DOI: 10.32606/IJSR.V10.I1.00034 Received: 27-03-2019 Accepted: 17-07-2019

Indian J.Sci.Res. 10 (1): 215-220, 2019 Review Article ISSN: 0976-2876 (Print)

THE PSYCHOACOUSTIC PROPERTIES OF SOUND: AN INTRODUCTION

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ABSTRACT

This study presents a general review on four psychoacoustic properties of sound: pitch, loudness, duration and timbre. Most studies in this domain provide an extensive detail on the topic; however, this article presents a perspective to the beginner on how sounds and/or music can be influenced by these properties. This article has made an effort to provide a preliminary understanding of the domain by highlighting concepts associated closely with cognition of music. The present study is largely confined to four major psychoacoustic properties of sound and their effect on music perception and cognition. A review of existing literature was performed with the purpose of providing insight into the topic under study.

KEYWORDS: Psychoacoustics, Music Cognition, Psychological Acoustics

This article explores the area of psychological acoustics, also known as psychoacoustics. The scholarly materials selected for review in this paper are examined on the basis of four major psychoacoustic properties of sound, that is Pitch, Loudness, Duration and Timbre. Each of these sonic properties offers important insights on the perception and cognition of music and sounds.

PSYCHOACOUSTICS

This review article aims to examine the area of psychoacoustics. Rossing (2007) defines psychoacoustics as being the area of study which is involved in exploring the relationship between physical properties of sound and their perceptual attributes. It is that area of auditory research where behavioral methods are used to express how well listeners perceive sound (Buell, Trahiotis and Bernstein; 2009). Research on the effects of music on humans is made easier due to the fact that humans are naturally musical, an argument Schulkin and Raglan (2014) suggest. Schulkin and Raglan (2014) argue that music plays a pivotal part in our evolution and that we sang before we spoke in grammatically arranged sentences. Similary, Sloboda (2005) assumes since music and sound are a good example of something else i.e. "a complex motor skill; a language-like phenomenon; a complex auditory phenomenon; a set-theoretic entity" (p.101) researchers are interested in its attributes. Through their study, Levitin and his colleague demonstrated that music has physiological benefit too. Levitin and Menon (2005) were among the first people to explain the role of nucleus accumbens and ventral tegmental area along with hypothalamus and insula in music listening. Nucleus accumbens is the part of human brain that is involved in forming reward related behaviors (Day and Carelli, 2013). In one of his groundbreaking research, he and his colleague have also demonstrated, for the first time, that musical structures are processed in the language area of the brain (Levitin and Menon, 2003). Emphasizing on the deep-rooted nature of music on human brain, Oliver Sacks, a renowned British neurologist, affirms that even if someone suffers severe brain damage or injury, music is the last thing they lose. Music shapes our brain so much so it involves numerous parts of the brain including those of emotional, motor and cognitive areas (Sacks, 2006).

MAJOR PROPERTIES OF SOUND

Physical dimensions of sound give rise to its psychological features. Elaborating on the perceived parameters of sound, Moylan (2014) writes, "Our perception of sound is a result of the physical dimension being transformed by the ear and interpreted by the mind. The perceived parameters of sound are our perceptions of the physical dimension of sound" (p. 16). In particular, the perceived parameters of Frequency, Amplitude, Time and Timbre are Pitch, Loudness, Duration and Timbre (perceived overall quality), respectively. The following section will analyze the role of the four properties of sound – pitch, loudness, duration and timbre– and their influence on music perception and cognition.

Pitch

One of the most crucial aspects of sound is Pitch. Music without pitch would be drumbeats, speech without pitch processing would be whispers and identifying sound sources without using pitch would be severely limited (Yost, 2009). Pitch is one of the main dimensions along

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which a sound varies in a musical piece. Other dimensions are important as well, although the link between basic science and music is strongest in the area of pitch, mainly because much is known about how pitch is analyzed by the auditory system (McDermott and Oxenham, 2008).

