

HOW IMPORTANT IS PERCEPTION-ACTION COUPLING IN THE TENNIS SERVE?

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The purpose of this study was to examine how removing visual feedback affects ball and racket kinematics in the tennis serve. A 10-camera 500 Hz VICON MX motion analysis system recorded the service actions of 8 elite junior players as they performed three serves with eyes open and three serves with eyes closed. Removal of vision resulted in considerable differences in both racket and ball kinematics, and the interaction between the two. The results highlight that the service action is not pre-programmed, and that visual feedback is critical to the temporospatial regulation of the service action. These findings suggest that coaches need to be aware of the implications of removing perception-action couplings, and ensure that the drills that they prescribe represent the action being trained.

KEY WORDS: vision, closed skill, open skill, dynamic system, pre-programming.

INTRODUCTION: The serve ranks among one of the most practiced strokes in tennis, with coaches and players dedicating large proportions of their practice time to this skill. Over the past few decades, the serve has garnered considerable research attention, with much of this work dedicated to describing serve biomechanics (Elliott, Marsh, & Blanksby, 1986; Reid, Elliott, & Alderson, 2008). More recently, empirical evidence has been presented that questions the validity of drills often used by coaches to promote specific kinematic changes (Reid, Whiteside, Giblin, & Elliott, 2013). Traditionally, tennis coaches have propagated the idea of mechanical consistency in stroke production, which directly contrasts the more contemporary skill acquisition that advocate functional movement variability (Glazier, Wheat, Pease, & Bartlett, 2006; Reid, Whiteside, & Elliott, 2010).

In what might be interpreted as the purest expression of this mechanical consistency, tennis coaches challenge players to hit serves with their eyes closed, on the basis that the action—a closed skill—should be repeatable and consistent. In the literature, two theories have been proposed to explain how performers control hitting actions. On one hand, researchers have suggested that hitting movements are preprogrammed and that, through acquisition, the performer knows the real time duration of the movement to be executed (Tyldesley & Whiting, 1975). Such an approach has been termed operational timing. Alternative research proposes that hitting actions are constrained by dynamic external factors, which ultimately dictate how performance emerges (Newell, 1986). In dynamic scenarios, the importance of perceptual feedback is emphasized, as this tool is required to inform appropriate actions. Conversely, the operation-timing hypothesis advocates a preprogrammed action that is independent of perceptual monitoring, implying that the action should remain similar even if visual information is removed.

The aims of this study were, therefore, to determine whether perception-action is critical to serve performance by evaluating racket and ball kinematics during serve performance in two conditions: (1) eyes open and (2) eyes closed. Given previous research has shown players couple their hitting movements to ball position at zenith (Whiteside, Elliott, Lay, & Reid, 2014) we hypothesized that racket and ball kinematics would be significantly different in the eyes closed condition.

METHODS: Eight internationally ranked junior male right-handed tennis players (age 17.3 ± 1.2 years, height 177.8 ± 9.7 cm, weight 69.7 ± 15.6 kg) participated in the study. Prior to participation players provided informed consent, after approval by the relevant human research ethics committee. Players performed their regular pre-match warm up prior to performing two tasks. First, players were required to hit maximal effort first serves, directed at a 1 m long x 1.2 m wide target area bordering the T of the deuce service box, until a total of 3 had landed in the target. Subsequently, players performed three serves aiming for the

same target, but with their eyes closed. The player was allowed to establish their position on the baseline, then instructed to close their eyes from the beginning of their service action until the whole action was completed, regardless of whether ball contact was achieved or not. Racket and ball kinematics of three successful regular serves were then compared to the serves in which visual feedback was removed (eyes closed).

The marker set consisted of: 3 retro-reflective markers on the ball, 5 markers on the racket and 1 marker on the first metatarsal of the left foot. All displacements were normalised to the location of player's front foot at address. A 10-camera, 500 Hz VICON MX optical motion system (Oxford Metrics Inc, UK) recorded marker trajectories. Gaps in marker trajectories were filled using the cubic spline interpolation function within VICON Nexus. To account for impact accelerations (where applicable), marker trajectories from one frame prior to impact were deleted and a customised polynomial extrapolation was applied to predict marker trajectories 10 frames post impact (Knudson & Bahamonde, 2001; Reid, Campbell, & Elliott, 2012). A Woltring filter with an optimal mean squared error of 3mm as determined by a residual analysis was applied to the raw data, which were then modelled using UWA's customized model to calculate racket and ball kinematics (Reid et al., 2010; Whiteside, Chin, & Middleton, 2013).

