Do discontinuous temporal windows in metrical music point to open-loop motor control? A musicological and cross-cultural analysis of rhythmic timing planning.

Andrew McGuiness (andymcguiness@yahoo.com.au)
Australian Centre for the Arts & Technology
Australian National University, Canberra ACT 0200

Abstract

Metrical music is commonly perceived as segmented into phrases at durations above the level of the tactus, up to temporal intervals of approximately 3 secs. These segments are normally contiguous and non-overlapping. Examples of similar temporal segmentation are found in human utterances and in human mother-infant interactions. Standard reference beat patterns such as the Cuban clave and African bell patterns are in this order of duration, and have rotation symmetry only at the level of the whole pattern. The start point of the patterns is either musically inherent or culturally understood. Various researchers have found the existence of musically meaningful deviations of less than 60ms from quantised rhythm, a level of timing control not possible through closed-loop kinaesthetic feedback control, which has a cycle time in the order of 100ms. I propose that reference beat patterns provide a guide to performers in a group as to the start point of a recurring open-loop timing control interval.

Introduction

This paper examines the evidence for the existence of open-loop control mechanisms for the perception and production of rhythms in metrical music over durations of ~3000ms.

For convenience, the "moderate tempo" pulse identified by (Parncutt, 1994) and others (Fraisse, 1982; Moelants, 2002) is here referred to as the tactus and its period is assumed to vary around ~600msec, with lower and upper limits roughly half and double that period respectively. Tactus subdivisions are discussed, and the paper also deals with finer-grained timing control, below the level of tactus subdivisions.

A review of motor theory relevant to control at tactus and tactus subdivision levels is followed by a review of Liberman and Mattingly's motor theory of speech perception. (Liberman & Mattingly, 1985) The fine motor control at tolerances of less than 60msec required for speech is related to systematic timing deviations from strict meter, found in a variety of musics. (Beran & Mazzola, 2000; Bilmes, 1993b; Freeman & Lacey, 2002; Stange-Elbe & Mazzola, 1998)

Temporal segmentation at the ~3 second level in human communication is identified with the psychological, or subjective, present (Turner & Pöppel, 1988). An important feature of the subjective present as identified here is its discontinuous, non-overlapping nature. Finally, a musicological discussion of period segmentation in traditional Central African and West African drumming, in Afro-Cuban music, and in North Indian music is related to the subjective present.

A model is proposed in which the subjective present is seen as a window in which fine temporal control of motor actions can be projected via a feed forward model, and carried out without reference to peripheral feedback.

Motor preplanning

Motor programs were defined by Keele, writing in 1968, (S. W. Keele, 1968) as "a set of muscle commands that are structured before a movement begins, and that allows the entire sequence to be carried out uninfluenced by peripheral feedback". Peripheral feedback may include both sensory and kinaesthetic feedback.

(Freund, 1989) showed that only hand movements with a frequency of 2 HZ (500ms intervals) are under visual control, with faster movements resulting from "subconscious automatic processes controlled by the cerebellum." (Seifert, Olk, & Schneider, 1995) Wing suggested that delayed tapping adjustments to small temporal perturbations (between –10msec and +50msec) in delayed feedback for 350msec periods indicated that normal operation of isochronous tapping was open loop. Wing concluded that repetitive response timing was normally under open loop control, but that subjects did process auditory feedback associated with the responses on some occasions. (Wing, 1977, 1980)

Kinaesthetic control at the tactus subdivision level

Keele reviewed experimental studies that tested the use of kinaesthetic feedback. Subjects with high kinaesthetic sensitivity became progressively better at the Two-hand Coordination Task than subjects with low kinaesthesic sensitivity. Kinaesthetic responses to a sudden increase in tension opposing a movement were in the order of .16 sec. (S. W. Keele, 1968)

Adams made a case for kinaesthetic feedback involvement in fast movements, such as the fastest movements made by a pianist's fingers, citing an EMG study by Sears and Davis (Sears & Davis, 1968) where EMG response in the respiratory muscles to a change of pressure load on the lungs showed a latency in the 50-60msec range. (Adams, 1976) It therefore appears that while sensory feedback may not be required for sequences of actions, peripheral kinaesthetic feedback may be used for control, and sequences may not be controlled exclusively by strictly open loop motor programs.

