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Synthesis of asymmetric movement trajectories in timed rhythmic behaviour by means of frequency modulation

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ABSTRACT

Results from different empirical investigations on gestural aspects of timed rhythmic movements indicate that the production of asymmetric movement trajectories is a feature that seems to be a common characteristic of various performances of repetitive rhythmic patterns. The behavioural or neural origin of these asymmetrical trajectories is, however, not identified. In the present study we outline a theoretical model that is capable of producing syntheses of asymmetric movement trajectories documented in empirical investigations by Balasubramaniam et al. (2004). Characteristic qualities of the extension/flexion profiles in the observed asymmetric trajectories are reproduced, and we conduct an experiment similar to Balasubramaniam et al. (2004) to show that the empirically documented movement trajectories and our modelled approximations share the same spectral components. The model is based on an application of frequency modulated movements, and a theoretical interpretation offered by the model is to view paced rhythmic movements as a result of an unpaced movement being "stretched" and "compressed", caused by the presence of a metronome. We discuss our model construction within the framework of event-based and emergent timing, and argue that a change between these timing modes might be reflected by the strength of the modulation in our model.

1. Introduction

There are two dominant traditions in behavioural studies of movement timing: *the information processing approach* and *the dynamical systems approach*, also referred to as *the nonlinear oscillator approach* (cf. Balasubramaniam, 2006; Beek, Peper, & Daffertshofer, 2000; Wing & Beek, 2002). The information processing approach deals with *discrete* aspects of timing behaviour, and the variables of major interest are time intervals, i.e., intertap intervals and asynchronies. On the other hand, rather than studying discrete synchronisation events, the dynamical systems approach investigates *continuous* movement trajectories, dynamic pattern formation, and the evolution of performance with time. In the dynamical systems approach, timing is considered to be an emergent property of the organisational principles that govern a particular coordinated action, whereas in the information processing approach, time is considered a mental abstraction that depends on central timing processes, represented independently of any particular effector system (cf. Wing & Beek, 2002). These different approaches in studies of movement timing are closely related to the theoretical framework that distinguishes between two forms of timing control: emergent timing and event-based timing (Delignières & Torre, 2011; Delignières, Lemoine, & Torre, 2004; Delignières, Torre, & Lemoine, 2008; Repp & Steinman, 2010; Robertson et al., 1999; Schöner, 2002; Spencer & Ivry, 2005;

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Spencer, Zelaznik, Diedrichsen, & Ivry, 2003; Zelaznik, Spencer, & Ivry, 2002). As stated by Delignières and Torre (2011, p. 313): "..., the essential difference between event-based and emergent timing is in the involvement or noninvolvement, respectively, of an abstract and effector independent representation of the time intervals to produce." Very interesting discussions related to whether event-based and emergent timing can coexist or not in a single task, are found in Repp and Steinman (2010) and Delignières and Torre (2011). In Delignières and Torre (2011) we read that some timing tasks tend to favour event-based timing (i.e., discrete finger tapping), some others emergent timing (i.e., continuous circle drawing or forearm oscillations), whereas other tasks appear more ambiguous. Moreover, they state: "Air tapping (in which taps are performed in the air, without contact with any surface) seems to present this ambiguity" (Delignières & Torre, 2011, p. 313).

An interesting empirical investigation that emphasises the importance of combining the dynamical systems approach and the information processing accounts of movement timing, is presented by Balasubramaniam, Wing, and Daffertshofer (2004). As a starting point for their study they comment that whereas previous investigations of paced repetitive movements with respect to an external beat have *either* emphasised the form of movement trajectories (the dynamical systems approach) *or* timing errors made with respect to the external beat (the information processing approach), – the question of *what kinds* of movement trajectories *assist timing accuracy* has not previously been addressed. Following up this question Balasubramaniam et al. construct a new experimental paradigm aimed at investigating how various timing tasks are reflected in different movement trajectories. This experiment involves synchronisation or syncopation with an external auditory metronome, and they show that the nervous system produces trajectories that are *asymmetric* with respect to time and velocity in the out and return phases of the repeating movement cycle (see Fig. 1).

Moreover, they find that this asymmetry is task specific and independent of motor implementation details (flexion vs. extension), and, furthermore, that the degree of asymmetry in the flexion and extension movement times is positively correlated with timing accuracy. On the basis of their findings, they suggest that "movement asymmetry in repetitive timing tasks helps satisfy requirements of precision and accuracy relative to a target event" (Balasubramaniam et al., 2004, p. 129). Thus, they point at an interesting result which is related to research questions that are basic to both of the two dominant traditions in behavioural studies of movement timing. Correlation between asymmetric movement trajectories and timing accuracy has also been discussed in Balasubramaniam (2006), Delignières and Torre (2011), Elliott, Welchman, and Wing (2009), Torre and Balasubramaniam (2009), and is given additional support by results from empirical investigation on synchronisation of the index finger with various visual pacing sequences (Hove & Keller, 2010). Empirical studies of drummers' movements in the performance of different rhythms and grooves also show that the movement of the drumstick produces trajectories that are asymmetric (cf. Dahl, 2004, 2006, 2011; Waadeland, 2003, 2006, 2011). Results from different investigations on gestural aspects of timed rhythmic movements thus indicate that the production of asymmetric movement trajectories is a feature that seems to be a common characteristic of various performances of repetitive rhythmic patterns. The behavioural or neural origin of these asymmetrical trajectories is, however, not identified.

In the present paper we outline a theoretical model that is capable of producing syntheses of characteristic features of the asymmetric movement trajectories documented in the empirical investigation of Balasubramaniam et al. (2004), and we conduct a spectral evaluation of our model to show that the observed movement trajectories and our modelled approximations share the same spectral components. The model is based on an application of frequency modulated movements and is constructed by means of a synthesis technique developed earlier by the author, which has shown to be useful in making syntheses of rhythmic expression in music (Waadeland, 2001). It should at this point be noted that in all of the conditions in the experiment of Balasubramaniam et al. (2004), the index finger made no contact with any surface during the movement trials. Thus, this experimental setup involves timing tasks that are considered to be ambiguous as to whether event-based or emergent timing is favoured in the performance (see Delignières & Torre, 2011). When we here propose a new model for the movement trajectories in the experiment of Balasubramaniam et al., we might therefore also generate some new thoughts concerning the relation between event-based and emergent timing. This will be discussed in the concluding sections of the paper.

2. The experiment of Balasubramaniam, Wing, and Daffertshofer

Before we present our model we take a closer look at some of the basic constituents of the empirical investigation of Balasubramaniam, Wing, and Daffertshofer. Their experimental setup is described in Balasubramaniam et al. (2004) and

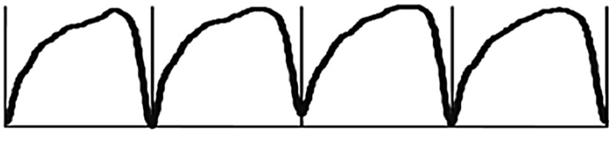

Fig. 1. Example of asymmetric trajectory. Illustration of asymmetric movement trajectory in the experiment of Balasubramaniam et al. This trajectory is the result of a subject being instructed to synchronise the minimal points of the movement of the index finger to the beats of a metronome adapted from Fig. 1 in Balasubramaniam et al., 2004, p. 130.