

Groove microtiming deviations as phase shifts

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ABSTRACT

Several studies of microtiming deviation in groove musics of the African diaspora have argued that deviations from a regular beat which do not affect the global tempo) are an essential component of the groove, rather than a product of poor timing by performers (Alén, 1995; Bilmes, 1993b; Cholakis, 1999; Freeman & Lacey, 2002; Waadeland, 2001). Data available from two studies (Alén, 1995; McGuinness, 2005) yield phase deviations in the range of approximately 5msecs to 50msecs in absolute values.

The existence of phase corrections in response to subliminal timing perturbations - below the detection threshold for ISI changes - has been established in a number of studies (Repp, 2000, 2001a, 2001b, 2002a, 2002b; M. Thaut, Tian, & Azimi-Sadjadi, 1998; M. H. Thaut & Kenyon, 2003). Entrainment models incorporating separate phase correction and period correction terms have been described by (E.W. Large & Kolen, 1994), (Mates, 1994a), (M. H. Thaut, Miller, & Schauer, 1998), and (E.W. Large & Jones, 1999); but make no prediction about the respective location of period and phase within the Wing & Kristofferson two-process model of internal clock and motor implementation (A.M. Wing & Kristofferson, 1973a).

This paper proposes that 1) systematic microtiming deviations are phase shifts; and that 2) phase correction processes in entrainment are located in the motor (implementation) stage of the Wing & Kristofferson model. The idea of functional anticipation is introduced, which accounts for entrainment phase corrections, microtiming deviations, synchronisation error in tapping studies, and adaptation to latency in musical instruments.

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INTRODUCTION

Several studies of microtiming deviation in groove musics have argued that the deviations are an essential component of the groove, rather than a product of poor timing by performers. The main argument for the musical, rather than random, nature of microtiming deviations rests on the consistency with which deviation patterns are repeated in the same or similar musical contexts.

Alén (Alén, 1995) found deviation patterns in *Tumba Francesca* music of Cuba, which were consistent for each drum part to each pattern in a dance; but which varied between drums in the pattern, and between patterns. 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. Analysis of the 8-bar drum break by drummer Clyde Stubblefield on the track *The Funky Drummer*, on the James Brown album *In the Jungle Groove* (Brown, 1986) by Clyde Stubblefield also shows consistent microtiming deviations (McGuinness, 2005). 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 tactus subdivision. Experiments in which resynthesised recordings were played to subjects found that listeners preferred the recording which had been quantised and then had recorded deviations added to it, over both the quantised track (which they found mechanical), and the quantised track with random deviations added to each attack time (which they characterised as "sloppy" or "random") (Bilmes, 1993a, 1993b). At least as convincing of the musical import of microtiming deviations as the studies above, because of their commercial viability, are Ernest Cholakis's DNA Beat Templates. The Beat Templates are files which can be loaded into a MIDI sequencer and which enable quantisation of rhythm patterns in the sequencer, according to typical deviation patterns as played by a famous drummer (eg. Bernard Purdie, or Clyde Stubblefield) (Cholakis, 1999). Each commercially available CD of Beat Templates files provides a variety of feels, each with its own characteristic microtiming deviation, which Cholakis extracts from audio files via his own beat detection software (Cholakis, 2003).

These studies, although limited in number, provide definite evidence that microtiming deviations are a musically significant phenomenon and at some level under the (probably unconscious) control of the performer. How does human entrainment (naturally central to rhythmic musical processes) work to produce – or at least to accommodate – systematic microtiming variation?

Phase correction in response to subliminal perturbations

As a preliminary to evaluating current models of entrainment in relation to microtiming deviations, it is useful to establish how experimental subjects respond to small perturbations in isochronous tapping experiments; and to conceptually separate *period* from *phase* in repetitive behaviours.

The existence of phase corrections in response to subliminal timing perturbations (below detection threshold for ISI changes) has been established in a number of studies. (Repp, 2000, 2001a, 2001b, 2002a, 2002b; M. Thaut et al., 1998; M. H. Thaut & Kenyon, 2003) In all, there is strong evidence that phase correction occurs in response to timing perturbations below the detection threshold of about 4% of ISI, and definite evidence that period correction does not occur below this threshold. Despite some studies by Repp (Repp, 2002a, 2002b) in which subjects were required to attempt to suppress corrections in response to event timing shifts or permanent phase shifts, there is no concrete evidence that phase correction disappears above the detection threshold for timing perturbations.

