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Some Examples of Complex Meters and Their Implications for Models of Metric Perception

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A music-theoretic discussion of metric structure. Describing a musical passage as "metric" usually implies that one can hear in it an isochronous series of beats and that these beats are hierarchically structured. In some cases, however, one cannot infer a wholly isochronous metric structure from the durations present on the musical surface. In particular, there may be some meters where the beat level of the metric hierarchy consists of a nonisochronous series of durations; these cases are referred to as *complex meters*. A number of these complex metric structures are presented and discussed. The implications of these structures for various models of metric perception are then considered, with particular reference to their implications for the entrainment model proposed by Jones and Boltz (1989). It is proposed that such meters must be accounted for under an additive rather than multiplicative formalism. The paper concludes with some considerations of how entrainment to complex meters might be tested, as well as the ways in which experiments that focus on complex meters might provide insights into other aspects of temporal perception.

Introduction: Complex Rhythmic Behavior and Complex Meters

How is it that we can dance to the merengue (or a fast tango, or a Bulgarian "Krivo Horvo")? Although there is a growing body of experimental evidence as to how we are able to construct simple metric hierarchies, interpolate missing elements of such hierarchies, find the beat (within certain tempo ranges), and so forth, most of us would readily admit that experimental studies of metric perception and cognition have documented only a small portion of the wide range of rhythmic behaviors of which we are capable. Among the many things that humans seem able to do is to sense a series of beats in a wide variety of intricate rhythmic surfaces. Most of the time these beats are perceived to be isochronous, whether or not the musi-

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cal surface is actually composed of an isochronous series of durations—indeed, in typical cases, the musical surface is composed of a series of various note lengths or interonset intervals between articulations.[1]

Along with perceiving a series of beats, listeners are also able (again, in typical cases) to confidently organize these beats into a metric framework. Furthermore, once listeners have identified the metric framework, they are then able to generate the metric pattern independently, even if the music stops or if the rhythmic surface may temporarily contradict the established metric framework. Thus while meter is yoked to the durations present on the musical surface, it remains an independent perceptual aspect of it. This is, in fact, the practical litmus test for "hearing metrically," in that once a meter is perceived, we then have the ability to internally maintain and/or externally reproduce it in the absence of (or even in contradistinction to) external stimuli.

When we dance to the merengue, what kind of metric pattern do we reproduce? It would seem that the counting, tapping, and/or dancing behaviors exhibited in such a rhythmic context require a more complex metric framework, one characterized by nonisochronous structures on various levels. In the first section of this paper, a number of these kinds of metric patterns are presented. In the second section of the paper, the implications of these patterns for models of listener behavior, especially attending behavior, are discussed.

A Series of Metric Examples

BEETHOVEN'S "ODE TO JOY"

Let us begin with a familiar musical example in order to define some terms and the graphic representations that will be used herein to describe metric structures (Figure 1). When Beethoven's melody is performed at a moderate tempo of 78 quarter notes per minute (each quarter note is 770 ms in duration), the following metric hierarchy ensues (Figure 2). What

1. A note regarding the use of the term "isochronous" here and throughout the rest of this paper: It is, of course, well known that in performance, metric timings are rarely isochronous, but in fact are subject to a degree of expressive variation—see, for example, Gabrielsson (1982), Sloboda (1983), Clarke (1985, 1989), Shaffer, Clarke, and Todd (1985), and Todd (1985). On the other hand, it is both necessary and desirable to distinguish between those temporal patterns that involve more-or-less even durations and those temporal patterns that involve categorically different durations. Therefore, when I speak of "isochronous" in the following examples, I am using the term as a shorthand for "an underlying representation of an idealized series of isochronous durations that are subject to expressive variation in performance."

Fig. 1. Beethoven's "Ode to Joy" from Symphony No. 9, 4th movement.

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HyperMeasures  |       |       |       |       |

Measures       |   |   |   |   |   |   |   |   |

Beats          | | | | | | | | | | | | | | | | | (etc.)
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Fig. 2. Metric diagram #1 of the "Ode to Joy."

exactly does this metric diagram represent?[2] Each "|" in this metric diagram represents an articulation or a metric event on some hierarchic level. But what are these "events?" Are they musical objects that are part of the acoustic signal or a product of the listener's processing of that signal (local peaks in acoustic energy and/or sound-event onsets)? Or are they not objects at all, but rather elements in a representation of listener behavior?

