Attending in complex musical interactions: The adaptive dual role of meter

Peter Keller

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Optimal Attending Behaviour in Complex Musical Interactions

Peter Keller

MARCS, University of Western Sydney, Macarthur

Complex musical interactions — such as performing in, and listening to, musical ensembles — require flexible attentional strategies. Here it is proposed that metric frameworks generated by the listener or performer function adaptively to facilitate this requisite flexibility by fulfilling a dual role. On one hand, metric frameworks serve as hierarchical templates for specifying the temporal organisation of events represented in memory, and on the other, they act as dynamic attentional schemes that guide real-time processing. Existing models of musical rhythmic behaviour typically focus on meter’s role in either representation or processing. However, both perspectives need to be considered in order to understand behaviour in complex multipart musical contexts.

This review article addresses questions relating to how listeners and performers pay attention to more than one instrumental part in musical textures where several parts occur simultaneously. The literature surveyed — including research on ecological adaptiveness, attending to temporal events, and the representation and processing of musical rhythm — invites the proposal that metric frameworks invoked by listeners and performers function in various ways to guide attending in multipart musical contexts. In particular, meter plays a role in both (a) the real-time processing (encoding and retrieval) of temporal information and (b) the organisation of persisting memory representations of temporal events. Existing theoretical approaches to rhythmic behaviour do not account for this dual role of meter adequately. This article elucidates why it is necessary to consider both processing and representation in explanations of rhythmic behaviour. Recent experimental results are cited in support some specific claims about meter’s dual role. The experiments described briefly in the latter part of this article are novel in the sense that their multipart stimuli invites a remarkable human cognitive capacity for attending to information that is multidimensional and dynamic. This capacity underlies a wide range of more general behaviours that can be characterised as cognitively mediated interactions between an individual and their temporal environment. It has been argued by theorists working in diverse domains that these interactions are understood best from a perspective of ecological adaptiveness (Anderson, 1990; Gibson, 1966, 1979; Marr, 1982; Michon, 1985). A fundamental concern in ecological approaches is to formally recognise that the perceptual and cognitive processes, as well as the biological mechanisms, underlying an organismic system’s behaviour are constrained by the adaptiveness of the goals of the system. In other words, there are “constraints on the behavior of the system in order for that behavior to be optimal” (Anderson, 1990, p. 22). So, in order to understand the attentional processes that underlie complex musical interactions, it becomes necessary to identify optimal behaviour in the context of these interactions.

Defining optimal behaviour in complex musical interactions is not straightforward. Nevertheless, behavioural ideals are easier to specify in the context of ensemble performance, where the goals of the interaction are necessarily objective and relatively fixed, than in situations characterised by only listening to multipart music, where goals are more likely to be subjective and variable. A universal goal in ensemble performance is the production of a unified, cohesive, and coherent musical structure from a collection of distinctive instrumental or vocal parts (Campbell, 1991). These parts are usually differentiated by a number of factors, including timbre (instrumental tone colour), tessitura (pitch range), rhythm, and spatial location, and hence combine to form a multidimensional musical tapestry.

The task faced by ensemble performers is usually to present the threads comprising this tapestry in a manner that encourages their integration by the audience. Thus, “ensemble performance may be viewed as a composite that is more than the sum of separate musical parts” (Campbell, 1991, p. 245). This synergy requires “meaningful interaction” between each individual performer and the rest of the ensemble: they must be in time, in tune, balanced in terms of relative loudness, and in agreement in terms of expressive parameters, including phrasing and articulation. The behaviour of each performer can be considered to be optimal, or adaptive, to the extent that it contributes to the realisation of these specific goals.

To effectuate optimal behaviour in ensemble performance, ensemble musicians employ a variety of divided attention strategies through which they simultaneously attend to the part they are playing and the parts played by others. The process of simultaneously attending to the features of different musical parts has been termed integrative attending (Jones & Yee, 1993; Jones, Jagacinski, Yee, Floyd, & Klapp, 1995). Jones and Yee (1993) point out that integrative attending involves the recognition of certain details about the relationship...
between features of separate parts, rather than simply being a matter of "spreading" attention over these parts.

Two types of integrative attending may be distinguished — prioritised and nonprioritised — which can be conceived as distinct “attentional sets”. Integrative attending is prioritised if the context demands that a single part, or a subset of parts, bear accents. Recognising the high priority parts, in order to derive the full musical texture. Thus, prioritised integrative attending differs from pure selective attending, wherein peripheral information is ignored. Prioritised integrative attending is required in ensemble contexts where the performer must divide attention between his or her own part, and the overall texture that results when all parts are combined. It may also occur when only listening to ensemble music, for example, when a concert-goer focuses on a melodically or rhythmically interesting part, whilst also absorbing the whole texture. On the other hand, when integrative attending is nonprioritised, all parts are equally important to the attender. Even though nonprioritised integrative attending may be relatively rare in musical traditions that emphasise the distinction between “melody” and “accompaniment”, it is more likely to occur when only listening, than when performing. Empirical investigations have addressed the perception of multipart musical textures under nonprioritised integrative attending and selective attending conditions (e.g., Jones et al., 1990; Klein & Jones, 1996), but prioritised integrative attending has been neglected.

