3D DATA WEIGH IN ON PRO TOSSING

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The first tennis book inclusive of tennis biomechanics, The Fundamentals of Tennis was authored by Stanley Plagenhoef Ph.D. in 1970. The book gives some quantified data on the strokes of many legends from the 1950s and 60s, e.g., Pancho Gonzales, Rod Laver, and Roy Emerson from live match play.

Olympic athlete, Gideon Ariel studied with Stanley Plagenhoef and advanced to earn PhDs in both exercise science and computer science, and to win the International Society of Sports Biomechanics most prestigious lifetime achievement award.

During his career, employing his expertise in computer science coupled with the skills learned from Plagenhoef, Ariel went on to invent the first 3D motion analysis system on a PC available to coaches and athletes: The Ariel Performance Analysis System (APAS).

HEIGHT INCHES	LEGENDARY PLAYERS *Figure 1*
0-1 INCH	JOHN NEWCOMBE (1)
1-3 INCH	ROY EMERSON (1)
3-5 INCH	ARTHUR ASHE (1)
6-9 INCH	PANCHO GONZALES(1), ROD LAVER (1) TONY ROCHE (1)
9-12 INCH	JACK KRAMER (1), KEN ROSEWALL (2) (1969)
12-15 INCH	STAN SMITH (1), MAUREEN CONNOLLY (1)
15-20 INCH	KEN ROSEWALL (2)(1952)
20-24 INCH	CLIFF DRYSDALE (4) MANOLO SANTANA (1)
25-30 INCH	NANCY CHAFFEE (4)

Plagenhoef's data shows most of the accomplished players were letting the ball drop 15 inches or less to impact. Employing the use of APAS technology we analyzed and can share some revealing data we have collected and processed from players contemporary to Dr. Plagenhoef's collection.(***Fig 1***)

TOSS DROP FROM PEAK TO CONTACT INCHES	*Figure 2* CURRENT WORLD #1S, GRAND SLAM, OR MASTERS 1000 CHAMPIONS
0-7	ISNER
8-15	RODDICK, NADAL, FEDERER, DENT
16-20	SAMANTHA STOSUR, VENUS WIIIAMS
20-25	DJOKOVIC (2014) KIM CLIJSTERS
25-30	ANDY MURRAY, DJOKOVIC (LOG-IL) KUZNETSOVA,SERENA (2009)
30-35	SERENA JANKOVIC
36-40	DEMENTIEVA, SERENA, SCHNYDER
40-50	SHARAPOVA
50- 60	SAFINA

And as Dr. Ariel later became my own mentor in 1989, his pioneering work has inspired my own work over the past 3 decades, in tennis and in 3D motion analysis.

The goal has been to develop teaching systems designed to collect, process and employ live 3D data at every level that will be beneficial to tennis coaches and players.

Most recently, we have analyzed a topic, contentious since the inception of tennis – ***HOW HIGH TO TOSS THE BALL WHEN SERVING.***

Utilizing the SCiO 3D Sports Library we studied twenty-first serves from tour matches that were aces or winners from seven male players who have been ranked #1 on the ATP tour, won Grand Slams, won Master's 1000 events, or served 149 mph. Also studied were serves with the same criteria on fifteen serves from 8 contemporary players from the WTA. ***(see table above Fig 2)***

In the SCiO Lab we ran statistics on racket tip velocities, the distance of ball drops to impact, vertical ball velocity and outgoing ball velocity on the contemporary players and their tosses. Anatomically there is a 4.5-inch significant difference in the average height of male vs female players ($p<.05$). Therefore, we broke the data into a male and female group for analysis.

There was a significant difference in the average drop of toss from the

ball's peak height to contact between elite men and women professionals ($p<.001$). It followed that we should look for the advantage or disadvantage of the toss difference.

One argument I often hear when coaches tell players to toss higher is," the player isn't contacting the ball high enough".