The serve was considered to begin when the ball was released from the tossing hand, as indicated when vertical acceleration of the ball became negative. Phases of the serve were defined using the following time points of interest: peak vertical displacement of the racket ("trophy position"); ball zenith during ball toss (BZ); racket low point immediately prior to forward swing (RLP), and; impact. Impact was defined as one frame (0.002s) prior to racket-ball contact. Where ball contact was not achieved in the eyes closed condition, impact was approximated in accordance with when the vertical displacement of the racket origin approximated its mean impact height under normal (i.e., eyes open) serving conditions. Given the limited sample size, differences between conditions were evaluated using Cohen's *d* effect sizes ($d < 0.2$ = small; $0.2 \leq d \leq 0.5$ = small-to-moderate; $0.5 \leq d \leq 0.8$ = moderate-to-large; $d > 0.8$ = large).

Table 1
Mean, standard deviation, and effects sizes
for ball, racket and timing kinematics.

	Eyes Open	Eyes Closed	<i>d</i>
Timing			
Preparation	0.64	0.54	1.13
Propulsion	0.20	0.21	0.36
Forwardswing	0.13	0.12	0.05
Total Action	0.96	0.87	0.89
Ball Position			
X at Zenith	-6.2	2.2	0.93
Y at Zenith	49.4	51.2	0.20
Z at Zenith	313.3	311.4	0.09
Racket Position			
X at Impact	-15.7	-4.9	0.59
Y at Impact	55.7	40.8	0.83
3D absolute distance between racket-ball			
	8.34	33.04	1.63

X: Lateral; Y: Anteroposterior; Z: Vertical.

RESULTS: The service actions were characterised by several sizeable effects in ball toss positioning, racket positioning and the resulting interaction between the two (Table 1). The ball, at zenith, was further to the right during eyes closed serving ($d = 0.93$), although height and anterior-posterior position was comparable to serving with the eyes open (both small effect sizes). Racket position at impact was also significantly further to the right and closer to the body, in the eyes closed condition. Absolute distance between the racket origin and the ball origin at impact was greater ($d = 1.63$) in the eyes closed condition. As seen in Figure 1., the players arrived at impact too early; consequently the ball was still positioned above the racket. In addition, the lateral distance between the racket and ball at impact was also greater with eyes closed (Figure 1). Preparation duration (BR-RHP) displayed a large effect size, and was significantly shorter when the eyes were closed, leading to a faster overall swing time.

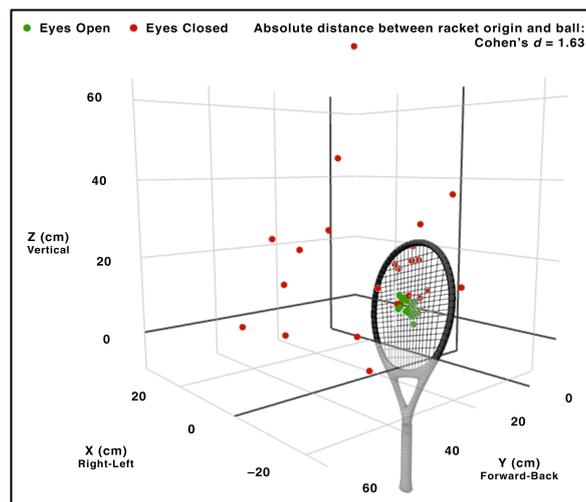


Figure 1. 3D ball locations at the instant when the racket was in an impact position in the eyes open (green) and eyes closed (red) serves.

DISCUSSION: This study examined temporospatial features of the serve when performed by players with the eyes open and eyes closed. The premise of the drill examined in the current study (i.e., serving with the eyes closed) is that, if the service action is sufficiently consistent, stroke production (including the motion of the ball and racket) should be preserved even when visual information is removed. However, with previous research having reported that spatial variation exists in the ball toss under normal conditions, it was hypothesised that removing visual feedback would critically disrupt the service action. The results of this study confirmed this hypothesis, as various temporospatial features of serve changed considerably when vision was removed. These findings underline the importance of perception-action coupling in successful serving.

Forward placement and height of the ball at the top of the toss displayed no differences between conditions. This finding was not particularly surprising, as the execution of the ball toss is not typically associated with visual feedback (players do not typically look at the ball prior to release). However, it was unexpected that the ball was placed further to the right in the eyes closed condition ($d = 0.93$). It is possible that these players used external visual cues to regulate the lateral direction of their toss during normal serves. Future research should consider whether players use external references to calibrate their ball placement.

