THE ROLE OF METRIC FRAMEWORKS IN THEPROCESSING AND REPRESENTATION OF MUSICAL RHYTHM

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In defining the role of metric frameworks in rhythm perception, it is important to consider their facilitatory effect upon the *efficiency* with which auditory temporal patterns are both *processed* and *represented*. Experiment 1, in which auditory inspection time and the effects of contextual cues to meter on memory were used as indices of processing and representational efficiency, respectively, found that metrical patterns were processed and represented more efficiently than nonmetrical patterns. This suggests that meter may serve to free attentional resources, in addition to acting as a temporal frame of reference. In support of this, the findings of Experiment 2 indicate that, in the context of multi-part patterns, an *integrative* attentional strategy(where rhythmically differentiated "integrant" parts are perceived by the listener to form an "aggregate pattern") is facilitated more by attention to metrical integrant patterns, than to nonmetrical integrant patterns. It is concluded that metric frameworks function adaptively to facilitate real-time musical interactions (e.g., performing in ensembles).

Introduction

Metric frameworks and the accuracy of rhythmic behaviour

Metric frameworks, consisting of beat-level pulsations and bar-level pulsations that are hierarchically nested in some ratio such as 3:1 (*triple meter*) or 4:1 (*quadruple meter*),have been described as cognitive frameworks, or schemas for organising auditory temporal patterns (Palmer & Krumhansl, 1990).Most approaches to rhythm perception would agree that the processes of abstracting and generating metric frameworks facilitate the performance of rhythm-related behaviours.

Investigations of rhythmic behaviour have typically found that *metrical patterns* (i.e., temporal patterns that are interpretable within a metric framework) are recognised and reproduced more accurately than *nonmetrical patterns,* and, further, that these behaviours are more accurate when metrical patterns fit a given metric framework well (e.g., Bharucha &Pryor, 1986; Essens, 1995; Franks & Canic, 1991; Povel &Essens, 1985). Such findings are usually interpreted as indicating that metrical patterns are processed or represented more *efficiently* than nonmetrical patterns, especially if they are interpreted according to the meter that they best fit. However, different approaches to rhythm perception emphasise processing and representation factors to differing degrees. For example, dynamic attending approaches, such as that proposed by Jones and Boltz(1989), seem inclined to focus on the role of processing efficiency, whereas coding-based approaches, such as the internal clock model of Povel and Essens (1985) and its modification by Essens (1995),emphasise the efficiency of the static symbolic code that they claim is used to represent patterns.

The importance of considering both processing and representational efficiency

The relative contributions of processing efficiency and representational efficiency to the accuracy of rhythmic behaviour is not a trivial issue, since it has implications for the precise role of meter. This echoes Rumelhart and Norman's (1985, p.20) concern with the notion that representational systems include both *representations* and the *processes* that act upon them: "The processes that evaluate and interpret the representations are as important as the representations themselves".

Focusing upon the efficiency of representations implies that meter functions mainly to provide a frame of reference within which to specify the temporal organisation of events represented in memory. This limits the role of meter to one of facilitating the accurate perception, recognition, and production of rhythm patterns by acting as some sort of template. On the other hand, focusing solely on processing efficiency precludes the explanation of some "memory confusion" effects reported in the literature (e.g., Palmer &Krumhansl, 1990). However, emphasising both processing and representational efficiency implies that meter functions to free the listener's attentional resources, as well as acting as a temporal frame of reference. Thus, the role of meter abstraction and generation can be seen as one of facilitating real-time musical interactions, such as listening to multi-part music and performing in musical ensembles.

Indices of processing and representational efficiency

Measures of processing efficiency should examine the "on-line" processing demands associated with the performance of a rhythm-related task. For instance, appropriate indices of processing efficiency may include (1) auditory inspection time - for example, the number of times a listener needs to hear a pattern in order to perform some task related to it, and (2) the degree to which processing a pattern interferes with a concurrent processing task.

Measures of representational efficiency should examine the nature of representations stored in memory (e.g., representations of hierarchical versus serial relationships), as well as their accuracy. Appropriate indices may be (1) the effects of contextual cues on the interpretation of stored representations and (2) memory confusions. These measures are assumed to indicate efficient representation to the extent that they provide evidence that the stored information relies on meter's recursiveness.