Traditional music theory talks about musical meter as if it were a particular arrangement of autonomous musical objects, and thus beats, downbeats, subdivisions, and other metric structures are deemed to be "part of the music" (although this view of meter has received its due share of criticism in the theory literature; see, e.g., Brower, 1993; Kramer, 1988; Lerdahl & Jackendoff, 1983; Lester, 1986; London, 1990). Some psychologists have adopted this traditional approach, for example: "A sequence of tones is perceptually organized with reference to an isochronous pulse or grid . . . one that maps onto as many stimulus onsets as possible" (Bharucha & Pryor, 1986). Lee (1991) gives an excellent summary and critique of these coding models for musical meter. An alternative to coding models has been proposed by Jones (1976, 1990a, 1990b, 1992; Jones, Kidd, & Wetzel, 1981), and given further attention by Desain

2. Readers may note that in Figure 2, the "Measure" level is at odds with the notated four-beat measures (although, as we shall see, this changes in Figure 3). The "Measure" level of the diagram simply refers to the level of metric structure immediately above the level of the perceived beat, although one should keep in mind that (a) there may be higher levels of metric structure, as there are in this example, and (b) the notated meter may not always demarcate the meter as it is heard [Caplin (1981) discusses the distinction between "notated versus expressed meter" in some detail].

(1992), Gjerdingen (1989, 1993), Jones and Boltz (1989), and Large, McAuley, and Kolen (1993). In these entrainment models, the focus is not on the coding of events within the musical/acoustic surface, but rather on the listener's attending behavior. In an entrainment model, the listener attunes his or her perceptions according to some cyclical temporal pattern, a pattern that focuses their expectations regarding the temporal location of both current and future musical events. Entrainment models of temporal attending are very attractive for musical meter as they provide a ready means of accounting for subdivision, durational judgments, syncopation, "accented" rests, and expectancy violations and other temporal anomalies (e.g., late note entries and tempo shifts).

In her discussion of entrainment, Jones (1990a) has noted that "temporal attending . . . rests on two overlapping and interactive activities: *abstraction* and *generation.* Abstraction refers to extracting invariant music information; generation refers to 'using' that information to produce expectancies in real time" (p. 193). Metric recognition thus necessarily involves some coding of musical surfaces (the recognition of baseline durations and durational comparisons to establish beat and meter, etc.). But extracting the invariant information in the musical signal involves more than simply correlating interonset intervals or peaks in acoustical energy; these features are then correlated with the listener's prior knowledge of metric hierarchies and their structural grammar. This prior knowledge allows the listener to invoke the appropriate metric framework (or at least make some tentative metric hypothesis) even in those instances in which it may be in some ways underdetermined by the invariant features of the musical surface alone. After this *recognition phase*, listeners then switch to a *continuation phase* in which, as Jones has noted, the meter that is extracted in the recognition phase becomes a pattern of entrainment.[3]

Thus, to return to our original question "what do these metric diagrams represent?," we may answer that they represent metric structure and that this structure is *both* the invariant features that are to be extracted at the beginning of the passage and the pattern of attending that the listener subsequently exhibits. Assuming that the meter remains stable throughout a given passage, this isomorphism should not surprise us. Thus, although the

3. Dowling, Lung, and Herrbold (1987) have used the term "expectancy window" to refer to spans in which salient musical events are likely to occur; in this sense the "|"s of the metric diagrams mark the center of each time window on a given hierarchic level.

4. In the continuation phase, meter is for the most part a pattern of attending energies, as the music usually supplies the requisite articulations in each slot of the metric pattern. In some interesting cases, as for example when a long duration continues through several beats or where a rest falls on a downbeat, I would posit that the attending pattern may trigger a metric articulation in the mind's ear of the listener. See London (1993) for a discussion of these "loud rests."

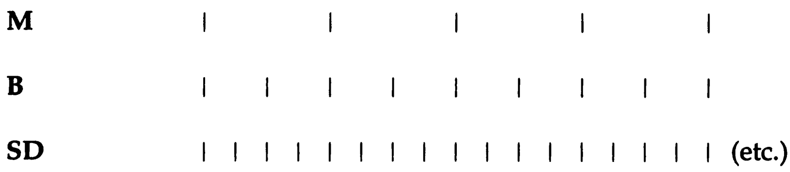

Fig. 3. Metric diagram #2 of the "Ode to Joy."

organization of the metric structure does not change from recognition to continuation phases, the elements within that structure change profoundly.[4]

In Figure 2, the beat level is the lowest (i.e., shortest) level that is present. Two additional levels of metrical organization above the beat level are also present: a level of two-beat units and then a higher level of four-beat units, each differentiated by melodic patterning. Each pair of beats gives rise to a duple measure, and as the four-beat units are created by concatenation of the duple measures themselves they are labeled as *hypermeasures*, as an indication of higher levels of meter.[5]

However, if this passage were to be performed at a rate of 138 quarter notes per minute (each quarter-note is now 435 ms in duration), our sense of the metric hierarchy is likely to change (Figure 3).[6] Formally, the relationships from level to level are the same, but the B level is now in the middle rather than at the bottom of the hierarchy and, as a result, (1) there is but one level of structure above the B level (i.e., we no longer have any hypermetric organization) and (2) each notated quarter note now is heard on the SD level.

