In time with the music:

The concept of entrainment
and
its significance for ethnomusicology

Martin Clayton, Rebecca Sager and Udo Will

Target article, Commentaries and Authors' response

To appear in:

ESEM CounterPoint, Vol.1, 2004

In time with the music: The concept of entrainment and its significance for ethnomusicology

Martin Clayton, Rebecca Sager and Udo Will

Abstract

Entrainment, broadly defined, is a phenomenon in which two or more independent rhythmic processes synchronize with each other. To illuminate the significance of entrainment for various directions of music research and promote a nuanced understanding of the concept among ethnomusicologists, this publication opens with an exposition of entrainment research in various disciplines, from physics to linguistics and psychology, while systematically introducing basic concepts that are directly relevant to musical entrainment. Topics covered include consideration of self-synchrony and interpersonal synchrony in musical performance, humans' innate propensities to entrain, the influence of cultural and personal factors on entrainment, the numerous functions of musical entrainment in individual health, socialization, and cultural identification, and a presentation of methodologies and analytical techniques. Finally, some case studies illustrating one methodological strand, that of chronometric analysis, exemplify how the application of the entrainment concept might lead to an understanding of music making and music perception as an integrated, embodied and interactive process.

1. Introduction

The aim of this publication is to stimulate research in ethnomusicology informed by the concept of entrainment, which describes the interaction and consequent synchronization of two or more rhythmic processes or oscillators. Entrainment as a concept has a considerable history - it was first identified by the Dutch physicist Christiaan Huygens in 1665 and has been applied widely in mathematics and in the physical, biological, and social sciences. It is a process that manifests in many ways, some of which involve human agency or cognition. Strangely though, it has had relatively little impact to date in studies of music, where it might be thought particularly relevant, and is only beginning to be seriously considered within ethnomusicology. This is, to our knowledge, the first publication to address the concept in detail from an ethnomusicological perspective.[1]

In music research, we have already seen an entrainment perspective adopted in the study of musical metre, particularly in the 1990s. Instead of looking for musical cues transmitted from performer to listener as the sole determinants of time and metre precepts, music psychologists have begun to apply an entrainment model in which rhythmic processes endogenous to the listener entrain to cues in the musical sound (Large and Kolen 1994). Although there is much to be done in this area, the entrainment model seems to reflect the cognitive processes much better than do previous models of metrical perception. Some recent work also points to new perspectives offered by the entrainment concept in the study of proto-musical behaviour in infants, and in the evolution of musical behaviour in the human species (Trevarthen 1999-2000, Merker 2000).

We believe that this concept could have a particularly significant impact if applied to ethnomusicological research because it offers a new approach to understanding music making and music perception as an integrated, embodied and interactive process, and can therefore shed light on many issues central to ethnomusicological thought. Entrainment may be central to an ethnomusicological orientation for which performance and listening are the focus of interest. Such a development is likely to be more productive if researchers share an understanding of what the concept implies (as well as what its limitations might be); we offer this contribution to colleagues in that spirit.

In later sections we discuss the relationship between entrainment and ethnomusicological research, and offer some suggestions regarding methods for investigation. Before that, however, it is important to establish what entrainment means and how other disciplines have characterised its main features. What follows comprises a summary overview of the concept of entrainment and its application in other fields, particularly the biological and social sciences (sections 2 and 3); some consideration of applications to date in music studies (section 4); some suggestions on the relevance of entrainment in ethnomusicology, with a preliminary consideration of possible methods (sections 5 and 6); and finally some case studies illustrating one methodological strand, that of chronometric analysis. Our focus is, of course, on music, but by discussing work in other fields we first aim to build up a more nuanced picture of entrainment and its ramifications, so that ethnomusicological research can build more productively on this base.

2. Entrainment basics

2.1 Introduction: the concept of entrainment

Entrainment describes a process whereby two rhythmic processes interact with each other in such a way that they adjust towards and eventually 'lock in' to a common phase and/or periodicity. There are two basic components involved in all instances of entrainment:

1) *There must be two or more autonomous rhythmic processes or oscillators*. Autonomy means that if the two oscillators are separated, i.e. if they do not interact, they must still be able to oscillate: the oscillations must be active processes requiring an internal source of energy. In other words, none of the oscillations (or the rhythmic processes) should be *caused* through the

[1] The authors of this paper have developed a collaborative approach through organising two panels at meetings of the European Seminar in Ethnomusicology, in Rauland, Norway (2001) and Druskininkai, Lithuania (2002). This article is partly a response to suggestions from some of those present that ethnomusicologists would benefit from a detailed description of the entrainment concept, presented with methodological suggestions and examples.

interaction. Resonance, for example, is not to be considered entrainment: if a tuning fork producing sound waves in a resonance box is removed, the oscillations in the box also cease. This is an important point, because it alerts us to the possibility that the mere observation of synchronized behaviour or synchronous variation in two variables does not necessarily imply entrainment.

2) *The oscillators must interact*. There is a variety of different forms of possible interactions or 'coupling', but in the majority of cases this interaction is weak, as demonstrated by Huygens' clock example. Strong coupling, on the other hand, puts too strong a limitation on the oscillators, and they lose their 'individuality' (for example, consider how one's arm movements would be limited if both hands held on to the same stick). As will become clear from the following discussion, identification and quantified description of the 'weak interactions' is one of the biggest challenges in entrainment research.

The tendency for rhythmic processes or oscillations to adjust in order to match other rhythms has been described in a wide variety of systems and over a wide range of time scales (i.e. periodicities): from fireflies illuminating in synchrony, through human individuals adjusting their speech rhythms to match each other in conversation, to sleep-wake cycles synchronizing to the 24-hour cycle of light and dark. Examples have been claimed from the fast frequency oscillations of brain waves to periods extending over many years, and in organisms from the simplest to the most complex as well as in the behaviour of inorganic materials and systems.

Obviously, the wide range of entrainment phenomena is not based on a single physical process. Rather, the concept of entrainment describes a shared tendency of a wide range of physical and biological systems: namely, the coordination of temporally structured events through interaction. In principle, it is easy to see how entrainment is relevant to music. If an ethnomusicologist were asked to suggest a familiar example of a "temporally structured event", it is likely that music, or some social or ritual event mediated through music, would quickly come to mind. Examples of rhythmic coordination to and through music, such as a foot tapping to the beat of a song, are equally easy to think of. However, entrainment studies in ethnomusicology are not limited to a few apparently obvious examples, and musical applications have to take into account the wider context of entrainment in human biological and social functioning.

Examples of endogenous or naturally occurring rhythms within the human body include the heart beat, blood circulation, respiration, locomotion, eyes blinking, secretion of hormones, female menstrual cycles, and many others. It has been suggested, indeed, that all human movements are inherently rhythmic: Jones writes that "All human performance can be evaluated within a rhythmic framework" (1976:340), while Bernieri, Reznick and Rosenthal suggest that "…human behavior is understood to occur rhythmically and therefore can be described in terms of cycles, periods, frequencies, and amplitudes." (1988:244). As we will see, these endogenous rhythmic processes may interact in many different ways, either within a single person or, in some cases, between individuals: both cases are relevant to ethnomusicology, although much of the material in this paper concerns interpersonal or social entrainment. Entrainment to and through music needs to be seen as a particular case of entrainment in social interaction, and its particular qualities explored - as indeed, we need to explore the specific possibilities for entrainment that different musical repertories or performances afford.

2.2 A short history of the entrainment concept

Huygens identified the phenomenon we know as entrainment as a result of his invention of the pendulum clock: he noticed that two such clocks, when placed on a common support, would synchronise with each other - even when the pendulum of one was deliberately disturbed, they would regain perfect synchrony within half an hour or so. Huygens' description of, as he put it, 'the sympathy of the clocks' as well as the apt explanation he supplied, were considered a singular phenomenon for more than 200 years. Then, in the second half of the nineteenth century British physicist Lord Rayleigh described the synchronization of two similar but slightly different organ pipes and introduced the distinction between forced and maintained oscillations (Rayleigh, 1945).[2] At the time these findings were not thought to be

[2] The first being 'forced' upon a system from outside, the latter being maintained autonomously by a system.

connected, but things took a different shape following Poincaré's development of a new approach for dealing with complex, non-linear systems at the end of the nineteenth century.[3] Following the advances made by Poincaré, it became possible to describe and understand the observations of Huygens and Rayleigh in terms of interacting non-linear systems. (In a linear system, changes in one variable produce predictable changes in a dependent variable. By contrast, in a non-linear system, small changes in one variable may cause large, erratic changes in a dependent variable.)

For more than 250 years after the time of Galileo and Newton, the sciences made considerable advances and it looked as if one day they might enable us to fully understand the world. This impression arose from the fact that classical physics had developed a method to analyse and describe the physical world in a simple way, namely in terms of sets of linear equations. This meant, given the initial conditions of a system, we could predict its behaviour and deduce any of its future states – we could 'understand' it. The only problem with this approach was that there seemed to exist a number of systems – Huygens' pendulum being one of them - that could not simply be described by linear equations. The remedy taken by classical physics was linearization: most non-linear systems can be described *approximately* by linear equations if one only considers a limited range of their behaviour. (For instance, the behaviour of a pendulum can be described quite well in linear terms if one only considers small movement amplitudes.) The differences between the actual behaviour and the linear descriptions were thought to be negligible. The linear approach was also successful because it allowed any complex problem to be broken down into parts, each part to be solved and then the part solutions put together to obtain the solution for the complex problem. The behaviour of the whole system could thus be described as the sum of the behaviour of its parts. However, many systems in our world do not act that way. Mostly, when parts of a system interfere, cooperate or compete, they produce non-linear interactions. At the beginning of the last century it became obvious that there were not only considerable differences in the behaviour of linear and non-linear systems – for example, the latter are not predictable – but that a severely biased world view was implied here, that of a predictable linear world. It was now realized that in our actual world, complex non-linear systems with chaotic behaviour are the rule, not the exception.

Following the new orientation in complex system dynamics introduced by Poincaré, mathematics and physics in the first half of the last century became mainly concerned with non-linear oscillators and their applications (such as in radio, radar, and later, lasers). In the 1920s, important theoretical groundwork was laid by Appelton and van der Pol when they were able to show how the frequency of an oscillator can be entrained or synchronized by a weak signal of a slightly different frequency. Finally, the invention of computers also meant a considerable push for non-linear system theory. From the 1960s, the computer allowed researchers to experiment with non-linear equations (e.g. to perform simulations) in a way that was unthinkable before, thereby offering new insights into the behaviour of non-linear systems.

In the 1970s the development in mathematics and physics of chaos theory had considerable impact on several other disciplines such as biology (early studies concerned chaotic phenomena in biological populations: for a review see May 1976), social sciences (Jantsch 1975; Allen et al. 1977) and neurosciences. The field of synergetics, the theory that is concerned with how the cooperation of individual components of a complex system leads to the formation of new macroscopic spatial, temporal and functional structures, considerably informed our present understanding of the functioning of the human brain (Haken 1983a, 1983b).

At least two aspects of the new view on the brain seem to be relevant in the context of this presentation: a) most brain functions can best be described as cooperative, synchronized activity of large, distributed ensembles of neurons, and b) a large part of this synchronized activity is of an oscillatory nature (Basar 1983; Nunez et al 1993). These autorhythmic oscillatory properties of neurons in the central nervous system are a consequence of their electrochemical properties. The cooperative and oscillatory activities of these neurons can be seen, amongst others, as the basis for the timing of sensory-motor coordination (for a review: Llinas 1988). With these new views on the functioning of the brain, it seems most promising to apply the concept of entrainment to the analysis of human interactions at the interpersonal and social level as well. Indeed, such applications have been pursued in the social sciences in parallel with the development

[3] Instead of asking quantitative questions that could not be answered at his time, Poincaré approached complex systems by emphasizing qualitative questions and developing a geometric analysis of complex system behaviour.

of neuroscientific approaches, the mathematics of coupled oscillators, and numerous other related strands of research. Many of the aspects most relevant for ethnomusicology are discussed in this publication.

2.3 Physiological rhythms

Although Huygens (see above) worked on mechanical rather than biological systems, and much of the succeeding work on entrainment - both theoretical and applied - has been carried out within the fields of mathematics and physics, our main emphasis is on the entrainment of physiological rhythms, especially in human beings.[4] One of the first applications of the entrainment model in biology is attributed to the French physicist de Mairan, who in 1729 first identified and studied photic entrainment - synchronisation to the cycle of light and dark - in plants (Chapple 1970). Apart from entrainment to such *environmental* cues, entrainment studies on various animal species have identified numerous examples of *mutual* entrainment between individuals, including crickets chirping in unison and fireflies flashing synchronously (Ancona and Chong 1996; Strogatz and Stewart 1993).[5] Thus, although the capacity to entrain may be exploited in particular ways by the higher animals, and particularly by man, it seems to be evidenced in some way or other by all animal and plant species, and the ubiquity of the phenomenon points towards its importance in the world of living organisms.

In modern times, a lot of research has concentrated upon studying the nature of rhythmic processes in living organisms. The proponents of chronobiology, as it is called, point to the fact that biological or physiological rhythms appear to be essential to life itself (Aschoff 1979, Strogatz and Stewart 1993, Glass 1996). Menaker reports that cyanobacteria, simple organisms that originated at least 3 billion years ago, "have fully functional circadian clocks", which may give support to the suggestion that biological rhythms and their entrainment are fundamental to life in any form (2002:2). Some have gone so far as to characterize any organism "as a (loosely coupled) 'population of oscillators'." (Pittendrigh 1975, quoted by Warner 1988:68-9). A good deal of current medical research is concerned with the behaviour of endogenous physiological rhythms in humans (such as the variation of body temperature over the 24-hour cycle), and how the study of those rhythms might be further developed as a tool in the diagnosis of pathological states and ultimately lead to the development of new treatments (see Glass 1996). An important part of this work is the consideration of entrainment and in particular, identifying which physiological rhythms entrain to which stimuli, and under what conditions.

These studies, needless to say, reveal that the entrainment of biological rhythms is a complex subject. As we have seen, in order to model the behaviour of these systems mathematically we need to consider the entrainment of oscillators whose interactions are non-linear and potentially chaotic. That is, even if the relationship between two biological rhythms is taken to be ruled by a relatively simple mathematical equation (telling us what the outcome ought to be, given a particular configuration of endogenous rhythm, entraining rhythm, and intensity of interaction), since that mathematical equation is non-linear the output behaviour of the system can be unpredictable, or at least, predictable only when those conditions fall within a fairly narrow band. An illustration of this would be that the behaviour of our endogenous cardiac rhythm ought to be predictable when stimulated by a pacemaker, but if the period of the pacemaker were set outside a certain range, the behaviour of the cardiac rhythm would be for practical purposes unpredictable.

The relationship between entrainment, the stability of biological rhythms and health is not easily summarised. There are many examples where relatively stable and entrained biological rhythms are associated with good health (the enhanced stability of the heart rate afforded by a pacemaker is an example of this), while conversely asynchrony and instability of rhythmic processes can be associated with pathologies. However, the situation overall is not quite so simple. Entrainment does not necessarily imply

[4] Beyond the introductory comments in section 1, the present article will not address applications in mathematics and physics, nor will it deal in detail with the mathematical modelling of entrainment in any detail, although we will need to make brief reference to some of the implications of the mathematics. The interested reader may want to consult the respective literature (e.g. Kelso, 1995; Pikovsky et al., 2001; Strogatz, 2000).

[5] In what may have been the first scientific observation of this kind, the Dutch physician Engelbert Kaempfer, following his journey to Siam in 1680, described the synchronization of light emission in large populations of glowworms (Buck and Buck 1968).

stability of biological rhythms, and in any case stability is not necessarily associated with good health. In the case of brain waves, for example, we have a different pairing: stable brain waves may indicate a pathology (epilepsy) while unstable waves may indicate a healthy state. Indeed, a certain amount of flexibility and dynamic equilibrium seems to be associated with health in many systems, as is a degree of "noise", or random variation in normal physiological rhythms (Glass 1996: 281). One might suppose a connection here with the well-known 'humanising function' in music sequencing software, where a random element is introduced: this 'noisy' behaviour is perceived as 'natural', whereas clean behaviour is perceived as 'artificial'. Similarly, there is a link here with Keil's theory of 'participatory discrepancies,' which will be discussed below (see section 5.1).

Although we should be careful not to oversimplify, it does seem that there are healthier and less healthy, or pathological, ways in which to be entrained. If the healthy functioning of a system requires a certain degree of entrainment, then either a lack of entrainment, a weakening or even an excessive strengthening of entrainment could be associated with a change to a pathological state. Pathological states involving a disruption of 'normal' entrainment within or between individuals include conditions such as epilepsy, Parkinson's, and autism. Autism, to take one particularly relevant example, is clinically defined in terms of "impairments affecting social interaction, communication and creativity": it can be associated with motor incoordination and co-occurs with abnormal circadian rhythms and "probably universally - a very poor intuitive sense of time" (Boucher 2001:111). Boucher suggests that people with autism suffer from deficits in their timing systems, a finding supported by Condon's studies of the coordination of social interactions (e.g. Condon 1982; see below, section 3.2). Not surprisingly, then, music therapists have developed the use of rhythmic entrainment to successfully treat clients with autism (see below, section 4.3).

2.4 Circadian rhythms and entrainment to environmental stimuli

An important part of chronobiology, since de Mairan, is the study of entrainment to environmental stimuli. This can be characterized as *asymmetrical* entrainment, in that the individual cannot influence the entraining rhythm (e.g. the alternation of light and dark). In the case of asymmetrical entrainment, a body is 'forced' to adjust to externally set, cyclically varying conditions without being able to influence the latter. (Where one rhythm appears to be driving another, the former is referred to as the 'entraining rhythm', or Zeitgeber: the adjusting rhythm is sometimes termed the 'entrained' rhythm.)[6] Circadian rhythms of living organisms are examples of this type of entrainment, demonstrating the adaptive capabilities of living systems (e.g. Wang and Brown 1996; Zeng et al. 1996).

The importance of the circadian rhythm is not limited to the regular alternation of sleep and wakefulness: this same rhythm entrains a host of other physiological rhythms such as the daily temperature cycle and the endocrinal system. The detail of those systems need not concern us here: more interesting perhaps are attempts to model the entrainment to light cycles, which might have parallels with entrainment to auditory cues (see for instance the summary in Groos 1983, Moore 1990). The mechanism of this entrainment process has been the subject of considerable research aiming to identify the entraining pathway; to determine whether the brain contains a single pacemaker or several linked oscillators; and to locate the pacemaker or pacemakers. Moore (1990) suggests that synchronisation of circadian rhythms depends on the entrainment of a pacemaker located in a part of the brain known as the suprachiasmic nuclei. The endogenous rhythm of this pacemaker is reset by exposure to light, this information being relayed via the optic nerve. The central pacemaker, in turn, entrains a number of other oscillators that regulate particular physiological systems, and maintains stable phase relations between these oscillators (Rusak 1990). A similar volume of research has yet to be carried out on entrainment to auditory cues, although recent research on motor performance and metrical perception employ models of multiple, linked, oscillators in the brain (see section 4.1) that are similar to models of entrainment to light cycles.

2.5 Ultradian rhythms and interpersonal entrainment

Chronobiologists are turning their attention increasingly to ultradian rhythms, i.e. those with periods of less than a day. The term 'ultradian' covers a wide range of possible periods, from milliseconds up to 12 hours, although it tends to refer particularly to the range from a few minutes up to a few hours: faster rhythms are sometimes referred to as supra-ultradian. There are of course numerous examples of

[6] In some contexts the more loaded terms 'master' and 'slave' rhythm are used.

ultradian biological rhythms, so it is not possible here to do more than cite a couple of examples and draw out some features of ultradian rhythm research that are of interest to ethnomusicologists. One of the important findings of chronobiology was the discovery of cycles of rapid eye movement (REM) in sleep, with a period in the order of 90 minutes. Slightly more controversial is the hypothesis that this 90-minute cycle continues throughout the day, in wakefulness as well as in sleep (Kleitman 1963), a pattern known as the Basic Rest-Activity Cycle.

An important feature of ultradian biological rhythms is that they are never simple, symmetrical patterns (the same is true, of course of the 24-hour patterns of light and dark). Patterns of activity and rest in humans, for instance, are not balanced. As Sing puts it, "more time is spent in activity than in the rest phase, and its exact period from one day to the next is very variable. Hence, predictability of exact circadian periodicity is not possible - one can only give probable periods within a narrow range of values." (Sing 1992:353).

An important difference may also be observed between circadian and ultradian rhythms: the former, which entrain to the environmental light-dark cycle, are the same for all species, whereas for many ultradian rhythms, period length varies with body mass (an illustration of this is that the heartbeat of a mouse is approximately 20 times faster than that of an elephant, and its maximal life span is roughly 20 times shorter; Gerkema 2002). Gerkema suggests, therefore, that circadian rhythms could be said to reflect " 'objective', environmental time", while internal ultradian rhythms "reflect subjective, physiological time" (2002:212, citing Brody). Of course if one takes into account social interactions, different individuals do mutually entrain their "subjective, physiological rhythms", so the distinction is perhaps more appropriately expressed as that between different modes of entrainment than between the objective and the subjective. The two modes would be (a) asymmetrical entrainment to environmental cues at the circadian level, and (b) symmetrical entrainment to other individuals at the ultradian level. (As Gerkema goes on to point out, mutual entrainment or social synchrony is reported in a wide variety of species including "amoebas, the barnacle gees, voles, cattle and rhesus monkeys" (2002: 212, references omitted).) These observations nonetheless perhaps support the idea that entrainment may relate phenomenologically to a sense of social belonging, or of one's subjectivity relating to "something larger": impressions that are frequently linked to musicking,[7] among other activities.[8]

2.6 Self-entrainment

Not all entrainment involves an external stimulus, either environmental or inter-personal. 'Self-entrainment' describes the case where two or more of the body's oscillatory systems, such as respiration and heart rhythm patterns, become synchronized. Port et al. (1996) have pointed out that humans and animals typically exhibit self-entrainment in their physical activity. By self-entrainment they mean that in actions by a complex body, a gesture by one part of the body tends to entrain gestures by other parts of the body. For example, arm movements in walking could - in principle - be independent from leg movements, but in fact they are not. It 'feels' much easier, is more harmonious, and less strenuous if the arms lock into the leg movements. A similar effect is reported for the locking of step and inhalation cycles in jogging (Bramble and Carrier 1983), or between respiration and heartbeat in high performance swimmers (Schäfer et al, cited by Glass 1996:280). The degree and kind of self-entrainment exhibited depends on the individual and the task being carried out. For some of the cases just mentioned, it could be argued that the coupling is due largely to a direct physical link between physical oscillators: legs and arms are mechanically connected via the trunk. However, entrainment does not imply a rigid mechanical coupling between oscillators. On the

[7] To borrow a verb from Small 1998.

[8] Another related application of entrainment theory is Moore-Ede, Sulzman and Fuller's distinction of two clusters of ultradian rhythms, "System X and System Y" (discussed in McGrath and Kelly 1986: 82-83). Their System X describes a collection of oscillatory processes organized around core body temperature and REM sleep; System Y describes a second collection of oscillators, organized around the rest-activity cycle, and including skin temperature and slow-wave sleep (82). System Y seems to be located in the suprachiasmic nuclei (see above), and is usually entrained to environmental circadian rhythms, while System X is located elsewhere and not so entrained. The different rhythms in each system seem to be strongly mutually entrained, while the two clusters entrain each other rather more loosely as well as asymmetrically, with System X influencing System Y more strongly than the converse.

contrary, with rigid mechanical coupling, entrainment will be lost because the two oscillators lose their independence and form a new, unified system.

It has been a longstanding discussion whether or not multiple motor actions in humans are governed by a central clock. Recent research, however, seems to be in favour of a multiple timer theory in which each motor action is controlled by an independent timer (Ivry and Richardson 2002). The multiple timer model that Ivry and Richardson developed is a form of coupled oscillator model. The coordination of motor actions appears to be ensured by a neural gating mechanism[9] that, at the same time, improves temporal stability of the actions involved. Ivry and colleagues have shown this for bimanual coordination as well as for experimental tasks involving repetitive movements of two hands and one foot (this is not unlike keeping time by clapping while tapping a foot). The difficulty people have in temporally uncoupling their limbs suggests that the gating process may reflect a fundamental constraint in human performance. At present, however, this constraint has only been identified in coordinated limb movements. It is not clear whether the same or a similar gating mechanism exists for all types of motor actions, for example between limb movement and speech acts. In any case, the fact that such gating mechanisms would hardly be able to constrain entrainment between actions located in different bodies justifies us in distinguishing between self-entrainment (within one body) and interpersonal entrainment.

Self-entrainment in speaking has been studied by Port et al. (1996). They report the results of some experiments in which they test the relation between onsets of repeated phrases and the timing of stressed syllables within these phrases under various repetition rates. They suggest that ordinary human speech exhibits self-entrainment more or less whenever given the opportunity to do so, and that self-entrainment may be deeply revealing about the way in which time is handled in the nervous system of animals, for many purposes going well beyond the coordination of limbs. Below, in case study 2, we report the analysis of two cases of musical self-entrainment where a musician simultaneously sings and plays a rhythm accompaniment.

The motor system is not only responsible for *producing* a rhythm, but is also involved in the *perception* of rhythm: this allows us to understand in part why we experience a visceral response to rhythm. While not yet clearly understood, research is ongoing to determine "how the gestural experience of producing a sound in a physical world interacts with its perception" (Risset & Wessel 1999:142 fn 6, citing Cadoz, Lisowski and Florens 1984, 1993). Keil has referred to this phenomenon as ‘kinaesthetic listening,’ where music listeners experienced in performing music "[feel] the melodies in their muscles, [and imagine] what it might be like to play what they are hearing" (Keil 1995:10). Keil’s comments have been corroborated with numerous examples (among them Blacking 1983:57, Sager 2002:198, Sundberg 1999:210). While this phenomenon has broad implications for ethnomusicological research and interpretation, its importance here is to emphasize the significance of entrainment in listening to music, and to suggest that the study of entrainment in listeners is as important as that in performers. (Needless to say, as ethnomusicologists we are aware that the distinction between “listener” and “participant” is not always easy to make in any case!)

2.7 Entrainment and brain waves

The term entrainment, in the specific sense of frequency-following, is also widely used in connection with brain waves. The technique of recording electrical activity of the human brain from the scalp originated in 1875 with observations of Richard Caton and was developed into electroencephalography by Hans Berger in the late 1920s. Berger found that the recorded activity can be described in terms of four frequency bands: delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), and beta (14-30 Hz) waves.[10]

---

[9] Neural information for the motor actions passes through a ‘gate’ that opens only when simultaneously activated by the different oscillators involved.

[10] The electrical activity that is recorded in electroencephalograms (EEGs) is largely attributable to postsynaptic potentials (PSPs; i.e. graded potentials produced by synaptic activities that eventually lead to firing of neurons) in cell bodies and dendrites of cortical neurons (Lopes da Silva and Storm van Leeuwan 1978). Neurons of the human brain, the ‘gray matter’, come in two principal arrangements: layered they form a cortex and in non-layered agglomerations they form a nucleus. Two cortices, the cerebral and the cerebellar cortex form the surface layer of the human brain; nuclei are located beneath the cortex and in the

Despite persisting uncertainties about the actual neuronal processes that generate EEG (i.e., electroencephalogram) waves, and despite the fact that EEGs are incomplete records of neuronal activities in the brain, it has been obvious since Berger's days that EEGs reflect certain mental states. A dominance of low-amplitude beta waves (14-30 Hz) was observed in busy and alert states, whereas alpha waves (8-12Hz) with larger amplitudes dominate in a relaxed, inattentive state. In the early days of EEG research it was also discovered that some of the alpha and beta waves could be synchronized – entrained – to the frequency of an external, bright strobe light stimulus. The English neurosurgeon Gray Walter was the first to report that at certain 'entrainment' frequencies of the external stimulus, his subjects would enter trance-like states where they began to experience deep peacefulness, dream-like visions, and other unexpected sensations (Walter 1953). Later it was discovered that not only strobe lights but also rhythmic noises could produce such effects. Although this phenomenon is still not fully understood, it does indicate that external stimuli are able to affect brain states.

The problems surrounding the interpretation of spontaneous EEGs probably explain why those few studies concerned with the relationship between external stimuli and brain waves often end up with general findings, for instance that pleasurable stimuli tend to increase the theta wave components (e.g. Walter 1953; Maulsby 1971; Walker 1977; Ramos and Corsi-Cabrera 1989). So, while studies of brain wave patterns via EEGs present some enticing research opportunities, the limitations mean that this research method has so far only provided rather general conclusions about the function of musical phenomena (as sources of external entraining frequencies) upon changes in mental states.

2.8 Degrees and phases of entrainment

Where two or more rhythmic processes or oscillators have the potential to interact, they do not synchronize automatically and instantaneously, and in some cases do not synchronise at all. Some of the factors determining whether two oscillators will entrain, and the different entrainment possibilities, are the following:

First, not all oscillators will entrain: it is generally observed that, for instance, the periodicities of autonomous oscillators need to be fairly close to each other for entrainment to happen (see Aschoff 1979: 6).

Second, oscillators may entrain more or less strongly and more or less quickly (partially-entrained or transient rhythms are exhibited during the entrainment process: see Chapple 1970). The term entrainment does not only include cases of strict phase and frequency synchronization, and may cover a spectrum from weak to strong coupling. A rhythmic process may adjust towards the frequency or phase of another rhythmic process without attaining absolute synchronisation.

Third, we can distinguish two aspects of entrainment that need not necessarily co-occur. One is frequency or tempo entrainment, where the periods of the two oscillators adjust toward a consistent and systematic relationship (see Ancona and Chong 1996). The other is phase entrainment, or phase-locking: where two processes are phase-locked, focal points (such as a foot striking the floor when dancing) occur at the same moment (this is discussed in greater detail section 3.3 below).

Fourth, the phenomenon of entrainment is further complicated by the fact that oscillators may entrain in states other than exact synchrony. For instance, two entrained oscillators have two possible phase-locked states, namely synchrony and anti-synchrony: a normal human gait exhibits the latter, i.e. one foot comes up as the other goes down. The more oscillators are involved, the more phase-locked states are possible. These possibilities can be derived mathematically using the theory of coupled oscillators, and can be observed in natural phenomena: for instance, quadruped gaits closely resemble the natural patterns of four-oscillator systems. Stewart and others deduce from this fact that "The most likely source of this

---

brain stem. The columnar arrangement of neurons in the cerebral cortex facilitates summation of these potentials and their registration at the scalp. However, other geometric arrangements of neuronal assemblies can lead to extracellular attenuation or even cancellation and therefore not all activities of brain cells can be recorded in the EEG. The regular spontaneous EEG components are thought to be due to PSPs synchronized by discharges from deep nuclei (thalamus) and the degree of synchronicity is reflected in the amplitude and form of the EEG (Lopes da Silva 1991). If cortical activity is synchronous over a larger area it produces larger potentials (e.g. Cooper et al. 1965). Desynchronisation of the EEG and reduction of its amplitudes presumably reflects increased interaction of several neuronal sub-populations engaging in cooperative activities.

concordance between nature and mathematics is in the architecture of the circuits in the nervous system that control locomotion" (Strogatz and Stewart 1996:73).

As Bluedorn puts it, then,

> Entrainment is the process in which the rhythms displayed by two or more phenomena become synchronized, with one of the rhythms often being more powerful or dominant and capturing the rhythm of the other. This does not mean, however, that the rhythmic patterns will coincide or overlap exactly; instead, it means the patterns will maintain a *consistent relationship* with each other. (2002:149)

Such a "consistent relationship" could be, as we have seen, one of synchrony or anti-synchrony, or of some other definite relationship (e.g. one oscillator runs twice as fast as another). Moreover in real-life situations, it is often the case that two periodic processes lock frequency, but remain out of phase. The relationship between two oscillators can therefore be described as either lagging, synchronous, or leading. Where one oscillator either lags or leads the other, the difference in phase can be expressed in terms of phase angle. The period of oscillation is represented by the 360 degrees of a circle (this terminology is based on the representation of a periodic rhythm by a cyclical motion mapped onto a circular shape). Where two oscillations are in precise anti-synchrony the phase-angle difference is 180 degrees; if one is 1/4 out of phase with the other (a musical example would be when one musician is one beat out of phase with another in a four beat metre) the phase-angle difference is 90 degrees; and so on. A rhythm that 'follows' another is described as "lagging" and having a negative phase-angle difference; one which anticipates is called "leading" and has a positive phase-angle difference. Some entrainment studies assume that entrainment necessarily involves synchronisation of phase, but in real life systems this is not always the case. This concept and the terminology of phase difference can be useful in studies of musical entrainment, as will be demonstrated in case studies 2 and 3 below.

3. Further applications of the entrainment concept

3.1 Social psychology

Applications of the entrainment model also extend into a number of areas of social scientific research, including social psychology, linguistics and communication studies, and cognitive psychology. Social psychologists routinely employ the term entrainment, describing phenomena such as the synchronization of an individual's activity cycles to his or her working hours. Some of the findings in this area are of interest to ethnomusicology, such as McGrath and Kelly's application of entrainment to social psychology – referred to as the "social entrainment model" (McGrath and Kelly 1986: 83-84; see also Kelly 1988, Ancona and Chong 1996, and Warner 1988).

The social entrainment model rests on five major propositions:

> 1. That much of human behaviour, at physiological, psychological, and interpersonal levels, is temporal in character; that is, that the behaviour is regulated by processes that are cyclical, oscillatory, or rhythmical.
> 2. That these are endogenous rhythms; that is, that they are inherent in the life processes of the organisms involved.
> 3. That sets of such rhythms, within the individual, become mutually entrained to each other, hence that they come to act in synchrony in both phase and frequency or periodicity.
> 4. That the temporal patterns of individuals who are in interaction become mutually entrained to one another, that is, that they get in synchrony of phase and period.
> 5. That temporal patterns of behaviour of individuals and sets of individuals become collectively entrained to certain powerful external pacer events and entraining cycles. The former alter the phase or onset, and the latter alter the periodicity, of those endogenous and mutually entrained rhythms (McGrath and Kelly 1986: 83-84).

This model is useful in as much as it sets a precedent for bridging the gap between neurological and biological studies on the one hand, and social scientific research (in this case, social psychology) on the other. Their conclusion here is that:

> During a period of social interaction, the members of [a] social system must work out a "negotiated temporal order" in which they adjust their activity patterns to coordinate with each other. Each member of the social system can be viewed as an oscillator (or as a set of loosely coupled and mutually entrained oscillators); that is, the person's activity will show one or more patterns of alternation over time… The multiple independent cycles of activity of the members of a social system become coordinated with one another into a temporally patterned system of activity that is characterized by a dynamic equilibrium rather than by a fixed homeostatic pattern (1986: 89-90).

We reflect below on some of the ways in which these ideas may be applied to ethnomusicology. For now, it is enough to note that this is a precedent for regarding entrainment not only in physiological but also in social terms. When we entrain to a piece of music this synchronization can also be analysed in terms of its social conditions and implications (whether relatively symmetrical, as between two or more performers, or asymmetrical, where a group responds to amplified recorded music). The degree of entrainment, and the negotiation of symmetrical entrainment between individuals, can be studied in terms of a negotiation of relative power between those individuals (i.e. if there is a significant imbalance of power or authority, the less powerful individual(s) may adjust their endogenous rhythms further and more readily than do the more powerful). An illustration of this will be found in case study 3.

3.2 Interaction and communication

Arguably the most significant areas of entrainment research for ethnomusicologists are those concerning interaction and communication between human individuals: this includes verbal and nonverbal communication and the relation between the two (roughly speaking, language and gesture). Considerable evidence from social scientific studies points to the rhythmic organization of both verbal and gestural communication, to the mutual entrainment of speech and gesture, and to entrainment between the communicative rhythms of interacting individuals (Davis 1982; Montagu and Matson 1979). Research in the biological sciences also demonstrates the existence of inter-personal entrainment. For instance Schmidt et al. (1990) report that subjects tend to synchronize their leg movement with that of other subjects observed visually. This makes entrainment a promising concept for the study of musical performances, where exchange and communication takes place over some physical distance, via visual and auditory channels, not via direct mechanical 'coupling'.

An early contribution to this strand of research was the work of Lenneberg, who made a case for rhythm as the "essential organizing principle" of language, and developed analyses which treated the rhythmic patterns of speech as a kind of "carrier signal" for what is normally considered linguistic meaning, analogous to the carrier signal of a radio wave (Lenneberg 1967). Subsequent researchers have identified periodicities in communicative rhythms on a number of different levels, from the alternation of speech and silence in conversation down to the alternation between consonants and vowels in each phrase (see Jaffe and Anderson 1979).

An interesting finding in the study of speech rhythm that might suggest entrainment is that in certain situations the periodic rhythms of speech continue across turn boundaries - in other words, a speaker may conform to precisely the speech rhythms of the preceding speaker (e.g. Couper-Kuhlen 1993, Auer et al 1999, Webb 1972). This is not the case for all communicative interaction, which raises the question under what circumstances this apparent synchrony will manifest, and what its presence or absence (or degree) indicates about interpersonal relationships.

A productive line of research concerns the coordination of these speech rhythms with other motor movements. Indeed, among the main interests in studies of verbal and nonverbal communication has been the relationship between speech-related and speech-independent gesture, the ways in which gestural communication may be like (or unlike) linguistic communication, how gesture is co-ordinated with speech (for an accessible textbook introduction to this subject, see Knapp and Hall 1997), or how gestures may even be at the origin of speech (McNeilage 1998).

Speech and gestures are apparently strongly coupled in adults. Coupling is so effective that when speakers stutter, the gestures tend to stop until the speech is recovered (Mayberry et al., 1998). In analysing the ontogenetic development of this interaction, Iverson and Thelen (1999) invoke the concept of coupled oscillators. They propose that hand and mouth activity are loosely coupled from birth, and this initial linkage (e.g. the Babkin reflex) seems to be established phylogenetically through the feeding system.

Through rhythmic activity, and later in the life-cycle, through gesture, the arms gradually entrain the activity of the vocal apparatus.[11] Mutual activation increases as vocal communication through words and phrases becomes more practised, leading to strong synchronization of speech and manual gestures for communicative purposes in adults.

