HOW DO TENNIS PLAYERS CONTROL THEIR BALANCE DURING THE SERVE?

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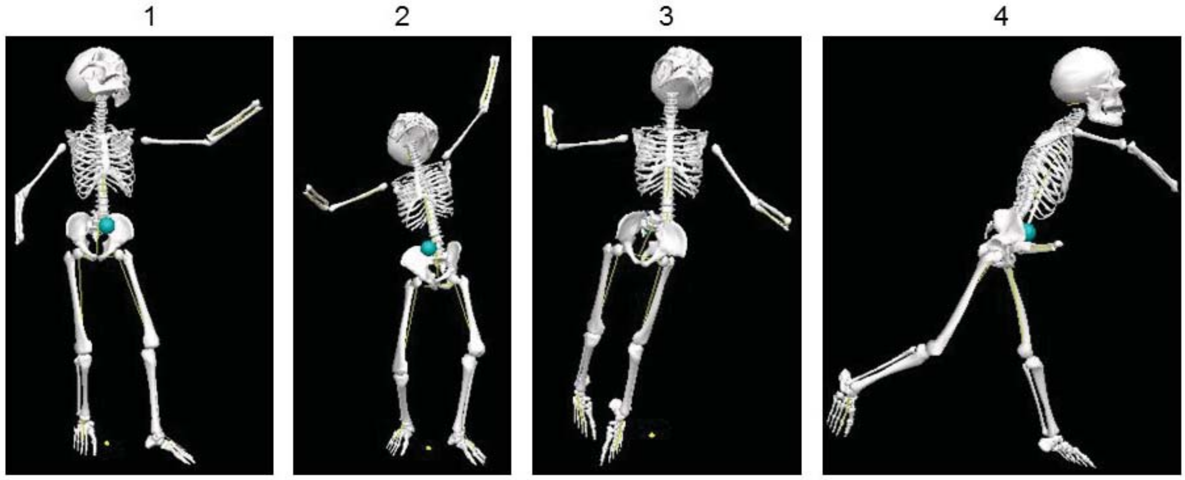
The purpose of this study was to investigate how postural balance is manifested in high level tennis players, and whether movement variability is phase dependent. Twelve experienced tennis players (8 males and 4 females; age 21.5±4.11 years; height 174.75±6.06 cm; body mass 66.83±8.12 kg) completed 10 tennis successful serves. Whole-body kinematics were recorded and whole-body extrapolated centre of mass trajectories calculated. Within-subject variation was presented temporally to evaluate phase-dependent differences. Overall, our results showed individual balance control preferences and a progressive increase of within-subject variability throughout the serve movement. This knowledge will help trainers and coaches identify learning and performance needs associated to whole-body balance control.

KEYWORDS: balance control, extrapolated centre of mass, movement variability.

INTRODUCTION: The serve is the most essential stroke in tennis (Reid et al., 2013), providing the player with the first chance of winning the rally. Many previous studies have investigated how the tennis serve is performed, focusing mainly on upper limb and racquet kinematics, in search of the key performance indicators such as, for example, shoulder, elbow, arm, hand angular velocities or racquet velocities (Reid et al., 2013, Whiteside et al., 2013, Whiteside et al., 2014). Two key features of the tennis serve is that it is performed under player controlled circumstances (excluding weather conditions) and it is mostly pre-programmed and goal-directed. As a consequence, the repetitions of kinematics movement are expected to show low trial-to-trial variability. The question is whether this is also the case for how players control their balance throughout the serve.

Postural balance control involves controlling the position of the centre of mass (COM), traditionally defined in static terms, that is, as long as the projection of the COM remains within the horizontal bounds of the base of support, one remains stable (Winter, 1998). This definition cannot, however, be applied to a tennis serve for two reasons: (1) the initial base of support behind the serve line can be exceeded by leaping forward and hitting the ball during flight and (2) there is benefit from increasing the forward velocity of the COM to aid racquet velocity and as such ball speed. To address these limitations, the trajectory of the extrapolated COM (XCOM) can be observed, which adds a velocity component to the COM based on the principles of an inverted pendulum (Hof et al., 2005). Observing the trajectory of the XCOM is therefore expected to help us understand how whole-body balance is controlled, with particular emphasis on how tightly this is constrained over time. Namely, throughout a pre-programmed task like the tennis serve, some aspects or phases require more tight control for a successful outcome, while others allow more variability (Langdown et al., 2012). Our aim was therefore to investigate how experienced tennis players control their XCOM throughout a serve movement.