To even begin to address the issues of beat and tempo perception, preferred tempo, and natural pace, which give rise to this shift in metric orientation, is beyond the scope of this paper. Various experiments have shown that listeners have a preferred range of tempo for the recognition and organization of periodically recurring stimuli, with periodicities falling between 70 and 120 beats per minute being regarded as relatively easy to remember and assimilate (Clynes & Walker, 1982; Dowling & Harwood, 1986; Fraisse, 1982; Halpern, 1988). Recent work in neural-network design suggests that natural pace may be a property of certain neural network circuits (Desain & Honing, 1991; Povel, 1981), which would place natural pace at a fairly

5. Hypermeter is an accepted term in music-theoretic discussions of rhythm and meter. It is defined in most instances as a higher-level analog of meter, whereby the downbeats on the M level are said to function as "hyperbeats" on a higher level, and so forth. See especially Lerdahl and Jackendoff (1983), Lester (1986), Benjamin (1984), Schachter (1987), Kramer (1988), Rothstein (1989), London (1990), and Brower (1993).

6. Henceforth, the following abbreviations will be used: HM for hypermetric level(s); M for the measure level (the level immediately above the beat level); B for the beat level, and SD for subdivision level(s) below the beat level.

low level in temporal cognition. Even though the behavioral evidence for natural pace is relatively weak (see Dowling & Harwood, 1986, p. 182), the phenomenon nonetheless suggests that not all periodicities are alike and that faster and slower periodicities should be construed in relation to those periodicities that fall within the preferred range as delimited by natural pace. Suffice to say that we shall proceed from the assumption that listeners do not treat all metric levels equally and that one level in particular, namely the beat level, is of central salience in structuring the metric hierarchy. Indeed, Jones and Boltz discuss a "referent level" for entrainment hierarchies that "functions as an anchor or referent time level for the perceiver" (p. 470). In metric hierarchies, the beat level normally functions as such a referent. Both larger/slower and smaller/faster events are both described in terms of their relationship to this level: higher levels arise from the concatenation of beats and beat groups, whereas smaller levels are regarded as subdivisions of the beats' temporal span.

TCHAIKOVSKY'S SIXTH SYMPHONY, SECOND MOVEMENT

Having defined the three basic classes of metric levels, we may now consider a number of more complex patterns (see Figures 4 & 5). First, one should note that here, as in many passages, there is an intermittent level of SDs. Indeed, it would seem to be a special property of the SD level that it can come and go rather freely within the metric hierarchy. This property is consonant with Jones' and Boltz's observation regarding the distinction between analytic and *future-oriented* attending:

> *Future-oriented* attending involves a global focal attending over time periods higher than the referent level [where the referent level is denoted by j] ($n > j$), whereas *analytic attending* directs attending energies to relatively low levels in a temporal hierarchy ($n < j$). . . These focal attendings rest on different temporal perspectives of the same event" (p. 471).

If the beat level of the meter functions as a referent level, then analytic attending, which is retrospective, may be characteristic of our attention to intermittent subdivision. In this particular case, rather than maintaining a level of SD where it is not always present or salient in the musical surface,

Fig. 4. Tchaikovsky, Symphony No. 6., 2nd movement, mm. 1–4.

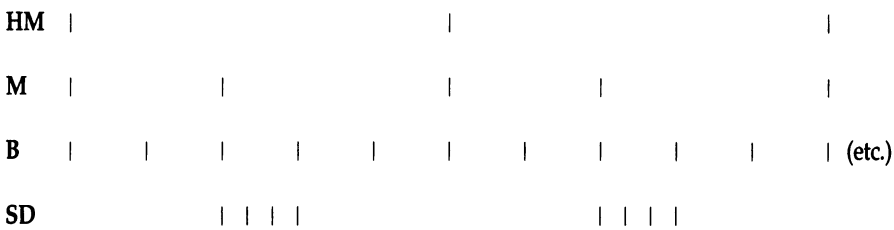

Fig. 5. Metric diagram of Tchaikovsky, Symphony No. 6., 2nd movement.

it is minimally assumed that listeners will set up entrainment patterns for the higher levels of the metric hierarchy and may then treat the occasional instances of SDs as unexpected events within the span of the established beat.[7]

Figure 5 is of most interest for the organization of its M and HM levels. There is a clear sense of 2 + 3 beat organization, what might be regarded as a continuing alternation of $\frac{2}{4}$ and $\frac{3}{4}$ measures along with a sense of the larger five-beat aggregate. Thus, as in Figure 2 (the slower Beethoven example), we have a level of Ms as well as a level of HMs. However, the $\frac{5}{4}$ passage differs from the "Ode to Joy" in one crucial way: although the B and HM levels of Tchaikovsky's pattern are isochronous, its intervening M level is not. The HM level, although manifest from the bottom-up unfolding of the durational and pitch-contour pattern, serves an additional function as a top-down guarantor of regularity and hence entrainability: its isochrony contains the nonisochronous M level.[8]

BERNSTEIN'S "AMERICA"

Here is a complex metrical pattern that should nonetheless be quite familiar to most readers (see Figures 6 & 7). It is instructive to consider how we are able to discover the invariant features of this pattern during the metric recognition phase. First, the rapid articulations that begin the melody

7. Along with being intermittent, the SD level may also freely shift in organization. It is quite common to find the occasional triplet inserted within the framework of primarily duple subdivisions (and vice versa), and such insertions do not seriously perturb the meter. By contrast, higher levels of the metric hierarchy do not accommodate such freely changing and/or intermittent structures.