Some, but by no means all, research on gestural communication has addressed the question of interaction - examining for instance, how an empathetic listener mimics a speaker's posture and gesture patterns. A subset of these interaction studies directly addresses the question of *interactional synchrony*. Because the study of interactional rhythms is of the greatest significance for ethnomusicological approaches to entrainment, we will consider here some of the key researchers and their methods and theoretical orientations here.

The first major figure to carry out empirical timing studies of interaction was the American anthropologist Eliot D. Chapple, beginning in the 1930s (Chapple 1939, 1970). His initial studies were based on simple timings of "action" and "inaction" of participants in interaction (for instance, the durations participants in a conversation spent speaking and listening). On the basis of these studies, Chapple became convinced that normal social interactions were rhythmically - that is, periodically - organized. His book *Culture and biological man*, published in 1970, makes it clear that he saw these rhythmic processes as located on a continuum of naturally occurring rhythms from the very fast (brain waves, muscle fibre firing) to those with much longer periods (menstrual cycles, migration patterns) – i.e., from the ultradian to the infradian. He also discusses the synchronisation of these rhythms explicitly in terms of entrainment (1970:27).

The next generation of researchers was able to develop more sophisticated methodologies for the study of interactional rhythms and synchrony, in particular employing the analysis of sound film. The first to apply film analysis to the study of interactional synchrony in any detail was William Condon, who carried out a number of detailed cinematographic studies of interaction in the 1960s using methods developed by Ray Birdwhistell.[12] This "microanalysis", as he called it, yielded a number of important results: Condon reported that "microanalysis of sound films of listener behaviour led to the surprising and unsuspected observation that listeners move in precise synchrony with the articulatory structure of the speaker's speech" (Condon 1976:305), which he interpreted as evidence of "entrainment or stimulus tracking" (309). Although in some respects Condon's methodology raised suspicions of researcher bias (his method for dealing with the key problem of the segmentation of behaviour "constituted re-viewing a sound film of human communication over and over for many hours until forms of order began to be seen" [1976:288]), his findings that this synchrony could not be observed in subjects "with severe psychopathology or communication disorders" such as autism, dyslexia and schizophrenia (1982:61), and that the detailed features of the interactional synchrony varied with the ethnic origin of his subjects, do suggest that his work should not be casually dismissed. At one point, Condon even suggested that the periodicities he observed in behaviour were uncannily close to the frequency ranges of the different types of brain waves, and in light of this he coined the term "behavioural waves" (1986: 63-66).[13] Following in the footsteps of Chapple and Condon, among the most prominent researchers of the latter part of the 20th century (and into the 21st) were Adam Kendon and David McNeill. Kendon's studies concentrate on the

[11] Entrainment of vocal activity by manual activity is also suggested in some ethnomusicological studies (see discussion of case study 2 and Will, in press).

[12] Ray Birdwhistell pioneered sound film analyses of interaction: his particular approach is referred to as 'kinesics', and amounts to a quasi-linguistic study of nonverbal communication. He was convinced that there was no distinction between verbal and nonverbal communication - he refused to use the latter term - and worked to analyse gestural communication in the terms of structural linguistics. Thus, he attempted to define the basic units of gestural communication as 'kinemes' (analogous, in his view, to phonemes), and to show how they were built up in successively larger units of meaning. Birdwhistell's approach is unusual, since studies of verbal communication are more often seen as contributing to a critique of the Saussurian structural tradition, which saw linguistics as the study of the structural relationships between units of meaning, working up from the phoneme (Gumperz 1996).

[13] It is also noteworthy that Condon is responsible for one of the few direct cases where the entrainment model has influenced ethnomusicological thinking - through his contact with Alan Lomax.

coordination of speech with body movement, again employing sound film analysis (e.g. Kendon 1972, 1981, 1982). David McNeill has developed this approach further, working up a detailed theoretical model of the interrelationship between speech and gesture (concentrating in fact on a particular category of gesture, alternatively labelled "gesticulation"). McNeill argues that gesture and speech "arise from a single process of utterance formation. The utterance has both an imagistic side and a linguistic side" (1991:29). His approach thus differs from that of Birdwhistell (see footnote 12): where Birdwhistell looked for language-like structures in gesture, McNeill sees gesture as an imagistic complement of language. This view is apparently influenced by Kendon's distinction between digital and analogical encoding: "Words and other discrete symbol systems… convey their messages digitally. Actions, whether practical or expressive, convey their messages analogically" (Kendon 1981: 5).[14] This may be a significant observation for future entrainment studies - many musical behaviours may be thought better suited to description in analogical rather than digital terms (for instance, the continuous, flowing melodic figures used in much Indian classical music).

A useful critical discussion of some of these approaches can be found in Rebecca Warner's article "Rhythm in social interaction" (1988). Warner discusses, with reference to the work of Chapple, Condon and others, concerns of observer bias as well as the possibility of statistical artefacts,[15] proposing what she suggests are more reliable methods for studying synchrony in social interaction. One of her proposals is to treat rhythm in terms of recurrent cycles modelled as sinusoidal waveforms, rather than as alternations of activity and rest (square-tooth waveforms) or as sequences of events occurring at discrete time points. Interestingly, a similar suggestion is made in a specifically musical context by Robert Gjerdingen (1993): this will be discussed in more detail in section 4.1.

We noted above the need to take care in correlating entrainment and health. The same caution applies here in correlating types and degrees of social entrainment with emotional affect. However, there does seem to be some evidence of a correlation between entrainment and positive affect in communication. One study reported that women who are "notoriously skilful conversationalists, are particularly adept at modifying their endogenously generated speech rhythms to match those of their dialogic partners. Furthermore, the degree of rhythmic entrainment to an exogenous speech source is associated with positive social evaluation and interpersonal attraction." (Marcus, Welkowitz, Feldstein and Jaffe quoted by Jaffe and Anderson 1979:18-19). It seems reasonable to speculate that in music, as in verbal interactions, particular modes of entrainment are associated with desirable (or in some cases undesirable) types of emotional response or affect.

As noted above, rigid entrainment and precise synchrony in human rhythmic processes are not necessarily associated with health or positive affect: Warner et al. have shown experimentally that "*moderately* rhythmic social interactions [were] evaluated most positively" (1987:57, emphasis added).It seems that entrainment that is not too 'perfect' generally provides a more positive social experience than either entrainment that is too tightly coordinated or not coordinated at all. What is considered a desirable tightness of entrainment seems to vary at a cultural level, and this knowledge is also an important aspect of

[14] The other major figure in this area has been Paul Ekman - however, his work seems to be less directly relevant for entrainment studies. Ekman took a slightly different line, concentrating more on the relationship between nonverbal behaviour and feeling states (Weitz 1974). Ekman considered gestural communication as a rather disparate phenomenon and worked on the taxonomy of gesture types. He proposed four major categories of gesture: (i) emblems (movements tied to specific verbal meanings), (ii) body manipulators (head scratching, nose picking etc), (iii) illustrators (tied to the content or flow of speech, and (iv) emotional expressions (Ekman 1977: for a more extensive discussion see Ekman and Friesen 1969). The distinctions between different types and functions of gestures may explain some of the apparent differences between the orientations of different researchers discussed in this section. Although we would suggest this work is only indirectly relevant to entrainment studies, it is worth pointing out that Ekman's work is cited in several musicological works: see e.g. Blacking 1977 and Frith 1996: 215-217.

[15] One suggestion is that the mathematical manipulation of timing data may generate the appearance of regularities or periodicities even where the data is completely random. Another factor here, which is discussed in more detail below, is that correlations between rhythmic processes do not in themselves prove entrainment.

any musical culture. Determining what is considered to be the optimum or preferred degree of entrainment in different cultures could serve as an important diagnostic of cultural style (e.g., see Waterman 1995:93).

3.3 Cognitive psychology

The entrainment concept has also had an important role in the development of theory in parts of the cognitive sciences. We will briefly consider some applications of entrainment in cognitive psychology that are relevant to music research: in particular, theories of attention.

Several cognitive psychologists hold that perception, attention, and expectation are all rhythmic processes subject to entrainment. In other words, even when a person is not speaking or performing music, but is only listening, their perceptions and expectations will be coordinated by their entrainment to what they hear. Entrainment is fundamental then, not just to coordinate with others, but even to perceive, react to, and enjoy music. Music, as an external oscillator entraining our internal oscillators, has the potential to affect not only our sense of time but also our sense of being in the world. Moreover, it is clear that people exercise a significant measure of self-control in negotiating musical entrainment. The cognitive psychology literature reviewed below addresses the relation of unconscious processes and individual agency as co-determinants of the entrainment.

The presentation in this section is based largely upon the work of Mari Riess Jones and her co-workers, as published between 1976 and 2002. Some basic assumptions about entrainment that we have already encountered above are quite similarly expressed in these studies. First, Jones assumes that human beings are inherently rhythmical, with "tunable perceptual rhythms" that can entrain to time patterns in the physical world. In other words, she postulates a propensity for an individual's endogenous rhythms to synchronize with perceived and expected rhythmic processes. Second, entrainment occurs as *both* period and phase synchronize (this is a more restricted definition than we are proposing; cf sections 2.8, 3.1). Third, entrainment varies in degree (cf. section 2.8).

Another basic premise of Jones' theory is the assumption that many of the time structures evident in real-world events are patterned in coherent and hierarchical ways (Jones 1976:353). According to Jones, a hierarchical time structure is one in which "the temporal distribution of markers [event onsets and relative stress] reveals nested time levels that are consistently related to one another… by ratio or additive time transformations" (Jones & Boltz 1989: 465). Examples of additive time transformations include gradual changes in velocity, such as musical tempo changes, or changes occurring with a shift in physical momentum, as when a person breaks into a run from a casual walk. Most musical meters are examples of simple ratio transformations between at least two distinct but nested time levels. "One is a referent time level, the beat period, and the other is a higher order period based on a fixed number of beat periods, the measure" (Jones & Boltz 1989: 467, see also Yetsin 1976). Nested time levels in music may extend upward from the smallest subdivisions of a beat, to a beat level, to a measure, to a phrase, to a period, to large order forms.

Perceived rhythms will also be interpreted according to learned knowledge structures (referred to as schemes or schemata in the cognitive sciences).[16] For this reason, even a novel rhythm may be assessed as being like a familiar, already learned rhythm. In all, varying rhythmic contexts, stages of development, as well as physiological and psychological factors will cause people to have "different temporal experiences of the same event," meaning people will have different entrainment experiences even though they may be participating in the same musical performance (Jones & Boltz 1989: 471).

Jones argues that people have an initial bias to entrain to simple, coherent rhythms (Jones & Boltz 1989: 470, Jones 1976:341). For example, we might assume that in speech, people will entrain to the

---

[16] It is a basic premise of cognitive theory that all experiences and sensations cause learning. This process of learning changes the physical structures of the body's nervous system (e.g., seventy-five percent of the neo-cortex—which includes the music association areas of the human brain—is unassigned at birth and is assigned according to experience and learning; see e.g., Hodges 1996a and Deutsch 1999). Since the very neurological formation of the brain is shaped by individualized learning, it follows that no two people could have exactly the same physical brain - even if they have shared in the same public, musical discourses. This learning and the resulting physical changes in brain structure are one way individuals come to "embody" or internalize their society's culture. This rather elegantly explains how individual music psychology and music culture overlap and are mutually inclusive—albeit imperfectly and always with individual variation.

speaker's "characteristic articulation rate," or in music, to "the beat period or measure span". This regular period to which we entrain, known as the "referent time level," serves as an anchor that locks the listener to the speech or music event. When an entrained rhythm is part of a hierarchical rhythmic context, people can selectively shift or focus their attending energies to different levels of referent periods in order to accomplish different goals.[17] In a musical context, such goals might include keeping track of the unfolding formal structures, or conversely, noting fine subtleties in timbre or pitch. Conversely, such shifts of attention are less likely to happen in events of low temporal coherence (Jones & Boltz 1989). An example of an event of relatively low temporal coherence would be unmetered music, sometimes described as 'free rhythm'. An implication of Jones's theory could be that listeners to such music are less likely to shift their attention between different temporal levels (beat, measure, hypermeasure, section) than they are when listening to strongly metered music. "Free rhythm" genres are however very diverse, and the category may include several different forms of temporal organisation (Clayton 1996), so we should not be too quick to jump to conclusions in this case.

Experiments testing entrainment theories in the cognitive sciences have begun to address how the complex patterns of real-world events relate to the cognitive bias toward entraining to simple patterns and hierarchical rhythms. Although speech and music "fail to fit the simplest time hierarchies" (Jones & Boltz 1989: 468), entrainment seems to occur in spite of these complexities. When considering entrainment processes involved in the perception, expectation, or attention to musics with so-called 'free' rhythms (e.g., what occurs in the improvisatory, solo introductions of Indian *alap* or Turkish *taksim*), the theory of "centering" suggests that even where there is no explicit pulse (and therefore no coherent or hierarchical rhythmic structure), a listener might entrain to what s/he perceives as the 'centered' or median period length (see especially Barnes and Jones 2000:290). Barnes and Jones also state that multiple expectancies may be generated by oscillators that entrain independently to different referent levels of an auditory signal; the expectations generated by these different oscillators may either coincide or conflict with each other. Jones and her colleagues' work shows entrainment to be a flexible process that can adapt and accommodate many ranges of rhythmic complexity and coherence found in the real world. Such a model of entrainment allows for a better understanding of music as a communicative and socially interactive process.

In terms of the mechanics of entrainment in human cognition, Jones theorizes that there are three primary stages: (1) perception, which primes the listener to form expectations; if expectations are met, (2) synchronization; and if expectations are not met, (3) adjustment or assimilation. Perception and the priming of expectations are nearly instantaneous occurrences. Cues from events unfolding around the attender are taken as indicators of where to focus attentional energies in order to 'catch' upcoming events. Anticipation of future events is facilitated by the presence of highly coherent (i.e., regularly patterned) temporal events, such as a steady beat (see Jones and Boltz 1989:466). Synchronization follows priming and occurs as our expectations are met. As such, synchronization is itself a verification of the correctness of our expectations. If our expectations do not match what happens next, then synchronization has not occurred. It should be noted, however, that the discrepancies between our expectations and the actual unfolding of events can cause arousal that in turn heightens attention and results in learning.

The disparities between actual event onsets and the expected onsets first cause a "time estimation response" in which the new time relationship is evaluated. Next, the disparity triggers an adaptive response. Adjustments in expectations and the focus of attention are made in an effort to accommodate the unexpected, new time relationship. Such an adjustment will either be made in terms of where a phase begins or in terms of a change in the period length. The *phase* of an internal oscillator (e.g. an attentional rhythm) is more susceptible to rapid adjustments, whereas changes in *period* occur relatively slowly (cf. McGrath and Kelly's social entrainment model, summarized in section 3.1).[18] The ease with which an

---

[17] Jones & Boltz (1989: 471) argue that this kind of *focal attending* "…is a tacit, how-to skill that is implicitly acquired." Even though they have found that people rarely can verbalize their use of such a rhythm generator, nor can they report which time levels they have focused upon or shifted between, their experiments have shown the presence of this type of attending. In a musical context, such goals might be keeping track of the unfolding structures of a large order form, or conversely, noting the subtleties of the slightest variations in timbre or expressive timing.

[18] According to Barnes and Jones (2000: 294), the period of an oscillator takes six times longer to adapt than does the phase.

oscillator's phase adjusts in comparison to the stability of the oscillator's period may explain why many temporary changes in musical timing, such as rubato or breaths taken between phrases, do not disrupt the underlying sense of rhythmic structure or tempo of a piece of music.

Jones's theories of "attending rhythms" are useful in describing entrainment as an adaptive process, capable of adjusting to widely different musical contexts under the influence both of conscious direction and of the musical stimulus. As a process directed by entrainment, attention can be understood as partly intentional and goal-directed and partly controlled by the pace of an external stimulus (through an involuntary, automatic assimilation of that rate). The complementarity of these facets of the process enables the attender to respond to the environment while also having some control over his/her experience.

Another insight of Jones' research with implications for the study of musical aesthetics, is the distinction between two different modes of attending: "future-oriented attending" and "analytic attending" (Jones & Boltz 1989, Drake, Jones & Baruch 2000). Future-oriented attending tends to occur where the stimulus has a coherent time structure, which facilitates a shift in attention to higher referent levels (i.e., longer time spans). For this reason, future-oriented attending "supports anticipatory behaviours," like those we might expect between musicians desiring to play in time with each other (Jones & Boltz 1989: 459). Analytic attending tends to occur when the event stimuli are less coherent and more complex, such as where expectations are extremely difficult to formulate. In analytic attending, attention is switched to focus on shorter time-spans, which facilitates the comprehension of the grouping of adjacent elements rather than repeating structures (see Jones & Boltz 1989:459; Drake, Jones & Baruch 2000:256). Again, this insight may well be a useful conceptual tool in understanding the performance and reception of unmetered music, such as Indian *alap*: a working hypothesis might be that the temporal structure of the music directs the listener's attention to an analytical, rather than a future-oriented mode, whereby subtleties of pitch, timbre and/or dynamics may be better appreciated.

In summary, Jones and her colleagues have shown how perceived rhythms set up expectation in the listener based upon the current context (e.g. musical cues) and schemata learned from previous musical experiences. Just as people have perceptual and attentional oscillators that are designed to automatically adapt to match external oscillators, these same perceptual and attentional oscillators may be influenced by our own cognitive capacities. According to the vision of entrainment offered by cognitive psychologists like Jones and her colleagues, entrainment is a form of interactive attending, creating a "synchronous interplay between an attender and an event in which the former comes to partially share the events' rhythmic pattern" (Jones & Boltz 1989: 470). Entrainment appears, therefore, to be one of the fundamental processes providing an intimate connection between individuals, others, and the world around them.

4. Applications in music research

Attempts to characterize musical behaviour in terms of entrainment, rare as they may be, do in fact go back over 30 years: the following quotation relates to Chapple's speculation on topics such as the relationship between possession and entrainment:

> Voodoo [sic] drums, the regular and driving rhythms of revivalist ceremonies, the incessant beat of jazz or its teenage variants in rock and roll, must synchronize with the rhythms of muscular activity centred in the brain and nervous system. (1970:38).

Notwithstanding Chapple's suggestion, given the volume of research on interactional synchrony in verbal and nonverbal communication, the rarity of such studies in music research is remarkable. In this section, we will summarize some of the important work that *has* treated music as a time-bound, interactive activity and experience.

4.1 Musical metre

Perhaps not surprisingly, much of the work on entrainment in music relates to metre and metrical perception. There are a number of strands of research here, but the most detailed and comprehensive application of the entrainment concept to music research comes via further application of Jones's theory of attentional periodicity (see section 3.3) to metrical perception. For instance, Large and Kolen (1994) present "a mathematical model of entrainment appropriate for modelling the perception of metric structure." This model comprises "a network of oscillators of various native periods that entrain simultaneously to the periodic components of a rhythmic signal at different time-scales, and to the outputs of one another." (1994: 178, 190). A similar approach is described by Eck, Gasser and Port, who report that a system of coupled oscillators can be modelled in which each oscillator will entrain to one of three pulses in a musical stimulus with ternary metre (2000). In addition, they suggest building a physical robotic arm and linking it to the computer simulation, so that it can literally 'beat time' to a musical stimulus, thus demonstrating experimentally how such behaviour is afforded by the entrainment of coupled oscillators.

Other applications of entrainment to metrical analysis include those of Justin London and Robert Gjerdingen. London employs the entrainment concept in his study of "complex meter" (otherwise known as additive metre), citing Jones' concept of the referent level (1995). Gjerdingen proposes that if rhythmic perception depends on the entrainment of oscillatory circuits in the brain, then the stimuli used in traditional psychological studies with "clearly demarcated durations, precisely located points of attack, and easily derived temporal ratios" are "among the worst imaginable" (1993:503). Gjerdingen **-** like the social psychologist Rebecca Warner (see section 3.2) **-** proposes the modelling of rhythm in terms of sine waves rather than discrete durations, in which he differs from Jones and her co-workers, who use more “traditional” musical stimuli in their experiments (i.e. they used European-derived music with highly coherent, hierarchical time structures). Gjerdingen's and Warner's position may also be supported by the approaches of Paul Fraisse, who stressed the fundamental importance of periodic motion in the psychology of time (see Fraisse 1963 and Clarke 1999). Physiological rhythms are always, however, far less symmetrical, or more 'complex', than sine waves, let alone than the simple alternations of square-toothed waveforms. A somewhat different approach to the same issue is Clynes's work on 'pulse microstructure' (see e.g. 1986).

Entrainment research in music will at some point have to grapple with these complexities, perhaps developing new "wave theories" for musical rhythm. Rudimentary wave theories of metre have been current for about half a century at least in Western musical thought, since the publication of Zuckerkandl's *Sound and Symbol* in 1956.[19] Entrainment research suggests that music theory may have to revisit these images, and find more systematic ways to describe musical rhythms in terms of the mathematics of wave functions.

4.2 Biomusicology

Interestingly, the entrainment concept is invoked in recent evolutionary accounts of music, as well as in studies of proto-musical behaviour in child development. Brown, Merker and Wallin see the ability to entrain bodily movements to an external timekeeper as a key distinction between man and other higher mammals:

> The human ability to keep time should be distinguished from the ability of most animals (including humans) to move in a metric, alternating fashion. What is special about humans is not their capacity to move rhythmically but their ability to *entrain* their movements to an external timekeeper, such as a beating drum. (Brown, Merker and Wallin 2000:12)

Merker argues elsewhere (1999-2000) that this ability, manifested in the development of "synchronous chorusing" in a sub-population of the common ancestors of humans and chimpanzees, may have marked a key phase in the emergence of the human species. If correct, this means that although all animal species exhibit entrainment in various ways, the human ability to entrain to music represents a propensity unique to our species.

In an important publication at the end of the last century, Colwyn Trevarthen sets out a view of the relation between music, gesture and communication centred on the notion of Intrinsic Motive Pulse: an example of research into music taking into account the endogenous generation of musical rhythm and the mutual entrainment of these rhythms.[20] Elsewhere in the same collection of essays, Wittmann and Pöppel suggest that "A neurobiologically determined tempo of all the participants can easily lead to the coordination of the individual clocks of the musicians, thus leading to synchronisation of musical

[19] See p. 168; for a discussion of this and of the relationship between the metaphors of the wave and the cycle in music theory, see Clayton 2000:ch.2

[20] Although Trevarthen uses the term 'entrainment' only intermittently (for instance, in discussing Condon's work), the idea is in fact central to the Intrinsic Motive Pulse thesis.

performance" (1999-2000:19) while Malloch discusses mother-infant interaction (another concern of Condon, incidentally) in terms of "attunement" (a synonym for entrainment). Entrainment is thus amongst the concerns of this emerging discipline.

4.3 Music therapy

Clinical applications of entrainment theory in music therapy may also be of interest to ethnomusicologists: although the therapeutic context is in many ways distinctive, music therapists' experience can both inform us about the nature of musical entrainment, and suggest perspectives on the relation between entrainment and socialisation. This work has been quite diverse. One therapeutic procedure, for instance, is for the therapist to play a piece of strongly metered music (using tempo in the range 50-65 bpm), with the intention of encouraging entrainment of autistic clients: the limited research data available suggests that this may be effective in modifying clients' behaviour (Orr, Myles and Carlson 1998). More sophisticated procedures include those developed by Nordoff and Robbins (summarized in Rider and Eagle 1986:231-2), and involve the therapist mimicking the spontaneous musical behaviours of autistic children in synchrony with them. In their experience, once a child realised his behaviour was being mirrored by the therapist, "there was almost universally a laugh, a smile, or some observed affective change which seemed to indicate the children were willing to enter into a more therapeutic relationship." (230-231). One way to characterize different therapeutic approaches is in terms of different levels of attention demanded of the client: in many cases musical stimuli are deliberately kept quite simple - especially, strongly metered - so that they require relatively little attentional energy to follow and can act as a 'carrier' for other learning tasks. Some studies have found that simply playing 'calm' music aids the learning of complex tasks, with the likely explanation being that the music "entrain[s] the subjects into a relaxation stage of the learning cycle." (236).[21]

Music therapists have distinguished three modes of entrainment for clinical purposes:

1. Primary entrainment: "the music, or some attribute of it, is matched directly to the physical or cognitive behaviour of the client. Once synchronized, modulation of the music causes change in those personal behaviours."
2. Secondary entrainment: "the music is synchronised with the material, skill, or concept to be learned. Many of the mnemonic uses of music utilize this process."
3. Tertiary entrainment: "the music is matched to the child's functioning or preference level to cause a change in an unrelated behaviour…." (all from Rider and Eagle, 1986: 229).

The experience of music therapists also reinforces the message that we are dealing with non-linear systems whose behaviour is difficult to predict. An example of this comes from the use of entrainment in therapy with subjects exhibiting pathological 'rocking' behaviour. One study found that "retarded adolescents who body-rocked at different speeds responded differently to varying tempi of music. Generally, (a) fast rockers tended to slow down when the music's tempo was slightly below that of their rocking tempo. (b) Slow rockers slowed down even further when the tempo of the music was slightly faster than their rocking tempo. (c) Music that matched the tempo of the rocking had a stimulative effect on the rocking of both groups. " (Stevens, summarised by Rider and Eagle 1986:232). On the basis of this and other studies Rider and Eagle conclude that "perseverative rocking behaviours of children are entrained best to musical tempi which are near, but not precisely the same as, the rocking state" (232).

Much of this work developed through therapeutic practice, without a clear sense of how or why auditory entrainment is an effective tool. Recent years have seen an increase in scientifically controlled studies of auditory entrainment however, many of them carried out by Michael Thaut and co-workers at Colorado State University. These studies have begun to demonstrate in greater detail how procedures such as "rhythmic auditory stimulation" can help those suffering from brain injuries or the effects of strokes, or diseases such as Parkinson's or Huntingdon's, with rehabilitation in tasks such as walking and reaching (see e.g. Hurt et al 1998, McIntosh et al 1997, Thaut et al 2002). There can be little doubt that further study of the use of entrainment in music therapy can yield further insights into the phenomenon, and in turn suggest lines of enquiry into non-clinical musical behaviours.

[21] For a recent review of studies of music therapy and autism, see Wigram 2002.

5. Entrainment and ethnomusicology

5.1 Ethnomusicological studies relating to entrainment

Although entrainment studies are only now beginning to take shape in ethnomusicology, a number of earlier ethnomusicological approaches relate to our concerns. Indeed, we would argue that entrainment relates directly to most of the key concerns of ethnomusicology: the challenge is to make that connection clear and to investigate musical behaviour and concepts explicitly in terms of entrainment. This section discusses some of the more explicit connections with earlier ethnomusicological inquiry, focussing in particular on the work of Alan Lomax, John Blacking, Charles Keil and Steven Feld.

Alan Lomax was one of the earliest ethnomusicologists to take an interest in entrainment. His 1982 article "The cross-cultural variation of rhythmic style" is a concise introduction to the rhythmic aspects of his comparative approach, and this piece makes clear that he was concerned with gesture, embodiment and 'rhythmic style'; the relationship between conversation and musical interactions; and the role of rhythm in social relations.

> Rhythm [plays a role] in linking people, by providing a common framework of identification. Rhythm is, after all, a prime mover in social relations. Rhythmic patterns facilitate the co-activity of groups and aid their members in coordinating energies and resources in work, nurturance, defence, social discourse, rites of passage, interchange of information, and, above all, expressive acts. The important role of rhythm in group behaviour suggests that we can view the rhythmic aspects of communication as essentially social in nature - a system that binds individuals together into effective groups and links groups into communities and polities. Each such "rhythmic style," passed on generationally, shapes many aspects of each cultural tradition… (Lomax 1982:149-150)

These fundamental concerns, however, were not pursued through study of the detailed mechanisms and effects of entrainment, but were developed as generalisations - using Lomax's Cantometrics system - of the relationship between rhythmic style as displayed in music, dance and conversation and the correlation of rhythmic style with other 'cultural' factors.[22] Perhaps more compelling are Lomax's reported findings that individuals in different societies tend to move in different metrical patterns: "You can walk in a 1-1-1-1 meter - or in a 1-2-1-2 meter, or even in a 1-2-3-1-2-3. The upper body can simply go along with the legs or it can move to an independent meter or in an accompanying pattern… The combinations of the rhythmic patterns in the upper and lower body give rise to more complex meters. For example, Africans produce polyrhythms by moving arms and legs to different meters. One favourite Oriental rhythmic style consists of a steady four in the legs (and the percussion section) while the arms follow a free metered melody of a lead instrument." While the degree of generalisation may grate with some readers, it is difficult to contest that Lomax's speculations served to "open up a complex subject" by suggesting "how much light may be shed on musical rhythm by a study of its corporeal basis." (1982:161-2).

Lomax was of course, like many ethnomusicologists of his day, influenced by a tradition of comparative musicological thought that looked - however speculatively - for the roots of musical rhythm in bodily motion (see for instance Hornbostel 1928; Sachs 1953). Another particularly important figure in this area was John Blacking.[23] Blacking's 1977 essay "Towards an anthropology of the body", for instance, talks about the importance of timing and movement, of the circadian cycle and the interrelationship of bodily rhythms. Blacking's writings make frequent reference to the concerns of this paper - interaction, both verbal and non-verbal communication, the biological underpinning of communicative behaviour, and shared emotional or somatic states. He related these ideas to elements of Durkheim's approach:

> Co-operation and social interaction are not the consequence of rational contract or of habits learned during a long period of infant-mother dependency: they are biologically programmed and a

[22] For instance: "The importance of women in the main productive system is related to the level of cohesiveness in the rhythmic style… The level of discipline in the child-rearing system is related to the regularity of rhythmic patterns" (1982:152-3).

[23] Blacking, of course, acknowledged his own debt to Hornbostel's famous 1928 paper: see Blacking 1955.

> necessary condition for the growth of distinctly human organisms. Durkheim's reference to [society as] 'a system of active forces'… implies powers of sensory awareness, of resonance and of communication between the individual parts of the social organism (Blacking 1977:8).

We would suggest that 'entrainment' would be a more appropriate term than 'resonance' here, as it seems that Blacking effectively describes the general parameters of entrainment, even though he never explicitly uses the term. He wrote elsewhere that the bodily basis of musicking requires "some degree of bodily resonance, as does monitoring speech" (1992:306). According to Blacking, "bodily resonance" (which he also referred to as "bodily empathy") is the sensation or awareness of synchronising with the physical movements of others in a musical situation. Blacking described this as "the experience of 'falling into phase' that players shared" (1983:57). Bodily resonance is felt by the body both as an emotional connection and the physical sensation of co-ordinated motion. "Thus," Blacking concludes, "sensuous, bodily experience was a consequence of correct musical performance… and a correct musical performance was a way of feeling" (1983:57). Blacking argued that when each performer played his/her part correctly, "the collective effort produced both new cultural forms for the ears of the performers and listeners and a richer, bodily experience for the participants" (ibid.) Blacking theorised there was a direct correlation between "bodily resonance" and increased "fellow feeling" - regard for others - through participating in social music-making, suggesting that the emotions and "somatic states" resulting from such profound aesthetic experiences were a critical force motivating a person's identification with the social group that made the musical experience possible.

Another important strand of ethnomusicological thinking relating to entrainment is the work of Charles Keil and Steven Feld on 'groove', as well as Keil's theory of 'Participatory Discrepancies' (PDs). Keil and Feld (1994:22-23) define "groove" in numerous ways that relate to entrainment, for instance, as the experience of "being together and tuning up to somebody else's sense of time." Among the many things that "groove" signifies, we suggest that "groove" could also be understood as the socio-musical process of being entrained at the preferred degree of synchronicity. The term "participatory discrepancy" is carefully chosen, as Keil demonstrates ([1987] 1994), to suggest both that musicking involves a sense of *participation* (referencing Levy-Bruhl and Barfield), and that participation is founded not on exact synchronisation but on appropriate degrees of being 'out-of-time'. According to Keil, discrepancies – particularly in timing – are what create 'groove', or an activation of positive feel in the music. This idea is developed by Alén and Prögler in a special issue of *Ethnomusicology* (39/1, 1995) and also by Steven Feld in his discussions of Kaluli aesthetics: "The essence of "lift-up-over-sounding" is part relations that are *in synchrony while out of phase*." ([1988] 1994: 119, emphasis in original). Again, the concept of entrainment per se is not explicitly addressed in these publications, but its significance is quite clear. It seems likely that an encounter between entrainment and participatory discrepancy would be productive for both theories. The latter theory could perhaps benefit from the broader base afforded by the entrainment concept,[24] while PDs may have a valuable role in directing entrainment studies towards phase differences (see section 2.8).

5.2 The significance of entrainment for ethnomusicology

We have seen how the entrainment model has proved a powerful tool in other areas of research. It has begun to be seriously applied in musical scholarship, inspiring new perspectives on musical meter and on music's role in human evolution, as well as practical applications in music therapy. It relates in profound ways to key issues in ethnomusicology, and resonates with the work of several ethnomusicologists of past and present generations - and yet there has been very little detailed work and virtually no empirical studies in ethnomusicology on entrainment processes and their ramifications. What, then, is the potential benefit of applying the entrainment concept in ethnomusicology? What kind of studies might this idea stimulate, and what might those studies tell us?

---

[24] For example, we might ask whether so-called "discrepancies" might be better described as complex rhythm patterns that are culturally defined. (Case studies 2 and 3 below offer examples of such complex rhythm patterns; see also Clynes 1986). We might also ask what are the physical and psychological parameters within which intentional play against a culturally defined rhythmic scheme is possible and potentially meaningful.

An entrainment model suggests we look at engagement with music not simply as a process of encoding and decoding information, but of embodied interaction and 'tuning-in' to musical stimuli. Musicking humans can be seen as embodying multiple oscillators (or endogenous rhythmic processes), oscillators which may be mutually entrained in a process of self-synchrony as well as entraining to external stimuli in the processes of making and engaging with musical sound. Entrainment in musicking implies a profound association between different humans at a physiological level and a shared propensity at a biological level. The implications of this view for studies of socialisation and identification are obvious, and so too is the link to questions of enculturation: someone’s ability to respond appropriately to a given musical stimulus can, since it is a learned application of a basic biological tendency, be a marker of the degree to which an individual 'belongs' in a particular social group (cf. Lomax).

The question of the degree of symmetry in entrainment has obvious links to larger ethnomusicological questions. Studies in non-musical communication have shown that more dominant individuals tend to force the less powerful to adapt further in the process of mutual entrainment, so that even where entrainment is mutual it is not necessarily equally balanced.[25] In some musical contexts, of course, some participants have little or no power to influence the sound production, directly or indirectly, and these might be seen as examples of asymmetrical entrainment.

We need not spend too much time, perhaps, demonstrating that entrainment exists in musicking - although even this would be a welcome development. The fact that musicians can synchronise their performances, and that they and others can dance or tap their feet, demonstrates that they are *in time with the music*, i.e. entrained to some degree. It would also be regrettable if a fragmented research effort appeared to confirm Chapple's unfortunate prejudice that entrainment is a phenomenon only, or primarily applicable to a subset of "regular and driving rhythms." If entrainment is a factor in any interpersonal interaction and communication, we should expect that it is a factor in any variety of musicking. We feel that there are a couple of questions that may help to direct more productive research efforts: What is special about *musical* entrainment?, and How do processes of musical entrainment vary between musical traditions and contexts (i.e. culturally), as well as individually?

- What is special about *musical* entrainment?

This is perhaps a key question, and one for which we have as yet only the sketchiest of answers. It seems that certain kinds of musicking can afford particularly precise synchronisation between individuals' behaviours. This may in fact be one of the basic reasons for the development of these kinds of musical repertories, since musical metre is often (although is not invariably) more regular, with more hierarchical levels, than the rhythmic patterning of speech and other communicative behaviour. Since certain degrees of entrainment between individuals seem to be associated with positive affect, is it the case that particular patterns, periodicities, hierarchies or intensities of entrainment afford particular affects? Could positive affect be associated with a greater degree of self-synchrony as well as closer synchrony with a social group (cf. Blacking 1983, see above)? Do particular kinds of music (or for that matter, music enculturation) promote the switching of attention between temporal levels? All of the above seem possible, even probable, but serious work demonstrating not only that entrainment occurs in musicking, but also how it differs from the kinds of entrainment experienced *without music*, has yet to begin.

- How do processes of musical entrainment vary individually and with culture?

Something we should not lose sight of is that entrainment is a process which varies between individuals. For instance, not everyone at a performance appreciates the music in quite the same way; some may not "get it", or might appear to be entraining to a different beat (be "out of time"), and even those thoroughly enculturated listeners enjoying the music may be attending more or less to different temporal levels (see discussion of Jones, section 3.3 above). If these individual responses are averaged or summed over groups of listeners, it appears that there are also "cultural" differences - as any ethnomusicologist

[25] Of course, power relations observed in musical settings do not necessarily simply reflect those evident in other contexts. For example, there is often an inverse relation between degrees of socio-political power and the power to control a musical situation, such as when musicians come from subaltern, economically or politically marginalised groups. Our point is that a study of the exact musical processes involved in entrainment has the potential to offer substantial evidence of who is entraining to whom and in which circumstances. Regardless of the specifics, one would expect studies of entrainment to shed light on the power relations relevant to the musical context.

might guess - in the value placed on various types and degrees of entrainment. Listeners unfamiliar with a particular musical stimulus may fail to demonstrate an appropriate response to that music because they have not learned the "right," i.e., culturally appropriate, way to do so. It may be that studies of entrainment, if carefully designed, can illuminate long-standing issues of "cultural difference", of enculturation and acculturation, of what it is to be an "insider" to a musical culture, and so on, in a productive new light.

At a more general or abstract level still, a greater role for entrainment could be part of an ongoing shift towards a paradigm that sees the business of ethnomusicology as the investigation of musicking as embodied, interactive, communicative behaviour. Many ethnomusicologists will, with justification, feel that this is what they already do and were trained to do. Nonetheless, we feel that serious consideration of the concept of entrainment, and the development of methodologies which are empirical and experimental *as well as* ethnographic, could potentially lead to a significant shift in the focus of ethnomusicological enquiry. We also believe that this kind of approach may offer a useful contribution to discussions of musical affect, the place of emotion in music, and the concept of musical meaning.

