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Ball velocity and spin at the impact of tennis serves: Reliability of a ball motion measurement instrument (TRACKMAN)

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ABSTRACT

To verify the reliability of the precision of TRACKMAN measurements, we analyzed 3 types of serves (flat, slice, kick) and compared the results to values obtained with the 3D motion capture system (VICON). Positive linear strong correlations were observed in velocity calculated with TRACKMAN(x) and VICON(y) ; ($r = 0.996$, $p<0.01$), as well as number of ball spin; ($r = 0.978$, $p<0.01$). This suggests that ball velocity and the number of ball spin values calculated with TRACKMAN, can provide immediate feedback and is provides sufficient reliability and would be useful in training situations.

Key words: TRACKMAN, VICON, velocity, spin
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INTRODUCTION

Takahashi(2007) and Cross and Pollard(2009) pointed out that serve velocity gradually increased for a decade from 1999 to 2009, and that a high-speed serve is an important advantage for controlling games and can thus underpin winning or losing a match. However, their research focused on serve velocity and the number of points won without serve characteristics analyses.

In 2011 to 2017, the author returned practice serves from Roger Federer, one of the top-ranked players in the world. This demonstrated to the author that in addition to higher ball velocity, Federer's serve has particular characteristics regarding to higher spins, which include the trajectory of the ball from impact until its entry into the service area and its specific motion after the bounce.

Kreighbaum and Hunt (1978) suggested 5 variables that influence pitched baseball trajectory: initial ball velocity, the direction of the ball's axis of rotation, the number of spins, the angle of delivery, and air density. Tennis serves can be categorized into 3 types: flat, slice and kick which include different combinations of ball speed,
spin and trajectory. In addition to velocity, the ball's trajectory and rotation, both factors that can change how a ball behaves after the bounce, can confuse an opponent's predictions and have a negative impact on the ability of the opponent to receive and respond to the serve. Consequently, these are considered factors that can induce errors and mistakes. Previous research has shown that among the top players in the world, the number of spins differs between the 1st and 2nd serves (Muramatsu et al.,2010, 2015). However, this analysis was performed based on image analysis of high-speed cameras; thus it was impossible to obtain immediate feedback on this data.

The recent development of TARCKMAN which provides immediate feedback on ball motion data, has made it easy to accurately measure the motion and velocity of balls widely in golf and baseball. TRACKMAN is an instrument that applies the Doppler effect, a military-use, radar-based projectile tracking system, to perform specific measurements. For tennis, the development of "TRACKMAN TENNIS RADAR" in 2003 enabled the immediate calculation of trajectory data, such as initial ball velocity, the number of spins, and ball path, as well as positional data, such as the impact point.

In a previous research study the precision of TRACKMAN was verified by using high speed cameras and speed guns, resulting in high levels of correlation in ball velocity and number of spins (Murakami et al.,2016). However, the data analysis in this experiment was

performed visually using images obtained from one high speed camera. Consequently, more detailed studies of 3-dimensional (3D) analysis of ball motion, using multiple cameras, are now required to further verify the reliability of TRACKMAN .

In the present study, we simultaneously measured ball velocity, and the number of ball spins from flat, slice, and kick serves using VICON and TRACKMAN. 3-D motion analysis of balls were conducted to verify the reliability of TRACKMAN data.

METHOD

Subjects involved in this study included 1 champion of the All Japan Tennis Championships (a professional player) and 19 male students belonging to sections 1 and 3 of the Kanto Inter-Collegiate Tennis Federation (mean age: 23.8±4.8 years; mean height: 171.8±3.3 cm; mean weight: 68.9±4.0 kg; mean competitive experience: 11.5±3 years). All the participants were right-handed. Experimental procedures and safety guidelines were explained and informed consent were approved for all subjects by the ethical committee of NSSU.

Experimental task

Before the measurements were taken, all participants warmed up by hitting each type of the 3 types of serve. The racquets used in the experiment were those that the participants used regularly; type Dunlop Fort balls were used in all experiments. A local coordinate system was constructed by placing 5 reflective markers on the upper hemisphere of the balls.

The experimental task consisted of hitting each of the 3 serves (flat, slice, kick) at full power until data was obtained on 5 balls for each type of serve. For flat and kick, the serves were hit to the center (T-zone), while for slice, the serves were hit wide. A successful task was defined as when the ball bounced on the court with the markers attached and hit the target area. In our experiment, which used the experimental procedure developed measurements of service velocity and the number of spin, made by TRACKMAN and VICON were compared (Sakurai et al.,2012)

Experimental equipment

Ball velocity and the number of spins were measured using a 3-D motion capture system (VICON MXV5) with 12 cameras, and TRACKMAN. VICON used a personal computer to control the cameras and perform the measurements, VICON MXV5 cameras, a 16-bit 64-channel AD conversion box, and a VICON MXV5 wand to construct the 3D coordinates. VICON Nexus version 1.3 was used as the measurement software. Two MXV5 cameras were attached to the ceiling and 5 cameras were placed on both the left and right sides of the server to surround the subject. Ball velocity and the number of spins for each serve were calculated based on the coordinates of the reflective markers. The TRACKMAN instruction manual was followed and the device was placed so that its center was on a line that extended from the center mark.

Figure 1. Experiment environment and TRACKMAN.

