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Musical Meter in Attention to Multipart Rhythm

PETER E. KELLER

MARCS Auditory Laboratories, University of Western Sydney, Sydney, Australia & University of Finance and Management, Warsaw, Poland

DENIS K. BURNHAM

MARCS Auditory Laboratories, University of Western Sydney, Sydney, Australia

Performing in musical ensembles can be viewed as a dual task that requires simultaneous attention to a high priority "target" auditory pattern (e.g., a performer's own part) and either (a) another part in the ensemble or (b) the aggregate texture that results when all parts are integrated. The current study tested the hypothesis that metric frameworks (rhythmic schemas) promote the efficient allocation of attentional resources in such multipart musical contexts. Experiment 1 employed a recognition memory paradigm to investigate the effects of attending to metrical versus nonmetrical target patterns upon the perception of aggregate patterns in which they were embedded. Experiment 2 required metrical and nonmetrical target patterns to be reproduced while memorizing different, concurrently presented metrical patterns that were also subsequently reproduced. Both experiments included conditions in which the different patterns within the multipart structure were matched or mismatched in terms of best-fitting meter. Results indicate that dual-task performance was best in matched-metrical conditions, intermediate in mismatched-metrical conditions, and worst in nonmetrical conditions. This suggests that metric frameworks may facilitate complex musical interactions by enabling efficient allocation of attentional resources.

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MUSIC is often complex, with multiple patterns sounding concurrently across the different instrumental parts within an ensemble. In such multipart textures, parts are usually differentiated by a number of factors, including rhythm. This article focuses on how musicians contend with

Address correspondence to Peter Keller, Department of Cognitive Psychology, University of Finance and Management, Warsaw, ul. Pawia 55, 01-030 Warsaw, Poland. (e-mail: keller@vizja.pl)
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rhythmic complexity during multipart musical interactions. The central claim is that metric frameworks—that is, cognitive/motor schemas that guide rhythmic perception and action—enable efficient allocation of attentional resources and thereby facilitate the performance and perception of multipart music.

Metric Frameworks

Metric frameworks consist of multiple levels of pulsation that are generated within an individual during music performance or listening. In their simplest form, metric hierarchies are made up of beat-level and bar-level pulsations that are nested in ratios such as 4:1 (quadruple meter) or 3:1 (triple meter). Pulsations at the beat level—which are often reflected in foot tapping while performing or listening to music—are thought to play a dominant role in rhythmic organization by serving as a "referent" level of periodicity (Jones & Boltz, 1989; Parncutt, 1994). Higher level bar pulsations allow a person to group beat-level pulsations into units that can be used to measure the length of musical phrases (e.g., a 4-bar phrase) or larger musical sections (e.g., the 12-bar chord cycle typical in Blues music).

The degree to which a rhythm pattern is interpretable within a metric framework is one determinant of its complexity (Gabrielsson, 1993; Pressing, 1997; Shmulevich & Povel, 2000). In *metrical patterns*, the placement of individual pattern elements and the accents (i.e., salient locations in pattern structure) associated with these elements imply periodic metric divisions. This is illustrated in the left panel of Figure 1, which shows notated examples of metrical and nonmetrical patterns. In Figure 1, elements in the patterns labeled A and B are positioned so as to suggest periods belonging to a quadruple and triple meter, respectively. Furthermore, the periodic elements that demarcate metric bars—and hence occur at points where beat- and bar-level impulses coincide in the patterns labeled A and B—would most likely be perceived as accented (even though they are physically identical) because they are followed by relatively long silent intervals (see Povel & Okkerman, 1981). Metrical ambiguity can arise when a pattern contains evidence of periodicities that are consistent with more than one framework. Even so, it is generally the case that a metrical pattern will fit best within a particular framework—usually the framework that maximizes the number of pattern elements, and minimizes the silences, that coincide with metric pulsations (McAuley & Semple, 1999; Povel & Essens, 1985). For example, although the pattern (labeled G) shown in the bottom right panel of Figure 1 fits within quadruple and triple frameworks, the quadruple fit is better. (This was

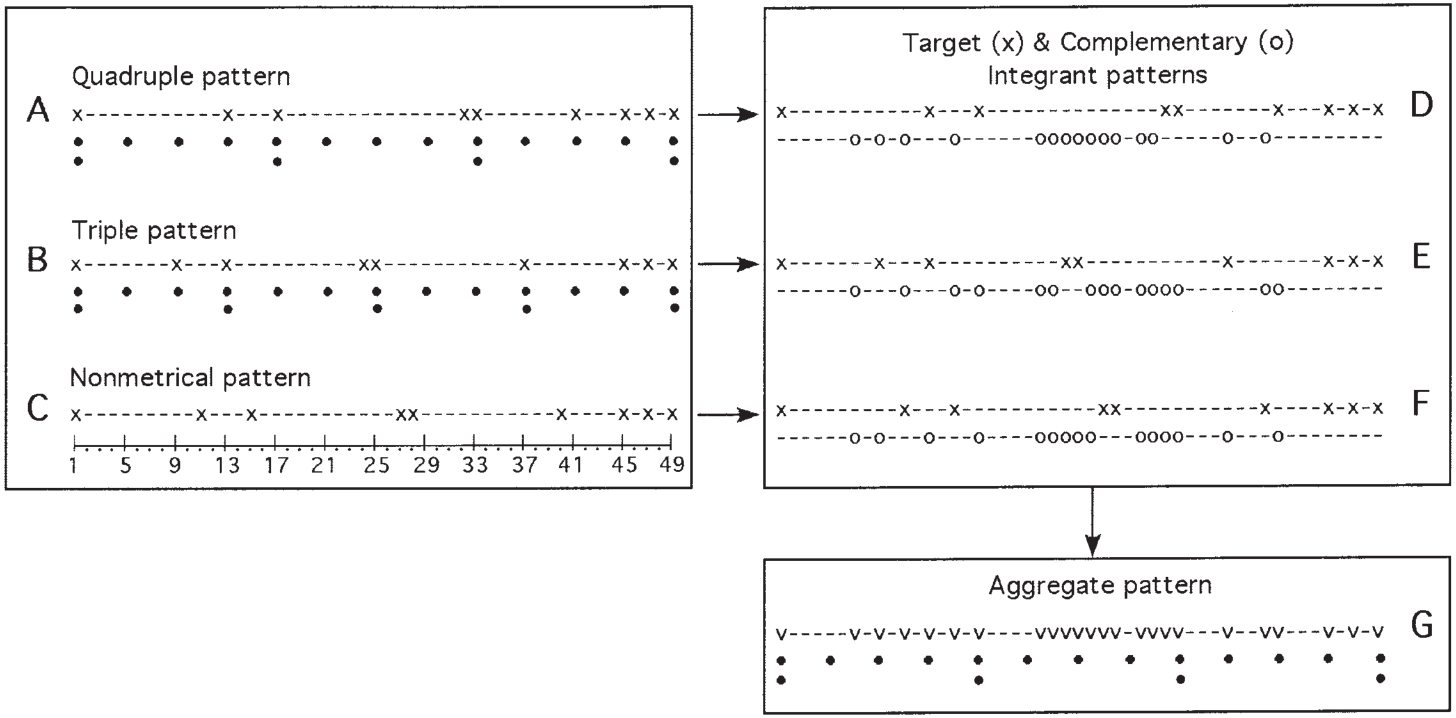

Fig. 1. Examples of rhythm patterns. Quadruple and triple patterns are notated in A and B, respectively, with beat and bar-level metric pulsations depicted below as dots. A nonmetrical pattern is notated in C, with an underlying 49-unit grid (each unit ≅ 150 ms). Multipart patterns, in which the quadruple, triple, and nonmetrical patterns (from A, B, and C) serve as target integrant patterns, are notated in D, E, and F, respectively. The aggregate pattern that results when target and complementary integrant patterns are combined is shown in G. Note that "x," "o," and "v" each represent a sound onset (with a different instrumental timbre for each letter), and "-" represents the absence of a sound onset.

determined empirically; see Experiment 1, Stimuli and Apparatus section.) *Nonmetrical patterns* lack (explicit and implicit) periodicity and do not encourage metric framework generation. Because of their structural irregularity, nonmetrical patterns are more complex than metrical patterns composed of the same number of elements (see the pattern labeled C in Figure 1).

Numerous empirical studies have demonstrated that recognition memory and reproduction accuracy are superior for metrical patterns compared with nonmetrical patterns (e.g., Bharucha & Pryor, 1986; Essens, 1995; Franks & Canic, 1991; Povel & Essens, 1985). Furthermore, metrical patterns are recognized poorly and judged to be complex when they are interpreted according to a meter other than the one that they fit best. This result has been demonstrated in studies where recognition tests and complexity judgments were carried out on patterns that were presented in the presence of periodic auditory markers that were either consistent or inconsistent with the patterns' best-fitting meter (e.g., Keller, 2001a; Povel & Essens, 1985). On the basis of such findings, it has been argued that metric frameworks facilitate both the efficient processing and representation of rhythm (Keller, 1999).

With regard to real-time *processing*, metric frameworks provide expectancy schemes that guide attention to important locations in a pattern's structure (Desain, 1992; Gjerdingen, 1989; Jones, 1990; Jones & Boltz, 1989; Jones & Yee, 1997; Large & Jones, 1999; Yee, Holleran, & Jones, 1994). Based on these expectancies, an individual will automatically invest more attentional resources at "strong" metric locations (e.g., the beginning of bars and beats) than at "weak" locations (e.g., between beats). This results in efficient processing because, in music, pattern elements are statistically more likely to occur at strong locations (Palmer & Krumhansl, 1990; Palmer & Pfordresher, 2003).