The separate timing control theory

Later conceptions of motor program theory, taking account of growing evidence against a feedback-based account of timing, do not deny that feedback (including proprioceptive feedback) plays an essential role in movement control, but suggest that feedback-response associations are not the mechanism used to time sequences of movements. (Summers & Burns, 1990) Summers & Burns argue for a separate representation for timing in motor programs, on the basis of studies showing that relative timing within a movement series remains constant across changes in the speed and size of action.

Analyses by Summers of learned keypress sequences (Summers & Burns, 1990), and by Terzuolo and Viviani of the timing of keystrokes in typing and in handwriting (Terzuolo & Viviani, 1980; Viviani & Terzuolo, 1980) also supported separate encoding of timing; as did a study of speech by (MacKay & Bowman, 1969).

Timing below the tactus-subdivision level

William Calvin, in several articles and books (Calvin, 1983, 1993), has argued that the evolution of accurate throwing for hunting (rather than threat-throwing, as practised by chimpanzees) involved a rise in the facility for offline planning of novel sequences of actions. (Calvin, 1983, 1993) Of particular interest is the fine control of timing required for accurate throwing. Calvin calculated that, to hit a rabbit-sized animal at 4 metres using an overarm throwing technique, release of the projectile needs to occur within an 11msec window. At 8 metres, the angle subtended by the target is halved and the launch velocity must be doubled to reach the target, so the release window required for accuracy shrinks to only a few milliseconds. (Calvin, 1983)

Humans can perceive the serial order of sounds in a familiar word such as "sand" at rates of 20msec per segment (R.M. Warren & Warren, 1970); with training (800 repetitions) listeners were able to identify the order of non-speech sounds (hiss-vowel-buzz-tone) with durations of less than 20msec. (R.M. Warren, 1974)

Shaffer et al examined durations of notes in "equal-note" groups (according to the notation), averaged over repeated performances by the same pianist of a piano piece by Erik Satie. Within-group differences were of the order of 50msec-100msec; Shaffer states that differences in form between different 4-note groups in the piece were large(Timmers, Ashley, Desain, & Heijink, 2000)r than differences between repetitions in different performances of the same group. (Shaffer, E.F.Clarke, & N.P.Todd, 1985)

The motor theory of speech perception

In their 1985 paper on a revised motor theory of speech perception, Liberman & Mattingly (Liberman & Mattingly, 1985) marshal evidence for the idea that speech perception distinguishes motor commands, rather than auditory events. They make a claim a specialised phonetic module that prevents listeners from hearing speech signals as ordinary sound, but translates auditory patterns into perceptions of the underlying phonetic gestures. (Liberman & Mattingly, 1985) Thus, perception of the distinction of the syllable ba versus pa would not (in the motor theory) depend on a general auditory ability to perceive temporal disparity as such, as suggested by (Pisoni, 1977), but would indicate unmediated perception of a gesture involving relative timing of vocal tract opening and start of laryngeal vibration. (Lisker & Abramson, 1964) Liberman & Mattingly argue that, since the distal object of perception in speech is neuromuscular processes giving rise to the phonetic gesture, perception must be carried out by analogy with neuromuscular processes within the listener; that is, the phonetic module is characterised by a link between perception and production. (Liberman & Mattingly, 1985)

It is clear from Liberman & Mattingly's examples that a fine-grained temporal control is required for speech at a level below that of the tactus subdivision, and down to the 10msec region. A noteworthy feature of perception in this region of temporal difference is that the perception comes whole: the perceiver can distinguish between percepts which depend on small temporal differences for their difference, but do not have access to the acoustic properties which trigger one percept rather than another.

Broadbent & Ladefoged found that untrained listeners could not initially discriminate the order of pairs of sounds with onsets separated by 150msec. With practice, they were able to discriminate order at interonset intervals of 30msec – not by perceiving order, but by a distinguishing each pattern by its perceived 'quality'. (Broadbent & Ladefoged, 1959)

Warren et al found subjects could distinguish between same and different orders of three synthesized vowels with item durations ranging from 10msec through to 5000msec, and with accuracy at all durations. At durations below 30msecs, the sequence of vowels were heard as temporal compounds, and distinguished by their timbre. (Richard M. Warren, 1993)

