis Escher (1898-1972), a Dutch visual artist, engraver, and graphic artist. In Escher's lithography *Ascending and Descending* (1960), the infinite staircase is embedded within a monastery where monks perpetually climb and descend endless stairs (Fig. 7) (Seckel, 2004, p. 83).

Shepard describes the psychoacoustic effect named after him as a finite sequence of specially synthesised tones, played in a closed circular sequence, inducing the illusion of an endless musical scale to the listener (Shepard, 1964, pp. 2346-2353).

The *Shepard Scale* has been identified in several musical works, ranging from classical to rock music. Thus, the endlessly ascending canon appears in the *Canon a 2 per Tonus*, in 3 voices – violin, viola, cello – from *Das Musikalisches Opfer* (*The Musical Offering*), BWV 1079 by Johann Sebastian Bach, featuring an apparent infinite modulation.

Das Musikalisches Opfer (1747) was composed after the composer's last journey to Potsdam (1747), to the royal court of Frederick II, the King of Prussia, where his son, Philipp Emanuel, was a harpsichordist. Upon Johann Sebastian's arrival at the court, King Frederick II gave him a musical theme on which he brilliantly improvised on the harpsichord. Returning to Leipzig, he continued to improvise on the royal theme, known as *Thema Regium* (Wolff, 1991, p. 324) (Fig. 8, public domain).

Fig. 8 J. S. Bach, *Thema Regium*, *Das Musikalisches Opfer*, BWV 1079, *Ricercar*, autographed manuscript, fragment

[3] The *Penrose Triangle* (also known as the Impossible Triangle, Penrose Tribar) represents an optical illusion created by the Swedish graphic artist Oscar Reutersvärd (1915-2002), rediscovered by Lionel and Roger Penrose.

This theme serves as the foundation for the enigmatic work dedicated to the King of Prussia, *Das Musikalisches Opfer*, with a Latin subtitle that forms an acrostic of the word ricercar: *Regis Jussu Cantio Et Reliqua Canonica Arte Resoluta* (*a theme given by the king, with additions, resolved in canonical style*) (Basso, 1983, p. 713).

The ascending modulation in *Canon a 2 per Tonos* (Fig. 9) was designed by the composer as a wish for the king's glory to ascend, a notion noted in the canon's subtitle: *Ascendenteque Modulatione ascendat Gloria Regis*.

Fig. 9 J. S. Bach, *Canon a 2 per Tonos* from *Das Musikalisches Opfer*, BWV 1079, fragment, mm. 1-11

The work begins in *C minor*, and during the first 8-bar phrase, it modulates upward so that the second phrase starts in *D minor* (m. 9). The upward modulation continues successively, every 8 bars, from key to key: the 8-bar phrases are repeated six times, resulting in 48 bars. At bar 49, the sound material is repeated, starting from *C minor* but an octave higher than the beginning of the work. Thus, after a series of modulations, it returns to the initial tonal identity with the possibility of restarting the ascending modulation. The ascending modulating spiral creates an illusion in auditory perception, generating the sensation of endless modulation.

Fig. 10 G. Ligeti, *L'escalier du Diable* (fragment)

The sound effect generated by the Shepard Scale is also present in *Study No. 13* for piano titled *L'escalier du Diable* (1993) (Fig. 10), a work by the composer György Sándor Ligeti (1923, Târnăveni, Târnava Mică County – 2006, Vienna). In the score, the work precedes the study *Coloana fără sfârșit* (*Endless Column*), the title referencing the sculpture of the same name by Brâncuși, located in Târgu-Jiu (Ligeti, 1988, p. 69). *L'escalier du Diable*, with a piano writing style typical of a *toccata*, structures the sound material into an extremely rapid ascending auditory flow: *Presto legato, ma leggero*, in a 12/8 meter (Ligeti, 1988, p. 48). The upward movement is accompanied by an extreme dynamic increase, starting from an indication of triple *forte* (*fff*, mm. 3-20), which gradually intensifies to eight-fold *forte* (*ffffffff*, m. 28). The sound effect achieved by the composer is that of a continuously ascending chromatic scale (mm. 1-18).

2.3. *The Mysterious Melody*

It is known that a melody that has been heard before becomes recognisable and easy to follow, but when the same sound material is distributed across different registers and sometimes different instruments, in a random manner, it can lose its familiarity, often becoming unrecognisable. However, if the listener is guided in recognising the mysterious melody, they will gradually uncover the melodic progression stored in their musical memory. This psychoacoustic illusion is named the *Mysterious Melody*, having been discovered and described by Diana Deutsch in her book *Perception and Psychophysics* (1972) (Deutsch, 1999, p. 356).

Such a sound illusion is present in Anton Webern's *Fuga Ricercata a 6 voci* (1934), which contains an orchestral arrangement of the Ricercar a 6 from J. S. Bach's *Das Musikalisches Opfer*, BWV 1079 (based on the same *Thema*

Regium, see Fig. 8). The theme follows a winding path through different registers and instruments: the trombone plays the first 5 notes of the theme (mm. 1-3), the next two notes are played by the horn in F (mm. 3-4), then the melodic line continues with the trumpet in C – two notes (mm. 4-5), the horn in F (mm. 5-6), the trombone (mm. 6-7), and finally the trumpet and harp (m. 8) (Fig. 11).