Evidence that prioritised integrative attending is typically necessary for the realisation of the goals of ensemble performance can be gleaned from testimonials of highly accomplished ensemble musicians (e.g., Fink & Merrell, 1985) and music educators who teach in both Western (see Casey, 1991) and non-Western (see Chernoff, 1979) musical cultures. Despite the opinions of these expert musicians, there is a surprising scarcity of empirical work devoted to identifying the factors that influence ability to engage in prioritised integrative attending.

Recently, however, some basic issues relating to this attending mode have been addressed in an exploratory survey-based study conducted by Keller (1999). The findings of this study are consistent with the proposal that prioritised integrative attending constitutes optimal, or adaptive, behaviour in ensembles. Western ensemble musicians of varying status (professional and amateur orchestral musicians, and jazz musicians) rated highly the ability to simultaneously pay attention to one’s own part and others’ parts, especially for the realisation of goals relating to rhythmic cohesion. Furthermore, with regard to factors influencing ability to engage in prioritised integrative attending, these musicians rated rhythmic complexity and texture to be the most influential, followed by tonality, melodic contour, and pitch interval size. These findings imply that theoretical models of musical rhythmic behaviour should be prominent in attempts to understand attending in complex musical interactions.

THEORETICAL APPROACHES TO MUSICAL RHYTHM AND METER

Rhythmic Behaviour and Metric Frameworks

Theoretical models of rhythmic behaviour are concerned with explicating the relationship between rhythmic complexity and the accuracy of rhythm-related behaviour. Rhythmic complexity is typically defined according to how a musical pattern’s temporal structure maps onto a metric framework (Gabrielson, 1993; Jones & Boltz, 1989; Povel & Essens, 1985; Pressing, 1997). Metric frameworks have been described as cognitive frameworks, or schemas, for organising temporal sequences (Clarke, 1987; Desain, 1992; Jones, 1981, 1982, 1990; Narmour, 1992; Palmer & Krumhansl, 1990). These frameworks are psychological correlates of the concept of musical meter, and, as such, usually consist of beat-level pulsations and bar-level pulsations that are hierarchically nested in some ratio such as 4:1 (quadruple meter), 3:1 (triple meter), or 2:1 (duple meter) (see Figure 1).

Temporal sequences that encourage the generation of metric frameworks to guide their interpretation are termed metrical patterns. Conversely, nonmetrical patterns do not encourage the generation of metric frameworks. The distinction between metrical and nonmetrical patterns derives from their fundamentally different types of temporal structures (Essens, 1995; Essens & Povel, 1985). In metrical patterns, the placement of pattern elements, and the distribution of accents (i.e., perceptually salient temporal locations) associated with these elements, imply regular underlying time periods. These pattern elements and accents therefore have the potential to mark the beat- and bar-level pulsations that constitute metric frameworks. On the other hand, nonmetrical patterns are not characterised by consistently regular element placement or accent distribution, and hence do not imply regular time periods. Due to their inherent recursiveness, metrical patterns are less complex than nonmetrical patterns (Jones & Boltz, 1989; Povel & Essens, 1985; Pressing, 1997).

Examples of metrical (quadruple and triple) and nonmetrical patterns are shown in Figure 2 (Panels A, B, and C, respectively). Note that pattern elements (x) occur periodically only in metrical patterns, whereas periodicities for quadruple and triple patterns correspond to their respective bar-level metric pulsations. Also note the relatively long silent intervals following elements that coincide with bar-level pulsations in Panels A and B. Povel and Essens’ (1985) description of the conditions that give rise to the experience of accent suggests that the time points associated with these elements should be perceived to bear accents. Therefore, the patterns in Panels A and B should contain periodic accents that correspond to quadruple and triple bar-level pulsations, respectively. Although accents should also

