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Action–perception coordination dynamics of whole-body rhythmic movement in stance: A comparison study of street dancers and non-dancers

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HIGHLIGHTS

- We investigate action–perception coordination in street dancers and non-dancers.
- Two coordination modes in stance (knee extension/flexion on the beat) are examined.
- Self-organized phenomena (phase transition and hysteresis) are observed.
- Bifurcation frequency is greater in street dancers than in non-dancers.

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ABSTRACT

This study investigated whether whole-body, rhythmic action–perception coordination in stance is organized in terms of dynamic principles. We observed whether phase transition and hysteresis occur during the execution of dancing movements. Nine skilled street dancers and 9 novice controls performed 2 types of rhythmic knee-bending movements to a metronome beat in the standing position. Participants performed down-on-the-beat (in which knee flexion coincides with the beat) and up-on-the-beat (in which knee extension coincides with the beat), which are both typical components of street dance. All participants were instructed not to intervene in the pattern change. The auditory stimulus beat rate increased or decreased between 60 and 220 beats per minute (bpm) in steps of 20 bpm. We calculated the phase angle of beat time that is superposed on knee movement trajectory on a phase plane. Under the up-on-the-beat condition, phase transition and hysteresis were observed. The bifurcation frequency at which phase transition occurred significantly differed between groups, indicating that dancers were able to perform up-on-the-beat at higher movement frequencies than non-dancers. This suggests that dynamical properties may differ between Dancers and Non-dancers. The present results provide additional evidence that whole-body action–perception pattern formation is governed by general and common dynamical principles.

1. Introduction

Human neural systems exhibit characteristics indicating that perceptual information organizes the coordination of patterned movement [17,19,20]. One of the most dramatic examples of this dynamic relationship between a neural system and perceptual information is known as the phase transition phenomenon. Phase transitions refer to sudden and spontaneous shifts between 2 different coordinated states. They can be formulated within a dynamical systems framework [15]. For instance, Kelso et al. [16] reported phase transition in rhythmic finger movement coordinated with a regularly occurring environmental event. In their experiment [16], participants were required to synchronize peak flexion of the index finger off the beat (syncopation) to a metronome beat, while the beat frequency gradually increased over time. At a critical frequency, the coordination pattern suddenly changed to peak flexion on the beat (synchronization) instead of off the beat. In Carson's experiment [6], participants were instructed to extend their index finger in time with a gradually increasing metronome beat, and a sudden transition to a flexion on the beat pattern occurred at a critical frequency. Mechsner et al. [20] have indicated that bimanual finger coordination exhibits preference for perceptual, rather than anatomical patterns of symmetry. A dynamical systems approach is well suited to describe and formulate the interaction between these types of coordinated movements and perceptual information.

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One advantage of a dynamical systems approach to study pattern coordination lies in the practical application of the results. Recently, this approach has been applied to evaluate performance skills such as drumming movements [9] using theoretical models of bimanual coordination [12]. In recent decades, dynamical systems approaches have mainly focused on finger [6,16,20] and arm movements [4,9], and there are only a few studies investigating whole-body coordination dynamics [1,22]. Considering its applicability to a variety of sports or dance movements, investigation of the dynamical features of coordination between dynamic whole-body movement and perceptual information is important.

Miura et al. [22] reported 2 distinct coordination modes in action–perception coordination during whole-body movement in stance: down-on-the-beat (knee flexion coincides with the beat) and up-on-the-beat (knee extension coincides with the beat) modes. Both of these coordination modes are typically seen in street dance movements. In Miura et al.'s study [22], non-dancers with no prior experience in street dance could perform down-on-the-beat relatively stably over a wide range of movement frequencies. However, when the non-dancers tried to perform up-on-the-beat at high frequencies (over 120 bpm), unintentional replacement of up- by down-on-the-beat occurred. These results suggest the existence of 2 distinct coordination modes in whole-body action–perception coordination in stance.

In Miura et al.'s study [22], the metronome beat rate did not vary systematically or continuously within a trial, and participants attempted to continue the prescribed coordination pattern. Thus, this study design cannot address certain phenomena associated with dynamical principles that govern human coordination, such as phase transition between 2 different modes, the bifurcation frequency at which phase transitions occur, and hysteresis (a phenomenon in which the phase angle time series or bifurcation frequency differs between ascending and descending frequency conditions). We hypothesized that if whole-body action–perception coordination is governed by dynamical organizing principles, then these phenomena may be observed during rhythmic knee-bending movements under the experimental condition where participants do not intervene in spontaneous pattern changes and the metronome beat frequency changes systematically and continuously.