Any sound or melody is recognized even when the notes are shifted upwards or downwards in pitch by the same amount (McDermott and Oxenham, 2008). Thompson (2013) writes, "Shifting the pitch of a single note of a melody is highly noticeable, even when it only alters the original pitch by one semitone" (p. 120). Tan *et al.*, (2010) distinguish pitch in terms of two-dimensions: pitch height and chroma. Pitch height is the frequency of vibrations, whereas chroma refers to a category represented by a certain pitch: "The name we give to the notes in western tonal music (e.g. C, D, E) refer to the pitch chromas" (p. 74). The tones that are separated by an octave exhibit the same chroma, whereas within the same octave, change is referred to in terms of pitch height (Tan *et al.*, 2010). Also, Seashore points out various factors – such as physiological limit, relation to intelligence, relation to age, relation to training, inheritance, frequency level and sensation level, binaural versus monoaural discrimination, duration and masking – that define pitch discrimination, also known as a sense of pitch (Seashore, 1967). Our ability to discriminate between two different pitches can be explained in terms of *place* theory of pitch perception. The perceived pitch of a sound can be directly understood in terms of the place of maximum excitation caused in the basilar membrane. Occasionally, two tones may have similar frequency so much so that it may overlap the same area in the basilar membrane, termed as the critical band. However, the smallest change in frequency that a listener can detect, know as just noticeable difference, may as well determine pitch perception. As the gap between frequencies exceeds the critical band, tones are perceived as being different. An alternative to place theory, the periodicity theory of pitch perception, suggests that the time interval in which the signal repeats, determines its frequency. As a matter of fact, the controversy persists between place and periodicity theorists (Sethares, 2005). All things considered, pitch and frequency should not be considered to be the same. The mathematical concept of frequency and pitch as musical tones are used interchangeably (Walker and Don, 2013), however, "The pitch of a sound corresponds to the frequency of the sine tone that is judged to have the same pitch" (Beauchamp, 2007) (p. 33).

Loudness (Intensity)

Loudness is understood in relation with its physical variable – amplitude, although other variables may also have an effect. Amplitude is commonly measured in decibels (dB) and is expressed as sound pressure level, SPL (Hodges and Sebald, 2011). Unlike most other scales, the decibel scale is logarithmic. In a decibel scale if we go up three decibels, then we double the volume of the sound. Which is to say, a 103db sound in twice as loud as a 100dB sound. The three decibels increase in sound pressure, doubles the power of sound however, ten decibels increase in sound, multiplies the sound power ten times, but human ear perceives it only twice the increase in original loudness (Utz, 2003). With every 10dB increase, the power of a sound increases by the factor of 10 (Smith, 2003).

Loudness perception is not a unitary phenomenon but is influenced by the nature and the context of the sound in terms of its psychoacoustic effect (Howard and Angus, 2006). Above all, our judgment of loudness is comparative besides being subjective in nature. The objective measure of sound pressure level is certainly not equivalent to subjective measure of loudness sensation (Beament, 2001) (Howard and Angus, 2006) (Meyer, 2009) (Florentine, 2011). Meyer (2009) suggests, "When tones of different frequency are compared to a tone of 1,000 Hz, the so called equal loudness curves are obtained" (p. 7). These curves explain the relationship between objective sound pressure level and the loudness level as perceived by the ear. Commonly, loudness is measured in sone. "One sone is defined as the loudness of 1-kHz tone at 40-dB SPL heard binaurally in a free field from a source in the listener's frontal plane" (Florentine, 2011) (p. 4). Florentine (2011) further adds that tones with loudness of 2.0 sones is twice as loud as 1-kHz, 40-dB SPL and the tones having loudness of 0.5 sones is half as loud.

In early 1930's, Fletcher and Munson at Bell Laboratory conducted a study to examine, "How louder or softer different frequencies had to be in order to be perceived as loud a 1 kHz" (Izhaki, 2012) (p.11). Fletcher-Munson curves, generally known as equal–loudness contour are the result of loudness matching, one of the two methods used to measure loudness perception. In this technique, the subject may be asked to compare the intensity of a presented tone to a standard tone. The study conducted by Fletcher and Munson had 1 kHz as standard tone. If the similar process is repeated for number of other frequencies the outcome will result in equal-loudness contour (Mather, 2006). Loudness of different frequencies is represented through equal-loudness contour, however through loudness scaling method, the measurement of loudness with its increase in intensity is defined. In this method, the subject is asked to assign numbers to sounds with respect to the standard tone. That is, whether the presented tone is 100 times or 200 times as loud as the standard tone and so on, the technique known as magnitude estimation (Moore, 2013). Equal-loudness contour shows that highs and lows of any sound are more prominent with high volumes. On the contrary, at low volumes the mid range frequencies sound more prominent. Generally, low volumes are associated with power whereas highs with definition, clarity and spark (Izhaki, 2012). This can be understood in terms of the 'bass boost' function in audio equipment. The 'bass boost' function in an audio equipment accentuates low frequencies at low intensities making it relatively louder at the same intensity (Mather, 2006).

