Psychology of Music

From sound to significance

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Psychology Press
Taylor & Francis Group
HOVE AND NEW YORK

6 Perception of musical time

A 1997 study by Mangione and Nieman, which appeared in the *Journal of the American Medical Association*, examined over 500 physicians in training and medical students on their ability to identify common irregularities in recordings of human heartbeats. An unexpected secondary finding was that doctors who played a musical instrument were more accurate at identifying cardiac events than doctors who had no musical training. Cardiac auscultation is one of the most difficult diagnostic skills that doctors must master. 'In 0.8 seconds, you have four or five acoustic events at the threshold of audibility. You need to be able to separate them, and pick them up as a pattern,' explained Dr. Mangione when interviewed about the study (*New York Times*, August 2, 1997). While a direct causal relationship cannot be drawn, it is possible that musical training hones one's ability to hear a rhythmic pattern against an imagined pulse and to detect deviations from it. In this chapter we explore this mysterious 'sense of beat,' a fundamental but complex musical ability that eludes simple explanation.

As we will see, musical timing involves a sense of beat and much more. Time gives life and structure to music. Consider what music would be like if every pitch of a symphony or song was sounded at once! This rather extreme example highlights the importance of time, if only as a way of separating notes from each other. But the succession of notes in time clearly also matters – a scrambled version of a tune as simple as 'Mary Had a Little Lamb' would be unrecognizable. Moreover, we know that tone durations also matter. Consider the first several notes of 'Mary Had a Little Lamb' and 'The First Noel.'[1] When sung in the same key, each melody has the same succession of pitches; it is only the timing of the pitches that differentiates them. Moreover, in music with little or no variation in pitch, emotion can be conveyed in the timing of sounds produced. For instance in drumming, performers can express a range of emotions simply by varying produced temporal patterns (Laukka & Gabrielsson, 2000). In fact, one might be tempted to speculate that the temporal domain is even more important to music's evolutionary history than pitch. Some have suggested that music-making may have served an adaptive purpose for our ancestors based on its tendency to encourage synchronization, whether on the level of groups (Huron, 2003), or in mother–infant relationships (Dissanayake, 2000) as we will discuss in chapter 9. In any case, it is important not to discount the role of rhythm and timing in music.

This chapter is structured around the idea that musical time is multifaceted. Moreover, we propose that it is this diversity that makes musical rhythms so compelling. First, we discuss research on the formation of *rhythmic patterns* and the way in which these patterns help us to better comprehend and enjoy music. Second, we consider another aspect of musical time: *tempo*, or the rate at which a piece of music is performed. Though conceptually independent of rhythm, there is a complex interplay between rhythm and tempo. Finally, we consider the role of another form of musical time – *meter* – that is associated with perceived regularity in musical time. Following these sections we review possible sources of rhythm, including rhythm's neural bases.

Rhythmic patterns

What, exactly, is rhythm? One of us (PQP) attended a workshop on rhythm held by the neuroscientist Aniruddh Patel. As part of the workshop, the participants (all researchers in music cognition) offered their definitions of rhythm. Nearly every definition was strikingly different! The diversity of our responses highlights an important point. In comparison to a construct like tonality, for which we have a reasonable degree of consensus, the concept of rhythm resists simple definitions.

The simplest way to define rhythm, which we use here, is that it is the time pattern created by notes as music unfolds over time. More specifically, rhythm is a set of time-spans that elapse between note onsets. Ultimately there is more to rhythm than this but we will address this later. Importantly, it is *onsets*, and not note durations, that determine rhythms. Take, for instance, the melody shown in Figure 6.1. Though the version in 6.1a has many durations that differ from the melody shown in 6.1b, both rhythms would sound as if the same. Duration is important in music because it can add emphasis to certain notes (e.g., the note beginning 6.1a); however, durations are not the primary generator of rhythms.

An important fundamental characteristic of rhythms is that they are based on relative time rather than absolute time. Absolute time is time as indicated by a stopwatch, a time-span with no comparison. However, in music, rhythms are supposed to remain constant even when *tempo* (the rate at which music unfolds) speeds up or slows down. Rhythm thus cannot depend on absolute time because the absolute time of every note changes when tempo changes. The fact that rhythms are based on relative time leads to the conceptualization of rhythmic relationships as ratios. The ratio formed by two adjacent time-spans is their *serial ratio* (Jones, 1976). Note that there is a similarity to melody (see the previous chapter). In both cases, the experience of music is thought to be based on perceiving relationships rather than properties of sound heard in isolation.