8. It is also possible to treat Tchaikovsky's melody as a three-tier rather than a four-tier metric pattern by eliminating the nonisochronous M level of the metric hierarchy. Instead we would have a series of five-beat measures with (i.e., the HM level of Figure 5 would now serve as the M level) intermittent triplet subdivision. However, this analysis would ignore an important invariant structure in the music, and it also would run counter to the findings of Essens (1986), who posits that lower-order primes (i.e. 2s and 3s) are used in the construction of metric hierarchies.

Fig. 6. Bernstein's "America" (from *West Side Story*), mm. 1–4.

Fig. 7. Metric diagram of Bernstein's "America."

can immediately be relegated to a level of SD—they are too fast to lie within the preferred range of beats. The subsequent triplet patterning makes the B level readily manifest. Indeed we may initially (i.e., after the first six notes) think that this passage is in a regular meter with ternary subdivision of the beat. But as the second half of the notated measure unfolds in quarter notes (and does so again in the second bar), we suspect that our initial metric assignation was incorrect. As listeners track the durational patterning, the shift from eighth-note triplets to quarter notes must be accounted for. The initial triplets give a clear sense of SD and B duration; the following quarter notes are at odds with this sense—they are too long to be SDs, yet not long enough to be proper Bs. I propose that we may resolve this conundrum if we allow that the *Bs themselves need not be isochronous*. Indeed, musicians might refer to this passage as a pattern of "3 + 3 + 2 + 2 + 2" or "an alternation of $\frac{6}{8}$ and $\frac{3}{4}$ measures." Indeed, describing this melody as an alternation of $\frac{6}{8}$ and $\frac{3}{4}$ is a way to account for a series of nonisochronous beats using the nomenclature of Western musical notation. Yet to simply leave the description of this passage as an alternation of $\frac{6}{8}$ and $\frac{3}{4}$ is inadequate, as it does not acknowledge the way in which these two metric units are integrated into a larger whole. A more accurate and complete way to characterize the passage is as a larger, five-beat metric structure: two long beats followed by three shorter beats (L-L-S-S-S). Thus, as with the $\frac{5}{4}$ pattern, we have a metric structure in which one level is nonisochronous.

What distinguishes Bernstein's melody from Tchaikovsky's is its nonisochronous B level. A series of nonisochronous Bs poses a special problem because I have posited that the B level functions as the reference level in the construction of the metric hierarchy. How can a nonisochronous level function as the temporal "anchor" for the construction of other levels of the metric hierarchy? The answer is that it can do so via the stabilizing presence of a level of isochronous SDs, and it is for this reason that the SD level is maintained throughout Figure 7, unlike Figure 5. The metric diagram for "America" indicates that in this musical context the listener will make an extra effort to maintain the SD level in order to assist with her/his comprehension of the B level. Recent work of Yee, Holleran, and Jones (1994) suggests that musically experienced listeners can and do make use of interpolated SDs in problematic metric contexts. In their work, SDs were interpolated when the spans between successive beats became excessively long. In the context of Bernstein's melody, the interpolated SDs serve a different function: they provide an isochronous baseline upon which nonisochronous levels of the metric hierarchy may be constructed.

Here are some additional examples of complex metric structures and their metric diagrams (Figures 8–13). Notice that in these various patterns, the L(s) may fall in any position in the metric pattern—initially, internally, or in the final "slot." This flexibility of position for the long beat is contrary to the hypotheses of Longuet-Higgins and Lee (1982), Povel and Essens (1985), Lerdahl and Jackendoff (1983), Benjamin (1984), and Berry (1985),

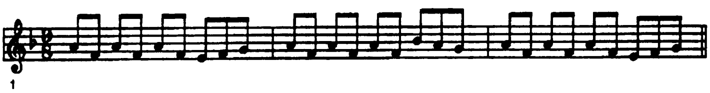

Fig. 8. Dave Brubeck's "Blue Rondo al à Turk," mm. 1–3.

M | | | |

B | s | s | s | L | | | | | | | | | |

SD | | | | | | | | | | | | | | | | | | | | | | | | | | | | (etc.)

Fig. 9. Metric diagram of "Blue Rondo al à Turk" (S-S-S-L pattern).

Fig. 10. Bartok's "Dance in Bulgarian Rhythm No. 6," from *Mikrokosmos*, vol. 6.

M | | | |

B | L | L | s | | | | | | |

SD | | | | | | | | | | | | | | | | | | | | | | | | | (etc.)

Fig. 11. Metric diagram of "Dance in Bulgarian Rhythm No. 6" (L-L-S pattern).

