Human Movement Science 56 (2017) 98–108

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Uncontrolled manifold analysis of joint angle variability during table tennis forehand

Yoichi Iino*, Shinsuke Yoshioka, Senshi Fukashiro

The University of Tokyo, Japan

ARTICLE INFO

Keywords:
Racket sport
Uncontrolled manifold analysis
Redundancy
Table tennis

ABSTRACT

This study was conducted with the objective of evaluating the variance structure of the trunk and racket arm joint angles in table tennis topspin forehand using the uncontrolled manifold (UCM) approach, regarding racket orientation as the task variable. Nine advanced and eight intermediate male collegiate table tennis players performed the topspin strokes against backspin balls. The trunk, upper limb, and racket were modeled as six rigid-link segments with a total of 16 rotation degrees of freedom. The UCM analysis was conducted using 30 trial datasets per participant to quantify the degree of redundancy exploitation needed to stabilize the vertical and horizontal angles of the racket. Irrespective of the performance level, the variance of the joint angle vector increased towards ball impact. The degree of redundancy exploitation increased towards ball impact. As a result, the variability of the racket angles was minimal at impact. Both groups of players used the relative movement between the racket and the hand to stabilize the racket angles at ball impact. The variance of the joint angle vector that affected the vertical racket face angle at ball impact was significantly smaller for advanced players than for intermediate players, and the degree of redundancy exploitation to stabilize that angle at impact tended to be larger for the advanced players. The ability to use the redundancy of the joint configuration to stabilize the vertical racket face angle at impact may be a critical factor that affects performance level.

1. Introduction

The topspin forehand is one of the most attacking shots in table tennis. In a recent study, Malagoli Lanzoni, Di Michele, and Merni (2014) found that it was used more often in winners than other stroke types, suggesting that mastering this shot is critical to winning matches. Several studies have investigated the biomechanical aspects of the forehand. For example, Lee and Xie (2004) examined the upper limb kinematics of the forehand for elite players at an international competition. Other studies investigated whole body kinematics (Kasai & Mori, 1998), upper limb kinematics (Iino & Kojima, 2009), upper limb kinetics (Iino & Kojima, 2011), lower limb kinematics (Qian, Zhang, Baker, & Gu, 2016) to determine possible differences among different expertise populations. These studies analyzed one or several trials for one participant but did not focus on the variability of kinematic and kinetic variables. Movement variability is worth investigating in table tennis strokes because it is related to the consistency with which a player can hit a ball to an intended location. Consistency of ball placement is critical to winning a match because it is related to the probability of losing a point by error and the capability of hitting the ball outside the opponents' power zone that gives a player a decisive advantage in a rally (Seemiller & Holowchak, 1997).

* Corresponding author at: Graduate School of Arts & Sciences, Sports Science Laboratory, The University of Tokyo, 3-8-1 Komaba, Meguro-ku, Tokyo 1538902, Japan.

E-mail address: iino@idaten.c.u-tokyo.ac.jp (Y. Iino).

http://dx.doi.org/10.1016/j.humov.2017.10.021
Received 6 July 2017; Received in revised form 13 October 2017; Accepted 29 October 2017
0167-9457/

Previous studies (Bootsma & van Wieringen, 1990; Sheppard & Li, 2007; van Soest et al., 2010) examined variability of racket kinematics in table tennis forehand to determine the role of visual information in a fast interceptive task. Bootsma and van Wieringen (1990) reported that the variability of the horizontal direction of racket trajectory decreased towards ball impact, which was replicated by van Soest et al. (2010). Sheppard and Li (2007) found that the variabilities of the vertical direction of the racket trajectory and the orientation angles of the racket also decreased towards ball impact. Decreasing variability of kinematic variables that affect performance of the task towards a critical moment is also observed in long jumps (Lee, Lishman, & Thomson, 1982; Montagne, Cornus, Glize, Quaine, & Laurent, 2000; Scott, Li, & Davids, 1997) and somersaulting (Bardy & Laurent, 1998). Thus, it is of great interest to examine how the joint movements are coordinated to decrease the variability of racket kinematics towards impact in table tennis forehands from a viewpoint of motor control.

