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Attentional Resource Allocation in Musical Ensemble Performance

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Abstract

Individual performers in ensembles must attend simultaneously to their own part and parts played by others. Thus, they allocate attentional resources skilfully and flexibly between different sound sources in order to (*a*) monitor their own part and other parts, and (*b*) group together elements from these parts to derive the whole ensemble texture. The theory of Attentional Resource Allocation in Musical Ensemble Performance (ARAMEP) presented here accounts for how attentional flexibility is influenced by various musical and extramusical factors. It is claimed that these factors act directly upon cognitive/motor mechanisms that regulate attentional resource allocation. Particular focus is given to the role of meter in modulating resources in a manner that is plastic and efficient, and hence conducive to optimal attentional flexibility. Specifically, metric frameworks enable the availability of resources to be varied systematically, so as to compensate for fluctuations in resource activity that arise due to variability in the concentration of events at different metric locations in the music.

This theoretical paper is concerned with the topic of how musicians contend with the high attentional demands that arise during performance in musical groups, or ensembles. These demands differ from those that characterise solo performance primarily in terms of the requirement to monitor the sounds produced by fellow ensemble members, as well as one's own sound. The theory of Attentional Resource Allocation in Musical Ensemble Performance (ARAMEP) presented here aims to provide a framework for studying the cognitive mechanisms that underlie, and the factors that influence, attention in ensembles. As an *a priori* theory, ARAMEP is inferred mainly from the results of research that does not relate directly to ensemble performance. The theory is valuable because it provides a stockpile of testable predictions that has the potential to fuel empirical research into a topic yet to receive the consideration it deserves.

Why attending in ensembles is important

Much of the world's music is performed by ensembles consisting of two or more individuals. Usually these individuals aim to interact during performance in a manner that is conducive to producing a coherent and cohesive musical entity. Clearly, to realise this goal, each performer must simultaneously listen to their own part and parts played by others. This process, which has been termed *prioritised integrative attending* (Keller, 1999; 2000; 2001a; 2001b), essentially involves dividing attention between a high priority part (one's own part) and the overall aggregate structure that emerges when all parts (including one's own) are combined.

Of course, it may not be practical, or even optimal, to engage in prioritised integrative attending in every instance of ensemble music. Other relevant attending modes that have been identified include selective attending – wherein the performer attends exclusively to their own part – and non-prioritised integrative attending – wherein all parts are equal in importance and the aggregate structure is the focus of attention (see Keller, 2000; 2001a). Selective attending to one's own part may be desirable in musical contexts that seek to emphasise the independence of parts, sometimes in order to create a chaotic effect (*e.g.,* aleatoric music). Non-prioritised integrative attending is more likely to occur in the context of ensemble listening than ensemble performance because one's own part presumably needs to be monitored with some degree of independence from other parts. However, in some instances of prioritised integrative attending, the importance of attending to the aggregate structure may override the need to pay attention to one's own part (*e.g.,* when sections of a vocal choir have many members, who are each highly familiar with their part, the ensemble will benefit most from these individuals attending to the overall choral sound rather than their own voice). In any case, the fact that performers in a wide variety of ensemble settings and cultures consider prioritised integrative attending as somewhat of an ideal (see Keller, 2001b) suggests that, whereas selective attending and non-prioritised integrative attending are exceptions, prioritised integrative attending is the norm.

Surprisingly, despite the pervasiveness and apparent cultural significance of ensembles, theoretical knowledge is lacking about the factors that influence prioritised integrative attending, and the mechanisms that underlie it. Identifying the factors that affect ability to engage in prioritised integrative attending should be particularly useful for developing systematic music educational techniques aimed at fostering ensemble skills. Such techniques are needed because, although existing techniques are based upon expert musical intuition, evidence of their success is only anecdotal (*e.g.,* Casey, 1991). At a more general level, gaining an understanding of the cognitive mechanisms underlying prioritised integrative attending should benefit theories of attention and multiple task behaviour, which have neglected to address this attending mode. Indeed, ensemble performance can be viewed as a multiple task to the extent that it requires the performer to allocate attentional resources skilfully and flexibly between different sound sources. ARAMEP (which is described in greater detail by Keller, 2000) is presented here as a heuristic for studying the dynamics of prioritised integrative attending.

Resource components of prioritised integrative attending

Broadly speaking, *resources* are the sensory, perceptual, cognitive, and motor processes that underlie human behaviour. Modern theories of multiple task behaviour claim that resources are arranged in multiple pools that are differentiated in terms of the types of activity (*e.g.,* auditory *versus* visual) they support and the stages of processing (*e.g.,* encoding *versus* retrieval) during which they are accessed (Smyth, Morris, Levy and Ellis, 1987; Wickens, 1980; 1991). Multiple task theories also typically hold that resource capacity within each pool is limited (Kahneman, 1973; Wickens, 1980; 1984). It follows that multiple-task performance should proceed relatively unimpaired when component tasks each tap exclusive pools of resources (Allport, Antonis and Reynolds, 1972; Wickens, 1984), but,

if the component tasks rely upon common resources, then they may interfere with one another (Neumann, 1996; Wickens, 1989; 1991).