Metric frameworks also facilitate the *representation* of rhythm patterns in memory by providing a grid-like template for organizing pattern elements with respect to their position relative to one another in time (Essens & Povel, 1985; Handel, 1998; Palmer & Krumhansl, 1990; Palmer & Pfordresher, 2003; Parncutt, 1994). Representations based on metric hierarchies are efficient in the sense that if elements from each particular metric level are connected in memory, then temporal information is effectively chunked in a manner that highlights the relationship between nonadjacent elements (Martin, 1972; Palmer & Pfordresher, 2003; Palmer & van de Sande, 1995). Efficient processing and representation are jointly important because musical interactions, for performers and listeners alike, involve monitoring a dynamically unfolding auditory event while retrieving information from memory to guide one's participation in the event. Here we investigate whether the processing and representational efficiency associated with metric frameworks is beneficial specifically in the context of multipart rhythmic interactions, wherein attentional resources must be allocated to separate instrumental parts.

Attention to Multipart Musical Patterns

In multipart rhythmic textures, such as those that characterize polyphonic (contrapuntal or chordal) music, separate parts articulate different rhythm patterns concurrently. These contrast with single-part rhythmic textures, in which either there is only one part (monophony), or multiple parts articulate the same rhythm (homophony). In Keller's (1999, 2001b) terminology, each part in a multipart texture is called an *integrant pattern* (see Figure 1D, 1E, 1F), and the structure that emerges when these parts are combined is called an *aggregate pattern* (see Figure 1G). Multipart textures afford four main attending modes: selective attention, divided attention, nonprioritized integrative attention, and prioritized integrative attention. *Selective attending* (SA) occurs when the individual focuses attention on a particular integrant pattern and ignores other integrant patterns. Standard *divided attention* (DA) involves attending simultaneously to several integrant patterns without necessarily integrating them. On the other hand, *nonprioritized integrative attending* (NPIA) involves combining all integrant patterns and focusing on the emergent aggregate pattern. Note that NPIA differs from DA in the sense that it necessarily involves recognizing the relationship between the features of perceptually distinct streams of information, rather that simply being a matter of "spreading" attention across such streams (Jones & Yee, 1993). SA, DA, and NPIA have been studied in musical contexts (e.g., Crawley, Acker-Mills, Pastore, & Weil, 2002; Janata, Tillmann, & Bharucha, 2002; Satoh, Takeda, Nagata, Hatazawa, & Kuzuhara, 2001).

Prioritized integrative attending (PIA) is a hybrid of SA and NPIA. It involves simultaneously attending to a high priority "target" integrant pattern (e.g., the part that carries the melody, or a performer's own part in a musical ensemble) *and* the aggregate structure that results when all integrant patterns are combined. Thus, PIA can be viewed as a dual task to the extent that it requires attentional resources to be divided between (a) producing and/or tracking the target integrant pattern and (b) grouping together the elements of all integrant patterns to derive the aggregate (Keller, 2001b). For present purposes, it is assumed that, during PIA, attending to the target integrant pattern is the primary task and attending to the aggregate pattern is the secondary task (as would certainly be the case in ensemble performance). Dual task demands also arise during DA when attention is divided between the integrant patterns in a multipart texture made up of only two parts. It is important to note that PIA is a form of DA, albeit one where it is *necessary* to attend to the interrelationship between two (or more) integrant patterns. Such integration is not a necessary condition with standard DA.

The current study addresses the dual task demands of both PIA and DA in the context of multipart musical rhythm. However, the main focus is on PIA because it seems to correspond more closely than standard DA to the goals of ensemble performance: To produce an aggregate pattern that presents a coherent and cohesive musical entity (see Keller, 2001b).

The Dual-Task Demands of PIA

In dual-task situations generally, it is typical to observe a trade-off wherein performance on the secondary task suffers as the difficulty of the primary task is increased (see Wickens, 1980). This trade-off has been demonstrated in numerous studies investigating standard DA (see Damos, 1991, and Pashler, 1998, for reviews), and we assume that a similar trade-off occurs with PIA in the context of multipart music. Thus, aggregate pattern perception should become less accurate as the rhythmic complexity of the target integrant pattern is increased. Specifically, aggregate perception should be compromised when target integrant patterns are nonmetrical relative to when they are metrical. Such a finding would be consistent with the notion that attending to a nonmetrical target integrant pattern places greater demands on resources than attending to a metrical target integrant, and therefore produces greater interference to aggregate pattern perception. Thus, metric frameworks may promote the efficient processing of the target integrant and thereby free attentional resources for the task of processing the aggregate. In a sense, this idea is related to Michon's (1985, p. 29) more general claim that the process of synchronizing one's biologically based rhythms with periodicities implied by an environmental event enables the individual to function with a certain degree of independence from the event, in effect granting the freedom to "do other things in between the instants at which perfect coincidence is crucial." However, it is unlikely that this type of independence is sufficient for optimal dual-task performance in the case of PIA, as the two tasks are inextricably linked through an overlap in stimuli: The target integrant pattern is itself part of the aggregate pattern. This overlap suggests that it might be useful to consider the degree to which the tasks of attending to the target integrant and the aggregate are *compatible* with one another, in addition to the complexity of the target integrant itself.

In the domain of dual-task research, two concurrent tasks are considered to be compatible to the extent that "some dimension or aspect of one stimulus can be used to predict a dimension or aspect of the second stimulus" (Damos, 1991, p. 105). In the context of multipart musical rhythm, dual-task compatibility varies as a function of how well the target integrant and the aggregate pattern can be accommodated within the same metric framework (Keller, 1999, 2001b). This conception of compatibility allows multipart patterns to be classified as illustrated in the top right panel of Figure 1. Each of the three multipart patterns shown here (labeled D, E, and F) consists of a target integrant pattern and a complementary integrant pattern that combine to form the same aggregate pattern, which, when isolated—see the pattern labeled G in the bottom right panel of Figure 1—is metrically ambiguous but best fits a quadruple meter. The letters x, o, and v in the Figure correspond to sounds that differ in instrumental timbre.

The manipulation of interest occurs in the target integrant patterns, which we constructed so as to fit either a quadruple (pattern D) or a triple (pattern E) meter (i.e., these patterns house an implicit underlying beat, with pattern elements occurring either every four or three beats, respectively), or to be nonmetrical (pattern F) in structure (i.e., there is no implicit beat). The complementary integrant patterns were then constructed by placing elements around the elements of each target integrant pattern in a manner that gave rise to the same aggregate pattern in all three cases. Thus, the metric identity (quadruple, triple, or nonmetrical) of the target integrant pattern changes across the three multipart patterns to produce three levels of multipart rhythmic compatibility relative to the aggregate pattern. In pattern D in Figure 1, the target integrant and aggregate patterns both best fit a quadruple meter and are hence highly compatible. Compatibility is lower in pattern E, where the target integrant—if considered in isolation—is triple meter whereas the aggregate, although metrically ambiguous, best fits a quadruple meter. Compatibility is lowest in pattern F, where a nonmetrical target integrant meshes with its complementary integrant to yield the metrical aggregate. Although the patterns shown in Figure 1 are obviously contrived (they correspond to a subset of the experimental stimuli described below), there are plenty of examples of real multipart music in which integrant patterns yield different metric interpretations depending on whether they are presented in isolation or in combination with other integrant patterns (e.g., see Yeston, 1976).

PIA should benefit from compatibility between target integrant and aggregate aspects of multipart patterns because, as in compatible dual-task situations generally, "a common mental set, processing routine, or timing mechanism can be activated in service of the two tasks" (Wickens, 1991, p. 23). Metric frameworks may provide such a common mechanism during multipart rhythmic interactions. Although this hypothesis has not previously been tested in the context of PIA (i.e., by manipulating compatibility between a target integrant and aggregate pattern, as in the present study), it has been shown that attention can be divided more effectively between separate integrant patterns when they are temporally compatible with one another than when they are incompatible. For example, Klein and Jones (1996) required listeners to detect subtle timbre changes in concurrent high- and low-frequency tone sequences that were either compatible or incompatible (i.e., the ratio between periods marked by the isochronous high-tone sequences and those implied by the nonisochronous low-tone sequences was simple or complex, respectively). When listeners were instructed to respond to changes in the high sequence and to ignore the low sequence (SA), detection was better with incompatible than with compatible sequences. However, when listeners were instructed to respond to changes in both sequences (which may be interpreted either as DA or NPIA),[1] detection was best with compatible sequences. Together, these findings suggest that incompatibility between integrant patterns favors SA to individual parts, whereas compatibility between integrants—which presumably allows them to be processed according to a single scheme—in fact encourages attention to be cast across parts in the multipart texture.

Aims of the Current Study

Two experiments are reported in the current article. The aim of the first experiment was to investigate whether temporal compatibility between target integrant and aggregate aspects of multipart patterns affects ability to engage in PIA. This was tested by using a dual-task paradigm in which musically trained participants were required to memorize, and subsequently recognize, both the target integrant aspect and the aggregate aspect of multipart patterns (such as those shown in Figure 1D, E, and F). When target integrant and aggregate patterns are matched in terms of best-fitting meter, the structural boundaries between bar-level units coincide, and hence a common metric framework provides an appropriate scheme for processing and representing both aspects of the multipart pattern. Moreover, the fact that both the target integrant and the aggregate share an underlying beat structure, which affords synchronization, should prove advantageous. It was hypothesized that attending to the target integrant would produce minimal interference to aggregate perception under such circumstances. However, when a nonmetrical target integrant pattern is embedded within a metrical aggregate pattern, structural incompatibility is relatively high. Aggregate perception is expected to be impoverished under such circumstances because attending to the aperiodic structure of the target integrant may (at least) divert a proportion of resources from

1. Klein and Jones (1996, p. 36) refer to this as a divided attention condition but their instructions specified "to *integrate* high and low tones to form a unified rhythm."

the task of encoding the aggregate pattern or (at worst) enlist processing routines that totally preclude metric framework generation, thus distracting the attender from the periodicity underlying the aggregate. In any case, resource allocation should become effortful and not conducive to PIA when target integrant patterns are nonmetrical. Finally, when the target integrant and aggregate patterns are mismatched in meter, they share a common underlying beat structure, but their structural bar-level boundaries are in conflict. If it is assumed that only one metric framework can be generated at a time, then, in such situations, the aggregate pattern may be processed and represented relatively inefficiently according to the framework belonging to the target integrant. The second experiment examined similar issues in the context of a pattern reproduction task requiring DA.