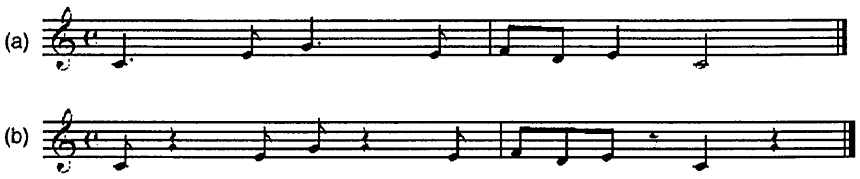

Figure 6.1 Two melodies comprising tones of differing durations that yield the same rhythm based on the timing of onsets.

We now turn to a paradox. Although rhythms are serial ratios, not all serial ratios sound rhythmic! We all know of rhythms that can be difficult or easy to comprehend or reproduce. Others are more complex. We also know of people who attempt to produce rhythms that end up sounding 'un-rhythmic.' Fortunately, serial ratios can help predict how complex (or even un-rhythmic) a musical pattern will be. Simple rhythms come from simple ratios, which are those that can be reduced to an integer value. For instance, if one time interval is exactly half the length of an adjacent interval, regardless of their order, that ratio can be expressed as a 2:1 ratio. This is the so-called 'swing ratio' (though in practice it can be quite variable). However, if one time interval is 500 milliseconds and the adjacent interval is 157, the ratio of 3.18471 . . .: 1 is considerably more complex. The simplest ratio is a 1:1 ratio, followed closely by 1:2, 1:3, et cetera.

The role of rhythmic regularity has been thoroughly explored by Mari Riess Jones, one of the most influential figures in the study of musical rhythms, and her colleagues. A series of experiments explored the way in which rhythmic regularity allows the listener to detect the timing and/or pitch of a forthcoming note. The logic of these studies is that the listener uses rhythms to target attention to forthcoming points in time (Jones, 1976). Rhythmic regularity, in fact, may even help listeners hear pitch (Jones, Moynihan, MacKenzie, & Puente, 2002). Jones et al. used a memory paradigm introduced by Deutsch (1972). The listener is presented with a 'standard' tone to hold in working memory while a series of subsequent 'distracter' tones are presented. Following the distracter tones, the listener hears a final tone and determines whether the pitch of the final tone matches or does not match the initial tone. Listeners were better able to judge matches between the first and last tones based on pitch when the intervening tones were temporally regular than when the intervening tones were irregular.

Here we run into another paradox. Rhythms are simpler when adjacent intervals form interval ratios. However, if one were to analyze the actual performed ratios in recorded music, one would find few such ratios, yet the music can sound quite 'rhythmic.' Chapter 11 (on music performance) will discuss why it is that performers might produce rhythms in this way; here we consider why the listener may hear simplicity in the face of apparent complexity. A possible answer lies in the phenomenon of *categorical* *perception*, a tendency to treat a range of values along a physical continuum as if they were the same until one reaches a point at which the percept abruptly changes. For example, one might present listeners with a series of speech sounds that gradually change from /p/ to /b/. Even though the physical change is smooth and incremental, listeners commonly report hearing a sudden shift – or 'boundary' – at which the repeated presentations of /p/ 'turn into' /b/. Categorical perception of speech is well documented from an early age (see Jusczyk, 1997, for a review). Does categorical perception help us hear rhythm regularity even when presented with variably timed performances?

Clarke (1987) performed a series of simple experiments to test whether listeners have categorical perception for rhythm. Participants were asked to listen to 10 short musical items of five or six notes, regularly timed. Following this initial context, three test notes were played that formed a range of serial ratios between 1:1 and 1:2. Clarke found that people tended to hear either 1:1 or 1:2 even if the timing of the notes actually formed a more complex ratio. Listeners perceived a categorical boundary separating these ratios. Similarly, listeners had difficulty discriminating intervals that did not cross the perceptual 'boundary' between 1:1 and 1:2. Clarke proposed that the more complex ratios were interpreted simply as the result of 'expressive information, or perhaps accidental inaccuracy' (p. 30).