\begin{figure}
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
\textbf{Panel A} & 4 & 4 & \ldots & \ldots & \ldots & \ldots \\hline
\textbf{Panel B} & 3 & 4 & \ldots & \ldots & \ldots & \ldots \\hline
\textbf{Panel C} & 2 & 4 & \ldots & \ldots & \ldots & \ldots \\hline
\end{tabular}
\caption{Graphic representation of beat- and bar-level pulsations defining quadruple meter (Panel A), triple meter (Panel B), and duple meter (Panel C). In each panel, the upper row of dots marks bar-level pulsations, and the lower row marks beat-level pulsations. Conventional musical “time signatures” for describing the number of beats per bar are included before their related frameworks (e.g., $\frac{4}{4}$ indicates four beats per bar).}
\end{figure}
be experienced with the nonmetrical pattern in Panel C, the behaviour emphasises representation and processing factors to redundancies that can be accounted for by relatively few rules. This suggests that models of rhythmic generation of metrical teamwork facilitates the performance of patterns, engendering efficient representation and, consequently, accuracy in a given metric framework (Bharucha & Handel, 1973; Handel, 1992; Jones & Martin, 1974). Such findings are usually interpreted as indicating that metrical patterns are better fit than nonmetrical ones. However, Jones (1985) has pointed out that representational models describe temporal organisation in terms of serial order event relations, which they specify according to rules that are essentially non-temporal, or static, in nature. This form of description limits the ability of representational models to account for certain real-time phenomena, such as perceptual shifts accompanying changes in presentation rate. Auditory streaming effects exemplify such perceptual shifts, where at slow rates a sequence of alternating high- and low-frequency tones is perceived as a single stream, whereas at fast rates the sequence segregates into a stream of high tones and a stream of low tones (see Bregman, 1990; Jones, 1985; Jones, Kidd, & Wetzel, 1981; Jones & Yee, 1993). Relatively recently, Parncutt (1994) has outlined a representational model that overcomes some real-time limitations by incorporating routines that account for primacy and recency effects, as well as absolute durational limits on attentional processes.

Procedural Models

Procedural models describe the action of perceptual and cognitive processes that are engaged during pattern encoding and retrieval. In contrast to representational models, procedural models typically focus on the role of processing efficiency in determining the accuracy of rhythmic behaviour. These models interpret patterns by examining successive temporal intervals in a progressive fashion, with a view to detecting structural regularities that hold potential to serve as bases for metric frameworks. As a consequence of this bottom-up approach (which does not permit a static view of pattern structure), procedural models are generally able to account for real-time phenomena more successfully than representational models.

There are two broad varieties of procedural model: algorithmic and dynamic. In algorithmic-procedural models (e.g., Lee, 1991; Longuet-Higgins & Lee, 1982), the changes in pattern structure that occur across time are viewed as an ordinal series of discrete steps. In contrast, dynamic procedural models consider structural changes to be continuous. Although procedural models are better suited than representational models to deal with real-time phenomena, real-time constraints are incorporated more fully in dynamic- than in algorithmic-procedural models.

Dynamic-procedural models of rhythmic behaviour belong to a more general, ecologically motivated, dynamical approach to cognition (Van Gelder & Port, 1995), which recognises explicitly the real-time and continuous nature of mental processes. Several recent attempts to model rhythmic behaviour within a connectionist framework are compatible with the dynamical approach (e.g., Desain, 1992; Gjerdingen, 1989; Large & Kolen, 1994; McAuley, 1994; Page, 1993). Todd’s (1994) primal sketch model of rhythmic grouping, which is based on a sophisticated understanding of the physiology of the auditory and motor systems (also see Todd, 1996).
exemplifies another class of model that embraces dynamical concerns (although some of its formal assumptions are very different from those of orthodox dynamical models of rhythm). However, perhaps the most fully developed account of temporal event processing based on dynamical concepts is the dynamic attending theory of Mari Riess Jones (Jones, 1976; Jones & Boltz, 1989; Large & Jones, 1999).

It is proposed in the dynamic attending theory that events differing qualitatively in terms of "temporal coherence", or rhythmic complexity in the case of musical patterns, support different modes of attention (Jones & Boltz, 1989). Temporally coherent events, such as metrical patterns, support "future-oriented attending". This attending mode is characterised by the process of "attunement", whereby the attender's biologically based rhythms, or "attentional oscillators" (Jones & Yee, 1997; Klein & Jones, 1996; Large & Jones, 1999) become synchronised with some referent focal period/s implied by the pattern's structure. According to Jones and Boltz (1989), attunement:

- involves a synchronous interplay between an attender and an event in which the former comes to partially share the event's rhythmic pattern. This involves an entrainment of organic rhythms whose frequencies and amplitudes can mirror those of an event (p. 470).\(^1\)

After a referent period is established through attunement, other periods based on ratio time transformations of the referent are determined. Thus, attentional oscillators may become phase-locked in a way that reflects the ratios defined by beat- and bar-level divisions of metric frameworks, for example, 4:1 for quadruple patterns and 3:1 for triple patterns. This pattern of oscillator activity embodies temporal expectancies that automatically guide attending (Jones, 1982, 1990). So long as these expectancies experience only a limited degree of violation, processing will be efficient and attention will be flexible.