Experiment 1

Experiment 1 employed a recognition memory paradigm designed to simulate the PIA demands that arise in many instances of listening to ensemble music. We focus exclusively on individuals who have experience at musical ensemble performance in this article. In each experimental trial, listeners are first exposed to a multipart pattern composed of a target integrant pattern and a complementary integrant pattern, and then they are immediately tested for recognition memory of either the target integrant or the aggregate structure (made up of the sum of the target and complementary integrant patterns). Following each single presentation of the multipart exposure pattern, listeners are required to rate how confident they are that correct and incorrect memory test patterns are the same as, or different from, either the target integrant or the aggregate aspect of the exposure pattern (see Figure 2). Whether memory is tested for the target integrant or the aggregate pattern is varied randomly from trial to trial, and participants are cued only after the exposure item has ended as to which type of memory test will occur. We assume that engaging in PIA is

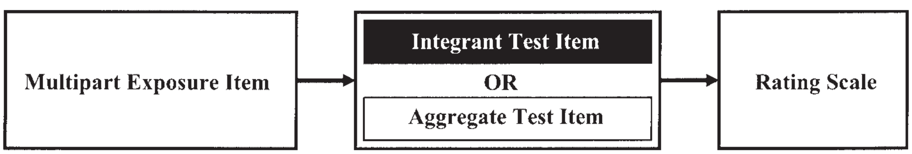

Fig. 2. Diagram depicting the contents of a single trial from Experiment 1. First, a multipart exposure item is presented, during which PIA is required. This is followed by a recognition test phase, wherein either an integrant or aggregate test item is presented, and finally a scale appears for the listener to make a same/different confidence rating of the test item.

the optimal strategy (and indeed the one that was instructed) in this task because in each trial the listener does not know whether memory will be tested for the target integrant or the aggregate pattern until the presentation of the multipart pattern is over.

Multipart rhythmic structure was manipulated to produce a matched-metrical condition (target integrant and aggregate patterns both best fit a quadruple meter), a mismatched-metrical condition (the target integrant best fits a triple meter whereas the aggregate best fits a quadruple meter), and a nonmetrical condition (a nonmetrical target integrant is embedded within an aggregate that best fits a quadruple meter). Our main prediction was that recognition accuracy for target integrant and aggregate patterns would be more accurate in the matched-metrical condition than in the nonmetrical condition. The inclusion of the mismatched-metrical condition was somewhat exploratory, as the psychological validity of conflicting bar-level periodicities has not (to our knowledge) been empirically tested before. Our tentative prediction was that recognition accuracy in the mismatched-metrical condition would fall approximately midway between accuracy in the matched-metrical and nonmetrical conditions. However, it was also considered possible that performance in the mismatched-metrical condition would be better than intermediate (which would indicate that bar-level structure was not influential) or worse than intermediate (which would indicate that neither beat nor bar-level structure were influential).

METHOD

Participants

Twenty-four musicians (14 women, 10 men) volunteered to participate in Experiment 1. Median age was 22 years (range = 18–32 years). The sample was composed of students and staff from the School of Music and Music Education at the University of New South Wales. The participants had, on average, 11.5 years experience playing an instrument (range = 7–20 years), and all performed in ensembles regularly (average ensemble experience = 8.29 years).

Stimuli and Apparatus

The stimulus patterns used as multipart exposure items and target integrant/aggregate memory test items were drawn from 12 sets of rhythm patterns. Each of the 12 rhythm sets contains three multipart patterns that were used as exposure items. These multipart patterns are composed of a target and a complementary integrant pattern that combine to form the same aggregate pattern structure. Although aggregate structure is constant within each rhythm set, it varies between rhythm sets.

One of the multipart patterns within each rhythm set has a target integrant pattern that best fits a *quadruple meter*, in another the target integrant best fits a *triple meter*, and the remaining multipart pattern has a *nonmetrical* target integrant pattern. Target integrant patterns from the 12 rhythm sets are notated in Figure 3. Each target integrant pattern

	Rhythm Set I	Group
Quadruple	`x-----------x---x--------------xx-------x---x-x-x`	3
Triple	`x-------x---x----------xx-----------x-------x-x-x`	1
Nonmetrical	`x---------x---x-----------xx-----------x----x-x-x`	5
Aggregate	`v-----v-v-v-v-v-v----vvvvvvv-vvvv---v--vv---v-v-v`	
	Rhythm Set II	
Quadruple	`x--------------xx-----------x--xx-------x-----x-x`	4
Triple	`x----------xx-------x--xx-----------x---------x-x`	2
Nonmetrical	`x------------xx--------x--xx-----------x------x-x`	6
Aggregate	`v--------vvvvvvvv-v-vvvvvvvvvvvvv---v--vv-----v-v`	
	Rhythm Set III	
Quadruple	`x-----------x---x-------------x-x-------x---x--xx`	5
Triple	`x-------x---x---------x-x-----------x-------x--xx`	3
Nonmetrical	`x---------x---x----------x-x-----------x----x--xx`	1
Aggregate	`v-----v-v-v-v-v-v---v-vvvv-vv-v-v---v--vv---v--vv`	
	Rhythm Set IV	
Quadruple	`x-----------x--xx-----------x---x-------x-----x-x`	6
Triple	`x-------x--xx-------x---x-----------x---------x-x`	4
Nonmetrical	`x---------x--xx--------x---x-----------x------x-x`	2
Aggregate	`v-----v-vvvvvvvvv-v-vvvvvvvvv-v-v---v--vv-----v-v`	
	Rhythm Set V	
Quadruple	`x-----------x---x-----------x-x-x-------x-----x-x`	1
Triple	`x-------x---x-------x-x-x-----------x---------x-x`	5
Nonmetrical	`x---------x---x--------x-x-x-----------x------x-x`	3
Aggregate	`v-----v-v-v-v-v-v-v-vvvvvvvvv-v-v---v--vv-----v-v`	
	Rhythm Set VI	
Quadruple	`x-------------x-x--------------xx-------x---x--xx`	2
Triple	`x---------x-x----------xx-----------x-------x--xx`	4
Nonmetrical	`x-----------x-x-----------xx-----------x----x--xx`	6
Aggregate	`v-------v-v-v-v-v----vvvvvvv-vvvv---v--vv---v--vv`	

	Rhythm Set VII	Group
Quadruple	`x-------------x-x-----------x--xx-------x------xx`	2
Triple	`x---------x-x-------x--xx-----------x----------xx`	4
Nonmetrical	`x-----------x-x--------x--xx-----------x-------xx`	6
Aggregate	`v-------v-v-v-v-v-v-vvvvvvvvvvvvv---v--vv------vv`	
	Rhythm Set VIII	
Quadruple	`x-----------x---x-----------x--xx-------x------xx`	1
Triple	`x-------x---x-------x--xx-----------x----------xx`	5
Nonmetrical	`x---------x---x--------x--xx-----------x-------xx`	3
Aggregate	`v-----v-v-v-v-v-v-v-vvvvvvvvvvvvv---v--vv------vv`	
	Rhythm Set IX	
Quadruple	`x-------------x-x-----------x-x-x-------x------xx`	6
Triple	`x---------x-x-------x-x-x-----------x----------xx`	4
Nonmetrical	`x-----------x-x--------x-x-x-----------x-------xx`	2
Aggregate	`v-------v-v-v-v-v-v-vvvvvvvvv-v-v---v--vv------vv`	
	Rhythm Set X	
Quadruple	`x-----------x-x-x-------------x-x-------x---x---x`	5
Triple	`x-------x-x-x---------x-x-----------x-------x---x`	3
Nonmetrical	`x---------x-x-x----------x-x-----------x----x---x`	1
Aggregate	`v-----v-v-v-v-v-v---v-vvvv-vv-v-v---v--vv---v---v`	
	Rhythm Set XI	
Quadruple	`x-----------x--xx--------------xx-------x-----x-x`	4
Triple	`x-------x--xx----------xx-----------x---------x-x`	2
Nonmetrical	`x---------x--xx-----------xx-----------x------x-x`	6
Aggregate	`v-----v-vvvvvvvvv----vvvvvvv-vvvv---v--vv-----v-v`	
	Rhythm Set XII	
Quadruple	`x-----------x-x-x-----------x---x-------x------xx`	3
Triple	`x-------x-x-x-------x---x-----------x----------xx`	1
Nonmetrical	`x---------x-x-x--------x---x-----------x-------xx`	5
Aggregate	`v-----v-v-v-v-v-v-v-vvvvvvvvv-v-v---v--vv------vv`	

Fig. 3. Quadruple, triple, and nonmetrical target integrant patterns and (metrically ambiguous) aggregate patterns from 12 rhythm sets. Rhythmic figures are indicated by ellipses in the quadruple integrant pattern from Rhythm Set I. Assignment of rhythm sets to the six levels of the between-group factor (see Experiment 1, Design and Procedure) is indicated in the columns headed "Group."

consists of nine elements (i.e., sound events) that are clustered throughout the pattern to form four to five "rhythmic figures," that is, isolated elements or short runs of (two or three) elements (see Handel, 1992, 1998; Hébert & Cuddy, 2002). (These figures have been highlighted in the Quadruple target integrant pattern notated in Figure 3.) Target integrant patterns from different rhythm sets are distinguishable on the basis of their constituent rhythmic figures and/or the serial order in which these figures occur. Target integrant patterns within each rhythm set consist of identical rhythmic figures, but the positioning of these figures relative to an underlying 49-unit grid varies such that figure-final elements occur periodically in quadruple and triple patterns and aperiodically in nonmetrical patterns. Specifically, the final element of each successive rhythmic figure is placed at (a) grid unit 1, 17, 33, and 49 (i.e., every 16 units) in quadruple patterns, (b) grid unit 1, 13, 25, 37, and 49 (i.e., every 12 units) in triple patterns, and (c) grid unit 1, 15, 28, 40, and 49 (irregularly) in nonmetrical patterns. These arrangements were intended to encourage the perception of quadruple meter, triple meter, and nonmetrical structure when patterns are presented at a rate corresponding to a grid-unit duration of 150 ms. At this rate, the beat-level period in the metrical patterns spans four grid units (corresponding to a beat duration of 600 ms, which is within the range of 400–900 ms at which pulse salience is thought to be maximal; see Fraisse, 1982; Parncutt, 1994). This leads to three bar-level periods (each spanning 16 grid units) in quadruple patterns and four bar-level periods (each spanning 12 grid units) in triple patterns, given that the overall length of all patterns is 49 grid units (and the 49th unit serves merely to allow all patterns to end with an element). Keller (2001a) has demonstrated the perceptual validity of the above classification of target integrant patterns as quadruple, triple, and nonmetrical in a series of experiments with participants that varied in terms of musical experience.