Entrainment research within ethnomusicology relies upon the integration of musical, cognitive, and cultural theory, thereby allowing a broader description of how musical experience, while individually unique in every case, is nevertheless always social. Through exploring the phenomena of entrainment, ethnomusicologists may be able to better understand how musical sound serves as an interface that connects selves—viscerally and cognitively—to society.

Our intention in this paper has been both to set out, for an ethnomusicological readership, some of the key features of the entrainment concept and its application in music and other fields, and also to encourage our colleagues in ethnomusicology to join us in building on this base. Not only ethnomusicology, but other academic fields as well, stand to reap enormous benefits if we can develop this study further, through both individual and collaborative projects. Ethnomusicologists have an opportunity to work with scholars from other disciplines and to build interdisciplinary bridges, but we also have a chance to make a significant contribution and develop theories of wide relevance in the biological and social sciences. We firmly believe that there is a great deal that we need to explore about human thought and behaviour, which can only be done with a significant input from ethnomusicologists.

In the following sections we make some suggestions, ranging from the general to the specific, about how entrainment in musical behaviour can be investigated. We do not, of course, intend to set a limit on either topics of investigation or methods - such an attempt would be futile in any case - but to present a mixture of our own experience and our speculations. We hope that respondents to this article will have further observations and reflections, and indeed methodological suggestions, so that this publication as a whole will take on the character of a collaboration between more than just the three authors of this presentation.

6 Methods and Methodology

What are the most appropriate procedures for the study of entrainment processes? It should be clear that traditional ethnographic and music-analytical methods may generate hypotheses regarding musical entrainment, and to suggest areas of further investigation. To *prove* the occurrence of entrainment, however, and to describe specific entrainment processes in any detail, will require the collection and analysis of timing data derived from the musical sound, from observed motor movements and/or from other physiological processes associated with the performance. Entrainment is manifest only in actual behaviour and it is the temporal analysis of motor performances that supplies the essential data for entrainment research. As has been pointed out earlier, entrainment processes are largely constrained by non-conscious structural and procedural factors; although we must consider performers' intentions or motivations as revealed by their explicit statements they have to be evaluated against the chronometric data. The subsequent analyses of the data allow for inferences about the underlying motor performance and cognitive processes, which help us to uncover the guiding constraints and interactions between processes, either within individual performers or between performers.

One of the paradoxes here is that time analysis research runs against the grain of current ethnomusicological methods, despite the fact that entrainment theory itself resonates strongly with certain aspects of ethnomusicological thinking. Entrainment requires empirical study of something which cannot be verbalised: ethnomusicological orthodoxy stresses the primacy of informants' verbal accounts, and most ethnomusicological reports operate at a meta-discursive level. Blacking recognized this problem, writing:

> How can we measure the apparently invisible and how can we presume to say that something not recognized by the actors is real[?] It is as real for purposes of explanation as atoms, genes, or successive differential counts of leucocytes: that is, it may be inferred from certain kinds of observable behaviour. (Blacking 1977:17)

Blacking was not himself known for empirical scientific work - and even those ethnomusicologists who are sympathetic to the idea of such study rarely have the scientific background to actually carry it out. Therefore, if we agree that empirical studies are in principle a good thing, there is a need for practical suggestions for how such studies can be carried out in the context of ethnographic work. The following discussion assumes that ethnomusicologists will want to develop methodologies that have an ethnographic element, even if they also incorporate empirical study based on evidence not collected ethnographically, and perhaps a limited amount of controlled experimental work.[26] Although this paper is not a manual on 'how to do entrainment research', we do present below some general suggestions regarding research methods. The following sections discuss ways of investigating entrainment, and for convenience are divided into three sections: data collection; data analysis; and finally ethnography and interpretation.

6.1 Data collection

We begin by considering the possible sources of evidence, or modes of data collection, available to ethnomusicologists. They can be considered in four categories:

1. Ethnographic investigation and introspection: We should be looking to establish how the degree, rate (and other aspects) of entrainment correlates with dance and other physical responses, and with ethnographic reports of affect, emotional response, and so on. Discourse about music - which is accessible only through ethnographic methods - can inform us about how entrainment *feels*, and incorporates the metaphors people use for being 'in good time' with fellow musicians (or not).
2. Musical sound: As the case studies on chronometric analysis below demonstrate, a lot can be inferred from recorded sound itself (*not*, we hasten to add, from transcriptions such as those rendered in Western notation, which can suggest entrainment possibilities only indirectly and unreliably). This is the main focus of the case studies below.
3. Visible physical behaviour (gesture): The work of Condon, Kendon, McNeill and others suggests that, apart from musical sound itself, the most important evidence for entrainment in musical behaviour might be the physical movements, or gestures, of participants, which can be studied by means including video or film analysis. This is an area that needs careful consideration. For instance, the problems of how to segment continuous behaviour into discrete gestures, and the difficulty of assigning gestures carried out over a finite *duration* to a specific *point in time*, are not trivial. If these methodological difficulties can be solved or by-passed, then this kind of study offers huge potential. This kind of data can be gathered either in 'real-life' or experimental situations.
4. Physiological processes (heart rate, respiration, brain waves etc): There are almost certainly important musical entrainment effects which cannot be observed either in the physical sound wave or in visible motor movements. Possible areas of investigation here include electroencephalograms (EEG, for recording brain waves), magnetoencephalograms (MEG, for recording the location of brain activity), electrocardiograms (ECG, for recording heart rate), electromyograms (EMG, for measuring muscular activity), body temperature, and more. In most cases, the procedures involved would present difficulties in field-work situations due to the intrusive nature of the equipment needed to make these types of measurements, and to most ethnomusicologists' lack of training in operating this kind of medical apparatus.

[26] We do not consider here methods such as those described by Large and Kolen for the investigation of metre, which are essentially theoretical and involve experimental testing of computer simulations of neurological structures: this is not to criticize such methods, simply to recognize that they lie outside the remit of ethnomusicology.

Nonetheless advances in technology, and developments in experimental and collaborative research methods, may in time overcome some of these difficulties.

Audio recording

Audio recordings are an essential form of data for entrainment research in music because of their excellent time resolution. With the audio equipment available today, good quality recordings are not very difficult to produce. It is advisable to generally use test or reference signals (e.g. 1kHz test tones) that allow estimation of the reliability in the reproduction and transfer processes. This does not only hold for analogue equipment, but also if digital gear is used: sometimes sound cards do not work properly with certain software (especially on PCs), or operating software may be corrupt; such malfunctioning can easily be detected by checking the reference signals.

Although recording machines do not cause too much of a problem, the number and placement of microphones requires careful consideration. The type of analyses afforded by audio recordings is very much dependent on the type of music performance recorded and the manner of recording. To be able to analyse simultaneous musical processes it is essential that the corresponding sound signals are separated or separable as much as possible. If the sounds involved have distinct spectra for instance, no other separation might be needed (for an example see the clapsticks in Appendix C), in other cases a well planned stereo separation may be necessary and sufficient. If more than two processes are to be analysed multitrack recording may be a necessity.

It has been our experience that extant field recordings can be useful for investigating entrainment phenomena that are evident in music. Our best success has been with recordings of music performances that involve small numbers of performers and/or relatively discrete, individually identifiable instruments. Examples of what can be done with such recordings follow in the three case studies below, all three dealing with recordings involving a small number of performers. Extant recordings of large groups of music participants (such as of festivals, ceremonies, and rituals) present added analytical challenges and may not be usable for some types of chronometric analysis. However, if the research focus is not on individual but in group behaviour – requiring a different type of analysis – even these recordings may offer interesting material. In some cases recording quality and the identification of individual musicians or instruments can be enhanced to a degree using digital audio processing tools (Peak and Pro-Tools are widely available tools for digital post-processing, but as far as complex filtering is required to isolate or enhance certain acoustic events from a recording, CoolEdit (only for PCs) is very flexible and easy to handle).

Video recording

While audio recording is of course indispensable to this research, for many (perhaps most) purposes some other form of data will also be required on motor movement patterns or other physiological processes. The most accessible method, after audio recording, is undoubtedly video recording. Although video may be valuable, it is important to bear in mind the relative strengths and weaknesses of audio and video data, the most obvious of which lie in the domain of sampling rates. Audio has a much higher definition than video (sampling rates up to 48kHz on standard digital audio equipment are some 2,000 times higher than standard film or video frame rates). Another factor is that proper set-up for video recording is far more critical than even for audio recording. With audio, it may be possible to get around the fact that microphones were poorly placed or levels not set optimally. But with video, if the camera is not properly set up, then the footage will certainly be unusable for movement analysis.

Some of the basic points regarding the collection of video data are the following:

- for movement analysis the camera shot needs to be static (no zooming, panning or tracking).
- footage from a single camera can be used to analyse movement in two dimensions only (perpendicular to the direction the camera is pointing); ideally a reference frame of known dimensions should be placed in shot to allow calibration (although in practice a rough idea of the dimensions of the space is often sufficient).
- three-dimensional movement analysis requires at least two cameras: these need to be calibrated using a specially constructed three-dimensional model, and synchronised. Depending on the performance situation, more than two cameras may be necessary. (Note that biomechanics laboratories tend to use at least five or six synchronised cameras).
- a variety of camera speeds is available (e.g. the PAL and SECAM standards use 25Hz, NTSC uses 30Hz, but specialist high-speed cameras are also available). 25-30Hz may prove to be

adequate for many research purposes, although this remains to be seen; using high-speed cameras in any case produces far more data, which takes proportionately longer to analyse, and therefore sets practical limitations.

There are other ways to gather movement timing data, and over the last century or more each generation has found ways to adapt extant technologies. For instance, some researchers in recent years have used the MIDI – musical instrument digital interface – system (see Clarke 1995, Arom 1976, Busse 2002).[27]

Modern motion capture systems,[28] such as those used in the entertainment industries, can offer possibilities not afforded by traditional video: by recording movement data directly rather than storing video images, they are able to use high-speed cameras and can handle data with timing resolution much higher than conventional video. Although promising, these systems are very expensive, intrusive (they require reflective markers to be fixed to subjects), and at present would be impossible to employ in most fieldwork situations.

For other physiological data standard medical equipment is required, which again can be difficult or impossible in many field-work settings. Some motion analysis systems (including high-end video recording systems) do allow other data such as EMG to be recorded in parallel with video or motion data.

6.2 Data analysis

Attempts at analysis of rhythm in ethnomusicological research go back to the early days of comparative musicology, and have been facilitated by important technological developments including Seeger's melograph as well as modern audio editing software. In spite of Seeger's promotion of this technology however, desire for this type of detail in musical analysis has waned and the methods he promoted have rarely taken centre stage in recent ethnomusicology. Recent efforts at detailed rhythm analysis in ethnomusicology based on audio timing data include the work of Prögler and Alén (of jazz rhythm section and Cuban dance: see Alén 1995, Prögler 1995), Widdess and Clayton (separately on Indian music: see e.g. Widdess 1994, Clayton 2000) and Will (on Australian Aboriginal music; Will, 1998; Will, in press).[29]

Film and video have also (of course) been widely used by ethnomusicologists to assist in musical transcription and analysis (see the work of Kubik (1965) with African xylophone players, Baily (1985) with Afghan lute players, and others), as well as for documentation. It has also been used in behavioural observation: the most detailed exposition of this method is in Qureshi's work on South Asian qawwali (1987, 1995[1986]).

Even in most of these cases, the analysis of timing data is relatively crude, and does not employ the scope offered by statistical analysis software. This section considers the latter possibility, beginning with methods for extracting timing data from audio and video recordings.

Audio analysis

Given good quality recordings, extraction and processing of audio data in computer programs does not seem to present serious difficulties. Recordings need to be uploaded to a computer (in the case of analogue recordings, most present day computers have the necessary analog-digital converters built in). Depending on the variables of interest (timbre, pitch, rhythm, or other large scale periodicities) the digitized audio files can be re-sampled (e.g. from 44kHz down to 11kHz) to reduce the data volume. For rhythm or periodicity analyses, the re-sampled sound files are then loaded into an editor program, e.g. Praat

---

[27] IRCAM, for example, has had a fruitful history collaborating with ethnomusicologists to develop and adapt technologies for experimental applications for use in the field.

[28] Such as those produced by Motion Analysis Corp. and VICON.

[29] A related and important contribution from jazz studies was published as a special volume of *Music Perception* (2002). A historical summary of methods of chronometric investigations related to jazz studies is included (Collier & Collier), as well as examples of measuring and analytical techniques, including the use of MIDI (Busse). Topics of the contributions cover swing and ensemble timing (Friberg & Sundström), as well as expressive "microtiming" (Iyer 387).

or Sigmund[30] that permits one to label or mark sound events of interest in a defined and consistent way. These markings, together with the respective time information, are then saved as text (ASCII) files that form the raw data of the measurements and can then be displayed, processed, and analyzed with a statistics program. The case studies below include practical examples of these procedures.

Video analysis

Data extraction and analysis from video can be split into two basic approaches:

a. **Behavioural observation** involves marking down event onsets (e.g. when someone starts or stops singing) and the frames at which they occur. In Condon's day, this work had to be done manually, which was a notoriously time-consuming business.[31] Nowadays, software exists for the automatic logging of behavioural observations, and the linking of these observations to video time code (e.g. Observer Video-Pro).[32] Such software itself can be used for statistical analysis, and/or allow export of timing data for further statistical analysis in other programs.

b. **Movement tracking** involves marking particular parts of the subject's body (e.g. joints) manually as they appear on a video frame displayed on a computer screen. Once this time-consuming job has been completed for a sequence of movement, software can analyse the movement and generate data on variables such as the velocity and direction of movement. This is fairly simply done for two dimensional analysis.[33] It can also be done for three dimensional analysis, provided the recordings have been properly prepared.[34] As noted above, three dimensional movement tracking can also be done automatically using modern motion capture systems. In some cases these systems integrate automatic motion tracking with video recording.

The tradition of sound-film analysis from Condon and Birdwhistell onwards has looked for a correlation between the articulations of speech and physical gestures, and has suggested that periodicities in the region of 0.1sec (frequencies c.10 Hz) can be observed. Using video shot at 30 frames per second, the limit for observation of periodic behaviours is maximally 15 Hz (0.06 sec); for 25 frames per second (PAL) this is 12.6 Hz (0.08 sec). [35] This might suggest the level at which we may look for periodicities in visible behaviour. If periodic behaviours with much faster frequencies are significant, they will have to be investigated using high-speed cameras or motion capture systems.

In these analyses we should be aware of the relationship between analogical and digital processes: gestures can often be described either in terms of an event occurring at a time point (e.g. a foot tapping, a stick striking a drum head) or as a continuous gesture (a melodic phrase or ornament, the movement of arm and hand preparing to strike the drum head). Since time points are much easier to deal with mathematically, it is often expedient to treat musical behaviours in such discrete, 'digital' terms, but one should be aware that this potentially oversimplifies the analysis.

Analysis of time series data

Although synchronization does not in itself prove entrainment, entrainment can only be suspected if two oscillators interact and their behaviour becomes coordinated or synchronized. The first step of

---

[30] Praat http://www.fon.hum.uva.nl/praat/; Sigmund: contact U.Will (will.51@osu.edu)

[31] See Condon & Ogston (1967) for a description and discussion of methods for segmenting filmed behaviours.

[32] Observer Video-Pro http://www.exetersoftware.com/cat/observer.html

[33] Using programs such as SiliconCoach: http://www.siliconcoach.com/

[34] Using systems such as Peak Motus, http://www.peakperform.com/; or APAS, http://www.sportscience.org/Main/adw-04.html

[35] Software is available for splitting each video frame into its two constituent two "fields" (e.g. SiliconCoach), which can effectively double the timing resolution of video recordings (with a commensurate loss of picture resolution).

analysis, therefore, is to look for synchronization. Generally, caution is demanded, as synchronization is a complex dynamic process, not a fixed state. A single observation is not sufficient to identify synchronization: what are required are time series data, i.e. a series of observation data or measurements of the respective (system) behaviours in time. These data can then be analysed in order to detect the presence of synchronization. In some cases, this may be an easy task. However, the detection of synchronization of irregular oscillators and noisy systems is not so easy. Simple visual inspection of the data may often not be sufficient and the mere estimation of phase and frequency of complex time series may be complicated in real world data. The noisier the data are – and real systems are always noisy, not only in ethnomusicology – the more difficult it is to distinguish between synchronous and asynchronous states or to detect transitions to synchronization. Some basic approaches in the analysis of chronometric data are demonstrated in the case studies that follow.

However, the mere demonstration of a covariation of two variables is not sufficient to prove the presence of entrainment (some studies have shown that correlated signals may in fact originate from unsynchronised oscillators, e.g. Tass et al. 1998). In order to identify entrainment one needs to examine perturbations or transitions of the synchronization process; only if synchronization is re-established after these disturbances - as in Huygens' clocks - does it seem justified to describe the interaction between the oscillators as entrainment. We mentioned above the complex oscillations of real life processes. Studies have clearly shown that, being coupled, irregular or complex oscillators can also undergo entrainment (e.g. Rössler 1976). In these cases, however, it might be necessary to use a different set of variables to describe the systems, for instance to replace frequency with short time mean frequency (i.e. frequencies averaged over some tenth or hundreds of milliseconds), because entrainment of these complex systems might follow a temporary mean value of these variables, not any instantaneous values. However, frequency related measures may not be the most adequate to analyse entrainment, because they concern events occurring in individual components of the entrainment process. The phase relation between the components involved is obviously better suited to describe observed patterns of interaction as well as transitions between them. The calculation of one such measure, a point estimate of the relative phase, is described in appendix C, and applications are demonstrated in case study 2 and 3.

6.3 Ethnography and interpretation

As we suggested above, it is our belief that empirical and/or experimental research can flow out of and serve to illuminate the interpretation of ethnographic research. Serious consideration of entrainment in ethnomusicological research, including the development of methodologies that are empirical and experimental as well as ethnographic, could potentially lead to a significant shift in the focus of ethnomusicological enquiry. The particular ways in which ethnographic and empirical methods can be integrated will vary substantially between research contexts, so it is difficult to offer detailed suggestions here. We do believe however that each should feed into the other: in other words, (a) ethnography ought to direct empirical research, as ethnographic research will offer intuitions as to which phenomena seem to be particularly important in particular performance contexts; and (b) empirical research can generate questions for ethnography; e.g. if the numerical data tells us that an interesting entrainment effect occurs at a certain point in a performance, we may show greater interest in that portion in future field work. Furthermore, if numerical analysis allows us to identify and analyse entrainment processes, in many cases it will be the ethnographic knowledge that permits the identification of intervening variables and order parameters[36] and an ethnomusicologically relevant interpretation of the analysis (for an example see case study 3).

7. Case studies of chronometric analysis of rhythm performances

In the following sections we are going to present some case studies that demonstrate a couple of entrainment phenomena and illustrate some basic procedures of entrainment research. We begin in case study 1 with an analysis of rhythmic motor behaviour by single performers and ask, what time series analysis can tell us about the individual components of an entrainment process. Although the focus is more on general aspects of rhythmic performances than on entrainment itself, this analysis will gives us a chance to present basic methodological approaches and elementary concepts in temporal analysis, a field largely

[36] These are parameters that determine a system's behaviour at transitions from one state into another, e.g. at transitions from synchrony to asynchrony or from an entrained to an non-entrained state and vice versa.

ignored by ethnomusicology but essential for entrainment research. In the second case study we will then analyse the phenomenon of self-entrainment, the coordination of simultaneous motor activities in individual performers. In that study we will also touch upon questions of experimental and non-experimental data and the importance of comparative studies. Finally, in the third case study, we are going to analyse a process of synchronization and entrainment between two performers. Although the analyses of these case studies are done here with virtually no ethnographic input, it will become evident, at least for cases two and three, that ethnographic data are an indispensable and integral part the interpretation of the analyses. These analyses are but a first, though essential, step in understanding how entrainment works in a socio-cultural context like music making. Before presenting the case studies we would like to introduce some basic concepts and procedures of time series analysis that, we feel, might be helpful in following the subsequent analyses.

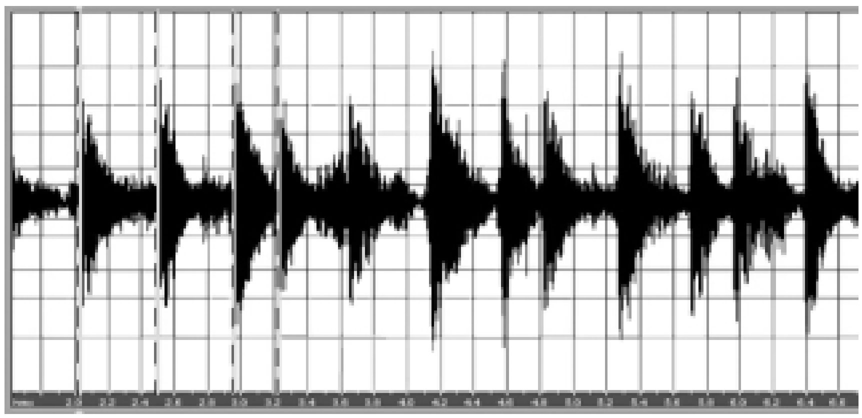

Fig.1: Sound wave of a rhythm played on an Ewe iron bell, gankogui (Kpegisu audio cassette, White Cliffs Media, 1992, ISBN#:0-941677-42-7) The maxima of the first four bell sounds are labelled by vertical markers. These markers and the respective time information form the basic data file for the chronometric analysis.

As discussed above (section 6.2), audio recordings can be saved on a computer, resampled, and loaded into an editor program such as Praat, where relevant events can be labelled (Figure 1 illustrates an audio file in such a program, with time labels for some of the bell strokes). The raw data sets which these labels generate are time-ordered series of measurements – sound events in performance time – in which the chronological sequence is characteristic for each data set. This is important, because time series analyses can inform us about the dynamics of the underlying processes, something a randomly sampled data set would not afford. Often the primary interest is not to know when a certain event occurred but rather how is it related to preceding or successive events. In these cases we need to calculate the time differences between successive events, which gives us the period length – if we are dealing with periodic events - or the duration between events. Fig.2 displays such a series of durations for the bell pattern of fig.1. This performance consists of two types of strokes, a short and a long one, displayed as two different groups of dots in fig.2.

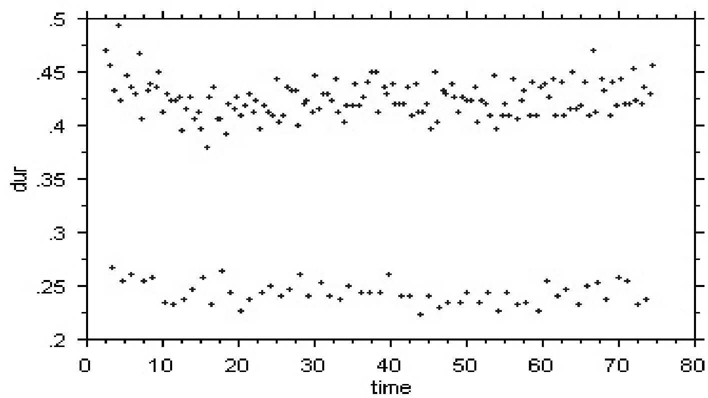

Fig.2: Plot of the bell stroke durations vs their time of occurrence in a Kpegisu song performance. Performance time (in sec) is displayed on the horizontal axis, and the duration of the bell strokes (length between two subsequent strokes) is displayed on the vertical axis. Obviously the performance consists of two different types of strokes, short (ca. 0.25sec; lower series of dots) and long ones (ca. 0.425 sec; upper series of dots).

In time series analysis, as in most other analyses, it is assumed that the data consist of a systematic pattern combined with random noise, which usually makes the pattern difficult to identify. Time series data can be described and analysed in terms of basic, identifiable classes of components: trend, cyclical or seasonal, and irregular components. The trend component, for example, represents a general systematic component that changes over time and does not repeat (or at least does not repeat within the time range captured by the data). Cyclical components are those variations in the data that occur repeatedly and contain information concerning the underlying processes of the rhythmic behaviour.

For the case considered here, the trend has an obvious musical interpretation; it is the variation in tempo during the performance. In the performance of the above Kpegisu bell pattern the tempo accelerates from the beginning towards the 15 sec time mark, lows down slightly towards the 35 sec mark, accelerates again and finally slows down after the 70 sec mark (see fig.3).

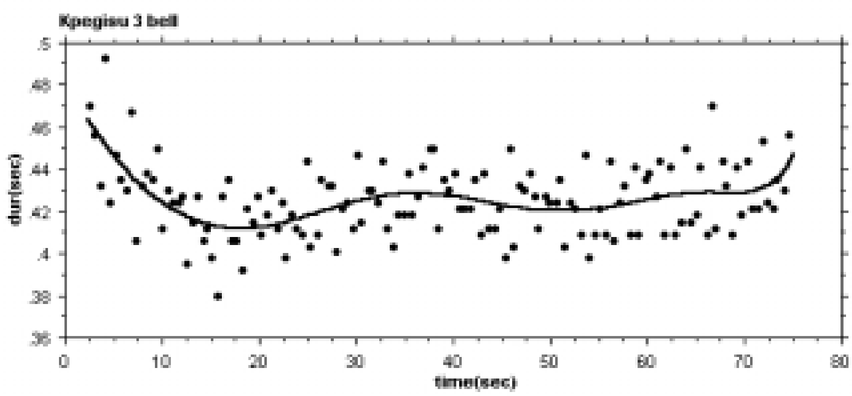

Fig.3: Plot of the long bell stroke durations vs. time of occurrence from fig.2. The continuous curve represents the trend component and indicates the tempo changes during the performance.

The trend may be an important component of the processes of interest – as it is, for example, in the first section of the third case study presented below. In other cases, however, it is not only important to identify the trend but to eliminate this component – to detrend the data – because the trend may interfere with the subsequent analysis that assumes stationary processes (for more information on time series analysis see e.g. Box and Jenkins, 1976). This is the case in the following study in which we are analysing the time structure of rhythm performances and its cognitive implications in order to better understand what is involved when a musical behaviour becomes entrained.

Case study 1: Production of one rhythm by one performer

In section 2.6 (self-entrainment), we pointed out the importance of an understanding of the internal timer organization for understanding the temporal organization of the various movement components in music making. We also indicated that the timer organization could put important constraints on the way in which rhythmic actions can interact and entrain. Take for example a musician performing two simultaneous rhythms: The possible ways in which these rhythms can entrain, the modes they can 'lock in' with each other, depend very much on whether the two rhythms are controlled by a central clock – a master timer – or not. Now, in order to analyse entrainment and to detect the constraints at work ethnomusicologists do not have to wait for psychologists or neuroscientists to tell them what the timer organization underlying the observed behaviour actually is. All the necessary information can be obtained from the data at hand, the audio tracks of the documented performances. In the following case study we are going to indicate some possibilities of how this information can be extracted, how certain assumptions about timer organization relevant for entrainment studies can be tested, and how such an analysis helps us to identify possible constraints for the entrainment of multiple rhythmic processes. Although this case study does not demonstrate entrainment as such, it illustrates some basic concepts and procedures essential to entrainment research.

The basic ideas to begin with are as follows. It is one of the basic tenets of cognitive sciences that cognitive processes consume time, and more complex processes consume more time than simple ones. This principle is for example exploited in reaction time experiments. These experiments study the effect of specific factors on cognitive tasks by analysing the influence they have on the timing of the task responses. Complex, temporally structured behaviour such as speech or musical performance requires two different operations, (1) the preparation of the movement components and their correct temporal arrangement (establishment of the serial order of the behaviour), and (2) the timing of the units of the behavioural stream.

Models of motor behaviour such as that of Sternberg et al. (1978), assume that abstract representations of the movements are assembled and their serial order established prior to the response onset. These motor programs are consulted prior to and during the response execution to activate the peripheral neuro-muscular effector system. Under these models, the complexity of the cognitive processing that leads to the generation of the motor programs is reflected only in the response onset time and the complexity of the motor program is reflected in the time needed to consult the motor program during the response execution: the more complex the motor program, the longer the response time. For these models, cognitive processes that prepare the motor programs for execution only exert an influence on the timing of the onset of the response units, but not on the time course of the response itself.

However, it has recently been shown that different hierarchical levels of language processing do in fact influence the time structure in written language production (writing and typing). These findings suggest a processing architecture in which the peripheral motor system essentially connects at several hierarchical levels with central processing units (Will et al. 2002, in press). Such an architecture can account for the fact that, besides influences of the peripheral motor system, central processes like lexical access are also reflected in the time structure of serially organized motor behaviour like writing and typing.

In contrast to speaking, writing and some other, implicitly timed motor behaviour, musical behaviour is generally explicitly timed, i.e. constrained by the tempo requirements of the performance. One interesting question in this case is, whether under these temporal constraints hierarchical representations can be reflected in the temporal structures of rhythmic performances or whether musical timing can be adequately accounted for by only the sequential organization of temporal behaviour (for a more detailed explanation of these two different timer models, see Appendix B). We are trying to get an answer by analysing two examples of rhythmic performances, a West-African bell stroke pattern and a clap stick pattern from North-Eastern Australia. We shall start our analysis by testing an existing model for the analysis of temporal properties of rhythmic performances.

This model, which seems to be of interest for analyses of musical performances, was originally proposed by Wing and Kristofferson (1973a,b) for the timing of inter-response or inter-onset intervals in periodic tapping. It is based on the idea that the temporal variation or inaccuracy in periodic finger tapping can be explained by two components, the variability of a (hypothetical) central timekeeper and the temporal noise in the executing motor system. The hypothesized underlying process is described as a first order moving average process, with the expected timekeeper interval as constant and the temporal noise as random errors: this means that the tapping interval at any point in the sequence equals the timekeeper interval plus a noise component that is proportional to the mean of some previous noise components. The hypothesis can be tested with the autocorrelation function. (This function describes how a variable (a sequence of values) correlates with a delayed or shifted version of the same variable. See Appendix A). For a first order moving average process the autocorrelation function for lags > 1 is zero, and in the Wing model the autocorrelation at lag 1 is negative. This makes it interesting for music performances, because it means that, as a stationary process, it is self-correcting: if one interval is larger than the expected value the next one will be shorter, and so forth. Models similar to the Wing model have been developed for speech timing (Kozhevnikow and Chistovitsch 1965) and for bio-rhythms (Ten Hoopen and Reuver 1967). However, the Wing model does not assume that higher cognitive processes are reflected in the time structure of motor performances and we want to test, whether this model is suited to adequately describe rhythmic process in performed music.

Case A: Kpegisu

The first item analysed here is one of the Kpegisu (Ewe war drum) songs, ‘Agbeme nuawo ken li’ as performed by Godwin Agbeli, who sings and plays the bell pattern (the Kpegisu audio cassette was published by White Cliffs Media, 1992, ISBN#:0-941677-42-7). For background information on this music see: Locke, 1992.

The Kpegisu bell pattern, which consists of seven strokes, has already been introduced above. In order to keep this presentation as simple as possible, we are going to analyse only the sequence of long strokes (5 per pattern), but the analysis can be extended to cover the complete bell pattern without changing the main results of our study. Prior to the autocorrelation analysis we ‘detrended’ the data, that is, we eliminated that component of the data variability that is due to tempo changes. The detrended data are plotted in fig.4. In comparing this graph with the previous one, a reduction in the range of variability (distance from the highest to the lowest data value) from about 0.13 sec to 0.085 sec is obvious, and the dotted line in the lower graph can be thought of as the flattened, straightened out tempo curve of the upper graph. The data variability that remains, then, cannot be explained by performance tempo variations, and we are now trying to identify the underlying process that produces these remaining variations in the data.
The apparent random variation of the beat durations is in fact highly structured. This structure is disclosed by marking all durations sequentially in their order of appearance within the pattern (see. fig.4; stroke numbers 3 and 7 are missing because they indicate the short strokes not considered here). Note for example the clear separation of strokes number 5 and 6.

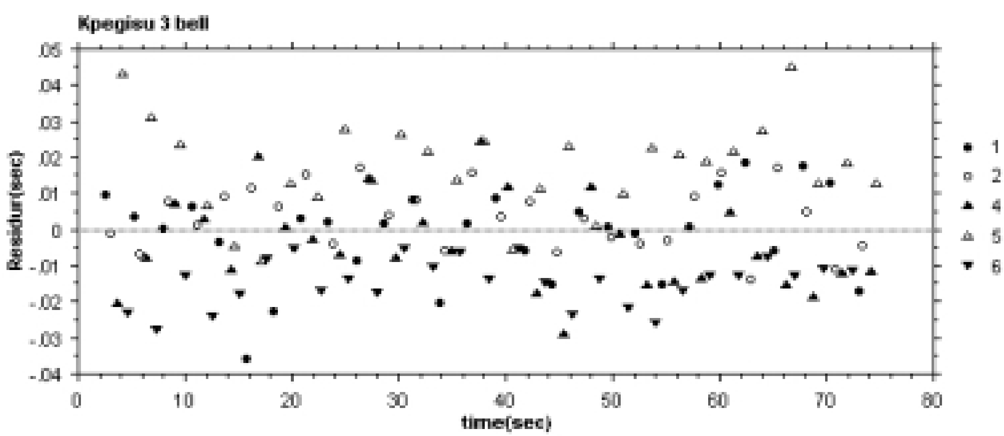

Fig.4: Plot of the residual values for the long bell stroke durations following the elimination of the trend.

In order to specify the underlying process for these data, we calculate the autocorrelation function. As predicted by the Wing model, the plot of the autocorrelation function (fig.5) shows a significant negative value at lag 1 (in musical terms: if one beat was too short the next beat makes up for it in being longer, and vice versa). However the values for lags>1 are not zero and for lag 4 and 5 and multiples thereof we obtain significant negative and positive values, respectively. Hence, the underlying process cannot be considered to be a first order moving average process as predicted by the Wing model. The autocorrelation function is periodic with a period length of 5 lags. As these sequential dependencies demonstrate, the sequence of long bell strokes is obviously organized into higher-level units the size of which is expressed in the periodicity of the autocorrelation function. Possibly this is an indication of a hierarchical timer organization in which a high-level timer controls the duration of the rhythmic groups and subordinate timers control the durations within the groups.

One possible realization of such an organization could be as follows: The highest level timer initiates the execution of the first stroke and subordinate timers activate execution of subsequent strokes. At the end of the pattern, in the present analysis after five strokes, the highest level timer becomes active again and the whole cycle repeats. Now, if we examine the variance of the sums of each five successive bell strokes, the model makes the following predictions: the variance should be smaller if the successive strokes belong to the same group (to the same cycle of timer activation, starting with the highest level one) than if they are taken from two adjacent groups (the variance of the sums of beats 1+2+3+4+5 and 3+4+5+1+2 should be different if in the second case 3+4+5 and 1+2 belong to different groups). This follows from the fact that in the latter case timing variations from two groups contribute to and increases the variance of the summed responses (see Appendix B). However, our tests for equality of variance, performed on the various sums did not reveal any significant differences (all $p > 0.27$). There seems to be no evidence for a hierarchical timekeeper organization; the results are, however compatible with a multiple sequential timer model.

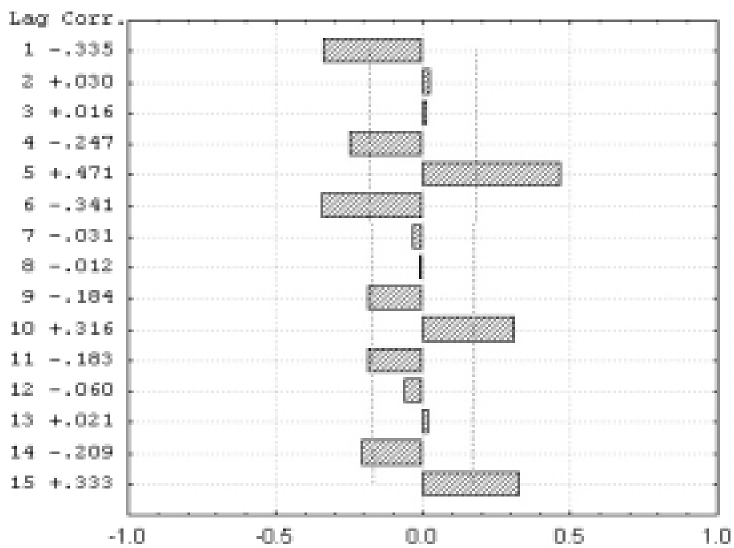

Fig.5: Autocorrelation plot of the detrended long bell strokes of a Kpegisu song (strokes 1, 2, 4, 5, and 6).

Obviously, the timing structure of the performance of the Kpegisu bell pattern is more complex than suggested by the Wing and Kristofferson model (1973a,b). On the one hand, the autocorrelation function clearly indicates an organization of the bell strokes into higher-level units, and it seems that it is a complex pattern of seven bell strokes (5 long and 2 short strokes), or rather a cognitive template of this bell stroke pattern, that is ‘programmed’, not just a sequence of individual strokes: The complete pattern has a time structure, that recurs with every repeat of the pattern. Interestingly, the timing structure shows no particular representation for the beginning of the group, which will have to be marked by additional, dynamic features. This finding may be an important factor in explaining the flexibility in performance and alignment of this pattern with other, simultaneously performed rhythmic patterns. On the other hand, there is no indication of a hierarchical time keeper organization and the execution of the strokes seems to be controlled by a sequential time keeper. However, our analysis does not support the assumption of a fastest pulse as the basis for the performance of bell patterns. This assumption is made by some scholars of African Music (e.g. Kubik 1998; Koetting 1970) to explain certain features of African rhythms. If this were the case, we should have been able to identify a hierarchical arrangement of a pulse generator plus additional generators for the short and long bell strokes. Furthermore, the mean stroke duration should have been the same for all long bell strokes as they all span two units of the ‘fastest pulse generator’. However, our results show (see fig.3) that stroke 5 and 6 differ significantly from the other long strokes, a result incompatible with the assumption of a common ‘fastest pulse generator’ for the performance of this pattern.

Case B: Gama AT

The second example is a song from the CD “Dyirbal Song Poetry” published together with a book of the same name by Dixon and Koch (1996). The musical tradition is that of the Dyirbal speaking people south of Cairns in North Queensland (Dixon, 1972). They have two categories of songs, ‘corroboree’ and ‘love songs’, and the example analysed here is from one genre of the former, Gama songs. Dyirbal songs are performed by individual singers, mostly accompanied by clap sticks or boomerangs, played by the singers, and in some cases by an additional ‘lap drum’ – a skin stretched across thighs, played by a woman (Dixon & Koch, 1996).

