



# Testing the co-existence of two timing strategies for motor control in a unique task: The synchronisation spatial-tapping task



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## ARTICLE INFO

### Article history:

Received 4 December 2014

Revised 19 June 2015

Accepted 20 June 2015

Available online 21 July 2015

### Keywords:

Timing control  
Rhythmicity  
Spatial control  
Anchor point  
Coexistence  
Trajectory

## ABSTRACT

The control of rhythmic action sequences may involve two distinct timing strategies, i.e., event-based and emergent timing, which are usually revealed through finger-tapping and circle-drawing tasks, respectively. There is a lively debate concerning the possibility of coexistence of the two modes of timing for the execution of a single task. If one considers emergent timing as simply an absence of explicit representation of a time interval, then by definition, the two modes of timing cannot coexist. However, if one considers that emergent timing engages control of another motor parameter, e.g., a control of movement through space rather than time, then the possibility of coexistence needs to be reassessed. In the present study, we designed a hybrid of finger-tapping and circle-drawing tasks for which the demands for space and time control were present at the same time in order to reassess the coexistence hypothesis. Seventy-eight participants performed a spatial-tapping task in which finger taps were to be produced in synchrony with a regular metronome to 6 visual targets presented around a virtual circle. The metronome set ten distinct tempi (1100–300 ms). Using autocorrelation analyses on timing variables, we show that motor timing was event-based at slow tempi and emergent at faster tempi. Through an analysis of the trajectory, we confirm that an increase in the spatial control of movement took place congruently with a switch from event-based to emergent timing modes. At these fast tempi, timing and spatial errors were correlated but only at the specific target location for which a dynamical anchor point was revealed. Hence, we conclude that the coding of emergent timing has a spatial nature from which emerge timing regularities. This spatio-temporal strategy insures the performance of sequential motor actions when cognitive effort is too high for the use of pure event-based timing strategies.

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## 1. Introduction

Most daily activities require the planning of actions through space and time. Nevertheless, the task goal can be geared towards the needs to produce actions at a specific moment in time. For example, drumming to a beat requires a player to set the focus on the time intervals needed between successive keystrokes to perform a given rhythmic pattern. In this case, an explicit internal representation of the intervals of time separating the successive actions is needed. In order to produce

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well-timed actions, e.g., repeated finger taps at a precise and regular rhythm, classical models of timing assume the existence of an internal clock, a model that is based on the possible existence of a pacemaker, counter, store and comparator (Treisman, 1963). The pacemaker produces regular pulses. The counter records the number of pulses arriving during a given time interval, e.g., between the two clicks of a metronome, and transfers this measure to a referential memory. The counter then records the number of pulses relative to the produced interval of time, and transfers this measure into working memory. The referential and the produced interval are then compared, and a judgement can be made (e.g., the interval produced is shorter than the referential). If the deviation to the referential interval is significant, a correction can be made through successive adjustments, at a later point.

This mechanism of time control through discrete event coding, referred to in the literature as predictive timing or event-based timing, can be revealed through time series analyses of the successive intervals of time produced during a simple finger-tapping task (Vorberg & Wing, 1996; Wing & Kristofferson, 1973b). Classically, inter-response intervals (IRIs) are measured as the difference in time between the onsets of successive taps. A given series of IRIs are staggered at one or more positions ( $I_n$  is compared to  $I_{n+1}$ ) and correlation measures are performed. When timekeeping processes act to maintain a regular rhythm between successive actions, negative autocorrelation values (AC) are revealed at lag-1 while the values at greater lags are equal to zero (Wing & Kristofferson, 1973a), suggesting that a short interval is followed by a longer one, and vice versa. According to the W–K model, this negative AC-1 does not reflect immediate compensation of timing errors, but rather subtends low variability of the pacemaker to produce regular pulses. Indeed, the W–K model assumes the existence of two sources of variances to explain the variability observed in series of produced IRIs: a central source of variance related to the clock mechanism and a peripheral source of variance that reflects the motor implementation of the response, i.e., neuromuscular transmission lags. As it has been revealed through heartbeat interval patterns, when the variability of the pacemaker increases (e.g., in patients showing atrial fibrillation as compared to healthy individuals), negative dependencies in the heartbeats intervals significantly decreased at lag-1 (Ten Hoopen & Reuver, 1967). Hence, according to this biological model, the negative interdependency in series observed at lag-1 might reflect the stability of the pacemaker to produce regular pulses while a decrease in the negative AC-1 indicates an increase in the pacemaker instability. The measure of AC-1 values of IRIs are largely used today as an indicator of the involvement of event-based timing in motor timing tasks (see Repp, 2005; Repp & Su, 2013, for reviews on motor timing tasks, methods and measures).