Statistical processing [coordinate system definition]

For the global coordinate system, the X axis was the direction of movement, the Z axis was in the vertical direction, and the Y axis was perpendicular to the X axis. Correlations with maximum ball velocity and the number of spins calculated with TRACKMAN were determined by calculating Pearson product-moment correlation coefficients. Statistical analysis software (IB) was used for all statistical processing. Data for the 3 serve tasks and figures calculated from the measurement instruments were subjected to 2-way analysis of variance (ANOVA). Multiple comparisons with the Bonferroni method were performed when significant main effects were observed. A risk ratio of 5% or less was considered to be statistically significant.

RESULTS AND DISCUSSION

Correlation of service velocities measured by TRACKMAN and VICON

Figure 2 shows the correlations between service velocities measured using TRACKMAN(x) and VICON(y). A high

correlation coefficient was observed for the 3 serves; r = 0.996; p<0.01). High correlation coefficients were also obtained for the respective serve conditions (flat: [r = 0.996]; slice: [r = 0.992] ; kick: [r = 0.996] , p<0.01). In this study, the velocities of 3 serves performed by top Japanese players were measured using TRACKMAN and a speed gun. Although a high correlation coefficient (r = 0.997) was obtained, TRACKMAN generally tended to show higher velocity (5.5 km/h) than a high speed camera (Murakami et al., 2016). This shows that velocity cannot be measured accurately if the speed gun lens surface (an optical axis) does not line up with the direction that the object being measured is travelling and that the larger the angle between the electrical wave and the object's trajectory, the larger the measurement error becomes(Morimoto et al., 2007). Consequently, it is possible that the values were affected by the angle between the speed gun and the ball's trajectory (Murakami et al., 2016). In contrast, the ball velocity values obtained from TRACKMAN and VICON in the present study were almost an exact match. We believe that this is because the entire singles court could be exposed to radar with TRACKMAN, which enabled more accurate velocity measurements over a larger area than is possible with a speed gun.

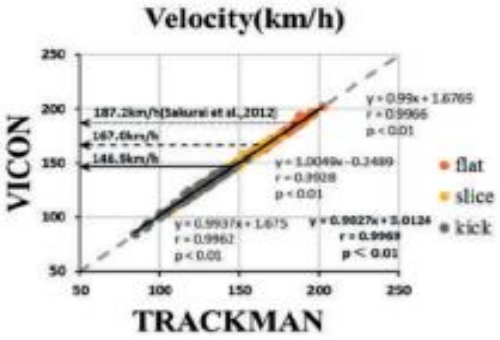

Figure 2. Ball velocity measured by TRACKMAN and VICON.

Number of ball spin measured by TRACKMAN and VICON

Figure 3 shows the correlation of the number of ball spins (rpm) from the three serves as measured using TRACKMAN(x) and VICON(y). A high correlation coefficient was observed for all 3 types of serve (flat, slice, kick ; r = 0.978, p<0.01). High correlation coefficients were also obtained for the serves individually (F: r = 0.949]; S:[r = 0.906,]; K:[r = 0.885] p<0.01). The r values for the number of spin for the 3 serves increased successively as the serve type changed from kick to slice to flat. The number of ball spins was obtained with TRACKMAN by exposing the entire singles court to radar and based on the information obtained 300 ms after ball impact. In the present study, the kick values exhibited a higher correlation than flat or slice when compared to the VICON values, although the error was very slight. This is thought to have occurred because this type of serve had the largest number of spins. In any case, the number of spins calculated with TRACKMAN exhibited a high level of reliability, suggesting that this instrument could be useful in training situations. For ball velocity, the 2-way ANOVA results between the TRACKMAN and VICON instruments showed no interaction and no statistically significant difference. Significant main effects were observed between the three types of serves (flat, slice, kick), but there was no significant difference between the measurement instruments. With regard to the number of ball spins, 2-way ANOVA results between the TRACKMAN and VICON instruments showed no interaction and no significant difference. However, while significant main effects were observed between the 3 types of serves, there was no significant difference between the instruments.

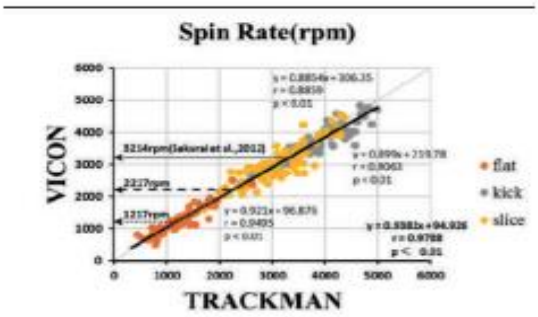

Figure 3. Ball spin rate measured by TRACKMAN and VICON.

CONCLUSION

To verify the reliability of the precision of TRACKMAN measurements, we analyzed 3 types of serve and compared the results to values obtained with VICON. Data showed that the correlation coefficient of ball velocities calculated with TRACKMAN and VICON conformed to (r = 0.996, p<0.01) and both measuring equipment had no significant effect. Furthermore, there was a high correlation coefficient for the number of ball spins: (r = 0.978, p<0.01) and both measuring equipment had no significant effect. This suggests that ball velocity and the number of ball revolution values calculated with TRACKMAN which provides immediate feedback, are highly reliable and would be useful in training situations. When the player knows the information of ball flight immediately, the skill can be adjusted immediately on court with this feedback.

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