The present research uses auditory inspection time and interference effects as indices of processing efficiency, and the effects of contextual cues to meter on the recognition of previously memorised patterns as an index of representational efficiency. Although some of these indices have been used before, aspects of the methodologies employed preclude the resolution of some issues of current interest. For instance, although Povel and Essens (1985) used an auditory inspection time measure, processing requirements and demands associated with motor production were possibly confounded in their procedure. Further, both Povel and Essens (1985) and Palmer and Krumhansl (1990) have examined the effects of contextual cues on rhythm perception, but in their tasks the context markers accompanied the exposure of temporal events. However, representations of real musical events are often formed in the absence of clearly marked metrical contexts. In order to examine the role of meter in representing such events, it may be appropriate to examine the effects of metrical context on the recognition of patterns that were encoded without explicit cues to meter. In accordance with ideas related to the encoding specificity principle (Tulving & Thomson,1973), providing appropriate metrical contexts should facilitate the recognition of patterns that are represented according to metrical hierarchies.

Experiment 1: Recognising patterns in different metrical contexts

Aims and predictions Experiment 1 aims to test the hypothesis that meter functions to facilitate both the efficient processing and representation of rhythm patterns. This is examined by using auditory inspection time and the effects of context on memory as indices of processing and representational efficiency, respectively. It is expected that (1) nonmetrical patterns will need to be heard more times than metrical patterns during memorisation, and (2) the provision of cues to metrical context will facilitate the recognition of patterns that fit the cued meter well, relative to those that do not.

Method The experimental task required participants (12musicians and 12 nonmusicians) to (1) listen to a pattern as many times as required to memorise it, and then to (2) rate the degree to which they were confident that one target (same) and two distracter(different) versions of the pattern were the same or different to the memorised pattern, when presented in different metrical contexts. The to-be-memorised patterns either (1) best fit a *triple* meter,(2) best fit a *quadruple* meter, or (3) were *nonmetrical*. Sounds in metrical patterns were positioned such that, according to accent rules specified by Povel and Essens (1985),accents would be perceived to occur periodically. Patterns were taken from 36 rhythm sets, each containing a triple, a quadruple, and a nonmetrical pattern (see Figure 1).

Tr bar-level	T-----------T-----------T-----------T-----------T
Qd bar-level	Q---------------Q---------------Q---------------Q
Tr/Qd beat-level	b---b---b---b---b---b---b---b---b---b---b---b---b
Triple	x--------x---x----------xx------------x--------x-x-x
Quadruple	x------------x---x---------------xx--------x---x-x-x
Nonmetrical	x----------x---x------------xx-----------x----x-x-x

Figure 1: Triple, quadruple, and nonmetrical patterns from a single rhythm set with triple (T) and quadruple (Q) bar-level and beat-level markers (b).

Combining various metrical pulsation level markers created the two metrical contexts that accompanied target and distracter memory test items: (1) bar- and beat-level markers defining a *triple* meter; (2) bar- and beat-level markers defining a *quadruple* meter.

Results and discussion When the number of times patterns were heard during memorisation was considered, it was found that (1)metrical patterns required less hearings than nonmetrical patterns($p<.01$), and (2) quadruple patterns required less hearings than triple patterns ($p<.01$). This suggests, not only that metrical patterns are processed more efficiently than nonmetrical patterns, but that quadruple patterns afford the greatest degree of processing efficiency.

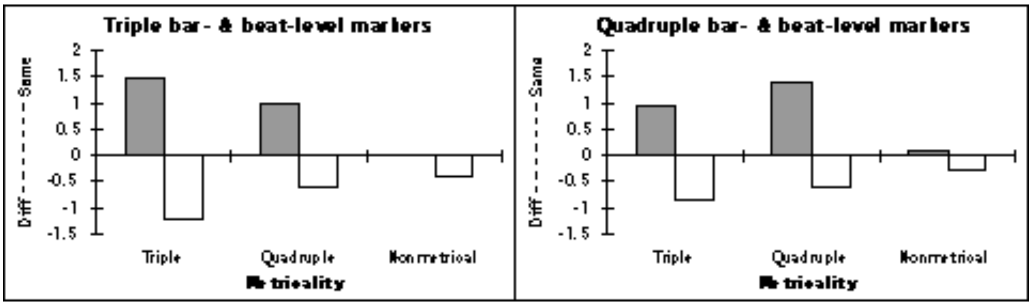

Figure 2: Same/different confidence ratings for target(filled grey) and distracter (unfilled) patterns that best fit a triple meter, a quadruple meter, or were nonmetrical, in contexts where bar- and beat-level

markers defined a triple meter (left panel)and quadruple meter (right panel). +ve ratings indicate "same" (maximum confidence = +3); -ve ratings indicate "different" (maximum confidence = -3).

