

# Rhythm in Music

Patel Chapter 3.1-3.2

# Introduction

- Rhythm: “the systematic patterning of sound in terms of timing, accent, and grouping.”
- Although all periodic patterns are rhythmic, not all rhythmic patterns are periodic.

# Rhythm in Music

- Music often has a regularly timed beat, a perceptually isochronous pulse to which one can synchronize with periodic movements such as taps or footfalls.
- Western music
  - Beats are organized in hierarchies of beat strength, with alternation between strong and weak beats.
- Ch'in zither music of China has no sense of beat.
- Balkan folk music
  - Long intervals are  $3/2$  the length of short intervals.
  - Rhythmic cycles: S-S-S-L or S-S-L-S-S.
- Ghanaian West African drumming: e.g. [Djembe](#) drums
  - Drummers keep time relative to a non-isochronous rhythm of handbells.
  - Each drum has its own repeating temporal pattern creating a polyrhythmic texture.

# A simple melody

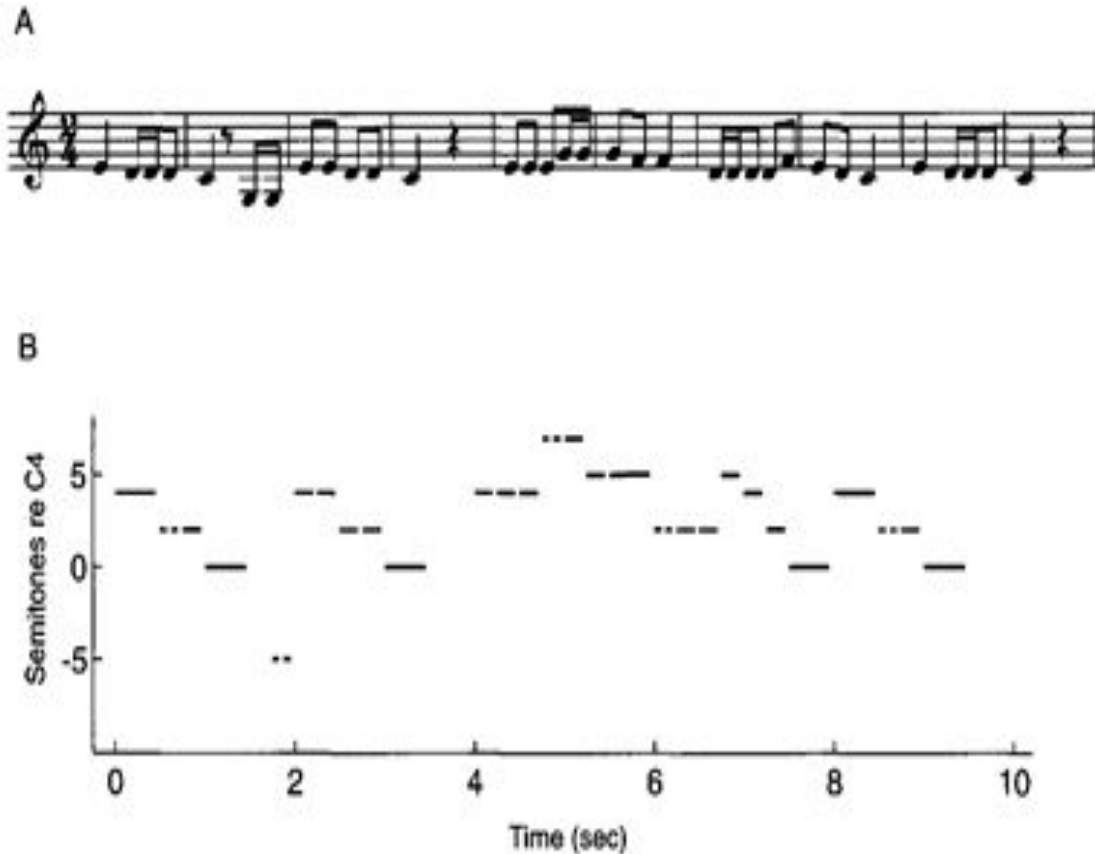


Figure 3.1 A simple melody (K0016) in (A) music notation and (B) piano roll format. In (B), the y-axis shows the semitone distance of each pitch from C4 (261.63 Hz).