According to the dynamic attending theory, frequent failures of the attunement process are experienced with temporally incoherent events, such as nonmetrical patterns, due to a high degree of expectancy violation (Jones & Boltz, 1989). Consequently, nonmetrical patterns elicit a more "analytic" mode of attending, wherein elementary mnemonic strategies (e.g., figural grouping, counting, and associative labelling) are employed to establish low-level relationships among adjacent pattern elements. These mnemonic strategies are effortful, and hence diminish efficiency and flexibility in processing. Thus, the dynamic attending theory accounts for differences in the accuracy of behaviour related to metrical and nonmetrical patterns by proposing that the process of attending to the former is the more efficient and flexible.

Formal predictions about magnitude of expectancy violation, and its effects on attending, are generated by a temporal contrast model, which quantifies "the difference between observed and expected focal periods" (Jones & Boltz, 1989, p. 473). The temporal contrast model is supported by observations from a broad range of experimental paradigms, including time estimation (e.g., listeners indicate the temporal location of "expected endings" in incomplete melodies) and detection tasks (measuring sensitivity to alterations in the timing, frequency, or spectral composition of tones) (e.g., Boltz, 1989; Jones & Boltz, 1989; Jones & Yee, 1997; Klein & Jones, 1996; Yee, Holleran, & Jones, 1994). For example, both Yee et al. (1994) and Jones and Yee (1997) tested the ability of skilled and unskilled listeners to detect small time changes within prospectively specified regions of various types of regular and irregular patterns. The target regions were identical across all pattern types. In general, results indicated that temporal sensitivity was greater when the context surrounding target regions was regular, than when it was irregular. Such effects of global pattern structure on processing at specific temporal locales can be explained parsimoniously in terms of dynamic attending processes: as irregular patterns unfold in time, "accumulated violations of expectancies (contrasts) retard the entrainment of an oscillator (relative to a simple sequence) and the momentary period of the oscillator does not yield a finely focused temporal expectancy; the result is poorer temporal acuity" (Jones & Yee, 1997, p. 707). Large and Jones (1999) have recently presented an elaborate mathematical formulation of the dynamic attending theory, and have produced successful computer simulations of time estimation and discrimination behaviour.

**IMPLICATIONS OF REPRESENTATIONAL AND PROCESSING EFFICIENCY FOR THE ROLE OF METER**

The relative contributions of representational efficiency and processing efficiency to the accuracy of rhythmic behaviour is not a trivial issue, as it has implications for defining the role of metric frameworks in musical interactions. This echoes Rumelhart and Norman's (1985) concern with the notion that representational systems include both representations and the processes that act on them: "The processes that evaluate and interpret the representations are as important as the representations themselves" (p. 20). This idea is embodied in connectionist models, wherein representation and processing are inextricably linked, as both are realised through weighted patterns of connectivity between individual units within neural networks.

To focus solely on the efficiency of representations implies that meter functions to provide a frame of reference within which to specify the temporal organisation of events represented in memory. This limits the facilitative role of meter to that of a static template, thus precluding the explanation of real-time phenomena. On the other hand, to focus solely on processing efficiency produces insufficient explanations of the persistence of complex, multidimensional memory representations of music. That is, theories devoted to encoding and retrieval processes do not necessarily account for the mediating memory representations. Evidence for the importance of such representations has come to light in studies of how musical behaviour is affected by episodic and implicit memories (see Crowder, 1993), as well as by abstract knowledge-based schemas, such as those reflecting the structure of metric hierarchies (Palmer & Krumhansl, 1990).

The dilemma of neglecting either real-time phenomena or memory representations can be solved by emphasising both representational and processing efficiency. This double-barrelled approach implies that metric frameworks function to promote attentional flexibility, as well as acting as a temporal frame of reference. A similar proposal emerges from the confluence of views about ecologically adaptive temporal behaviour expressed by Michon (1985) and Jones and Boltz (1989).

Michon (1985) claims that forming internal representations of external temporal events enables adaptive behaviour by allowing an organism to function independently of the external events. Furthermore, he argues that real-time correspondence between external events and internal representations is achieved by a synchronisation process (which can be viewed as qualitatively similar to attunement). According to Michon (1985), synchronisation frees the organism to "do other things in between the instants at which perfect coincidence is crucial" (p. 29). Jones and Boltz (1989) discuss possible benefits of this flexibility in situations that involve attunements related to temporally coherent motor behaviour, or body movements. There are several existing quantitative models of motor timing synchronisation (see Vorberg & Wing, 1996).

Jones and Boltz (1989) argue that the temporal predictability of motor gestures:
not only affords a basis for individual motor coordination and self
synchrony, it also means that visual action patterns created by one
individual can support various interactive nonverbal communications
with others, including turn-taking behavior, dance, nurturing, and
prey-stalking, all of which partake of interactional synchrony (p. 466).