The strongest evidence for engagement of phase correction below the perturbation detection threshold, and for period correction above that threshold, comes from a series of experiments by Bruno Repp, introducing a small timing perturbation at the end of the stimulus sequence in a synchronisation-continuation task (Repp, 2001b). Either the last inter-stimulus interval (ISI) was changed only (a phase shift in the stimulus train, since no further tones were heard), or the last three or the last five were changed (a step tempo change in the stimulus train). The introduced changes – at +10msec or –10msec or 0msec – were below the threshold of detection and participants reported not noticing any ISI changes. Where only the last ISI was changed, the change was echoed immediately but inter-response intervals (IRIs) during continuation tapping returned to the baseline period of the stimulus train, so indicating a probable phase correction response. Where the last three ISIs were changed, the IRI adapts to the new period after a lag of one position and the adaptation partially persists during continuation tapping – indicating a probable period correction response. A stronger adaptation effect appears in the condition where the last five ISIs are changed, although the full 10msec correction to the period is still not evident in continuation tapping. Repp concludes that rapid phase correction is followed by more gradual period correction (Repp, 2001b).

MODELLING ENTRAINMENT

The Wing & Kristofferson two-process model for repetitive timing

As noted in (Edward W. Large, Fink, & Kelso, 2002), models of entrainment generally depend on the concept of an intrinsic frequency to give the period of rhythmic behaviour, with some degree of independence from the stimulus periodicity. The basic two-process model for the timing of repetitive discrete motor responses introduced by Wing and Kristofferson (A.M. Wing & Kristofferson, 1973a; A. M. Wing & Kristofferson, 1973b) has been influential in the literature: a central timekeeping process triggers motor responses; lags due to the time taken for neuromuscular transmission and for physical movement introduce a delay between the clock trigger and the motor response; and independent noise in both the central clock and the motor processes introduces variance to the timing of the IRI.

The fundamental model described by Wing and Kristofferson includes neither period correction nor phase correction and is intended only as a model of repetitively-timed actions – it models the autonomous rhythmic behaviour which is the basis for models of entrainment to an external stimulus. Models of entrainment have in general retained the concept of separate clock and motor responses, including (Aschersleben, 2002; Madison & Merker, 2002; Mates, 1994a, 1994b; Mates & Aschersleben, 2000; Mates, Müller, Radil, & Pöppel, 1994; Mates, Radil, & Pöppel, 1992; O'Boyle & Clarke, 1996; J. Pressing, 1998; Jeff Pressing, 1998, 1999; J. Pressing & Jolley-Rogers, 1997; Repp, 2000, 2001b; Semjen, Schulze, & Vorberg, 2000; M. Thaut & Miller, 1994; M. Thaut et al., 1998; M. H. Thaut & Kenyon, 2003; M. H. Thaut et al., 1998).

Entraining to a repetitive stimulus

For entrainment to occur, error correction processes must be introduced to the basic Wing and Kristofferson two-process equation. Pressing (Pressing, 1998a; Pressing, 1998b, 1999) extended and elaborated the Wing and Kristofferson model to produce an entrainment model with period correction (J. Pressing, 1998; Jeff Pressing, 1998, 1999). Although acknowledging the possibility of some control by expert musicians of phase shifts (Jeff Pressing, 1999) Pressing did not introduce error correction for phase independent of period: rather, adjustments to the clock interval are made to minimise phase asynchronies.

Error correction for entrainment has only one perceptual reference on which to base its process: the asynchrony between the stimulus and the produced response. Error correction processes for the internal clock can alter either its period, or its phase. As Repp demonstrates, the behavioural consequences of phase correction of the internal clock and period correction of the internal clock are indistinguishable in terms of the following observable asynchrony (Repp, 2001a). In fact, the stimulus which produces corrective behaviour in the model – a perception of a change in asynchrony – is itself ambiguous, in the sense that there is no way of knowing whether the first change in asynchrony represents a phase change or period change in the stimulus train. A phase shift (say, of 100msec in the positive direction) which affects the *phase* all subsequent stimulus onsets without altering their ISI, could theoretically elicit period change in the model (a longer period, then a return to the original period) – although a one-off phase shift would seem more economical. Conversely, a step tempo change (say, adding 100msec to the initial *period*, so that all subsequent ISIs were 100msec) could in theory be accommodated by an ongoing series of phase shifts, although in this case a corresponding period change would probably be expected.

