AERODYNAMICS OF SOCCER BALLS AND VOLLEYBALLS

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INTRODUCTION

The balls used in ball games are different in size, mass, profile, internal air pressure, material and surface structure. The initial velocity of the served, kicked or batted balls is produced according to the principle of conservation of linear momentum. The trajectory of balls travelling in the air depends on the ballistics and aerodynamics of the balls being used. The drag force is directly proportional to the area of the ball facing the movement direction and to the square of the velocity. Smaller and heavier balls with low skin friction behave more according to the laws of ballistics. With other combinations of profile drag and skin drag more aerodynamic effects will be observed. When the velocity of balls is high enough aerodynamic crisis can exist. When comparing the aerodynamic drag of soccer balls and volleyballs in a wind tunnel the ratio of aerodynamic and gravitational forces has been for soccer balls and volleyballs 2.38 and 3.86 at speed of 29-30 $m.s^{-1}$, respectively (Plagenhof, 1971; Frolich, 1984). However, in these conditions the Reynolds number has been about the same, 4.31 x 105 for a soccer ball and 4.23 x 105 for a volleyball. Both in soccer balls and volleyballs a floater phenomenon can be observed during real matches when the balls are traveling at fast speed. Lateral force of a baseball has been studied in a wind tunnel when evaluating the erratic motion of a knuckleball (Watts and Sawyr, 1975).

The purpose of this study was to investigate range, flight time, speed and trajectory of selected official soccer balls and volleyballs in a constant release angle shot by a ball gun with a hydraulic shooting steel leg mechanism in a placed indoor soccer hall.

METHODOLOGY

Five officially authorized soccer balls (m=0.422 ± 0.010 kg, d=0.216 ± 0.004 m, p=(0.69 + 0.01) x 105 Nm-2) and five volleyballs (m=0.278 ± 0.006 kg, d=0.210 ± 0.004 m, p=(0.69 + 0.01) x 105 Nm-2) were used. Three speeds (V1, V2 and V3) of the kicking steel leg were applied to the stationary (R0=0 rad.s-1) and rotating balls with two constant angular velocities (R1=45.6 and R2=65.0 $rad.s^{-2}$). The release height and angle of the balls was 0.31 m and 18°, respectively. The 3-D orthogonal reference frame was 8.92 m, 6.03 m and 1.55 m in length, width and in height, respectively. All shots of the balls were recorded with two camcorders (50 Hz) for kinematics motion analysis. An APAS performance analysis system was used for detailed 3-D analysis of the release phase of the shots inside the reference frame. The x-y-z coordinates, instantaneous velocities and direction angles of the balls were calculated. The landing point of the ball was measured in x-z coordinates on the Astroturf ground. A Panasonic camcorder with timer was used to measure the flight time of the balls. The ground speed was calculated by dividing the range by the flight time.

The procedure of three-way ANOVA was applied in order to study the differences in the placid air for the release velocity, range and deviation of the landing point from the sagittal plane in respect to the type of ball, impact speed and instantaneous rotational velocity or spin.

RESULTS

The average 3-D release velocity of soccer balls and volleyballs can be seen in Figure 1.

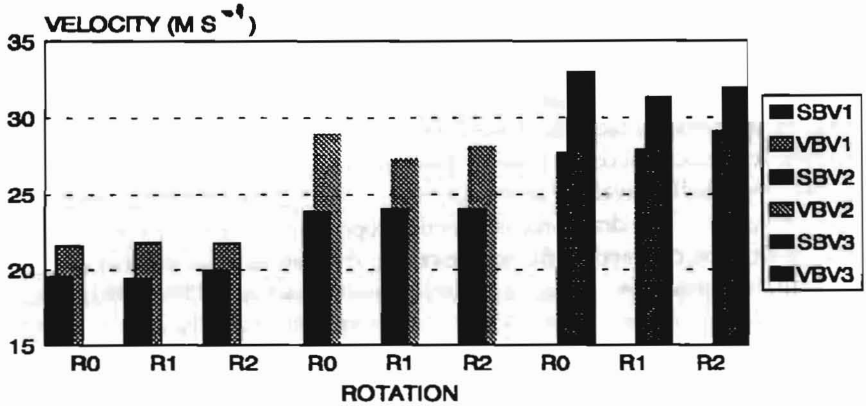

Figure 1. The average 3-D release velocity of soccer balls (SB) and volleyballs (VB) with different release velocities (V3, V2 and V1) and initial rotational velocities (R0, R1 and R2).

The average range of soccer balls and volleyballs during flight is shown in Figure 2.

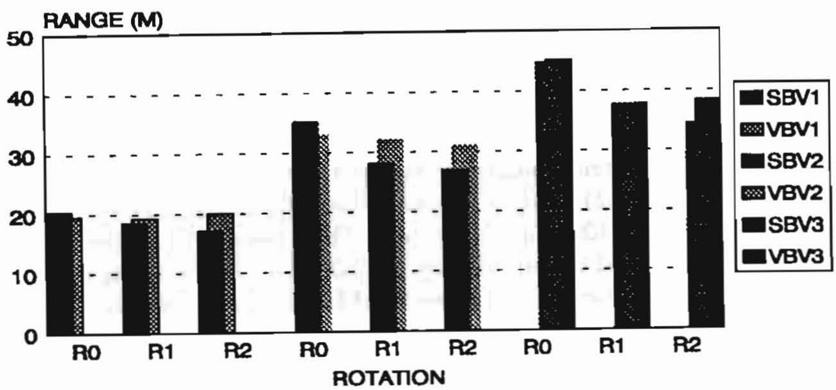

Figure 2. The average range of soccer balls (SB) and volleyballs (VB) with different release velocities (V3, V2 and V1) and initial rotational velocities (R0, R1 and R2).