Duration (Time)

Time is one of the important aspects as it gives life and structure to music (Tan *et al.*, 2010). In order to understand duration and timing in music, component concepts such as beat, tempo, meter and rhythm need to be defined (Hodges and Sebald, 2011).

Beats are psychological organizing feature of music. Steady beats provide a framework for the listener to organize the music whereas unsteady beats might prove to be psychologically distressing. Research shows that the ability to extract a regular pulse from a piece of music is universal in humans (Hodges and Sebald, 2011). Aniruddh Patel, Professor of Psychology at Tufts University, states that "synchronization to a musical beat relies on the brain systems designed for vocal learning involving auditory-motor networks not restricted to the cortex" (as cited in Altenmuller *et al.*, 2013) (p. 138). Second most important aspect in duration is tempo. Tempo is the rate at which the beat occurs. Commonly, a tempo under 60 beats per second is considered slow. Furthermore, tempo slower than 42 beats per minute and faster than 168 beats per minute is rarely used in music (Hodges and Sebald, 2011). Tempo has its role in evoking emotions in its listeners. Even though the perception of emotions through tempo varies across cultures, generally slower tempo are associated with sadness, melancholy, low spirit and other unpleasant emotions whereas fast tempo is associated with pleasant emotions including happiness, excitement and so forth (Levitin *et al.*, 2018). Similar concept is that of Meter. Meter refers to the arrangement of strong and weak beats in a musical piece. Broadly, the listeners of western music divide the meter into two's and three's even though there are no strong or weak beats in it. This phenomenon is defined as subjective rhythmization. 100 ms (millisecond) or one tenth of a second is the shortest interval in which we can organize beat metrically, such that if the beats are 1800 ms (nearly two seconds) apart, the tempo is too slow to organize (Hodges and Sebald, 2011). Finally, Rhythm is defined as time patterns created by notes as music unfolds over time (Tan *et al.*, 2010). However, Tan *et al.*, (2010) argue that time durations are not the primary generators of rhythms. Hodges and Sebald (2011) affirm, rhythm in music is so important that sometimes we just identify a melody by just its rhythmic pattern. The important fundamental characteristic of rhythm is that they are based on relative time than absolute time, absolute time meaning time-span with no comparison like that of stopwatch. Rhythm remains constant even when the tempo in a musical piece changes. Therefore, rhythm cannot depend on absolute time as absolute time changes with the change in tempo (Tan *et al.*, 2010). These components– beat, tempo, meter and rhythm – make up the duration in a musical piece.

Timbre (Tone Color)

Timbre is the perceived sound quality through which the listener can distinguish between sounds having similar pitch and loudness as being dissimilar. It is a unique attribute of sound that allow humans and other animals to distinguish among different sound sources on the basis of their perceptual qualities such as pitch, loudness and duration (Patil *et al.*, 2012). Timbral descriptors of sound include, "mellow, rich, covered, open, dull, bright, dark, strident, grating, harsh, shrill, sonorous, sombre, colorless and lacklustre" (Howard and Angus, 2006) (p. 216).

A major component of timbre is the dynamic envelope. It can be understood as the contour of the changes in the overall dynamic level of the sound with: Attack, Decay, Sustain and Release, as its components.