Accordingly, in dual tasks (*i.e.,* two concurrent activities), a difficulty–performance trade-off is often observed wherein performance on the secondary task suffers as the difficulty of the primary task is increased (see Wickens, 1980). The degree of interference may also depend upon the compatibility of the two tasks (Damos, 1991; Wickens, 1989; 1991). Tasks are considered to be compatible if "some dimension or aspect of one stimulus can be used to predict a dimension or aspect of the second stimulus" (Damos, 1991, p. 105). Compatible tasks produce minimal interference because "a common mental set, processing routine, or timing mechanism can be activated in service of the two tasks" (Wickens, 1991, p. 23).

In ARAMEP, prioritised integrative attending is characterised as a dual task in which one component involves paying attention to one's own part, and the other component involves paying attention to the aggregate structure. Processing one's own part can be considered to be the primary task, in which case processing the aggregate structure is the secondary task. Insight is gained into the resource demands associated with prioritised integrative attending by reducing each of these components to several constituent sub-skills.

The primary task of processing one's own part typically involves (*a*) retrieving from memory information that is relevant to performing the part, (*b*) executing motor programs that underlie the technical aspects of producing the part, (*c*) tracking, or monitoring the sound that one is producing, and (*d*) forming a memory representation based upon the current production. Several researchers have discussed aspects of these sub-skills (Gabrielsson, 1999; Palmer, 1997; Sloboda, 1982; 1985).

The retrieval processes that characterise the performance of familiar music include the recall of performance goals and performance plans. Performance goals, which are established during the preparation of a musical piece for performance, reside in memory as idealised mental representations of the patterns constituting the piece (Palmer, 1997; Rideout, 1992). They embody the performer's intentions and expectations about their own sound and the ensemble sound. Performance plans that serve as strategies for transforming representations of goal patterns into sound are also acquired during preparation (Drake and Palmer, 2000; Gabrielsson, 1999; Sloboda, 1982). These are used to direct motor processes involved in pattern production (Palmer, 1997; Shaffer, 1985). Even though performance goals and plans are not directly relevant in all performance contexts, other types of information may be retrieved. For example, when sight-reading, pattern recognition processes are employed to identify familiar melodic or rhythmic figures, and thus facilitate the priming of appropriate motor control programs (Gruson, 1988). Irrespective of the performance context, tracking one's own part during production relies upon feedback received through auditory, and perhaps even visual and proprioceptive (tactile and kinaesthetic) channels (see Gabrielsson, 1999; Pressing, 1998; 1999). In line with the proceduralist position on memory (Crowder, 1993), it is assumed here that representation formation is a natural consequence of the processing that takes place during tracking.

The secondary task in prioritised integrative attending – *i.e.,* processing the aggregate aspect of the ensemble texture – involves (*a*) tracking other parts, (*b*) grouping together elements belonging to one's own and other parts, (*c*) forming

an internal representation of the aggregate structure, and (*d*) retrieval of information about the aggregate structure. Therefore, the resource demands of aggregate pattern processing differ from those associated with attending to one's own part mainly in terms of the grouping process that combines elements from different parts. This process, which may be termed "between-part grouping", requires considerable attentional flexibility as it involves scanning between parts continuously, and in real time, to determine their interrelationship.

It is assumed here that, apart from between-part grouping, the tasks of attending to one's own part on one hand, and the aggregate structure on the other hand, are subserved by common processes. Accordingly, the tracking and representation formation processes associated with the perception of aggregate structures operate similarly to those employed in relation to one's own part (except that tracking other parts occurs mainly via the auditory, and perhaps the visual, channel). Likewise, retrieval demands arise if the performer recalls performance goals relating to the aggregate structure. The importance of such performance goals has been demonstrated by Goodman (1998; 2000), who investigated how "model" conceptions of aggregate structures develop and influence interactions between individual performers in ensembles.

Clearly, due to the substantial overlap between resources involved in attending to one's own part and the aggregate structure, these two components of prioritised integrative attending should be susceptible to mutual interference. Two primary sources of interference are identified in ARAMEP: (*a*) the degree to which tracking one's own part disrupts the tracking of other parts, and (*b*) the disruption of between-part grouping caused by the structural complexity of the interrelationship between parts. Following from principles in multiple task theory, interference to tracking is related mainly to the difficulty of one's own part, whereas interference to between-part grouping is largely a function of the compatibility of one's own part and the aggregate structure. The factors that influence these considerations are discussed next.

Factors that influence prioritised integrative attending

The difficulty of one's own part is a subjective consideration insofar as it is the product of attentional and motor constraints that operate within the individual performer. Thus, difficulty is prone to be affected by general, relatively extramusical factors (*i.e.*, qualities of the performer rather than the music) that are related to both attention and motor control, such as anxiety, arousal, mastery of instrumental technique, familiarity with the music in question, and other factors relating to musical expertise (Gabrielsson, 1999; Ryman, Naitoh and Englund, 1985; Salmon and Meyer, 1992; Sloboda, 1996). However, there are also some more objective determinants of difficulty. These include several musical factors that have been found to affect attentional processes under a wide variety of circumstances, *e.g.*, rhythmic complexity (*e.g.*, Bharucha and Pryor, 1986; Essens, 1995; Handel, 1973; 1992; 1998; Jones and Boltz, 1989; Klein and Jones, 1996; Povel and Essens, 1985), pitch-related factors such as the size of the interval between adjacent tones and the jaggedness of the melodic contour (*e.g.*, Dowling, 1978; Dowling and Bartlett, 1981; Dowling, Kwak and Andrews, 1995), and tonality and harmonic context (*e.g.*, Dawe, Platt and Racine, 1993; Holleran, Jones and

Butler, 1995; Krumhansl, Sandell and Sargeant, 1987; Palmer and Krumhansl, 1987; Schmuckler, 1989; Smith and Cuddy, 1989). It is assumed in ARAMEP that these factors disrupt the tracking of other parts to the extent that they augment the perceptual, motor, and cognitive demands associated with producing and monitoring one's own part.