Fig. 12. Bulgarian folk dance "Krivo Horvo," aggregate rhythm.

M | | |

B | s | s | L | s | s | | | | | |

SD | | | | | | | | | | | | | | | | | | | | | | (etc.)

Fig. 13. Metric diagram of "Krivo Horvo" (S-S-L-S-S pattern).

which associate longer durations with metric accent (i.e., that long durations are markers of downbeats, all other things being equal). Note also that these are three-tier patterns, and hence there is no level of HM in any of these cases. What is common to all of these complex meters is that their tempos are sufficiently quick to make the SD level too fast to be regarded as a beat, and therefore the nonisochronous level above it functions as the beat.

SUMMARY COMMENTS REGARDING METER IN GENERAL AND COMPLEX METERS IN PARTICULAR

We may make the following observations regarding the necessary and sufficient conditions for musical meter in simple as well as more complex contexts:

1. Taking the necessity for a level of beats as a given, in order for a meter to be established, there must be at least one additional level of organization. Thus meter minimally consists of two levels: B and M (where M = some modular ordering of Bs).
2. A meter can be said to be relatively "thick" or "thin" by virtue of the minimum number of levels required to specify (and hence generate) its basic period. Thick meters require extra levels (SD and/or HM levels) in order to give a complete specification of

9. Although it is possible to instantiate additional metric levels above the minimal description, as in the case of the "slow Beethoven" example (Figure 2), in important ways these additional levels are redundant. That is, if some level *n* is isochronous, and if all higher levels are produced by some constant multiple of the *n*-level span, then these extra levels do not specify any additional sense of regularity to the pattern, for by attending to level *n* , listeners will generate all of the higher level metric expectations and their concomitant articulations. Of course, there may well be higher levels of invariant structure in the music, and it is a vexing question as to under what conditions listeners will direct their attending energies to these higher levels. Indeed, this has been the fundamental debate in music-theory circles as to the scope and limits of hypermetric structures (see sources listed in footnote 5).

their metric structure. The highest level of a metric pattern is always isochronous.[9]

3. In contexts in which the B level is isochronous, the SD level need not be continuous; it may come and go, or may be absent entirely. Similarly, in these contexts, the SD may freely shift in organization.
4. If the B level is not isochronous, then the SD level must be isochronous. Furthermore, the listener will maintain this level even when it is not present in the musical signal in order to stabilize and track the nonisochronous patterning of the B level (and perhaps higher levels as well).
5. There appears to be a general correlation between metric complexity and fragility: complex meters require "explicit specification" of their invariant features through the patterns of duration and organization on the musical surface, and once established, these patterns can be varied only within extremely narrow limits. Regular meters do not require such explicit specification and are subject to a much wider range of rhythmic and/or melodic variation.

Implications of Complex Meters for Models of Entrainment

As noted above, Jones and Boltz posit that we begin our entrainment by first attuning to a referent level, and then, via time transformations, generate/attend to other levels based upon the referent:

> In hierarchical events, each nested level is associated with a recurrent time period, denoted by ΔT_n, in which ΔT refers to the marked time span and n refers to a level in the hierarchy ($n = 0, 1, 2, \ldots$). The smallest time period, denoted ΔT_0, occurs at the lowest level. . . .In an ideal hierarchy, other nested periods are related to ΔT_0 by simple time ratios. . . . Simple time hierarchies are based on C_t [a time-ratio constant] values that are small and constant integers (i.e., $C_t = 1, 2, 3,$ etc.). . . .When different C_t values appear at different levels (e.g. $C_{tm} = 2$ and $C_{tp} = 3$; $n = 1 \cdots m \cdots p \cdots$) more complex hierarchies are specified. (p. 465).

Thus the simplest temporal hierarchies are those that are thoroughly binary or ternary; in Western music, this means simple duple (e.g., $\frac{4}{4}$) and compound triple (e.g., $\frac{9}{8}$) meters. Somewhat less regular time hierarchies—and thus less "ideal" hierarchies—are those that mix C_t values, such as $\frac{6}{8}$ or $\frac{12}{8}$ (compound duple) or $\frac{3}{4}$ (simple triple) meters.[10] Both of these two classes

10. The scarcity of $\frac{9}{8}$ (and the relative frequency of both $\frac{3}{4}$ and $\frac{6}{8}$) in musical practice, however, suggests that there may be more to hierarchic complexity than single versus multiple C_t value(s).

of hierarchic time structures exhibit wholly isochronous relationships on each and every temporal level. That is, because ΔT_0 is by definition a constant time transformation, if the time spans on the lowest level are isochronous and if all other levels are based on constant transformations (working upward in their formalism from the lowest level), then all of the resulting levels will also be isochronous.