It seems reasonable to hypothesise that the attunements under-
lying metric frameworks benefit complex musical interactions
in a similar fashion. Thus, metric framework generation may
function adaptively to facilitate the attentional flexibility that
is requisite for prioritised integrative attending in multipart
musical contexts.

CONTRIBUTIONS OF REPRESENTATIONAL
AND PROCESSING EFFICIENCY TO
ATTENTIONAL FLEXIBILITY

The Dual Role of Meter

The representational/procedural dichotomy in theoretical
models of rhythm implies that representational and processing
efficiency contribute differentially to behavioural accuracy.
Representational efficiency is beneficial because coherent
memory organisation allows a greater amount of information
to be retained and readily accessed for use as a basis for
behaviour, whereas the benefits of processing efficiency relate
mainly to the promotion of real-time encoding and retrieval of
temporal information. This distinction suggests that meter has
a dual role. On one hand, metric frameworks serve as hierar-
chical templates that allow temporal information to be repre-
sented efficiently in memory. On the other hand, they provide
dynamic attentional schemes that guide real-time processing.

In order to investigate the implications of the dual role of
meter for complex musical interactions, representational and
processing efficiency need to be demonstrated independently.
This objective presents considerable methodological
challenges because standard experimental procedures
employed in behavioural studies of rhythm are not well
equipped for teasing apart these different types of efficiency.
For example, simple recognition tasks (i.e., judging whether
test patterns are the same as or different from a pattern
exposed earlier) and reproduction tasks (i.e., tapping a pattern
exposed earlier) are inadequate in this regard because it is
likely that both representational and processing efficiency
contribute to accuracy on these measures. It is therefore neces-
sary to use different types of measures to illuminate the effects
of each brand of efficiency.

Representational Efficiency

Measures of representational efficiency examine the nature of
representations stored in memory (e.g., organisational struc-
tures based on hierarchical versus serial relationships), as well
as their accuracy. Appropriate indices of representational
structure include *memory confusions* and *context effects*
(Palmer & Krumhansl, 1990). Memory confusion measures
assume that errors committed in memory-based tasks reflect
the organisation of information in memory. Measures of
context effects examine how contextual cues, such as
isochronous sequences marking beat- and bar-levels of
hypothetical metric hierarchies, affect the interpretation of
stored representations. Like memory confusion measures, they
assume that behaviour is facilitated when the contextual cues
are consistent with the way in which information is organised
in memory. Although processing efficiency also contributes to
context effects (e.g., appropriate contextual cues aid retrieval
processes; Tulving & Thompson, 1973), representational
efficiency is paramount because efficient processing (at
retrieval) is contingent on efficient memory organisation.
Memory confusion and context effect measures both indicate
efficient representation to the extent that they provide evidence
that the stored information relies on meter's recursiveness.

Several studies examining context effects and memory
confusions, as well as other measures, have shown that
musically skilled and unskilled listeners represent metrical
patterns according to hierarchical organisational schemes that
closely resemble the theoretical conception of meter (Keller,
1997; Palmer & Krumhansl, 1990; Povel & Essens, 1985;
Pressing, Summers, & Magill, 1996; Vorberg & Hambuch,
1984). For example, Keller (1997) investigated the effects of
explicit metrical context markers on the recognition of theoreti-
cally metrical and nonmetrical patterns. The experimental task
involved a series of trials, each consisting of a pattern exposure
phase followed immediately by a recognition memory test
phase. Listeners memorised a quadruple, triple, or nonmetrical
pattern in each exposure phase. Then, in each test phase, they
rated the degree to which they were confident that target (same)
and distracter (different) test items were the same as, or differ-
ent from the pattern in the preceding exposure phase. Target
and distracter test items for all pattern types (quadruple, triple,
and nonmetrical) were accompanied by isochronous sequences
marking beat- and bar-level pulsations of either a quadruple or
a triple meter (as well as some control contexts, e.g., only beat-
level markers or no markers). Results indicated that metrical
patterns were recognised best when context markers were
consistent with their theoretical metricality. However, metrical
context did not affect performance with nonmetrical patterns,
for which recognition accuracy was generally low. Overall
findings suggest that memory representations for metrical
patterns are organised according to metric hierarchies.