It is also assumed in ARAMEP that the compatibility of one's own part and other parts may affect both tracking and between-part grouping, but it is the latter is of primary concern here. In multiple task theory, two broad varieties of compatibility have been identified: spatial and temporal (Wickens, 1989; 1991). Both spatial and temporal compatibility are relevant in music, where their analogues are pitch and rhythm, respectively (see Jones, 1981; 1992).

The compatibility of the relationship between parts in terms of pitch is dependent upon factors such as tonality and pitch range. In particular, the between-part grouping process should be more difficult when parts are in different keys (as in polytonality – see Krumhansl, 1990; Thompson and Mor, 1992) or when there is large pitch separation between parts. The latter is exemplified in auditory streaming demonstrations where (at certain presentation rates) a sequence of alternating high- and low-pitch tones is perceived as a single stream when pitch separation is narrow, whereas the sequence segregates into a stream of high tones and a stream of low tones when pitch separation is wide (Bregman, 1990; Brochard, Drake, Botte and McAdams, 1999; Jones and Yee, 1993; van Noorden, 1975; for an insightful review, see Ten Hoopen, 1996). Even though under some circumstances streaming tendencies can be overcome through deliberate attempts by the attender to integrate sequences, this process of grouping between parts breaks down when critical levels of pitch separation and tempo are reached (van Noorden, 1975; also see Jones, Jagacinski, Yee, Floyd and Klapp, 1995).

Temporal compatibility in ensemble music is a matter of the rhythmic complexity – *i.e.,* the coherence of the temporal relationship – between parts comprising the multipart texture. Here coherence relates mainly to whether or not the time periods defined by structural elements in different parts are ratio related, and, if so, whether the ratios are simple (*e.g.,* 1:1, 2:1) or complex (*e.g.,* 4:3, 5:4). Lack of such coherence has been found to interfere with between-part grouping in studies of auditory streaming (Jones, Kidd and Wetzel, 1981), and related work has been done with polyrhythm (Handel, 1984; 1989; Pressing, Summers and Magill, 1996; Summers, Rosenbaum, Burns and Ford, 1993).

In richer musical contexts, rhythmic complexity can be defined according to how a pattern's structure fits within a metric framework. Metric frameworks are defined here as cognitive/motor schemas consisting of hierarchically nested pulsations (usually at bar, beat, and beat-subdivision levels) generated in the performer. Put simplistically, rhythmic complexity is low to the extent that the placement of pattern elements, and the distribution of accents (*i.e.,* perceptually salient temporal locations) associated with these elements, imply regular underlying time periods that map neatly onto a metric framework (for more detail see Keller, 2000). In situations requiring prioritised integrative attending, multipart rhythmic complexity concerns the degree to which one's own part and the aggregate structure can be accommodated well within the same metric framework. This is not always the case, as a particular part may yield different

metric interpretations depending upon whether it is presented in isolation or in combination with other parts (see Yeston, 1976).

Spatial and temporal compatibility do not necessarily operate independently in music. Combined effects arise within textural factors such as density, which is dependent upon the number of parts in the ensemble, and how differentiated they are in terms of rhythm (even if low in complexity), tessitura, and timbre. It has been found in both musical (Huron, 1989; Rasch, 1988) and non-musical contexts (Scharf, 1998; Smyth *et al.,* 1987; Wickens, 1980; 1984; 1991) that, when the attender is required to monitor several sources of information simultaneously, performance deteriorates with increases in the number and complexity of the information sources. Accordingly, the difficulty of between-part grouping in ensembles should generally increase with increases in the number of parts and differences in rhythm, tessitura, and timbre.

The findings of a survey-based study conducted by Keller (2001b) with practising ensemble musicians are consistent with the above ideas about difficulty and compatibility. Musicians were asked to rate how influential upon their ability to engage in prioritised integrative attending are various extramusical factors (anxiety, arousal, and technical mastery) and musical factors (complexity relating to rhythm, texture, and several pitch-related factors). A particular order of importance emerged, with extramusical factors generally being rated as more influential than musical factors. Within the musical factors, rhythm and texture were considered to be most influential, followed by tonality, melodic contour, and pitch-interval size. In response to open-ended questions about situations in which prioritised integrative attending is compromised, musicians listed several additional influential factors (*e.g.,* an uncomfortable performance environment and poor balance in terms of loudness between parts). Another interesting finding is that musicians claimed that personal relationships between ensemble members impact upon ability to engage in prioritised integrative attending. This highlights the value of approaches that examine interactions within ensembles from a social psychological perspective (*e.g.,* Davidson, 1997; see Hargreaves and North, 1997).

However, the most noteworthy outcome of this study for present purposes is that the *rhythmic complexity of one's own part* and the *rhythmic complexity of the relationship between parts* were claimed to be particularly influential. This finding implies that metric frameworks may have a special role in prioritised integrative attending. Specifically, metric framework generation may facilitate the processing and representational efficiency, and thereby the attentional flexibility, required in ensemble performance (Keller, 1999).