Jones and Boltz also make a broad distinction between *hierarchic* and *nonhierarchic* temporal patterns. For them, hierarchic temporal structures display "nested time levels that are consistently related to one another at a given level by ratio or additive time transformations" (p. 465). Nonhierarchic temporal structures are those that cannot be accounted for by using these formalisms, and as a result, are less coherent (p. 466). In their model, coherence and entrainability are positively correlated. The temporal taxonomy that results from their definitions can be summarized as follows, starting with the most coherent/most regular structures and then moving on to less coherent/more complex structures:

1. An ideal temporal hierarchy in which all levels are related by same C_t; A hierarchy in which $C_t = 2$ is better than one in which $C_t = 3$, as a "trinary structure . . . is (somewhat) less coherent than the binary one because the time ratio involves a larger integer" (p. 465).
2. A temporal hierarchy in which C_t may change from level to level, but is always either 2 or 3.
3. A temporal hierarchy that is essentially binary ($C_t = 2$) with additive time changes.
4. Nonhierarchical structures I: polyrhythms.[11]
5. Nonhierarchical structures II: complex meters
6. Nonhierarchical structures III: "mixed meters" as well as any random series of durations.[12]

This taxonomy is unfortunate in at least two respects. First, if polyrhythms and complex meters really are *meters*, it is then problematic to categorize

11. Polyrhythms, or more properly, polymeters, are aggregate patterns formed by the concurrence of two different meters that have some large-cycle congruence. For example, when a (3 + 3 + 3 + 3) and a (4 + 4 + 4) pattern are superimposed (each of their SDs having the same duration), the aggregate pattern repeats every 12 SDs, although the two B levels are in conflict. A full discussion of the problems of polymeter is beyond the scope of this paper, but I would argue that in most cases listeners may treat polymeters either (a) by ignoring one of the metric cycles and focusing on the other, especially when the SD level is fully specified (Handel & Oshinsky, 1981), or (b) by construing an alternative metric pattern (one with a nonisochronous B level, in a manner analogous to the examples given earlier), especially when the SD level is not fully specified.

12. By "mixed meters," I mean a notated context of putatively shifting meters, for example: $\frac{2}{4} + \frac{3}{8} + \frac{3}{4} + \frac{2}{2}$, and so forth. Although this notation may give rise to perceivable groupings, I would assert that such passages are not metric in any of the senses outlined earlier.

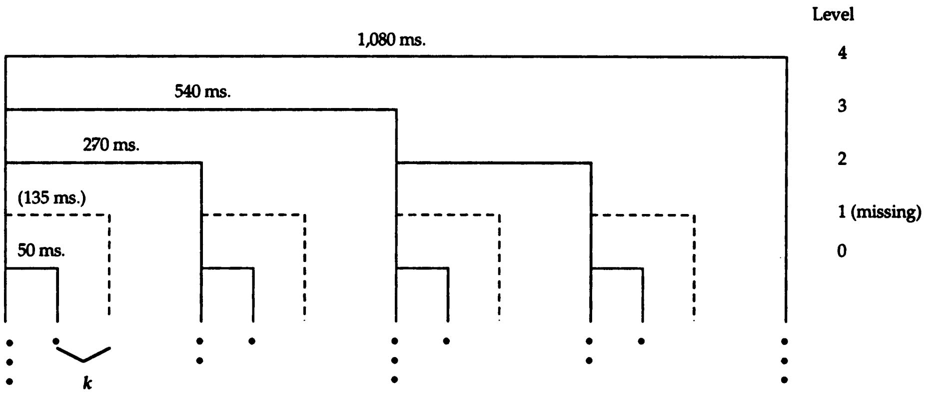

Fig. 14. Binary temporal nesting with additive variations. After Jones and Boltz (1989).

them as nonhierarchical along with mixed meters and random strings of durations, as these last two types of temporal structures are assuredly *not* metric and hence not entrainable. Second, even though polyrhythms and complex meters contain nonisochronous structures on one or more levels, it is perhaps misleading to label them as nonhierarchical, as they both exhibit a clear organization of nested structural levels.[13]

Jones and Boltz are able to accommodate one type of nonisochronous relationship through what they term "additive time changes" (category 3 listed above). These adjustments allow them to regard some nonisochronous surface patterns as based on underlying isochrony (see Figure 14). Regarding this figure, they note:

> This change essentially shifts the (missing) ΔT_1 to form the lowest time level. . . . All such structures are hierarchical for two reasons: (a) The additive transform is invariant for all periods at a given level, and (b) other time levels (here $n > 1$) are consistently related by $C_t = 2$. (p. 465).

Thus Jones and Boltz posit that there is a "missing level" at 135 ms, and that the 50-ms interval at level 0 can be accounted for by a constant subtraction of 85 ms (represented by their constant *k* in the diagram) from every "even" position in the temporal series. By instantiating and then transforming the missing level, this pattern can be treated as a temporal hierarchy that is essentially binary and essentially isochronous.

