Available online at www.sciencedirect.com
SCIENCE DIRECT®
Human Movement Science 24 (2005) 218–233
HUMAN MOVEMENT SCIENCE
www.elsevier.com/locate/humov

Limiting the recruitment of degrees of freedom reduces the stability of perception–action patterns

L. Milliex, S. Calvin *, J.-J. Temprado

UMR 6152 "Mouvement et Perception", Faculté des Sciences du Sport, Université de la Méditerranée, 163, avenue de Luminy, CP 910, 13288 Marseille Cedex 9, France

Available online 15 June 2005

Abstract

The goal of the present study was to examine how recruiting/suppressing degrees of freedom affects the (differential) stability of two rhythmic perception–action patterns. In particular, participants synchronized either adduction-on-the-beat or abduction-on-the-beat movements of the right index finger with an auditory metronome. The stability of both patterns as performed in the horizontal plane was predicted to depend on the utilization, or recruitment, of the vertical plane of motion. Movements of the index finger were either free or physically restricted to the horizontal plane. The results showed that in the free condition, the vertical plane was recruited more in the more stable pattern (abduction-on-the-beat) than in the less stable pattern (adduction-on-the-beat). In the constrained condition, abduction-on-the-beat pattern was destabilized, whereas the stability of the adduction-on-the-beat pattern was preserved. These results suggest that the recruitment of the vertical plane of motion in the abduction-on-the-beat movements brought about an increase in the stability of this pattern. More generally, the trade-off between the stability of coordination patterns in the horizontal plane is based on a self-organizing process of recruitment in which neuromuscular factors are an intrinsic aspect.

PsycINFO classification: 2330; 2520; 2530

Keywords: Coordination dynamics; Self-organization; Recruitment; Synchronization; Perception–action pattern

* Corresponding author. Tel.: +33 4 91 17 22 79; fax: +33 4 91 17 22 52.
E-mail address: calvin@laps.univ-mrs.fr (S. Calvin).

0167-9457/$ - see front matter
doi:10.1016/j.humov.2005.04.004

1. Introduction

Human movement coordination involves the assembly of several joints, limbs and muscles (Bernstein, 1967). An important question is how such a high dimensional system can be organized temporarily to achieve a given (task) goal. The study of coordination dynamics provides a set of principles and methods to explain how the neuro-musculo-skeletal system (dis)assembles coordination patterns according to task demands (Kelso, 1995). Most studies on phase transitions within this perspective have been focused on rhythmic tasks in which coordination was spontaneously reordered across the same biomechanical degrees of freedom at a critical oscillation frequency (Haken, Kelso, & Bunz, 1985; Kelso, 1984). However, other solutions are possible to functionally adapt to task demands. For instance, Bernstein (1967) hypothesized that degrees of freedom that are controlled within a coordinative structure can be released and incorporated into a new structure in order to enhance efficiency and reduce energy costs. This process has been called "recruitment of degrees of freedom" (Kelso, 1995).

During the last decade or so, the recruitment of degrees of freedom in interlimb coordination has been studied in a series of experiments carried out by Kelso and colleagues (Buchanan, Kelso, de Guzman, & Ding, 1997; Kelso, Buchanan, de Guzman, & Ding, 1993). These experiments focused on recruitment of the vertical plane of motion while participants performed repetitive bimanual abduction–adduction movements of the index fingers in the horizontal plane. Results showed that the typically observed frequency-induced transition from antiphase to in-phase coordination (in the horizontal plane of motion) was accompanied by another transition from the horizontal (adduction–abduction) to the vertical plane of motion (i.e., flexion–extension movement of the index fingers). Such recruitment of a new plane of motion was systematically preceded by an increase in fluctuations of the relative phase in the horizontal plane. These findings suggested that the recruitment of degrees of freedom occurred when the stable coordination modes in the horizontal plane were depleted. The findings also suggested that stability and loss of stability play an important role in the recruitment/suppression of additional biomechanical degrees of freedom. Kelso et al. (1993; see also Buchanan et al., 1997) concluded that recruitment of additional (available) degrees of freedom resulted from a self-organizing process that occurred because the system was no longer able to support task demands in a stable manner when a control parameter crossed a critical value. This conclusion was further supported by the results of similar experiments on pendulum swinging (Buchanan & Kelso, 1999; Fink, Kelso, Jirsa & de Guzman, 2000) showing that recruiting a new degree of freedom delays or even eliminates transitions, and thus confirming that recruitment is an essential source of coordinative flexibility and adaptation in biological coordination (Fink, Kelso, et al., 2000).

The present study addresses the relationship between the recruitment of the vertical plane of motion and coordinative stability in a unimanual task involving synchronization of right index finger movements (i.e., abduction-on-the-beat and adduction-on-the-beat) with an auditory metronome. In particular, we examined