A weakness of the above approach is that it relies solely upon introspective self-reports by musicians. Nevertheless, the proposed link between metric frameworks and prioritised integrative attending is supported by some recent, more rigorous experimental research (see Keller, 1999; 2000). The experiments employed novel dual-task paradigms that were intended to simulate the attentional demands arising in ensemble performance. Both recognition memory and reproduction-based tasks were used. In all tasks, participants were presented with multipart patterns, and required to attend simultaneously to a particular "target" part and the aggregate structure. The target parts comprised either metrical patterns (*i.e.,* patterns that fit a metric framework) or non-metrical patterns (*i.e.,* patterns

that do not fit a metric framework), and the aggregate structures were always metrical (see Figure 1). Across experiments it was found that the task of processing the aggregate structures encountered greater interference when target parts were non-metrical than when they were metrical. Thus, attentional flexibility was enhanced when participants were able to use a common metric framework for both components of prioritised integrative attending.

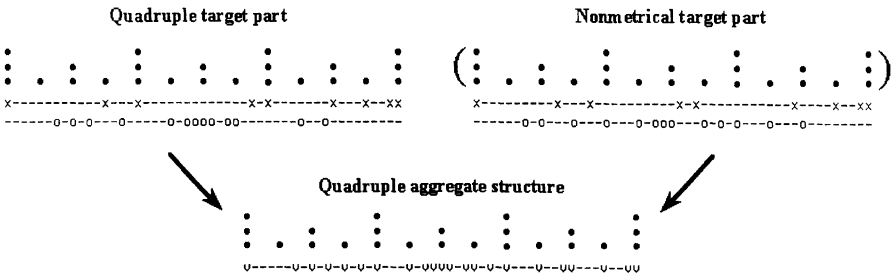

FIG. 1

Multipart patterns with a quadruple target part (top left of figure) and a non-metrical target part (top right). Notated below them is the quadruple aggregate structure, which is the same in both cases. Pattern elements are represented by 'x's in target parts, 'o's in complementary parts, and 'v's in the aggregate structure. Quadruple metric frameworks (represented by dots) are included to allow pattern structure to be gauged (even in the case of the non-metrical target part, which does not fit the notated framework).

Mechanisms underlying prioritised integrative attending

In ARAMEP, it is claimed that metric framework generation provides an attentional scheme that guides the tracking, between-part grouping, representation formation, and retrieval processes that were identified earlier as sub-skills of prioritised integrative attending. The notion of meter as an attentional scheme is a central concern in Mari Riess Jones' *dynamic attending* approach to rhythmic behaviour (Jones, 1976; Jones and Boltz, 1989; Large and Jones, 1999). It is proposed in the dynamic attending approach that attentional activity fluctuates lawfully in response to the structure of musical patterns. Specifically, attentional energy surges towards temporal locations at which events are expected to occur. In metrical patterns, due to underlying periodicities, events are statistically more likely to occur at strong metric locations (such as the beginning of bars and beats) than at weak locations (Palmer and Krumhansl, 1990). Therefore, when processing metrical patterns, expectancies occur periodically and the attender's "biological rhythms" synchronise with the pattern's structure. Consequently, the attender experiences periodic fluctuations in attentional activity that mirror metric structure. In other words, there is a greater attentional activity at strong metric locations than at weak locations. Gjerdingen (1989, p. 78) has suggested that it might even appear as if the attender is " 'paying more attention' to events occurring

on strong beats". In support of this notion, it has been demonstrated that perceptual acuity is finer for events at expected temporal locations than at unexpected locations (see Jones and Yee, 1997; Large and Jones, 1999; Ten Hoopen, 1996; Yee, Holleran and Jones, 1994). However, it should also be noted that acuity seems to decrease at important music structural locations (*e.g.*, melodic-rhythmic phrase boundaries, which often coincide with metric strong points) under some circumstances, such as when expressive timing deviations are anticipated (Penel and Drake, 1999; 2001; Repp, 1992; 1998a; 1998b; 1999a; 1999b).*

Although the concept of metric fluctuations in the activity of attentional resources is generally useful when accounting for efficiency and flexibility in processing, it is not sufficient for explaining prioritised integrative attending. If it is assumed that (*a*) resources are limited in the sense that there is a level ceiling on resource capacity, and (*b*) the attentional activity involved in prioritised integrative attending is effortful rather than automatic (see Keller, 2001a), then an increase in attentional activity at strong metric locations would bring resource consumption closest to full capacity at the corresponding points in time. This logically might lead to greater scarcity of resources necessary for processes such as tracking other parts and between-part grouping at strong, relative to weak, metric locations. This proposition is counterintuitive, as it implies that it should be more difficult for ensemble performers to engage in prioritised integrative attending at these specific locations. Although this has not been investigated directly, there appears to be little evidence for this conjecture based upon research on asynchrony between ensemble members (*e.g.*, Rasch, 1988; Shaffer, 1984).

Therefore, to accommodate prioritised integrative attending, ARAMEP incorporates a two-factor account of attentional resource allocation that specifies how variations in resource availability compensate for fluctuating resource activity. In this account, *resource availability* refers to the proportion of the attender's resources that are free to serve in a given task at a particular point in time, and *resource activity* refers to the proportion of the attender's available resources that are actually employed in the service of the task.

