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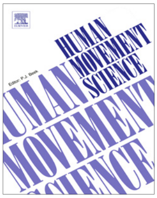

Robustness to temporal constraint explains expertise in ball-over-net sports

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ABSTRACT

The present study investigated motor expertise in interpersonal competitive ball-over-net sports in terms of a dynamical system with temporal input. In a theoretical framework, the behavior of the system is characterized by a fractal-like structure according to switching input, which changes uniquely according to the duration of input and internal parameter of the system. We investigated periodic movements, in which the player executed a forehand or backhand stroke repeatedly, and continuous switching movements, in which the player continuously switched between two movement patterns corresponding to hitting the ball under two ball directions and with six temporal constraint conditions during a table tennis rally. In the periodic movement, we observed two limit-cycle attractors corresponding to each direction in the phase space independent of temporal constraint or skill level. Conversely, in the continuous switching movement, a transition in trajectories between the two limit-cycle attractors was observed in the phase space, and this transition was characterized by a fractal-like structure. The fractal-like structure moved closer to the random structure as temporal constraint increased independent of skill level. However, the temporal constraint condition closest to the random structure was higher for the advanced players than for the novices, indicating that robustness to the temporal constraint was higher for the advanced players than for the novices. Our results suggest that motor expertise in interpersonal competitive ball-over-net sports is more robust to temporal constraints with various inputs.

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1. Introduction

Research on expertise in interpersonal competitive ball-over-net sports, such as table tennis and regular tennis, has shown that it is difficult for an individual player to produce the same level of skilled motor behavior in a match as is produced in a practice session. Novice players often find that they are able to successfully perform stable periodic movements in response to constant ball trajectories during long, repetitive practice sessions, but are unable to do so during competition. This is because during a match, the player is required to switch between different movement patterns within a finite period of time to hit every ball returned by the opponent.

Several recent studies have investigated hitting behavior during a match to clarify the skilled motor behavior involved in interpersonal competitive ball-over-net sports. Although several studies have investigated the discrete movements involved in serving and returning the serve (Abernethy, Farrow, Gorman, & Mann, 2004; Elliott, 2006; Hodges, Starkes, & MacMahon, 2006), little is known about the skills involved in continuous switching movements in which execution of the movement pattern corresponds to the current position of ball even as the direction of the ball changes constantly.

Rhythmic movements, as observed in repetitive practice, have been extensively investigated from the viewpoint of dynamical systems theory (Kelso, 1984; Haken, Kelso, & Bunz, 1985; Buchanan & Kelso, 1993). Extending this theoretical discourse, Yamamoto and Gohara (2000) developed a novel method for assessing continuous switching movement in tennis by incorporating a theoretical framework that took into account the behavior of continuous dynamical systems with external input (Gohara & Okuyama, 1999; Gohara & Okuyama, 1999).

Within this theoretical framework, external input is defined as a set of input patterns that represent spatio-temporal information with a finite time length. When the same input pattern is repeatedly fed into the system, the state of the system is a limit-cycle attractor. However, when the input patterns are switched stochastically, the state of the system is characterized by a fractal-like structure according to transitions between attractors, each of which corresponds to the current input pattern.

Yamamoto and Gohara (2000) defined a single input pattern as the tennis ball projecting to either the forehand or backhand side at a given time. One complete striking action was represented as a trajectory in the cylindrical phase space matching one cycle as the time length of one input pattern. Repeating the same input pattern was represented as two stable trajectory sets in the phase space, namely the two limit-cycle attractors, corresponding to each input of periodic movement. Moreover, the switch between the two patterns in the continuous switching movement was characterized by the transition of trajectories between subsequent attractors in the phase space. Thus, when inputs are switched stochastically, the dynamics are characterized by trajectories with fractal-like structures.

Gohara and Okuyama (1999) theoretically demonstrated how the characteristics of the fractal-like structure depend on internal and external parameters (Wada & Gohara, 2001; Nishikawa & Gohara, 2008). The internal parameter affects how the trajectory converges on an attractor, and the external parameter corresponds to the duration of the input pattern. Moreover, the authors identified a correlation between the period to converge on an attractor and the duration of the input pattern. When the time length of the input pattern is sufficient to converge on an attractor, the trajectory will converge on an attractor corresponding to the current input pattern before the next input is fed into the system. Following this, the trajectory will begin to converge on an attractor corresponding to the next input and will do so within a finite period of time. When these transitions are repeated, the behavior of the system reveals a limit-cycle attractor similar to the periodic input condition, even under the switching input condition.

Conversely, when the time length of the input pattern is shorter than the period to converge on an attractor, the trajectory cannot converge on the current attractor before the next input is fed into the system, and the trajectory therefore diverges from the attractor. The trajectory then starts from the divergent state and moves on to the next attractor corresponding to the next input. When these transitions are repeated, the behavior of the entire system is characterized by a fractal-like structure because the trajectories are distributed around each attractor in an orderly manner. If, however, the period to converge on an attractor is lengthened or the duration of the input pattern is shortened,