One of the complexities of rhythms is that they can exist at multiple levels. The definition of rhythm described earlier (times between note onsets) can be thought of as rhythms existing on a 'small' time scale. But rhythms can also exist across longer time-spans, and listeners can pay attention to smaller or larger spans, and within limits listeners can choose to attend to one or the other (Jones & Boltz, 1989). These larger time-spans can be created by patterns of emphasis in melody, such as the use of accents (Jones, 1987). An important implication of these larger time-spans is that they create perceived boundaries in music that help the listener to organize cognitively what he or she hears into musical phrases (also called 'groups', cf. Lerdahl & Jackendoff, 1983).

The influence of musical phrase structure on the perception of timing was addressed in a study by Sloboda and Gregory (1980) that borrowed a paradigm from psycholinguistics, called 'click migration.' The experiments on click migration began with an attempt to test the hypothesis that the hypothetical structural properties that were presumed to underlie surface forms in language were psychologically real, rather than convenient abstract representations. Take this example: 'That he was happy / was evident from the way he smiled.' The transition point between first two phrases is marked by a '/'. Participants were asked to indicate with which word a superimposed 'click' was simultaneous. If the click was produced with the fourth word 'happy,' it tended to be heard later than its physical time of occurrence. If it coincided with the word 'was' it tended to be heard earlier. Thus, the click tended to 'migrate' to a natural structural boundary in the speech sequence. The phrasing, a semantic/cognitive aspect of the word sequence, influenced the auditory experience of hearing the click.

In music, Sloboda and Gregory found the same phenomenon. First they presented their participants with musical phrases, the tones of which had been generated by a computer to be of exactly equal length. The tone sequences were structurally identical, yet a click placed on the fifth note (in sequences in which the phrase ended on the fourth note) tended to migrate backwards toward the previous phrase ending. Further, the phenomenon was more striking when the phrase boundary was marked by a longer tone than that with which the click was actually associated. Clearly, musical hearing is more than the mere perception of the physical stimulus.

Tempo

Conceptually, rhythm and tempo are independent of each other. Whereas rhythm refers to relative time, tempo refers to absolute time. More specifically, tempo concerns the speed at which rhythmic patterns unfold.

Tempo is typically considered to be the rate of the 'beat' – a time-span associated with the rate at which a listener will tap his or her foot. Unfortunately this definition is rather too simplistic. In general, people typically try to maintain the percept of a beat that is in the vicinity of 600 milliseconds (which is about 100 beats per minute) even when tempo fluctuates (Parncutt, 1994). Consider a case in which a melody is repeated and is continually sped up after each repetition. Let's say that during the first repetitions, quarter notes (crotchets) occur every 600 ms and so they establish the perceived beat. As the music speeds up, the perceived beat speeds up with each repetition for a while. But then we get to a point where the durations of half notes (minims) near 600 ms. Now the listener may start hearing the beat as being 600 ms again, only now based on the timing of half notes rather than quarter notes. Thus, in a sense, the beat can only speed up so much. Note, however, that when such a perceptual readjustment occurs, the listener is not fooled into thinking that the music has slowed down. In fact, the music can sound quite fast even when the beat may 'slow down' as in this example. Similarly, when a Dixieland Jazz group enters 'double time' (literally doubling the speed), a listener is likely to keep tapping her foot at the same rate, but will easily hear the change in tempo. Thus, though beat and tempo are related, their relationship is complex and not always equivalent.

Why do people cling to a beat that is around 600 ms? One possibility is that the beat, more so than perceived tempo, is linked to the rate at which we like to move in general. Specifically, one's preference for the rate of the beat is highly linked with the concept of spontaneous tempo, first discovered in the landmark research of Paul Fraisse (Fraisse, 1982). Fraisse found that individuals are surprisingly consistent when asked to simply tap at a rate that is comfortable. This behavior varies across individuals but leads to an overall tendency for people to prefer tempos with a beat period around 600 ms. Interestingly, this rate has nothing to do with the heartbeat (sometimes presumed to be the source of rhythm), but is quite similar to the rate at which people walk. As one might expect, differences in preferred walking rate do predict differences in spontaneous tempo during tapping! Fraisse also found that when people were asked to tap prototypically 'long' and 'short' durations, they tended to produce durations that were related by a 2:1 ratio – hence a possible motoric source for rhythmic regularity, discussed earlier.

