# Microtiming deviations in groove

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# DECLARATION

**The thesis and computational model comprising this submission are my original work. All sources of data and other information are acknowledged in the list of references.**

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# PREFACE

## *Physical creativity*

I was originally drawn to study fine motor control in musical performance because of a phenomenon I have experienced when performing at the piano. I found that, in situations where a musical piece (of Western notated art music, in this case) was sufficiently well known and any technical difficulties sufficiently overcome, the most finely-tuned and expressive execution of short passages was always unplanned and in fact not the execution which I had practised. I discovered that I could at times allow my hands to take over the performance, and that the result would be more subtle and musically successful than I had consciously anticipated. In light of the theory described in this thesis, it seems possible that those short passages were in fact under the control of open loop motor programs. The schemata for the motor programs appear to have been dynamically generated, and to have taken into account both the musical structure of the piece, as laid out in the notation, and ephemeral details of the current performance.

According to the theory outlined in this thesis, a series of open loop motor programs, triggered at intervals within the macroperiod, control timing at finer temporal levels than the tactus. The short passages I played seemed outside of cognitive control and yet took account of the musical context at different levels. If they were in fact under open loop motor program control, it would seem that the mechanism for generating the schemata for the motor programs is capable of dynamically integrating input and making creative decisions – a kind of *physical creativity*.

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# Extended Abstract

## Overview

Much work has and is being done on the topic of timing variation in Western notated art music: see Appendix A to this thesis and, representatively, (Bresin, 1998,2000; Bresin, De Poli, & Vidolin, 1992; Canazza, De Poli, Di Federico, & Drioli, 1999; Canazza, De Poli, Drioli, Roda, & Zamperini, 2000; Canazza, De Poli, Roda, & Vidolin, 1997; Canazza, Roda, & Orio, 1999; Cannazza, De Poli, Di Sanzo, & Vidolin, 1998; Clynes, 1983; Clynes, 1986a,b; Clynes, 1987; Clynes, 1992; Clynes, 1995; Clynes & Walker, 1982; Desain & Honing, 1991,1992,1993,1996; Epstein, 1988; Friberg, 1995; Friberg & Bresin, 1997; Friberg, Bresin, Fryden, & Sundberg, 1998; Gabrielsson, 1982; Honing, 1992; Honing, 2001; Mazzola & Zahorka, 1994a,b; Palmer, 1989,1996; Palmer, 1997; Palmer & Pfordresher, 2003; Palmer & van de Sande, 1995; Repp, 1990,1992,1998; Shaffer, 1980,1981; Shaffer, 1985; Shaffer, Clarke, & Todd, 1985; Sundberg, Friberg, & Fryden, 1991; Timmers, Ashley, Desain, & Heijink, 2000; Todd, 1985,1989; Widmer, 1994,1996,2000,2001). However, less investigation has been undertaken into microtiming deviations in repetitive musics with globally stable tempo. Such musics are here referred to inclusively as *groove musics* – some examples are: traditional African drumming; funk; and Latin music.

This thesis presents a theory (the *Covert Clock Theory*) and proposes a model of the production of musical groove. The computer model presented rests on arguments regarding what constitutes groove, both in a musical sense and - beyond the scope of musicology - in terms of how and why humans produce and respond to groove.

Through the examination of human perception and production of rhythm, I propose to develop a model, based on the Covert Clock Theory, of the generation of microtiming deviations characteristic of groove. Ideally, the model should be intuitively controllable by a musician setting a small number of parameters, and should generate deviation patterns which are musically useful and have similar characteristics to those generated by human musicians.

### What is groove microtiming?

Groove musics can be characterised as synchronic and repetitive. A macroperiod is defined within the music and material is repeated, with variations, in successive macroperiods. Systematic, consistent and musically significant variations from the temporal grid of strictly proportional timing have been found to exist in these musics, with deviations typically in the range ~5ms to ~50ms. Some limited musicological studies (see eg. (Bilmes, 1993b; Cholakis, 1999b; Freeman & Lacey, 2001; Freeman & Lacey, 2002)) of microtiming deviations in groove have been undertaken but these do not attempt to account for microtiming in terms of underlying timing processes. This thesis represents an attempt to integrate the musicology of microtiming with psychological and human movement theories of rhythmic timing control, in order to develop a theory of the process by which performers generate microtiming deviations. The theory and results have implications for the psychology of rhythm, for music technology, for musicology and music performance, and for motor planning theory in general.

### A new theory of rhythmic timing and entrainment

Theories and models of human rhythmic entrainment, musical timing and motor control are critically reviewed in light of the experimental and musicological literature. Evidence is presented for different psychological or perceptual processes for *a)* timing control within the range of rhythmic synchronisation, and *b)* time intervals below that range.