Microtiming – expressive deviation of rhythm in music

Various authors have undertaken studies of expressive timing variation in Western notated art music. Typically, this involves both local tempo changes as well as systematic variation of tactus subdivision durations that do not affect tempo. (Beran & Mazzola, 2000; Bilmes, 1993b; Freeman & Lacey, 2002; Stange-Elbe & Mazzola, 1998) Less work appears to have been undertaken on systematic timing deviation in groove music, where tempo, if not precisely invariant, does not vary locally. (Arom, 1991; Bilmes, 1993a; Iyer, 1998; Ladzekpo, 1995) Freeman & Lacey's work (Freeman & Lacey, 2002) on jazz swing in recordings by individual performers has identified consistent delays on specific beats of the bar that fall within 30msec windows. Bilmes applied computer beat extraction techniques to a multitrack recording of a Cuban drum ensemble, and found the variance for attacks of three of the drums, in relation to a reference timing pattern. Analysis of the deviations showed repeating patterns of deviation, mainly in a range of approximately 20msec-80msec ahead or behind the smallest tactus subdivision. (Bilmes, 1993a, 1993b)

Forward models for physiological motor control

Keele & Summers put forward a theory of motor programs in which "a central representation of a motor sequence [...] can in the absence of error be initiated and carried out without subsequent stimulation from kinaesthetic feedback." (Steven W. Keele & Summers, 1976)

Miall & Wolpert give one of the potential uses of forward models as distal supervised learning – where the goal and outcome of a movement are defined in task-related coordinates. (Miall & Wolpert, 1996) In terms of a physiological theory of rhythm, the coordinates would be in dimensions of both space and time, and might reference, for example, a particular point to strike on the drum head, at a particular point in the meter. Time coordinates could be given in terms of an hierarchical meter involving a reference pattern and tactus subdivisions (see the discussion of metrical reference patterns, below).

An important feature of the model I propose is that forward models of motor control may be used to achieve fine timing control of rhythm at timing resolutions below the tactus subdivision level, where neither sensory nor kinaesthetic feedback can provide online feedback.

The psychological present

Pöppel defined the "subjective present" as the temporal integrating level where temporal gestalt perception appears. (E. Pöppel, 1983)

Turner and Pöppel state that a human speaker will pause for a few milliseconds at about three second intervals, in order to determine syntax and wording of the next three seconds. They assert that meter in metered poetry functions to synchronise the speaker with the hearers' "so that each person's three-second present is in phase with the others". (Turner & Pöppel, 1988)

Dissanayake, in her survey of studies of mother-infant early interaction noted that mothers and babies participate in coactive (occurring almost simultaneously) and alternating kinesic patterns of emotionally expressive behaviours of face and body. (Dissanayake, 2000)

Pöppel provided a review of evidence for temporal segmentation at the 3 second level. Speakers, independently of language or age, tend to construct closed verbal utterances up to about 2 to 3 seconds. (Kowal, O'Connell, & Sabin, 1975; E. Pöppel, 1988; Vollrath, Kazenwadel, & Krüger, 1992) The duration of spontaneous intentional acts falls in a temporal window of approximately 3 seconds. (Schleidt, Eible-Eibesfeldt, & Pöppel, 1987) Pöppel concludes that there is a general temporal segmentation mechanism, and he terms the single states of 3-second segmentation "states of being conscious" (STOBCON, each representing "a mental island of activity distinctly separated from the temporally neighbouring ones". (Ernst Pöppel, 1996)

Period segmentation in traditional Central African music

An important device in the organization of central African rhythm is the production of macroperiods through the superposition of two or more periods of different length, in a ratio to each other of (for example) 2:3 or 3:4. The macroperiod in this case is defined by the coincidence of the beginning of all periods, which occurs at a tactus count of their lowest common denominator. (Arom, 1991) The periods themselves comprise groupings of subdivisions of the tactus (which may or may not make up a whole number of tactus pulses). How long them, are the macroperiods defined by these different devices?

The rhythmic cells for the dance of the Dakpa male initiation rites carry over two pulses, and Arom gives the tempo as 112 bpm, making the longest period defined only about 1070msec. However, Arom gives several two- and three-part

examples drawn from Aka pygmy music of macroperiods four pulses long, and six three-part examples which are eight pulses long – even at a faster tempo of 160 bpm, these macroperiods would be 3000msec long.