Importantly, the target aggregate pattern in each rhythm set has the potential to "contain" each of the three target integrant patterns belonging to its set. That is, if a target aggregate was presented simultaneously with one of its related target integrants, then at no point would a sound in the target integrant coincide with a silence in the aggregate. The number of elements in aggregate patterns varies across rhythm sets (although overall length is a constant 49 grid units), ranging from 21 to 28, with an average of about 25 elements. Although all aggregate patterns are metrically ambiguous (they have the potential to contain either a quadruple or a triple target integrant, and hence can be accommodated by either a quadruple or triple metric framework), a pilot experiment (Keller, 2001a) involving judgments made by musical experts confirmed that they best fit a quadruple meter. Specifically, four professional musicians were required to rate the aggregate patterns from each rhythm set *twice* on a goodness-of-fit scale. One rating measured how well the patterns are perceived to fit a quadruple meter, and the other measured triple fit (the order in which ratings were made was counterbalanced). For each aggregate pattern, the musicians were unanimous in giving a quadruple rating that was higher—indicating better fit—than the corresponding triple rating.

Each rhythm set contains three multipart exposure items—matched-metrical, mismatched-metrical, and nonmetrical—in which a quadruple aggregate structure houses either a quadruple, a triple, or a nonmetrical target integrant pattern, respectively. Specifically, multipart exposure items were derived by combining each of the three target integrant patterns from a given rhythm set with a complementary integrant pattern so as to yield the aggregate pattern from that set. These complementary integrant patterns—which are not notated in Figure 3—simply consist of the elements that are necessary to produce the relevant aggregate pattern (as in Figures 1D, 1E, and 1F).

Memory test stimuli consisted of target and distracter integrant items and target and distracter aggregate items. The target integrant patterns presented in isolation served as target integrant test items. There are three distracter integrant items for each of the three target integrant patterns (quadruple, triple, and nonmetrical) within each rhythm set. Distracter integrant test items were created by temporally displacing either one or two rhythmic figures forward in time by two grid units relative to their position in the target integrant patterns. The second rhythmic figure was shifted in early-change distracter items so that the temporal deviation was located in the initial half of the pattern; the third rhythmic figure was shifted in late-change distracter items, resulting in a temporal deviation in the final half of the pattern; and the second and third rhythmic figures were both advanced in both-change distracter items, resulting in a large chunk of the target pattern being displaced (see Figure 4).

There are also one target and three distracter aggregate test items per rhythm set (see Figure 4). The target aggregate item is a single-part version of the aggregate pattern from the rhythm set. The three distracter aggregate items were created by first partitioning the target aggregate pattern into three groups (A, B, and C) of 16 grid units in accordance with its quadruple structure. Then the order in which these three groups occurred was varied for each distracter item: BAC in early-change distracters, ACB in late-change distracters, and CBA in both-change distracters. Thus, the quadruple structure implied by target aggregate patterns is preserved in distracter aggregate items, but the serial order of bar-level groups of elements varies.

Thus, altogether, the stimulus pool consists of 36 multipart exposure items (matched-metrical, mismatched-metrical, and nonmetrical items from the 12 rhythm sets), 36 target, early-, late-, and both-change distracter integrant test items (three each per rhythm set), and 12 target, early-, late-, and both-change distracter aggregate test items (one each per rhythm set). In multipart exposure items, the target integrant pattern was articulated by a conga drum sound and the complementary integrant pattern was articulated by a cowbell sound. Integrant test items were articulated by a conga drum sound and aggregate test items were articulated by a snare drum sound. (We used different instrumental timbres mainly to avoid potential confusion about whether integrant or aggregate memory was being tested, but also to allow us to examine how well listeners are able to abstract the aggregate structure from two interleaved integrant patterns). All sounds were taken from

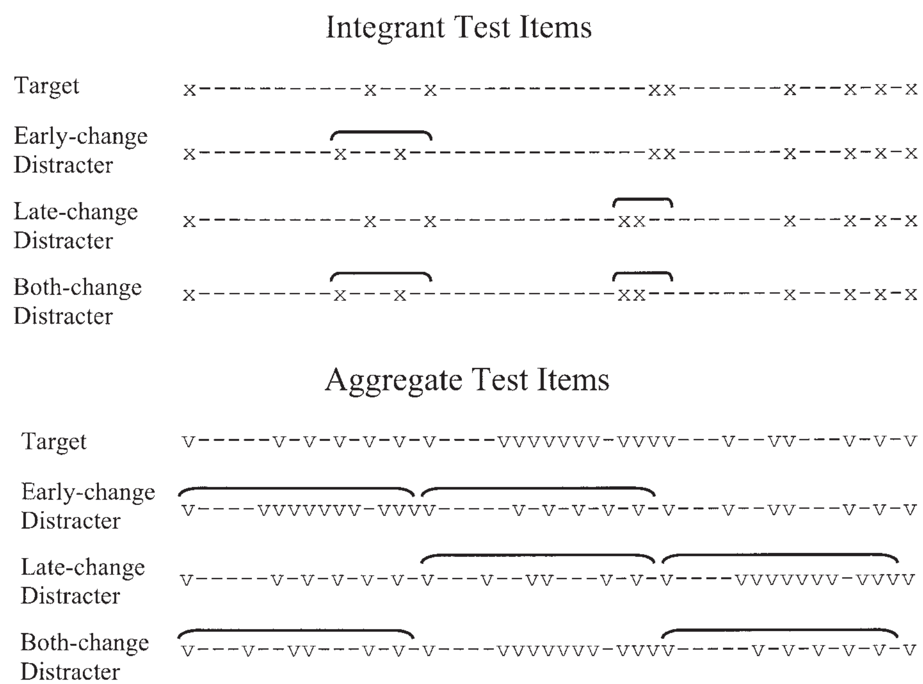

Fig. 4. Target and distracter versions of integrant and aggregate test items from a single rhythm set. Brackets indicate regions where the structure of distracter items deviates from target structure.

an archive in Sample Cell (a sample player/editor developed by Digidesign). Other apparatus consisted of AKG K270 headphones and MAX (Version 3.5) software running on a Macintosh IIvx computer.

Design

Multipart rhythmic structure (matched metrical; mismatched metrical; nonmetrical) was varied within participants. In addition, a between-group factor with six values (Group 1-6) was included for control purposes; specifically, to allow multipart rhythmic structure to be treated as a within-group factor without individual participants encountering the same aggregate pattern in more than one experimental block (see Procedure for more information). Participants were allocated randomly to the six groups in equal numbers. The dependent variable was recognition accuracy for integrant and aggregate test items (see Data Transformation and Analysis).

Procedure

Participants were tested individually at the computer in a small sound-attenuated chamber, and sounds were presented over headphones at a comfortable loudness level. Each participant first completed a training session consisting of (a) a computer-based tutorial aimed at establishing whether the participant could detect the types of changes that distinguished target and distracter test items, and (b) an exercise that provided detailed instructions and an opportunity to practice the task in one experimental block (using stimuli from either the matched-metrical, mismatched-metrical, nonmetrical multipart rhythmic structure condition; randomly assigned on a participant-by-participant basis). This was followed by a test session consisting of six blocks—two for each multipart rhythmic structure condition (matched metrical; mismatched metrical; nonmetrical) with block order randomized. The identity of the rhythm sets from which stimuli were drawn for use in these blocks was determined by the group to which the participant had been allocated. Each of the six groups accounted for the three types of structure with different combinations of target integrant patterns (quadruple, triple, or nonmetrical) and aggregate patterns, with the constraint that all possible integrant/aggregate combinations were exhausted across groups. The assignment of rhythm sets to groups is shown in Figure 3. Thus, each participant encountered target integrant and aggregate patterns from two different rhythm sets in each of the three multipart rhythmic structure conditions, with rhythm sets and conditions being combined differently for participants in different groups.

The task involved a series of trials, wherein each trial consisted of an exposure phase in which a multipart exposure item was presented once, and a recognition memory test phase in which a single test item was presented. Each of six experimental blocks contained 10 such trials, across which the same multipart exposure item was presented. To guard against metricality carryover effects (maintaining metric pulsations from one block to the next), pattern presentation rate was varied from block to block by choosing between three grid-unit durations: 129, 150, and 179 ms. These values were chosen to encourage the perception of beat-level periods (516, 600, and 716 ms) based on groups of four grid units in metrical patterns. The task took approximately 1 hour to complete.

To initiate a trial, the participant depressed the space bar on the computer keyboard. The participant was required to listen to the multipart exposure item that ensued, and simultaneously to memorize the target integrant, or "part," pattern (played by the conga drum), and the aggregate, or "whole," pattern that resulted from combining the target (conga drum) and complementary (cowbell) integrant patterns. Instructions specified that both aspects of the task, that is, memorizing the target integrant and memorizing the aggregate pattern, were equally important: Hence, PIA was required. One second after the exposure item ended, either the words "PART TEST" or "WHOLE TEST" appeared on the computer screen. When PART TEST appeared, a target or distracter integrant test item (played by the conga drum) was presented 3 s later. When WHOLE TEST appeared, a target or distracter aggregate test item (played by the snare drum) was presented after a 3-s silent interval.