As the tempo variation for this performance is considerably smaller than the variability in beat duration, we did not eliminate any trend from the time series. At first glance, the plot of the beat durations (fig.6) looks like a series of random variations around a mean of about 0.3 sec, but in fact, it is highly structured. Marking all durations sequentially by two arbitrary labels (dots and circles in fig.6) and plotting them correspondingly discloses this structure: on the average, every second beat seems to have a slightly longer duration. This grouping into two beats is confirmed by an analysis of variance, showing that the difference between the two types of beat duration is highly significant ($F(1,100)=39.298$, $p<0.0001$) with a mean duration for the two types of 291 msec and 310 msec, respectively.

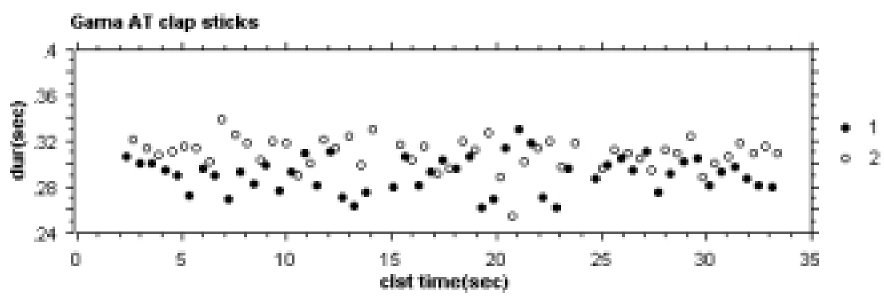

Fig.6: Time-duration plot of clap stick beating in Gama AT.

The calculated autocorrelation function shows a significant negative value at lag 1, as predicted by the Wing model, but as for the Kpegisu bell, values for lags>1 are not zero. The autocorrelation function is again periodic, but now with a period length of 2 lags. The significantly positive values at lag two and multiples thereof is obviously an indication of the higher-order grouping of the clap stick beats into units of two. Again, the test for a hierarchical timer arrangement was negative (see previous case): The variance for summed clap durations within and between the groups did not show any significant differences ($F(1,48)=0.735$, $p= 0.289$), and therefore suggests a sequential timer model.

Discussion

The timing structure in both the African and the Australian example is clearly more complex than suggested by the Wing and Kristofferson model (1973a,b). A comparison of the variance of within- and between-pattern durations showed that the higher-level units of organization of the clap stick beats, as revealed by the autocorrelation function, are not an indication of a hierarchical timer organization. In both examples the results are, however, compatible with a sequential timer model. What, then, is the significance of the periodic structure of the autocorrelation function?

Following the interpretation of comparable results from a grouped tapping experiment by Vorberg and Hambuch (1977), we suggest that the higher-level organization indicated by the autocorrelation function reflects the establishment of serial order of the pattern to be performed. It is a more central, cognitive aspect of the behaviour and relates to the mental representation of the bell pattern, the pattern template. This means, what performers recall or activate in performance is not a series of individual strokes but complete patterns with distinct temporal fine structures. On the other hand, a ‘peripheral’ sequential timekeeper seems to control the duration of the sequence of strokes during motor execution and its organization is reflected in the variance of the stroke timing.

In both the Kpegisu bell pattern and the Gama AT clap stick pattern, the time structure of the rhythmic performance appears to contain information about at least two aspects of the motor behaviour, the control of timing and control of serial order of the rhythmic pattern. The time structure therefore informs us not only about the execution of motor programs but also about some aspects of the cognitive processes that lead to these motor programs, and musical behaviour shares this feature with other timed behaviour like writing and typing (Will et al. 2002, in press). It is these two aspects of the temporal structure of musical rhythmic activities that we are dealing with when we try to understand the phenomenon of synchronization and entrainment between two or more of such activities. Because of the time constraints of most musical behaviour, it would be most interesting and challenging to explore how these two aspects are involved in and contribute to the observed phenomena.

Case study 2: Simultaneous production of two rhythmic activities by one performer

In this case study we are going to examine two examples of simultaneous rhythmic processes in one body. The question in these examples is: How can we detect the presence or absence of synchronization between the processes and what does the identification of synchronization tell us about entrainment? We are going to show this by a further examination of the two musical examples from case study 1. The analysis of the individual examples, being somewhat representative for a range of ethnomusicological material, shows that the mere identification of synchronization may hint at, but is no proof for entrainment. Interestingly, however, the cross-cultural comparison of the two examples suggests that socio-cultural factors may influence entrainment, thereby requiring a reformulation of certain entrainment phenomena that hitherto have been interpreted exclusively on the basis of results from laboratory experiments. This control function, the re-evaluation within a variety of different contexts, is obviously one of the important contributions ethnomusicology can make to entrainment research.

On the central issue of coordination of limbs and body in performance of complex actions, dynamic system theory in motor control provides a tool for analysing the way that individual body parts cooperate to form patterns in space and time (e.g. Kugler and Turvey 1987). Cooperation is thought to result from the coherence of the movements of the parts under certain energetic constraints, without any explicit or conscious control, i.e. without cognitive intervention (Kelso 1995). Among the best studied cases are those concerning rhythmic limb movements in humans and other animals – several of these studies have already been mentioned in previous sections – and it seems that quasi automatic self-entrainment is dominantly found in homologous limb movements, for instance in coordination of movements of the right and left arm. Kinsbourne's functional distance principle may provide a possible explanation for this. It posits that two concurrent (motor) activities interfere with each other to the extent that they are based on similar neuronal activity patterns in highly connected cerebral regions. Now, simultaneous movements in two corresponding limbs requires, amongst others, the activation of homologous structures on both sides of the brain, some of them directly connected via the corpus callosum, which might contribute to the strong coupling observed in this type of movement coordination. However, strength and automaticity of self-entrainment for movements in non-homologous body parts are less clear. Although numerous experimental studies have found an influence of vocal activities like speaking on arm or finger movements, the review of Kinsbourne and Hiscock (1983) clearly indicates that whether the two tasks interfere depends very much on two factors: the difficulties and the nature of the motor tasks. It seems that the more difficult and the more similar the tasks, the stronger the interference. Speaking is generally reported to affect (to slow down) the tempo of arm or finger movements. However, the study of Inhoff and Bisiacchi (1990) demonstrates that speaking significantly constrains the timing of concurrent unimanual tapping, i.e. it reduces the tapping variability.

As both manual motor activity and speaking are controlled by the left hemisphere (Kimura 1993; Mattingly and Studdert-Kennedy 1991), several studies have been performed to test whether non-verbal vocalization, supposedly controlled by the right hemisphere, also interferes with manual movements. Results are not unanimous: Lomas and Kimura (1976) as well as Johnson and Kozma (1977) did not find any influence of nonverbal vocalization on concurrent movements with either hand, whereas an effect was reported by Hicks (1975) and Hicks et al. (1978). An interesting question arising from these studies concerns the type of interactions between manual movements and vocalization that occurs if vocalization implies the involvement of both hemispheres, as is the case in song performance.

In the following examples our analyses focus on coordination, and the degree of synchronization between singing and manual performance of a rhythm by individual musicians from two different cultures. The two cases presented here are a continuation of the analyses from case study 1. In addition to playing a rhythm instrument, both performers were also simultaneously singing in both performances. The data for the manual activity (playing the rhythm instrument) have already been presented (see case study 1). Singing, the vocal motor activity, is analysed here in terms of timing of speech segments, i.e. the onset of consonants and vowels. As both instrumental rhythm and singing were part of the same recordings, they share a common time base and the chronometric data of both activities can be compared directly. The segment onsets were marked with a computer program that allows for simultaneous display of the original sound wave as well as the spectral representation of the sung voice (see fig.7), and the markings, together with the associated time information was combined with the data for the manual rhythm and saved as an ASCII file for further treatment.

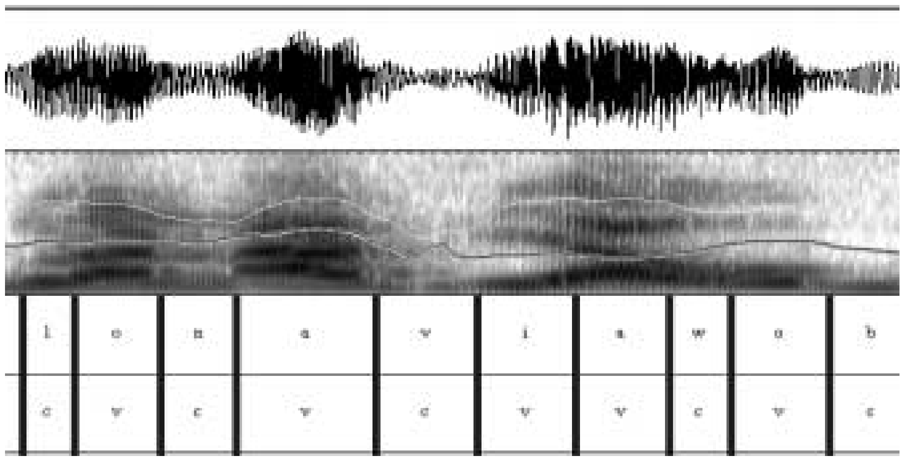

Fig.7: Example of sound wave (upper tier), spectral display (middle tier, with curves showing intensity (upper curve) and pitch (lower curve)), with segment transcription, segment labels and segment onset markings (vertical lines) in the lower tier. The example is from a section of a spoken song text.

<u>Case A: Kpegisu (Ghana/Africa)</u>

For every segment onset a special program function calculated the distance to the closest bell stroke. These measurements are plotted against the time of the bell strokes and split by segment type (c = consonants, v = vowels) in fig.8. Obviously the segments are aligned with the bell strokes, graphically represented by their arrangement in parallel to the zero line (the bell stroke reference), with c and v segments having different distances to the bell strokes. The vowel onsets tend to be placed on or close to the bell strokes (mean distance 0.009 sec), whereas there are two populations of c segments, a large, ‘early’ group with a mean distance of about -0.076 and smaller, ‘late’ group with a mean of 0.146 sec. This seems to indicate that the vowel onsets are synchronized with the bell strokes.

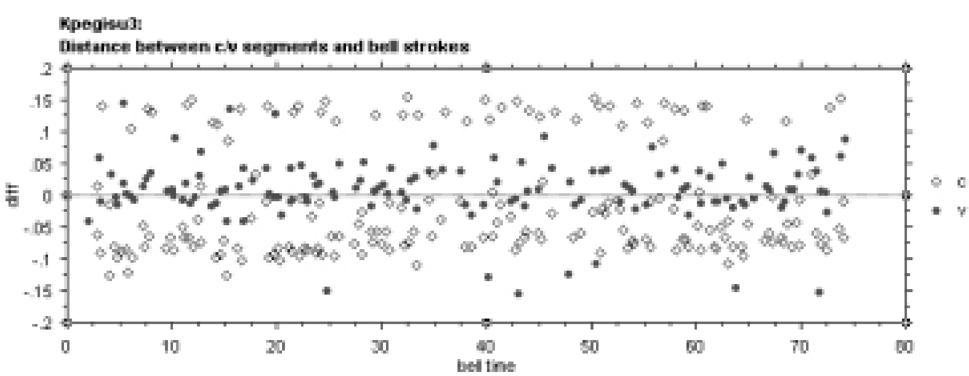

Fig.8: Plot of segment distances to the nearest bell strokes in a Kpegisu song.

The absolute differences, however, do not inform us about the synchronization pattern. To find this, we need to express the difference between the two variables (i.e. timing of bell strokes and c/v onsets) with respect to the time cycle or period of one of the variables. This measure is called the relative phase, and can be calculated, for example, by dividing 360 degrees by the time between two beats and multiplying the result by the difference between the first of the two beats and the c/v onsets. If this calculation is done for all bell stroke pairs and their respective c/v onsets (see Appendix C) we can plot the data and obtain the distribution pattern for the vowel and consonant phases as shown in fig.9. The relative phase for the vowels (v phase) has a major peak close to 0 degrees. The actual peak is about 8 degrees off, and this difference is part of the 'groove' of the music. Another characteristic is the minor peak close to 180 degrees, a synchronization of vowels in antiphase to the bell stroke corresponding to the off-beat feel of this music.

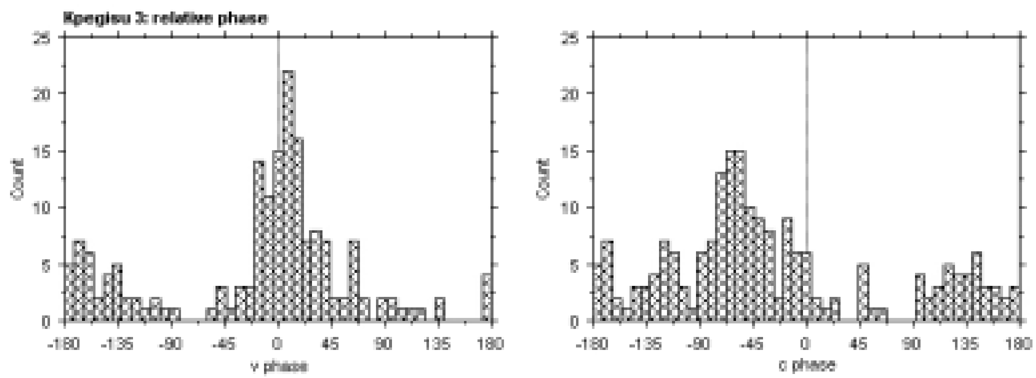

Fig.9: Relative phase of bell strokes and vowel (v phase) and consonants (c phase) in a Kpegisu song

The relative phase for the consonants (c phase) shows a flatter distribution and a broader peak at about –60 degree. The consonant onsets are neither in phase nor antiphase with the bell strokes, but there appears to exist a timing relationship with the vowel onsets. Indeed there is a highly significant, strong correlation ($R=0.967$, $p<0.0001$) between the c segments and the corresponding v segments. This correlation strongly suggests that the stream of sung language can be characterized in the same way as the speech chain in spoken language, as a continuous vowel flow probably represented by the alternate movement of jaw openings and closings (Rhardisse and Abry 1995) on which consonant gestures are superimposed (Fujimura 1995; Öhmann 1996). It seems that in this music the timing of the vowel flow is such that vowel onsets are synchronized with the timing of the bell strokes.

<u>Case B: Gama AT (Queensland/Australia)</u>

Again, following the labelling of segment onsets, a special program function calculated the distance between segment onsets and the closest clap stick beat. These measurements are plotted against the time of the clap stick beat and split by segment type (c=consonants, v=vowels) in fig.10. In contrast to the Kpegisu song, there seems to be no obvious alignment between c or v segments and clap sticks.

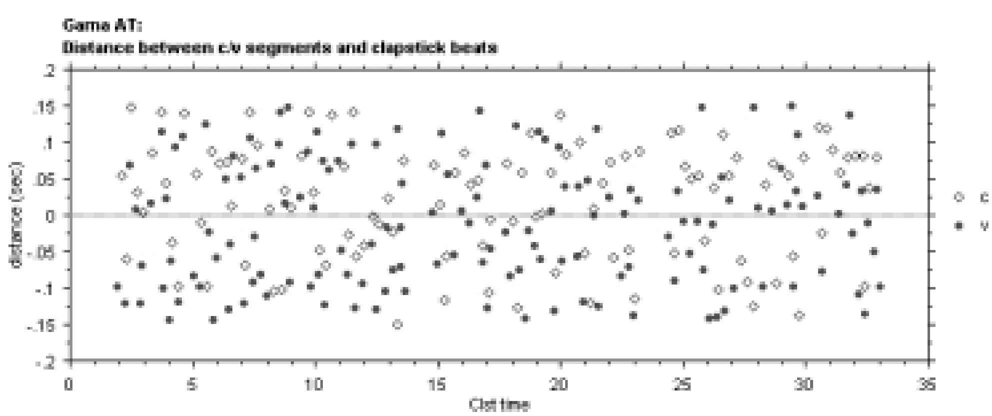

Fig.10: Plot of segment distances to the nearest clap stick beats in Gama AT.

This is confirmed if we examine the relative phase plots for the clap stick beats and c/v onsets in fig.11. The relative phase for both consonants and vowels is rather flat, with the vowels showing a moderate peak at +90 degrees and hence a slight preference to occur after the beat.

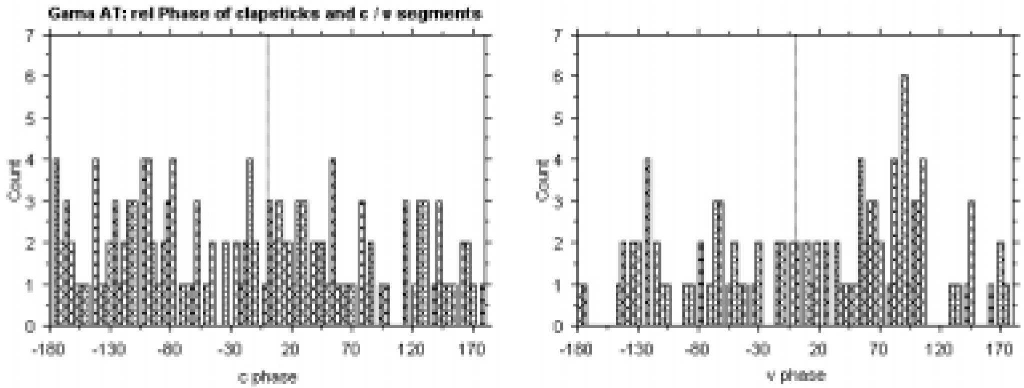

Fig.11: Relative phase of bell strokes and consonants (c phase) and vowels (v phase) in a Gama song

Despite the lack of synchronization between clap sticks and c/v segments there is again a high correlation between v and c segments (with a correlation coefficient of $R= 0.845$ and $p<0.0001$). It seems therefore that the temporal relationship between consonant and vowel segments is independent from whether or not one of these segment types is synchronized with another activity. This supports our suggestion following from the previous analysis that segmental time structure in song language can be understood in analogy to that of spoken language.

Discussion

Although entrainment has not been proven in either of the two cases - that can only be done by analysing the dynamics of the interaction at a point of perturbation or rate change – their comparison demonstrates that there is no automatic synchronization or self-entrainment between simultaneous manual and vocal activities in one body. It is possible, as in the coordination of speaking and arm or hand movements, that synchronization is more likely to occur with the more difficult tasks, as in the present examples the Kpegisu pattern is evidently more demanding than the Gama clap stick pattern. This hypothesis could easily be tested by analysing a series of comparable songs in which the rhythmic accompaniments cover a broad range from simple to complex forms. However, the complexity of the accompanying rhythm does not seem to be the only factor that influences synchronization. Although all Dyirbal Gama songs have essentially the same clap stick pattern, they actually show a variety of clap stick-singing interaction pattern that range from non-synchronization, like in Gama AT, to significant synchronization (Will, forthcoming) and the degree of synchronization seems to be a 'trade mark' of individual performers, just as it seems to be the case for melodies in this culture (Dixon and Koch, 1996). This suggests that the degree of coherence in synchronization or entrainment is also affected by musical and cultural factors whose influence needs to be determined and analysed. For example, in a recent study Tom Beardslee (unpublished) was able to show how the introduction of electronic rhythm machines and sequencers affected the synchronization between singers and rhythm section in West African High Life music.

In the present case study we were able to quantitatively describe the different degrees of synchronization between the two concurrent activities of beating/clapping and singing. With the given examples it was not possible, however, to show how the two activities influence each other. However, there are other musical genres that would allow for such an analysis. For instance, in North Australian music there are genres that consist of sections with clap stick beating only, sections with clap sticks and concurrent singing, and sections with singing only. In these genres it should in principle be possible to analyse whether clap stick beating affects singing or vice versa and, finally, to describe by what processes the synchronization is established. For Central Australian music, one of us found that when songs are accompanied by beating, there is a noticeable entrainment effect on the singing with beat and syllable alignment and regularization of the sung text rhythms (Will, in press). Nevertheless, the experiments of

Inhoff and Bisiacchi (1990) suggest that, at least in principle, an inverse entrainment – that of the beating accompaniment by singing - might also be possible.

Case Study 3: Coordination of rhythms between two performers

While the previous case study concerned processes within individual musicians, we will now take a look at synchronization and entrainment between two performers. This case study will also demonstrate that analyses of recorded performances are not limited to the mere identification of the degree of synchronization. As already indicated in section 6, in order to be able to analyse the *process* of synchronization in non-experimental studies, we have to look at non-stationary sections ('perturbations') in the performance, for example tempo or pattern changes. Only by analysing the behaviour of the performers at these transitory sections are we able to identify the presence (or absence) of entrainment, that is the re-establishment of synchronization, and to describe the dynamics of the underlying processes. The example for this case study was chosen because it contains several non-stationary sections – an initial phase of coordination and three pattern changes – within the short time span of about 35 seconds. It also demonstrates that in music we are rarely, if at all, dealing with strictly periodic oscillations, but exact periodicity has been shown to be not a prerequisite for entrainment (e.g. Pikovsky et al. 2001). In addition we want to show how to describe the interaction between the two rhythm performances in terms of their relative phase, an important measure in the behavioural analysis of complex systems. For the kind of data we are dealing with here, we can construct a point estimate of the relative phase by calculating the latency (time of occurrence) of one series of clap stick beats with respect to the period (duration between two successive beats) of the other (see Appendix C). Such a description is also accessible for musicologists, because 'relative phase' can immediately be translated into 'musical' terms: if the reference period (the pulse) is represented as a quarter note, a phase difference of 180 degree corresponds to a binary subdivision of the reference period (e.g. 8^{th} note), a 90 degree phase difference means the timing of the players differs by a 16^{th} note, etc.

The example for this case study is taken from the first track of the Djambidj recording, a clan song series from Arnhem Land, published by Clunies Ross and Wild (1982, 1984). The performance includes two singers who also play clap sticks, and a didgeridoo player. Djambidj songs have been described to consist generally of three parts distinguished clearly by the accompaniment: part one is accompanied by clap sticks, part two by clap sticks and didgeridoo and part three is unaccompanied (Clunies Ross and Wild 1982). The clap stick beating of the first Djambidj song consists of several sections (see fig.12). Following some initial beats at 'half speed', there is a long section of more or less regular clap stick beats with average durations of 0.26 sec (see also fig.13). At the 22 sec time mark, the performers change the pattern; at the 28 sec mark, they return to the first pattern. Finally, they introduce a concluding pattern at about 33 sec. We are going to start this analysis by looking first at the clap stick performances in the first part up to the time mark of 22.6 sec. The different clap sticks of the two players were identified on the basis of their different sound spectra.

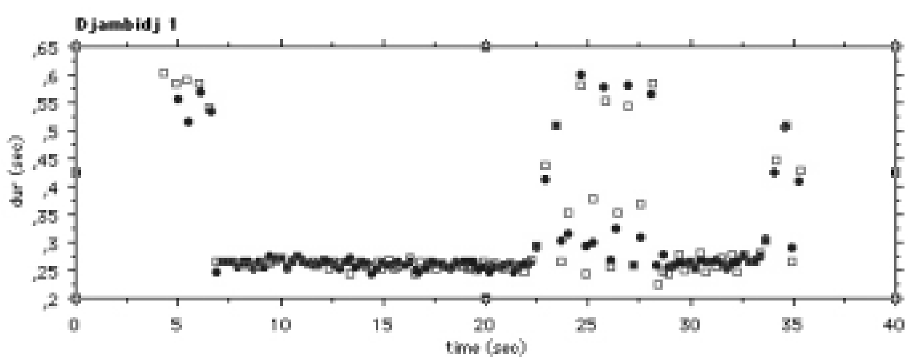

Fig.12: Clap stick beat durations of a Djambidj song played by two performers (circles and squares).

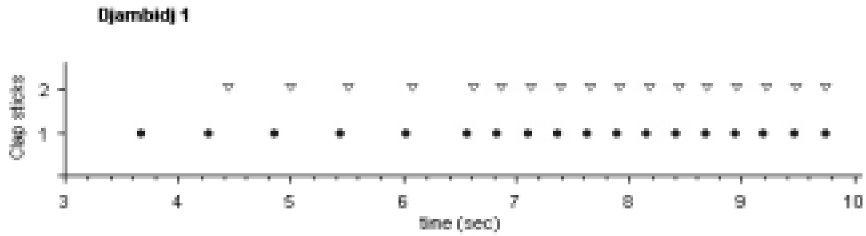

Fig.13: Temporal alignment between the clap stick beats of the two players (1 and 2) in the first 10 seconds of the Djambidj song from fig.12.

One of the singers starts with the beating and after his second beat the other player begins. If we compare the timing of the two players (fig.14) we see that the initial difference of 0.17 sec is rapidly reduced and within a couple of clap stick beats the performers achieve synchronization of their clap stick beats, i.e. entrainment takes place. The regression of the data (continuous line in fig.14) reflects this entrainment effect with an initial exponential reduction in timing differences and a subsequent plateau with values of about 10 milliseconds, which is reached at the time mark of 9.4 sec. As can be seen from both fig.14 and fig.15 (relative phase plot), the initial entrainment proceeds in several steps. Following a quick reduction of the timing differences at the start of the performance, there is a short stabilization of the phase, a 'locking in' with a mean phase of about 40 degree for about nine beats (see fig.15). After the 8 second mark there is a change in phase and a further reduction of the differences to a mean phase difference of 9.6 degree and the performance between the 9th to the 22nd second settles down to a quasi-stationary section. The mean phase is also called a phase attractor: it seems to 'attract' the behaviour of the system in this part of the performance. Synchronization during this section is characterized by a peculiar pattern of differences in clap stick timing between the musicians: The phase shifts randomly, and there is only a weak, hardly significant cross correlation ($r = 0.25$, $p = 0.053$) between the musicians, indicating that the timing of the beats of one player has only a very weak influence on the timing of the other. Residual analysis suggests that it is actually the timing difference between the two players that is crucial here: these differences drift randomly within a band of ± 30 milliseconds and only when they exceed this value does there seem to be a directed correction. Furthermore, the autocorrelation function for the beat durations of the first player – the one who starts the song – shows a significant negative correlation at lag 1 and corresponds to the function as predicted by the Wing model that means this player controls his beat sequence through self-correction. In contrast, the autocorrelation function for the second player has no significant values for any lag, suggesting that external factors influence the timing of his beatings.

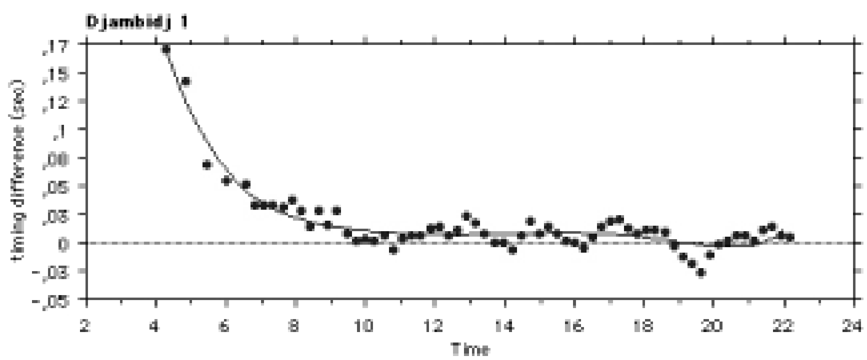

Fig.14: Differences in clap stick timing between the two players for the first section of the Djambidj song from fig.11. Continuous line indicates the regression on the data set (see text).

In the following section, starting at 22.5 sec (first mark in fig.15) with the change to a different beat pattern, we find a break down of the previously achieved synchronization. The range of phase variation increases notably, even reaching a value of 71 degrees for the penultimate beat of this section. Although the phase is not stable there seems to be a certain patterning, a self-similarity of the phase changes with a period of three. As can be seen from fig.12, the players perform a three beat pattern with one long and two unequal short beats. The phase change pattern seems to indicate that the musicians do not synchronize individual beats. It seems that the reference point for their synchronization, for their ‘playing together’ is the starting point of the pattern, as there is minimum discrepancy at the beginning of each pattern (two of these points even have nearly zero phase), but increased phase differences within each pattern. The type of synchronization in this section can best be described as intermittent phase locking where repeated beat patterns tend to be synchronized at their onset but not within the pattern.

At 28.3 sec (second mark in fig.15) there is another pattern change, the return to the first pattern. For the first beat of this pattern there is a phase difference of 60 degrees, but within two beats phase synchronization is re-established and phase variation is limited to the same narrow band as in the first section. The final pattern change, the introduction of the concluding formula at about 34 sec is not marked by a noticeable phase change and therefore will not be considered separately here. With the analysis of several such pattern changes it would be possible to arrive at a more precise description of the coupling force. In the present case the relaxation time, the time it takes a system to return to a previous state following a perturbation (an indicator of the coupling force), does not seem to be longer than one or two clap stick beats (a detailed study of Djambidj beating accompaniment is in preparation).

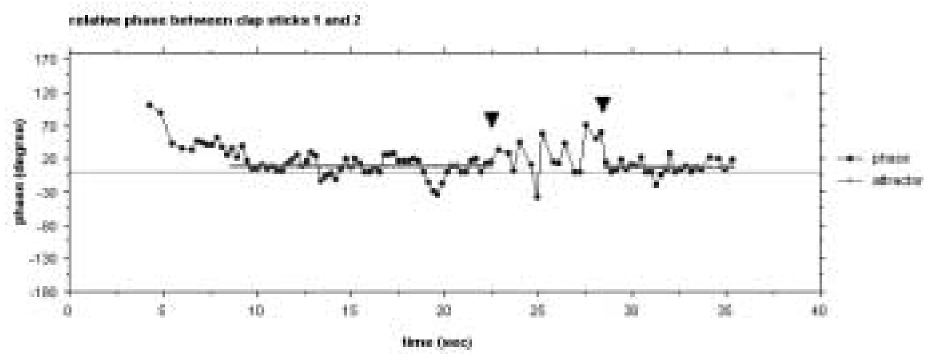

Fig.15: *Relative phase between the two clap stick beatings of the Djambidj song from fig.12. For markings see text.*

The mean phase for the whole last section (i.e. from 28.6 sec) is about 7.6 degrees and slightly smaller than in the first section (where it was 9.6 degrees). Interestingly the two sections with continuous phase locking seem to have a phase attractor that is not zero but has a marked positive value. With our two calculated phase means we might guess that the phase attractor probably lies somewhere between 7 and 10 degrees.

<u>Discussion</u>

Our analysis has shown that the synchronization between the clap stick beats of the two musicians is not a complete or absolute one, but one marked by fluctuations within specific limits. One obvious explanation for this ‘synchronization bandwidth’ of approximately 30 milliseconds comes from psychophysics: It has been shown that this time is necessary to evaluate the temporal-spatial order of acoustic stimuli (for review, see Pöppel 1997). If the time difference between two musicians is considerably less than 30 milliseconds then, although they can still hear that the sounds they produce are not absolutely synchronous, they cannot tell which of the two is first and therefore cannot take directed action to improve synchrony. Only when the difference between them is larger than this interval is it possible for a musician to take explicit action in order to reduce the difference. Interestingly, the mean absolute difference between bell strokes and the ‘synchronized' vowel onsets in the Kpegisu song of case study 2 was also of this magnitude, i.e. slightly larger than 30 milliseconds (see fig.8). This interval is a reflection of some basic neuronal mechanisms, as is suggested by the fact that attentive brain states in which incoming stimuli are evaluated, produce EEG patterns with a strong 30 Hz component indicating heightened, synchronized cortical activity in this frequency range.

However, our results are not meant to suggest that synchronization cannot be better than about 30 milliseconds. It is well known that skilled performers can overcome this limitation and improve their synchronization considerably. The point here is that this improvement can only be done with recourse to other means than an evaluation of the time structure of the produced auditory events, for example by using anticipatory action. Anticipation studies seem to suggest that the superior reactions of highly skilled performers in some cultures are due largely to learning. Although players are generally not conscious of the cues they are responding to in anticipation, careful analyses of performance contexts and detailed experimentation might unveil at least some of the cues guiding the performers.

The finding that the attractor, the mean relative phase between the musicians, is located between 7 and 10 degrees, is interesting in connection with modelling of coupled oscillators in music psychology (e.g. Large and Jones 1999). There, it is simply assumed that the phase attractor is located at phase zero. However, the instabilities of that location due to psychophysical constraints (see above), make it possible that the actual location of the phase attractor in non-laboratory, real world situations can easily be influenced by socio-cultural and/or performance conditions. We are going to argue that the position of the phase attractor in this case reflects the specific socio-cultural condition of the entrainment process under consideration, an entrainment between a ‘song owner’ and an ‘accompanying’ performance participant.

Ethnographical background knowledge is essential in interpreting the analysis and understanding the socio-cultural significance of the identified entrainment process. Generally, the ethnomusicologist who performs the analysis is also the one who did the recording and can, therefore, identify the musicians. This is not the case for the present example and despite the excellent booklet accompanying the record we cannot tell from the recording, which of the musicians is playing which pair of clap sticks. However, our analysis seems to suggest that those clap sticks that show a negative autocorrelation at lag 1 are played by the ‘song leader’: it is he who starts first, his performance is strongly controlled by his internal pulse, and his beat durations show the smaller variance of the two. The performance of the other musician, which exhibits a larger variance in his timing and less reliance on an internal pulse – as indicated by the autocorrelation function - seems to indicate that we are dealing here with a case of asymmetric entrainment: while the first player ‘sets the pace’, it is the performance of the second that establishes and assures the synchronization between the musicians. The processes that are indicated by our analysis, led to a degree of synchronization that satisfies the culturally defined criteria for ‘playing together’ of the two musicians with different roles in the performance. Different sets of criteria in other cultures might necessitate the recruitment of additional or different processes in order to establish the respective degrees of synchronization.

Musicians’ brains obviously cannot be thought of as just a memory store for motor routines - blind, inanimate warehouses which produce stereotyped responses when triggered by conscious commands or external stimuli. Analyses of entrainment processes produce abundant evidence to show that there is considerable leeway for - if sub-conscious – intelligence and creativity that mark entrainment as an important adaptive capability of living systems to be found whenever coordination and cooperation within a group, not the achievements of individuals, are of importance.

8. Appendix

A. The autocorrelation function

Autocorrelation describes the correlation of a signal or a variable with shifted versions of itself. Take for instance the variable represented by the series of connected dots in figure 16. If we shift all values by one data point we obtain the sequence of open triangles in the upper graph. This shift by one data point is called lag 1. Comparing dots and triangles at the same points on the abscissa, we see that the values of the two series change in opposite directions: when point values increase, triangle values decrease, and vice versa. This is the reason why the correlation coefficient for these two data series is negative.

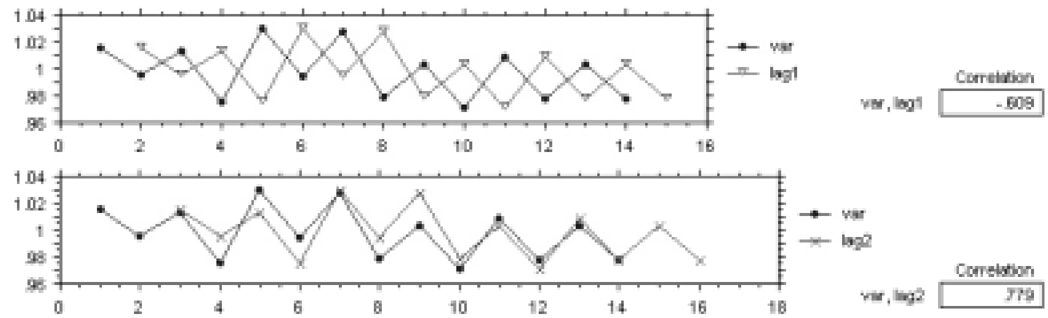

Fig.16: Plot of a variable (dots) and two lagged versions of the same variable, shifted by one data point (lag 1, triangles, upper graph) and by two data points (lag 2, x, lower graph). Numbers on the right show the correlation coefficients for the correlation between the variable and lag 1 (upper number) and lag 2 (lower number).

Shifting the lag 1 series by another data point we obtain the lag 2 sequence (lower graph). In this case the data values of the original and the lag 2 series vary in the same direction, if one increases, so does the other, and the correlation between them is positive.

The autocorrelation function produces a series of numbers that are the correlation coefficients for the variable and a specified number of lagged versions thereof.. This function allows us to detect whether values of a variable are dependent on previous values of the same variable, for example whether the duration of beats or tones is influenced by the duration of preceding ones. As demonstrated by case study 1, it also permits us to identify (e.g. temporal) patterns hidden in the data series: these would show up as repetitive pattern in the autocorrelation function.

B. Sequential and hierarchical timer models

Timed complex behaviour seems to require the activation of multiple timers. Even as simple a movement as a drum stroke, for example, needs time-coordinated activation of a large set of different muscles. One of the interesting questions is whether timing of musical behaviour, e.g. the production of a rhythmic pattern, can adequately be accounted for by only a sequential organization of temporal behaviour or whether it requires a hierarchical organization. The basic idea behind these different models is as follows.

According to the proposal of Wing and Kristofferson (1973a,b) the timing structure of motor behaviour can be considered to consist of two components: a) temporal structures produced by timers (e.g. neural oscillators) and b) temporal structures produced during the execution process (implementation of timer 'instructions' in the muscular system involved). This second component, the 'executional' part, is assumed to be the same in both sequential and hierarchical models. However, the difference between the two models lies in the arrangement of the timers.

We will examine these arrangements with an example of a pattern of four movements or strokes of unequal duration. In the sequential model (fig.17) each timer starts a motor action and initiates the activation of a subsequent timer. The timer for the last motor action in the series (T4) re-activates the first timer (T1) and then the cycle starts all over again.