It is proposed here that, to overcome capacity limitations, both resource availability and resource activity have the potential to be modulated in tandem in a manner that is highly plastic and efficient. In musical contexts, this potential is released by the generation of metric frameworks. This conception of resource allocation, which is depicted in Figure 2, is based upon several assumptions. The

*The apparent paradox that perceptual acuity decreases when attentional activity is increased can be resolved by distinguishing between the intensity of attention and the width of the temporal region at which attention is focused. Large and Jones (1999) argue that finer temporal acuity at strong metric locations is due to the narrowing of attentional focus. Even though it seems reasonable to claim that the narrowing of attentional focus is accompanied by increases in the intensity of attention, whereas widening focus is associated with decreased intensity, this is not necessarily the case. For example, attention can be deployed with high intensity over relatively wide temporal regions, although such extended activity is fatiguing to attentional resources (Koelega, 1996). Failure to detect timing deviations at locations where expressive deviations are expected may occur because the width of attentional focus (as well as its intensity, perhaps) increases at these locations. This increase in width may reflect the relaxation of the boundaries of quantisation units that underlie low-level categorical rhythm perception (see Clarke, 1987; Desain, 1992; Desain and Honing, 1989), and therefore may be independent of the higher-level control of attentional intensity. In any case, the picture is complicated because several separate – albeit interactive – processes have been implicated in expressive timing phenomena, ranging from low-level obligatory psychoacoustic effects, through automatic perceptual biases, to high-level cognitive expectancy schemes (see Penel and Drake, 1999; 2001; Repp, 1998a; 1998b).

most important of these assumptions is that resource availability fluctuates across time points in a manner that mirrors the profile of metric frameworks if an appropriate cognitive/motor schema is invoked. This may occur either in an automatic bottom-up fashion in response to the structure of an unfolding pattern, or in a deliberate top-down manner when the performer generates a metric framework independently of an external stimulus (see Keller, 2000). It is also assumed that the default pattern of resource activity mirrors the distribution of resource availability across time. Furthermore, activity is regulated by a feedback mechanism that is sensitive to availability limits, and thus functions to ensure that activity remains within these limits.

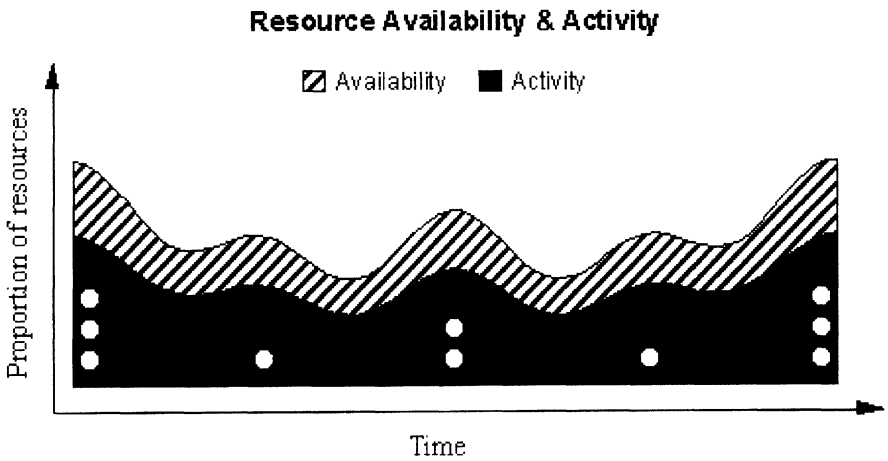

FIG. 2
Both resource availability and resource activity mirror metric structure (the dots represent metric pulsations).

This tight relationship between resource availability and resource activity enables the efficient processing of metrical patterns. In accordance with the dynamic attending approach (*e.g.*, Large and Jones, 1999), it is assumed here that resource activity becomes focused at space/time regions where target events occur, or are expected to occur. Consequently, due to variability in the concentration of events at different metric locations in music, resource activity is usually increased at strong locations. When resource availability and resource activity operate in concert, however, compensatory increases in availability accompany the momentary increases in activity. Therefore, sufficient resources are available so long as the pattern continues to conform to the established metric structure, as a greater proportion of resources is "on standby" at strong metric locations. Note that this account differs from the dynamic attending concepts described earlier mainly in that it addresses resource availability in addition to resource activity: both factors come to share metric structure. Furthermore, the current account deviates from traditional resource theory (a notable exception is the theory described by

Kahneman, 1973) in that it emphasises lawful fluctuations in resource availability at the time scale where rhythm and meter reside (2 to 5 seconds; see Fraisse, 1982; Parncutt, 1994). Although some existing resource theories do address the variability of capacity limits, these theories typically focus upon variations in resource availability that are associated with larger-scale changes in the attender's general level of arousal (*e.g.*, Johnson and Shapiro, 1989).

The two-factor conception of resources described above becomes particularly useful when attempting to explain resource allocation during prioritised integrative attending. At weak metric locations, resource activity associated with processing one's own part is typically relatively low, and therefore the performer is free to track other parts and engage in between-part grouping. At strong metric locations, even though resource activity associated with processing one's own part may be higher, tracking and between-part grouping are enabled by increased resource availability. Thus, the efficient distribution of attentional resources provides a foundation for flexibility in attending. These benefits cease to exist in the absence of metric framework generation.