The data in this study showed however that, there is no correlation between the height of the toss and the height of ball - racket contact in the men's group, the women's group, or in combined grouping.

The take away is that: tossing the ball higher does not mean the player will impact the ball higher.

Another argument I hear for tossing higher is that "you will get more power on your serve." (See my article in Tennis Industry Sept/Oct 2018 page 48, "A New Direction for Racket Head Speed" for an explanation on the misuse of the word power).

Coaches tend to use two reasons for insisting higher ball tosses give more ball speed toward the target. First, the ball is coming down faster and it will go out faster. Second, the higher toss will give more time to load the body. Research at the SCIO lab at Racket and Health 91 in Tulsa shows there to be no correlation between higher tosses and outgoing forward ball velocity.

Another commonly heard argument for tossing higher is that the player will get more topspin. There are two alleged reasons. First. it is alleged that the increased downward velocity of the ball will cause it to scrape against the strings faster creating more topspin. Second, that there is more time to load the body, therefore, increased ability to swing up stronger with the racket and thus get more topspin.

The first reason alleges you will get more topspin by tossing the ball higher and therefore, tacitly concludes that tossing higher is productive. In further reflection one might question, however, why one would want topspin? Topspin is productive for consistency. Topspin curves the ball downward. Topspin gives a player a larger window over the net in which to be successful and topspin in most cases causes a trickier bounce. The greater downward velocity on the ball created by a higher toss theoretically gets a little more topspin on the ball. But, should we consider the trade-offs required to get this small amount of extra topspin? As an example, let's compare a serve by Dinara Safina and Venus Williams.

Safina's toss drops 58 inches to contact. Venus's drops 16. Safina's ball arrives at impact going down 12.01mph while Venus's is going 6.4 mph. Depending on the strings and the overall coefficient of friction, Safina might gain a little topspin here. What is the price? Safina's toss must travel 6.5 feet farther than Venus's. If we assume the racket has a nine-inch vertical area in which the players can meet the ball on the string bed, the ball will be in this region 79 milliseconds for Venus compared to 42 milliseconds for Safina. That puts the ball in Venus's strike zone almost two times longer.

To check the validity of second reason, we checked the upward velocity of the racket tip which is correlated with topspin on serve in other research. We found no correlation between toss height and upward racket tip velocity. Since the purpose of the high toss is to allow one to better load the body than a low toss, and the purpose of loading the body is to swing the racket swiftly upward, and the racket is not swinging more swiftly upward, the argument that a higher toss better loads the body fails.

From our data we were able to confidently determine a strong correlation of success when male and female professional players impact the ball at 1.5 times their height ($p<.001$). And comparing our two charts, we see the lion's share of Grand Slam Championships are won are by players whose ball tosses drop a maximum of 20 inches.

In conclusion our study using data from Roger Federer, Rafael Nadal, Novak Djokovic, Pancho Gonzales, Rod Laver, Roy Emerson Serena Williams, and Maureen Connolly has shown agreement that tossing higher will not facilitate hitting the ball towards your target with more speed. Tossing higher will not give you an advantage in upward racket velocity to cause greater topspin. Even though small gains of additional topspin due to friction will occur when tossing much higher, it will cost you increased exposure to wind, require you to be very accurate with a riskier and larger toss distance and cause a need for your timing to be substantially more precise to make solid contact. There are other kinesiological advantages to tossing lower not discussed. However, when it comes to the toss, historic and contemporary 3D data reveals less is more.

James R. Shaughnessy MSS, CSCS, is a USPTA Master Pro specializing in the application of sports biomechanics to elite tennis players training at Tucker Tennis Academy a USTA Regional Training Center Racquet and Health 91 located in Tulsa. He is an award-winning professional with 30 years of experience as a speaker, researcher, analyst and consultant in tennis biomechanics, 3D motion analysis and computerized exercise prescriptions. He is the founder of SCiO 3D Sports. ***Special thanks to Hank and Molly Pellegrini who make this work possible.***