Some complex meters may be accounted for by virtue of such additive time changes. Consider the S-S-S-L pattern from Dave Brubeck's "Blue Rondo al à Turk" (Figures 8 & 9). The L member of this pattern can be construed as an additive deviation to the last beat of the B level of the

13. Perhaps what is required here is a distinction between recursive and nonrecursive hierarchical structures. Although polymeters and complex meters are nonrecursive, they remain hierarchical although distinct from the recursive hierarchies based on time transformations that Jones and Boltz discuss.

hierarchy, an addition that is equal in length to one unit of the SD level. This approach is not entirely unproblematic, however. The fact that the constant k is equivalent to an entire unit on the lower level of the temporal hierarchy presents formal problems of level crossing, as there are three distinct events on the SD level during the span of the long beat, rather than two elongated events (or two events, one of which is elongated by k). One might be tempted to use $C_t = 2$ for this passage (2 SDs for each normative B, and then 2 Bs for each notated measure—this would generate an extra level of metric structure not present in the diagram). Yet to avoid the formal problem of applying the additive time change "every other measure" (on the 2B level), one would have to use $C_t = 4$ on the B level, with an additive time change applied on the fourth beat.

Other complex meters cannot be so readily accommodated using additive time changes; consider the "America" pattern (Figure 7). Because it contains two Ls and three Ss, there is no single position in the pattern to which an additive time change would be applied. Rather, one would have to posit either (a) that the S beat is normative and that the first two beats in the pattern both contain additive time changes (a highly counterintuitive notion), or (b) that the L beat is normative, and that the last three beats in the pattern all contain subtractive adjustments.

There is, however, an alternative approach, one that does not rely on multiplicative relationships between metric levels. In the Bernstein example (Figure 7), one could proceed in the following manner. First an isochronous level of SDs is stipulated; this grounds the metric hierarchy on some isochronous periodicity (and as noted below, this grounding has interesting ramifications for our sense of the reference level of the meter). Next, one may define events on the B level as either Ls or Ss—each beat is a series of SDs (L = SD + SD + SD, S = SD + SD)—this allows us to distinguish between the two varieties of beats. As there are two classes of Bs, and as they must occur in a particular order, one cannot generate the B level by some C_t applied to the SD level. Instead, one must minimally specify the pattern as a string of Ls and Ss. As a result, however, one cannot specify the B level of the hierarchy without also specifying the M level. Thus, one cannot build this hierarchy simply from the bottom up (or the top down);

14. This additive algorithm may be formalized in a number of ways. First, one may treat the entire pattern as a series counted in modular arithmetic, *modulo* 12, using the SD level as a set of primitives. One may then specify equivalence classes between certain subportions of the pattern, relative to particular levels. The beat series would be specified as follows (1–3), (4–6), (7–8), (9–10), (11–0), where 0 = 12 mod 12. The B level is then articulated at positions 1, 4, 7, 9, and 11. One can define similar equivalence classes for the intervening M level (discussed below), that is (1–6) and (7–0). Alternatively, one can specify a series of nonisochronous Bs as a string of SD modules of varying cardinality. Indeed, traditional metric signatures are often tweaked in this way in order to indicate a nonisochronous series of beats (e.g., the "Blue Rondo al à Turk" (Figure 8) is often notated as in a $\frac{2+2+2+3}{8}$, rather than a $\frac{9}{8}$ meter). It is precisely because the level-to-level relationships in complex meters are nonmultiplicative that these alternative time signatures were developed.

the SD, B, and M levels all must come into being together and be maintained together, in order for the integrity of the meter to be preserved.[14]

This being the case, when faced with complex, partially nonisochronous temporal patterns, listeners must come up with a mapping of *all* its features and then use this mapping as a generator for subsequent expectations— one cannot begin with a partial map and then build additional levels (as with a standard entrainment model). Furthermore, in many cases the SD level of a complex meter is intermittently present on the musical surface. Yet it is this level that provides the isochronous baseline for the construction of other levels of metric structure. In such cases, metric entrainment would depend on the listener's internal generation of this isochronous level, rather than the usual case in which entrainment is based on attuning one's perceptions to an external, regularly occurring stimulus. Finally, the sense of tempo and beat in such complex metric hierarchies is based on a nonisochronous level. Although it would seem problematic to regard this level as the "referent level" for the metric hierarchy, it would seem equally problematic to claim that an intermittent SD level functions as the referent. Perhaps in these contexts the notion of a referent level is itself less useful, as one cannot navigate through these temporal hierarchies by means of multiplicative operations on a referent level.

Discussion

Throughout this paper, I have simply asserted that these various complex meters are in fact metric and represent potential patterns of entrainment. This assertion is based on my musical intuitions, but such intuitions do not a make a proper theory of meter. Therefore, the first question for subsequent research in this area would be to determine whether or not subjects can indeed entrain to temporal patterns that have nonisochronous beats. I would take it to be a positive sign if subjects in various experimental contexts could demonstrate their ability to internally maintain and/or externally reproduce a complex metric pattern in the absence of external stimuli.