Any model incorporating separate phase- and period-correction will have to deal gracefully with these two stimulus conditions, as well as others. As Semjen et al note, inter-response interval (IRI) variability is the result, at least in part, of error correction processes. In other words, the perceptual goal is stability of the phase error or asynchrony – also known as the synchronisation error (SE) – and correction processes will orient toward this goal (Semjen et al., 2000).

Introducing separate phase and period correction

Entrainment models incorporating separate phase correction and period correction terms have been described by (E.W. Large & Jones, 1999; E.W. Large & Kolen, 1994; Mates, 1994a; M. Thaut

et al., 1998). Thaut et al point out that the interdependence of the phase and period timing mean that the original phase relationship can only be restored following an unanticipated step change in ISI duration by a temporary ‘overcorrection’ – because changing the IRI duration to simply match the ISI will not correct for the phase change introduced by the first and any other ISI periods before the IRI duration was adjusted (M. Thaut et al., 1998).

Note that these models make no explicit prediction about the location of the phase correction process in the Wing & Kristofferson two-process model, locating it implicitly with the central clock process rather than in motor implementation, where I shall argue it should be.

Synchronisation error

Closely related to the problem of phase correction in human entrainment processes, is the phenomenon of persistent *synchronisation error* (SE) or small negative phase asynchrony in synchronisation tasks. Experimental studies of synchronisation tapping (Dunlap, 1910; J. Pressing, 1998; Repp, 2001a; Semjen et al., 2000; M. Thaut et al., 1998; Vos, Mates, & van Kruysbergen, 1995) show that taps tend to anticipate the metronome, with the amount of anticipation increasing with period. Pressing ascribes SE to compensation for consistent delays in neuroanatomical transmission and processing (Jeff Pressing, 1999).

Semjen et al raise a difficulty with this interpretation, finding that tap-metronome asynchronies in a synchronisation task varied with IOI, whereas anticipation which depended purely on the different delays with which auditory stimuli and motor responses are registered centrally would be (presumably) nearly constant (Semjen et al., 2000). Semjen et al’s experiment tested timing synchronisation tapping to a perfectly isochronous metronome, finding a mean phase difference across all subjects and trials of about –10msec for the shortest period of 200msec (where a negative asynchrony means that the tap preceded the metronome), about –15msec for a period of 400msec, and about –30msec for the longest period of 640msec (data in the paper is provided graphically) (Semjen et al., 2000). Thaut et al found a similar covariance of SE with ITI (inter-tap interval) size, with a mean asynchrony of –21msec for a 400msec period, and –30.3msec for a 600msec period (M. Thaut et al., 1998).

Synchronisation error is therefore due to some other cause than compensation for delays in auditory feedback or motor efferent transmission. In an experiment by Repp, auditory feedback from the subject’s taps made it more likely that the SE would be reduced so that the sound of the tap was closer to the (antiphase, in Repp’s experiment) synchronisation point (Repp, 2001a) – a result suggesting that clear sensory-motor goal may be an important factor affecting the amount of SE.

Functional anticipation

Repp suggests (Repp, 2001a) that phase resetting may occur as the result of motor persistence competing with sensorimotor coupling, an hypothesis which is similar to the ‘mixed reference’ strategy described by Hary and Moore (in which the subject is presumed to reference either the stimulus or their own tap) (Hary & Moore, 1987).

A different account (hereafter referred to as the *functional anticipation* theory) might consider the consistent anticipation in terms of the function negative asynchrony of action to stimulus might serve in timing purposeful actions. Hary and Moore use the term

‘reference interval’ for the delay between the clock trigger and the sensorimotor goal, occupied by neurophysiological transmission time, and possibly other latencies (Hary & Moore, 1987). Synchronisation tapping in experimental settings does not provide a clear perceptual goal for the subject, unless the tap produces audible feedback. If the evolutionary function of entrainment is to allow preparatory anticipation of and actual synchronisation with critical time points relative to processes external to the organism, then a consistent anticipation in the initiation of movements would enable synchronisation of the completion of the movement with external events.