# The beat: a stable mental periodicity

- The beat can coordinate synchronous movement: dance.
- The beat provides a common temporal reference for ensemble performance.
- For listeners, beat perception is linked to movement: synchronization to the beat.
- 2008: Only humans synchronize to the beat.
  - 2009: [Cockatoo](#) synchronizes to the beat.

# The beat: a stable mental periodicity cont.

- Tempo range: 200 ms – 1.2 seconds
  - 500-700 ms preferred,
- Although people gravitate toward one particular beat tempo, they can tap at other tempi that are simple divisors or multipliers of their preferred rate.
  - [K0016](#) played twice, with two different indications of the beat.
- What a listener selects as the beat is just one level (their *tactus*) in a hierarchy of beats.

# The beat: a stable mental periodicity cont.

- Beat perception is robust to moderate tempo fluctuations, e.g. due to expressive performance.
- There is cultural variability in beat perception.
  - Drake & Ben El Heni 2003
    - French listeners tapped at a slower rate to French music than to Tunisian music, Tunisians were the opposite.
    - Listeners can extract larger-scale structural properties in music with which they are familiar.

# The beat: a stable mental periodicity cont.

- A perceived beat can tolerate a good deal of counterevidence in the form of syncopation.
  - Patel, Iversen et al. 2005 asked participants to synchronize their taps to isochronous tones and then continue tapping at the same tempo during complex sequences that were strongly metrical (SM) or weakly metrical (WM)
  - People were able to do this pretty well even for the WM sequences.
  - [Examples](#).
- Beat perception involves a mental model of time in which periodic temporal expectancies play a key role.



# The beat: a stable mental periodicity cont.

- Temperley & Bartlette 2002: six factors that are important in beat finding:
  - For beats to coincide with note onsets.
  - For beats to coincide with longer notes.
  - For regularity of beats.
  - For beats to align with the beginning of musical phrases.
  - For beats to align with points of harmonic change.
  - For beats to align with the onsets of repeating melodic patterns.
- Application: synchronization with a beat helps patients with neuromotor disorders such as Parkinson's disease initiate and coordinate movement.