The Derler system

The Derler system was developed as a formal theory by Alfons Dauer, Rudolf Derler and Michael Pfob (Dauer, 1988, 1989). Taking the number of fastest pulses in a recurring cycle (ie. subdivisions of the tactus) as the form number, its subset of the number of actual onsets in the cycle gives the beat number. The set of all possible positions of the onsets in one cycle is called the rhythm set. (Seifert et al., 1995) A form number of five and a beat number of three allows 10 possible distributions of the three beats on the five pulses, or 10 elements in the rhythm set. The 10 elements of the form-5, beat-3 rhythm set are shown in Table 1.

Rhythms A, C, F, G and J in Table 1 form an equivalence set in the Derler system. Rhythms B, D, E, H and I form the only other equivalence set for form number 5 with beat number 3. (Seifert et al., 1995)

Table 1. Drawn from a figure provided in (Seifert et al., 1995).
Form number = 5; beat number = 3
x represents a realized beat; . represents an empty fastest pulse.

A	x	x	x	.	.
B	x	x	.	x	.
C	x	x	.	.	x
D	x	.	x	x	.
E	x	.	x	.	x
F	x	.	.	x	x
G	.	x	x	x	.
H	.	x	x	.	x
I	.	x	.	x	x
J	.	.	x	x	x

Bell patterns and other reference patterns

The circular nature of the time cycle in Central and West African drumming is asserted by (Anku, 2000). The cycle is defined by a recurrent bell pattern, which however may not necessarily be realised in all musical situations. Only one element of the equivalence class from the appropriate rhythm set is used by a particular culture, while other cultures will utilise a different element from the same equivalence set. Different elements of the same equivalence class, as used by three different cultures, are shown in Table 2.

Table 2. Drawn from figures given in (Anku, 2000).

Region Culture	Bell pattern (equivalence class element)
Ghana	x . x . x x . x . x . x
Anlo Ewe people	| | | |
Central Africa	x . x x . x . x . x x .
Bemba people	| | | |
Nigeria	x . x . x x . x . x
Yoruba people	| | | |

The only difference between the patterns shown in figure 2 is their relation to the tactus (shown beneath the bell rhythm), and the point in the pattern at which they start. Once a starting point for the pattern is fixed (by cultural convention), the expert listener can always unambiguously identify the starting point of the whole pattern – the macroperiod – from hearing the realised pattern.

The standard clavé pattern of Afro-Cuban music functions in a similar way (Figure 3). Here, although cultural agreement still applies, the starting point can be argued to be perceptually determined through experimentally determined onset salience and grouping effects. Only the first onset and the last onsets in the pattern actually fall on a tactus. The second of the two realised beats at the end of the pattern separated by a distance of two fastest pulses will tend to be heard with an accent, as the second of the two is followed by a longer empty interval. The first of those two beats might otherwise be heard as the beginning of the group, as it follows the longest empty interval (3 fastest pulses). Instead, the other group of 3 empty pulses that follows the two end beats produces a grouping effect, so that the next beat is heard as the beginning of the pattern. The clavé, like the West African bell patterns shown in Table 2, exhibits no rotational symmetry, except at the level of the whole pattern. It functions to effectively define the start and duration of a macroperiod, in the same way as African bell patterns.

Table 3. Cuban clavé pattern

	x . . x . . x . . . x . x . . .
tactus	| | | |

Similarly, the first beat of the tal in North Indian music does not need to be marked with a special gesture, despite its structural importance in the music, because it is determined unambiguously by the asymmetrical nature of the clap pattern - musicians and musically-educated listeners know

where the first beat lies. The tal as a whole, however, is always explicit. (Clayton, 1997)

The clavé, the West African bell patterns, and the tal all seem designed to synchronise the phase of the "specious present" for musicians and listeners alike, in a similar way to the universal 10-syllable line of metered verse, noted by Turner and Pöppel above.

Summary

The physical embodiment of rhythm in movement and dance to groove music (including traditional African drumming, and African diasporic musics) has been discussed by many authors. (Arom, 1991; Blacking, 1973; Iyer, 1998; Ladzekpo, 1995) Pressing (Pressing, 2002) suggest that stimulation to movement assists memory by providing multiple codings of timing (auditory and motor). I propose that a common forward planning mechanism for physiological control of timing may be at work in rhythmic behaviours which segment time into discontinuous periods of approximately 3 seconds (the "psychological present"); and that it is mechanism which provides the control of timing required for both fluent coarticulation of phonemes in speech, and the systematic microtiming deviations found in groove musics.

Acknowledgments

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