When same/different confidence ratings for target and distracter memory test items were considered, it was found that (1) metrical patterns were recognised more accurately than nonmetrical patterns($p<.01$), and (2) triple patterns were better recognised in the context where bar- and beat-level markers suggested a triple meter, than where context markers defined a quadruple meter, whereas the opposite was the case for quadruple patterns ($p<.05$) (see Figure2). These findings suggest that the representations formed by participants for metrical patterns were efficient in the sense that they were based on a metric hierarchy consisting of both bar- and beat-level pulsations.

The findings of Experiment 1 indicate that metric frameworks can be, and indeed are used to interpret auditory temporal patterns by both musically skilled and unskilled listeners. Moreover, patterns that can be interpreted according to metric frameworks afford both efficient processing and efficient representation. Emphasising efficiency in terms of both processing and representation implies that metric frameworks serve not only as a frame of reference that allows patterns to be accurately remembered and reproduced, but also play a role in minimising demands on listeners' attentional resources. This claim encourages the proposal that the abstraction and generation of metric frameworks are processes that function to facilitate real-time musical interactions, including activities such as performing in musical ensembles. True tests of this hypothesis can only take place in the context of multi-part patterns.

Attention to multi-part patterns

Activities such as listening to multi-part music and performing in musical ensembles involve simultaneously monitoring more than one instrumental part. When considered from the perspective of ecological adaptiveness (e.g., Jones & Boltz, 1989; Michon, 1985), optimal behavior in such contexts is a form of *integrative attention,* where the listener/performer attempts to focus on the relationships between features of different instrumental parts. One's ability to adopt such an attentional strategy is presumably affected by the processing and representational efficiency afforded by various parts in the multi-part texture (e.g., one's own part and parts played by others in an ensemble). However, given the real-time demands associated with activities such as performing in ensembles, processing efficiency is perhaps the more crucial aspect.

It was proposed earlier that auditory inspection time is an appropriate index of processing efficiency. However, auditory inspection time is not, strictly speaking, a direct measure of on-line processing demands. A more direct index of processing efficiency than auditory inspection time is the degree to which processing a pattern interferes with a concurrent processing task. This issue can be addressed best in the context of multi-part patterns.

Multi-part patterns are comprised of what may be called *integrant patterns* (e.g., patterns played by separate instrumental parts in an ensemble) that, when presented concurrently, result in an *aggregate pattern*. A variety of recognition memory tasks can be used to investigate processing efficiency in multi-part patterns by requiring a listener to divide their attention between an integrant pattern (the "target integrant") and the aggregate structure in which it is embedded. To the extent that the target integrant pattern is efficiently processed, integrative attending should be efficient and, therefore, result in the aggregate pattern being represented efficiently (and accurately) in memory.

Due, in part, to its emphasis upon processing efficiency, the dynamic attending approach (Jones & Boltz, 1989) has greater potential for explaining integrative attention than coding based approaches (e.g., Povel & Essens, 1985). The dynamic attending approach proposes that processing metrical patterns involves the attunement of endogenous oscillators that may become phase locked in a way reflecting the ratios defined by beat- and bar-level divisions of metric frameworks. This pattern of oscillator activity then forms the basis for temporal expectancies that guide attending. So long as these expectancies experience only a limited degree of violation, processing will be efficient and attention will be flexible (Jones & Boltz, 1989; Klein & Jones, 1996). Therefore, in the context of multi-part patterns, when target integrant patterns are metrical, attention should be flexible and thus permit the "scanning" of other parts with a view to integration.

Experiment 2: Integrative attending to multi-part patterns

Aims and predictions Experiment 2 aims to test the hypothesis that meter functions to facilitate integrative attention in multi-part contexts by enabling efficient processing and representation. This is examined by measuring the degree to which memorising target integrant patterns that vary in metricality interferes with the simultaneous memorisation of aggregate patterns in which they embedded. It is expected that, generally, more accurate representations will be formed for aggregate patterns when the target integrant patterns are metrical, than when they are nonmetrical.

Method The experimental task involved a series of trials where, in each trial, participants (24 musicians and 24 nonmusicians) were (1) exposed once to a multi-part pattern comprised of a target integrant pattern and a "complementary" integrant pattern (see Figure3[I]), and (2) immediately tested for recognition memory of either the target integrant, or the aggregate pattern (made up of the sum of the target and complementary integrant patterns) (see Figure 3[IIa & IIb]). The target integrant pattern, the complementary integrant pattern, and the test pattern (integrant or aggregate) were each articulated by a different percussion sound. The same patterns that served as stimuli in Experiment 1 were used as target integrant patterns. Therefore, target integrant patterns either (1) best fit a *triple* meter, (2) best fit a *quadruple* meter, or (3)were *nonmetrical,* depending on experimental condition. All aggregate patterns best fit a *quadruple* meter.