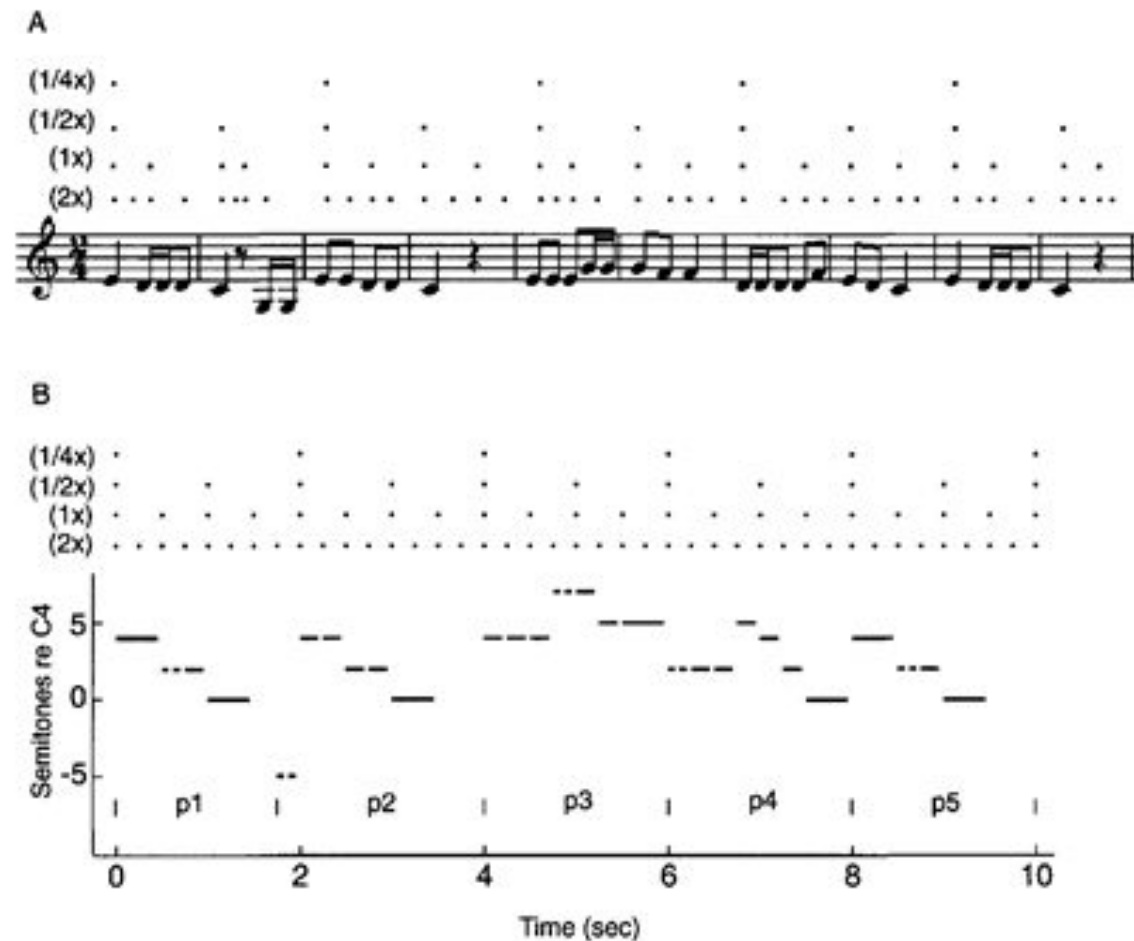
# Meter: multiple periodicities

- Meter: Some beats are stronger than others, and this serves to create a higher level of periodicity in terms of the grouping and/or the accentuation of beats.
  - March: 2 or 4 beats per measure, each divisible into 2.
  - Waltz (3/4 time): 3 beats per measure, each divisible into 2.
  - 6/8 time: 2 beats per measure each divisible into 3.

# Meter: multiple periodicities cont.

- Meter typically has one unit of subdivision below the beat, plus periodicity above the beat created by the temporal patterning of strong beats.
- This can be represented in a Metrical Grid.
  - The relative strength of each beat is indicated by the number of dots above it.
  - Dots at the lowest and highest levels must fall within the temporal envelope for meter: 200 ms to 4-6 sec

# K0016



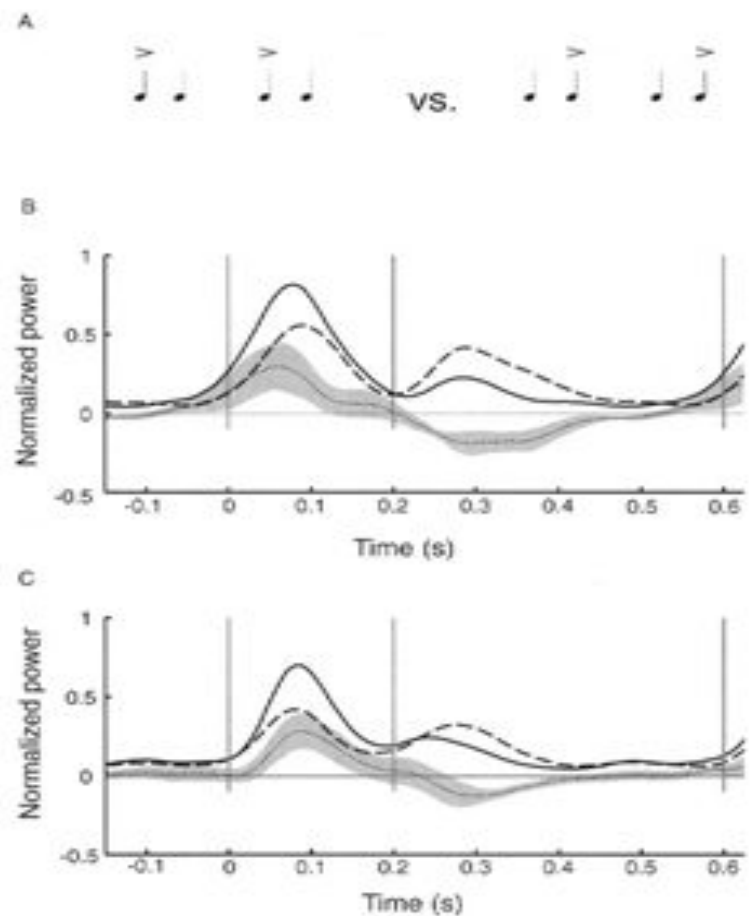
**Figure 3.2** Metrical structure of K0016. A typical tactus is shown by the metrical level labeled 1x. Phrase boundaries are indicated below the piano roll notation (p1 = phrase 1, etc.).