It is assumed in ARAMEP that resource availability is no longer modulated systematically when metric frameworks, or other appropriate schemas, are not generated. Resource availability is instead constant over time (or characterised by minute random fluctuations) in these situations – such as when attention is directed to a non-metrical pattern. Nevertheless, resource activity continues to fluctuate, typically quite wildly, in response to the unfolding non-metrical pattern. Thus, resource activity and resource availability may become decoupled: fluctuations in activity are not compensated for by corresponding fluctuations in availability.

Furthermore, when attending to a non-metrical pattern, resource availability should eventually begin to decrease. Expectations about the temporal location of events comprising non-metrical patterns lack precision. Therefore, there must be a corresponding increase in the size of the temporal region during which the attender is prepared for the events. As is the case in metrical patterns, this preparedness is manifested as increased resource activity. However, in non-metrical patterns, these relatively high levels of resource activity must extend over regions of greater duration than those circumscribed by strong locations in metric frameworks. Based upon the assumption that sustained focused activity is effortful and leads to decreases in resource availability (see Koelega, 1996), the present account postulates that adequate increases in resource availability are not sustainable over the extended regions of high resource activation demanded by non-metrical patterns.

In any case, when attending to non-metrical patterns, resource availability and resource activity are less likely to be correlated than when attending to metrical patterns. This independence becomes especially problematic in multipart contexts where prioritised integrative attending is required. This is because resource activity associated with attending to non-metrical target parts frequently nears, or even meets, resource availability. Recovering from these frequent disturbances interferes with processing and leaves little scope for the flexible attending that underlies tracking other parts and between-part grouping.

Interactions of factors and mechanisms

The primary goal of ARAMEP is to explicate how the musical and extramusical factors identified earlier interact with the resource availability and resource activity mechanisms described above. It is claimed that this interaction is initiated when the factors impact upon the "state" of the performer and their environment, *i.e.*, the surrounding musical context. ARAMEP is concerned with three aspects of the performer/context relationship: intrinsic cognitive-motivational state, intrinsic executive state, and extrinsic state.

Intrinsic states in general occur within the performer, and include the degree to which his or her perceptual, cognitive, and motor resources are prepared to deal with the ensemble interaction at hand. Two varieties of intrinsic state are distinguished: cognitive–motivational and executive. *Intrinsic cognitive–motivational state* refers to high-level cognitive phenomena such as attentional sets, and motivational or emotional factors such as mood. Musical factors that contribute to intrinsic cognitive–motivational state include performance goals and musical schemas – *e.g.*, metric frameworks and abstract knowledge of tonality. Extramusical factors that influence intrinsic cognitive–motivational state include anxiety, arousal, and motivation. *Intrinsic executive state* incorporates strategies that are available to the performer for producing target behaviour. Intrinsic executive state is defined jointly by the performer's mastery of instrumental technique and the schemas that guide their motor actions (*e.g.*, performance plans).

In contrast to the intrinsic states, *extrinsic state* is a product of the performer's external environment, which comprises the ensemble sound, physical surroundings, and ambient social context. Extrinsic state is affected by musical factors such as rhythm, texture, tonality, melodic contour, and pitch-interval size, and extramusical factors such as acoustic conditions, lighting, background noise, and comfortableness of the performance space.

It is proposed here that the three performer/context states are linked systematically to resource availability and resource activity (see Figure 3). Intrinsic cognitive–motivational state modulates both resource availability and resource activity, whereas extrinsic and intrinsic executive states have a direct influence only upon resource activity. In other words, the temporal profile of resource activity is determined by the full range of musical and extramusical factors, but the time-course of resource availability is determined exclusively by schematic musical factors – metric frameworks in particular – and physiological extramusical factors – anxiety, arousal, and motivation. Nevertheless, resource availability may be affected indirectly by the other factors through causal links between the three performer/context states (see Figure 3). Extrinsic state affects both intrinsic executive state (*e.g.*, comfort may influence technique) and intrinsic cognitive–motivational state (*e.g.*, ensemble sound structure determines which schemas are invoked, and social context influences anxiety); intrinsic cognitive–motivational state modulates intrinsic executive state (*e.g.*, anxiety affects motor control); and intrinsic executive state influences extrinsic state (*e.g.*, motor control affects ensemble sound). A feedback link from intrinsic executive system to the intrinsic cognitive–motivational system is also assumed to exist for the endogenous regulation of motor control (*e.g.*, error correction based on proprioceptive feedback, rather than external acoustic sources).