The efficiency engendered by hierarchical representational
structures yields related benefits in performance- and listening-
based musical interactions. In performance, pattern production
is guided by reference to goals (ideal representations of musical
patterns) and plans (strategies for transforming ideal representa-
tions into sound) that reside in the performer's memory
(Gabrielsson, 1999; Sloboda, 1982). Listening is similarly goal-
oriented (Jones, 1982, 1980), especially when the listener relies
on specific knowledge about familiar musical pieces (see
Bharucha, 1987; Schmuckler, 1989). The hierarchical ordering
of performance and listening goals increases both the range of
elements they can accommodate and the potential number of
perspectives (each corresponding to a different hierarchical
level) from which to consider the pattern (Jones & Bolz, 1989;
Pressing, 1997). Another advantage of hierarchical representa-
tions is they allow relationships between nonadjacent events to
be appreciated (Martin, 1972). Thus, representations based on
metric hierarchies are furnished with sufficient scope to provide
a basis for coherently integrating the multidimensional aspects
of multipart patterns, and to encompass parts that progress at
different time scales and hence become anchored to different
hierarchical levels. Using representations of musical structure
to guide real-time attending and performance becomes a matter
of processing efficiency.

Processing Efficiency

Measures of processing efficiency examine "online" process-
ding demands associated with the performance of rhythm-
related tasks. *Auditory inspection time* indices, which are
assumed to be analogous to visual inspection time indices
often used to assess processing efficiency in studies of individ-
ual differences (e.g., Deary & Caryll, 1990), have been
employed in this capacity. Auditory inspection time can be
measured by the number of times a listener needs to hear a
pattern in order to produce a designated response.

In a study examining auditory inspection time, Keller and
Burnham (1999) found evidence that processing efficiency
Attending in Complex Musical Interactions

decides with increasing rhythmic complexity. Highly skilled musical listeners were required to judge the complexity of various metrical and nonmetrical rhythm patterns indirectly by rating how well they fit different hypothetical metric frameworks (e.g., quadruple and triple). The number of times listeners chose to hear each pattern when rating was recorded as a measure of auditory inspection time. In general, a linear relationship between judgments of pattern complexity and auditory inspection time was observed, wherein increasing complexity was associated with increasing inspection time. An earlier study by Povel and Essens (1985), in which they recorded the number of times listeners chose to hear repetitively presented patterns before attempting to reproduce them, yielded similar results. However, it is possible that in their procedure task demands were augmented with relatively complex patterns, not only by increased processing requirements, but also by an increase in motor requirements associated with rehearsing pattern reproductions, because participants were "encouraged to tap along with the sequence during stimulus presentation" (Povel & Essens, 1985, p. 422).

Auditory inspection time, although informative, is not an ideal index of processing efficiency because it is only an indirect measure of online processing demands. Interference effects, measured by the degree to which processing a given stimulus interferes with a concurrent processing task, provide a more direct index of processing efficiency. Examining interference effects in general necessitates the use of multiple-task paradigms. Therefore, multipart musical rhythm textures provide an appropriate context in which to address interference effects specific to rhythmic behaviour.

Multipart rhythmic textures are comprised of integrant patterns (e.g., patterns played by separate instrumental parts in an ensemble) that, when presented concurrently, result in an aggregate pattern (see Figure 3). Interference effects can be studied in the context of multipart rhythm textures by measuring the degree to which processing a target integrant pattern influences perception of the aggregate pattern in which it is embedded. Therefore, appropriate experimental paradigms for examining these effects should present similar attentional demands to those that arise in complex musical interactions where prioritised integrative attending is required.

Prioritised integrative attending in multipart rhythmic contexts may be achieved through either switching or parallel processing strategies. Switching strategies involve shifting attention from target to complementary integrant patterns in the attempt to form interdependent representations of target integrant and aggregate pattern structures. Parallel processing strategies, on the other hand, involve attending simultaneously and continuously to target and complementary integrant patterns, with a higher proportion of attentional resources devoted to processing the target integrant pattern. A distinction has been drawn between these strategies in discussions of timesharing in general multiple-task contexts (e.g., Barber, 1988), and both have been implicated in explanations of specific auditory temporal phenomena such as auditory streaming (Jones, 1976; Michon & Jackson, 1984) and the perception of polyphonic versus homophonic musical textures.

Intergrant 1

Integrant 2

Aggregate

Figure 3

Multipart pattern comprising two integrant patterns that combine to produce the aggregate pattern notated beneath them.

Figure 4

Multipart rhythmic structures varying in complexity. In Panel A, the target integrant pattern (Integrant 1) is metrical and best fits the same meter as the aggregate pattern; in Panel B, the target integrant pattern (Integrant 2) is metrical but best fits a different meter from the aggregate pattern; and in Panel C, nonmetrical integrant patterns mesh to form a metrical aggregate pattern.