After the test item, a six-point rating scale automatically appeared on the computer screen, with points labeled from left to right "very sure different," "moderately sure different," "not very sure different," "not very sure same," "moderately sure same," "very sure same." The participant was required to rate (by clicking on the scale) the degree to which they were confident that the integrant or aggregate test item was the same as, or different from, the target integrant or aggregate pattern, respectively. Information about whether memory would be tested for the target integrant or aggregate pattern was withheld until after the exposure item had been presented in order to encourage the participant to attend simultaneously to integrant and aggregate aspects of the multipart pattern. The first four trials of every block contained a target integrant, a both-change distracter integrant, a target aggregate, and a both-change distracter aggregate test item (presented in random order for each participant). Each of the remaining six trials within a block contained either a target, an early-change distracter, or a late-change distracter integrant test item, or a target, an early-change distracter, or a late-change distracter aggregate test item (in random order). Thus, three integrant test items (one target plus two distracters) and three aggregate test items (one target plus two distracters) were presented in random order across the last six trials of each block. The randomized presentation order of test items was intended to ensure that in each trail within a block the listener was unable to predict reliably whether memory would be tested for the target integrant pattern or the aggregate pattern. Thus, we assume that listeners were forced to engage in PIA in each trial.

Data Transformation and Analysis

To separate sensitivity from response bias (i.e., a tendency to favor "same" or "different" ratings), same/different confidence ratings for integrant and aggregate test items were converted to *d*' and *c*' scores (see Macmillan & Creelman, 1991) after collapsing across the three levels of confidence within the "same" and the "different" category. Only ratings from the final six trials of each experimental block—which comprised target, early-change distracter, and late-change distracter integrant and aggregate test items—were thus converted. (Earlier trials—with target and both-change distracter items—served to familiarize the participant with the multipart exposure item.) Early-change and late-change distracters were collapsed for the computation of *d'* and *c*'. Analyses of variance (ANOVAs) were conducted for the *d*' and *c*' scores, with the criterion for statistical significance set at α = .05. The Greenhouse-Geisser correction was applied when the value of the degrees of freedom numerator exceeded 1.

RESULTS

Recognition scores (*d*') for integrant and aggregate test items in matched-metrical, mismatched-metrical and nonmetrical conditions are shown in Figure 5.[2] High scores indicate high sensitivity to changes from exposure to test. Response bias scores (*c*') are reported later.

To determine whether listeners were in fact engaging in PIA, we examined whether recognition accuracy for target integrant and aggregate patterns was reliably greater than chance by comparing listeners *d*' scores against zero in separate *t* tests. These tests revealed better than chance performance both for integrant patterns (M d' = 0.78), $t(23) = 2.78$, $p < .01$, and for aggregate patterns (M d' = 1.94), $t(23) = 7.89$, $p < .001$. Finding

2. The error bar on the right—labeled 2**SE*—represents double the standard error of the mean. The standard error was computed in the manner suggested by Loftus and Masson (1994) for repeated-measures designs.

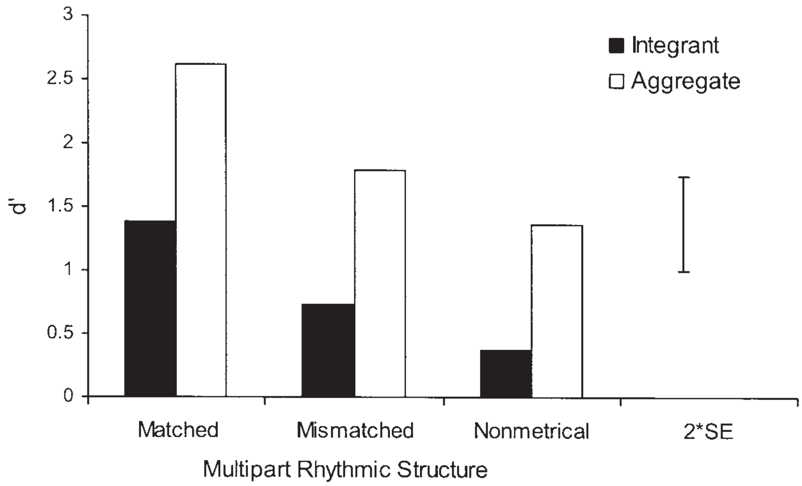

Fig. 5. Recognition accuracy (mean *d'*) for target integrant and aggregate patterns in matched-metrical, mismatched-metrical, and nonmetrical conditions in Experiment 1. (The error bar on the right—labeled 2**SE*—represents double the standard error; see footnote 2.)

that aggregate recognition was better than chance is particularly important because indicates that listeners were able to abstract the aggregate structure from two interleaved integrant patterns. We would not have obtained this result if listeners had simply divided their attention between the target and the complementary integrant patterns without integrating them (because the aggregate test items were presented in a single instrumental timbre). Similarly, recognition accuracy for target integrant patterns would not have been better than chance if listeners were focusing exclusively on the aggregate structure (pure NPIA). Thus, we conclude that the listeners were most likely engaging in PIA.

A preliminary ANOVA on the d' scores revealed that the between-group factor had no significant effect on recognition, $F(5, 18) = 1.34$, $p > .2$, so we collapsed across this factor for the main analysis. The main analysis examined the effects of multipart rhythmic structure on recognition at both the target integrant and the aggregate textural levels in a 3 (matched-metrical, mismatched-metrical, nonmetrical) × 2 (integrant, aggregate) ANOVA. This analysis revealed significant main effects of multipart rhythmic structure, $F(2, 46) = 4.98$, $p < .02$, and textural level, $F(1, 23) = 11.12$, $p < .01$, but no significant interaction between these factors, $F(2, 46) < 1$.

The effect of multipart rhythmic structure was unpacked by using two planned orthogonal contrasts that are based on the predictions stated in the introduction to the current experiment. The first contrast compared recognition accuracy between the matched-metrical condition and the nonmetrical condition. In accordance with our main prediction, the recognition of target and integrant and aggregate patterns was reliably better in the matched-metrical condition than in the nonmetrical condition, $F(1, 23) = 6.79$, $p < .02$. The second contrast tested our more tentative prediction that recognition accuracy in the mismatched-metrical condition would be intermediate to accuracy in the matched-metrical condition and the nonmetrical condition. This contrast compared accuracy scores from the mismatched-metrical condition with the average of the accuracy scores from the matched-metrical and nonmetrical conditions combined. In support of our second prediction, accuracy scores from the mismatched-metrical condition were intermediate: They were not significantly different from the average of the accuracy scores from the matched-metrical and nonmetrical conditions combined, $F(1, 23) = 0.52$, $p > .4$. This result seems to support a null hypothesis, which raises the question of whether our test had sufficient statistical power. Our analysis indicates that it did: For the main effect of multipart rhythmic structure, partial ε^2 (a measure of effect size) was .17 and observed power was .77 (which is around conventionally accepted levels).

The main effect of textural level—indicating that recognition was generally better for aggregate patterns than for target integrant patterns—may be due to (a) participants treating aggregate recognition as the primary dual-task component, and/or (b) the types of changes from target to distracter items being easier to detect in the case of aggregate test items (wherein the serial order of figural groups was changed) than integrant test items (wherein the time interval between figural groups was changed, while the order of these groups remained the same). It was not a purpose of the current study to distinguish between these alternatives.

The fact that textural level did not interact with multipart rhythmic structure indicates that the effects of multipart rhythmic structure were commensurate at both the target integrant level and the aggregate level of multipart texture. (A significant interaction between multipart rhythmic structure and textural level would have justified analyzing accuracy scores for integrant test items and aggregate test items separately.)

The c' scores—representing response bias—were analyzed in an analogous fashion to the d' scores. Neither the preliminary ANOVA (testing for effects of group) nor the main ANOVA (testing for effects of multipart rhythmic structure and textural level) on c' scores revealed any statistically significant effects, ps > .3. Furthermore, a t test revealed that c' scores ($M = -0.09$) were not reliably different from zero, which indicates that response biases were negligible, $t(23) = 1.09$, $p > .2$.

DISCUSSION

The current results indicate that the dual task of simultaneously memorizing the target integrant and aggregate aspects of a multipart pattern—a task that we assume requires PIA—can be performed more accurately when the target integrant pattern and the aggregate pattern fit within the same metric framework than when the target integrant pattern is nonmetrical. Furthermore, such dual-task performance is of intermediate accuracy when the target integrant and aggregate patterns do not fit well within the same metric framework. Thus, attentional resource allocation is enhanced, and PIA proceeds most efficiently, when metric framework generation is encouraged by multipart rhythmic structure, though these benefits appear to be affected by whether or not the target integrant pattern and the aggregate pattern are compatible in terms of best-fitting meter.

The results for the mismatched condition—which was included in the study for exploratory reasons—are particularly interesting because they provide behavioral evidence that the incompatibility between metric bar-level periodicities produces a degree of rhythmic complexity that lies somewhere between the complexity of metrically compatible patterns and nonmetrical patterns. This incompatibility can be considered to be analogous to the conflicting pulses underlying polyrhythms, wherein isochronous integrant patterns divide the same overall time period into temporal units that combine to form inharmonic ratios such as 2:3 and 3:4 (e.g., Handel, 1984; Jones, Jagacinski, Yee, Floyd, & Klapp, 1995; Klapp, Hill, Tyler, Martin, Jagacinski, & Jones, 1985), although the incompatibility lies at the beat level rather than the bar level in polyrhythm.