# Meter: multiple periodicities cont.

- Strong beats are perceptually accented points in the music: metrical accents.
- There are also phenomenal (physical) and structural accents (Lerdah & Jackendoff 1983).
- The interplay of different accent types is a source of complexity in music.
  - E.g. syncopation.
- The metrical grid is a *mental* pattern of multiple periodicities in the mind of a listener, and not simply a map of the accentual structure in a sequence.

# Meter: multiple periodicities cont.

- Sloboda 1983
  - Pianists played the same tone sequence set to different time signature and often didn't realize they were playing the same tone sequence.
- Patel, Iversen et al. 2005
  - Taps to the first beat of each metrical cycle were closer to the physical beat than taps on other beats, but the tones were identical in intensity and duration.
- Iversen, Repp & Patel 2009
  - Musicians mentally imposed a downbeat on either the first or second tone of a metrically ambiguous repeating two note pattern.
  - Brain response differed depending on where they imagined the downbeat, and the response mirrored the neural response when the tone was physically accented.



**Figure 3.3** (A) Repeating two-note rhythmic pattern, in which the listener imagines the downbeat on either the first tone (left) or second tone (right). (B) Evoked neural responses (measured over auditory brain regions) to the two-tone pattern subjectively interpreted in two different ways, in other words, with the downbeat on tone 1 versus tone 2. (The onset times of tones 1 and 2 are indicated by thin, vertical, gray lines at 0 and 0.2 s). The solid and dashed black lines show across-subject means for the two imagined beat conditions (solid = beat imagined on tone 1, dashed = beat imagined on tone 2). Data are from the beta frequency range (20–30 Hz). The difference is shown by the dotted line, with shading indicating 1 standard error. (C) Evoked neural responses in the beta frequency range to a two-tone pattern physically accented in two different ways, with the accent on tone 1 (solid line) versus tone 2 (dashed line).

# Telemann Flute Fantasia 6, Movement 3.

X  
X X X  
X X X X X

Nancy: T T T T T T  
3/2 time

X  
X X  
X X X X X

Kate: T T T T T T  
6/4 time

Spiritoso

6



# Grouping: the perceptual segmentation of events

- Grouping: “the perception of boundaries, with elements between boundaries clustering together to form a temporal unit.”

## K0016



Figure 3.4 K0016 segmented into melodic phrases (p1 = phrase 1, etc.).

# Grouping: the perceptual segmentation of events cont.

- Lerdahl & Jackendoff 1983
  - Grouping is distinct from meter, and the interaction of these two rhythmic dimensions plays an important role in in shaping the rhythmic feel of music.
    - Anacrusis (upbeat): when a phrase starts on a weak beat. (Phrase 2 of K0016)

# Grouping: the perceptual segmentation of events cont.

- Psychological evidence for perceptual grouping in music.
  - Dowling 1973
    - Memory for a brief tone sequence is better when the excerpt ends at a group boundary.
  - Sloboda & Gregory 1980
    - Clicks placed near phrase boundaries perceptually migrate to those boundaries.
- Cues listeners use in inferring grouping structure.
  - Local durational lengthening and lowering of pitch.
    - Infants prefer to listen to musical sequences in which pauses are inserted after longer and lower sounds than at other locations.