According to this account, the SE – which is more prominent in the absence of a clear sensorimotor goal – would result from the automatic anticipation by the clock trigger of the stimulus, thus allowing time for the completion of the action so as to coincide with the stimulus. Where auditory feedback is available, it allows adjustment of the SE (or functional anticipation) to achieve the sensorimotor goal.

It would be necessary for the amount of functional anticipation by the clock trigger of the motor-sensory goal to be *variable*, in order to meet the different requirements of different actions and goals. However, once the amount of functional anticipation was established for a particular goal in the current context, it would need to be *consistent*, within the tolerance required in order to achieve the goal. The ability to adjust the amount of functional anticipation would be required in actions such as: catching, striking a target, throwing to hit a target, speaking in turn, striking a drum in time with others. Musicians routinely compensate for the different amount of time to make a violin, piano, trumpet, voice, trombone or drum speak, so that the perceptual onset will be in time with the beat and with other instruments. A keyboard player, for instance, can adapt to different electronic instruments with different latencies – so long as the latency is consistent for each instrument. Wright discusses the problem of latency for electronic instruments, and proposes 10msec as a good goal for manufacturers, while noting that the *jitter* - or variation - of the latency should be no more than 1msec (Wright, 2002).

It is apparent that functional anticipation utilises absolute, not relative, timing, since the time required to make eg. a brass instrument speak, or the latency of an electronic keyboard, will not scale with tempo. While SE *has* been found to scale with tempo, synchronisation tapping experiments where auditory feedback was provided each time the subject touched the key showed a reduced asynchrony (Aschersleben & Prinz, 1995; Mates et al., 1992; O’Boyle & Clarke, 1996), supporting the theory that where a sensorimotor goal is set up, taps are timed to achieve the goal.

In studies where a small delay (<100msec) was introduced between the touch on the key and the auditory feedback, (Aschersleben & Prinz, 1997; Mates & Aschersleben, 2000) an increase in asynchrony was observed with increasing delay, consistent with the functional anticipation theory. The observable synchronisation error, in this view, is one component in the total functional anticipation amount, which also includes the motor delay which is modelled in the classic two-process model of repetitively-timed movements of Wing and Kristofferson. To make explicit the whole chain from its source, the timed clock trigger travels through neural pathways to signal the start of the motor program, which is then executed to achieve a sensorimotor-temporal goal (such as the synchronisation of a drum sound with another onset.) For a human being, there will be a delay between the clock trigger which initiates the tapping action and the arrival

of auditory feedback from the tap in the central representation area, resulting from the cumulative delay of the nerve path from brain to muscles, the time taken to complete the physical action, the time taken for the sound to travel through the air to the ear drum, and finally the delay from ear drum to central representation area. The total functional anticipation amount is the time from clock trigger to the critical moment of perceived synchrony with the external event. Apart from the necessary and predictable delays associated with the transmission of the command and the actual physical execution of the movement, other factors may become part of the total delay between the clock trigger and the sensorimotor goal. For example, any latency inherent in the mechanism of a musical instrument will contribute to the delay – and therefore to the required amount of functional anticipation, so that the clock trigger would need to fire that much earlier at its central source.

If a timing inaccuracy occurs (perhaps due to a modification in the external goal), this will need to be accommodated by a correction to the amount of functional anticipation – this appears to an observer as a *phase correction* or *phase resetting*, but rather than a correction to *central clock* phase, it is one of the processes comprising *physical implementation* of an action timed to achieve a sensorimotor goal. If a negative correction is required (if the process is to be completed a little sooner after the clock trigger time) it will be useful for the chain to have included a small amount of gratuitous delay, part of which can be taken up to compensate for the timing shift in the stimulus.

Microtiming deviations as variations of functional anticipation amount

The latency between clock trigger and sensorimotor goal (the functional anticipation) will in general be of the order of the synchronisation error observed in tapping tasks, ie. less than 100msec and probably closer to 50msec. These amounts are consistent with microtiming variations found in Clyde Stubblefield's eight-bar drum break, on the James Brown album, *In The Jungle Groove* (Brown, 1986; McGuinness, 2005).