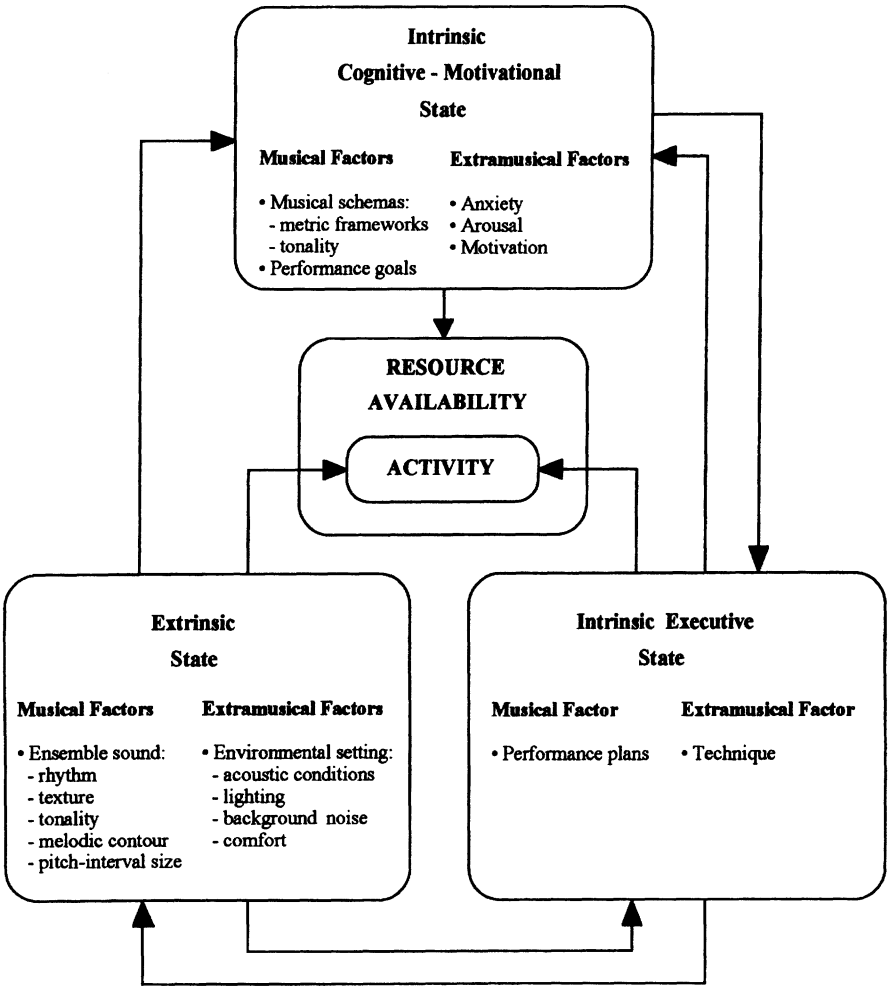

FIG. 3

Interaction between performer/context states and resource availability and resource activity.

The connections between performer/context states and resource availability and resource activitiy in ARAMEP embody predictions about how the musical and extramusical factors under discussion interfere with prioritised integrative attending. Basically, different factors lead to three different types of interference: (Type A) decreased resource availability, (Type B) increased resource activity, or (Type C) decoupled availability and activity. In both Type A and Type B interference, resource availability and activity maintain a lawful relationship based upon metric structure, but spare attentional capacity (for tracking other parts and grouping between parts) is reduced either due to decreased resource availability

(Type A) or increased activity (Type B). Type C interference differs qualitatively from Types A and B in that reductions in spare capacity arise because resource availability and activity no longer stand in a metrically lawful relationship. Some predictions that arise from this taxonomy of interference effects are listed in Table 1. Keller (2000) has described several multiple task paradigms that are suitable for testing these predictions.

TABLE 1

Summary of ARAMEP's predictions about the factors that interfere with prioritised integrative attending.

Factors	*Effects*
• High multipart rhythmic complexity	→ Decoupling of availability and activity
• Dense texture (*i.e.*, large number of parts)	→ Increased activity without corresponding increase in availability
• Poor balance	→ Narrowing (spatial) focus of activity to monitor softer parts
• Large pitch-interval size (leaps rather than steps) in own part	→ Increased activity to overcome technical hurdles
• Large pitch-interval size in other parts	→ Increased activity (intensive shifting in focus) to accommodate greater distances in cognitive pitch space
• Jagged (as opposed to smooth) melodic contour in own part	→ Increased activity to overcome technical hurdles
• Jagged melodic contour in other parts	→ Increased activity to recover from interruptions to attentional trajectories as melodic motion changes direction
• Unfamiliar or unstable tonality	→ Increased activity to generate local expectancies online, and/or to recover from expectancy violations
• Uncomfortable surrounds:	
– poor acoustics	→ Increased activity to overcome difficulty hearing
– distractions	→ Increased activity causing interference
• Extreme (high or low) levels of anxiety, arousal and motivation	→ Reduced availability
• Inadequate technical mastery	→ Increased activity to overcome technical difficulties
• Impoverished cognitive/motor schemas	→ Increased activity to gather missing information, or to recover from expectancy violations
	→ Less than optimal availability profile

It is useful to distinguish between the above types of interference because their aetiology differs, and hence each should benefit most from a different remedy. Type A interference occurs when global decreases in resource availability are brought about by factors such as impoverished musical schemas and extreme levels of anxiety and arousal. To overcome Type A interference it may be useful to develop further the generalised musical schemas already possessed by the performer (through experience with idiomatically appropriate music – see Krumhansl, 1990; Palmer and Krumhansl, 1990) or to employ anxiety management techniques (see Gabrielsson, 1999). Type A interference can be studied experimentally by examining the effects of level of idiom specific musical experience and/or level of anxiety upon ability to engage in prioritised integrative attending.

The increases in resource activity that characterise Type B interference are related to rhythmic, textural, and pitch-based complexity. To manage interference arising from these factors, it may be beneficial to develop automaticity in instrumental technique, in addition to cognitive strategies for dealing with complexities in the music (*e.g.*, see Thurmond, 1982). A straightforward way to study Type B interference is to examine how prioritised integrative attending is affected when the technical demands associated with performing one's part, and the perceptual/cognitive demands associated with tracking other parts and grouping between parts, are manipulated experimentally.

