THE ROLE OF TARGET LOCATION ON THE INTERACTION BETWEEN POSTURAL BALANCE MECHANISMS AND END-EFFECTOR PERFORMANCE IN THE TENNIS SERVE

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The purpose of this study was to evaluate the relationship between end-effector (tennis racket) performance and postural balance across 4 serving locations. Eleven right-handed experienced tennis players participated in this study. Participants completed 10 successful tennis serves each to 4 serving locations. 12 optoelectronic cameras at 200 Hz (BTS bioengineering, Milan, Italy) were used to collect whole body kinematic data. Statistical parametric mapping (SPM) with regression was used to identify the relationship between postural balance control (extrapolated centre of mass displacement and changes in arms/trunk angular momentum in forward/backward direction; 1D data) and end-effector performance (maximum racket forward velocity, 0D data) across the four serving locations. The results showed no systematic relationship between postural balance control mechanisms and end-effector performance across 4 different serving locations. It was concluded that serving to different locations likely involves different balance control mechanisms to adjust for target-specific serve technique constraints. For practical application, we found no evidence that balance control and end-effector performance are tightly related within an elite tennis serve performance and that these could be trained separately.

KEYWORDS: Balance, End-effector, Extrapolated centre of mass, Tennis serve

INTRODUCTION: Tennis serve is the most vital stroke for successful performance (Reid et al., 2011). When serving, the players have to control the stroke arm and racket, referred to as end-effector, to hit the ball at the right place, in the right direction and with the maximum speed possible. Also, the serve is a goal-directed sporting task as the players have to serve to various serving locations. A player can create an advantage if they are capable of producing efficient serves (high speed and accuracy) into the targeted areas to make the opponents return more difficult. Three main techniques for the tennis serve including the flat, kick, and slice serve (Reid et al., 2008). In the first serve, more than the second serve, one of the key factors is the generation of maximal ball speed, which is priority in a flat serve technique. This ball speed is generated by moving the body segments, and not only upper extremity segments but also lower extremity segments. In fact, the tennis serve is a complex activity, in which the player needs to control balance whilst controlling the movement of body segments and racket (Gillet et al., 2009). The ability to serve to an appropriate location is the most beneficial for winning the point. Significantly, the serve location of first serves dictates the serve technique, namely, flat first serves are used significantly more often down the T corner near the centre serve line, whereas the kick and slice serves are used more often into the wide location, especially on the advantage side of the court (Gillet et al., 2009). This means that across target locations the body kinematics, balance control strategy, and end-effector performance are likely to change. However, Reid and colleagues. (2011) stated that a player serving to different parts of the court uses the same ball toss, and hence a constant relationship between balance control mechanisms and end-effector performance across serving locations may still be expected. Understanding whether the interaction between postural balance mechanisms and the end-effector performance is different between altered serving locations will allow coaches to apply and develop appropriate training programmes.

Interestingly, studies comparing the kinematics of serves to different locations in the service box are limited (Chow et al., 2009). In our own previous work, we already found little relationships between trunk movements and end-effector performance during the forward swing phase of serving to one location (Jamkrajang et al., 2020). The comparison of the interaction between dynamic balance control mechanisms and serving performance in a maximum tennis serve across the serving locations are still unexplored. Therefore, the purpose of the study was to explore the interaction between postural balance control and end-effector performance between four main serving locations.