Another issue that is more complex than it seems at first is the supposed independence of tempo and rhythm. Though this independence holds across a range of tempi, it does not hold in all cases. Various research findings have led some to speculate that the perception of rhythms only holds for time-spans ranging from 200 ms (300 beats per minute) to 1000 ms (60 beats per minute) (e.g. Drake & Botte, 1993), whereas shorter durations are heard as clusters of tones (e.g., grace notes), or as subdivisions of rhythms (London, 2004). By contrast, intervals longer than 1000 ms are heard as separate events, and cannot be heard as reflecting an underlying rhythm unless the interval is subdivided by other tones (e.g., when a solo instrument holds a suspended tone that is subdivided by accompanying instruments). Figure 6.2 illustrates the relationship between tempo and rhythm, generalizing across several studies.

Meter

So far we have equated rhythmic simplicity with *isochrony*, meaning equal inter-onset intervals. But many very simple rhythms are nonisochronous. Take the popular rhythm corresponding to the lyrics, 'shave and a hair cut . . .'. People find this rhythm easy to reproduce but the inter-onset intervals differ from each other (e.g., the note associated with 'shave' is longer than the note associated with 'and'). How do people hear regularity (simplicity) in a rhythm like this? One answer is that rhythms are simple when they clearly match a particular *meter*.

The problem with defining meter is that the definition from musical practice tells only part of the story. Those with musical training are probably familiar with the following treatment: the number of beats in a measure or bar. In this treatment, two components emerge. First is the beat, which as mentioned before is an isochronous time-span that is perceptually salient within the musical structure. People often dance to the beat. The second component is the cyclical nature of meter. Meter outlines a recurring period that frames the structure of music. Western music favors cycles that are multiples of twos (marches) or threes (waltzes), Indonesian Gamelan favors fours, while Indian music makes use of very complex interweaving meters.

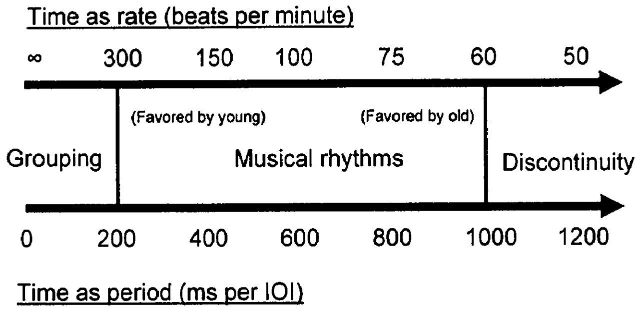

Figure 6.2 The continuum of musical tempi, delineating boundaries in which note events rhythms are typically heard as rhythmic. Copyright © Peter Pfordresher. (IOI = inter-onset interval.)

However, there is another important component to meter that plays an important role in perception. Meter is also conceptualized as a pattern of alternating strong and weak time points. An example of the match between a rhythm and its meter is shown in Figure 6.3. In this representation, called a 'metrical grid,' Xs mark time points on which a note might occur, and the number of Xs determines how prominent or *accented* that time point is. Note that the grid is entirely cyclical, in that Xs at each level repeat regularly. The grid here matches the counting of 4/4 time, but also establishes which sounded notes are more prominent (e.g., the first note and to a lesser extent the third note of the notated melody) and which are less prominent (e.g., the second note and fourth note of the melody). In some cases, a metrical accent can in fact coincide with a silent point; as a result, musical silences can seem conceptually 'loud' (Margulis, 2007). A classic example that she cites occurs in Beethoven's *Eroica* (third) symphony; at one point (measure 280) in the first movement a sudden silence appears at the beginning of a measure – a strongly 'accented' silence.