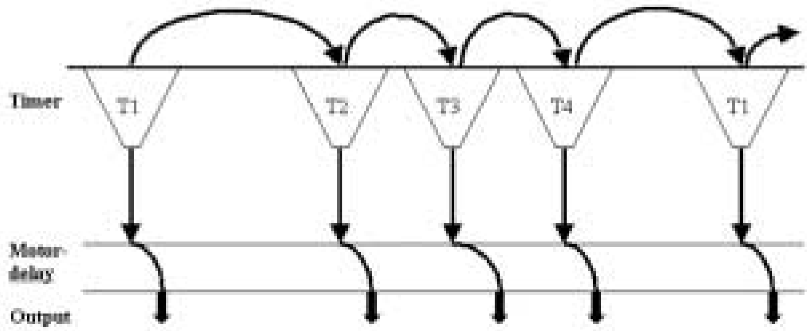

Fig.17: Sequential timer model for four timers activated in a cyclical fashion. The model has two components of variance, variance due to the imprecision of the timer and variance produced at the level of the motor delay (e.g. imprecision caused by the activation of the muscular system).

In the hierarchical model (fig.18) the first timer (T1) starts a motor action and initiates the activation of the subsequent timer (T2). The second timer starts a motor action and initiates the activation of timer 3 and 4. In contrast to the sequential model, the subsequent cycle is not initiated by the last timer in the sequence (T4) but by the first timer (T1). This 'high-level' timer T1 controls the duration of the whole cycle. The model shown in fig.18 is but one possible arrangement; with four timers 24 different arrangements are possible.

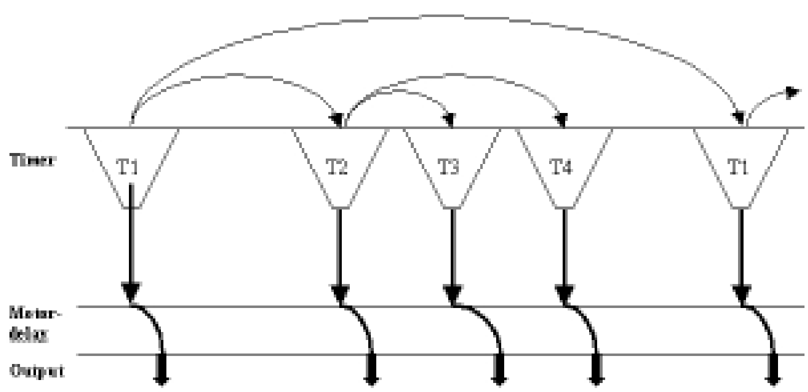

Fig.18: One possibility of an hierarchical arrangement of the four timers. Timer 1 is at the highest level and controls its motor command, the activation of timer 2 and the (re-)activation of the whole cycle. Timer 2 is at the next level, controlling its motor command and the activation of timer 3 and 4, which are at the lowest level of the hierarchy.

Vorberg and Hambuch (1977) have shown that – at least in principle -a sequential timer organisation can be distinguished from a hierarchical organisation on the basis of the time structure of the resulting motor actions. In our case studies we make use of this to distinguish between sequential and hierarchical arrangements, a distinction that seems to be relevant for understanding and interpreting musical entrainment processes. The distinction can be made, as demonstrated by Vorberg and Hambuch (1977), by comparing the variance of the inter-response intervals summed up within a cycle and across cycles. The summed interval within a cycle is $I_w = I_1(t1,t2) + I_1(t2,t3) + I_1(t3,t4) + I_1(t4,t1)$ and a sum across cycles is e.g. $I_a = I_1(t3,t4) + I_1(t4,t1) + I_2(t1,t2) + I_2(t2,t3)$, where $I_n(tm,tm+1)$ is the interval of the n-th cycle, between the actions initiated by timer Tm and the subsequent timer. With a sequential timer arrangement the variance of the sum of the response intervals should not depend on how they are chosen, the variance of I_w and I_a should be the same. Under the hierarchical assumption the variance of I_w should be smaller than the variance for I_a, because in the variances from two cycles add up in the latter case.

C. The relative phase of two event series

Figure 19 shows how the relative phase between two periodic events series can be calculated. The figure shows waveform and spectrogram of an excerpt from a recording of singing with clap stick beating. There are two pair of clap sticks (played by different performers) that can easily be discerned by their spectral components: one pair shows a lower and higher frequency component (arrows to the right of the last pair of beats) that are missing in the other pair.

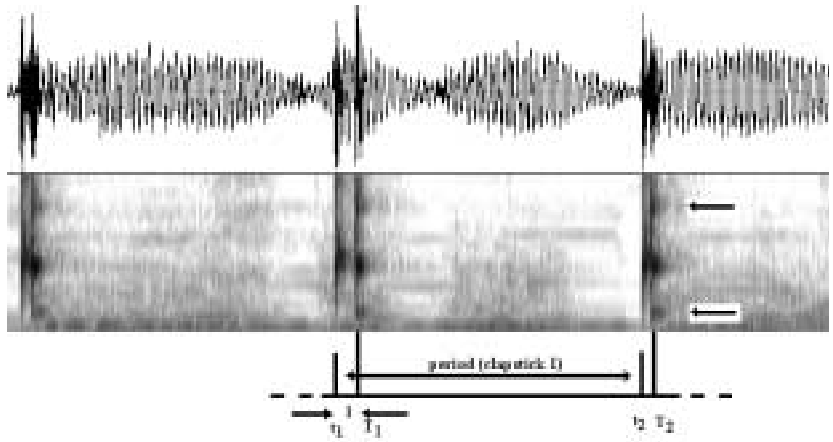

Fig.19: Sound wave (upper display) and spectrogram (lower display) section from a recorded performance of singing with clap stick accompaniment (two pairs). For explanation see text.

To calculate the relative phase we need the period of one clap stick pair, for example clap stick one, which is $t_2 - t_1$ in the above example. Then we need to calculate the latency of the second clap stick pair, which is $l = T_1 - t_1$. The relative phase can then be calculated as $\Phi = l * 360/(t_2 - t_1)$. This procedure is repeated for the next period $t_3 - t_2$ and all subsequent ones.

Notes on the authors

Martin Clayton studied at the School of Oriental and African Studies (SOAS) in London, where he completed a BA in Music and Hindi (1988) and a PhD in Ethnomusicology (1993). He has worked in the Music Department of the Open University since 1995, and has also taught at several other institutions including the universities of London, Cambridge, and Chicago. He served as editor of the *British Journal of Ethnomusicology* from 1998-2001 (with Suzel Reily), and is currently Chair of the British Forum for Ethnomusicology.

Email: m.r.l.clayton@open.ac.uk

Web pages: www.open.ac.uk/arts/music/mclayton.htm

Rebecca Sager holds a MM (1993) and PhD (2002) in Ethnomusicology from the University of Texas at Austin, receiving research funding from the Wenner-Gren Foundation for Anthropological Research. She has taught in the Department of Music at Istanbul Bilgi University and currently lives at 1017 Cherokee Dr., Tallahassee, FL 32301, U.S.A.

phone: +1 (850) 219-9966

Email: rsager@music.org.

Udo Will studied music, sociology, and neuroscience. He holds PhDs in both musicology and neurobiology and is professor of cognitive ethnomusicology at The Ohio State University. He currently leads research projects on cognitive aspects of music performances in oral cultures, on rhythm and melody processing by the human brain, and on a comparison of the cognitive architecture of music and language production.

Email: will.51@osu.edu

Web pages: www.arts/ohio-state.edu/Music/Ethnomus/Ethno.html

IDENTIFYING THE ENTRAINMENT PROCESS BY THE DEGREE OF SYNCHRONISATION

Regine Allgayer-Kaufmann
Universität Wien, Institut für Musikwissenschaft
Vienna, Austria
Email: regine.allgayer-kaufmann@univie.ac.at

It may be difficult to decide whether an observed synchronisation is the result of an entrainment process or not. Synchronisation on the basis of entrainment is never absolute or complete, instead it is realised up to a certain degree. Beyond this it is never maintained throughout the music on constant level. So it seems fair to assume that the 'synchronisation bandwidth' is intrinsic to the entrainment process.

We do need a comparative perspective if we want to understand the complexity of rhythm in music. There is no doubt. The best proof is Mieczyslaw Kolinsiki's article on meter and rhythm a thirty years ago (Kolinski 1973:494ff). The perspective of Western art music alone did not allow to draw the necessary conclusions from it. The nature of meter and rhythm and the interaction between them was unclear so far, because Western music is poor in contrametric structures. Western music is mainly commetric, and it is this experience that nourished the illusion that meter and rhythm either meant the same or one was subordinated to the other. There was a lot of confusion with both terms. However, to distinguish strictly between meter and rhythm is fundamental in understanding the process of making music as well as that of perceiving it, and they are music's most characteristic parameters, since music is the art in time as such.

Entrainment is not limited to synchronising meter and rhythm, nor is it necessarily limited to the dimension of time in music at all. It is fascinating indeed to have here for the first time such an extensive perspective: from colloquial speech rhythms over biological cycles to patterns in music. I plead for the idea to extend the concept of entrainment even more, following Charles Keil in this point. Keil (1995) did not limit his theory of participatory discrepancies to discrepancies in time. Instead, he thought of them in the broadest sense including pitch and timbre discrepancies as well. This seems to me quite logical and consequent. There has been a debate in ethnomusicology since the very beginning on musical scales and their artificial, even arbitrary nature. Man's faculty and his readiness to adjust and correct discrepancies following his respective expectations still is a matter of debate, leading finally to coining the term of "elastic scales" (Kubik 1983:364ff), which was observed and described many, many times, but never fully understood. Why not consider this eagerness of adjusting as entrainment in another dimension?

Only the third of the three case studies clearly showed entrainment. This result is highly interesting, but not surprising. In the third case study the behaviour of performers in situations of 'playing together' was analysed, exclusively viewing the transitory sections, i.e. moments of tempo or pattern changes, an aspect that was deliberately eliminated in the first case study. Anyway, playing together as a musical activity is highly intentional, and in my opinion this intention is quite simple: it is to synchronise. If there were not such an intention we could hardly speak of 'playing together' irrespective of the fact that things happen simultaneously. But we could ask in what respect and to what degree the intended synchronisation is achieved or realised. Apparently there is a 'synchronisation bandwidth' instead of a complete or absolute synchronisation. And the musicians make use of it. The authors make the point that the degree of synchronisation might increase with the degree of complexity. This should be proved by further investigations. Instead another fact is that the process of entrainment so easily is affected or superimposed by another one: it is the process of imitating, reproducing, copying, matching. To give an extreme example: I need not necessarily entrain to a military march to march in step with a military company. I could even synchronise my steps without listening to any music at all. There is good reason to doubt whether we do have an entrainment process here. The absolute degree of synchronisation is a suspicious fact. There is a fundamental difference between synchronising by entrainment and synchronising by imitation, of course. How do we find out, which one it is? I argue that the 'synchronisation bandwidth' is symptomatic for the real entrainment process. A complete or absolute synchronisation apparently is not achieved, maybe even not intended. This could explain why the minimum discrepancy, i.e. the highest degree of synchronisation, is confined to the reference point (here the starting point of the pattern).

This is one of the most exciting points in this most exciting article.

Bridging the Gaps – Music as a Biocultural Phenomenon.

John Bispham,
University of Cambridge,
Department of Music.
Email:jcb59@cam.ac.uk

The concept of entrainment and the application of empirical methods to ethnomusicological research is supported as a means of understanding music as a biocultural phenomenon. The author argues that a synthesis of ethnomusicology and musical psychology (as well as their methodologies) is an essential step toward future cross-disciplinary, and illuminating, musical scholarship. Furthermore, a psychological model, viewing interpersonal musical entrainment as a conglomeration of sub-skills, is offered, as a means to cogent and thorough data analysis.

This article is, in effect, proposing more than the application of the concept of entrainment to ethnomusico1ogical research. On a broader scale, it is advocating the use of empirical and scientific methodologies within the field of ethnomusicology as a complement to more traditional ethnographic fieldwork. Research of this nature has great potential to further our understanding of music as a universal feature of human culture regardless of whether the reader considers him/herself to be an ethnomusicologist, music psychologist or musicologist. In fact, the proposals made by the authors, quite rightly, go beyond any traditional delineation between the fields of musical psychology and ethnomusicology. The existence of a perceived demarcation of the two fields is in many ways understandable. Differences of approach have often been seen to reflect not only differences of academic focus but also seemingly irreconcilable teleological and philosophical differences between the two parties. Put bluntly (too bluntly) ethnomusicologists have in recent times sought to explore music as a culturally constructed, cross-culturally diverse phenomenon, whereas cognitive musicologists or music psychologists, by investigating the biological determinants of musical abilities, are, at least implicitly, concerned with the search for musical universals[1]. This should not, however, present us with an insurmountable barrier for cooperation and integration. It simply requires members on both sides to take on the intuitively sensible view that music is a culturally constructed phenomenon built upon universal biologically determined foundations[2]. Viewing music in this way, together with subsequent cross-disciplinary study, is an essential step toward a fuller understanding of both musical cultures and the psychology of music. The often all too clear partition between the fields of ethnomusicology and music psychology is responsible for considerable gaps in the knowledge of both groups. Music psychology has for far too long suffered from relying almost exclusively upon data collected from western subjects using materials largely confined to western musical traditions. Subsequently, conclusions regarding universal psychological abilities (i.e. not culturally learnt) are severely restricted. Conversely, ethnographic data, of the kind that has dominated ethnomusicological research, collected without the support of psychologically grounded theory cannot determine which factors are a construct of a free cultural imagination and which are a partial result of (or confined within) biologically determined parameters. Music seen cross-culturally is, as we know, hugely diverse, yet infinitely less diverse than the bounds of imagination. Only through extensive dialogue and cooperation between musical psychologists and ethnomusicologists can we get closer to understanding this very important facet of musical behaviour. The concept of entrainment in musical performance is in many ways ideally suited to a cross-cultural psychological perspective as it is a biological phenomenon with functionality seemingly rooted in sociality and culture – in the words of the authors 'an integrated, embodied and interactive process'. As such I strongly welcome the concept of entrainment as a theoretical paradigm for musical research, as well as the cohesive data collection methodologies (e.g. p.28) proposed in the article.

[1] The notion of musical universals has, of course, become a highly unpopular notion within the field of ethnomusicology (as it has in western musicology). However, a notable exception, and useful discussion, is Bruno Nettl's article: 'An Ethnomusicologist Contemplates Musical Universals' (Nettl, 2000).

[2] A stance that is reflected and readily accepted in the study of other cultural phenomenon and social behaviours (e.g. Boyd & Richardson, 1985; Durham, 1991)

The overview presented on the history of entrainment and on research undertaken within diverse academic fields is useful in that it positions musical entrainment within the wider context of entrainment as a physical and physiological phenomenon common to a wide range of subjects, contexts and behaviours. In other words it correctly and importantly establishes that we are not talking about a concept or mechanism that is unique to musical behaviour. It is, however, of paramount importance that we recognize that, although entrainment is not unique to musical behaviour, there is something unique or at least distinguishable about entrainment in musical contexts. The authors, albeit offering some putative insight, admit that the question of what is special about musical entrainment is one for which they have, as yet, only the sketchiest of answers (p.26). One way in which we may be able to gain a clearer distinction of 'musical entrainment' (or at least the potential thereof) is by making a clear theoretical distinction between self-entrainment in musical contexts (SEiMC) and interpersonal musical entrainment (IME) and subsequently developing clear models, exploring the psychological nature of these two distinct behaviours. These models could, in turn, be used to contrast these (SEiMC & IME) with other physiological or contextual manifestations of entrainment.

I have suggested (Bispham, 2003) that IME[3] be viewed as a conglomeration of six concurrently operating, hierarchically organized, overlapping yet putatively distinguishable sub-skills[4]:

- A fundamental ability to perceive and produce synchronized and temporally separated events
- The ability to produce a reasonably steady periodic pulse
- The ability to perceive synchronized events across modalities
- The ability to rapidly adjust to small (and large) perturbations in pulse as well as changes in tempo i.e. phase and period correction mechanisms
- The ability to perceive and internalize a pulse in complex auditory phenomena
- The ability to co-ordinate bodily movements (whether in the production of musical sound or in dancing) with simple and complex auditory phenomena. (p. 18)

At first sight this may not seem to offer much in addition to what is being proposed in the present article, and we are still left with the same constrained theoretical insights into what is unique about IME, but a clear division of this kind offers a cogent quasi-checklist for data analysis and, importantly, offers clear comparisons to the extensive psychological literature[5] that exists on each of the sub-skills. As such it may offer the possibility for clearer delineations (or continuities) between IME and other manifestations of entrainment in terms of the psychological components used and the natures thereof.

Instances of self-entrainment in musical behaviours would seem to be less easily extractable and explicable. The issue is complicated by our lack of an undisputed model of how self-entrainment occurs and by the question of whether couplings or entrainment are responsible for individual instances of self-synchronous behaviours. Although the multiple timer model[6], as described by Ivry & Richardson (2002), suggests that separately controlled motor actions interact with each other by means of oscillatory gating and entrainment, this remains a theoretical, although well supported, suggestion. As yet, cases must be interpreted individually until more is known about the underlying psychological mechanisms. The authors state that "in order to analyze entrainment and to detect the constraints at work, ethnomusicologists do not have to wait for psychologists or neuroscientists to tell them what the timer organization underlying the observed behaviour actually is" (p. 36). While this is certainly correct it misses an important point: Research of this nature, in addition to being supported by psychological and neuroscientific theory, has considerable potential in the uncovering of the psychological nature of timing mechanisms. Data collected in the manner suggested on p.28, when interpreted correctly[7], can offer

[3] IME is defined as: Interpersonal behavioural synchrony based upon the perception of pulse in acoustic signals created by human movement.

[4] It is important to note, particularly when considering the concept of entrainment, that although the sub-skills are putatively distinct they should most likely be seen to overlap considering particularly in relying on common internal oscillatory mechanisms.

[5] Desain & Honing (Eds.) (2000) provides a good introduction into many of the relevant issues and literature. Also, a recent special edition of Brain and Behaviour (48:3) on timing is a very useful source of up-to-date information and ideas.

[6] Which the authors support on p. 9

[7] Of particular importance, in this regard, is extensive analysis of the nature of corrections to temporal fluctuations.

important input into the nature of timing mechanisms, by demonstrating which intra-individual factors are entraining in a musical performance and which are more inextricably coupled. Ethnomusicologists indeed do not have to wait for psychologists or neuroscientists to tell them what's what; by taking account of the psychological and neuroscientific literature they can empower themselves with the knowledge that they have a unique insight into music and musical cultures *and* (potentially) into many uncovered facets of the human mind.

Timers, oscillators and entrainment.

Eric F. Clarke
Music Department,
University of Sheffield, UK
Email: e.f.clarke@shef.ac.uk

Entrainment is an interesting way to try to understand the interactions of performers, and of listeners with performers. There is a need, however, to be attentive to the distinction between periodic and non-periodic rhythmic processes in assessing the explanatory value of the idea of entrainment. Similarly, this commentary questions the value of the idea of 'internal clock' mechanisms in discussing entrainment, whilst nonetheless endorsing the potential utility of the entrainment concept within the psychology of music and ethnomusicology.

How do people engage with music, and how do co-performers engage with one another? Playing music on one's own or with others, and listening to the performances of others in any kind of participatory manner invariably requires the flexible synchronization of different agents' actions with one another, and Clayton, Sager and Will (2003) present a wide-ranging and stimulating case for the relevance of the principle of entrainment for the study of music based on this. Entrainment, they propose, "offers a new approach to understanding music making and music perception as an integrated, embodied and interactive process, and can therefore shed light on many issues central to ethnomusicological thought." (2) The paper makes a strong case for this bold claim, and brings together an impressively diverse literature (ranging from mathematics and physics through psychology and neuroscience, to the social sciences) that demonstrates the broad applicability of the concept of entrainment as an explanatory principle. In this commentary I focus specifically on the discussion of timing mechanisms and movement control in the paper, since these form central pillars of the entrainment principle, but before I do so, let me register my enthusiasm for the broad project which this paper proposes, and for the stimulating questions which the perspective promises to open up. In general terms the paper strikes me as offering a very interesting way to address issues of communication, embodiment and coordinated action in music.

Now to specifics. First, a comment on periodic movement, non-periodic movement, and entrainment. The principle of entrainment as it is presented in the paper applies principally - perhaps even solely - to periodic processes. Huygens' original demonstration of entrainment in 1665 arose out of his observation of the spontaneous synchronization of the (periodic) pendulums of two clocks resting on the same shelf: entrainment is the process whereby two periodic process with initially different periods mutually 'steer' one another towards synchrony. The movements involved in playing music certainly involve periodic or quasi-periodic movements (such as body sway, or the arm movements of a jazz drummer playing a ride cymbal), but also significant numbers of non-periodic movements (the left arm movements of a violin player or guitarist shifting positions; the finger movements of string, wind and keyboard players in most music). The periodic component may be understood in terms of oscillatory systems (as Clayton et al discuss), but there is also an important layer of non-periodic movements superimposed upon, or tangled up with, that periodic component - and it is these non-periodic movements that have been explained in terms of motor programming. One way to see motor programming is as the means whereby the spontaneous oscillatory properties of the human body (the basically pendular character of the limbs and torso) are 'driven' to move in the non-periodic ways that music performance may often require. The bow arm movements that a folk fiddler may need to make in order to produce a particular sequence of notes in a particular key across four strings tuned in a certain specific manner will often not be straightforwardly periodic, and therefore don't easily lend themselves to entrainment explanations - even if the same fiddler's quasi-periodic foot tapping, for example, might. In the enthusiasm to see how far the idea of entrainment can go in explaining musical phenomena, it is important to remain alert to the distinction between periodic and non-periodic components, and therefore to the kinds of phenomena that the entrainment principle may *not* be able to explain.

Second a comment on timing models: is it really plausible to assert that rhythmic skills are based on clocks? The discussion of the timing models of Wing and Kristofferson (1973) and Vorberg and Hambuch (1977) picks up on three decades or more of theorizing about how human beings control the temporal component of behaviour, but it seems to me increasingly implausible to explain the continuously produced and finely judged sequences of events that typically characterize musical performance in terms of clock-like mechanisms that judge the inter-onset intervals between events by counting numbers of time quanta. Researchers may choose to *measure* and *represent* rhythmic sequences in this way - and for perfectly good analytical reasons. But what the clock inside a computer does in the service of measurement is not necessarily any realistic reflection of the internal process within the human that has produced the behaviour. An alternative might be that we make use of 'rate detectors' rather than timers - that we may be very sensitive to the rate at which events (both our own self-initiated events, and external events) unfold without having any direct or immediate sense of the durations that these events demarcate or occupy. Todd, O'Boyle and Lee (1999) propose an interesting model of this kind, based on a multiscale filtering approach. Their paper concludes that internal clocks (for which there is no direct evidence) are an unnecessary fiction, and that "we do not perceive 'time' as such but, rather, the temporal structure of the stimulus events … for which our sensory systems are evolutionarily adapted." (Todd, O'Boyle and Lee 1999: 26). I wonder, therefore, whether the discussion of these rather speculative timing mechanisms (whose rationale seems more to do with explaining the data in a mathematically elegant manner, rather than actually positing the psychological or biological reality of the mechanisms themselves) isn't something of a distraction from the main aims of the paper: to use entrainment as a principle to understand behaviour (and behaviour within an ethnomusicological context in particular), rather than timing mechanisms to understand entrainment.

As an example, I like the idea (derived from Jones and her co-workers) that different kinds of rhythmic structures might induce different styles of attention - that entrained rhythms may encourage a future-oriented style of attention which in turn supports predictive and anticipatory behaviours; while less coherent and periodic rhythmic structures, which do not allow entrainment, encourage a more 'present-centered' and analytic style of attention. These styles of attention may also be associated with rather different kinds of experience - the former with teleology and larger-scale organization, the latter with immediacy and the specific qualities of material. I would have thought that here the connection between psychological phenomena and ethnographic factors could be very interesting and productive: what kinds of experience are different kinds of musical materials 'designed' to elicit, and how do those different kinds of experience (and musical material) relate to the social functions and social values with which they are associated?

This brings me to a final point relating to timing - the distinction between synchronization and entrainment. As the authors themselves point out, synchronization isn't necessarily indicative of entrainment, and it is slightly disappointing that at least two of the three case studies presented at the end of the paper are not really able to make any specific claims about entrainment. The crucial evidence for entrainment, it seems, is what happens to the two rhythmic sequences of a possibly entrained 'coupling' when there is a perturbation in either of them. If entrainment (rather than the less specific notion of synchronization) is really the central concept of the paper, then an important first step must be to identify a range of phenomena in music where entrainment (identified through the behaviour of the coupled systems during perturbation) can be convincingly demonstrated. Having done so, and having provided empirical support for the pervasiveness of the phenomenon, then it will become more possible to assess more convincingly the consequences and explanatory value of the principle, and in particular its connection ethnographic considerations.

Exploring Musical Entrainment

Mari Riess Jones
Department of Psychology,
The Ohio State University
Columbus, Ohio, USA
Email:Jones.80@osu.edu

This commentary considers two issues related to the provocative essay of Clayton, Sager and Will on the applications of entrainment theory and analyses to ethnomusicology. The first issue concerns strategies for identifying entrainment phenomena in individual performers. The second raises interpretative questions about interactive performances in two performer situations.

The essay of Clayton, Sager, and Will is thorough, thoughtful and provocative. It provides an insightful and competent overview of the basic elements of entrainment as it has been and might be applied to human behaviours in various contexts (e.g., social and cognitive psychology, and music perception and production). The main goal of this essay is to consider ways to extend the entrainment approach to facilitate an understanding of behavioural phenomena in ethnomusicology. In addressing this goal, the authors sketch a path that includes exploring entrainment in three different exemplar contexts (case studies). Here I raise two issues touched upon by the authors in discussing these case studies. The first issue concerns ways in which a researcher recognizes and identifies signature entrainment phenomena. The second issue concerns the pinpointing of parameters that might guide entrainment and their interpretation in different cultural contexts.

The authors clearly mean to address the first issue in all three of their case studies, all of which focus upon the behaviour of musical performers. They want to extend an entrainment approach even to the behaviour of a single individual performing one rhythm. At least with respect to this first case study, they are almost by necessity forced to rely on the motor production model of Wing and Kristofferson (1973a,b) to describe a series of produced gestures. This is because model is simple and elegant and, moreover, it is the most influential and well-developed approach available. Nevertheless, it is essentially a *linear* model. However, entrainment is inherently a *nonlinear* process so it is not surprising that the authors find this model unsatisfying for their chronometric descriptions of single productions. But it is curious that in rejecting the simple single-level production model of Wing & Kristofferson, the authors seem to embrace multi-level version of it that implies a top-down (central clock) control of serial order grouping of behaviour. To be sure, musical performance does operate on different (nested) time levels, but the typically such a cognitive model carries with it baggage which, as Wing & Vorberg (1996) make clear, implies a central command or executive timer. Finally this sort of model seems at variance with basic entrainment assumptions. Entrainment approaches for the single performer case would probably emphasize, instead, an acquisition stage of behaviour and the development of different landscapes of attractors that would guide final productions. Thus, while linear motor models of Wing and his colleagues are elegant, in the long run, they may not suffice for explaining musical productions. In this regard, they are often contrasted with nonlinear motor models of Kelso (1995) and Turvey (e.g., Treffner & Turvey, 1993). These nonlinear approaches are admittedly less simple and therefore less popular than linear approaches, but in the long run, they may have more to offer researchers dealing with complex motor productions. This is important because the kinds of experimental operations and the particular data analyses suggested by linear models versus nonlinear ones differ. In the former, the acquisition stage and growth of attunement is not important; they rely on detrended production data and use variance and autocorrelations to describe codes associated with a central clock. However in some cases, these methods and measures obscure nonlinearities that are signatures of entrainment. For example, detrending removes drift, which, arguably, could reveal gravitation to an intrinsic frequency (favoured tempo). With nonlinear motor models, behaviour is assessed in terms of the persistence of induced periodicities, their stability and the degree to which a control variable can induce a re-organization of behaviour. To return to my original point, I think that even in cases where an individual produces a single rhythm, the authors should attempt greater consistency in applying the entrainment approach and seeking signature behaviours in order to discover if entrainment (i.e. nonlinear) models might offer the best path for understanding performance at this level or whether an executive command clock (linear) is better suited to description at this level.

The second issue that I raise is more speculative. It is most applicable to the authors’ third example, which involves interactions between two performers. In this case, it is easier (than in the first case) to find ways of identifying entrainments, as the authors correctly note. This is because here the behaviour of one performer can be temporally gauged relative to that of another performer (e.g., by observing changing phase relationships). Moreover, conceptually, this allows the authors to resume a somewhat detached (behaviourist?) stance vis à vis their data in that they do not need to appeal to central cognitive timers as a basis of control of productions (ala Wing & Kristofferson); one performer’s gestures essentially provide a basis for control of the other’s. Thus, the authors elegantly describe timing differences in terms of intermittent phase locking. Of course to verify this as true entrainment, ultimately intervention techniques are necessary; real experiments that systematically disturb the performance of one performer will allow researchers to assess and interpret entrainment properties that are associated with effects of specific perturbations on timing of the other performer. Nevertheless, at this stage of development such analyses are useful and provocative. They point to ways in which we can begin to examine and interpret certain entrainment parameters, such as coupling strength parameters. Indeed, they touch on this in their presentation. To go further however is ambitious in that it requires a more specific entrainment model with distinct coupling strength parameters. And it is in this regard that researchers will have to become more specific theoretically about just exactly what these parameters mean and precisely what will affect them. For example, do coupling strength parameters simply represent the quantifiable physical force with which one oscillating motor activity (the overt behaviour of driving performer) impacts another oscillating motor activity (the other, driven, performer)? Or is the coupling that determines intermittent synchronies more subtle? Is it possible that this situation stimulates entrainment of respective *attending* rhythms; these automatically determine anticipations of gestures (or future sounds) of the other performer that ultimately guide the interactive performance. In other words, is the real source of entrainment found not in overt gestures but amongst internal attending oscillations of performers and these in turn merely guide gestures? Of course, this is speculative, because we are now back to inferring an internal activity instead of concentrating on describing overt behaviour. But the internal activity in this case is nonlinear.

Some remarks on music as reorganized time

Frank Kouwenhoven
Chime Foundation,
Leiden, The Netherlands
Email:chime@wxs.nl

Measured music is a realm of ‘reorganized time’, but so is non-measured music. Both types of music display high temporal coherence, at least if they are studied as dynamic systems, not as static products. A brief glance at Chinese folk songs may serve to illustrate this. Just how many new hard core facts we will be able to unearth via ‘entrainment’ remains to be seen: if entrainment is the study of ‘reorganized time’, it is also, by definition, the domain of metaphysics – a realm where poets operate more successfully than most academics.

Clayton, Sager and Will are blithesome optimists. In their tough but impressive overview article, they express faith in the potential of ‘entrainment’, hinting that it may bring about ‘a significant shift in the focus of ethnomusicological enquiry’. Perhaps this is overstating the aim. Ethnomusicology, like other disciplines, has (for its own good) outgrown the stage of representing one field or one method of enquiry. But I agree that entrainment is well worth investigating. Even if it remains the domain of a passionate few – those with an open mind for the specialized tools and modes of thinking of biomusicology and music cognition – it could yield important new facts and insights.

In their article, the authors introduce entrainment almost as a kind of container notion, incorporating all or much of what we might possibly want it to be. In any case they make clear that entrainment is not one specific phenomenon: it refers to a great many related or unrelated events in very different contexts, from Huygens’ clocks to bio-rhythms, from calendar rituals (large time scale) to psycho-physical processes. By contrast, in the authors’ own case studies, their focus is noticeably narrowed down to what happens during milliseconds in the brain and in the motor system of the body, in the course of a mere snippet of music making. In brief, while the authors acknowledge that entrainment can be detected on all sorts of levels, their own primary concern is ‘micro’ events, which they feel have been neglected so far by most ethnomusicologists. In my view, studies of macro-events could equally well lead to interesting discoveries, if approached in the light of 'entrainment'.

If, as I believe, the ultimate foundations of music are biological as well as metaphysical – and if we accept the fearful call to arms to investigate this – the main challenge will be to develop methodologies that do not just yield loads of complex digital data. What we hope to detect is basic truths about different (micro *and* macro) levels of time organization in music. Below I would like to focus specifically on some questions about measured versus nonmeasured music, because Clayton, Sager and Will do not venture far out into this territory: measured music seems to be so much more persuasive, less 'dissident', more cooperative than nonmeasured music when subjected to structural analysis. But in the end this idea may simply be a fallacy. The study of nonmeasured music could bring equal rewards, if not bigger ones, and we can't do without it.

Measured versus nonmeasured

Fair enough: the notion of music as a 'synchronizing' force is powerful. Many of us would probably identify rhythm or 'swing' as the most luring asset of music, and might even describe it as one of those things that actually *make* us human. But is the capacity to entrain to an external timekeeper really the key defining point of music in human evolution, as Brown et al suggest (p.21)[8] ? Then how about the circumstance that some of the humblest forms of life demonstrate this same capacity (to entrain to an external timekeeper), as the chronobiological studies quoted on p.6 indicate? Should crickets and fireflies disturb us?

I can actually relate to this from personal experience. One day, in a park close to my hometown Leiden, I was humming a tune when I noticed that clouds of midgets in the air above my head started to 'dance' to my music. The insects moved in unison (in up- or downward direction) in response to the rhythmical sound signals they 'heard'. Presumably they reacted to air vibrations, but it was less obvious why or how all of them would respond to me – the external timekeeper – in synchronic fashion.

It is not my aim here to make musical claims about animals, least of all midgets. What intrigues me is the idea that we would be sharing the most powerful asset of music not with higher animals, but with some of the 'lower' forms of life.[9]

Björn Merker suggests (p.21) that 'synchronous chorusing' may have marked a key phase in the emergence of the human species (and, presumably, in the emergence of music). Does it automatically follow that nonmeasured music was a 'later' development, a 'spin-off', something that emerged at a time when music was being 'decontextualized', taken out of its context of dance, trance and communal movement? This is not necessarily Merker's view, but the question how measured and nonmeasured music relate – technically and historically – is important.

Simha Arom notes that we do not know of any human society that lacks music, or 'that does not express itself through dance' (Arom, 2000: 28). He adds that in Africa, nonmeasured music – music one cannot dance to – is not usually considered music at all, but is classified as a lamentation ('tears') or a type of signalling device. Clayton, Sager and Will are a bit like the Africans in not knowing entirely where to place nonmeasured music. They have not involved it in the three case studies presented towards the end of their article. They quote Jones and Boltz who apparently define nonmeasured ('unmetered') music as 'an event of relatively low temporal coherence' (p.18). That definition takes measured music as the yardstick, but in doing so, it seems to be missing the mark. Jones and Boltz' description is reminiscent of the term 'free rhythm', used mostly to refer to rhythms which are hardly free at all

I cannot think of the nonmeasured folk songs that Antoinet Schimmelpenninck and I collected in China as 'events of low temporal coherence'. Sure, if you look at the time ratios of subsequent pitches in a single performance, these evidently do not add up to a regular and repetitive pattern, as in measured music. But musicking is a dynamic system. The 'same' tune is never the same tune, and considerable variations occur in every new performance. Yet if you ask a Chinese singer to repeat a 'free-flowing' song *with the same words*, even after several months, the same or

[8] Page numbers refer to the text by Clayton, Sager and Will, unless otherwise stated.

[9] In our capacities to entrain we are apparently closer to insects and toads than to most of the higher forms of life. At the same time we losely attribute abilities to 'sing' to such 'higher' animals as birds, whales, and gibbons. The challenge is to investigate properties of sound communication on all possible levels and in all realms. The term 'song' may be anthropomorphic and tricky in this context, but I support the ethologist Frans de Waal's view that trying to get rid of anthropomorphism is not easy or risk-free either: 'By changing our language when we describe [the behaviour of] animals, we may also be concealing genuine similarities' (De Waal, 2001, 35, 40 ff).

a very similar organization of time may re-emerge in performance, except in those places where words in the text have been omitted or altered. (See fig.1).

The point is that it is not just proportional note lengths within any specific tune that matter. What matters, too, is consistency of relative note lengths of corresponding pitches in different performances of a song.

[FIGURE 1]

***Figure 1**. Four corresponding melodic excerpts from the 'Wu-a-hei-hei' tune from Luqu, Southern Jiangsu, performed by two different singers (A and B). The first three excerpts are sung to (roughly) the same text, the last one to a different text. Singers in the Luqu area use the 'Wu-a-hei-hei' tune to perform the bulk of their textual repertoire (hundreds of different lyrics); they hardly use any other tunes. Lines II and III (sung by singer B, with a time difference of sixteen months) suggest that singers adopt fixed individual patterns in the 'free' rhythmic and melodical rendering of specific texts.*

Music as reorganized time

To put it more plainly: if we think of music as a dynamic system, both measured and nonmeasured forms of music are events of *considerable* temporal coherence. The actual nature of this coherence may differ for different kinds of music, but we are invariably dealing with 'reorganized time'.

Joseph Brodsky applies the term 'reorganized time' to poetry and speech (Volkov, 1998: 40, 41, 149) and links it with metaphysical concerns. I have borrowed the term from him, and I gladly take the connection with metaphysics into the bargain. It should be worthwhile to dwell briefly on 'metaphysics'.

I have witnessed numerous Chinese folk song performances in which the lyrics sung were essentially meaningless. In these performances the whole act of singing seemed meaningless, *except* in its quality of 'organized time': a capacity of people to employ sound (i.e. voices) to revive bonds and fates shared beyond daily realities, in the realm of metaphysics.

Brodsky defines poetry – and basically all 'art' – as prayer, and stresses that a poet primarily works from the voice: 'For [a poet], content is not as important as is ordinarily believed. For him, there is almost no difference between phonetics and semantics' (Volkov, 1998: 92, 160). The statement reveals an important truth not just about poets but about singers (and speakers!) too.

Chinese folk singers often show little concern for any textual coherence or sense of direction. Yet their singing remains a firm profession of musical or personal faith. In the words of one particular singer: 'What I sing is not necessarily what you find in that booklet [i.e. the text]. What I sing comes from my own belly. '

In performance, 'reorganized time' is realized either as an expression of prayer or put into motion by the same mechanisms as prayer (excessive repetition, going through the motions, 'altered' voice, 'altered' state, etc.). This can be a highly emotionally charged activity, involving dance or trance, but it can also be practically void of emotional content, as in many folk song performances that I witnessed, which featured neither any physical movement nor any vivid facial expression. 'Still' and 'motionless' modes of performance are probably more in evidence in (some) nonmeasured repertoires than in most of the measured ones (which stimulate the motoric capacities of the body more easily).

