The Neural Code of Pitch and Harmony

Harmony is an integral part of our auditory environment. Resonances characterized by harmonic frequency relationships are found throughout the natural world, and harmonic sounds are essential elements of speech, communication and, of course, music.

Providing neurophysiological data and theories that are suitable to explain the neural code of pitch and harmony, the author demonstrates that musical pitch is a temporal phenomenon and that musical harmony is a mathematical necessity based on neuronal mechanisms. Moreover, he offers new evidence for the role of an auditory time constant for speech and music perception as well as for similar neuronal processing mechanisms of auditory and brain waves.

Successfully relating current neurophysiological results to the ancient ideas of Pythagoras, this unique title will appeal to specialists in the fields of neurophysiology, neuroacoustics, linguistics, behavioural biology and musicology, as well as to a broader audience interested in the neural basis of music perception.

Gerald Langner received a diploma in physics from the Technical University of Munich in 1971. He then worked at the Max-Plank Institute in Göttingen and at the TU Darmstadt, where he studied hearing in birds and electroreception in fish. In 1985, during a research stay in Canberra, Australia, he discovered – together with Henning Scheich – the electric sense in platypus. From 1988 to 2008 he was Professor of Neurobiology in Darmstadt, with his research focusing on spatial and temporal aspects of processing in the auditory system.

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Preface

Sound is a vital tool for humans and animals. We communicate with each other through speech, we convey emotion by laughing or crying, but we also purposefully create sounds using our voices or musical instruments just because we perceive them to be appealing or beautiful. The pitch, rhythm and melody of speech and music can communicate emotions like fear, pleasure and anger quite quickly and efficiently. Moreover, as humans we seem to have a powerful urge to fill the world with sounds of our own creation, with the result that these days music surrounds us virtually everywhere. The need to make, listen and dance to music stretches back to the very beginnings of our history: for many thousands of years music has played an essential role in our social interactions, rituals and ceremonies. The sixth-century Roman philosopher and great musical theorist Boethius stated quite simply:

> it appears beyond doubt that music is so naturally united with us that we cannot be free from it even if desired.

We all know that some combinations of musical tones sound particularly good when played together or subsequently; we call these 'consonant' or 'harmonious', while others sound harsh or 'dissonant'. If asked what combinations of sounds they find pleasant, or at least interesting, people from different cultural backgrounds may not completely agree. Different forms of music prevail in different regions of the world, and musical instruments and composition have become progressively more sophisticated as civilization advances. Nevertheless, there are certain combinations of tones that seem to have universal appeal. They are preferred everywhere and form the basis of musical systems throughout the world. Clearly, there must be some universal rules that are crucial to our perception of musical harmony.

The question of what these rules are and what might be the role of whole numbers dates back to the time of the ancient Greeks. They believed that the mathematical rules of musical harmony are the very same that govern the entire universe. Besides neurophysiologic data and theories that are suitable to explain auditory processing of pitch and harmony, this book provides new evidence for this ancient philosophical concept. The conclusion is that our sense for musical harmony is an unavoidable consequence of mathematical rules underlying temporal processing in our hearing system. As we progress through this book, theories and models of pitch perception and harmonic perception, both historical and current, will be presented and explained. Finally, in the last chapter I will suggest that neuronal dynamic processes similar to those in the hearing system are involved in other crucial brain functions: motor control, emotion and memory processing.

The book is intended not only for neuroscientists and musicologists, but also for a broader audience interested in the perceptual basis of music. Therefore boxes in various chapters contain additional information that may be helpful, although perhaps unnecessary for the specialist. Moreover, in the times of internet it should be quite easy to obtain additional information for those who want to go into details.

Foreword

Human sensing abilities have been shaped and refined over long evolutionary periods. Hearing has adapted to serve us well in many different tasks and situations, helping us to orient ourselves and to survive in the world. The general properties of peripheral and central mechanisms of hearing are highly conserved across vertebrates due to very similar environmental conditions. Species-specific variations do exist, such as the use of ultrasound for orientation in bats and cetaceans, but they are usually founded on quantitative and not qualitative differences to generally applicable principles of hearing and brain mechanisms. Basic hearing tasks for survival include detecting, localizing and identifying sound sources in cluttered or noisy environments. Another critical role of vertebrate hearing is the control and analysis of communication sounds which, in humans, lead to the highly developed ability of speech production and perception. Speech, like many other sounds involving resonance phenomena, contains harmonic elements, i.e. frequency components that are integer multiples of a common 'fundamental' frequency. These sounds can evoke a perceptual phenomenon, periodicity or virtual pitch that is distinct from other perceptual dimensions of sounds. A most human endeavour, the production and enjoyment of music, is fundamentally based on this perceptual phenomenon. Studies of the brain mechanisms that lead to this perception, its psychophysical manifestation and, eventually, cognitive and emotional benefits have progressed for more than a century, as is outlined in this volume, but still many aspects remain unresolved.

A helpful aspect in resolving this matter may be found in the fact that humans have surrounded themselves with an environment of their own creation. Based on our ability to use tools we have created artificial soundscapes that serve, entertain and move us. Unsurprisingly, many of those sound aspects have been, often inadvertently, chosen to match or most effectively engage our biological sound analysis system. Examples include the choice for frequency transitions in ambulance sirens to catch our attention, or the relationship of voices in polyphonic music. Both of these examples can be traced to specific psychophysically verified and physiologically implemented principles of sound processing. Furthermore, instrumental music is a solely human development that emerged early in our evolution to become human, as indicated by the recovery of Palaeolithic flutes created more than 40 000 years ago. The sound effects emanating from these old – and current, electronic – artefacts of musical sound generation also must reflect and potentially reveal basic properties of our auditory system.

The author of this book has been fascinated by these aspects for a long time and has tried to create a unifying perspective. In the early 1980s, I joined the Coleman Memorial Laboratory at the University of California in San Francisco, which is dedicated to the study of the physiological basis of hearing and deafness. Shortly thereafter, Dr Gerald Langner arrived for his first of many extended visits to explore sound processing in the central auditory system, especially in the auditory midbrain, an obligatory processing station between the inner ear and the auditory cortex. Over the years we embarked on several studies, especially with regard to the processing of amplitude-modulated sounds, a simplified exemplar of a harmonic sound. As a trained physicist, Gerald was keen to approach biological phenomena from a theory-driven perspective. A theory of pitch processing, understood as a construct of hypotheses based on physical, psychophysical and physiological aspects, should be able to provide verifiable predictions of the processing and role of harmonic coding in animals and humans. I recall many discussions of new data points, derived over long days and nights in the laboratory, in which he invoked his credo: 'Never trust data, unless you have a theory.'

In this book the author outlines his conclusions from this lifelong pursuit of potential links between aspects of our neural machinery of pitch processing and their reflection in our self-created sound environment. Drawing on theoretical, computational, physiological, psychophysical and music-historical evidence, he has created a compelling scenario of the properties of some brain mechanisms and their expression in our percepts as well as their reflection in the cultural world we have created around us. He provides a fascinating journey into the history and future of pitch and brain studies and suggests intriguing interactions of fine-scale neural processes in our brain with our cultural history of sound creation.

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