Metric incompatibility between target integrant and aggregate patterns is one possible explanation for the intermediate performance accuracy observed in the mismatched-metrical condition. However, the mere fact that we used triple target integrant patterns in this condition may have also played a role. Triple meter is less common than binary (duple and quadruple) meters in Western music (Lerdahl & Jackendoff, 1983), and there exists evidence that rhythm perception and production are poorer with triple patterns than with patterns fitting a binary meter (Drake, 1993; Fraisse, 1982; Smith & Cuddy, 1989). We circumvented this issue in Experiment 2 by testing professional percussionists, for whom triple metric structures should not be problematic. However, the main aim of Experiment 2 was to investigate whether the benefits of matched-metrical target integrant/aggregate relations over nonmetrical integrant/aggregate relations found in the current experiment generalize to a dual task with different behavioral (reproduction rather than recognition) and attentional (DA rather than PIA) demands.

Experiment 2

Experiment 2 employed a pattern reproduction paradigm to simulate DA during ensemble performance. The reproduction task involves a rhythmic canon wherein the "lead" part is presented by computer and the performer is required to "follow" this lead by reproducing it at a lag interval. The lead part always consists of a model antecedent/consequent pair of patterns, where the consequent follows the antecedent immediately and both have the same overall duration (see Figure 6). In fact, the antecedent and consequent patterns were adapted from the rhythm sets used in Experiment 1: Antecedent patterns were identical in structure to the target integrant patterns, and consequent patterns were identical to the target aggregate patterns (see Figure 3). The participant's task is to begin reproducing the antecedent/consequent pair at the point when the consequent pattern begins in the computerized lead part. This produces a situation where the performer is required to (a) memorize the antecedent pattern, (b) memorize the model consequent pattern while reproducing the antecedent pattern, and (c) reproduce the consequent pattern.

The temporal relationship between antecedent and consequent patterns was manipulated to produce three multipart rhythmic structure conditions that correspond to those examined in Experiment 1: (a) matched metrical—antecedent and consequent patterns best fit a quadruple meter; (b) mismatched metrical—antecedent and consequent patterns best fit different meters (triple and quadruple, respectively); (c) nonmetrical—the antecedent pattern is nonmetrical, whereas the consequent pattern is metrical (quadruple). Our main prediction was that reproduction accuracy for antecedent and consequent patterns should be better in the matched-metrical condition than in the nonmetrical condition.

Several possible informative outcomes can be distinguished with regard to how performance in the mismatched-metrical condition relates to performance in the matched-metrical and nonmetrical conditions. First, per-

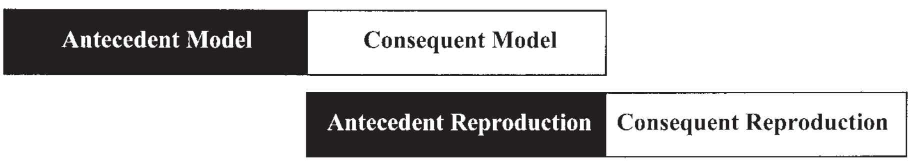

Fig. 6. The rhythmic canon task used in Experiment 2. The model antecedent/consequent pattern (presented by computer) is reproduced by the participant at a lag interval. DA is required during the section of the canon where computer and the performer overlap (i.e., consequent model accompanies antecedent reproduction).

formance accuracy in the mismatched-metrical condition could be intermediate to accuracy in the metrical and nonmetrical conditions both for antecedent and consequent patterns (similar to the result for integrant and aggregate patterns in Experiment 1). This outcome would indicate that metric incompatibility and/or triple structure present problems for participants. Second, performance in the mismatched-metrical condition could be better than intermediate to performance in the metrical and nonmetrical conditions both for antecedent and consequent patterns. This would indicate that neither metric incompatibility nor triple structure are problematic. Third, there could be a dissociation between performance in the mismatched-metrical condition relative to performance in the metrical and nonmetrical conditions for antecedent and consequent patterns. One possibility is that performance in the mismatched-metrical condition could be intermediate to performance in the matched-metrical and nonmetrical conditions for consequent patterns, but not for antecedent patterns. This would indicate that triple structure per se is not problematic (i.e., triple antecedent patterns can be reproduced with better than intermediate accuracy), suggesting that incompatible antecedent/consequent metric structure is the problematic factor (i.e., quadruple consequent reproduction accuracy is intermediate when antecedent patterns are triple). The only remaining alternative—that is, performance in the mismatched-metrical condition is intermediate to performance in the matched-metrical and nonmetrical conditions for antecedent patterns, but not for consequent patterns—could be interpreted similarly.

Note that although the current rhythmic canon paradigm presents a dual task—reproducing the antecedent pattern while memorizing the consequent—it does not require PIA: Accurate performance is, in principle, achievable by simply *dividing* one's attention between the two task components. In the context of ensemble performance, such a strategy would amount to attending simultaneously to one's own part and another musician's part without necessarily integrating the two. Nevertheless, the cognitive processes underlying attention to both parts are not entirely independent under such circumstances (cf. Klein & Jones, 1996). These processes must be linked together, or time-locked, in order to for the parts to remain synchronized, which is necessary for performance in ensembles and the current experimental task alike. In the case of synchronization with a computerized performance, this time-locking is most likely achieved by the same processes—phase correction and period correction—that enable sensorimotor synchronization with an auditory metronome (Large & Jones, 1999; Mates, 1994; Pressing, 1999; Repp, 2001, Repp & Keller, 2004; Vorberg & Wing, 1996). However, these processes are augmented in the current task by the need to abstract a beat- and bar-level periodicity from the nonisochronous computerized pattern (see Snyder & Krumhansl, 2001).

METHOD

Participants

Participants were 12 professional percussionists (20–52 years old). All had extensive experience as performers in symphony orchestras and smaller ensembles specializing in contemporary music.

Stimuli and Apparatus

The stimulus patterns used as antecedent and consequent patterns were drawn from the same 12 rhythm sets used in Experiment 1. The target integrant patterns from each rhythm set—labeled "Quadruple," "Triple," and "Nonmetrical" in Table 1—served as antecedent patterns and the "Aggregate" patterns served as consequent patterns. The entire stimulus pool consisted of (a) 12 quadruple antecedent patterns, (b) 12 triple antecedent patterns, (c) 12 nonmetrical antecedent patterns, and (d) 12 consequent patterns, each best fitting a quadruple meter. These patterns were concatenated to form stimulus items in which a consequent pattern follows each antecedent pattern immediately (i.e., the final element of an antecedent is treated as the first element of the consequent). Thus, three stimulus items were adapted from each rhythm set. Across items from a set, the same consequent pattern is preceded by either a quadruple, a triple, or a nonmetrical antecedent pattern, corresponding to the three multipart rhythmic structure conditions. All patterns were presented at the same rate: grid unit duration = 150 ms.

Apparatus included (a) a PowerBook 5300cs Macintosh computer, (b) MAX (version 3.0) software, (c) a Roland MT-32 sound module, (d) a Roland SPD-11 MIDI percussion pad, and (e) a Creative SBS-300 loudspeaker.

Design

As in Experiment 1, multipart rhythmic structure (matched metrical; mismatched metrical; nonmetrical) was varied within participants, and a between-group factor (Group 1-6) that determined the assignment of rhythm sets to multipart rhythmic structure conditions was included for control purposes. The dependent variable was reproduction accuracy for antecedent and consequent patterns (see Data Collection and Analysis).

Procedure

Each participant was tested at his or her private residence. After written and verbal instructions were given, the participant completed three blocks of practice trials (one block per multipart rhythmic structure condition), followed by six blocks of test trials (two blocks per multipart rhythmic structure condition). Thus, in the test trials, each participant encountered two different antecedent and consequent patterns in each of the three multipart rhythmic structure conditions, with the patterns and conditions being combined differently for participants from the six different groups. Each block consisted of two phases: A familiarization phase and a test phase.

In the *familiarization phase,* the participant was given the opportunity to gain familiarity with the antecedent pattern that was to be featured in the test phase of the current block. Clicking with the mouse on a virtual button on the computer screen triggered one presentation of the antecedent pattern, which was articulated by a snare drum sound emanating from the loudspeaker positioned directly in front of the participant. The participant was instructed to listen to the antecedent pattern as many times as were required in order to memorize it. The number of times that the participant chose to listen to the antecedent pattern was recorded by the computer as a measure of *auditory inspection time,* which is a crude behavioral index of pattern complexity (see Povel & Essens, 1985).

The *test phase* consisted of three identical "performance trials," each initiated by depressing the spacebar on the computer keyboard. The task in each performance trial was based on a rhythmic canon, wherein the computer presented the lead part and the participant followed. The lead parts consisted of antecedent/consequent pairs of patterns articulated by a snare drum sound (with a MIDI velocity value of 96). In each pair, the consequent pattern followed the antecedent pattern immediately. The transition from the antecedent to the consequent pattern was not signaled explicitly, but should have been assisted by familiarity with the antecedent pattern.

In each performance trial, the participant was required to begin reproducing the (familiar) antecedent pattern (by tapping with a pair of drum sticks on the percussion pad) at the point when the consequent pattern began. While reproducing the antecedent pattern, it was necessary for the participant to attempt to memorize the consequent pattern that was being presented concurrently by the computer, in order to reproduce the consequent immediately after their reproduction of the antecedent. Each strike of the percussion pad produced a single cowbell sound (with a fixed MIDI velocity value of 118).