Execution of many motor tasks has more degrees of freedom (DOF) in control variables than in task variables. This proposition holds true for table tennis strokes because racket orientation is one of the task variables and joint configuration can be considered control variable. The uncontrolled manifold (UCM) analysis (Scholz & Schöner, 1999; Latash, Scholz, & Danion, 2001) examines how control variables are coordinated with respect to task variables. In the UCM analysis, the variance of control variables is partitioned into that which affects task variables (V_{orth}) and that which does not (V_{ucm}). If V_{ucm} is larger than V_{orth}, the motor system is said to structure the variabilities of control variables or to exploit redundancy, in order to stabilize the task variable. This analysis has been successfully applied to a variety of motor tasks, including finger force production (Latash et al., 2001), throwing (Yang & Scholz, 2005), stone knapping (Rein, Bril, Nonaka, & Hautes, 2013), robotic teleoperation (Nisky, Hsieh, & Okamura, 2014), and golf swing (Morrison, Mcgrath, & Wallace, 2016) tasks. The decreasing variability of the racket kinematics towards impact in table tennis forehands reported earlier may be accomplished by increasing the degree of redundancy exploitation towards impact. In stone knapping (Rein et al., 2013) and robotic teleoperation (Nisky et al., 2014), experts showed a higher degree of redundancy exploitation to stabilize the task variables: the positions of a hammer and the hand, respectively. In golf swing (Morrison et al., 2016), high-skilled golfers showed lower total variance per DOF and a higher degree of redundancy exploitation to stabilize clubhead orientation than intermediate skilled golfers. Therefore, the UCM analysis may provide a deeper understanding of how table tennis players deal with the movement variability and useful implications for skill assessment.

This study was conducted with the objective of evaluating the variance structure of the joint angles to stabilize the racket orientation using the UCM approach during the table tennis topspin forehand for advanced and intermediate players. We tested two hypotheses: (1) the degree of redundancy exploitation increases towards ball impact and (2) advanced players show a higher degree of redundancy exploitation than intermediate players.

2. Methods

2.1. Participants

Seventeen male collegiate table tennis players participated in the study. Nine of the participants were Division I players who had qualified to compete in national championships in high school and/or college, these were categorized as "advanced." Eight were Division III players who had not qualified for national championships, these were categorized as "intermediate." The mean (s) age, height, body mass, and playing experience were 20.4 (1.3) years, 1.72 (0.07) m, 65.3 (5.4) kg, and 11.3 (2.2) years for advanced players and 20.9 (0.9) years, 1.73 (0.07) m, 62.5 (6.3) kg, and 7.8 (1.0) years for intermediate players. All participants provided informed consent, and the procedure was approved by the local ethics committee.

2.2. Procedure

After warming-up, the participants were asked to hit topspin forehands against backspin balls projected using a ball machine to accustom themselves with the experimental environment (Fig. 1). Then, in each set, each participant was asked to hit five consecutive cross-court topspin forehands against backspin aiming at a target on the table as fast and as accurately as possible. The target was located 30 cm from the baseline and 30 cm from the sideline of the table (Fig. 1). Each participant repeated the set until he hit at least 30 strokes, including miss shots.

2.3. Data collection

Twenty-three reflective markers with diameter 16 mm were attached to the trunk and upper limb anatomical landmarks of each participant. A twelve-camera motion capture system (8 × Kestrel and 4 × Hawk, MAC3D System, Motion Analysis, Santa Rosa, CA, USA) was used to collect three-dimensional coordinates of the markers at 200 Hz. A high-speed video camera (HAS 220, Ditect, Tokyo, Japan) was used to capture images of the racket-ball impact at 200 Hz. The motion capture system and the high-speed camera were synchronized by the motion capture system sampling a signal to trigger the camera at 2000 Hz.

Separately from the main experiment, the backspin balls with some ink marks were projected by the ball machine to determine the spin rates immediately after the first bounce on the table. The ball motions were recorded at 500 fps from a lateral side using a high-speed camera (HAS 220, Ditect, Tokyo, Japan). The spin rate of the backspin balls was 8.6 ± 1.3 rps (n = 16).