It has been recently claimed that another mode of timing might exist for motor control, namely emergent or implicit timing, which is fundamentally different from the clock-like timing mode described above (Huys, Studenka, Rheaume, Zelaznik, & Jirsa, 2008; Robertson et al., 1999; Studenka & Zelaznik, 2008; Zelaznik, Spencer, & Doffin, 2000; Zelaznik, Spencer, & Ivry, 2002). While event-based timing is involved in tasks that require maintaining an explicit representation of the timing interval, emergent timing is assumed to result from the control of movement dynamics (Turvey, 1977). The first experimental evidences to distinguish between the two timing strategies were reported by Robertson et al. (1999), who compared variance measures of the IRIs between drawing and tapping tasks and found that temporal precisions in these tasks were not correlated. In addition, the autocorrelation values of IRIs varied with the distinct motor tasks with values being negative at lag-1 in finger-tapping tasks, and greater than zero in drawing tasks. Authors suggested that, in discrete tapping tasks, participants need to estimate when to bring the finger down on the surface device without any particular trajectory constraints, while in continuous drawing tasks information about the entire space trajectory is crucial to produce consistent and stable intervals of time. These results have now been replicated (Studenka & Zelaznik, 2008; Torre & Delignières, 2008; Zelaznik et al., 2000) and circle-drawing tasks are considered today as a valuable paradigm in the motor timing domain to reveal emergent timing properties. Importantly, clinical studies are now providing converging evidence that distinct neuronal systems are engaged according to each specific timing strategy that is implemented (Ivry, Spencer, Zelaznik, & Diedrichsen, 2002; Spencer & Ivry, 2005, 2007; Spencer, Zelaznik, Diedrichsen, & Ivry, 2003). Abnormalities in event-based timing are reported in patients with cerebellar damage whereas distortions of emergent timing are seen rather in Parkinson's disease, i.e., in patients with basal ganglia abnormalities.

While event-based and emergent timing are usually conceived as mutually exclusive timing strategies, it has been recently suggested that the two modes of timing could in fact coexist in a dual task situation. In their study, Repp and Steinman (2010) required participants to tap with their left hand and to draw circles with their right hand. After introducing phase shifts in a metronome series, phase correction responses (PCRs) were measured as the difference between the asynchrony associated with the phase shifted tone and the asynchrony associated to an estimate of when the response event should have occurred in the absence of phase shift. This measure was used as an indicator of the timing strategy used to control sequence production, with larger mean PCR expected in the case of event-based timing (in this case, several taps are usually required to correct for the error) as compared to emergent timing (in this case, the timing stability is assumed to be poorly disturbed by a phase shift because the actions are not controlled through pure timing processes – see Repp, 2008). Results revealed that in this dual task situation, the tapping activity of the left hand was event-based in nature (large PCRs) while the drawing activity of the right hand was emergent (small PCRs). In addition, it was shown through an interaction effect that the circle-drawing activity inhibited the PCR of the tapping activity especially at faster tempi, suggesting that the two tasks were in fact coordinated together, at least at fast tempi. Thus, authors concluded that the two timing strategies may coexist, i.e., be used simultaneously and be coordinated together when speed constraints are important. As such, they took the results one step further by suggesting that the two timing strategies could in fact coexist within a same task under any constraints, with however a predicted predominance of one or the other strategies as a function of task

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