It is through meter that we get a better understanding of 'the beat' in music. We again draw on the regularity of the grid notation. Notice that there are four vertical 'levels' in the grid, with each level associated with a duration value. Each level should be considered as a possible 'beat' duration. Most people would hear the beat at the quarter note (crotchet) level, hence the time signature. Typically it is thought that the beat lies somewhere in the middle

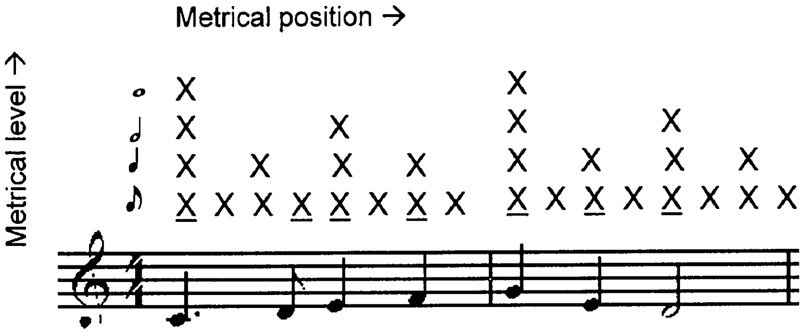

Figure 6.3 A metrical grid. Positions within the grid that are marked by note onsets are indicated by underlining at the lowest metrical level.

(vertically speaking) of the grid, with lower levels constituting subdivisions of the beat.

Why are meter and rhythm thought to be different manifestations of musical time? This is a more sophisticated question than it seems, and not all theorists agree with the dominant view that meter and rhythm are distinct. Arguments for this distinction typically invoke the invariance of meter in the face of varying rhythms. Rhythms rely on the presence of tone onsets. Metrical accents, such as the beat, can exist when no tone is there. Moreover, rhythm and meter can be heard to conflict, as in *syncopation*, an aspect of music that is particularly important to genres like rock and jazz. Syncopation occurs when tone onsets align mainly with weak metrical accents, whereas tones are conspicuously absent at strong accents. Paradoxically, syncopation does not cause the underlying beat to become ambiguous. David Temperley (2000) has pointed out that in rock music the sung lyrics regularly occur just prior to a strong metrical accent and are thus dominantly syncopated in a way that anticipates the beat. 'Let It Be,' by The Beatles, is a good example; the accented syllables (in capital letters) 'MO-ther MA-ry COMES to ME' all anticipate the piano chords that mark the beat. He argues that the use of syncopation in this way draws the listener's attention to the beat, rendering the music more 'danceable.' In general, music that promotes motion (a state often referred to as 'groove' within African-descended genres that dominate current popular music) is often syncopated and often contains events 'on the beat' that actually fall slightly off the beat (Iyer, 2002).

If meter and rhythm are truly separate, where does meter come from? Most would argue that meter originates somehow in the first rhythmic patterns in a piece, which form a context that leads to meter (e.g., Longuet-Higgins & Lee, 1982). However, there is evidence that meter may exist somewhat independently of a particular rhythmic structure. For instance, Palmer and Krumhansl (1990) demonstrated that meter may be generated in the mind based on intentions. They asked listeners to imagine different meters by counting silently, and then presented listeners with simple tones at various times. They found that listeners thought tones sounded 'better' when tones coincided with strongly accented positions, based on the meter that the listener was imagining. This finding was particularly strong for musically trained listeners. Other data suggest that meter persists even when the rhythm has vanished. In one study, Desain and Honing (2003, Exp 2), played a series of 66 rhythms to highly trained musicians and asked them to notate the rhythms as accurately as possible. It was found that the prior presentation of a specific meter (duple or triple subdivision) influenced how musicians conceptualized ambiguous rhythms presented afterwards. Thus, presentation of a specific musical meter may prime listeners to hear metrically ambiguous rhythmic patterns in that meter (see chapter 5 for more on priming).

Several papers have examined the way in which the fit between rhythm and meter can help people remember rhythms and isolate the 'beat.' Perhaps the most influential study in this category is a paper by Povel and Essens (1985). The authors proposed a model that predicts the kind of overarching time-span that might best be suggested by a temporal pattern of inter-onset intervals. Their model focused on the pattern of accents suggested by a temporal pattern. According to their view, a more complex rhythm is one that does not unambiguously suggest a single beat. More generally, this finding suggests that our perception of rhythm is influenced by the degree to which a rhythm can be heard as belonging to a particular meter.

