Encyclopedia of Cognitive Science

Volume 3

Editor-in-Chief

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nature publishing group

London, New York and Tokyo

Published by
Nature Publishing Group, 2003
The Macmillan Building, 4 Crinan Street, London, N1 9XW, UK

Associated companies and representatives throughout the world

www.nature.com

ISBN: 0-333-792610

Distributed on behalf of the Nature Publishing Group in the United States and Canada by
Grove’s Dictionaries, Inc.
345 Park Avenue South,
New York,
NY 10010-1707,
USA

British Library Cataloguing in Publication Data
Encyclopedia of cognitive science
1. Cognitive science – Encyclopedias
I. Nadel, Lynn
153′.03

ISBN 0333792610

Library of Congress Cataloging in Publication Data

A catalog for this record is available from the Library of Congress

Typeset by Kolam Information Services Pvt. Ltd., Pondicherry, India
Printed and bound by The Bath Press, England

Music Cognition

Introductory article

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INTRODUCTION

Music cognition addresses the mental activities involved in perceiving, learning, remembering, and producing music. Most of these mental activities are implicit and unconscious; even listeners without musical training can make sophisticated judgments about music. Psychological studies of music include perception of sound properties, understanding of pitch and rhythm, development of musical abilities, musical skill and performance, and parallels with language.

PERCEPTION OF SOUND PROPERTIES IN MUSIC

Four qualities of sound are especially important in music perception: pitch, duration, loudness, and timbre. Pitch arises from the perception of a sound wave's frequency (number of vibrations per second); loudness arises from the perception of amplitude or intensity (sound pressure change); duration is the perception of the time over which a sound is heard. Most musical instruments produce complex sound waves, which contain several frequencies (called harmonics) and amplitudes that change over time; timbre arises from the perception of these harmonics and their onsets (called attack transients). The lowest frequency in a complex tone, called the fundamental frequency, determines the perception of pitch.

UNDERSTANDING OF PITCH AND RHYTHM

Pitch and rhythm may be the most psychologically important dimensions of music. Most music in Western cultures, including classical, rock, and jazz styles, is based on 12 pitch classes, referred to as tones C, D, etc. (Music in most cultures uses pitch classes, but they are often tuned to different frequencies.) Tones whose frequencies differ by a factor of two, called an octave, are perceived as having the same pitch quality or 'chroma' and belong to the same pitch class. Each musical piece is composed primarily of tones from seven of the pitch classes, called a diatonic scale. Major and minor scales are defined for each pitch class by the intervals (number of pitch steps) between the tones. The key often refers to the pitch class from which the scale is built. There is a hierarchy of relative importance among tones in a key; tonality is the perception of pitches in relation to the tonic, the central prominent tone. Interestingly, each tone is perceived differently, depending on its key context. For example, the tone C is perceived as most important (the tonic) in the key of C and less important in the key of F.

Despite this complexity, listeners' understanding of pitch structure does not require explicit training. The statistical regularity with which tones, chords, and keys occur provide enough information for listeners to identify the tonic, or judge two tones as related. Tones that occur more often are perceived as more stable or less likely to change. Listeners can recognize a familiar melody based on the up-and-down pattern of pitch changes, called the melodic contour, even when the pitch classes have changed. With training, most listeners acquire the ability to name the pitch of a tone in relation to other pitches, called relative pitch. A few listeners have absolute pitch, or the ability to name pitches heard in isolation (without a reference pitch). Acquisition of absolute pitch may be related to the age at which musicians first learn to name pitches.

When listeners tap along with music, they are often responding to the rhythm: a temporal pattern that arises from many variables, including duration (from a tone's onset to its offset) and inter-onset interval (from one tone's onset to the next tone's onset). Meter and tempo also influence the perception of rhythm. Meter is a regular alternation of strong and weak beats in twos (such as marches) or threes (such as waltzes) at many hierarchical temporal levels. Tempo is the pace or rate of music; listeners show preferences for tempi around 300–900 ms per beat. People tend to tap and reproduce rhythms accurately at this tempo, suggesting that an internal pulse operating around this tempo guides perception and performance.