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and aggregate patterns best fit different meters (despite the common metric used in Holst's score). The rhythmic cell that occurs twice in the context of Integrant 2 — two short (eighth) notes, a longer (quarter) note, followed by a quarter note rest, and then four more quarter notes — defines a nine-beat period, which is inconsistent with the six-beat period indicated by the time signature, and indeed the aggregate pattern. Panel C gives the first four bars of the seven-bar rhythmic ostinato that underlies the second movement from Game for Eight by K. Blomdahl (1916–1968). If Integrant 1 is nominated as target, then the target integrant pattern (although notated metrically) is strictly speaking nonmetrical, whereas the aggregate pattern is metrical. The two integrant patterns shown here are only part of the overall rhythmic texture, which is comprised of eight simultaneous integrant patterns in some sections of the movement.

According to the dynamic attending approach, increases in rhythmic complexity are accompanied by more frequent failures of the attunement process and a corresponding increase in expectancy violations (Jones & Boltz, 1989). These attunement failures and expectancy violations constrain attentional flexibility by disrupting the process of metrical framework generation that would otherwise serve to guide attending. Standard accounts of multiple-task behaviour (see Damos, 1991; Smyth, Morris, Levy, & Ellis, 1987; Wickens, 1980, 1984) lead to the prediction that the process of recovering from these perturbations should interfere with performance on concurrent tasks. Therefore, in multipart contexts requiring prioritised integrative attending, behaviours associated with attending to aggregate pattern structure should suffer less when target integrant patterns are metrical than when they are nonmetrical.

Empirical research has only recently begun to address attentional flexibility in multipart contexts. It has been demonstrated that the relationship between integrant patterns can be manipulated so as to produce conditions that are conducive to either selective attending to individual integrant patterns or integrative attending to aggregate patterns (Jones et al., 1995; Klein & Jones, 1996). For example, Klein and Jones (1996) have shown that multipart structures where the constituent integrant patterns are temporally incompatible encourage attending to individual integrant patterns more so than attending to the aggregate pattern. On the other hand, when integrant patterns are temporally compatible, attending to the aggregate pattern is achieved more readily than attending to integrant patterns individually. Thus, multipart rhythmic complexity constrains the efficacy of selective and nonprioritised integrative attending strategies. To extend the scope of these findings, Keller (1997, 1998) examined the effects of rhythmic complexity on attentional flexibility in situations that require prioritised integrative attending.

Keller (1997) tested the ability of musically skilled and unskilled listeners to memorise the aggregate aspect of multipart patterns under prioritised integrative attending conditions. Listeners were presented a series of experimental trials, where each trial consisted of (a) a single exposure to a multipart pattern comprised of a target integrant pattern and a complementary integrant pattern, which was immediately followed by (b) a recognition memory test for either the target integrant, or the aggregate pattern. To encourage prioritised integrative attending, listeners were not informed whether memory was to be tested for the integrant or the aggregate aspect until after the exposure pattern had been presented. Recognition memory was tested by instructing listeners to rate (on a 6-point scale) how confident they were that target and distracter test items were the same as, or different from, the relevant aspect (integrant or aggregate) of the exposure pattern.

Stimuli had three possible levels of multipart rhythmic complexity that correspond roughly to the multipart structures shown in Figure 4. In each of the specially constructed multipart patterns, target integrant patterns were either metrical (quadruple or triple) or nonmetrical, and the aggregate patterns always best fit a quadruple meter (see Figure 5). Every listener heard several exemplar patterns from all three levels of complexity during the course of the experimental procedure. The main finding was that aggregate patterns were recognised more accurately when target integrant patterns were metrical than when they were nonmetrical (i.e., the difference between ratings for target and distracter aggregate test items was greatest following exposure items with metrical integrant patterns; see Figure 6). This suggests that metrical integrant patterns were processed more efficiently than nonmetrical integrant patterns, and therefore interfered less with aggregate pattern processing.
Thus, the types of structures that emerged in the stimuli were consistent with those described in Figure 7 that were quadruple, triple, or nonmetrical (see Figure 7).

The simulated ensemble performance paradigm employed by Keller (1998) involves a form of rhythmic canon in which the lead part is presented on computer and the participant follows by tapping this computerised part at a lag interval. The lead parts consist of antecedent/consequent (i.e., question/answer) pairs of rhythm patterns. Consequent patterns were always metrical (quadruple), whereas antecedent patterns were either metrical (quadruple or triple) or nonmetrical. Participants, all of whom were professional percussionists, were required to begin tapping (on a MIDI percussion pad linked to the computer) the antecedent/consequent pair at the point when the consequent pattern began in the lead part. The location of this point relative to some example stimulus items is marked by an arrow in each panel of Figure 7.

Across the entire experiment, participants encountered antecedent/consequent pairs where the consequent pattern is quadruple, but antecedent patterns are either quadruple (Panel A), triple (Panel B), or nonmetrical (Panel C).

![Figure 7](image_url)

Figure 7
Antecedent/consequent pairs where the consequent pattern is quadruple, but antecedent patterns are either quadruple (Panel A), triple (Panel B), or nonmetrical (Panel C).