Adaptation to subliminal perturbations (below detection threshold for ISI changes) has been shown in a number of studies (Repp, 2000, 2001a, 2001b, 2002a, 2002b), including to continuously varied perturbations, on a sine wave curve (M. Thaut et al., 1998; M. H. Thaut & Kenyon, 2003), in a similar contour to varied microtiming deviation found in *Tumba Francesca* drumming of Cuba (Alén, 1995) and in Clyde Stubblefield's Funky Drummer break (McGuinness, 2005).

Repp has established that *period* correction is very small or non-existent for timing perturbations which are less than an amount approximately equal to the Weber fraction for tempo discrimination – approximately 5% of IOI (Repp, 2000, 2001a). In practice, microtiming deviations found in groove music appear range up to about 5% of period, with only a few individual deviations in some examples exceeding the 5% level by a significant amount (McGuinness, 2005) – ie. in a range too low to engage period correction (although of course, this does not exclude the possibility of period variation due to some other cause, such as the coupling of the clock oscillator with a driving oscillator with different period).

In all, it seems at least possible that groove microtiming is a property of phase processes located in the motor implementation stage

of human entrainment; although the precise mechanism by which particular patterns are produced is unclear.

IMPLICATIONS

On the assumption that microtiming variation is a variation in phase of implementation resulting from adjustment of the amount of functional anticipation, and given a central clock with stable period, a revised model of human entrainment would need to allow constrained variability of phase during motor implementation, while referencing the stable central clock. Microtiming deviations in groove¹ should not engage the period correction process, as it is essential the clock period remains stable. Phase corrections should consist of an adjustment in the amount of functional anticipation (the latency between the clock trigger and achievement of the sensorimotor goal); functional anticipation should include any allowance for neuroanatomical delays in afferent and efferent pathways, and time for the completion of the physical action required for the achievement of the sensorimotor goal. The phase correction process should be independent of clock period correction process, although both may be triggered by the same asynchrony between stimulus and response.

An important implication of the concept of functional anticipation is the identification of clock impulses as triggers for action. Since the range of synchronisation does not extend to periods smaller than 200msec (and possibly not that low) (Fraisse, 1982; Parncutt, 1994), some other mechanism must be hypothesised for timing control below this level. Since IOIs at this level (shortest values can be lower than 100msec) are too small to allow for adjustment based on peripheral feedback (Schmidt, 1975; Welford, 1974), they are presumed to be under the control of *open loop motor programs* (S. W. Keele, 1968; Steven W. Keele, 1987; Steven W. Keele & Summers, 1976). Given that, in musical situations at least, timing at the entrainment or tactus level and timing below that level are closely integrated, it appears that the tactus clocks may act to accurately trigger motor programs under open loop control. The upper temporal limit for such open loop programs appears to be so far undetermined, and there seems to be no evidence to indicate that their duration may not extend to the upper limit for entrainment to a tactus beat, in the region of 1000msec.

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¹ Note that groove microtiming appears to be based on entirely different processes from the subtle tempo changes which constitute much expressive timing in Western notated art music – see, for example, extensive work in (Battel, Bresin, De Poli, & Vidolin, 1994; Beran & Mazzola, 2000; Bresin, 1998, 2000; Canazza, De Poli, Di Federico, & Drioli, 1999; Canazza, De Poli, Drioli, Roda, & Zamperini, 2000; Canazza, De Poli, Roda, & Vidolin, 1997; Canazza, Roda, & Orio, 1999; Clynes, 1983, 1995; Desain, 1993; Desain & Honing, 1993; Friberg, 1995; Friberg & Bresin, 1997; Friberg, Bresin, Fryden, & Sundberg, 1998; Hirata & Hiraga, 2002; Hirata, Hiraga, & Aoyagi, 2000; Henkjan Honing, 1992; H. Honing, 2001; Madison, 2000; Mazzola & Zahorka, 1994a, 1994b; Palmer, 1989, 1996; Repp, 1990, 1992; Shaffer, 1980; Stange-Elbe & Mazzola, 1998; Sundberg, Friberg, & Fryden, 1991; Timmers, Ashley, Desain, & Heijink, 2000; Todd, 1985, 1989; Trilsbeek, Desain, & Honing, 2001; Widmer, 1994, 1996).

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