A new theory of production is presented in which a system of interlocking interval timers or clocks provides trigger signals to motor programs at the start of each isochronous interval. Interval timers with resting periods close to the period of the driving stimulus (which may simply be an isochronous pulse train) alter their period to entrain to the driving stimulus. Entrainment may be in any harmonic relation to the stimulus – clock triggers and stimulus pulses may be in a one-to-one relation, or a 1:2, 1:3, 1:4, 2:1, 3:1, or 4:1 relation. The ratios of clock period to stimulus period are effectively limited by the range of synchronisation, which is approximately between 200ms and 1500ms. Within this range, nested harmonic clocks may occur, with the longest period perhaps four times the shortest period. Harmonic relations between clock periods are more stable because they lead to most reinforcement between clocks, but non-harmonic ratios, although less stable, are also possible.

Interval timers with onsets which are temporally close interact to reset phase so that their onsets tend to occur together, without the involvement of any period correction process. In this way, clocks with harmonically related periods help to stabilise each other to produce more precise timing. No phase information is available from interval timers between triggers.

Timing control at intervals smaller than the current synchronisation period (ie. between the triggers of the fastest active interval timer) is achieved by open-loop motor programs triggered by the interval timer. Timing at this lowest level might (hypothetically) be achieved by means of a very fast (perhaps 1000Hz) oscillation and a counter mechanism, which are not available to cognitive control. Revisions to timing in the motor program schema are made following execution of the motor program, on the basis of sensory feedback.

The delay for revisions to take effect following execution is equal to the time needed for planning, sensory feedback, and any other delays attributable to the neuromuscular system. At least some of these delays contribute to the necessity for *functional anticipation* by the timer trigger of the sensorimotor goal. *Functional anticipation* is defined as the time between the timer trigger and the completion of the action. For instance, a sensorimotor goal of eg. producing a drum attack to be heard at a defined time within the rhythmic stream, requires a functional anticipation at least equal to the time needed to convey the command to the muscles and for the physical completion of the action.

Phase correction is modelled in the implementation of the Covert Clock Theory as a separate process from period correction - although referencing the same asynchronies between sensory feedback and expected sensory feedback following the interval timer trigger. Phase correction is thus a motor implementation process. In the theory, phase correction involves an adjustment to the amount of *functional anticipation.* The phase correction process functions in the same temporal range as microtiming deviations (ie. below ~50ms) and may be invoked in response either to subliminal timing perturbations of the driving stimulus, or to asynchronies resulting from interval timer errors or motor implementation errors.

## Original contribution

### The *Covert Clock* Theory

A new theory and computational model of microtiming deviations in groove music are presented. The *Covert Clock Theory* of microtiming deviations posits the existence of an internal clock or interval timer at a cross-rhythm to the tactus clock – that is, with a period at a non-harmonic ratio to the tactus period. Such cross rhythms are made explicit in eg. African traditional drumming, where a cross-rhythm of three beats against four beats of the tactus is often established.

The Covert Clock Theory suggests that the covert clock and the tactus interact so that a given clock onset may occur earlier or later, but without the actual period of the clock being adjusted. Early or delayed triggering of the beginning of the interval timer cycle will of course result in some inter-trigger periods being shorter or longer than the clock period; but a key point of the theory is that the clock retains its previously established period.

The coincidence of the main and covert clocks at every four beats of the tactus and every three beats of the covert clock (in the example given) defines the start of the macroperiod. The macroperiod has duration within the capacity of echoic memory – the ‘psychological present’.

The *Covert Clock Theory* can be seen as a means of extending the duration of motor programs. Other devices found in traditional African drumming are also discussed as fulfilling the same function.

### The *VROOGE* model

The *VROOGE* model of microtiming deviations in groove is a software implementation of the microtiming process described by the Covert Clock Theory. (The name *VROOGE* is simply an anagram of ‘groove’.) The VROOGE model entrains to an external isochronous pulse train through period correction of a main tactus interval timer. Weighted referencing by the motor timing process to both the tactus and the covert clock results in changes to the local tempo of motor program implementation, without altering the period of the underlying clock. This facet of the model corresponds to expansion or contraction of motor program duration, as described in the Covert Clock Theory. Local tempo changes in motor program implementation from one tactus trigger to another result in progressively increasing or decreasing deviations through the duration of the tactus. The deviation amount is in fact the integral of the tempo change relative to the base tempo given by the (unchanged) tactus clock.

The *VROOGE* model is evaluated through analysis of microtiming data of examples of groove music and comparison with model –generated data. Predictions of the theory are tested against the data and some agreement is found.

The VROOGE model is successful in providing a means of generating new musically meaningful microtiming deviation patterns by making a low number of parameter settings, to which the model responds in a musically intuitive way.