METHODS: Eight male and four female experienced right-handed tennis players (≥ 5 years participating at the national and international level), with mean (±SD) age 21.50 ± 4.11 years, height 174.75 ± 6.06 cm, and body mass 66.83 ± 8.12 kg, participated in the study. Participants were questioned on their injury history and none had a recent (< 6 month) muscle injury. This study was approved by the Liverpool John Moores University ethics committee (15/SPS/016) and Mahidol University ethics committee. Sixty eight reflective markers were placed on anatomical landmarks to record segmental motions. After completing a 10-min warm up consisting of light jogging and tennis serve movements, participants performed at least 10 maximal effort flat serves towards a 1x1 m floor target area bordering the T of the service box of the deuce court, with a 2-min rest between serves. Only successful serves hitting the target area were analysed. Kinematic data were collected with 12 infrared cameras at 200 Hz (BTS bioengineering, Milan, Italy), and using a full-body six-degree-of-freedom kinematic model. This kinematic model tracked the segmental motion of 13 segments, including the head, upper arms, forearms, thorax, pelvis, thighs, shanks and feet. The tennis serve was divided into 3 phases based on four key events as shown in figure1.



Phases	Key events
1-2 Preparation	Event1: Non-racquet upper arm horizontal
2-3 Propulsion	Event2: Highest of distal Non-racquet upper arm
3-4 Forward swing	Event3: Lowest point of racquet head
	Event4: Hitting arm horizontal

Figure1: tennis serve phases based on four key events

The displacement of the whole body CoM was estimated from segmental mass locations using segmental data from Dempster (1955). The XCOM displacement was then calculated for the direction perpendicular to the serve line (along A/P lab axis in Figure 1), using a correction factor based on leg length and COM velocity. The XCoM equation was implemented in Visual3D (C-motion, Germantown, MD, USA). Trials were time normalised to 100% of cycle time (phase 1-3). The within-subject variability of XCoM trajectories was then calculated from the standard deviation (SD) of trajectories from the 10 trials. As this was an exploratory study, the analysis was restricted to qualitative interpretations of trajectories and no inferential statistical tests were used.

RESULTS AND DISCUSSION: The propulsion phase was the longest phase as it was approximately half of the total time, while initial preparation and final forward swing phases were each about one quarter of the total time (see Figure 2).

