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Local stability in coordinated rhythmic movements: Fluctuations and relaxation times

M.L.J. Court [a,*], S.J. Bennett [b], A.M. Williams [a], K. Davids [c]

[a] *School of Human Sciences, Research Institute for Sport and Exercise Sciences, Henry Cotton Campus, Liverpool John Moores University, 15-21 Webster Street, Liverpool L3 2ET, UK*

[b] *Department of Optometry and Neuroscience, Institute for Science and Technology, University of Manchester, Manchester, UK*

[c] *School of Physical Education, PO Box 56, Dunedin, New Zealand*

Abstract

An experiment was conducted to examine the stability of the anti-phase and in-phase modes of coordination by means of both fluctuations and relaxation times. Participants ($n = 6$) performed a rhythmic bimanual forearm coordination task that required them to oscillate their forearms in-phase and anti-phase while grasping two manipulanda at fixed frequencies ranging from 0.6 to 1.8 Hz. Relaxation times were measured as the time taken to return to a stable mode following the application of a transient mechanical torque. It was found that relaxation times were not different statistically across participants, frequencies, and coordinative modes. However, fluctuations, as indicated by the mean S.D. of relative phase across individual frequency plateaus, were significantly greater in the anti-phase than in the in-phase mode of coordination, $p < 0.05$. Whilst providing new empirical support for the notion that relaxation times should be of the same order of magnitude at frequencies outside transition regions, the findings suggest that the level of stochastic noise in the anti-phase mode is greater than that of the in-phase mode. Implications are made for the future assessment of local pattern stability.

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* Corresponding author. Tel.: +44-0151-231-4360; fax: +44-0151-231-4353.
E-mail address: hhsmcour@livjm.ac.uk (M.L.J. Court).

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1. Introduction

1.1. General overview

Dynamical systems theory has provided opportunities to determine principles that govern the organization and development of stable coordination patterns. Central to the dynamical systems approach has been the observation of stable, rhythmic anti-phase and in-phase modes (e.g., finger or forearm oscillations) at the level of the order parameter relative phase. The identification of pattern switches or phase transitions from the anti-phase to the in-phase mode in response to increases in the control parameter oscillation frequency led to the development of the HKB model of bimanual coordination (Haken, Kelso, & Bunz, 1985). To explain changes in the variability of coordination patterns, Schöner, Haken, and Kelso (1986) provided a stochastic extension of the HKB model. Within the current paper indices of local pattern stability (i.e. fluctuations and relaxation times), stemming from the work of Schöner et al. (1986), are compared below critical regions. Whilst findings provide information on stochastic and deterministic contributions to pattern stability they will have direct implications for the future assessment of local pattern stability with relaxation times and the mean S.D. of relative phase.

1.2. Standard deviations

Deviations from stable coordination patterns or attractor states are caused by stochastic noise of a supposedly constant strength that arises from the system's many interacting degrees of freedom (Kelso, Schöner, Scholz, & Haken, 1987). To account for the presence of such fluctuations, Schöner et al. (1986) extended the HKB (1985) model by incorporating a stochastic noise term ξ with strength parameter Q. In doing so, Schöner et al. (1986) were able to provide a quantitative account for the enhanced fluctuations observed by Kelso (1981, 1984) in the vicinity of phase transitions from anti-phase to in-phase coordination. Fluctuations are typically assessed by measuring the standard deviation (S.D.) of relative phase across individual frequency plateaus and averaging those across multiple trials. As the size of fluctuations is determined by the stability of an attractor and the magnitude of stochastic noise in the system (Schmidt, Treffner, Shaw, & Turvey, 1992), they provide a relative indication of the local stability of a particular mode.

Theoretically, the influence of stochastic noise on the stable stationary behavior of the system may be understood in terms of the attractor landscape defined by a so-called potential. Contained within the landscape is the in-phase attractor with a narrow, steep-sided concave well. Across scaled changes in the required movement frequency the system minimally deviates from the in-phase attractor in response to perturbations from stochastic noise. In contrast, the anti-phase attractor has a shallower, less concave well and less pronounced minimum (Kelso & Ding, 1993). When the system is in the anti-phase attractor constant stochastic noise causes greater deviations from the minima, relative to those observed in the in-phase attractor. When approaching a transition region elevated fluctuations termed 'critical fluctuations'