METHODS: Eleven right-handed experienced tennis players (six males and five females; age, 22 ± 4.11 years; height, 1.74 ± 0.07 m; body mass 65 ± 8.06 kg) participated in this study. The inclusion criteria were that the player had an experience participating ≥ 5 years at the national and international level. Participants were questioned about their injury history and none had a recent (< 6 month) muscle injury. This study was approved by the Liverpool John Moores ethics committee (15/SPS/016) and Mahidol university ethics committee (MU-CIRB 2016/013.2201). Sixty-eight reflective markers were placed on anatomical landmarks to record segmental motions. Participants then completed a 10 min warm up (consisting of light jogging and tennis serve movement). Players used their own rackets to complete the protocol. After a standardised warm-up routine, subjects performed at least 40 maximal effort first serves successful shots directed at a 1 x 1 metre of 4 different target locations. Participants were asked to produce the maximum serve (first serve) in every trial. For serving purposes, the tennis court is divided into two sections, deuce court and advantage court. If the server stands facing the net, the half court on the right-hand side is called the deuce court and the left-hand side called the advantage court. The different serving locations were: condition1 located at the junction of the service line represented the location of a wide serve of the deuce court, condition2 was the broader location of the T line of the deuce court, condition3 was the broader location of the T line of the advantage court, and condition 4 was the location of the wide serve of the advantage court. A 2-min rest was foreseen between serves. Forty successful serves were analysed. The inverted pendulum mechanism was observed by observing the XCoM in anteroposterior direction. A 13-segment model was used to calculate the whole-body CoM. The XCoM was calculated using the position of the vertical projection of the CoM added with its velocity multiplied by a factor $\sqrt{l/g}$ (l being leg length and g the gravitational acceleration) (Hof, 2005). The tennis racket represented an end effector segment in this study. End-effector performance was quantified through maximum racket velocity, calculated from the peak forward velocity of a marker on the top of the racket. All calculations were implemented in Visual3D software version 6.0 (C-motion, Germantown, MD, USA). The serve was divided into three separate sets of 1D data, i.e., a preparation phase, a propulsion phase and a forward swing phase (figure 1). Statistical Parametric Mapping (SPM) was used to analyse the kinematic continua associated with the balance mechanisms. Linear regression was used to examine the within-subject interaction between the kinematic continua and maximum racket velocity (0D data). The significance of each SPM{t} was then determined topologically using random field theory (Adler and Taylor, 2007). The greater the values of the β- trajectories, the stronger the relationship. Positive values indicate a positive relationship, negative values indicate a negative relationship. SPM analyses were implemented using the open-source spm1d code (www.spm1d.org) in Matlab (R2016a, 8.3.0.532, The Mathworks Inc, Natick, MA).

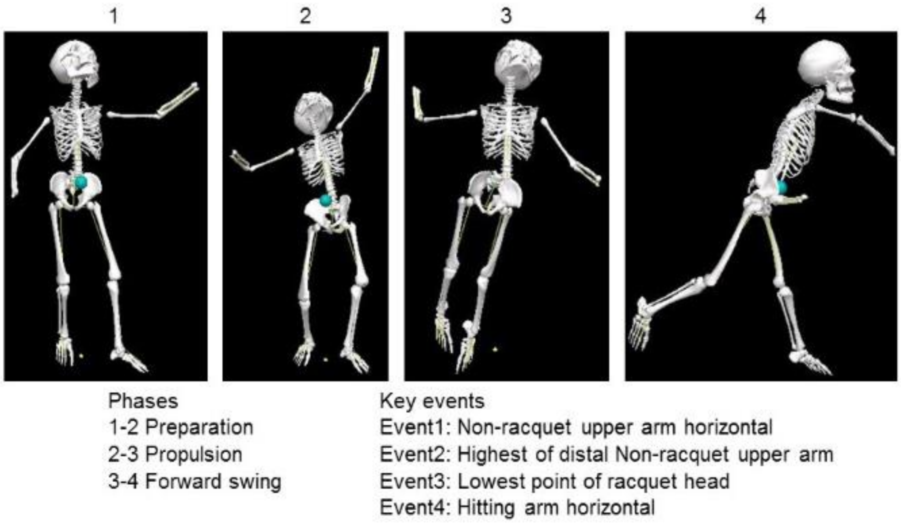

Figure 1: The key events that divide the tennis serve in three separate phases.

RESULTS: Overall, no evident individual relationships between balance control mechanisms and end-effector performance were observed across serving conditions, except for a relationship between the change in arms angular momentum and maximum racket velocity when serving into the right corner of the advantage court (condition 4) (figure 2).