Bearing all this in mind: how should we interpret the differences of musical process between measured and nonmeasured music ? What can we really hope to learn ?

The challenge of nonmeasured song

Both measured and nonmeasured musical forms evidently contain a great many elements of symmetry and periodization. Chinese folk songs are no exception to this. Even the most 'free-flowing' songs demonstrate an impressive degree of organization (read: repetition), at least if you take the trouble to study large enough quantities of same/similar materials to detect this. The idea that the process of entrainment in such songs takes place in terms of 'oscillators entraining independently to different levels of an auditory signal' (p.18) sounds either attractive and plausible, or unnecessarily reductionist and a bit contrived, depending on your specific academic background. I wonder if we will ever be able – neurologically or musically – to put our finger on such multilevel processes in satisfactory ways.

Yet if the question is whether measured and nonmeasured music constitute different planets, or only different sides of the same medal, the only way out is *through*: we must study entrainment *specifically* in nonmeasured repertoires, first and foremost in vocal repertoires, because it is here that language and music operate as primeval twin-brothers.

I tend to go along with Clayton, Sager and Will in thinking that time organization – perhaps more so than pitch organization, although this obviously plays a role, too, and merits separate discussion in the context of entrainment – can offer the key to many basic questions.

Pre-condition for the study of nonmeasured songs is that researchers screen sufficiently large quantities of (same or closely similar) materials, so that the process of music can be studied *in time*, not as a static product. Folk songs sung in monothematical areas (Schimmelpenninck, 1997: 225-227) seem to offer a near-ideal resource for this. May they become the ‘banana flies’ of ethnomusicology!

Nonlinear resonance: A musical universal?

Edward W. Large
Center for Complex Systems and Brain Sciences
Florida Atlantic University
Email:

Entrainment is one of several properties of nonlinear resonance that may be relevant to understanding musical rhythm. But do the principles of nonlinear resonance apply equally to the musical rhythms of all cultures? Ethnomusicology is uniquely suited to addressing this issue. If so, then nonlinear resonance may provide a universal grammar for musical rhythm, and this may be the most important insight to be gained from this line of research.

Nonlinear oscillation and nonlinear resonance are ubiquitous in nature; therefore they must be relevant to understanding musical rhythm, at least so goes the argument of the target article. After all, human motor rhythms behave as coupled nonlinear oscillators (Haken, Kelso, & Bunz, 1985), and nonlinear resonance is a general property of neural computation (Hoppensteadt & Izhikevich, 1997). It has further been proposed that human neural rhythms resonate with the rhythms of music, and that this phenomenon gives rise to the perception of meter in Western tonal music (Large & Kolen, 1994). However, the authors of the current target article take this reasoning a step farther, arguing that nonlinear resonance underlies musical rhythm *in all cultures*. The implication is that nonlinear resonance represents a substantive musical universal, a principle so fundamental as to apply equally to all music. Do the principles of nonlinear resonance provide a universal grammar for musical rhythm? If so, what are the implications of this claim?

The term universal grammar, borrowed from linguistics, is shorthand for the idea that there exists a set of general principles that underlie all human languages (Chomsky, 1980). The principles provide a set of innate constraints that define the set of possible human languages (Prince & Smolensky, 1997). These constraints further enable children to acquire linguistic competence from impoverished learning data (Jackendoff, 1997). Is it possible that nonlinear resonance provides a set of constraints that would constitute a universal grammar for musical rhythm? To answer this question, it is necessary to consider: 1) What constraints does nonlinear resonance put on musical rhythm?, and 2) How could a particular rhythmic “language” be learned?

Nonlinear resonance is often understood by asking how a nonlinear oscillator behaves when coupled to a periodic stimulus. Some stimulus frequencies will lead to resonance and entrainment, others will not. It is possible to create a bifurcation diagram that shows which frequency relationships lead to resonance (Figure 1). This is called an *Arnold tongues* diagram, due to the shape of the resonance regions. To generate this diagram, a nonlinear oscillator is driven with a stimulus rhythm. Stimulus frequency is held fixed, while the natural frequency of the driven oscillator is varied. As oscillator frequency approaches integer ratio relationships with the stimulus, the oscillator resonates to, and entrains with, the stimulus. When the frequency ratio is near 1:1, one cycle of the oscillator is observed for every cycle of the stimulus, but as the ratio approaches 4:5, for example, a new, polyrhythmic pattern emerges: four cycles of the oscillation for every five cycles of the stimulus. This analysis also applies to a network of oscillators whose frequencies span the range of musical rhythm (Large, 2000; Large & Kolen, 1994), as might exist in the central nervous system. The resonance regions describe which oscillators in this network will resonate to the stimulus rhythm.

[Figure 1]
Figure 1. An Arno’d tongues diagram. The frequency ratio (horizontal axis) is the ratio of the oscillator’s natural frequency to the stimulus frequency. The coupling strength (vertical axis) describes the amount of force the stimulus rhythm exerts on the oscillator. Dark regions represent parameter values that result in resonance and entrainment. There are an infinite number of resonance regions, one corresponding to each ratio

of relatively prime integers. For clarity, only a few regions are shown.

Nonlinear resonance entrainment opens up range of possibilities with respect to music. First, it would constrain the rhythmic structures observed in music. The analysis above predicts that, while an infinite number of frequency relationships are possible, some relationships are more stable than others, as illustrated by the width of the various resonance regions. More stable patterns are more likely to spontaneously emerge in the rhythmic styles of various cultures. Second, specific rhythmic “languages” can be learned. There is a simple learning procedure for networks of nonlinear oscillators (Hoppensteadt & Izhikevich, 1996). It predicts that as an individual hears a particular rhythm, the connection between the corresponding neural oscillations increases in strength. As a result, exposure to particular rhythms can reshape the resonance regions, changing stability relationships to reflect the rhythms of a particular style or culture.

Thus, nonlinear resonance is a good candidate for a universal grammar of musical rhythm. Furthermore, ethnomusicology is well equipped to address the musical universality of these principles. But what questions are the right ones to ask? It will be important to know which rhythmic frequencies are found in each musical example, in both absolute terms (tempo) and relative terms (frequency ratios), and how common these values are in the musical style under study. Furthermore, as described in the target article, it is important to understand the details of timing and phase relationships. Unfortunately, although the reasoning of the target article is based on nonlinear systems, the analytical methods described are mainly ones that make strong assumptions of linearity. Nonlinear systems have a range over which they behave more-or-less linearly, and often – in the lab – we study behavior in this range. However, for analyses of recordings collected in the field, this is an issue that needs to be approached with caution. For example, complex, nonlinear systems generate structure on multiple time scales, leading to fractal time series (Chen, Ding, & Kelso, 1997), so for example, detrending following by auto-correlation may not be the best analysis for such data. In addition, in studying synchronization, small departures from phase synchrony are responded to linearly, but as the departures become larger nonlinearities are significant (Repp, 2002). Moreover, as illustrated in Figure 1, at higher coupling strengths resonance regions overlap. When this happens the system behaves in a chaotic fashion. For these sorts of reasons, model-based analyses should be applied with care.

The rhythms of music are far more complex than rhythms that have been studied in physics and biology to date. Individual researchers will need to experiment somewhat with analytical techniques as the inquiry unfolds, but this is to be expected. Furthermore, entrainment is just one of several properties of nonlinear resonance that may be relevant to musical rhythm. Perhaps the most significant questions to be addressed are whether the principles of nonlinear resonance apply to the musical rhythms of all cultures, and how the rhythmic “languages” of various cultures differ from one another in this regard. With this in mind the research program proposed by the authors is likely to lead to significant discoveries, not only for ethnomusicology, but for psychology and neuroscience as well.

An Ethnographic Perspective of Musical Entrainment

Glaura Lucas
Universidade do Rio de Janeiro
Rio de Janeiro /Brazil
Email: glauralucas@hotmail.com

This commentary discusses the role of ethnography in the entrainment model presented by Clayton, Sager and Will, since it was less focused in the article, relatively to empirical analyses. Then, it presents a specific musical situation that happens in the Brazilian religious ritual of Congado, which is analysed by using the idea of entrainment at macro levels of social interactions.

Clayton, Sager and Will present ethnomusicologists with a new theoretical approach for the study of human cognitive processes behind musical performances. One of the advantages claimed by the authors regarding previous methods is the potential of the entrainment model to better integrate the study of physiological and psychological factors with cultural analyses. This is the focus of my commentary.

The article concentrates on the processes regarding endogenous rhythms at micro-levels of music making in such a way that the reference to cultural aspects is largely restricted to how humans’ innate potentials are specifically shaped through experience. Beyond this, it’s important to broaden the application of the concept of entrainment to larger socially relevant questions of ethnomusicological inquiry, those involving individual and collective motivations, worldviews, struggles and aspirations expressed through music making, which mix conscious and unconscious attitudes. Although entrainment is said to require the study of something that cannot be verbalised, the unconscious processes can be matched with peoples’ various concepts and meanings of music, and their own evaluations of their music making.

The case studies presented, for example, are interesting to reveal cultural particularities at an unconscious level. However, if a musical context presents a large range of variability in different performances, and if the participants perceive these variations as being equal, too precise measurements may not be culturally relevant at a conscious level. The authors do stress the importance of the integration of empirical and ethnographic research, but it is important to reinforce that ethnography must guide, for example, the choice of the musical recordings to be empirically analyzed and compared. Besides informing about the overall context, ethnographic data is important for statistical analysis in empirical research to tell us about issues such as: how long has the person (group) been playing? Under what conditions? Are they also moving about or dancing? Are they in transformed states of awareness (trance, drugs)? Do they regard these recordings as good performances? What are their judgments of correctness, similarity and difference (for example, are strokes 5 and 6 in case study 1A culturally perceived as different from the other long strokes?).

Shifting the focus to macro levels, I would like to present a particular musical/social situation, which involves the idea of entrainment, though my analysis relies solely on ethnographic data, that is, on participants’ accounts of their experience and on my observation. This situation reveals power relations between different musical groups through their conscious decisions and responses towards (somewhat) unconscious processes involving human endogenous rhythms.

These musical interactions happen during the *Congado* Festival, an Afro-Brazilian religious ritual rooted in colonial times, in which slaves reinterpreted Catholicism under the light of their worldview. Our Lady of the Rosary, Catholic saints and their own ancestors are worshipped in the rituals, where playing, singing and dancing constitute a single act of praying. Different kinds of groups celebrate the rosary of Mary, each with its own costumes, having different functional, musical and choreographic characteristics. Among them are the *Congos*, *Marujos*, *Mozambiques*, *Candombes* and *Caboclos*.

Music is non-stop throughout the four days of the rituals. Each group is defined by its own rhythmic patterns, which are performed in the percussion instruments along with call-and-response songs, and specific choreographies. The rhythmic performances are developed through the periodic repetition of patterns organized according to an explicit reference pulse, which is readily expressed by the participants’ bodies. This basic body movement generates more complex choreographies.

Each Congado community promotes its own Festival, in which other invited communities participate, gathering from ten to twenty different groups in a same ceremony during its most public days. Within the community’s areas and along the streets, these groups perform different songs simultaneously, making an effort not to play and move about at the same tempo. This becomes more evident when two groups meet and perform a greeting ritual, one standing in front of the other. A lady carrying the group’s guiding flag comes to the front of her group. Right behind her, one or two drummers stand on each side and the captains – the leaders – in the centre. Each group is carrying out its obligation. For example, one may be singing to ask permission to enter the other’s territory and take part in the feast, whereas the other is saluting the visitors with a welcome song. The captains, while singing their songs simultaneously, are also performing a specific gesture of salutation. Meanwhile, the ladies exchange their flags, turn around facing their group and pass the other group’s flag over the head of each participant of her own group (which may have from around twenty to seventy people), and then, exchange their flags again. The drummers of each group, therefore, will be facing the other group’s drummers during the time needed for this greeting ritual to take place, which demands a great self-control so as not to synchronise their tempi.

This specific musical situation presents the two basic conditions for the occurrence of entrainment: a) there must be two or more autonomous rhythmic processes or oscillators (the groups’ performances); b) the oscillators must interact. The tendency for musical synchronisation is recognised by the participants. They prepare themselves spiritually for these encounters, since the musical/choreographical unity, tightly linking the group's members in space and in time, is a sign of spiritual strength.

The participants, thus, have to develop a very particular musical skill to be prepared for these meetings. On one hand, a drummer has to keep the musical flow of his own group, by entraining himself with the other participants, players and singers, according to a desired, culturally defined, degree of synchronicity. On the other hand, he has to resist and avoid entrainment with the other group's music, which becomes a complex task, especially if the groups happen to be playing patterns with close periodicities (tempi), since there is a tendency towards synchronisation.

The congadeiros are aware of this difficulty and describe it in their own terms, as can be seen in the following accounts: "You cannot look at what the other is doing, you have to look at what you're doing, what you have to do. Each one is carrying out his obligation. Only rarely will one's strokes match the other's. My rhythm is my rhythm, your rhythm is your rhythm. You can be playing a *Dobrado* [Congo pattern], and I can be playing my *Dobrado* too, but my strokes won't meet your strokes, they won't coincide exactly."(Congo captain Jose Apolinario, in: Lucas 2002, p. 73, my translation)

"These are the moments we need more strength and firmness, we have to be very careful and only look at the skin of our drum."(Mozambique drummer Geraldo da Luz, ibid.)

And Congo captain Mario da Luz, explains why this is ritually necessary: "If they both play the same way, it becomes a same meaning."(ibid.)

Besides the different ritual functions determined for each kind of group by the legend that structures the ceremonies, host and visiting groups also have distinct obligations to fulfil, accounting for some of the necessary differences in their music making, so as not to become 'a same meaning'. These particular meanings are expressed through different songs and rhythmic behaviour as well as through distinctive paces imposed to the groups' performances.

Thus, music involves each group in a particular sonorous aura, co-ordinating its participants' acts, pulse being a cohesion element of intra-group identity[10]. However, tempo also becomes an individuation process, through which the various communities, though united as beads in the chains of the rosary by a common faith and similar social conflicts, also express their idiosyncrasies, once they carry specific histories and are guided, each one, by their own group of ancestors. In this context, the tendency for entrainment is taken as a means for power demonstration and negotiation during performance, similar to processes that happen through other means of expression, which dynamically revive and recreate the philosophical, cognitive and aesthetic knowledge of the *Congado* universe. As Pereira and Gomes put it: "knowledge is understood by the community as a common patrimony that emerges from the conflict and interaction between its several individuals." (2003: 18, my translation)

In this case, the concept of entrainment offers theoretical background for analysis. However, I do not find it necessary to check entrainment through empirical measurements (if entrainment really takes place, in what circumstances, who entrains who, with what degree of symmetry etc.) to understand the social processes involved in these musical interactions. The participants' conscious reactions demonstrated by their musical and bodily responses as well as through their verbal expressions tell us that the desired state of synchronisation is to be entrained within their own group, keeping its musical, bodily, spiritual and functional unity, and avoid entrainment with the others.

Intellectual Entrainment and Openness toward Subjectivity

Marin Marian-Balasa
Runanian Society for Ethnomusicology
Bukarest, Rumania
Email:mmbalasa@yahoo.com

This response stresses the necessity for a conceptual expansion of the entrainment theory. Means for approaching with "objectivity" the so numerous

[10] A positive state that can be due to entrainment, which has been highlighted by many researchers, as can be seen in Lomax's and Blacking's statements cited by Clayton, Sager and Will: 23-24.

subjective aspects of culture-making and performing should be developed within the framework of the same concept and methodology. Examples from India (spanda theory and mantra yoga) and Romania (lullaby rhythms and breathing rhythm of sleeping body) are evoked in order to support the development and openness/expansion of the theory of entrainment.

Entrainment is a process-phenomenon of universal occurrence, covering maybe just a small portion of the complexity of the fact that, in the living universe, everything is influenced by everything. Buddhism and ecology are very familiar with this basic truth, and it is nice that ethnomusicology, finally, joins in a scholarly manner the club of most thriving yet unresearched wisdom. My only hope is that, in quest for its own definition, distribution, generalization and application, this concept will neither forget about its main purpose nor end up by becoming self-sufficient; my hope is that it will remain instrumental in deciphering the real body and function of music, which is less rational and was metaphorically called *charm*. What is the benefit of calling this now compromising forwards. In the following I will argue for the semantic expansion and opening of the entrainment concept.

At first sight, the material brought to our attention seems to deliver too much ado about one single concept: extensive technical turns and collections of pretentious data, for the benefit of popularizing a common fact and word. This impression is given by the fact that many common and known aspects are evoked or reconfirmed, and the question “what’s new beyond presenting known things anew, beyond presenting a technical language just to discuss handy observations!?” sometimes arises. My point is, that if one goes further than what the authors are specifically saying, it becomes clear that “entrainment” can open up larger understandings. However, for the time being there is no clear border between prolegomenon and conclusion, means and result, discourse and demonstration, empiric and logic, factual analysis and theoretic construction, elementary observation and visionary invention. Perhaps, some of these are intellectual values that do not enter the authors’ intentional focus; yet, in post-modern times one can hardly conceive of dismissing them.

From stricto sensu to lato sensu

As the target article shows, there are rhythms, oscillations, movements, which influence human rhythms, periodicities, vibrations, movements, states of mind. What about the other way round? There are so many mythologies and religions erected on the trust that humans can influence the nature’s (gods’?) elements, rhythms, consciousness, processes, actions. Are these just mindless superstitions and irrelevant representations? Does the highly positivistic, reductive, almost materialistic (in Marxist terms) approach or science forwarded as cognitive musicology have anything to say about such things? It is true that this type of cognoscibility focuses on physiology, neurology, experimental psychology and behaviour, but I do not think that entrainment/attunement is just unilateral, coming from outside and influencing the physical human body. Rhythms made by people should induce entrainment within them, as well as in the surrounding sensitive world. This surely happens, no doubt, and the continuation of the essay we discuss here will perhaps internalize such aspects too. What I want to add is that the entire body of knowledge labelled “spiritual-oriented” is unjustly ignored, or willingly left aside, although its integration and reformulation could do a great deal of good for this entrainment theory. Perhaps not for its “strict” version, because what we are offered here is of that scientific quality or ideology which, apart from benefits for specialization, means selective discriminations, elimination of elements unsuitable for a handy approach, divorcing objects from whatever they can touch or have from the realm of imagination, irrationality, metaphor, poetic vision, and sacred experience. All such things, heavy weights of any cultural construction and experience, can neither be reduced to neuronal tickings nor churned and evaluated by computers; and I am afraid that entrainment, a wonderful concept and reality, works also within such “impalpable” realms, perhaps with similar virtuosity and relevance.

Indeed, “rhythmical entrainment” and its physicality are not everything. The biophysicism of rhythmical entrainment leads to the attuning of other psychological realms, to the transformation of persons’ state of mind, which is also a form of periodicity. By disconnecting the mind from its ordinary cycles (regularities or irregularities), inner oscillators and oscillations set up an affected perception, sensitivity or emotional availability. This is how – in an “extended” version of the theory of entrainment – the contextual variety of music’s effects can be understood or explained.

On the other hand, repetition acts like an oscillator, like a source for entrainment;

how this (generalized) entrainment will be perceived, what mental shapes and linguistic expressions it will take, is a matter of cultural experience, norm, and tradition. Yet, computers and calculation have no cultural openness, thus they will say nothing about what’s really important to humans.

Such types of rationale make me think that technological equipment, mathematical proficiency, neurological experience, and reproducible experiments, cannot suffice to explain culture; and that ethnomusicology, as any other anthropologic-humanistic knowledge, is possible, though emasculated, if conceived only within the frames of exact sciences. In this field, intuition and theoretical creativity are valid elements of appropriate knowledge because of the simple fact that they can resound (i.e., entrain) with the imagination, intuition, inventiveness or creativity that generated that object. Interdisciplinarity or multidisciplinarity without equal right to philosophy is just hypocrisy. A full acceptance and application of the concept of entrainment leads to acceptance and application of all possible idea-facts that “validate” the subtle, apparently immaterial manifestation of life, expressive culture, beliefs or faith. Objective analysis of phenomena does not mean ignoring subjectivity, but incorporating it into its sphere of interests and competence.

Mirror bits from India

I think that a useful addition to what is offered by the target article can be found in the Indian metaphysical theory of *spanda*. This is a crucial concept in Shivaism, especially in the highly esoteric, tantric Kashmirian Shivaism, which postulates that *spanda* (from “dynamism of the Absolute Consciousness” up to worldly “vibration”) is the first and ultimate element in the entire universe. Moreover, *spanda* is the only common element for all worlds, the spiritual one included.[11] Further, many oriental philosophies envisioned the ultimate reality as sonic. From such metaphysical/ontological consideration, some elaborated different sorts of “sonic mysticisms”, which were not far from technicistic yoga schools that elaborated strategies for modifying physiologies and mental states by the means of mentally (inaudibly) induced oscillations, as well as by the means of slowing down and diminishing the number of naturally existing internal oscillators and oscillations.poetical term in a *scientific* manner “entrainment”? An answer to this could be, I think, the real and ultimate contribution, if made convincingly, that the scholarly proposition of our three colleagues

Although Berendt’s bestseller (1990) might not be considered an ultimately academic-scholarly book, his idea of taking into account also the “static rhythms” and their entrainment is irrepressibly logical!... In fact, all aesthetics—both analytical and speculative—that focus on rhythms took, with great and delightful intellectual results, also the numerical ratios as factors that alter and govern the vast territories of subconsciousness. In the end, however, music should not be limited to what acoustics and computer can provide in terms of frequencies and milliseconds, because *music is equally the culture generated around it*. Consequently, under such a broader perspective, scholarly research will surely arrive at demonstrating that faiths related to sonic or inaudible vibrations are equally capable of generating different brain waves, mental states, and sensitivities.

According to the most popular layers of Shivaism, the universe itself was made, and is constantly maintained, destroyed and recreated, by entrainment to the dance of Shiva (Nataraj). Consequently, the worldly realm and consciousness is the “dream” or the narcosis of this entrainment to that “dance” of the Absolute Consciousness. In India both popular religions and minor cults have each developed their different, yet essentially identical forms of practicing *mantra yoga*. This practice is a way of using continuous rhythmical vowels or words for tuning, synchronizing and linking individuals to “gods” or superior layers of consciousness, for setting the human experience and existence on the same frequencies which supposedly belong to other forms of existence. Like prayers, chanting/reciting mantras leads to the alteration of the sense of time *and* space. Such practices – nothing but performed chronometrical processes, forms of consciously induced entrainment – belong to philosophies, sciences, techniques, ideologies that used entrainment since millennia and exploited it up to ultimate meanings and possibilities. Out of the reality of entrainment, thus, Oriental thinking has made history (be it religious and cultural).[12]

---

[11] For this see: (translation of a fundamental Sanskrit text) Singh 1980. Alternatively, for a Western-style approach, see Dyczkowski 1989.

[12] In this respect, Alper’s (1991) collection of essays written by Western scholars, as well as Beck 1995, are excellent references for positivists and sceptics.

So, the issue of entrainment is basic to many ancient and contemporary Oriental schools of thought, and basic to both old and recent spiritual/religious practices. Unfortunately, Westerners have started to talk about entrainment as of the 17th century, and the trio of our contemporary colleagues decided to take the task of re-popularizing it. Yet, as suggested, a deserving conceptual expansion is necessary.

Mirror bits from Romania

Traian Mîrza (1923-1985), my ethnomusicology professor, used to say that the iambic formula, which he assumed to characterize most of Romanian lullabies, was the rhythm of the sleeping body. Mothers, he said, succeeded in putting their children to sleep particularly because the lullabies were set in this rhythm. Yet, the entire significant Romanian literature mentioning the rhythm of lullabies showed that they were mostly built on both iambic *and* trochaic formulas. On the other hand, however, ethnomusicologists failed to connect those musical patterns to the breathing rhythm during sleep. It would be interesting if someone were to demonstrate that indeed the successions of iambic and trochaic rhythms in lullabies entrains a child's body, leading to a change of bodily state, to sleep.

Trance, ecstasy, mental states for which, as G. Rouget (1984) had clearly demonstrated, there is no unique, unequivocal, universally valid element to be called responsible for causing/inducing them. Everything is a matter of cultural conditioning and there is no specific rhythm, timbre, melody, or noise leading to identical results in different cultures. Yet, with the iambic and trochaic rhythms of Romanian lullabies it might be different – as long as one could demonstrate that babies do breath with a short-long-short-long (quaver-crotchet-quaver-crotchet) pattern, and that the observation of physiological phenomenon had helped the plain folks to conceive of a pragmatically functional musical genre in accordance with it. Yet, people breath not only in iambic pace (short-long); both during sleep and awake states, perhaps/sometimes alternatively, some breath in a trochaic (long-short), some in a pyrrhic (long-long) pace.

"In lullaby, the rhythm has the role of a decisive element within the process of making the baby fall asleep, whether it is accompanied or not by rocking" (Sulițeanu 1986: 104). Rocking might support the pyrrhic rhythm. Yet, Sulițeanu noticed that "the rocking movement is rarely uniform" (ibid.: 13), thus it could equally support other rhythmic cells and contribute to the creation of polyrhythmic textures. If the late T. Mîrza noticed only the iambi, Sulițeanu specified that in lullabies the most frequent rhythmical cells are iambi (the iambus often becomes quaver + dotted crotchet), followed by pyrrhic and trochaic cells. All of them are grouped by Sulițeanu under the psycho-physiological category of *timpul ritmic primar* (the primary rhythmical pulse/beat). In fact, the value or importance of the "primary rhythmic pulse" was a key concept elaborated by Sulițeanu, which she linked to kinesthetics (Sulițeanu 1972, 1978). She also saw in kinesthetics a source for many intonational, i.e. melodic, elements.[13]

A very interesting aspect of lullabies is also that, in the course of singing, a mother gets to arrest and entrains herself, somehow forgetting that her singing was addressed to the baby. Perhaps the baby fell asleep already, perhaps the mother became aware of the fact that her lyrics had little importance, thus she turns her child-oriented song and singing into an adult-oriented, very personal song and singing. Mothers often slide into improvising new lyrics and tunes, in which they refer to their private life, their pains, worries, fears, or happiness. This is the reason why some lullabies end up by being ballads, songs proper, and laments. Should one not speak, in such cases, of the endorphic/narcotic effect of entraining oneself?

Although the authors of the target article go only for the path of objectively deciphering what is objective, I hope they will also arrive at objectively deciphering the subjectivity. Ultimately, I wonder whether the thesis of the subjective basis of objectivity can be rejected or confirmed through their type of performed cognition.shaman's journey, can equally be analyzed as induced extreme

Cognitive vs. physical entrainment

Jonathan G. Secora Pearl
University of California, Santa Barbara
and Masaryk University, Brno, Czech Republic
Email: jpearl@umail.ucsb.edu

[13] "This specific intonation seems to be indistinctly depending on the occasion of putting a baby to sleep, and it is actualized only during this action. It is the expression of a primary, vital impulse, which I called kinesthetic - interoceptive, an impulse of a body nature in an obvious psychophysiological extemporization" (Sulițeanu 1986: 12).

The case of Christiaan Huygens' observation of the "sympathy of the clocks" serves as a useful metaphor for distinguishing two separate though related aspects of entrainment. *Physical entrainment* refers to the synchronization of concrete objects in the world, determined by some objective measure. *Cognitive entrainment* refers to the appearance of synchronization as determined by the subjective measure of an observer or participant. It is argued that the separation of these two aspects is crucial for any discussion of the human experience of musical entrainment.

This article is a welcome contribution to the efforts to reconcile science with humanistic enterprises, especially ethnography. The authors do an admirable job of setting the two on equal footing, each contributing to the strength of the other. I wish to point out one major theoretical issue that has been raised by this article which over time will require further clarification.

First and foremost is the matter of defining *entrainment*. The implicit but tacit attitude of the authors is that entrainment refers to synchronization which is observable, either by an outsider or by a participant. I would argue that the concept of entrainment as presented in this article refers however to at least two independent processes, and that their distinction is crucial to any discussion of human cognition in this context. Difficulties arise when we attempt to reconcile the feeling of synchrony (which I propose be called *cognitive entrainment*) with the separate though related process of *physical entrainment*. Physical entrainment refers to the synchronization between concrete oscillators in the world, of the sort described by Huygens in observation of his pendulum clocks. Interestingly, the case of Huygens presents us with both varieties of entrainment, that obtaining between the clocks, and the observation itself. So far as we know, there was no objective measure involved in Huygens' determination, but rather it was the subjective measure of his perception.

Synchronization can be defined in terms of *its appearance* to an observer, or in terms of *absolute physical measures*. In many cases, these two will coincide, but it is yet to be determined how closely linked they are. Any objective measure is in a sense arbitrary, unless defined in terms of specific empirical criteria. Even so, we are not assured that a human observer's experience at any given time will correspond with this objective measure. It is possible that a sense of synchrony may vary in ways that appear disjunct by physically absolute terms. We must be open to the possibility that a perception of synchronization may occur when events in the world are not strictly speaking synchronized, and conceivably, that a percept of asynchrony might correspond to events in the world which by some objective measure are nonetheless synchronized. Even where our perceptions correspond with states in the world, it is necessary for us to recognize that these are separate processes.

What appears to be uniquely human is our capacity to wilfully imitate, repeat, and manipulate rhythms that we experience. But precise periodicities are almost non-existent in the natural world. Our task therefore is not so much to explain a capacity to precisely match periodic events, as the ability to approximate them in performance and perception. This however produces some difficulties for theory and analysis. Approximations are far more difficult to determine objectively than would be periodicities; yet it is this sort of noisy phenomena that we most commonly observe when dealing with musical entrainment, and which we must determinedly attempt to explain. Without empirical data to sustain a single measure for both physical and cognitive entrainment, it was best to consider them two independent features of the same event. This is crucial to understanding the variety of experience in the world, in particular those aspects which the authors rightly point out as culturally-dependent. Otherwise, our definitions may lean too heavily towards finding a least common denominator or towards considering averaged human capacities (such as least noticeable difference) without regard to actual experience, thereby defeating the goal of uncovering and explaining individual and cultural variance, an inherent aim of ethnography.

Conceivably, we might uncover neurological timekeepers that could be viewed in terms of what I have called physical entrainment. However, it is important to recognize that even when we take recourse to such physiological explanations, as for instance the timing of electro-chemical processes in neurons, the qualitative experience of a listener or performer is not necessarily the same thing as the physiological processes that take place in their brains and bodies. The authors themselves make note of the 30 millisecond constraint for determining the order of events, yet they observe that skilled performers can at times overcome these constraints through a process of anticipation through learning. The wilful intentions of the participants permit them to supersede the erstwhile limitations of biology. That is to say, the mind may be more than the sum of the brain’s physical parts. If we are dealing primarily with the appearance of synchrony, then we must recognize that the studies are still forthcoming which would allow us to directly correlate neurological events with the qualia of subjective experience.

The feeling of synchronization is the crucial element in the performance of and attending to music. The degree of actual synchronization varies not only by the limitations of physiology, but in other as yet to be determined ways, which analyses such as that presented by the authors can go a long way to uncovering. This is significant, because it necessarily adds an additional layer to any precise definition of entrainment in cognitive terms. I would propose therefore, as a supplemental definition, that *cognitive entrainment is the process whereby an individual comes to sense a certain degree of synchronization between two or more rhythmic processes in the world.*

We begin to see why there has been a sometime gap between the aims of physicists and those of ethnographers. Ethnographers often point out the feeling of what happens, regardless of the actual state of affairs; scientists are often interested in the state of affairs, without regard to how they are perceived. It is the role of cognitive science to reconcile these two domains, to make sense of our perceptions in terms of their relationship to the physical world. This is the mind-brain problem writ large.

Socio-cultural Interpretation of the Case Studies/ The Concept of Entrainment Applied to Western Music Cultures

Britta Sweers
Institut für Musikwissenschaft und Musikpädagogik
Hochschule für Musik und Theater Rostock
Rostock, Germany
Email: B.Sweers@t-online.de

The commentary discusses two different issues: 1) regarding the case studies it is suggested to add a socio-cultural interpretation of the cognitive findings and psychoacoustic visualizations; 2) it is argued in an additional commentary that the concept of entrainment could bridge the gap between ethnomusicology and historical musicology, because the aspects mentioned in the article are valid for western music cultures as well. This assumption is elaborated with examples from the Early Music and New Music directions.

Socio-cultural Interpretation of the Case Studies

Regarding the way of proceeding in the case studies (chapter 7), there is one aspect which could be further elaborated. On page 26, the authors argue that musical, cognitive, and cultural theory belong together. It has been remarked from other sides as well that socio-cultural observations are still too rarely verified by natural scientific methods within ethnomusicology (e.g., from psychoacoustics), despite Helmholtz's early efforts (see also Franz Födermayer's keynote lecture in Gablitz/Vienna 2003). Against this background, it is more than reasonable to set the case studies' focus on the chronometric data analyses. However, although it is hereby demonstrated how processes that cannot be verbalized are made visible, I now miss a larger socio-cultural interpretation that bridges these two different areas--particularly as this article presents a model to stimulate further research. I think it would make the article stronger if it could be outlined how to proceed further--even though these case studies were undertaken without ethnographic data. For example, looking at case study 1A (Kpegisu (Ewe war drum) songs): how would this example--as a next step--be interpreted in a cultural context? What does the obtained data material (e.g. that the Kpegisu play a highly complex bell pattern) tell us about the culture/people investigated? Or rather, to take up the questions you posed at the beginning (page 26): "What is special about musical entrainment" (in the cultures of your chosen examples) and "How do processes between musical traditions and contexts vary" (between these cultures)?

The concept of entrainment applied to western music cultures

The concept of entrainment could open up many interesting research areas within the study of western classical music. On page 20 "verbal and non-verbal communication between two human individuals" and "metre and metrical perception" are determined as two central aspects of entrainment studies--issues that are likewise essential to western music. Already John Blacking used ethnomusicological perspectives to reflect on western classical music in *How Musical is Man?* Interestingly enough, his chosen examples (1976:110) seem to resonate with the concept of entrainment--which hence might be an important means to bridge the gap between ethnomusicology and historical musicology.

The field of Early Music performance practice serves as a good illustration for this assumption--particularly with regard to the aspect of "metre and metrical perception." Apparently, the knowledge of the rhythmic-metric (and tempo) scheme that forms the basis of western notated music is a major key to the musical feeling of earlier epochs--and to the modern performer-audience interaction, i.e. entrainment. The importance of metric feeling becomes particularly evident when the knowledge of how to find these emphases in notated music is missing (with regard to historical material, this knowledge can only be obtained by additional sources).

One student happened to play me her guitar exam program, which included a fantasy by the English composer John Dowland (1562-1626)--that was characterized by long, floating lines of sixteenth notes. She tried to play these sixteenth lines expressively, yet the impression was unbalanced and abstract. As she admitted afterwards, she had never found a real emotional access to the piece--very much in contrast to the rhythmically more complex and lively works of the Brasilian composer Villa-Lobos where the right emphases seem to be immediately obvious. I suggested that she should try to think of the *tactus*, a metric concept underlying any piece of the sixteenth to the eighteenth century (nearly any sixteenth century theory discussed this concept in length). The concept of *tactus* emerged during the fifteenth century, being defined as the unit of the up- and downbeat pattern (indicated by hand or foot movements and oriented on the human heart beat) that determined the nature of the metric pulse. Metric prescriptions like "2/3" or "3/4" actually conveyed a code of emphasized and less important beats, and the bar-line that emerged around 1600 was initially just meant as an indication of regular emphases within the time-flow. Therefore, already by emphasizing the first beat of each bar a bit stronger, it seemed that the Dowland fantasy--oriented on contemporary dance music anyway--"fell into place" and started to be filled with emotional life as well. We still do not know if this piece really sounded like that--but, as it hence seems, entraining with this inner metric pulsation is a key allowing us to lock into and comprehend this music.

There is also a strong biological component in early music perception. Those familiar with seventeenth century music theory (like Johann Joachim Quantz's *Versuch einer Anweisung, die Flöte traversiere zu spielen* from 1752) might recall that the beat was actually measured on the human pulse (Quantz gives clear references to the state in which the pulse should be taken--ideally from a choleric-sanguine person after the early evening meal). It thus becomes apparent that human body resonance (and, in a larger sense, entrainment) has been an important issue for western music for a long time. With regard to our twenty-first century, there has been much theoretical discussion about the various concepts and the right tempo; however, this knowledge is still too rarely put into practice again.

Blacking did not use the same terminology, but seemed to have developed similar thoughts when speaking of a "deep feeling" that is essential for cross-cultural music understanding, e.g., by slowing down the breath. This also includes western classical music: "A similar control of the body makes it easier to catch the *innigster empfindung* of Beethoven's Piano Sonata, Op. 109, last movement. Just breathe slowly, relax the body completely and play--and the *empfindung* comes through the body..." (1976:110) As he continues, "[s]ince this experience might often begin as a rhythmical stirring of the body, it may be possible for a performer to recapture the right feeling by finding the right movement." Blacking's body resonance goes beyond mere rhythmic feeling when suggesting to find a hand position similar to Debussy's while playing the Impressionist's music.

We can even go further: The concept of entrainment could well explain why listeners often have problems with compositions of the so-called New Music direction. On page 18, musics with so-called free rhythms are mentioned. Listeners can still find access, as they "might entrain to what s/he perceives as the 'centred' or meridian period length." Many modern compositions lack this component; the absence of rhythmic-metric "anchors" could hence be a reason why modern concepts like that of Pierre Boulez's serial music had to fail, as they do not allow the listener to entrain with the music. Good counterexamples are the works of the Hungarian composer György Ligeti, who, in pieces like *Lontano* (1967) still kept a (nevertheless distorted) inner pulse that allows the listener to entrain with the music.

In summary, all these examples would benefit from research addressing the process of entrainment, and ethnomusicology, performance-oriented anyway, could add further important knowledge from cross-cultural studies.

Analysing coordination in Western Art Music: Lessons for Ethnomusicology?

W. Luke Windsor
School of Music and
Interdisciplinary Centre for Scientific Research in Music (ICSRiM),
University of Leeds, UK
Email: w.l.windsor@leeds.ac.uk

This paper engages with the concept of entrainment behaviour in musical contexts in relation to existing work on synchronisation, coordination and control of timed behaviour, especially in the context of non-stationary time-series, and through specific reference to research on timing and motor control in the solo and ensemble performance of music in the Western concert music tradition. It is argued that ethnomusicologists may benefit from the methods and findings in this domain, despite obvious limits on generalisation.