(I) EXPOSURE	
Target integrant	x-----------x---x---------------xx-------x---x-x-x
Complementary integrant	------o-o-o---o----ooooooo-oo-----o--o-----------
(IIa) MEMORY TEST	**PART TEST**
Target integrant	x----------x----x------------------xx--------x---x-x-x
(IIb) MEMORY TEST	**WHOLE TEST**
Target aggregate	x---x-x-x-x-x-x-----xxxxxxx-xxxx---x--xx---x-x-x

Figure 3: Notated example of a single trial from Experiment2 illustrating two possible memory test options. After each exposure in the actual experiment, either the words "PART TEST" or "WHOLETEST" appeared on a computer screen, informing listeners that they should compare the memory test item to the target integrant, or the aggregate pattern, respectively.

Participants received six experimental blocks, each consisting of10 trials. The target integrant pattern and the aggregate pattern were the same across the trials within a block, but were different between blocks. Each participant received two blocks featuring triple target integrant patterns, two blocks featuring quadruple target integrant patterns, and two blocks featuring nonmetrical target integrant patterns.

For each trial, participants were instructed to divide their attention between the target integrant, and the aggregate aspects of the exposed pattern, and to attempt to memorise both. So as to encourage such an attentional strategy, participants were not informed whether memory was to be tested for the integrant or the aggregate pattern until after the end of the exposure phase. The memory test following each exposure consisted of either an isolated target or distracter "integrant" pattern, or a target or distracter aggregate pattern. Participants were asked to rate the degree to which they were confident that the memory test item was the same as, or different to the memorised patterns.

Results An ANOVA carried out on aggregate test pattern ratings revealed that, in accordance with predictions, aggregate patterns were better recognised (i.e., there was greater difference between ratings for target and distracter patterns) when target integrant patterns were *metrical* than when they were *nonmetrical* ($p<.02$) (see Figure 4). This finding supports the idea that metrical patterns are encoded more efficiently than nonmetrical patterns, and that this efficiency facilitates integrative attention in multi-part contexts.

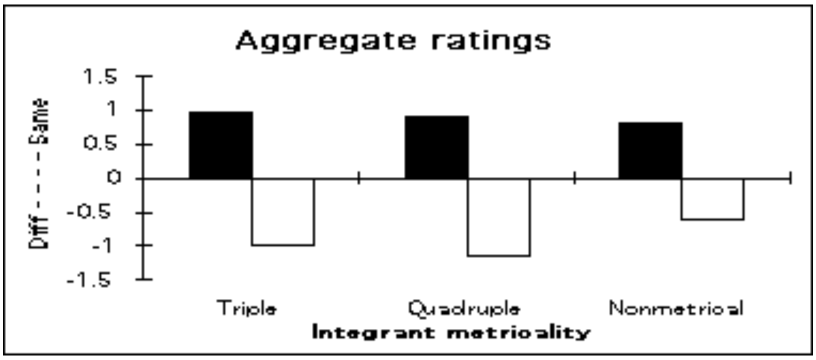

Figure 4: Same/different confidence ratings for target(filled black) and distracter (unfilled) aggregate patterns, when the target integrant patterns were triple, quadruple, or nonmetrical.

Conclusions and future directions

The results of Experiment 1 provide evidence that metric frameworks promote efficiency in terms of both processing and representation. The results of Experiment 2 then indicate that the efficiency afforded by metrical patterns facilitates integrative attention in multi-part contexts, where attention must be simultaneously directed to more than one instrumental part. An attractive explanatory candidate for the mechanism underlying this effect is the dynamic attending view that the attunement of endogenous oscillators, reflecting an appropriate metric hierarchy, is used to generate expectancies (Jones & Boltz, 1989), and thus enables an attentional strategy flexible enough to allow more than one part to be attended. It follows that meter may function, as an ecologically adaptive mechanism, to facilitate real-time musical interactions such as listening to multi-part music and performing in ensembles. Tasks involving pattern *production*, perhaps in the context of interactions with computer based simulations of ensemble performance, would be appropriate for addressing this issue further. Indeed, related tasks may provide suitable contexts in which to test models of more general cognitively mediated interactions between an individual and their temporal environment.

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