An illustration of the approach advanced by Povel and Essens is illustrated in Figure 6.4. Two rhythms are represented by vertical lines (tone onsets) superimposed above rows of dots that represent candidate time points for tone onsets. Note that both melodies contain similarly complex serial ratios. Thus the perceived complexity of rhythms would only result from how well each rhythm matches a particular beat-based (metrical) structure.[2] As can be seen, the top rhythm clearly matches a structure based on counting in fours (like a 4/4 meter), in that tone onsets always align with group boundaries. However, counting in threes (as in 3/4 meter) does not work as well for this rhythm; thus the rhythm is fairly unambiguous in being binary rather than ternary. By contrast, the lower (complex) rhythm, does not match either organization very well as group boundaries for both organizations can fall on silent points. Povel and Essens found that rhythms like the one shown on the bottom of Figure 6.4 were more difficult for listeners to remember and reproduce than rhythms like the one shown above it.

It should be noted that meter, like rhythm, can range from the simple to the more complex. Certain meters are common and considered to be simple; these meters establish accent patterns that highlight recurring time periods based on roots that are binary or ternary. However, some meters do not reduce to either sort and are referred to as complex. Complex meters often highlight periods of five, seven, or nine. Two of the best known recent examples of complex meters include the jazz piece *Take 5* (a count of five) and the Pink Floyd song 'Money' (a count of seven). In cultures in which these meters are rarely used (like much of Western Europe and North America), such meters can be difficult to conceptualize and might be considered difficult for dancing. In other cultures, such as the Balkans, these meters are quite common. An important set of studies by Erin Hannon and Sandra Trehub (2005a) demonstrated that adults with no exposure to Balkan music had difficulty discriminating deviations from a standard based on a complex Balkan meter, whereas listeners raised in the Balkans had no trouble with this task. At the same time, infants from non-Balkan households were able to perform similarly to the Balkan listeners after only a few weeks of exposure to Balkan meters.

We close the section on meter with a reconsideration of the beat. Earlier we referred to the finding that listeners on average prefer beats that hold close to a 600 ms period. This finding is qualified by age and by musical experience, however. When exposed to the same melody, a younger person would tend to