Empirical studies of Western Art Music tradition often take as their starting point the measurement, analysis and modelling of the timing of soloists' performances. Indeed, the vast majority of such studies are limited to the study of a single instrument, the piano. Nonetheless, I will argue in this paper that there may be existing studies of both coordinated and solo timing in the literature on musical and sporting performance which may be relevant to ethnomusicological studies of entrainment (Clayton, Sager and Will, 2003).

Only a small number of studies have attempted to analyze coordinated timing in Western Art Music (e.g. Shaffer, 1984, Rasch, 1988; Appleton, Windsor and Clarke, 1997), with some studying the kinds of rehearsal or communication strategies used to achieve coordination (e.g. Goodman, 2002; Williamon and Davidson, 2002). These may provide some starting points for further research, and the more general literature on synchronization and coordination of action (much of which is extremely lucidly reviewed by Clayton *et al*, 2003) may indeed also be applicable (such as Wing, Allison, Cooper and Thompson, 1992; Wing and Woodburn, 1995). However, many empirical studies of timing in Western Art Music have now shown that the perception and production of expressive timing are both systematically related to the kinds of features identified by music-theorists as being of potential structural importance. Such studies (see e.g. Clarke, 1988; Repp, 1992a; Palmer, 1989; 1997; Repp, 1998; Clarke, 1999; Gabrielsson, 1999) have argued that the location and extent of deviations from metronomic performance can be predicted from analyses of phrase structure, metrical structure and voice prominence. Hence, according to Shaffer (1984) and Appleton, Windsor and Clarke (1997), the remarkable ability of musicians to minimize asynchrony in Western Art Music performance is not primarily to do with skill in synchronization *per se*. Rather, it is to do with musicians sharing a similar mental representation of the structure of the music that they are playing, Such a shared representation, tied as it is to the motor programme which organizes their actions, allows for mutual prediction of when and to what extent the tempo should be modified. That such 'expectations' have perceptual and motor consequences has been experimentally demonstrated by Repp (e.g. 1992b; 1999b): subjects find it hard to perceive deviations from metronomic performance which occur in positions that one might expect them in in an expressive performance, and their synchronization behaviour to such performances also reflects this bias.

It may be that when we attempt to coordinate to an expressively modulated time-series, we are not necessarily engaged in tracking or coupling so much as predicting where the next to be synchronized event will likely be. Clearly, feedback is important to regularly correct for drift and to ensure simultaneous initiation of the performance, but it is by no means clear that continuous online tracking is necessary. It may be that performers in an ensemble play from internally generated motor programmes (which must of course co-develop in rehearsal, see Goodman, 2002) which are similar enough to enable an extremely economical process of coordination in which once the start-rate is set the modulation of the rate-parameter is generated individually, with only periodic error-correction. It is also pertinent at this point to distinguish between synchronization to a fixed series of events, and coordination between two theoretically independent agents. Appleton, Windsor and Clarke (1997) found that their duet performers achieved greater synchrony coordinating with a live performer than with the same performance as a recording, whether or not they had visual contact with the co-performer in the former condition. Although this requires further study, one might speculate that despite the added complexity of the former condition, better synchrony is achieved because there are two performers taking care of error correction, increasing the (shared) resources available to deal with drift.

If there are indeed two mechanisms generating timing in music, one a motor programme which specifies the variation of a rate parameter, and the other a serial timer which controls the sequence of timed actions (Shaffer, 1984; Shaffer, Clarke and Todd, 1985; Clarke, 1987; Vorberg and Wing, 1996); then it is more than possible that such a division may be reflected in perceptual or active tracking of expressive timing. Shaffer (1984) has argued that synchronization in expert performance is not achieved by coordinating actions at the level of individual events or even the lowest level of nominal isochrony (beat) or tactus, but at the level of the bar. His data certainly suggests that timing control is most clearly observable at these intermediate structural levels. Moreover, it appears that the hierarchical level at which performers achieve coordination (as well as the extent of their expressive timing, and the degree of asynchrony) can be experimentally manipulated by varying the degree to which players are able to perceive visual information about each other: where visual feedback was unavailable the players in a study of piano duet performance were not only less expressive, and less closely synchronized, but also it was found that asynchrony was minimized at the bar level, rather than the beat level (Appleton, Windsor and Clarke, 1997).

Such studies of musical co-ordination also raise some issues about different kinds of relationships between members in an ensemble, or between ensemble and conductor: just as there may be a hierarchy of roles in a boat which are reflected in timing dependencies (Wing, Allison, Cooper and Thompson, 1992; but also see Wing and Woodburn, 1995), these may also exist in musical situations. One might speculate that cox and stroke fulfil roles similar to section leaders and/or conductors, and that such roles are of greater importance at periods of temporal uncertainty, but with much coordination in Western Art Music actually being afforded by the predictability of expressive timing given a known and agreed structure. In Western Art Music performance there is some debate regarding the importance of visual information for coordination. It may be that the body movements of performers have predictable relationships with tempo and/or musical structure (see e.g. Clarke and Davidson, 1998; Windsor, Ng, Davidson and Utley, 2003), allowing for simple visual monitoring of coordination, or that a range of more deliberate and discrete cues located at salient moments (see Williamon and Davidson, 2002) help facilitate coordinated timing.

A word of caution is warranted here before concluding: autocorrelation analysis and summed variances are used to attempt to identify different processes of timing control in Clayton *et al* (2003). Such techniques, as they note, originate in the analysis of rhythmic tapping (see e.g., Wing and Kristoffersen, 1973a and b; Vorberg and Hambuch, 1978; Vorberg and Wing, 1996). They are heavily reliant on the analysis of a temporally stationary time series of intervals (see Vorberg and Wing, 1996: 197-198). Indeed, Shaffer's significant attempt to apply timing control analysis to naturalistic musical performances which are non-stationary in terms of tempo (Shaffer, 1984) is justifiably questioned by Palmer (1997) on these grounds. Although Vorberg and Wing (1996: 199; also see Wing and Woodburn, 1995 for an analysis of periodic non-stationarity) do suggest that such trends can be removed with a degree of caution, it is not clear in the case of Clayton *et al* (e.g. 2003: 39) what grounds have guided the choice of method, and whether it has indeed been successful in removing long term drift (whether periodic or not). Indeed, the existence of positive autocorrelations at lags up to 15 in the data for long bell strokes in the Kpegisu song they analyze could be the result of periodic non-linear drift, in which case the summed variance analysis should also be viewed with caution.

Clearly there are many differences between the practices of archetypal music of the Classic or Romantic periods and that of, for example, Ewe drumming. Nonetheless it may be that certain findings in one musical domain may cross into another, or provide hypotheses to be tested. Clayton, Sager and Will (2003) review of entrainment research as it applies to ethnomusicology is a welcome engagement with quantitative methods, and with the cultural, physiological and psychological processes which might underlie coordinated musical performances. Such a starting point, however, will only flourish in a climate of open discussion and debate, and part of this should include an ongoing engagement with the details of movement and timing research, as well as studies of timing in related domains such as coordinated sporting activity and, especially, the performance of Western Art Music.

Entrainment – expanding the scope of orality in culture

Nurit BenZvi
The Hebrew University,
Jerusalem, Israel.
Email: nourit@netvision.net.il

This commentary discusses two aspects: internal de-synchronization and anticipatory action. The former refers to the provocative statement made by the authors in concluding case 2 i.e., that no self-entrainment is found in an individual performing two simultaneous rhythms. Focusing on Gamma song in case 2, I argue that it exemplifies a state of internal de-synchronization. This raises the question of the relationship between relative phase and the comparison of two separate phenomena based on a different structural parameter. Reference is also made to synchronized vowels and their relation to syllables in oral traditions. It is argued that "anticipatory action" to improve synchrony and entrainment might lead to change of attractor layout that is culturally and musically based. Anticipation-entrainment in the context of the Djambidj-song provokes issues regarding memory and consciousness.

The challenging target article "In Time with the Music" touches upon one central characteristic of human cognition, i.e. temporality, by investigating synchronization and entrainment processes in different oral cultures. Hence, the essay is a contribution to our knowledge of orality that is thought a key concept in ethnomusicology. The analytical approach to the music recordings – as presented in the analysis of three case studies– produced stimulating, though sometimes controversial results. I have chosen to discuss two of the results in this commentary.

Self-entrainment or a state of internal de-synchronization?

The claim that "there is no automatic synchronization or self-entrainment between simultaneous manual and vocal activities in one body", with which the authors conclude the analysis of case 2, is interesting because it contradicts our natural, everyday experience – e.g., listening to music while nodding our head that is an embodied behaviour manifesting self-entrainment. But this claim is also provocative because it is quite different from what we find in studies indicating that human beings exhibit a strong tendency toward self–entrainment (and synchronization) in a perception-action behaviour (e.g., in a process of internal synchronization that is working when an individual is performing simultaneously two motor movements, e.g. with the mouth for singing or speaking and simultaneously with hands for drumming or any gestures, as found in case 2. see also: Kelso, 1984). For example, Iverson and Thelen suggest that systems of mouth and hand movements interact and entrain each other – the hand movements entrains the vocal apparatus "leading to tight synchrony of speech and gesture" that is considered by Iverson and Thelen an entrainment behaviour observed with 16-18 months infants (Iverson and Thelen, 1999:36). Similarly, Rubin (1995) is indicating that motor and speech systems entrain each other within a single individual.

Then, could it be that the Gamma song (case 2, Fig 10 and 11) exhibits a state of internal de-synchronization? The reason for this question is rooted in the following observation:

(1) Though there exists a high correlation between V and C segments, as the authors show, they both:
- (a) run on a *different* rhythm *than* of clap stick beats, and
- (b) share the *same* period of 35 sec *with* clap stick beats

Fig 10 shows clearly this "disobedience" behaviour of segments timing with clap stick beats rhythm. In other words, the lack of phase locking characterizes an unstationary state, the internal (i.e., within one body) desynchronization.

(2) However, it is not a continuous state of internal desynchronization but a flux motion (possibly because tempo variances?) – as if searching for stability – that is:
- (a) starting from a state of lack of interaction (up to 14 sc, on the time scale),
- (b) continuing with a *tighter* coupling of C *and* V segments (interestingly, in contrast to only V synchronized with bell strokes, in Kpegisu song) that is close to and is on the zero line of clap stick (14 sc to 24 sec on time scale),
- (c) returning back to a state of internal desynchronization (from 25 sec to 35 sec), though not exactly the same previous internal

desynchronization state but a "new" form (like: a/*b*/a[1]).

State: **Segment Interaction:**	**1. InternalDsync**	**2. sync**	**3. InternalDsync**
On zero line	---	2 'C' + 2 'V'	1 'V'
Touching zero line	3 'C'	2 'C' + 3 'V'	1 'V'

(3) From a temporal perspective, each state (or phase) has different time duration – 14 sc, 10 sc and 11 sc, respectively – and is displaying different array of C and/or V with regard to clap stick beats. It is interesting to note that it is the temporal pattern, underlying the coupling of V segment and the zero line of bell strokes or clap sticks, that indicates the type of time-arrangement state – whether synchronization or internal de-synchronization (as with the Kpegisu and Gamma song, respectively; comparing v-phase in Fig 9 and 11 of the target article). This might have some implications for our conception of the *syllable* in spoken/sung language in oral/literate traditions, however, not necessarily following McNeilage's debatable 'mastication' theory of origin of syllable structure.

The above three items indicate that case 2 includes two different examples of rhythmic coordination: whereas the Kpegisu song analysis displays a continued-time synchronization – vowels are synchronized with bell strokes – the Gamma song is a case of a discrete-time state of internal de-synchronization. Therefore, the two rhythmic performances differ from each other not only in tempo – which caused the authors to use the relative phase methodology to overcome tempi variances – but also from their structure parameter: continued-time sync and discrete-time internal de-synchronization. In view of that, to what extend can the methodology of relative phase serve us if comparison is between two separate phenomena each based on a different structure parameter, and not only on factors responsible for changes (as, e.g., tempo)?

Anticipation and Entrainment

'Synchronization bandwidth' of approximately 30 milliseconds is one of the results of the analysis of entrainment in case study 3. As the authors suggest, this is a time interval between two performers crucial to synchronization: should the later be less than this frequency range, performers can improve synchrony by adopting an *anticipatory* action, i.e., *learning* the coordination pattern of responses. However, a recent study points clearly to the fact that coordination is not necessarily dependent on the learning of specific rhythmic patterns "or response strategies" (see: Large et al. 2002:14).

Even so, one would wonder, at first glance, why should the Djambij "learn" to coordinate? But on a second thought, the concept of "anticipation" in the sense of "learning" – within the context of phase attraction, as the authors put it – is more complex. Indeed, it is common, within recent anticipation studies (e.g., Rosen, 1985; Bertil, 1998; Dubois, 1998), to assume that "anticipatory system" is a "learning process" – as, e.g., within neuronal systems (Rosen, 1985). In other words, from an "anticipation" point of view, "learning" means – in the context of the Djambij singers – to construct an internal predictive model, assembling future *responses* to any event potentially to occur in the present. Activating such model would then mean for the singer to determine – most likely in an "on line" *rapid* action – among multiple patterns for the fittest one. Should this active process take place, it means that –

(1) The performance of the Djambij songs will involve three types of memory: long - term memory (from past experience), working memory (dominant within the real-time singer-environment interaction) and "anticipatory memory". By "anticipatory memory" I mean here not that something that has not yet happened is stored – this might sound a bit paradoxical – but rather stored implicitly forecasted responses patterns (e.g., motor behavioral patterns). But, although we know there exist some correlation between synchronization and short-term memory (Strogatz, 2003), we nevertheless do not have evidence regarding the process of entrainment and its linkage to memory.

(2) Entrainment would change into a goal-oriented, because the singer is taking multiple *future states* into present consideration – basically an intentional action. Indeed –

(3) Anticipation is an intentional and conscious action, because it is goal-oriented, rather then "unconscious" as it is claimed – although implicitly – by the authors in the target article. However, in light of the above anticipation-entrainment related, a question is then arisen as to what degree is entrainment a conscious process and how far is it from being an unconscious behavior?

Obviously, "anticipation action" implies a *change* of the coordination pattern but also the *attractor layout* (Kelso, 1995). Than, if the location of the phase attractor in real world environment performance is reflecting both a stylistic feature inherent in the Djambij musical practice and its socio cultural conditions, then to what extend can learning take place without violating the cultural and musical characteristic of the phase attractor (which is an immanent component of the stylistic performance)?

On the other hand, Kelso relates to *modes of anticipation* – but in the sense of planning. Within the context of sensory motor coordination, he is referring to an experiment performed at the Juilliard School of Music, in which musicians were asked to syncopate with an auditory stimulus (repeated tones), than switching to a synchronized state with increasing frequency of the repetitions. In other words: performing a transition from an anti-phase to a phase with the metronome. Additionally, he compared the magnetic field of the left side of the brain during these two perception-action tasks – syncopation and synchronization – pointing out to an interesting phenomenon, paradoxical in its nature because we would expect just the opposite: apparently, there seems to exist an inverse correlation between strong brain periodicity in anti-phase (i.e., coherence in brain state during syncopation) and less brain coherence in phase with the stimulus, i.e., during synchronization, in spite of the fact that the stimulus (and consequently manual responses) are rather rapid. One possible explanation for this seems to be that syncopation is more difficult to perform, since it demands the attention of not only anticipating where the next beat is (as is the case in synchronization), but also estimating the temporal location of the in-between beats point – a task which increases attention load. Consequently to Kelso's experiment, it seems that stimulus rate is not necessarily an influencing factor, or at least is not in direct correlation with the degree of brain state coherence.

In view of the above, and returning for a moment to the entrainment process identified in case study 3, I think that it would be interesting to make an experiment basing solely on data of case study 3, in order to detect brain states during the transition from pre-entrainment mode to in-entrainment mode and within each of the modes, as presented in Fig.12 in the target article.

Summarizing, I think one needs to establish a precise and coherent framework for further discussion and investigation the subject of synchronization and entrainment within cognitive ethnomusicology research. It should include clarification of certain ambiguities and consider some questions arising from the study of entrainment, for example:

(1) Questions like: how to use the method of Time Series in an analysis of unmeasured music? How far can this method attest the linkage between synchrony and entrainment memorization processing in oral culture?

(2) Clarification of ambiguities, like: cognitive template (of seven bell strokes, of the Kpegisu song) is '*programmed*'. This is a computer metaphor – the kind of digital computer that symbolized the brain in early phase of cognitive science – and it stands in sharp contrast to 'self-organization' that is central to dynamical system theory, that seems to be the preferred platform in this target article. And the fact that a timekeeper activates this pattern at a specific moment as part of its evolving in time does not mean that the pattern computes itself (see: Kelso, 1995).

Authors' response to the commentaries

Writing on entrainment phenomena can indeed seem, at times, like little more than stating the obvious, and yet a serious attempt to explain real life entrainment phenomena in musical behaviour throws up numerous, often unexpected complexities that are yet to be unravelled. The commentaries on our target article have helped us to get a little closer to untangling some of these difficulties, and we hope our article has done the same for other readers. It was fascinating to read the very different responses of such a diverse group of scholars and we are grateful for all critical and thoughtful remarks and suggestions received, which have helped to clarify and advance the discussion and debate on the issue. Some important themes have emerged from these commentaries on which we have organized our responses. Our reply focuses on areas where we feel that our intention and position was insufficiently clear in the original presentation, and where we feel the need to supply additional information about current developments in entrainment research, as well as areas where we take a view different from those expressed in the comments.

Scope

As **Pearl** points out in his commentary, our target article is partly an attempt to set ethnographic and empirical/scientific approaches to music research on an equal footing. Moreover, we think that in addition to complementing standard ethnomusicological methodologies with empirical and scientific ones (**Bispham**), the entrainment concept offers the chance to overcome, at least in one domain, the long-standing and seemingly insurmountable opposition of the two approaches. One of the reasons for this unifying potential is the fact that entrainment theory is a kind of 'open theory' that supplies basic principles and procedures, but leaves it to the respective disciplines to apply them to specific systems, identify the oscillatory processes and analyse the interacting forces. The theory permits understanding of certain phenomena of human behaviour (entrainment) in terms of the bodily realizations of the underlying oscillatory processes, and there is no a priori distinction between conscious and unconscious processes. On the contrary, entrainment theory is able to deal with both and acknowledge their respective roles, without favouring one over the other. This is why entrainment theory seems able to avoid the cognitivistic bias ('consciousness bias': only what is conscious is real) dominant in many a discipline dealing with human behaviour and contributing much to the ethnological/scientific divide, as we are reminded, for example, by **Balasa**'s commentary. For entrainment theory any bodily implementation of interacting processes is real, no matter whether it is consciously experienced or not.

Unfortunately, **Pearl**'s introduction of the term 'cognitive entrainment', made along the lines of the cognitivistic body/mind divide, creates a confusion of terms: it suggests that 'cognitive entrainment' is a type of entrainment distinguishable from other types of entrainment, when in fact it is defined as 'feeling of synchrony', referring only to the awareness of a process of synchronization, not a specific type of synchrony or mode of entrainment. Although we object to introducing 'cognitive entrainment' as a distinct category, we do agree with **Pearl** that a clear distinction needs to be made between the feeling of what happens and the actual physical processes. As the comments of **Pearl**, **Sweers**, **Lucas** and **Allgayer-Kauffmann** affirm, feeling and appearance to the observer of synchrony and entrainment are central to many a study in ethnomusicology. Conscious states and socio-cultural interpretations, however, should not be confounded with synchronization itself. What entrainment theory offers is, in our view, a chance to analyze how these appreciations and evaluations can, in turn, become factors influencing entrainment..

Bispham suggests distinguishing 'musical entrainment' from other forms of entrainment, but it is not clear to us how his distinction between *'self-entrainment in musical contexts (SEiMC) and interpersonal musical entrainment (IME)'* offers a new perspective beyond that presented in the target article. The generally accepted distinction between self-entrainment and other forms of entrainment only concerns the organizational level (entrainment within or between organisms, bodies, etc). Self-entrainment may be based on physical forms of interactions that do not and cannot exist if entrainment takes place between different bodies or organisms. The principal entrainment mechanisms and phenomena, however, hold in both cases. Furthermore, if there is something unique to musical entrainment (**Bispham**), it will be up to music researchers to establish this by analysing specific realizations of entrainment in musical context. Until such uniqueness is proven, we remain wary of a hypothetically distinct classification for musical entrainment. For the present, "musical entrainment" should simply denote general entrainment processes occurring in the presence of music.

Expansion

Allgayer-Kaufmann proposes expanding the concept's remit, since entrainment "is [not] necessarily limited to the dimension of time...", and **Lucas** wants to broaden the application of entrainment "to the larger socially relevant questions of ethnomusicological inquiry". Here it is important for us to assert that entrainment *is* precisely concerned with the dimension of time: We do not think this necessarily precludes for example its application to studies of timbre or pitch, which are both temporal phenomena, but any entrainment studies concerning timbre and pitch would be time-based. On the other hand, entraining stimuli do not necessarily have to be acoustic ones; they could also be visual or tactile (although entrainment to acoustic stimuli may have characteristic that distinguish it from other varieties - see above). We have given some examples of entrainment to non-acoustic stimuli in the target article, and **Allgayer-Kaufmann**'s marching band offers an additional one. In all cases, however, what matters is that we are dealing with temporal relationships of two or more autonomous processes. This limitation to the temporal domain is at the same time the conceptual strength of the theory. Entrainment, after all, is no more than an interpretive and explanatory model that can be applied to certain aspects of human behaviour. Its explanatory power may be great, but it is not, and we do not intend that it be taken for, a theory of everything musical.

Allgayer-Kaufmann also brings up a couple of other ideas that might be explored further. One is the role of memory and its use to predict likely changes in musical periodicities – an issue also discussed in illuminating fashion by **Windsor**. The idea that listeners may have learned enough about likely processes in musical performances to mean that prediction is at least as important as tracking in the entrainment process is a topic not developed greatly in our target article, and we are grateful for the suggestions here. Likewise, the point made by **Clarke**, with reference to the work of M. Jones and co-workers, that different rhythmic structures might induce different styles of attention, which in turn may be associated with different kind of experiences, deserves further consideration as it clearly indicates one of the possible links between entrainment and subjective experience.

Synchronization bandwidth

The reference to "synchronization bandwidth" by **Allgayer-Kaufmann** and **BenZvi** leads us to reiterate two relevant aspects of synchronization. The first is that entrainment or phase locking of two processes does not necessarily imply equality of their phases (that their phase difference is zero). Rather, phase shifts and (limited) fluctuations of the phase differences are a general feature of synchronizing dynamical systems, not just of human behaviour. The defining criterion for phase locking is that the phase differences between processes stay smaller than a certain value. That value depends on the processes, the interacting forces, and the noise components involved. Despite these fluctuations, the "synchronization bandwidth" or degree of synchronization can nevertheless be described in quantitative terms.

The second point is that conceiving "synchronization bandwidth" as something ambiguous or imprecise misses the essential point that the 'bandwidth' or degree of synchronization informs us about important features of the interaction between two oscillatory processes: the weaker the interaction or the more noise it contains, the broader the synchronization bandwidth. For example, familiarity with a certain style of music can affect the degree of synchronization (i.e. reduce the variance of the phase differences) in response to this music and the response variability may represent the factor 'familiarity with the music'. If necessary, this bandwidth can also easily be described in quantitative terms, for example in terms of dispersion around mean values. Furthermore, synchronization – as defined above, i.e. a state in which the phase differences are smaller then a certain value, but not necessarily constant – is not just contrasted with a-synchrony. In-between these two states we find a zone where the dynamics of phase differences is intermittent: epochs of relative stability of phase differences (i.e. synchronization) alternate with epochs of unbounded phase changes. This region of intermittent synchronization, often encountered in the interaction of processes that are not strictly periodic, is probably of special interest for musicologists dealing with non-periodic and free rhythms. Beyond this intermittency zone synchronization is lost. The great challenge is to determine the onset of intermittent synchronization, especially if interactions and forces are weak, processes are non-periodic, and systems are noisy. Individual phase measurements, such as applied by **BenZvi**, are obviously inadequate. However, given a sufficient number of phase difference measurements, these can be tested for instance against an equal distribution or random walk distribution, and it is possible to detect even relative weak and noisy synchronization. (For the Gama song of our case study 2, none of the applied tests revealed peaks in the distribution of the relative phases that would justify talking about synchronization – not even partial or intermittent.)

Periodic, quasi-periodic and chaotic oscillators

Concerns and reservations are voiced that movement and rhythmical processes relevant in music making may not be adequately described and analysed within a framework of entrainment research, because 'precise periodicities are almost non-existent in the natural world' (**Pearl**; similar **Allgayer-Kaufmann**) and 'non-periodic movements' may constitute an essential component of musical performances (**Clarke**). We want to emphasize here that entrainment does not apply 'principally – perhaps solely - to periodic processes' (**Clarke**). Entrainment research is not dependent on the assumption of strictly periodic, noise free oscillators - these are but a special case of autonomous oscillators that can entrain and are rarely found in real life processes. Entrainment research is concerned with quasi-periodic oscillations with bounded (limited) or unbounded noise components, and these would already allow coverage of a wide range of music related processes. Furthermore, since Lou Pecora's work on chaotic transmitters and receivers in communications (Pecora and Carroll, 1990), we know that even chaotic – i.e. non-periodic – systems can entrain and synchronize. Both frequency and phase synchronization of chaotic oscillators have been described (e.g. Pikovsky, 1985; Parlitz et al., 1996, Pikovsky et al., 2001). During the last two decades synchronization and entrainment research has developed a rich set of conceptual and analytical tools for dealing with a wide spectrum of oscillatory systems covering simple harmonic, noisy periodic, and non-periodic chaotic oscillators. In the following we present a short theoretical example indicating one possible approach for dealing with non-periodic movements.

If chaotic oscillators can synchronize, these oscillators must have some features that correspond to the frequency and/or phase of periodic (and quasi periodic) oscillators. One of the features shared by periodic and chaotic movements is the recurrence of events. The time between corresponding events is fixed for periodic oscillators and constantly changing and non-repeating for chaotic oscillators. In the latter case it does not make sense to talk about 'the frequency' of the oscillator as its motion contains a multitude of frequencies: it is, however, possible to use the concept of 'instantaneous frequency', corresponding to the inverse time interval ('instantaneous' period length) between two subsequent events. In the case of the fiddler's bow arm, for example, an identifiable recurring event would be the point where the downward-outward movement changes into an upward-inward movement. For any two subsequent events of this kind one can define a 'return time', i.e. a period length that defines an instantaneous period of the oscillatory movement. Where the fiddler is accompanied by a periodic (quasi-periodic) drum beat, we have two series of return times (changes in the direction of the bow arm and drum beats). Then we can ask, how are the two series of 'instantaneous' periods related, and we can also ask, what is the 'instantaneous' phase relationship between them? Mathematically this involves the same procedure of calculating the relative phase as we have demonstrated in our case studies. The only difference is that the period length of one of the movements (bow arm) is not constant. In the given example we could e.g. find that the return points of the bow arm are close to the 3rd, 11th, 15th, 21st, etc. drum beat. Then we have two possibilities for analysing the phase relationship: with reference to the non-periodic arm movement or to the quasi-periodic drum beats. For both cases, if there is synchronization between the two movements this would show up in the measurement of the phase differences; for our example the phase difference between the 3rd, 11th, 15th, 21st, etc. drum beat and the corresponding return time points for the bow would be stable around a certain minimal value.

We do not therefore see any obstacle in principle, that would prevent us from dealing with non-measured, non-metered, or non-periodic rhythms (**Kouwenhouven, Clarke**) or investigating entrainment phenomena related to these type of rhythms. In our target article we already made reference to studies indicating entrainment of non-periodic limb movements. In addition, Steven Strogatz (2003), has given several some telling descriptions indicating how the concept of synchronizing non-periodic oscillators can be applied to music making and dance. With this in mind, it seems reasonable to hypothesize that the non-periodic movement of the fiddler's bow arm[1], referred to by Clarke, may very well show phase synchronization with other oscillatory processes like foot movements, singing or the rhythm of accompanying instruments. In a different case, Berg and Will (submitted) have recently forwarded evidence for significant – though noisy - phase synchronization in listeners' tapping responses to alap, the non-metered, largely non-periodic section of Hindustani raga performances. Listeners' responses showed recurring, intermittent epochs of phase stabilization that relate to temporal structures of the music. We are therefore confident that a major part, if not all, of the non-periodic aspects of musical (and dance) performance Clarke is referring to, can be dealt with within an expanded entrainment framework that includes non-periodic oscillators.

Timing mechanisms, clocks, and oscillators

Clarke considers the discussion about possible timing mechanisms as a distraction from the main focus of our paper, which is the use of entrainment to understand behaviour. However, limiting entrainment research to the behavioural level – if that is at all possible **-** could only lead to a very restrictive understanding of the phenomena. The bulk of entrainment research seems to indicate, as **Jones** put it, that 'the real source of entrainment (is) found not in overt gestures but amongst internal attending oscillations of performers and these in turn merely guide gestures'. Entrainment is not something given a priori; it only exists under certain conditions, and for temporal analysis and appropriate interpretation of behavioural data, a certain knowledge, or at least a well supported model, of the underlying processes is needed. Fortunately, over the last two decades or so, neuroscience has accumulated ample evidence that oscillations in neural networks are essential mechanisms in the working of vertebrate brains, as they allow for synchronization and integration in spatially distributed populations of neurons. Autonomous neuronal oscillations seem to structure and guide behaviour, perception, cognition and even consciousness (Schwender, 1994), and evidence indicates that oscillatory processes form the basis of timing mechanisms for sensorimotor synchronization (Mates et al., 1994) and periodic performance of behavioural pattern. The analyses of the pattern performances in our case study 1 are compatible with the assumption that neural (relaxation) oscillators are the 'timer' for the periodic performance of the respective pattern. They are, however, clearly incompatible with the assumption, which **Clarke** seems to imply we are making, of a computer clock cum counter for basic time quanta: The temporal analysis indicates that the Kpegisu and Gama rhythms are organized at the pattern level and not at the level of the smallest units or individual events (**Windsor**), and can be interpreted as the repeated sequential execution of a recalled or re-activated pattern.

Case studies

The comments by **Clarke**, **Windsor**, and several others, on methods applied in the case studies show that we were not completely successful in specifying their place and purpose within the whole of our presentation. Our idea was to present ethnomusicologists, who are generally not familiar with methods of time series analysis, with some of the analytical methods useful in entrainment research. Case study 1 was obviously not chosen as an example of entrainment but as a case that permitted us to introduce several principles of time series analysis.

Jones and **Large** have an important point in alerting us that certain methods and procedures applied to the data may obscure important system features (e.g. non-linearities) and prevent adequate, subsequent analyses. One of the assumptions applied in case study 1 was that the underlying processes are stationary – an essential assumption in linear as well as non-linear system analyses. Stationary means that either the relevant system parameters do not change during the period of observation, or that phenomena belonging to the dynamics of the system are represented in the data with sufficient frequency. Clearly, with the limited data set presented in case study 1, detrending is a justifiable procedure in order to analyse the

[1] Just how non-periodic these bow movements are, though, is open for debate. Every string player will tell us that there is at least a considerable amount of 'intermittent' periodicity in these movements.

underlying process as stationary. Only a larger set of song items would supply us with sufficient data to take the obvious tempo variation into account and to investigate, for example, **Jones**' suggestion that the tempo variations may drift towards a 'favoured tempo' of the performers.

It was not our intention to simply assume non-linearities but to present some ideas about basic approaches in time series analysis in a comprehensible and accessible form. It should be pointed out that these approaches are not limited to linear systems. Non-linear generalizations of ARMA (autoregressive, moving average) models have in fact been developed and put into practice (see e.g. Kantz and Schreiber, 1997), and the autocorrelation function can be applied to linear as well as non-linear processes. For example, it can be used to test for synchronization of chaotic oscillators.[2]

Finally, in the current literature one not infrequently encounters the application of non-linear system theory concepts, - for example measures that describe chaotic systems, like the correlation dimension -, without demonstration that the systems or processes concerned do in fact possess features that would justify the application of those concepts. Therefore, we would like to stress that it is important not to simply assume non-linear or chaotic behaviour, but rather to demonstrate that the data cannot be adequately analysed otherwise. Even though, as **Jones** reiterated, entrainment is inherently a non-linear process, not all oscillators and interactions are a priori non-linear. Thus, until entrainment has been demonstrated, one also has to consider the possibility that an observed behaviour could be caused by a quasi-linear noisy process.

The challenge of subjectivity

A concern with how entrainment is experienced is a particular concern not only of **Pearl** but also of the ethnomusicologists **Lucas** and **Balasa**. **Lucas** gives a superb demonstration of the way an entrainment perspective can contribute to ethnographic research, and vice versa. The example she describes is exactly the kind of ethnographic data that necessitates the use of more empirical, quantitative approaches to balance interpretation and explanation. Her description demonstrates the potential relevance of entrainment research for investigating questions about the social negotiation, identity, and ritual significance of music performances. While we understand her personal preference for ethnographic modes of enquiry, however, we nonetheless suspect that empirical studies of the situations she describes would not only enrich her interpretations, but also feed ethnographic insights into the worlds of psychology and cognitive science, to the benefit of the latter. As she herself says, "unconscious processes can be matched with peoples' various concepts and meanings of music, and their own evaluations of their music making". This matching is what we are calling for here.

Balasa also stresses the subjective and the experienced, to the extent of throwing scorn on scientific, 'positivistic' methods. His rhetoric suggests a number of misunderstandings – of our intentions and of the nature of scientific enquiry in general – yet his provocation articulates apprehensions not unfamiliar in ethnomusicological circles and offers some interesting perspectives. **Balasa**'s observation that the discourses of certain philosophical or mystical traditions relate to modern scientific perspectives is not new – the writings of Fritjof Capra spring easily to mind (e.g. 1975), and in this case the perspectives of Sufi mystics such as Rumi would be as relevant as **Balasa**'s example from Shaivism (see e.g. Khan 1996). Each approach, no doubt, can learn from the other, and as the tone of this commentary makes clear, the two approaches have often, unfortunately, been set in opposition to each other with the added assumption that one is superior over the other. By contrast, it might prove more productive to see mystical writings in the way **Lucas** sees her informants' comments: as examples of how phenomena that are otherwise amenable to empirical observation *feel*, and of what they mean to the experiencing individual. For all the insight that he offers, we must disagree with **Balasa**'s suggestions that the concept of entrainment is a scientistic statement of the obvious (if it were, why would so many explanations of music so conspicuously fail to take account of it?), or a restatement of wisdom already achieved by other means.

---

[2] For example, the power spectrum of a chaotic process has a broad-band component and a peak at the mean frequency of the oscillations. If this process is synchronized by an external periodic force, then there is an increase in the spectral component that corresponds to the frequency of the driving (synchronizing) force. This component appears in the autocorrelation function of the chaotic process as a series of non-decreasing maxima at intervals corresponding to the period of the driving force.

References

(bold face initials refer to the commentary or to the authors' response (**rCSW**))

Alén, O. (1995). Rhythm as duration of sounds in *Tumba Francesa. Ethnomusicology, 39*(1), 55-71.

Allen, P. M., Deneubourg, J. M., Sanglier, M., Boon, P. & dePalma, A. (1977). *Dynamic urban growth models*. Report No. TSC-1185-3. Cambridge, MA: Transportation Systems Center, US Dept. of Transportation.

Alper, Harvey P. (Ed). (1991). *Understanding Mantras*. Delhi: Motilal Banarsidass Publishers. **MM**

Ancona, D. & Chong, C. L. (1996). Entrainment: pace, cycle, and rhythm in organizational behavior. *Research in Organizational Behavior, 18*, 34.

Appleton, L. J., W.L. Windsor, and E.F. Clarke. (1997). Cooperation in piano duet performance. In A. Gabrielsson (Ed.), *Proceedings of the Third Triennial European Society for the Cognitive Sciences of Music Conference* (pp.471-474). Uppsala: Uppsala University. **LW**

Arom, Simha. (2000). Prolegomena to a Biomusicology. In Nils L. Wallin, Björn Merker, and Steven Brown (Eds.), *The Origins of Music* (pp. 27-29). Cambridge, MA: MIT Press. **FK**

Aschoff, J. (1979). Circadian rhythms: General features and endocrinological aspects. In D. T. Krieger (Ed.), *Endocrine rhythms*. New York: Raven Press.

Aschoff, J. (1990). Circadian temporal orientation. In D. E. Blackman, and H. Lejeune (Eds.), *Behaviour analysis in theory and practice: Contributions and controversies* (pp. 3-31). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Auer, J. C. P., Couper-Kuhlen, E. & Müller, F. (1999). *Language in time: the rhythm and tempo of spoken interaction*. New York: Oxford University Press.

Baily, J. (1985). Music structure and human movement. In P. Howell, I. Cross and R. West (Eds.), *Musical structure and cognition* (pp. 237-258). London: Academic Press.

Barnes, R. & Jones, M.R. (2000). Expectancy, attention, and time. *Cognitive Psychology, 41*, 254-311.

Başar, E. (1983) EEG and synergetics of neural populations. In Başar, E. et al. (Eds.), *Synergetics of the brain* (pp. 183-200). Berlin, Heidelberg, New York: Springer. **rCSW**

Beck, Guy L. (1995). *Sonic Theology: Hinduism and Sacred Sound*. Delhi: Motilal Banarsidass. (2nd ed.). University of South Carolina. **MM**

Berendt, Joachim-Ernst. (1990). *The World is Sound: Nada Brahma. Music and the Landscape of Consciousness*. Foreword by Fritjof Capra, translated by Helmut Bredigkeit. Rochester: Destiny Books. **MM**

Berg, E and Will, U. (submitted) Pulse and phase synchronization in tapping responses to North Indian alap. **rCSW**

Bernieri, F., Reznick, J. S. & Rosenthal, R. (1988). Synchrony, pseudosynchrony, and dissynchrony: Measuring the entrainment process in mother-infant interactions. *Journal of Personality and Social Psychology*, *54*(2), 243-253.