There are a number of experiments that could produce an insight into listeners' perceptions of these patterns. One possible experiment could involve tempo judgments with respect to complex meters. Subjects could be asked to judge whether a passage was heard as relatively fast or slow; stimuli would include both regular and complex meters, both with and without the SDs explicitly articulated in the music. If subjects are able to perceive a complex metric pattern as relatively "slow" even when there is a relatively rapid surface of SDs, then we might conclude that they were attending to beats on the nonisochronous beat level, rather than the SD level.

In a different experimental context, subjects could be asked simply to reproduce various metric patterns (again, both with and without SDs). If subjects are able to maintain a complex pattern at a stable tempo—that is, with little drift in tempo and in relative duration—we would have additional evidence that subjects are able to engage in complex metric behavior(s). On the other hand, if subjects tend to "even out" the pattern over time, this would indicate that the complex patterns I have proposed as metric paradigms are not metric, but simply regular patterns of duration (i.e., complex figural groups).[15] This experimental context might be modified from a tapping task to a judgment task (following Jones' and Boltz's expectancy/contrast model). If a complex meter is stable (and entrainable), Ss should be able to predict where a future downbeat/phrase ending ought to occur. An eight-bar melody (or a number of such melodies, including nonmetric foils) that uses the L-L-S could be constructed, preferably using a 4 + 4 measure parallel phrase construction. The last two measures of the melody would then be omitted, and subjects could be asked to indicate where they believe the beginning of the next phrase (i.e. the downbeat of a hypothetical measure 9) would occur. Subjects could either (a) be instructed to internally audiate the metric pattern, or (b) might be permitted to "silently beat" the meter to aid in their indication. Correct predictions (and/or perhaps surprises due to expectancy violations?) would indicate the presence of complex meters in the perception of these passages, whereas significant tempo drifts would again indicate that these patterns are not being heard metrically.

One of the basic goals of research in temporal cognition and perception is to distinguish between those perceptual capacities that seem to be innate versus those perceptual capacities that are the product of (or at least greatly enhanced by) learning and environment. A hypothetically ideal experiment would involve naive, untutored listeners who are nonetheless able to report on their temporal perceptions and responses—they could report not only what they are doing, but how they are doing it. In the real world, however, we find that those subjects who are best able to report on their metric responses are of course those with the most extensive musical training. Such training enhances their ability to shift attention between metric levels, has taught them how to apply the same counting strategy to differ-

15. A tapping experiment that used a L-L-S pattern (3 + 3 + 2) might yield interesting results in a number of ways. If there is a tendency to even out the beats via a shortening of the Ls (a regression toward the S unit duration), and if this shortening process is concomitant with a shift from a ternary to binary beat pattern (gauged by relative stress of tapped beats using a velocity-sensitive input device), then we would have good evidence (a) that the complex patterns I have discussed are not metric, (b) that there is indeed a strong bias toward 2:1 proportional relationships in the construction of metric hierarchies, as proposed by Essens (1986) and Jones and Boltz (1989), and (c) we may get information regarding natural pace/spontaneous tempo through the timing mean to which subjects tend to drift. Similarly, if subjects are able to maintain a ternary meter but lose the irregular beats through an elongation of the short units, we would again have some information regarding the "binary bias hypothesis" (albeit a negative result).

ent levels, and in general has sought to expand their temporal performance capacities as much as possible. When these subjects are presented with simple meters, it is therefore not surprising that they can report on a broad range of tempo or beat perceptions; they can not only maintain an even tempo but also can track the beat through a variety of tempo shifts, and so forth. For musically skilled subjects, simple meters are both familiar and easy. These tasks are often easy for the musically untutored as well. Halpern (1988) has proposed that for her duple meter patterns "beat placement is arbitrary under powers of two" (p. 196), because in her study, listeners were equally comfortable with a sense of beat or tempo at either of two tempos (i.e., every beat or every other beat in a $\frac{2}{4}$ measure). In her study, Halpern used simple meters in which more than one level would fall within or relatively close to the beat range. A study of listener attunement that used complex meters might yield a less equivocal result as such patterns would preclude simple binary or ternary transformations that would allow for attentional shifts according to a multiplicative time-transformation. Complex meters may thus provide researchers in temporal perception with a means of "leveling the playing field," between skilled and unskilled subjects as complex meters are both unfamiliar and difficult.[16]

As a result, complex meters force listeners, even musically skilled listeners, back to "first principles," so to speak, in order to locate the beat level, find periodicities at other levels, and so forth. By virtue of their complexity these meters may also provide a window onto more basic aspects of metric and temporal cognition.[17]

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16. For this reason, it may be crucial to contrast results in tapping and/or comparison tasks between unskilled and "metrically tutored" subjects. That is, some subjects could be taught various counting strategies for complex meters. Although subjects (whether musically trained or untrained) have considerable experience with regular meters in our musical culture, they have limited experience with complex meters. Contrasting tutored versus untutored subjects may reveal familiarity effects with respect to these various experimental tasks. Indeed, it may be interesting to use a group of trained percussionists as a subject pool and compare their ability to reproduce various patterns against the abilities of other musicians and nonmusicians.

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