Data Collection and Analysis

To measure reproduction accuracy, the percussion pad was sampled every 150 ms, starting 50 ms before the beginning of each model (i.e., computer-presented) consequent pattern. Sampling units were thus offset by -50 ms relative to grid units underlying model consequent patterns in order to allow for anticipations of the veridical position of pattern elements. (In fact, informal pilot tests had revealed that—when tapping nonisochronous rhythms with drumsticks—delays were more common than anticipations, which is contrary to what is usual when the task is to produce isochronous finger taps in synchrony with a metronome; see Aschersleben, 2002). If a tap occurred during one of the 150-ms sampling units, a "1" was recorded; otherwise a "0" was recorded. The resultant string of binary code for each performance trial represents the participant's reproduction of a single antecedent/consequent pair of patterns. We parsed each data string into antecedent and consequent sections according to features such as rhythmic figures and total number of elements, in order to take into account errors involving phase-shifted consequent reproductions (e.g., early or late entries due to erroneous antecedent timing). Such errors affected, on average, 14% of matched-metrical trials, 14% of mismatched-metrical trials, and 68% of nonmetrical trials. Phi coefficients—a measure of the correlation between two dichotomous variables—were calculated (a) between the binary code version of each antecedent pattern reproduction and a similarly coded version of the relevant model antecedent pattern and (b) between the coded version of each consequent pattern reproduction and the relevant coded model consequent.[3] These correlations were used as an index of performance accuracy.[4]

Correlations between antecedent models and reproductions, and consequent models and reproductions, were converted to Fisher z' scores and then analyzed in an ANOVA

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3. The coded version of each model antecedent and consequent pattern was appended with a string of 15 "0"s to increase the number of grid units so that it matched the number of sampling units in the antecedent and consequent reproduction codes (which was increased by a corresponding amount of units to accommodate potential errors that resulted in the lengthening of pattern reproductions). Although these appended zeros increase the absolute value of the phi coefficients slightly, they do not affect how the coefficients from different multipart rhythmic structure conditions compare relative to one another.

4. An alternative would have been to employ the Unix "diff" command (see Finney, 1997). This would have been useful for identifying different types of errors (e.g., commissions vs. omissions) and their location in pattern structure. However, for present purposes, we were more interested in a global measure of accuracy, and hence correlations were considered to be an appropriate index.

with the criterion for statistical significance set at $\alpha = .05$ and the Greenhouse-Geisser correction applied when appropriate. Auditory inspection time data—that is, the number of times that participants chose to hear antecedent patterns during familiarization phases—were also analyzed in an ANOVA with the same criterion for significance and correction technique. Preliminary ANOVAs revealed that group had no significant effects (*p*s > .1), so we collapsed across this factor in the analyses reported below.

RESULTS

With regard to auditory inspection time, the mean numbers of hearings for the three types of antecedent pattern during familiarization (i.e., before each block of three rhythmic canon trials) were as follows: quadruple = 5.00 (*SD* = 1.93); triple = 5.92 (*SD* = 3.32); nonmetrical 16.21 (*SD* = 14.26). An ANOVA revealed that the type of antecedent pattern had a significant effect on auditory inspection time, $F(2, 22) = 6.87$, $p < .03$. This effect was unpacked by using two planned orthogonal contrasts. The first contrast compared auditory inspection time for quadruple and nonmetrical patterns, and revealed that, as expected, the number of hearings was significantly greater for the latter, $F(1, 11) = 6.21$, $p < .03$. The second contrast tested whether the number of hearings required for triple patterns fell midway between the number of hearings required for quadruple and nonmetrical patterns. Borrowing the logic used in Experiment 1, this contrast compared the number of hearings for triple patterns with the average number of hearings for quadruple and nonmetrical patterns combined. The finding that this contrast yielded a significant difference, $F(1, 11) = 8.89$, $p < .02$, indicates that the number of hearings required for triple antecedent patterns was in fact not intermediate. As can be seen in the mean values listed above, the number of hearings required to gain familiarity with triple patterns was closer to the number of hearings required for quadruple patterns than to the number of hearings required for nonmetrical patterns.

Figure 7 shows the results for antecedent reproduction accuracy and consequent reproduction accuracy (mean z' scores were converted back to phi coefficients for the presentation of these data in order to facilitate interpretation). High scores indicate a high degree of accuracy. A 3 × 2 ANOVA examining the effects of multipart rhythmic structure on reproduction accuracy for both the antecedent and the consequent part of the canon revealed significant main effects of multipart rhythmic structure, $F(2, 22) = 29.68$, $p < .001$, and part of the canon, $F(1, 11) = 19.67$, $p = .001$, and a significant interaction between these factors, $F(2, 22) = 18.56$, $p < .001$.

The main effect of part of the canon indicates that reproduction accuracy was generally better for antecedent patterns than for consequent patterns. We hesitate to make strong claims about how this effect should be interpreted, because it has several potential sources that are not of inter-

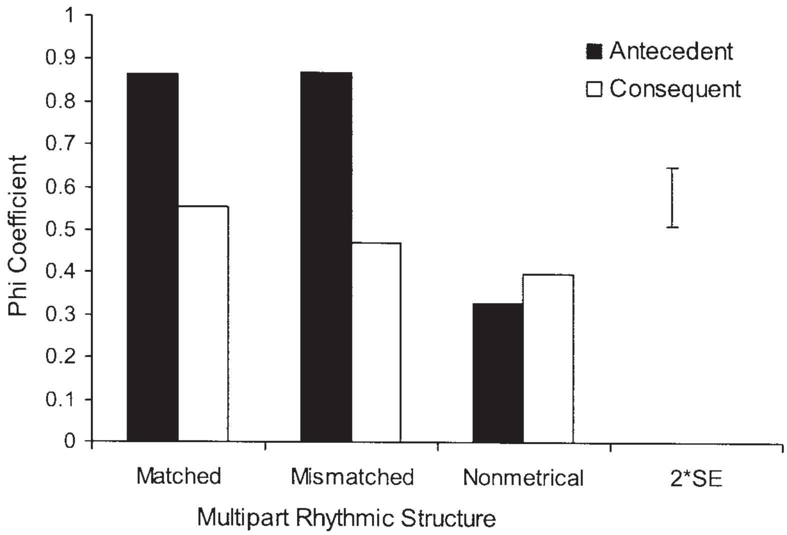

Fig. 7. Reproduction accuracy (mean phi coefficients) for antecedent and consequent patterns in matched-metrical, mismatched-metrical, and nonmetrical conditions in Experiment 2. (The error bar on the right—labeled 2*SE—represents double the standard error; see footnote 2.)

est in the current study (e.g., the difference in the number of elements in antecedent and consequent patterns, the fact that only the antecedent patterns were encountered during familiarization phases, and the fact that antecedent reproduction was paced by the ongoing model consequent, while consequent reproduction was unpaced). The effects of multipart rhythmic structure and the interaction between multipart rhythmic structure and part of the canon are more remarkable.

The effect of multipart rhythmic structure on reproduction accuracy for antecedent and consequent patterns was unpacked by using two planned orthogonal contrasts (following the logic from Experiment 1). The first contrast compared reproduction accuracy between the matched-metrical condition and the nonmetrical condition. In accordance with our main prediction, the reproduction of antecedent and consequent patterns was reliably better in the matched-metrical condition than in the nonmetrical condition, $F(1, 11) = 41.55$, $p < .001$. Furthermore, there was a significant interaction between part of the canon and the effect of matched-metrical versus nonmetrical structure, $F(1, 11) = 34.76$, $p < .001$, indicating that the advantage of the matched-metrical condition over the nonmetrical condition was more pronounced for antecedent patterns than for consequent patterns. This may reflect the fact that rhythmic complexity was manipulated directly in the case of antecedent patterns (wherein physical pattern structure was varied), but only indirectly in the case of consequent patterns (wherein physical pattern structure was held constant in order to allow us to examine the subjective effects of producing metrical versus nonmetrical antecedent patterns on the concurrent perception of a consequent pattern). To check whether the effect of matched-metrical versus nonmetrical structure was present for both parts of the canon, we analyzed the antecedent and consequent reproduction accuracy data separately. The results of this analysis confirmed that the advantage of matched-metrical over nonmetrical structure was present for both parts of the canon: antecedent, $F(1, 11) = 44.67$, $p < .001$; consequent, $F(1, 11) = 10.39$, $p < .01$.

The second contrast examined whether antecedent and consequent reproduction accuracy in the mismatched-metrical condition was intermediate to accuracy in the matched-metrical condition and the nonmetrical condition. This contrast compared accuracy scores from the mismatched-metrical condition with the average of the accuracy scores from the matched-metrical and nonmetrical conditions combined, revealing that reproduction accuracy in the mismatched-metrical condition was, on average, *better than intermediate* to accuracy in the matched-metrical and the nonmetrical condition, $F(1, 11) = 9.86$, $p < .01$. However, there was a significant interaction between this effect and part of the canon, $F(1, 11) = 15.75$, $p < .01$, perhaps suggesting that performance was better than intermediate for antecedent patterns, but not for consequent patterns (see Figure 7). To test this, we analyzed the antecedent and consequent reproduction accuracy data separately for the second contrast.

The analysis of antecedent reproduction data revealed that accuracy in the mismatched-metrical condition was indeed better than intermediate to accuracy in the matched-metrical and the nonmetrical condition, $F(1, 11) = 15.46$, $p < .01$. This result, taken together with the finding that auditory inspection time for triple antecedent patterns was relatively low, suggests that—as expected—participants had little trouble with triple structure. Importantly, however, the analysis of consequent reproduction data revealed that accuracy in the mismatched-metrical condition was intermediate to accuracy in the matched-metrical and the nonmetrical condition, that is, accuracy in the mismatched-metrical condition was not significantly different from average accuracy in the matched-metrical and nonmetrical conditions combined, $F(1, 11) = 0.02$, $p > .8$. (For the main effect of multipart rhythmic structure, partial ε^2 was .7 and observed power was 1).

DISCUSSION

The current results indicate that the dual task of simultaneously reproducing a rhythm pattern (the antecedent) while memorizing a concurrently presented pattern with different rhythm (the consequent)—a task that requires DA—can be performed more accurately when the two patterns fit well within the same metric framework than when the antecedent is nonmetrical. This finding demonstrates that the main result of Experiment 1 generalizes from a recognition memory paradigm requiring PIA to a reproduction paradigm requiring DA. Furthermore, the results of the current experiment are informative about the effects of producing one (antecedent) pattern while simultaneously memorizing another (consequent) pattern when they are mismatched in terms of best-fitting meter (triple vs. quadruple, respectively). Accuracy at subsequently reproducing the *consequent* patterns under such conditions was *intermediate* to accuracy under conditions where the antecedent pattern was nonmetrical and conditions where both patterns were matched in meter (quadruple), even though reproduction accuracy for the metrically mismatched *antecedent* patterns was itself *better than intermediate*. This dissociation suggests that antecedent/consequent metric incompatibility was responsible for the intermediate performance with consequent patterns, rather than disadvantages associated with triple structure per se. Thus, metric incompatibility at the bar level seems to be a tenable concept.