Bertil, E. (1998). Approximation of Anticipatory Systems. In *Proc. 2nd World Multiconference on Systemics, Cybernetics and Informatics* (pp.12-16). **NbZ**

Bispham, J. (2003). *An Evolutionary Perspective on the Human Skill of Interpersonal Entrainment*. Unpublished MPhil Dissertation. University of Cambridge, Faculty of Music. **JB**

Blacking, J. (1955). Notes on a theory of rhythm proposed by von Hornbostel. *African music, 1*(2), 12-20.

Blacking, J. (1967). *Venda children's songs: A study in ethnomusicological analysis*. Johannesburg: Witwatersrand University Press.

Blacking, John. (1976). [1973]. *How Musical is Man?* Faber & Faber. **BS**

Blacking, J. (Ed.), (1977). *The anthropology of the body*. London: Academic Press.

Blacking, J. (1983). The concept of identity and folk concepts of self: A Venda case study. In A. Jacobson-Widding (Ed.), *Identity: personal and socio-cultural* (pp.47-65). Stockholm: Almqvist and Wiksell.

Blacking, J. (1995). *Music, culture & experience: Selected papers of John Blacking*, R. Byron (Ed.). Chicago: University of Chicago Press.

Bluedorn, A. C. (2002). *The human organization of time. Temporal realities and experience.* Stanford, CA: Stanford University Press.

Boucher, J. (2001). 'Lost in a sea of time': Time-parsing and autism. In C. Hoerl & T. McCormack (Eds.), *Time and memory. Issues in philosophy and psychology*. Oxford: Clarendon Press.

Box, G. E. P. & Jenkins, G. M. (1976). *Time series analysis, forecasting and control*. San Francisco: Holden-Day.

Boyd, R. and Richardson, P.J. (1985). *Culture and the Evolutionary Process*. Chicago: University of Chicago Press. **JB**

Bramble, D.M. and Carrier, D.A. (1983). Running and breathing in mammals. *Science, 219*, 251-256

Brown,.S, Merker, B & Wallin, N.L. (2000). An introduction to evolutionary musicology. In N.L.

Wallin, B. Merker, & S. Brown (Eds.), *The origins of music* (pp. 3-24). Cambridge, MA: MIT Press.

Buck, J. & Buck, E. (1968). Mechanism of rhythmic synchronous flashing of fireflies. *Science, 159,* 1319-1327.

Busse, W. (2002). Toward objective measurement and evaluation of jazz piano performance via midi-based groove quantize templates. *Music Perception, 19*(3), 443-461.

Cadoz, C., L. Lisowski & J.-L. Florens. (1984). Responsive Input Devices and Sound Synthesis by Simulation of Instrumental Mechanisms. *Computer Music Journal, 14*(2), 47-51.

Cadoz, C., L. Lisowski & J.-L. Florens. (1993). CORDIS-ANIMA: A Modeling and Simulation System for Sound and Image Synthesis—the General Formalism. *op cit., 17*(1), 19-29.

Capra, F. (1975). *The Tao of physics : an exploration of the parallels between modern physics and eastern mysticism*. Berkeley, New York: Shambhala. **rCSW**

Chapple, E. D. (1939). Quantitative analysis of the interaction of individuals. *Proceedings of the National Academy of Sciences, 25*, 58-67.

Chapple, E. D. (1970). *Culture and biological man. Explorations in behavioral anthropology*. New York: Holt, Rinehart and Winston.

Chen, Y., M. Ding, and Kelso, J.A.S. (1997). Long Memory Processes ($1/f^a$ Type) in Human Coordination. *Physical Review Letters, 79*(22), 4501-4504. **EL**

Chomsky, N. (1980). *Rules and Representations*. New York: Columbia University Press. **EL**

Clarke, E. F. (1987). Levels of structure in the organization of musical time. *Contemporary Music Review, 2*, 211-238. **LW**

Clarke, E. F. (1988). Generative principles in music performance. In J. A. Sloboda (Ed.), *Generative Processes in Music* (pp. 1-26). Oxford: Oxford University Press. **LW**

Clarke, E.F. (1995). Expression in performance: generativity, perception and semiosis. In J. Rink (Ed.), *The practice of performance* (pp.21-54). Cambridge: Cambridge University Press.

Clarke, E. F. and J.W. Davidson. (1998). The Body in Performance. In W. Thomas (Ed.), *Composition – Performance - Reception. Studies in the Creative Process in Music* (pp. 74-92). Aldershot: Ashgate Press. **LW**

Clarke, E. F. (1999). Rhythm and Timing in Music. In D. Deutsch (Ed.), *The Psychology of Music* (pp. 473-500). New York: Academic Press. **LW**

Clayton, M. R. L (1996) Free rhythm: ethno-musicology and the study of music without metre. *Bulletin of the School of Oriental and African Studies, 59*(2), 323-332.

Clayton, M. R. L. (2000). *Time in Indian Music: rhythm, metre and form in North Indian rag performance*. Oxford: Oxford University Press.

Clayton, M., Sager, R., and Will, U. (in press). In time with the music: The concept of entrainment and its significance for ethnomusicology. *ESEM CounterPoint, 1,* 1-45. **GL**, **LW**

Clunies Ross, M. and Wild, S.A. (1982). *Djambidj: An Aboriginal Song Series from Northern Australia*. 33 1/3 rpm disc and companion book. Canberra: Australian institute of Aboriginal Studies.

Clunies Ross, M. and Wild, S.A. (1984). Formal Performance: The Relations of Music Text and Dance in Arnhem Land Clan Songs. *Ethnomusicology, 28*(2), 209-235.

Clynes, M. and Walker, J. (1982). Neurobiologic functions of rhythm, time and pulse in music. In M. Clynes (Ed.), *Music, mind and brain: The neuropsychology of music* (pp.171-216).New York: Plenum.

Clynes, M. (1986). When time is music. In Evans and Clynes (pp.169-224).

Collier, G. & J. Collier. (2002). Introduction. *Music Perception, 19*(3), 279-284. A Study of Timing in Two Louis Armstrong Solos. *op cit*, 463-483.

Condon, W. S. (1976). An analysis of behavioral organization. *Sign Language Studies, 13*, 285-318.

Condon, W. S. (1982). Cultural microrhythms. In M. Davis, (Ed.), *Interaction Rhythms*. New York.

Condon, W. S. (1985). Sound-film microanalysis: a means for correlating brain and behavior. In F.H. Duffy and N. Geschwind, (Ed.), *Dyslexia.* Boston/Toronto.

Condon, W. S. (1986). Communication: Rhythm and structure. In Evans and Clynes (pp.55-77).

Condon, W.S. and Ogston, W.D. (1967). A Segmentation of Behavior. *J. Psychiat. Res.* 5, 221-235.

Cooper, R., Winter, A., Crow, H, and Walter, W.G. (1965). Comparison of subcortical, cortical, and scalp activity using chronically indwelling electrodes in man. *Electroencephalogr. Clin. Neurophysiol.* 18, 217-230.

Couper-Kuhlen, E. (1993). *English speech rhythm : form and function in everyday verbal interaction*. Amsterdam, Philadelphia: J. Benjamins.

Davis, M. and Institute for Nonverbal Communication Research (New York N.Y.). (1982). *Interaction rhythms: periodicity in communicative behavior*. New York: Human Sciences Press.

Desain, P. and Windsor, L. (Eds.), 2000. *Rhythm Perception and Production*. Lisse: Swets & Zeitlinger Publishers. **JB**

Deutsch, D. (Ed.). (1999). *The Psychology of Music* (2nd ed.). San Diego: Academic Press.

Dixon R.M.W. and Koch, G. (1996). *Dyirbal Song Poetry. The Oral Literature of an Australian Rainforest People*. St. Lucia: University of Queensland Press.

Drake, C., Jones, M.R., and Baruch, J. (2000). The development of rhythmic attending in auditory sequences: attunement, referent period, focal attending. *Cognition, 77*(3), 251.

Dubois, M. Daniel. (1998). Introduction to Computing Anticipatory Systems. *Chaos, 2*, 3-14. **NbZ**

Durham, W. H. (1991). *Coevolution: Genes, Culture and Human Diversity*. Stanford, CA: Stanford University Press. **JB**

Dyczkowski, Mark S.C. (1989). *The Doctrine of Vibration: An Analysis of the Doctrines and Practices of Kashmir Shaivism*.Delhi-Varanasi-Patna: Modilal Banarsidass. **MM**

Eck, D., Gasser, M., and Port, R. (2000). Dynamics and embodiment in beat induction. In P. Desain and L. Windsor (Eds.), *Rhythm perception and production*. Exton, PA: Swets and Zeitlinger.

Ekman, P. (1977). Biological and cultural contributions to body and facial movement. In J. Blacking (Ed.), *The anthropology of the body* (pp.39-84).

Ekman, P. and Friesen, W.V. (1969). The repertoire of nonverbal behavior: Categories, origins, usage, and coding. *Semiotica, 1,* 49-98.

Evans, J. R. and M. Clynes. (1986). *Rhythm in psychological, linguistic, and musical processes*. Springfield, IL, U.S.A.: C.C. Thomas.

Fraisse, P. (1963). *The psychology of time*. Trans. J. Leith. New York: Harper and Row.

Friberg, A. and Sundström, A. (2002). Swing Ratios and Ensemble Timing in Jazz Performance: Evidence for a Common Rhythmic Pattern. *Music Perception 19*(3), 333-349.

Frith, S. (1996). *Performing rites. On the value of popular music*. Oxford: Oxford University Press.

Fujimura, O. (1995). Prosodic organization of speech based on syllables: the C/D model. *Proceedings of the XIII International Congress of Phonetic Sciences, 3*, 10-17.

Gabrielsson, A. The Performance of Music. In D. Deutsch (Ed.), *The Psychology of Music* (pp. 501-602). New

York: Academic Press. **LW**

Gerkema, M.P. (2002). Ultradian rhythms. In V. Kumar (Ed.), *Biological rhythms* (pp.207-215). Berlin: Springer-Verlag.

Gjerdingen, R.O. (1993). "Smooth" Rhythms as Probes of Entrainment. *Music perception, 10*(4), 503-508.

Glass, L. (1996). Synchronization and rhythmic processes in physiology. *Nature, 410* (6825), 277-284.

Goodman, E. (2002). Ensemble Performance. In J. Rink (Ed.), *Musical Performance: A Guide to Understanding*. (pp.152-167). Cambridge: Cambridge University Press. **LW**

Groos, G. A. (1983). Circadian rhythms and the circadian system. In J. Mendlewicz and H. M. von Praag (Eds.), *Biological rhythms and behavior*. Advances in Biological Psychiatry 11. S. Karger. pp. 1-9.

Gumperz, J. J. (1996). Foreword. In E. Couper-Kuhlen and M. Setting, *Prosody in conversation: Interactional studies.*

Haken, H. (1983a). *Synergetics: An Introduction*. Berlin, Heidelberg, New York: Springer.

Haken, H. (1983b). *Advanced Synergetics*. Berlin, Heidelberg, New York: Springer.

Haken, H., Kelso, J.A.S., and Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics, 51*, 347-356. **EL**

Hall, E. (1976). *Beyond Culture.* New York: Anchor Press.

Hodges, D. (1996). *Handbook of Music Psychology.* San Antonio: Institute for Music Research Press.

Hoppensteadt, F. C., and Izhikevich, E.M. (1996). Synaptic organizations and dynamical properties of weakly connected neural oscillators II: Learning phase information. *Biological Cybernetics, 75***,** 126-135. **EL**

Hoppensteadt, F. C., and Izhikevich, E.M. (1997). *Weakly Connected Neural Networks.* New York: Springer. **EL**

Hornbostel, E. M. von. (1928). African Negro Music. *Africa, 1*(1), 30-62.

Hurt, C.P., Rice, R.R., McIntosh, G.C., and Thaut, M.H. (1998). Rhythmic auditory stimulation in gait training for patients with traumatic brain injury. *Journal of Music Therapy, 35*(4), 228-241.

Inhoff, A.W. and Bisiacchi, P. (1990). Unimanual tapping during concurrent Articulation: Examining the Role of Cortical Structures in the Execution of Programmed Movement Sequences. *Brain and Cognition, 13*, 59-76.

Iverson, J.M. and Thelen, E. (1999). Hand, Mouth, and Brain. The dynamic emergence of speech and gesture. In R. Nuñez, and W.J. Freeman (Eds.), *Reclaiming Cognition. The primacy of Action, Intention, and Emotion* (pp.19-40). Thorverton: Imprint Academic. **NbZ**

Ivry, R.B. and Richardson, T.C. (2002). Temporal Control and Coordination: The Multiple Timer Model. *Brain and Cognition, 48*, 117-132. **JB**

Iyer, V. (2002). Embodied Mind, Situated Cognition, and Expressive Microtiming in African-American Music. *Music Perception, 19*(3):387-414.

Jackendoff, R. (1997). *The Architecture of the Language Faculty*. Cambridge: MIT Press. **EL**

Jaffe, J. and Anderson, S.W. (1979). Communication rhythms and the evolution of language. In A.W. Siegman and S. Feldstein (Eds.), *Of speech and temporal speech patterns in interpersonal contexts*. Hillsdale NJ: Lawrence Erlbaum Associates.

Jantsch, E. (1975). *Design for Evolution: Self-Organization and Planning in the Life of Human Systems*. New York: Braziller.

Johnson, H. Carl, Elliot, J., and Foster, R. (2003). Entrainment and Circadian Programs. *Chronobiology International, 20*(5), 741-774. **NbZ**

Johnson, O. and Kozma, A. (1977). Effects of concurrent verbal and musical tasks on a unimanual skill. *Cortex, 13*, 11-16.

Jones, M.R. (1976). Time, Our Lost Dimension: Toward a New Theory of Perception, Attention, and Memory. *Psychological Review, 83*(5), 323-355.

Jones, M.R. and Boltz, M. (1989). Dynamic Attending and Responses to Time. *Psychological Review, 96*(3), 459-491.

Journal of Brain and Cognition. Special Edition on Timing. Volume 48, Issue 1. **JB**

Kantz, H. and Schreiber, T. (1997). *Non Linear Time Series Analysis*. Cambridge: Cambridge University Press. **rCSW**

Keil, C. (1966). Motion and Feeling through Music. *Journal of Aesthetics and Art Criticism, 24*, 337-49.

Keil, C. (1995). The Theory of Participatory Discrepancies: A Progress Report. *Ethnomusicology, 39*(1), 1-19. **RAK**

Keil, C. and Feld, S. (1994). *Music Grooves: Essays and Dialogues.* Chicago: University of Chicago Press.

Kelly, J.R. (1988). Entrainment in individual and group behavior. In J.E. McGrath (Ed.), *The social psychology of time: New perspectives* (pp.89-110). Sage focus editions, Vol. 91. Thousand Oaks, CA, U.S.A.: Sage Publications, Inc. 271

Kelso, J.A.S. (1995). *Dynamic Patterns: The Self-Organization of Brain and Behavior*. Cambridge, MA: MIT Press. **MRJ, NbZ**

Kelso, J.A.S., Southard, D. and Goodman, D. (1979). On the nature of human interlimb coordination. *Science 203*, 1029-1031.

Kendall, M.G. and Stewart, A. (1968). *The advanced theory of statistics* (Vol.3). London: Griffin.

Kendon, A. (1972). Some relationships between body, motion and speech. An analysis of an example. In A. W. Siegman and B. Pope (Eds.), *Studies in dyadic communication* (pp.177-210). New York: Pergamon Press.

Kendon, A. (Ed). (1981). *Nonverbal communication, interaction and gesture. (Selections from Semiotica)*. The Hague: Mouton.

Kendon, A. (1982). The organization of behavior in face-to-face interaction: observations on the development of a methodology. In K. R. Scherer and P. Ekman (Eds.), *Handbook of methods in nonverbal behavior research*. Cambridge: Cambridge University Press.

Khan, H.I. (1996). *The mysticism of sound and music* (Rev. ed.). Boston, London: Shambala. **rCSW**

Kimura, D. (1993). *Neuromotor Mechanism in Human Communication*. New York: Oxford University Press.

Kinsbourne, M. and Hiscock, M. (1983). Asymmetries of Dual-Task Performance. In J.B. Hellige (Ed.), *Cerebral Hemisphere Asymmetry*. New York: Praeger Publishers.

Kleitman, N. (1963). *Sleep and wakefulness*. Chicago.

Knapp, M. L. and Hall, J.A. (1997). *Nonverbal communication in human interaction* (4th ed.). Fort Worth: Harcourt Brace.

Koetting, J. (1970). Analysis and Notation of West African Drum Ensemble Music. *Selected Reports in Ethnomusicology, 3*, 115-146.

Kolinski, M. (1973). A cross-cultural approach to metro-rhythmic patterns. *Ethnomusicology, 17*(3), 494-506. **RAK**

Kozhevnikov, V.A. and Chistovitsch, L.A. (1965). *Speech: Articulation and Perception* (Joint Public Research Service No.30543). Washington, D.C.: U.S. Department of Commerce.

Kubik, G. (1961). Transcription of Mangwilo Xylophone Music from Film Strips. *African Music, 3*(4), 36-41.

Kubik, G. (1983). Kognitive Grundlagen afrikanischer Musik. In A. Simon (Ed.), *Musik in Afrika.* (pp. 327-400).

Berlin: Staatliche Museen Preußischer Kulturbesitz.. **RAK**

Kubik, G. (1998). Intra African Streams of Influences. In R.M. Stone (Ed.), *Africa. The Garland Encyclopedia of World Music*, Vol.1, pp.293-326.

Kugler, P.N. and Turvey, M.T. (1987). *Information, Natural Law, and the Self-Assembly of Rhythmic Movement*. Hillsdale, NJ: Erlbaum.

Langer, S. (1953). *Feeling and Form: A Theory of Art.* New York: Scribner.

Large, E.W. and Kolen, J.F. (1994). Resonance and the perception of musical meter. *Connection Science: Journal of Neural Computing, Artificial*

Intelligence and Cognitive Research, 6(2-3), 177-208. **EL**

Large, E. W. and Jones, M.R. (1999). Articles - The Dynamics of Attending: How People Track Time-Varying Events. *Psychological review, 106*(1), 41.

Large, E.W. (2000). On synchronizing movements to music. *Human Movement Science, 19*, 527-566. **EL**

Large, E.W., Fink, P., and Kelso, S. (2002). Tracking simple and complex sequences. *Psychological Research, 66,* 3-17. **NbZ**

Lenneberg, E. H. (1967). *Biological foundations of language*. New York: Wiley.

Llinas, R. (1988). The intrinsic Electrophysiological Properties of Mammalian Neurons. *Science, 242*, 1654-1664.

Locke, D. (1992). *Kpegisu: A War Drum of the Ewe*. Tempe, AZ: WhiteCliffs Media.

Lomas, J. and Kimura, D. (1976). Intrahemispheric interaction between speaking and sequential manual activity. *Neurophsychologica, 14,* 23-33.

Lomax, A. (1982). The cross-cultural variation of rhythmic style. In M. Davis (Ed.), *Interaction rhythms. Periodicity in human behavior*. New York: Human Sciences Press.

London, J. (1995). Some examples of complex meters and their implications for models of metric perception. *Music Perception, 13*(1), 59-77.

Lopez da Silva, F.H. (1991). Neural mechanism underlying brain waves: from neural membranes to networks. *Electroencephalogr. Clin. Neurophysiol, 79*, 81-93.

Lopez da Silva, F.H., and Storm van Leeuwan, W. (1978). The cortical alpha rhythm in dog; the depth and surface profile of phase. In M.A.B. Brazier and H. Petsche (Eds.), *Architectonics of the Cerebral Cortex* (pp.319-333). New York: Raven Press.

Lucas, G. (2002). *Os sons do rosario: o Congado mineiro dos Arturos e Jatoba*. Belo Horizonte: Editora UFMG. **GL**

MacNeilage, P.F. (1998). The frame/content theory of evolution of speech production. *Behavioral and Brain Sciences, H. 21*, 499-546.

Mates, J., Müller, U., Radil, T., and Pöppel, E. (1994). Temporal integration in sensorimotor synchronization. *J.Cogn. Neuroscience, 6,* 332-340. **rCSW**

Mattingly, I. and Studdert-Kennedy, M. (1991). *Modularity and the Motor Theory of Speech Perception*. Hillsdale, NJ: Erlbaum.

Maulsby, L. (1971). An illustration of emotionally evoked theta rhythm in infancy: hedonic hypersynchrony. *Electroencephalogr. Clin. Neurophysiol, 31*, 157-165.

May, R.M. (1976). Simple mathematical models with very complicated dynamics. *Nature, 261*, 459-467.

Mayberry, R.I., Jaques, J., and Dede, G. (1998). What stuttering reveals about the development of the gesture-speech relationship. In J.M. Iverson and S. Goldin-Meadow (Eds.), *The Nature and Function of Gestures in Children's Communication. New Directions for Child Development*, no.79. San Francisco: Jossey-Bass.

McAuley, J. Devin. (1995). *Perception of Time as Phase: Toward an Adaptive-Oscillator Model of Rhythmic Pattern Processing*. Indiana University PhD Dissertation, Computer Science and Cognitive Science. Also: Cognitive Science Technical Report # 151.

McGrath J. E. (1988). *The Social psychology of time : new perspectives*. Newbury Park, London: Sage.

McGrath J. E. and Kelly, J.R. (1986). *Time and human interaction: toward a social psychology of time*. New York: Guilford Press.

McIntosh, G.C., Brown, S.H., Rice, R.R., and Thaut, M.H. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology Neurosurgery and Psychiatry, 62*(1), 22-26.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. Chicago: University of Chicago Press.

Menaker, M. (2002). Biological clocks at the end of the 20th century. In V. Kumar (Ed.), *Biological rhythms* (pp.1-4). Berlin: Springer-Verlag.

Merker, B. (1999-2000). Synchronous chorusing and the origins of music. In C. Trevarthen (Ed.), *Rhythm, musical narrative, and origins of musical communication. Special issue of Musicae Scientiae* (pp.59-73).

Montagu, A. & F. Matson (1979). *The Human Connection*. New York: McGraw-Hill.

Moore. (1990). The circadian system of sleep-wake behavior. In J. Montplaisir and R. Godbout (Eds.), *Sleep and biological rhythms: Basic mechanisms and applications to psychiatry* (pp.3-10). London: Oxford University Press.

Nettl, B. (2000). *An Ethnomusicologist contemplates Musical Universals*. In N. Wallin, B. Merker, & S.Brown
(Eds.), *The Origins of Music* (pp.463-472). Cambridge MA: MIT Press. **JB**

Nuñez, A., Amzica, F., and Steriade, M. (1993). Electrophysiology of Cat Association Cortical Cells in Vivo: Intrinsic Properties and Synaptic responses. *Journal of Neurophysiology, 70,* 418-430.

Öhman, S. (1966). Coarticulation in VCV utterances: spectrographic measurements. *J. Acoustic. Soc. Am.*, 39, 151-168.

Orr, T. J., Myles, B. S. and Carlson, J. K. (1998). The impact of rhythmic entrainment on a person with autism. *Focus-on-Autism-and-Other-Developmental-Disabilities*. Fal: *Vol 13*(3), 163-166.

Oxman, J., Webster, C.D., and Konstantareas, M. (1978). Condon's multiple-response phenomenon in severely dysfunctional children: An attempt at replication. *Journal of Autism and Childhood Schizophrenia, 8*(4), 395-402.

Palmer, C. (1989). Mapping Musical thought to musical performance. *Journal of Experimental Psychology: Human Perception and Performance, 15*(12), 331-346. **LW**

Palmer, C. (1997). Music Performance. *Annual Review of Psychology, 48*, 115-138. **LW**

Parlitz, U., Junge, L., Lauterborn, W., and Kocarev, L. (1996). Experimental observation of phase synchronization. *Phys.Rev.E, 54*(2), 2115-2118. **rCSW**

Pereira, E. A. & N.P.M. Gomes. (2003). *Ouro preto da palavra: narrativas de preceito do Congado em Minas Gerais.*Belo Horizonte: Editora PUC Minas. **GL**

Pikovsky, A.S. (1985). Phase synchronization of chaotic oscillations by a periodic external field. *Sov. J. Commun. Technol. Electron., 30*, 85. **rCSW**

Pikovsky, A., Rosenblum, M., and Kurths, J. (2001). *Synchronization. A Universal Concept in Nonlinear Science*. Cambridge: Cambridge University Press. **rCSW**

Pittendrigh, C. S. (1975). *Circadian oscillations and organization in nervous systems*. Cambridge MA: MIT Press.

Pöppel, E. (1997). A Hierarchical model of Temporal Perception. *Trends in Cognitive Sciences, 1*, 56-61.

Port, R., Cummins, F., and Gasser, M. (1996). A dynamic approach to rhythm in language: Toward a temporal phonology. In B. Luka and B. Need (Eds.), *Proceedings of the Chicago Linguistics Society*, 1995 (pp.375-397). Department of Linguistics, University of Chicago.

Prince, A., and Smolensky, P. (1997). Optimality: From neural networks to universal grammar. *Science, 275*, 1604-1610. **EL**

Prögler, J.A. (1995). Searching for Swing: Participatory Discrepancies in the Jazz Rhythm Section. *Ethnomusicology, 39*(1), 21-54.

Quantz, Johann Joachim. (1752). *Versuch einer Anweisung die Flöte traversiere zu spielen*. Berlin: Johann Friedrich Voß. **BS**

Qureshi, R. B. (1987). Musical Sound and Contextual Input: a Performance Model for Musical Analysis. *Ethnomusicology, 31*, 56–86.

Qureshi, R. B. (1995) [(1986)]), *Sufi music of India and Pakistan*. Chicago [Cambridge].

Ramos, J. and Corsi-Cabrera, M. (1989). Does Brain Electrical Activity React to Music? *Intern. J. Neuroscience, 47*, 351-357.

Rasch, R.A. (1988). Timing and synchronisation in ensemble performance. In J. A. Sloboda (Ed.), *Generative Processes in Music* (pp. 70-90). Oxford: Oxford University Press. **LW**

Rayleigh, J. (1945). *The theory of Sound*. New York: Dover Publishers.

Repp, B.H. (1992b). Probing the cognitive representation of musical time. Structural constraints on the perception of timing perturbations. *Cognition, 44*, 241-281. **LW**

Repp, B.H. (1998). A microcosm of musical expression: I. Quantitative analysis of pianists' timing in the initial measures of Chopin's Etude in E major. *Journal of the Acoustical Society of America, 104*, 1085-1100. **LW**

Repp, B.H. (1999b). Relationships Between Performance Timing, Perception of Timing Perturbations, and Perceptual-Motor Synchronisation in Two Chopin Preludes. *Australian Journal of Psychology, 51*(3), 188-203. **LW**

Repp, B.H. (2002). Phase correction in sensorimotor synchronization: Nonlinearities in voluntary and involuntary responses to perturbations. *Human Movement Science, 21*, 1-37. **EL**

Rhardisse, N. and Abry, C. (1995). Mandible as syllable organizer. *Proceedings of the XIII International Congress of Phonetic Sciences, 3*, 556-559.

Rider, M. S. and Eagle, C.T. (1986). Rhythmic entrainment as a mechanism for learning in music therapy. In J.R. Evans and M. Clynes (Eds.), *Rhythm in psychological, linguistic, and musical processes*. Springfield, IL, U.S.A.: C.C. Thomas.

Risset, J.-C. and Wessel, D. (1999). Exploration of Timbre by Analysis and Synthesis. In D. Deutsch (Ed.), *The Psychology of Music* (2nd ed.). San Diego: Academic Press.

Rosen, R. (1985). *Anticipatory System*. New York. **NbZ**

Rossi, E. L. and Lippincott, B.M. (1992). The wave nature of being: Ultradian rhythms and mind-body communication. In D. Lloyd and E. L. Rossi (Eds.), *Ultradian rhythms in life processes* (pp.371-402). London: Springer-Verlag.

Rössler, O.E. (1976). An equation for continuous chaos. *Phys. Lett. A*, 57(5), 397.

Rouget, G. (1984). *Music and Trance: A Theory of the Relations between Music and Possession*. Translation from the French revised by Brunhilde Biebyck. Chicago and London: The University of Chicago Press. **MM**

Rubin, D. (1995). *Memory in Oral Traditions*. Oxford: Oxford University Press. **NbZ**

Rusak, B. (1990). Biological rhythms: From physiology to behavior. In J. Montplaisir and R. Godbout (Eds.), *Sleep and biological rhythms: Basic mechanisms and applications to psychiatry* (pp.11-24). London: Oxford University Press.

Sachs, C. (1953). *Rhythm and tempo*. New York.

Sager, R. (2002). Musical Meaning of Haitian Vodou Singing: An Ethnography of Musical and Ritual Discourse at a *Lakou Ginen* in Northern Haiti. Ph.D. dissertation, University of Texas at Austin.

Schimmelpenninck, A. (1997). *Chinese Folk Songs and Folk Singers. Shan'ge Traditions in Southern Jiangsu.* Ph.D. Chime Foundation, Leiden. **FK**

Schmidt, R.C., Carello, C., and Turvey, M. T. (1990). Phase transition and critical fluctuations in the visual coordination of rhythmic movements between people. *JEP: Hum Percp & Perf 16,* 227-247.

Seeger, C. (1974). *Selected Reports in Ethnomusicology* [melograph issue] 2(1). Los Angeles: University of California Press.

Shaffer, L.H. (1984). Timing in Solo and Duet Piano Performances. *The Quarterly Journal of Experimental Psychology, 36A*, 577-595. **LW**

Shaffer, L.H., Clarke, E.F., and Todd, N.P.M. (1985). Metre and rhythm in piano playing. *Cognition, 20*, 61-77. **LW**

Sing, H.C. (1992). Human biological rhythms: the search for ultradians in movement activity behaviour. In D. Lloyd and E.L. Rossi (Eds.), *Ultradian rhythms in life processes* (pp.339-370). London: Springer-Verlag.

Singh, J. (1980). *Spanda Karikas: The Divine Creative Pulsation*. Delhi Varanasi-Patna: Motilal Banarsidass. **MM**

Small, C. (1998). *Musicking: The meanings of performing and listening*. Hanover: University Press of New England.

Sternberg, S., Monsell, S., Knoll, R.L., & Wright, C.E. (1978). Latency and duration of rapid movement sequences: comparison of speech and typewriting. In G.E. Stelmach (Ed.), *Information processing in motor control and learning* (pp.117-152). New York: Academic Press.

Strogatz, S. H. and Stewart, I. (1993). Coupled oscillators and biological synchronization. *Scientific American, 269*(6), 68-75.

Strogatz, S.H. (2000). *Nonlinear Dynamics and Chaos*. Cambridge, MA: Westview Press.

Strogatz, Steven. (2003). *SYNC: The Emerging Science of Spontaneous Order.* New York. **NbZ, rCSW**

Suliţeanu, Ghizela. (1972). *La valeur d'un "temps rythmique primaire" dans le folklore enfantin.* In *Rad XVI Kongresa Saveza Udruženija Folklorista Jugoslavije* [Proceedings of the 17th Congress of the Union of Yugoslav Folklorists] (Poreč 1970), Zagreb, pp.467-473. **MM**

Suliţeanu, Ghizela. (1978). *Le lieu et l'importance de la catégorie des chansons pour enfants dans le folklore musical*. In *Rad XVIKongresa Saveza Udruženija Folklorista Jugoslavije* [Proceedings of the 16th Congress of the Union/Association of Yugoslav Folklorists] (Igalu 1969), Cetinje, pp.323-333. **MM**

Suliţeanu, Ghizela. (1986). *Cîntecul de leagăn* [The Lullaby]. Bucureşti: Editura Muzicală. **MM**

Sundberg, J. (1999). The Perception of Singing. In D. Deutsch (Ed.), *The Psychology of Music* (2nd ed.). San Diego: Academic Press.

Tass, P., Rosenblum, M.G., Weule, J., Kurths, J., Pikovsky, A.S., Volkmann, J., Schitzler, A., and Feund, H.J. (1998). Detection of n:m phase locking from noisy data: Application to magnetoencephalography. *Phys. Rev. Lett., 81*(15), 3291-3294.

Ten Hoopen, M. and Reuvert, H.A. (1967). Analysis of sequences of events with random displacements applied to biological systems. *Mathematical Biosciences, 1,*.599-617.

Thaut, M. (1990). Physiological and motor responses to music stimuli. In R. F. Unkefer (Ed.), *Music therapy in the treatment of adults with mental disorders. Theoretical bases and clinical interventions*. New York: Schirmer.

Thaut, M.H., Kenyon, G.P., Hurt, C.P., McIntosh, G.C., and Hoemberg, V. (2002). Kinematic optimization of spatiotemporal patterns in paretic arm training with stroke patients. *Neuropsychologia, 40*(7), 1073-1081.

Todd, N. P. McA., D.J. O'Boyle, and C.S. Lee. (1999). A sensory-motor theory of rhythm, time perception and beat induction. *Journal of New Music Research, 28,* 5-28. **EC**

Treffner, P. and Turvey, M.T. (1993). Resonance constraints on rhythmic movement. *JEP: Hum. Percp & Perf., 19,* 1221-1237. **MRJ**

Treffner, J. P. and Kelso, S. (1999). Dynamic encounters: Long-memory during function stabilization. *Ecological Psychology, 11,* 103-137. **NbZ**

Trevarthen, C. (1999-2000). Musicality and the intrinsic motive pulse: evidence from human psychobiology and infant communication. In C. Trevarthen (Ed.), *Rhythm, musical narrative, and* *origins of musical communication. Special issue of Musicae Scientiae* (pp.155-215).

Volkov, Solomon. (1998). Conversations with Joseph Brodsky. A Poet's Journey Through the Twentieth Century. New York: The Free Press (Simon & Schuster). **FK**

Vorberg, D. and Hambuch, R. (1977). On the Temporal Control of Rhythmic Performance. In J. Requin (Ed.), *Attention and Performance*, vol. VII, (pp.535-555). New York: Academic Press. **EC**,**LW**

Vorberg, D. and Wing, A. M. (1996). Modeling variability and dependence in timing. In H. Heuer and S. W. Keele (Eds.), *Handbook of Perception and Action II: Motor Skills* (pp. 181-262). London: Academic Press. **MRJ**, **LW**

de Waal, Frans. (2001). *The Ape and the Sushi Master, Cultural Reflections by a Primatologist.* London: Allen Lane, Penguin Press. **FK**

Walker, J.L. (1977). Subjective reactions to music and brain wave rhythms. *Physiological Psychology, 5*, 483-489.

Walter, W.G. (1953). *The living brain*. New York: Norton.

Wang, Y., and Brown, M. (1996). A flexible model for human circadian rhythms. *Biometrics, 52*, 588-596.

Warner, R. (1988). Rhythm in social interaction. In J.E. McGrath (Ed.), *The Social psychology of time: new perspectives* (pp.63-88). Newbury Park, London: Sage.

Warner, R., Malloy, D., Schneider, K., Knoth, R., and Wilder, B. (1987). Rhythmic Organization of Social Interaction and Observer Ratings of Positive Affect and Involvement. *Journal of Nonverbal Behavior, 11*(2), 57-74.

Waterman, C.A. (1995). [Response to Participatory Discrepancies Special Issue]. *Ethnomusicology, 39*(1), 92-94.

Webb, J. T. (1972). Interview synchrony: an investigation into two speech rate measures. In A. W. Siegman and B. Pope (Eds.), *Studies in dyadic communication*. New York: Pergamon Press.

Weitz, S. (Ed.). (1974). *Nonverbal communication: Readings with commentary*. New York: OUP.

Widdess, D.R. (1994). Involving the performers in transcription and analysis: a collaborative approach to dhrupad. (with Ritwik Sanyal and Ashok Tagore) *Ethnomusicology, 38*(1), 59-80.

Wigram, T. (2002). Indications in music therapy. *British Journal of Music Therapy, 16*(1), 11-28.

Will, U. (1998). A Musicologist's dilemma: Technology and the Analysis of Music. *Finnish Yearbook of Ethnomusicology, 10*, 5-12.

Will, U. (in press). Oral Memory in Australian Song Performance and the Parry-Kirk Debate: a Cognitive Ethnomusicological Perspective. In E. Hickmann and R. Eichmann (Eds.), *Proceedings of the International Study Group on Music Archaeology, X*.

Will, U., Weingarten, R. & Nottbusch, G. (in press). Linguistic units, hierarchies and dynamics in word typing.

Will, U., Weingarten, R., Nottbusch, G. & Albes, C. (2002). Linguistische Rahmen und segmentale Informationen bei der Einzelwortschreibung. In Ch.Habel & T. Pechmann (Eds), *Sprachproduktion*. Opladen: Westdeutscher Verlag.

Williamon, R.A. and Davidson, W. (2002). Exploring co-performer communication. *Musicae Scientiae, 6*(1), 1-17. **LW**

Windsor, W. L., Ng,, K., Davidson, J.W., and Utley, A. (2003). Investigating musicians' natural upper body movements. Unpublished paper presented at the *International Conference on Music and Gesture*, Norwich, UK. **LW**

Wing, A.M. and Kristofferson, A.B. (1973a). The Timing of Interresponse Intervals. *Perception and Psychophysics, 13*, 455-460. **EC**, **MRJ**, **LW**

Wing, A.M. and Kristofferson, A.B. (1973b). Response Delays and the Timing of Discrete Motor Responses. *Perception and Psychophysics, 14*, 5-12. **MRJ**, **LW**

Wing, A. M., Allison, S., Cooper, N., and Thompson, S. (1992). Cooperative Timing on the River Cam. *Proceedings of the Fourth Workshop on Rhythm Perception and Production*. Paris: Université René Descartes. **LW**

Wing, A. M. and Woodburn, C. (1995). The coordination and consistency of rowers in a racing eight. *Journal of Sports Sciences, 13*, 187-197. **LW**

Yih, Y.M.D. (1995). Music and Dance of Haitian Vodou: Diversity and Unity in Regional Repertoires. Ph.D. dissertation, Wesleyan University.

Zeng, H., Oian Z., Myers, M., and Rosbash, M. (1996). A light-entrainment Mechanism for the Drosophila circadian clock. *Nature, 380*, 129-135.

Zuckerkandl, V. (1956). *Sound and symbol. Music and the external world*. New York: Pantheon.