- Grouping structure is conceived of as hierarchical.

40

*R. Jackendoff, F. Lerdahl / Cognition 100 (2006) 33–72*

The figure shows a musical staff in 4/4 time with a treble clef and a key signature of one sharp (F#). The melody consists of 16 notes: B4, B4, B4, B4, G4, F#4, E4, D4, C4, B3, A3, G3, F#3, E3, D3, C3. Above the staff, there are three rows of 'x' marks indicating metrical accents. The first row has 'x' above the 1st, 3rd, and 5th notes. The second row has 'x' above the 1st, 2nd, 3rd, 4th, 5th, 7th, 8th, 9th, 11th, 12th, 14th, and 15th notes. The third row has 'x' above the 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, 11th, 12th, 13th, 14th, 15th, and 16th notes. Below the staff, the lyrics are: "We all live in a yel-low sub-ma-rine yel-low-sub-ma-rine yel-low sub-ma-rine". Brackets below the lyrics indicate hierarchical grouping: a large bracket under the first three words, a medium bracket under the first two words of the second phrase, a small bracket under the first word of the second phrase, a medium bracket under the first two words of the third phrase, and a small bracket under the first word of the third phrase. A final large bracket underlines the entire phrase.

Fig. 3. The first phrase of *Yellow Submarine* with its metrical and grouping structures.

# Grouping: the perceptual segmentation of events cont.

- Lerdahl & Jackendoff 1983's Grouping Well-Formedness Rules:
  - GWFR1: Any contiguous sequence of pitch-events, drum beats or the like can constitute a group, and only contiguous sequences can constitute a group.
  - GWFR2: A piece constitutes a group.
  - GWFR3: A group may contain smaller groups.
  - GWFR4: If a group  $G_1$  contains part of a group  $G_2$ , it must contain all of  $G_2$ .
  - GWFR5: If a group  $G_1$  contains a smaller group  $G_2$ , then  $G_1$  must be exhaustively partitioned into smaller groups.
- Todd 1985
  - The amount of lengthening at a given phrase boundary in music is predicted by the position of that boundary in the hierarchical phrase structure of the piece.

# Lerdahl & Jackendoff 1983: 27-28

## Mozart's G minor symphony

To illustrate briefly the kind of analytic insight that can emerge from our proposed notation for grouping and meter, let us look again at the opening of Mozart's G Minor Symphony (2.14a), this time with both structures indicated. Examples 2.14b and 2.14c isolate fragments of the analysis for comparison. It is significant that the metrical structure of the first two-measure group (2.14c) is identical with that of the initial motive (2.14b), but at larger metrical levels. No doubt the theme as a whole sounds richer, more "logical," because of this rhythmic relationship.

2.14

a

The image shows the first five measures of the opening of Mozart's G minor Symphony. The notation is in G minor, 4/4 time. The right hand plays a melody with eighth and sixteenth notes, while the left hand plays a rhythmic accompaniment of eighth notes. Below the staff, a series of horizontal lines and brackets represent a metrical analysis. A central measure (measure 3) is marked with a circled '3' and a vertical dotted line, indicating a specific metrical level. The analysis shows how the rhythm of the first two measures (measures 1 and 2) is related to the rhythm of the first two measures of the next two-measure group (measures 3 and 4).

2.14 (cont.)

b

Musical notation for exercise b. It consists of a single staff with a treble clef and a key signature of one flat (B-flat). The staff contains a sequence of four eighth notes: B-flat, A, G, and F. Below the staff, there are three lines of rhythmic notation. The first line shows a quarter note followed by three dots. The second line shows a quarter note followed by two dots. The third line shows a quarter note followed by one dot, with a curved line underneath.