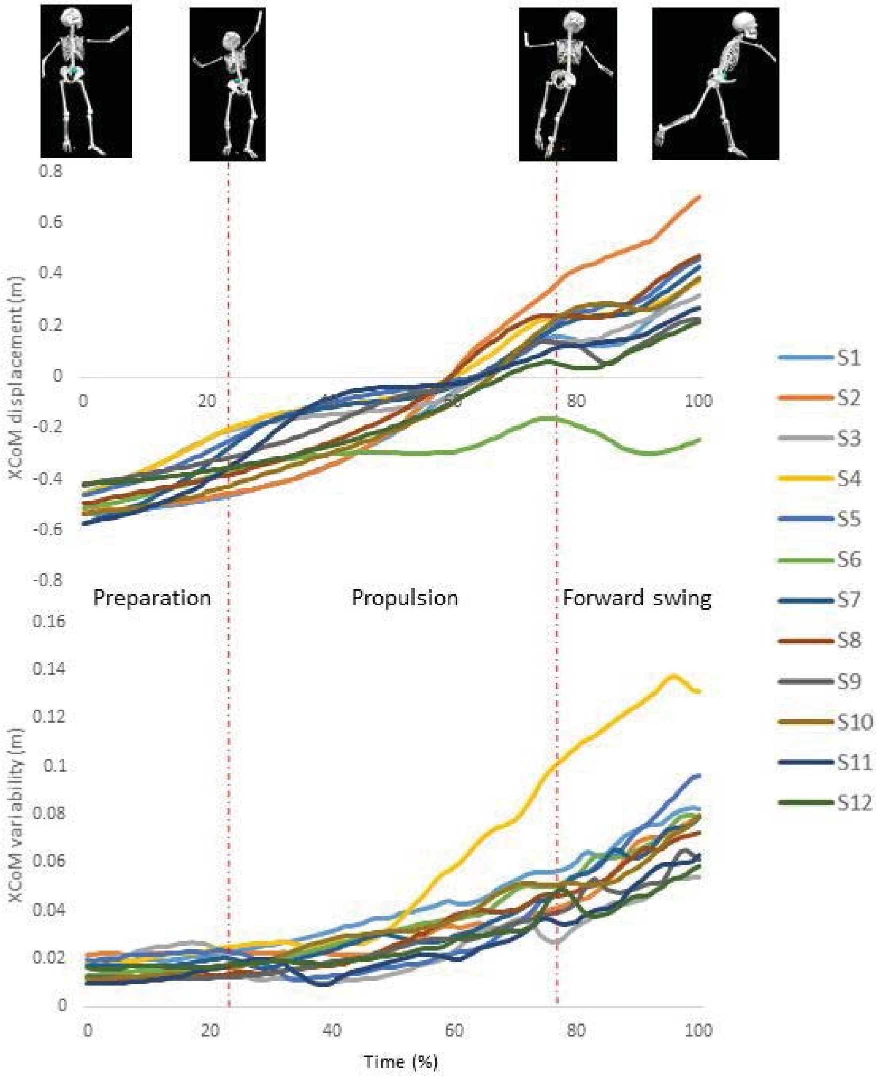


Figure 2: Average XCoM trajectories of all 12 subjects during 10 tennis serves (top panel) and within-subject XCoM variability trajectories using 0 as the baseline (bottom panel)

The XCoM moved forward similarly in all participants (see top panel figure 2). However, greater variation between participants was observed towards the end of the movement compared to the beginning, and some distinct movement patterns could be seen. For example, participant S6 had very limited forward XCoM displacement, and participant S2 moved forward more quickly and to a greater extent than all other players. The other 10 participants had a more similar movement pattern, but there were still some noticeable differences, particularly at the end of preparation and start of propulsion. The latter differences seemed to suggest a steady progression of XCOM movement during preparation and propulsion in some (e.g. S12), whilst a bi-phasic progression in others where for example the XCoM of S11 moved forward until halfway the propulsion phase, stopped for some time, and started to move forward again at the end of propulsion phase. The difference of XCoM trajectories may happen as the players had different serving technique.

The within-subject variability of XCoM trajectories was very low and constant throughout the preparation phase due to the serving line constraint (less than 2 cm, see lower panel Figure 2). Variability then gradually increased throughout the propulsion and more so in the forward swing phase of the serve. Whilst one participant (S4) showed considerably greater variability from the second half of the propulsion phase, all other participants demonstrated a very similar steady increase in movement variability, which likely reflects adaptations for variations in the ball toss. Hence, this study established that to produce the successful outcomes some phase required stability while others needed more variability that also supported Langdown et al. (2012) expressed that variability can be defined as the ability to produce the same final task outcome.

CONCLUSION: The results in this study supported the notion of Bartlett et al. (2007), that outcome invariance does not necessarily mean movement invariance, this time when considering whole-body balance control. Whilst our results demonstrated that individual preferences in whole-body balance control exist, a very similar progressive increase in within-subject variability during the latter phases of the serve was seen in 11 out of 12 participants. Recognizing that progressively reduced consistency in balance control during the propulsion and forward swing phases of a tennis serve is an inherent part of success will help trainers and coaches identify the learning and performance needs associated to whole-body balance control.

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