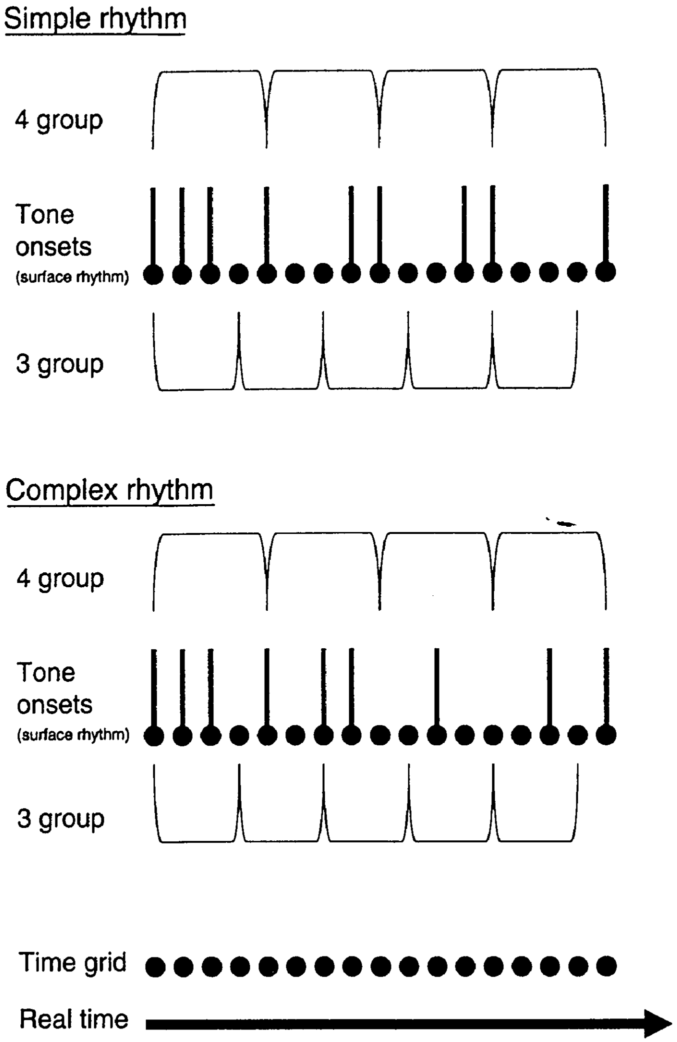

Figure 6.4 Two examples of rhythms used by Povel and Essens (1985). Time in this approach is discrete, represented by dots for candidate time points. The two manifested rhythms (simple, complex) are shown as vertical lines representing tone onsets above dots; dots presented alone represent silence. Brackets above and below represent candidate organizations based on beats that recur every four time points (above) or every three time points (below). Adapted from Povel and Essens, 1985, Figure 5, with permission from the University of California Press.

hear the beat at a faster rater (i.e., a lower metrical level) than would an older person (Drake, Jones & Baruch, 2000) and musicians tend to hear slower beats than nonmusicians (Drake, Penel, & Bigand, 2000). Why is this? For this we turn to possible basic mechanisms that lead to rhythmic behavior.

Sources of rhythmicity

How do we hear rhythms? At present there are two different approaches to this issue. One approach stems from information processing theory that is traditionally associated with cognitive psychology. It focuses on the way in which listening incorporates an internal counting mechanism that essentially computes statistics from musical structure. The other approach has its roots in physics and motor control, and suggests that rhythms are perceived via a process called *entrainment*, which is a process in which one rhythmic pattern achieves and maintains synchrony with another pattern. According to this view, the listener synchronizes internal rhythms with external rhythms, engaging in a kind of internal dance with music. Ultimately both approaches have different strengths and recent theories have attempted to combine the two (e.g., McAuley & Jones, 2003; Pressing, 1999).

The information processing approach has been a dominant force in music cognition, as in psychology overall. Information processing models of timing are typically called 'clock counter' models (e.g., Creelman, 1962). According to these models, tone onsets trigger the initiation of a counting process. During the subsequent inter-onset interval, a series of irregularly timed 'clock ticks' are produced while a second (subconscious) process counts them. There is thought to be variability in the timing of ticks as well as occasional counting errors. Lest this approach sound implausible, consider the fact that 'clock ticks' function like spontaneous neural spikes (action potentials); in fact this may be the neural basis for such a mechanism. Many researchers have been drawn to these kinds of approaches because they match the common intuition that behavior is probabilistic and error-ridden. Moreover, clock-counter approaches have been successful in mimicking the kinds of problems people often have in estimating the passage of time.

Despite these benefits of statistical approaches, many researchers have come to favor a second class of models that arise out of dynamical systems theory in mathematics. These models invoke the concept of *entrainment*. The basic idea is that people are inherently rhythmic, with internal rhythms that adapt to the rhythms of music. We take as a paradigmatic example the model of Large and Jones (1999). The main components of the model are illustrated in Figure 6.5. This model suggests that people time their attention to events in the world by adapting an internal rhythm (a neural oscillation of attentional energy) to note onsets. In Figure 6.5, we see that the peaks in the oscillation match tone onsets. Importantly, the adaptive nature of the internal oscillation can be used to follow music that fluctuates in timing, such as when a performer slows down at the end of a phrase. A further component of the model is the sharpness of the oscillator's peak, which models attentional focus. The peak grows sharper (narrower) when the timing of events is highly regular. Under such circumstances, attention is thought to be narrowly and precisely focused on particular time points. When timing in the world is more variable, attention spreads out in time as does the width of the pulse peak. Note that

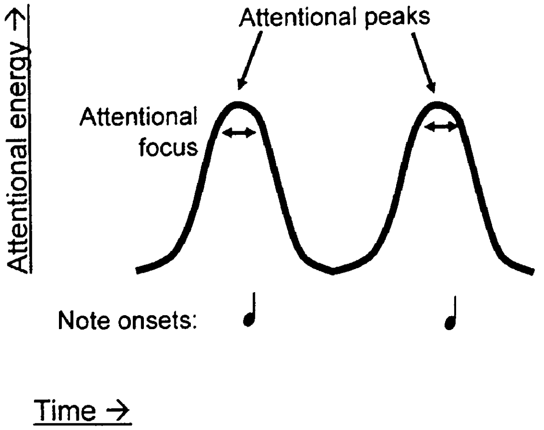

Figure 6.5 An illustration of the entrainment model of Large and Jones (1999). Horizontal double-arrows indicate the width of the pulse (attentional focus). Quarter notes (crotchets) indicate the timing of (acoustic) note onsets. Adapted from Large and Jones (1999, figure 4), with permission of the American Psychological Association.

this 'spread' of attention may explain the phenomenon of categorical perception described earlier.