Finally, in Type C interference, the decoupling of resource availability and resource activity occurs as a result of rhythmic complexity. This decoupling is most profound when the structure of the music denies the performer the opportunity to use metric frameworks. To overcome this type of interference it is necessary to maximise availability and minimise activity simultaneously. One way to achieve this is for the performer to optimise the expectancies associated with their performance goals by gaining greater familiarity with the piece in question (see Bharucha, 1987; Jones, 1990).

To investigate Type C interference experimentally is not straightforward (see Keller, 2001a). However, it should be possible to do so by measuring the effects of increasing rhythmic complexity in the target part upon a secondary task such as detecting deviant tones (*e.g.*, tones where frequency, timing, or spectral composition is altered) strewn across different temporal locations in a concurrent complementary part. The detection of deviant tones at different locations should be affected differentially by increasing target part complexity depending upon whether availability and activity are coupled (*e.g.*, a metrical target part) or decoupled (*e.g.*, a non-metrical target part). Specifically, the effects of increasing complexity upon deviant detection should vary as a function of location to a greater degree in the coupled case (where strong metric locations should be favoured), than in the decoupled case (where there is no differentiation of location based upon meter).

It may be useful to conceptualise the experimental paradigm described above in terms of task difficulty and compatibility, which were identified earlier as general causes of dual-task interference. According to this re-conceptualisation, difficulty is manipulated in the proposed task by increasing rhythmic complexity in both metrical and non-metrical target parts, and task compatibility varies as a function

of the complexity of the relationship between target parts and aggregate structures. If it is assumed that metrical aggregate structures result from combining target (metrical and non-metrical) and complementary parts (as in the experiments discussed by Keller, 1999; 2000), then target parts and aggregate structures will be more compatible when the former are metrical than when they are non-metrical. This re-conceptualisation leads to the prediction that increasing the difficulty of the target part should have more pronounced effects upon the detection of deviant tones when compatibility is high (where resource availability and activity are coupled) than when compatibility is low (where availability and activity are decoupled). Thus, varying difficulty and compatibility independently should allow the relationship between resource availability and activity to be gauged.

In addition to the interference effects described in the preceding paragraphs, interactive effects may also arise through combinations of musical and extramusical factors. Rhythmic complexity should be a particularly potent contributor in these interactions, given the intimate relation between metric frameworks and resource allocation mechanisms postulated in ARAMEP. If this claim is valid, then music educational techniques for dealing with rhythmic complexity by optimising metric framework generation should facilitate the development of prioritised integrative attending skills. There are several successful music educational techniques for developing metric skills (see Cuddy and Upitis, 1992; Jacques-Dalcroze, 1915; 1921; Radocy and Boyle, 1988). Exploring the effects of these techniques upon prioritised integrative attending specifically would be a worthwhile topic for future research.

Conclusions

Prioritised integrative attending in ensemble performance is a multifaceted skill composed of sub-skills including tracking multiple sound sources and grouping together their elements in order to derive the aggregate structure. ARAMEP accounts for how the attentional flexibility required for these sub-skills is influenced by a range of musical factors (*e.g.*, rhythmic and pitch-based complexity) and extramusical factors (*e.g.*, anxiety and arousal). The central claim is that these factors act directly upon cognitive/motor mechanisms that regulate attentional resource allocation during performance. The role of metric framework generation is paramount in this process. Through metric framework generation, resource availability and resource activity are modulated – in real time and continuously – in a manner that is both plastic and efficient, and hence conducive to attentional flexibility. Thus, the sub-skills involved in prioritised integrative attending encounter minimal interference when availability and activity maintain a lawful relationship. However, the decoupling of resource availability and activity that occurs in the absence of metric frameworks curbs attentional flexibility. The challenge for future research is to demonstrate empirically the distinction between coupled and decoupled resource availability and activity.

By identifying the factors and mechanisms underlying prioritised integrative attending, ARAMEP has potential to serve as a heuristic for directing research into ensemble skills. One recommendation that can be made on the basis of the theory is to study tracking and between-part grouping separately, as well as in combination. This could be the first step in a systematic investigation of the ways

in which task difficulty and compatibility contribute to the three types of interference (A – decreased resource availability; B – increased resource activity; C – decoupled availability and activity) that are recognised by ARAMEP. As noted earlier, manipulating difficulty and compatibility independently may provide a method for probing the resource availability and activity mechanisms that are hypothesised to underlie prioritised integrative attending. Although the effects multipart rhythmic complexity upon difficulty and compatibility are emphasised in ARAMEP, the influence of pitch-based factors also warrants serious consideration. Therefore, it should be profitable to study prioritised integrative attending in the context of multipart patterns wherein pitch-interval size and contour are manipulated within parts, and pitch separation and tonality are manipulated between parts. Eventually, the extramusical factors identified by ARAMEP should also be incorporated into empirical investigations of prioritised integrative attending.

In sum, ARAMEP highlights the complexity of the task faced by ensemble musicians. The theory implies that ensemble performance requires special capabilities that transcend the skills commonly identified in music education as indices of a performer's general musical ability (see Shuter-Dyson, 1999). Technical competence as an instrumentalist, accurate perceptual-motor skills, and artistry as an interpreter of music are necessary, but by no means sufficient, for excellence as an ensemble performer. Specific prioritised integrative attending sub-skills are fundamental to ensemble cohesion and coherence.

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