Music perception reflects a combination of pitch and rhythm at several hierarchical levels. Listeners tend to segment music into short groups: a group is a set of successive tones that are related. The perception of group boundaries is influenced by accents, or tones that stand out from others, caused by changes in pitch, duration, intensity, or timbre. Listeners also segment simultaneous or overlapping tones into perceptual parts or voices, called streams. Stream segregation is thought to reflect innate, 'bottom-up' perceptual processes, unaffected by general knowledge. Music perception is also influenced by 'top-down' knowledge: well-learned schemas, or acquired knowledge of tonal or metrical relationships. Schemas influence listeners' expectations and aid their memory for music. Schemas may also contribute to listeners' emotional response to music: schemas generate unconscious expectations for upcoming events, and musical events often occur that conflict with schematic expectations. Listeners experience arousal and an emotional response to the musically unexpected events.

DEVELOPMENT OF MUSICAL ABILITIES

Studies of musical development often focus on infants' responses, measured by attentiveness or listening preferences, because infants allow a test of which musical abilities are established prior to much musical exposure. Infants are typically exposed to certain types of music, including lullabies and play-songs sung by parents and other caregivers. Songs that adults sing to infants are higher in pitch, slower in tempo, and more expressive overall than the same songs sung to adults. By seven months old, infants are more attentive to these infant-directed songs than to other forms of singing.

Many basic perceptual abilities of infants resemble those of adults. For example, infants and adults are sensitive to the same pitch and rhythmic dimensions of music. Infants recognize the equivalence of pitches that are an octave apart. Around six months old, infants' babbling in response to music often preserves the melodic contour, and they respond the same way to melodies whose specific pitches are altered, as long as they retain the same melodic contour. By six months old, infants can produce body movements in response to the musical rhythm and they are sensitive to changes in tempo and rhythm. Finally, six-month-old infants prefer music that is segmented into natural phrase units more than music that is segmented in the middle of phrases (see example shown in Figure 1). Thus, infants attend to and group musical sequences according to the same perceptual principles as adults.

Other musical abilities develop with further musical exposure. By two to three years old, children spontaneously produce novel musical phrases in song, and can repeat short phrases accurately; by four or five years old, they can accurately imitate musical rhythms. By seven years old, children are sensitive to at least two metrical levels in musical rhythm; with musical training, adults show sensitivity to more metrical levels. Implicit knowledge of chord and key relationships also increases with musical exposure; the perception of hierarchical tonal relationships begins around the age of seven, but continues to develop into adulthood.

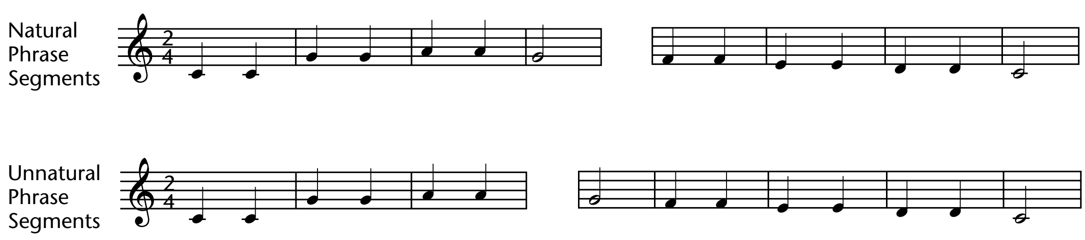

Figure 1. Example of natural (top) and unnatural (bottom) musical phrase segments in 'Twinkle, twinkle, little star'.

Interestingly, adults become less sensitive than infants to musical changes that preserve typical, schematic relationships of well-learned musical styles.

MUSICAL SKILL AND PERFORMANCE

Music performance is a rapid, fluent motor skill. Most people hum, clap, or perform in other ways that reflect sophisticated musical skills. Scientific studies of music performance, aided by computer-monitored musical instruments, focus on several cognitive and motor factors: segmenting and retrieving structural units from memory, coordinating motor movements, communicating structure and emotion with expressive features, and acquiring these skills.

Performers do not mentally prepare entire musical pieces at once, but instead segment them into smaller units such as phrases. In eye–hand span tasks, pianists are shown music notation briefly and then perform from memory; they recall musical segments that fit within short-term memory constraints. Errors in memorized performance indicate memory constraints on how far ahead performers can plan. Performance errors often result in tones that are similar to the intended tones in harmony, key, or meter. Thus, performers' musical knowledge reflects the same harmonic, diatonic, and rhythmic structures as listeners' knowledge.