General Discussion

Two experiments investigated the effects of multipart rhythmic structure upon musicians' ability to engage in PIA (i.e., to attend simultaneously to target integrant and aggregate aspects of multipart patterns) and DA (to attend simultaneously to two different rhythm patterns without necessarily integrating them). Experiment 1 employed a recognition memory paradigm in which musically trained listeners were required to memorize target integrant and aggregate aspects of multipart patterns simultaneously. Multipart rhythmic structure was manipulated such that the target integrant pattern either best fit the same meter as the aggregate pattern, best fit a different meter to the aggregate pattern, or was nonmetrical. Overall recognition accuracy—our index of success at PIA—was best when the target integrant and aggregate pattern were matched in meter, intermediate when they were mismatched in meter, and poorest when the target integrant was nonmetrical.

Experiment 2 extended these findings in a pattern reproduction task where, in the context of a rhythmic canon, professional percussionists first listened to a pattern (the antecedent) and then reproduced it while listening to a concurrently presented (consequent) pattern, which also had to be subsequently reproduced. In effect, attention had to be divided between two integrant patterns that were related such that they were either matched in meter, mismatched in meter, or one (the antecedent) was nonmetrical. Here it was found that reproduction accuracy—hence success at

DA—was best when the antecedent and consequent patterns were matched in meter and poorest when the antecedent was nonmetrical. However, a dissociation was observed when the antecedent and consequent were metrically mismatched (triple and quadruple, respectively): Reproduction accuracy was intermediate to accuracy in the matched-metrical and nonmetrical conditions in the case of consequent patterns, but better than intermediate for antecedent patterns. This outcome suggests that the ability to engage in DA was affected more by antecedent/consequent metric compatibility (quadruple/quadruple vs. triple/quadruple) than by the metric identity of the antecedent patterns per se (quadruple vs. triple). Thus, the results of Experiments 1 and 2 provide converging evidence that our conception of metric compatibility is psychologically valid.

On the whole, the results of Experiments 1 and 2 suggest that PIA and DA proceed efficiently so long as the target integrant pattern and the aggregate pattern (in PIA) or the two integrant patterns (in DA) share the same underlying metric structure. As mentioned at the start of this article, past studies have shown that the process of synchronizing one's biologically based rhythms with such hierarchical structure facilitates recognition and reproduction of rhythm. The current study extends that finding to a dual-task context, carrying the implication that synchronization provides a common mechanism that assists performance on both tasks that involve PIA (target integrant and aggregate processing) and tasks that involve DA (processing multiple integrant patterns). There are several ways in which synchronization may be beneficial. First, it may serve to time-lock the individual's cognitive/motor system to the pattern and then, following this form of calibration, it may form the basis for expectancies that delineate attentional trajectories (Jones, 1990; Large & Jones, 1999) for processing upcoming events at both the target integrant and the aggregate level during PIA, or for processing events in two separate integrant streams during DA. Thus, in the context of ensemble listening (Experiment 1), internal pulsations provide a common timing mechanism that can be used to predict events at both levels of multipart structure. In ensemble performance (Experiment 2), this mechanism additionally guides the process of retrieving from memory the performance plans used in producing a target integrant pattern (see Drake & Palmer, 2000; Palmer, 1997; Palmer & Pfordresher, 2003). Broadly speaking, the current findings are consistent with the hypothesis that metric frameworks serve as cognitive/motor schemas that promote efficient attentional resource allocation during PIA and DA.

However, when the target integrant pattern does not have an underlying metric structure (i.e., it is nonmetrical), ability to engage in PIA and DA is impaired even when the aggregate pattern, or a secondary integrant pattern, does have such structure. The decrement in performance going from (matched) metrical to nonmetrical conditions observed here provides empirical evidence that processing nonmetrical structure is costly in terms of attentional resources. Whether these costs arise directly or indirectly remains uncertain. Indirect costs might occur if, even though one is successful at synchronizing with the periodicities underlying the aggregate pattern (in PIA) or the secondary integrant pattern (in DA), measuring the complex structure of the nonmetrical target integrant against this regular structure were to divert resources from the task of encoding the aggregate, or secondary integrant, pattern. Specifically, when elements in the target integrant pattern cannot be reliably predicted or produced, the process of grouping together target and complementary integrant elements—or even simply attending to a second integrant pattern—may encounter interference. Alternatively, direct costs would arise if processing nonmetrical structure actually disrupts synchronization with the periodicities underlying the aggregate or secondary integrant, and thus precludes metric framework generation. Indeed, such disruption may occur because the processing of nonmetrical patterns involves strategies such as counting the number of elements within figural groups, estimating the time interval between these groups, and employing mnemonic devices (Bamberger, 1980; Handel, 1992; Hébert & Cuddy, 2002; Smith, Cuddy, & Upitis, 1994). Although counting elements in figural groups may be a relatively automatic process (when the number is small), time estimation and the use of mnemonics are generally effortful (Hasher & Zacks, 1979; Jackson, 1985) and, to the extent that they channel attention to aperiodic structural boundaries within the pattern, incompatible with the extraction of beat- and bar-level periodicities. Note that the foregoing is consistent with more general interference-based explanations of dual-task decrements, which posit that performance degradation is a consequence of the disruption of processing—synchronization in the current case—rather than scarcity of resources per se (see Neumann, 1996; Wickens, 1989, 1991). During PIA and DA, the disruption of synchronization would prevent time-locking between the attender and the external pattern, leading to a situation where target integrant and aggregate processing become independent, mutually interfering, tasks.

Several noteworthy issues remain unanswered by the current study. These relate mainly to the mechanisms that underlie PIA, which is a mode of attending about which little is known. One issue concerns whether target and complementary integrant patterns are processed in parallel, by switching, or by a mixture of these two strategies during PIA. Parallel processing involves distributing attention continuously across elements in target and complementary integrant patterns in a graded fashion, with more weight given to target elements, whereas switching involves shifting attention back and forth between target and complementary elements. These types of strategy have been studied in the context of DA in nonmusical tasks (see Moray, 1969; Pashler, 1998; Wickens, 1991). To the extent that the results of such research generalize to musical tasks, the choice of strategy is most likely context dependent, for example, switching may be optimal when target and complementary integrant patterns are rhythmically differentiated, or "interleaved" (as was the case in Experiment 1), whereas parallel processing may be more appropriate when target and complementary integrants are in rhythmic unison. Attenders may even adopt different strategies during the course of a pattern. Finally, it may be the case that if switching occurs, it is achieved with greater success in metrical conditions: The predictability of metric structure may grant listeners the latitude to shift attention freely between target and complementary patterns.

The preceding issues concerning switching versus parallel processing could be investigated in future research by examining the effects of presentation rate on ability to engage in PIA and DA.[5] If listeners employ a switching strategy, then aggregate perception should be better at slow rates than at fast rates because there is more time to shift attention between target and complementary elements; however, if parallel processing is used, then aggregate perception should either be unaffected by rate, or become most difficult at slow rates due to increased memory load. Precedent for such work has been set in studies addressing the distinction between integrated and parallel processes in the perception and production of polyrhythms (e.g., Handel, 1984; Jones et al., 1995; Klapp et al., 1985; Krampe, Kliegel, Mayr, Engbert, & Vorberg, 2000; Pressing, Summers, & Magill, 1996; Summers, Rosenbaum, Burns, & Ford, 1993).

Another potentially interesting issue concerns how PIA is affected by the degree to which integrant patterns are differentiated in terms of timbre and pitch range (see Keller, 2001b). These factors would be expected to be influential to the extent that they play a role in auditory stream segregation (see Bregman, 1990; Brochard, Drake, Botte, & McAdams, 1999; van Noorden, 1975). Earlier research has demonstrated that wide pitch separation between integrant patterns—which encourages each integrant pattern to be perceived as an independent perceptual stream—facilitates selective attending (SA) to a target integrant whereas narrow separation—which encourages the separate integrants to be perceived as a single stream—encourages nonprioritized integrative attending (NPIA) to the aggregate (Jones et al., 1995). Therefore, during PIA, pitch separation should influence both how well the target integrant can be segregated and how well target and complementary patterns can be combined to perceive the aggregate. Similarly, in DA, segregation should be easier with wide pitch separation and integration should be easier with narrow separation. Furthermore, pitch separation might influence whether a switching or

5. Although presentation rate was varied randomly between blocks in the current Experiment 1, this variation was not systematic enough to justify analysis.

parallel processing strategy is adopted because streaming is more conducive to switching whereas integrated percepts favor parallel processing (Jones, 1976; Michon & Jackson, 1984). Analogous effects should occur with timbre, as it has been shown that auditory stream segregation is affected by the perceived similarity of integrant patterns in terms of instrumental sound (Iverson, 1995).

A final topic that may be fruitful to explore concerns the neural mechanisms underlying PIA. Recent brain imaging studies have shown that the degree to which the various cortical areas implicated in attentive listening to music are activated differs for NPIA/DA and SA (Janata et al., 2002; Satoh et al., 2001). For example, Satoh et al. (2001) found differences in cortical activation based on whether the task for listeners was to detect minor chords in four-part Bruckner motets (NPIA) or to detect tonic or dominant tones in just the alto part of the motets (SA). This raises the question whether PIA produces an activation profile that is distinct from the profiles associated with NPIA and SA. That is, would Satoh et al. (2001) have found further differences in cortical activation if they had required their listeners to perform both detection tasks simultaneously, or would it simply be the case that both the NPIA and the SA profile arise together? Either way, brain imaging techniques may yield clues about the nature of the attentional resources—a traditionally rather amorphous concept—involved in PIA.[6]

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