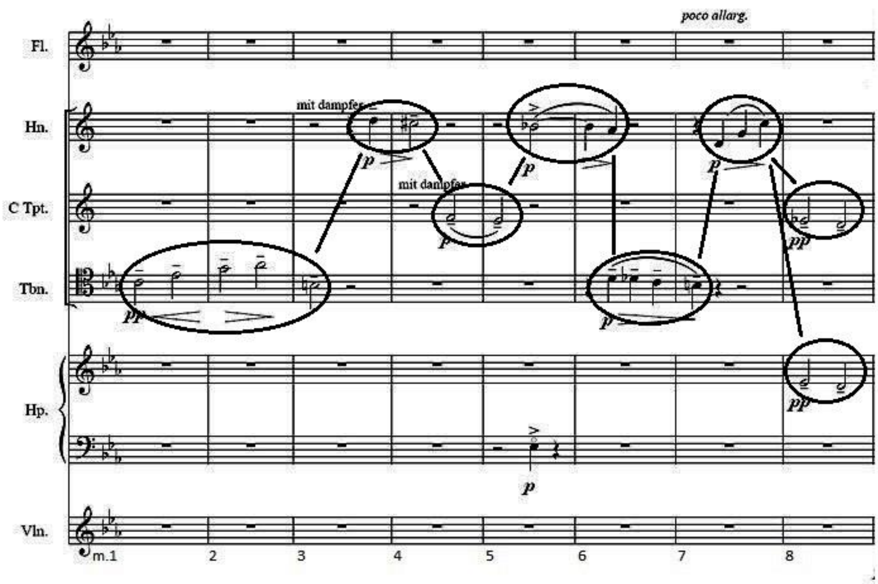


Fig. 11 A. Webern, *Fuga Ricercata*, arrangement for orchestra after *Ricercar à 6* from *Musikalisches Opfer*, BWV 1079 by J. S. Bach, mm. 1-9

3. Conclusions

The brain does not simply record sounds; it decodes and interprets the perceived sound material. The auditory presence of illusions confirms the existence of cerebral mechanisms that, in the decoding process, alter the reception and perception of sound material.

Auditory illusions are caused by the paradoxes of musical perception determined by the frequency of sounds and their spatial location. The spatial component of music and the overlapping of sound planes facilitate the creation of musical chimeras.

Studying auditory illusions and paradoxes contributes to the understanding of the perceptual and cognitive processes of decoding sound impulses, sound analysis and synthesis techniques, and the development of electroacoustic instruments. These illusions are caused by the paradoxes of musical perception determined by the frequency of sounds and their spatial location.

References

Basso, A. (1983). *Frau Musika. La vita e le opere di J. S. Bach* [Frau Musika.The life and works of J. S. Bach], Vol. II. Torino: EDT Musica.

Broadhouse, J. (2009). *Musical Acoustics; Or, the Phenomena of Sound as Connected with Music (1881)*. Kessinger Publishing.

Deutsch, D. (1999). *The psychology of music*, 2nd Ed. San Diego. California: Academic Press.

Durante, S. (2023). The Tartini Moment. *Eighteenth-Century Music*, *20/2*, September, 219-221. DOI: https://doi.org/10.1017/S1478570623000064

Gatti, E. (2001). Booklet CD Giuseppe Tartini – Enrico Gatti, Gaetano Nasillo, Guido Morini – Suonate A Violino E Violoncello O Cimbalo (2 CD ARCANA A420)

Goldstein B. (2009). *Encyclopedia of Perception*, Vol. 1. Sage Publications, Inc.

Ichimiya, I. Ichimiya, H. (2023). Modifying Deutsch's scale illusion for application in music. *PLoS ONE journal*, *18 (2)*. Retrieved from https://doi.org/10.1371/journal.pone.0280452

Lanzellotti, F. (2021). In search of perfect harmony: Giuseppe Tartini's Music and Music Theory in local and European contexts Ljubljana. *Eighteenth Century Music*, *18/2*, 329-331. Cambridge University Press. Retrieved from DOI:10.1017/S1478570621000038

Ligeti, G. (1988). *Études pour Piano*. *Deuxième livre* [Studies for Piano. Second Book]. Mainz: Schott Music International.

Mozart, L. (1756). *Versuch einer gründlichen Violinschule* [Complete treatise on the fundamental elements of violin study]. Augsburg: Johann Jacob Lotter.

Padula, A. (2008). *Consonanze: Dizionario di acustica, psicoacustica e accordatura di strumenti a tastiera* [*Consonances: Dictionary of Acoustics, Psychoacoustics, and Tuning of Keyboard Instruments*]. München: Grin Verlag.

Petrobelli, P. (1968). La scuola di Tartini in Germania e la sua influenza. *Analecta Musicologica* [The School of Tartini in Germany and Its Influence, in Analecta Musicologica], *V*, 1-17. Roma.

Scimemi, B. (2002). The Use of Mechanical Devices and Numerical Algorithms in the 18th Century for the Equal Temperament of the Musical Scale. In Assayag, G. & Feichtinger, H. G. & Rodrigues, J.F. (ed.), *Mathematics and music: a Diderot Mathematical Forum* (pp. 49-63). European Mathematical Society, Springer Verlag.

Seckel, A. (2004). *Masters of deception: Escher, Dalí & the artists of optical illusion*. New York: Sterling Publishing.

Shepard, R. N. (1964). *Circularity in judgements of relative pitch*. *The Journal of the Acoustical Society of America*, *36*/*12*, 2346-2353. Melville, New York.

Ștefănescu, I. (1995). *O istorie a muzicii universale* [*A History of Universal Music*], Vol. I. București: Editura Fundației Culturale Române.

Tartini, G. (1754). *Trattato di musica secondo la vera scienza dell'armonia* [Treatise on Music According to the True Science of Harmony]. Padova: Stamperia del Seminario.

Tartini, G. (1760). *Regole per arrivare a saper ben suonare il Violino* [Rules for Learning to Play the Violin Well], manuscript.

Wolff, C. (1991). *Bach. Essays on His Life and Music*. Cambridge, MA & London: Harvard University Press.