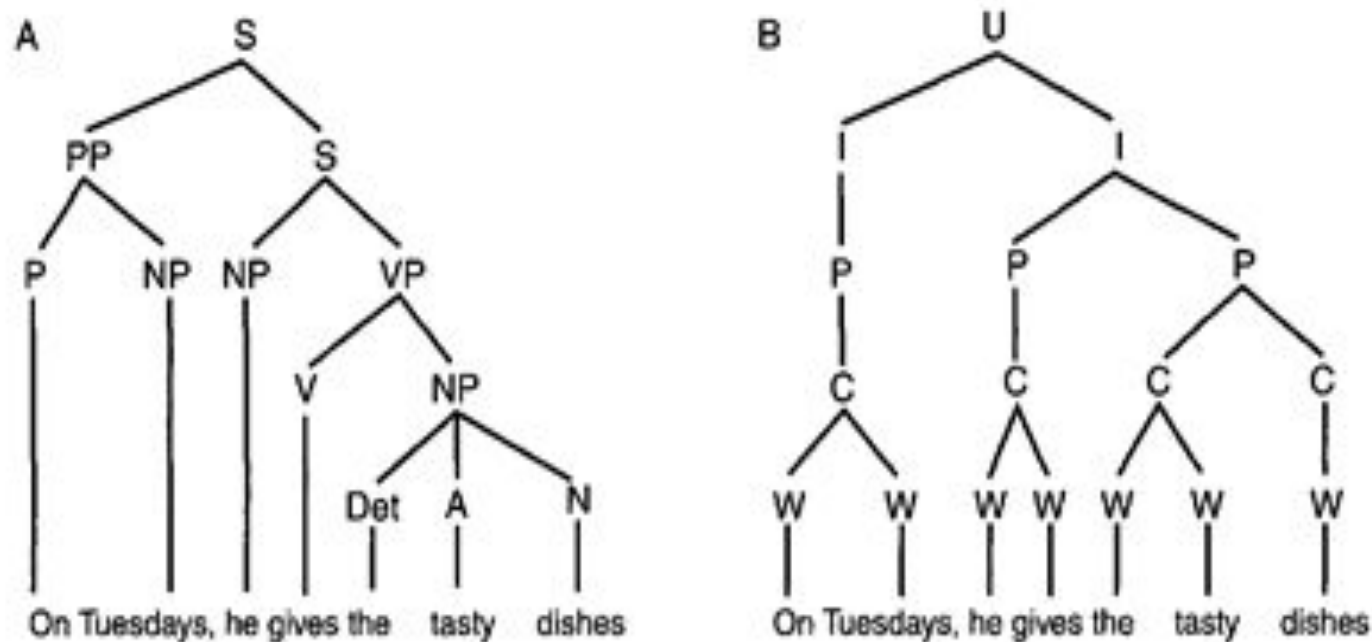
c

Musical notation for exercise c. It consists of a single staff with a treble clef and a key signature of one flat (B-flat). The staff contains a sequence of eight eighth notes: B-flat, A, G, F, E, D, C, and B-flat. Below the staff, there are three lines of rhythmic notation. The first line shows a quarter note followed by four dots. The second line shows a quarter note followed by two dots. The third line shows a quarter note followed by one dot, with a curved line underneath.

# Grouping: the perceptual segmentation of events cont.

- Grouping in language
  - Prosodic grouping reflects a separate phonological level of organization that is not directly determined by syntactic structure:
    - [This is [the cat [that caught [the rat [that stole [the cheese]]]]]]
    - [This is the cat] [that caught the rat] [that stole the cheese]





**Figure 3.5** (A) Syntactic and (B) prosodic hierarchy for a sentence of English. Abbreviations for (A): S = sentence, PP = prepositional phrase, NP = noun phrase, VP = verb phrase, Det = Determiner, A = adjective, N = Noun, V = Verb. Abbreviations for (B): U = utterance, I = Intonation phrase, P = phonological phrase, C = clitic group, W = word. Adapted from Hayes, 1989.