These components may or may not be present in any sound source. In fact, some musical instruments may have more parts of these in their envelope than other instruments (Moylan, 2015). Timbre is mostly dependent on signal shape, although it can be affected by numerous other physical variables (Hodges and Sebald, 2011). It has two broad characteristics that contribute to music perception. Firstly, it is the multitudinous set of perceptual attributes that are changing throughout the musical piece (e.g. attack, nasality, brightness etc.) also others which are discrete or categorical (e.g. 'blatt' at the beginning of a trombone, pinched offset of harpsichord etc.). Secondly, it is a vehicle to track, recognize and identify a sound source over time which gives the listener absolute categorization of the sounding object (McAdams, 2013). Timbre is related with the harmonic structure of a sound or a tone. It hugely depends upon tone's attack and decay pattern. However, to distinguish the tone between the same instruments having similar attack and decay pattern might be difficult. While identifying the sounds of musical instruments, if the onset and offset phases of notes are removed, then listeners may find it problematic to distinguish between sounds. In fact, the onset phase of stringed instrument will be different to brass instrument; the percussion will differ from wind instruments. The onset and offset phases provide an acoustic cue to identify the timbral quality of an instrument (Howard and Angus, 2006). For instance, if an audio recording is played backwards, even though its spectrum remains the same, it will sound completely different. This demonstrates the importance of time envelope in determining the timbral feature (Sethares, 2005).

Timbre can be defined as that quality of a tone that distinguishes between two sounds having similar properties: pitch, loudness and duration (Goldstein, 2010). A pure tone has a shape of a simple wave form with a single component. On the contrary, music instruments have a complex wave signal consisting of a fundamental and several overtones. Since none of the musical instruments produce a simple wave, attention to these components such as fundamental and overtones of complex sound waves result in the perception of timbre (Hodges and Sebald, 2011).

Harmonic Series

Anycomplex tone having more than a single sine wave contains the frequency that is heard as a pitch of the note along with few other frequencies above it, which is referred to as a fundamental frequency (Hosken, 2015). For instance, a plucked violin string will begin vibrating at a certain frequency known as fundamental frequency (Tomecek, 2010). The fundamental frequency will have the greatest amplitude in the spectrum and is the most prominent frequency as well. It is this fundamental frequency which is responsible for the perceived pitch of a tone (Meyer, 2009). The individual sine wave that make up a complex tone is referred to as partials. It is named after its partial characterization of making up the complex tone. In this manner, the lowest pitched partial is the fundamental frequency. Tones other than fundamental are generally pitched higher and are referred to as overtones (Loy, 2006). However, it should be noted, that both fundamental and overtones are partials. In like manner, the frequency component of a sound that are whole number multiples of the fundamental are harmonics. These harmonics adds up to the peculiarity of fundamental frequency in any individual sound. Similarly, those components of the spectrum that are not proportional to the fundamental frequency make up the overtones (Moylan, 2015). As a matter of fact, the term harmonic is equivocal. It could refer to frequencies above the fundamental including the fundamental, the first harmonic, the second harmonic and so on. Also, it could include fundamental as its first harmonic making the series first harmonic (fundamental), second harmonic, third harmonic and so forth (Hosken, 2015). Elaborating further, Hosken (2015) adds, "Overtone series would consist of fundamental frequency plus the first overtone, the second overtone etc." (p. 37). The melody and harmony in a musical piece is usually carried by instruments having harmonic partials. It is because the frequencies of the harmonics tend to be in tune along the frequency with the pitches of the diatonic scale. Since, the frequencies of the instruments with inharmonic partials (such as bells and drums) are not in tune with the diatonic scale, they usually don't carry melody and harmony in a musical piece (Loy, 2006). For any given instrument or voice, there are certain frequencies within the spectrum that are emphasized consistently irrespective of the fundamental frequency. The tones within that region all receive the same tone color. The change in amplitude in these tones does not change their frequencies with change in pitch. These areas are called formants (Moylan, 2015) (Meyer, 2009).

CONCLUSION

Possibly, music is hardwired into human brain (Masataka, 2007) (Bennet and Bennet, 2008) (Peretz, 2002). This exceptional ability of transformation from sound waves to neural impulses gives rise to the musical experience (Seashore, 1967). As mentioned above, the conversion of acoustic wave energy into electro-chemical energy (or nerve impulse) called transduction (Tan *et al.*, 2010) is rarely as simple as it seems, and it is the specificities and variances of this conversion that can result in various aural impacts on listeners. There are strong ongoing traditions of research in disciplines such as music psychology, psychoacoustics, systematic musicology and other areas to study the impacts of sounds on humans, including research that contemporary societies use to justify the importance of music. This study has made an effort to provide a preliminary understanding of psychoacoustics properties of sound indicating towards the existing interrelation of these four properties. Future studies may explore the effects of pitch on other properties of sound, as it is one of the crucial sonic property.

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