After musical events are retrieved from memory, they must be transformed into appropriate movements. Internal clocks or timekeepers regulate and coordinate the production of different parts of a performance, such as hands in instrumental playing or performers in ensembles. Performers are more accurate at reproducing musical rhythms whose durations form simple ratios (1:1 or 2:1) that coincide with a simple internal timekeeper, than those whose durations form complex ratios (3:2 or 4:3). Musical motion is often compared to physical motion; for example, performers reduce the tempo near phrase boundaries at a rate similar to slowing down from a run to a walk.

Performers communicate musical structure and emotion to listeners through acoustic variations in frequency, amplitude, duration, and timbre, often termed 'expression'. Expression differentiates one performance from another, similar to how prosody (the rhythm and intonation of speech) differentiates one speaker from another. Expressive features of performance often coincide with structurally important events, such as metrical accents or phrase boundaries. Expressive features also signal emotional content; 'happy' tunes tend to be performed louder and faster than 'sad' tunes. Emotional content is linked to musical structure in performance: the expressive performance features that convey emotion tend to coincide with unexpected (less likely) structural features. (*See* **Prosody**)

How are performance abilities acquired? With short-term practice (hours), performers segment music into larger units, anticipate future events more, and increase expressive features. With long-term experience (years), performers monitor and adjust their performances better, refine expressive features, and extend their knowledge of how to perform one melody to unfamiliar melodies. Individual differences in performance skills are tied in part to accumulated practice over a lifetime. General memory and motor factors in performance increase most during the first few years of skill acquisition, whereas sensitivity to specific musical features such as phrase structure and meter increases across all skill levels.

PARALLELS BETWEEN MUSIC AND LANGUAGE

Music and language show interesting parallels in their structure and in how people perceive and produce them. They are found in all human cultures, and children spontaneously acquire both. Potentially universal mental activities in language and music include: auditory grouping/segmentation strategies; rhythmic structure in perception and production; and grammatical rules that influence understanding of music and language.

Listeners segment a continuous stream of sound into discrete units in speech and music. Two basic perceptual principles influence segmentation in both domains: first is sensitivity to acoustic changes or contrasts that define the boundaries of a unit, such as attack transients that occur at musical tone onsets or noise bursts at phoneme boundaries. Contrasts also mark larger units, such as changes in tempo (slowing down) that mark phrase boundaries in both music and speech. Second is sensitivity to periodic or repeating patterns, such as meter in music and in language. Memory limitations also influence segmentation: for example, the size of musical and verbal phrases is usually within short-term memory limits.

Rhythmic structure influences the relative importance that listeners attribute to individual elements in both music and speech, especially poetry. Tones (music) and syllables (speech) are accented in production with higher pitch, longer duration, and greater amplitude, which lead to the perception of rhythm. Music and speech commonly build on a foundation of alternating strong and weak beats or pulses. Although human speech is not as rhythmically regular as most music, listeners tend to perceive alternating strong and weak stresses as rhythmically regular in both domains, and rhythmically regular music and language are better remembered.

Finally, humans have the capacity to understand an unlimited number of melodies or sentences: a grammar is a model of this capacity. Grammars, or a limited set of rules that generates an unlimited number of sequences, have been proposed for music as well as language. A compositional grammar can generate music in a particular style, such as counterpoint or jazz. A listening grammar applies a set of rules or implicit knowledge of the acceptable combinations of tones, chords, and rhythms in a musical style. The result is the perception of musical units such as phrases, hierarchical relationships among units, and harmonic or tonal tension and relaxation. A challenge for listening grammars is to accommodate different but equally correct segmentations of the same music. Thus, one difference between musical and linguistic grammars is that music is more flexible and less constrained in its grammar than language.

CONCLUSIONS

Scientific study of musical abilities has grown tremendously since the early 1990s, due to technological advances and theoretical overlap with related fields in cognitive science such as artificial intelligence, linguistics, neuroscience, and philosophy. Related topics include neural bases and computational models of musical behavior. Although music may be a specialized human ability, it is not special in its underlying perceptual, memory, and motor components.

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