# Grouping: the perceptual segmentation of events cont.

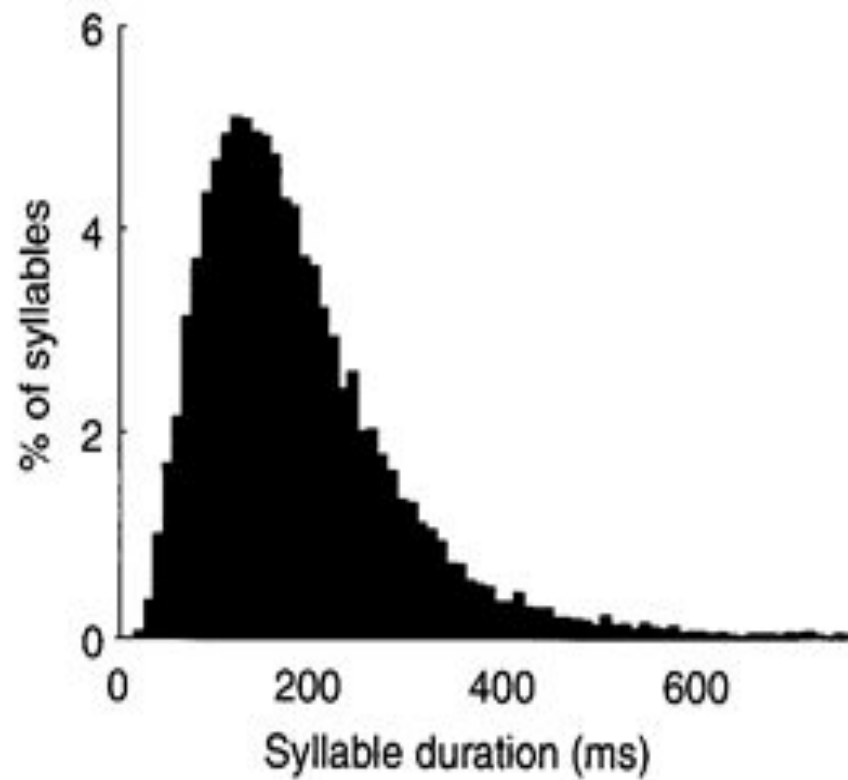
- Prosodic hierarchy .
  - Hayes 1989: /v/ deletion operates in the clitic group:
    - “Will you [save me] a seat”
    - “[Save] [Mom]”
  - Dilley et al. 1996: amount of glottalization of word-onset vowels is greater at higher boundaries.
- Break indices indicate the degree of juncture between words.
  - Price et al. 1991
    - Only 1 one 4 remembered 3 the 0 lady 1 in 1 red 6.
  - Wightman et al. 1992: correlation between perceived boundary strength and preboundary syllable lengthening.

# Durational patterns in music

- Beat and grouping boundaries: Points and edges in time.
- The durational patterning of events: How time gets filled.
- Durational patterning in music is measured by the time intervals between event onsets: interonset intervals (IOIs).
- Fraisse 1982: two categories dominate in Western music: short 200-300 ms and long 450-900 ms.
- Clark 1987: Music students showed categorical perception for duration ratios that varied between 1:1 and 1:2.

# Durational patterns in music cont.

- In speech, the duration of linguistic elements is influenced by many factors.
  - Articulatory constraints on how fast a sound can be produced.
  - Phonological rules like vowel lengthening before a voiced stop.
  - The number of phonemes in a syllable.
- Measurements of syllable or phoneme duration typically reveal a continuous distribution with one main peak.
- Duration is phonemic in some languages.
  - Estonian has short, long and extralong vowels.