Previous research has demonstrated that the intrinsic dynamics could be modified by motor learning. That is, intrinsically unstable coordination patterns (i.e., coordination patterns other than the in-phase mode) could be stabilized with learning. This notion was first reported by Zanone and Kelso using bimanual finger coordination [36,37]. This has also been confirmed in other types of coordination, such as inter-limb [30,33,35], intra-limb [3,5], action–perception [28], and postural coordination [8]. Miura et al.'s study [22] showed that skilled street dancers who have the ability to intentionally change their posture to musical beats could resist unintentional replacement of up- by down-on-the-beat, even at high movement frequencies, with the intention to maintain the up-on-the-beat. By contrast, non-dancers were unable to do so under the same experimental conditions. Although this suggests that the attractor layout of whole-body action–perception coordination in street dancers was modified by motor leaning, it remains unknown whether the change of attractor layout can be exclusively attributed to the effects of intention [15,29,31] or if it is also caused by a change in intrinsic dynamics [36,37]. Examining movements driven by a continuously changing metronome beat within a trial in which participants do not intervene in spontaneous pattern changes could clarify whether or not the intrinsic dynamics is modified in street dancers. If the intrinsic dynamics is modified by practice, the bifurcation frequency would be expected to be higher in street dancers than in non-dancers. Therefore, this study had 2 objectives: (1) to examine whether phase transition and hysteresis are observed during whole-body action–perception coordination, and (2) to investigate whether these phenomena could be affected by skill level. We compared skilled street dancers to non-dancers in their ability to change their posture to the beat stimulus.

2. Methods

2.1. Participants

Nine skilled street dancers and 9 novice controls participated in this experiment. The street dancers (men, age 26.9 ± 4.9 years, M ± SD) had 10.5 ± 5.4 years of dancing experience, and 6 of them were prizewinners in well-known national or international street dance competitions. The novice controls (men; mean age, 25.4 ± 2.1 years) had no experience in any type of dance. Hereafter, the dancer group is referred to simply as *Dancers* and the control group, *Non-dancers*. Informed consent was obtained from all participants for their participation in the experiment. This study was approved by the Ethics Committee of the Graduate School of Arts and Sciences at the University of Tokyo.

2.2. Experimental task

The experimental task consisted of a basic street dance movement consisting of bouncing up and down repeatedly by bending and extending the knees to a metronome beat. The task involved 2 kinds of movement patterns: the down-on-the-beat condition (in which knee flexion coincides with the beat) and the up-on-the-beat condition (in which knee extension coincides with the beat) [22]. The participants were instructed to hold their hands at waist level and not to move the neck or parts of the body other than the hip, knee, and ankle joints. The participants were instructed to maintain a 1:1 relationship between movement and beat, not to stop moving, and not to intervene in the spontaneous pattern change. The range of joint angles was not specified. The beat rate increased/decreased between 60 and 220 beats per minute (bpm) in steps of 20 bpm (9 frequency plateaus). Each frequency plateau continued for 16 beats.

2.3. Design and procedure

Participants performed 3 sets of 4 conditions [2 coordination conditions (down- and up-on-the-beat) × 2 beat rate direction conditions (ascending and descending)] in a pseudo-random order. Between trials, in order to exclude the influence of fatigue, the participants were allowed sufficient rest to ensure that they did not experience any fatigue or discomfort.

2.4. Apparatus and data collection

Angular displacement was measured by an electrogoniometer (Biopac Systems, Tokyo, Japan) attached to the right knee joint. Electrogoniometer signals and metronome beat signals were sampled at 1000 Hz with an MP100 recording system (Biopac Systems) and stored in a personal computer using wave recording/analyzing software (AcqKnowledge 3.7.3 for Windows; Biopac Systems). The metronome beat was programmed with a programmable metronome DR-880 Dr. Rhythm (Roland Corporation, Shizuoka, Japan).

2.5. Data analysis

The angular displacement data were smoothed using a low-pass filter (cut-off frequency: 6 Hz). Smaller values signified flexion, while larger values signified extension. Angular velocities were obtained by differentiation of angular displacement.