The primary demands arising in Keller’s (1997) listening-based paradigm relate to simultaneously encoding integrant and aggregate aspects of multipart patterns. However, many multipart contexts, such as those in which ensemble performance takes place, necessitate that retrieval processes (e.g., accessing performance goals and plans) are engaged to guide the production of the target integrant pattern whilst the aggregate pattern is encoded. These retrieval demands, as well as the overt behavioural consequences of performance (which is open to public evaluation and therefore calls for greater commitment to optimal attending strategies), ensure that prioritised integrative attending is more tightly constrained in situations requiring production than when only listening. To investigate whether Keller’s (1997) findings generalise to such contexts, a task was developed that simulates more closely the attentional demands that characterise ensemble performance (Keller, 1998).

The outcomes of Keller’s (1997, 1998) studies of interference effects in multipart musical rhythmic contexts are consistent with the dynamic attending view that metric frameworks enhance flexibility by serving as a guide for allocating attentional energy (Jones 1976; Jones & Bolz, 1989; Large & Jones, 1999). According to this view, attentional resources are not distributed uniformly across time. Rather, they modulate in a manner mirroring the temporal profile of metric frameworks. This plasticity enhances the processing of patterns that conform with metric structure.

The main contribution of the findings reviewed in this section is that they encourage the extension of dynamic attending claims to situations involving prioritised integrative attending, which, as noted earlier, is the attending mode recognised as optimal in complex musical interactions by a broad spectrum of performing musicians. Applying dynamic attending concepts to such contexts suggests that metric frameworks provide, more or less automatically, an attentional scheme that guides the processes involved in prioritised integrative attending. However, when the process of metric framework generation is disturbed, processing becomes inefficient, more effortful, and largely incompatible with flexible attentional strategies that foster prioritised integrative attending.

**CONCLUSION**

Complex musical interactions, especially those where prioritised integrative attending is optimal, call for remarkable attend-
tional flexibility. In accordance with the proposal that rhythm
mic complexity constrains this attentional flexibility through
its effects on the efficiency of memory representations and
dynamic attending processes, the experimental work cited in
this article provides evidence that metric patterns are both
represented and processed more efficiently than nonmetrical
patterns. When taken as a whole, such findings suggest that
metric frameworks play a dual role in complex musical inter-
actions requiring prioritised integrative attending. On one
hand, metric frameworks promote representational efficiency
by allowing listening and performing goals stored in memory
to be organised in a hierarchical fashion that can accommodate
large amounts of multidimensional information. On the other
hand, they enable processing efficiency by purposefully
guiding attention, and thereby allowing target integrant and
aggregate aspects of multipart patterns to be attended simulta-
neously as they unfold in real-time. By fulfilling this dual role,
metric frameworks facilitate optimal attending behaviour in
complex musical interactions. Thus, meter functions as an
adaptive mechanism in musical micro-environments such as
ensembles.

Both theoretical and practical advantages are gained by
acknowledging the adaptive dual role of meter. Theoretical
benefits include guidance when specifying the requirements to
be satisfied by models of rhythmic behaviour that are intended
to account for interactions with complex multipart textures.
Furthermore, recognising meter's dual role engenders mindful-
ness when selecting experimental methodologies to evaluate
these models of rhythmic behaviour, as well as when interpret-
ing the results of such empirical evaluations. The practical
benefits of this conception of meter relate mainly to applications
in music education. For instance, the postulated relationship
between metric frameworks and attentional processes has impli-
cations for the development of techniques aimed at fostering
prioritised integrative attending skills in ensemble performance.

Footnotes
1. These experiments are described here as a complete series, and,
consequently, only in brief. However, they will be reported elsewhere
separately, and in more detail.
2. Views expressed here on the "ecological adaptiveness" of musical
behaviour need qualification. The claim is not that musical ensemble
behaviour itself constitutes an adaptation, in the evolutionary sense, of
humans to ecological conditions. Rather, it is more likely that ensem-
ble behaviour is a by-product of mechanisms that were selected during
evolution because they function directly to ensure survival and repro-
duction; for example, mechanisms that allow organisms to interact
with temporal precision and to communicate nonverbally (using
gestures). In other words, ensemble behaviour is a side effect of
adaptation. For a general discussion of such side effects, or spandrels
see Gould and Lewontin (1979).
3. The identity of the biological mechanism underlying attunement is
presently unknown. However, it is worth noting that evidence for
multiple oscillators has been found in interval timing behaviour in rats
(Crystal, 1999) and human EEG data (Treisman, Cook, Naish, &
MacCrone, 1994), and that the cerebellum has been implicated in
timing functions (Ivry & Keele, 1989).

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