Terminal racket location exhibited sizeable differences between conditions. When the racket reached its typical impact height during eyes closed serves, it was further to the right ($d = 0.59$) and not as far forward into the court ($d = 0.83$). This finding confirms that players must be able to see the ball in order to wield the racket in a manner befitting each unique serve (Whiteside et al., 2014) and challenges the assertion that the service action is pre-programmed or that it can be classified as a “closed” skill. This position is endorsed by the relative ball-racket locations at impact denoted in Figure 1. It is obvious from this figure that, when the eyes were open, the ball locations at impact were clustered around the centre of the racket face. Conversely, when the eyes were closed players experienced difficulty “finding” the ball as evidenced by the fact that players failed to achieve racket-ball contact in 16 of 24 serves. This disparity in distance between racket-ball location at impact was the largest effect recorded and indicated that terminal ball and racket locations were more tightly coupled during normal serves but independent of one another in the eyes closed condition. In the context of previous research that has reported substantial spatial variation in the ball toss in normal serving (Whiteside, Giblin, & Reid, 2014) it is not surprising that these players experienced difficulty achieving racket-ball contact when their ability to control for this variability (i.e., through perceptual feedback) was removed. Consequently, these data appear to support the assertion that players couple their mechanics to the ball’s location to successfully achieve impact during the serve (Whiteside et al., 2014).

Closing the eyes also yielded a shorter preparation phase ($d = 1.13$). This may relate to the fact that players are postulated to use the ball's spatial location to regulate their mechanics such that they arrive in the trophy position as the ball reaches its zenith (Reid, Whiteside & Elliott, 2010). Given that the height of the ball toss was comparable in both conditions, it appears as though these players did not have sufficient awareness of ball zenith timing when their eyes were closed, explaining why preparation changed. However, it is noteworthy that the propulsion and forwardswing phase durations did not change when the eyes were closed. Consequently, it is possible that these phases could be temporally pre-programmed and unreliant on visual feedback. Although future research is required to corroborate as much, this theory does conform with previous research asserting that the forwardswing is an invariant feature of the serve (Whiteside et al., 2014).

Finally, it should be noted that the population in this study consisted of elite junior players and only considered first serves aimed at the T. It is possible that as players develop, mechanical consistency improves, however it is still likely that removing the perception-action coupling of the serve will disrupt its mechanics to some degree. The relatively select sample and one investigated serve type, may limit the extent to which these findings can be generalized. Similarly, it is worth noting that while the players involved in the study were familiar with rehearsing eyes closed serves, only three serves were provided (as compared to three successful eyes open serves), meaning that some of the observed differences may relate to this methodological approach.

CONCLUSION: Practically, the results suggest that coaches are too zealous in their expectation of a mechanically consistent service action. While it seems logical to assume that a more consistent action is beneficial for serve success, the results suggest that the service action is controlled online to some degree, rather than entirely pre-programmed, implying that visual feedback is a critical informant to serve mechanics. Consequently, there should be a premium placed on training drills that provide opportunities to develop perception-action coupling, as opposed to drills where the two are compartmentalised.

REFERENCES:

- Elliott, B., Marsh, T., & Blanksby, B. (1986). A three-dimensional cinematographic analysis of the tennis serve. *International Journal of Sport Biomechanics*, 2, 260-271.
- Glazier, P. S., Wheat, J. S., Pease, D. L., & Bartlett, R. M. (2006). The interface of biomechanics and motor control. *Movement system variability*, 1, 49-69.
- Knudson, D., & Bahamonde, R. (2001). Effect of endpoint conditions on position and velocity near impact in tennis. *Journal of sports sciences*, 19(11), 839-844.
- Newell, K. M. (1986). Constraints on the development of coordination. *Motor development in children: Aspects of coordination and control*, 34, 341-360.
- Reid, M., Campbell, A. C., & Elliott, B. (2012). Comparison of endpoint data treatment methods for estimation of kinematics and kinetics near impact during the tennis serve. *Journal of applied biomechanics*, 28(1), 93.
- Reid, M., Elliott, B., & Alderson, J. (2008). Lower-limb coordination and shoulder joint mechanics in the tennis serve. *Medicine & Science in Sports & Exercise*, 40(2), 308.
- Reid, M., Whiteside, D., & Elliott, B. (2010). Effect of skill decomposition on racket and ball kinematics of the elite junior tennis serve. *Sports Biomechanics*, 9(4), 296-303.
- Reid, M., Whiteside, D., Giblin, G., & Elliott, B. (2013). Effect of a common task constraint on the body, racket, and ball kinematics of the elite junior tennis serve. *Sports Biomechanics*, 12(1), 15-22.
- Tyldesley, D., & Whiting, H. (1975). Operational timing. *Journal of Human Movement Studies*.
- Whiteside, D., Chin, A., & Middleton, K. (2013). The validation of a three-dimensional ball rotation model. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 227(1), 49-56.
- Whiteside, D., Elliott, B. C., Lay, B., & Reid, M. (2014). Coordination and variability in the elite female tennis serve. *Journal of sports sciences*(ahead-of-print), 1-12.
- Whiteside, D., Giblin, G., & Reid, M. (2014). *Redefining spatial consistency in the ball toss of the professional female tennis serve*. Paper presented at the International Conference on Biomechanics in Sports, Johnson City, TN, United States.