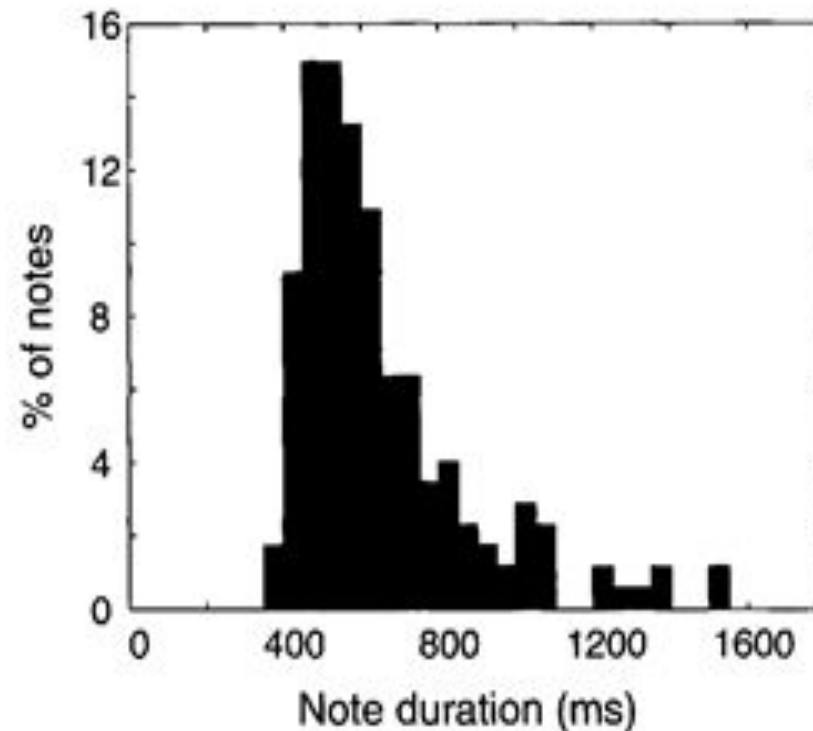


**Figure 3.6a** Histogram of syllable durations in a corpus of spontaneous speech in American English. Data are from approximately 16,000 syllables. Mean syllable duration = 191 ms, sd = 125 ms. Syllables with duration >750 ms are not shown (<1% of total).

# Durational patterns in music cont.

- Due to expressive performance, physical measurements of human performances reveal considerable deviations for notated durations.
- Different performances of the same piece resemble each other.
  - Repp 1992 found that all performances of Träumerei showed slowing at structural boundaries, with the amount of slowing proportional to the importance of the boundary.
- Articulation refers to the time between the offset of one tone and the onset of another:
  - Legato, staccato.
- Tone intensity is another rhythmic factor in music

## A performance of Träumerei



**Figure 3.6b** Histogram of durations of eighth notes from a performance of Schumann's *Träumerei* by Claudio Arrau. The large values in the right tail of the histogram are due to phrase-final ritards. Data are from approximately 170 eighth notes. Mean note duration = 652 ms, sd = 227 ms. Notes with duration > 1,600 ms are not shown (<1% of total). Histogram bin size = 50 ms.

# Durational patterns in music cont.

- Kendall & Carterette 1990
  - Listeners can reliably identify performances of the same music as expressive, deadpan or exaggerated.
- Gabrielsson & Juslin 1996
  - Listeners can identify the performer's intended emotion on the basis of expressive features.
- Clarke 1993
  - Extracted an expressive profile from a melody, and reimposed it several notes to the right.
  - Musicians preferred the original.



# Durational patterns in music cont.

- Palmer et al. 2001
  - Listeners could identify the performance they had heard before when choosing between a sequence embedded in larger sequences played in 3/4 vs. 4/4 time.
- Jungers et al. 2002
  - Tempo-persistence effect
  - Pianists played more slowly after hearing slow melodies, and played faster after hearing fast melodies.
- Dalla Bella et al. 2003
  - Musicians but not nonmusicians spoke faster after hearing a faster melody.
  - Musicians may be better at beat extraction.
  - But musicians didn't play faster after hearing faster speech.
  - No beat extraction in speech perception?

# The psychological dimensions of musical rhythm

- Gabrielson 1993
  - Listeners compared and classified a variety of rhythms using similarity judgments and adjective ratings.
  - 15 dimensions of rhythm experience were extracted statistically using multidimensional scaling and factor analysis.
    - Structure (meter, simplicity vs. complexity)
    - Motion (swinging, graceful)
    - Emotion (solemnity vs. playfulness)