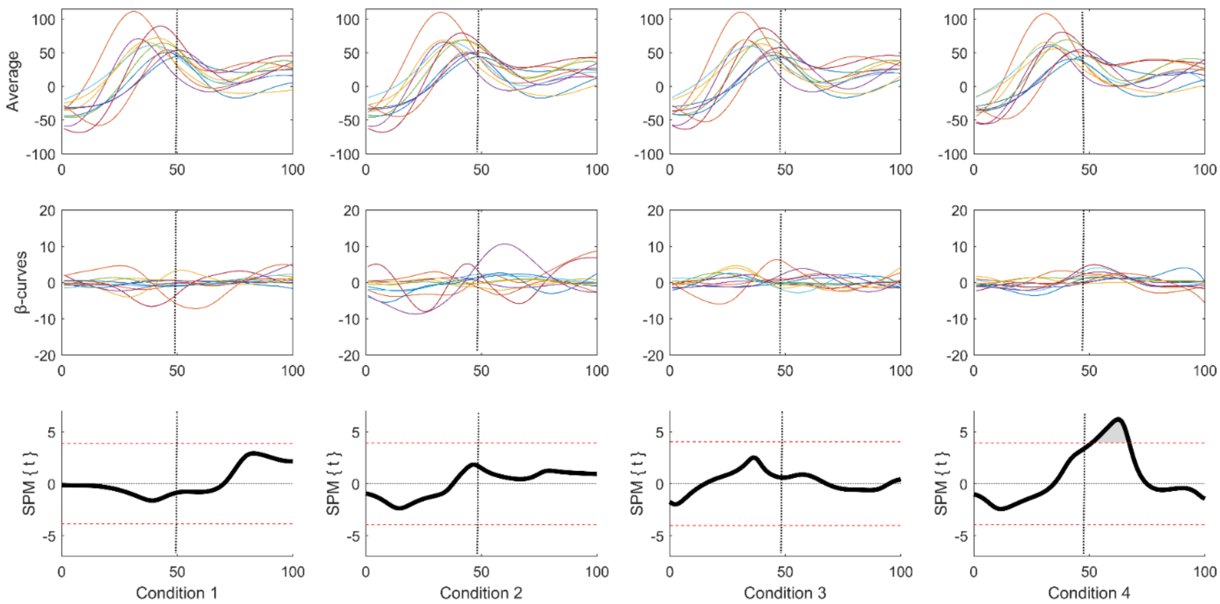

Figure 2: The relationship between the change in arm segments angular momentum and the maximum racket velocity in forward swing phase (4 conditions).

DISCUSSION: The aim of this study was to explore the consistency of the interaction between postural balance control and end-effector performance across 4 serve locations, focussing on the forward swing phase. This research found no meaningful relationships between postural balance control and end-effector performance except the interaction between the change in arm angular momentum and maximum racket velocity in condition 4 (figure 2). This was systematically positive between approximately 50%-70% of the forward swing phase. The reason might be that the upper extremities were used to contribute to racket velocity at impact to produce the power serve especially, for the kick serve (often used when serving to condition 4), the upper limb would be used to generate spin to send the ball to the target area. This

confirms observation from the training literature, with Elliott (2006) stating that the internal rotation of the upper arm plays an important role in the (kick) serve action.
Whilst there were no consistent significant relationships across conditions there were some trends towards a relationship that may well deserve some further attention. For example, a trend towards an interaction between trunk angular momentum and end-effector performance was observed just prior to the above mentioned observation concerning arm angular momentum (data available but not presented here). Rapid changes in angular momentum of the trunk are expected to precede those of the arms, the latter which are most likely to in fact occur after peak velocity is reached. Both mechanisms are expected to influence balance, but their impact is likely different. While the trunk mechanism occurs at a time when the player is still in contact with the ground, the arms mechanism occurs when the player is in the air. This means that the trunk mechanism acts according to the counter rotation of segments mechanism as described in the literature, generating a backwards directed horizontal force on the ground. The change in arm angular momentum is likely to compensate for undesirable changes in angular momentum elsewhere in the body, for example excessive forwards rotation of the lower extremity, leading to an overall body angular momentum that is not excessively rotating the body forwards. In terms of the practical application for coaches and players, the results from this study suggest that for the kick serve the counter rotation associated with the arms is an important performance enhancing mechanism, but otherwise postural balance mechanisms are not interacting directly with performance in a systematic way. This could be interpreted in two ways, first that if an interaction between postural balance mechanisms and end-effector performance exists this is highly individual, and second that learning different serve techniques likely involves learning different balance mechanisms. Concerning the arms mechanism, the impact of the counter rotation will also differ when the player serves without jumping, so during the learning process towards a jumped serve this involves learning how to cope with a different effect of the arms counter rotation balance mechanism.

CONCLUSION: Our findings showed no population-wide interaction (balance control vs end-effector performance) in the first serve. Hence, there is still no evidence to support that balance and serving technique should be trained simultaneously thus, balance and end-effector performance could be trained separately.

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