Entrainment models are attractive because they can predict the way in which listeners adapt to fluctuations of performance timing. Also, unlike statistical models, entrainment models offer a straightforward explanation for why periods that are integer multiples are treated as functionally similar, whereas such changes are considered to be extreme by basic statistical models. The pattern of internal oscillations in such models has led to predictions of listeners' ability to detect temporal fluctuations and to categorize time intervals, as discussed earlier. However, in some ways entrainment models are 'too good' to mimic human behavior, because they do not have any random variability. Such chance fluctuations may be better accounted for by clock-counter models.

The neural bases of rhythm perception

In considering the role of rhythm in the brain one might consider a suggestive fact about the brain: Brain activity is inherently rhythmical. One implication of research on steady-state EEGs is that brain activity often produces regular oscillations, albeit more so during the sleep state than during alert wakefulness. Moreover, some neuroscientists have suggested that the process of learning is guided by theta rhythms in the brain (Givens, 1996). Thus, it seems plausible that our affinity to musical rhythm occurs because our brain synchronizes with rhythms in the world, as in the entrainment approach discussed above.

Recent research suggests that the brain does synchronize with rhythms in the world. This evidence has been yielded by studies using *electroencephalography* (EEG, see chapter 4), due to the high temporal resolution of this technique. The brain responds to patterns of regularly timed events by synchronizing activity with the onsets of these events, and can even respond at the onset of an expected event that does not appear, as in the phenomenon of a 'loud silence' described earlier (Snyder & Large, 2005). When a participant imagines tapping regularly, the brain exhibits rhythms in the sensorimotor and parietal cortices that are equivalent in rate to the imagined rhythm (Osman, Albert, Ridderinkof, Band, & van der Molen, 2006).

It also appears as though our brains are predisposed towards certain kinds of metrical organizations. Patterns of oscillating activity suggest a preference for binary (two-beat) over ternary (three-beat) and other kinds of metrical organization (Brochard, Abecasis, Potter, Ragot, & Drake, 2003). Likewise, some neuroscience research supports the presumed separation of rhythm and meter, in that perception of metrical organization is hindered by damage to the temporal lobe in either hemisphere, whereas the temporal lobes may not contribute to rhythm perception (Liégois-Chauvel et al., 1998).

One topic of great concern in research on rhythm perception (and production) is what makes a rhythm simple or complex. We highlight one study that focused on the complexity of serial ratios in rhythm (Sakai et al., 1999). In this study, participants first heard and then reproduced rhythms that were based on integer or noninteger ratios. Functional magnetic resonance imaging (fMRI) was used to measure brain activity as rhythms were held in working memory prior to production. While participants retained simple (integer) rhythms, brain activity was located primarily in motor areas: the motor cortex and cerebellum (cf. Figure 4.2). While participants retained complex (noninteger) rhythms, additional activations were found in the prefrontal cortex. This suggests that the complex rhythms increased memory load given that the prefrontal cortex (just behind the forehead) is important for the functioning of working memory and decision making. In addition, complex rhythms were associated with a tendency for activations to change from being predominantly left hemisphere to being predominantly right hemisphere (suggesting a reduction of 'analytic' processing for complex rhythms). Thus, the brain may indeed do more 'work' while listening to a rhythmically complex piece like Stravinsky's *Rite of Spring* as opposed to 'Twinkle Twinkle Little Star.' It is possible that the difference between conditions may have something to do with people's familiarity with simple rhythms; other research has found that when people first learn rhythms, prefrontal lobe activation is found but then dissipates with time (Ramnani & Passingham, 2001).

Of course, rhythms in music are part of the overall auditory signal. This brings up two related questions: Does the auditory cortex show any specialization for rhythm, and to what degree do different parts of the brain contribute to rhythm versus pitch perception? With respect to the first