The average lateral deviation angle of the balls during the early flight phase can be seen in Figure 3.

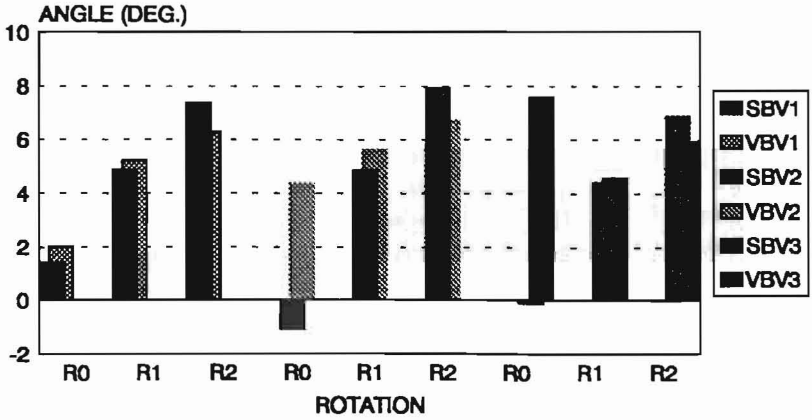

Figure 3. The average lateral deviation of soccer balls (SB) and volleyballs (VB) with different release velocities (V3, V2 and V1) and initial rotational velocities (R0, R1 and R2).

The fastest shot of the soccer balls measured from the landing points was on average 44.8 m with the lateral deviation being 3.3°. The average range of the volleyballs in the fastest shots without spin was 45.2 m with the lateral deviation being 4.8°. With the fastest spin and shot, the range and deviation of soccer balls and volleyballs measured, according to the landing points, were 34.4 m and 38.6 m and 19.7° and 21.4°, respectively.

Table 1 shows the main effects and interactions of the ball type, shot speed and spin on the range and lateral deviation.

Table 1. Statistics of 3-way ANOVA analysis concerning the range and lateral deviation of soccer balls and volleyballs with different speed and spin.

	Range		Lateral deviation	
	F	p	F	p
Main effects	200.61	0.000	103.73	0.000
Ball type	7.66	0.007	2.62	0.110
Shot speed	467.07	0.000	23.95	0.000
Spin	30.63	0.000	234.95	0.000
2-way interactions	4.05	0.001	3.53	0.002
Ball type Shot speed	0.28	0.755	1.11	0.335
Ball type Spin	5.71	0.005	0.36	0.701
Shot speed Spin	5.11	0.001	6.33	0.000
3-way interactions	0.93	0.454	0.18	0.949
Explained	61.13	0.000	32.21	0.000

The main effects of the ball type, shot speed and spin were significant ($p<0.001$) on the range, ground speed and lateral deviation. Several two-, and three-way interactions were found. The deviation of the landing points in x-z coordinates was significantly ($p<0.001$) smaller in both ball types with the highest angular velocity than with stationary balls.

DISCUSSION

The main effects of the shot speed and rotational spin were statistically significant ($p<0.001$) both for the range and lateral deviation of the flying balls. Also the two-way interaction of the shot speed and spin was significant ($p<0.001$).

The detailed results indicated that in the case of the stationary balls with each shot speed the average release velocity was higher in volleyballs than soccer balls. This was due to the lower mass of volleyballs. However, the range was about the same in both ball types, but the lateral deviation of the volleyballs was larger than in the soccer balls mainly due to the lower mass of volleyballs and sensitive air pressure changes round the volleyballs and direction changes. A small increment (n.s.) was found in the release velocity of soccer balls when progressive rotational movement was added to the ball. In the volleyballs the trend was contrary. This can be partly explained by the principle of conservation of mechanical energy. The additional rotational energy of the soccer balls could come through the higher moment of inertia, because the mass of the soccer ball was higher and the diameter larger than in volleyballs.

When comparing the ranges of both stationary soccer balls and volleyballs the corresponding differences were not found as was found in velocities. The ratio of the aerodynamic and gravitational forces in volleyballs means relatively higher deceleration for volleyballs than soccer balls and therefore the relatively shortened range of volleyballs. The influence of the initial rotational movement of the ball was similar in trend as in the stationary balls.

The floater phenomenon was observed both in soccer balls and volleyballs with the two highest shot speeds, without the rotational velocity of the ball. This was indicated also in the deviation angle of the balls (Figure 3) during the early flight phase. When the angular speed was applied to the balls, the floater phenomenon disappeared. With the increasing rotational velocity of the ball, the range was shortened and the landing area became narrower.

More attention should be paid to the detailed analysis of the reasons for the variations. For that reason wind tunnel measurements might be necessary. A high speed video analysis of the impact phase of the steel leg and balls might give more information about the decreasing rotational velocity of the balls.

It can be concluded that the trajectories of the balls were, in each ball type, so constant that a ball gun may be used in the training and evaluation of individual techniques of goalkeepers and field players in soccer. In volleyball all type of serves with spin and floater balls are also possible for teaching and training individual defense technique.

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