Rebound characteristics of the new table tennis Ball; Differences between the 40mm (2.7g) and 38mm (2.5g) balls

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Abstract The purpose of this study was to clarify the physical characteristics of the rebound of the new ball just after the impact against a racket with pimples inward-reversed rubber.
The velocity of incidence just before impact against a racket ranged from 14.19 m/s to 14.71 m/s, with three values of spin forward, 120 rps, 60 rps and 5 rps. The contact was filmed at 9000 Hz with a high-speed video camera.
As the incident rotational frequency was increased, the reflected frequency showed a progressively bigger decrement between the 40mm and 38mm balls; i.e. the decrement ratio of the rotational frequencies was bigger with the 40mm ball than with the 38mm. It is expected that it will be more difficult for players to spin the 40mm ball than the 38mm. In the experimental conditions of High and Medium spin, the reflection angle for the 40mm ball was different from that of the 38mm ball, but with Low spin there was no difference between the two balls. However, the restitution coefficient showed little difference between the two balls under any conditions.
(Key words: ball size, collision to racket, high-speed filming, normal and tangential coefficients of restitution)

1 Introduction

The International Table Tennis Federation changed the diameter of the ball from 38mm (2.5 g) to 40mm (2.7g) after the Olympic Games in Sydney, 2000. It is expected that this will change the playing style and the tactics. The purpose of this study was to clarify the physical characteristics of the rebound of the new ball just after the impact against a racket with pimples inward-reversed rubber.

2 Methods

To measure spin a ball marked on its surface was shot against the surface of a racket, by a robot machine, downward at 35° from the vertical in a laboratory controlled at 25℃ and at 70 % relative humidity.

Figure 1 illustrates the situation of this experimentation. The contact was filmed at 9000 Hz with a high-speed video camera, set up at the same height as the ball, at right angles to the direction of travel of the ball (Figure 2).

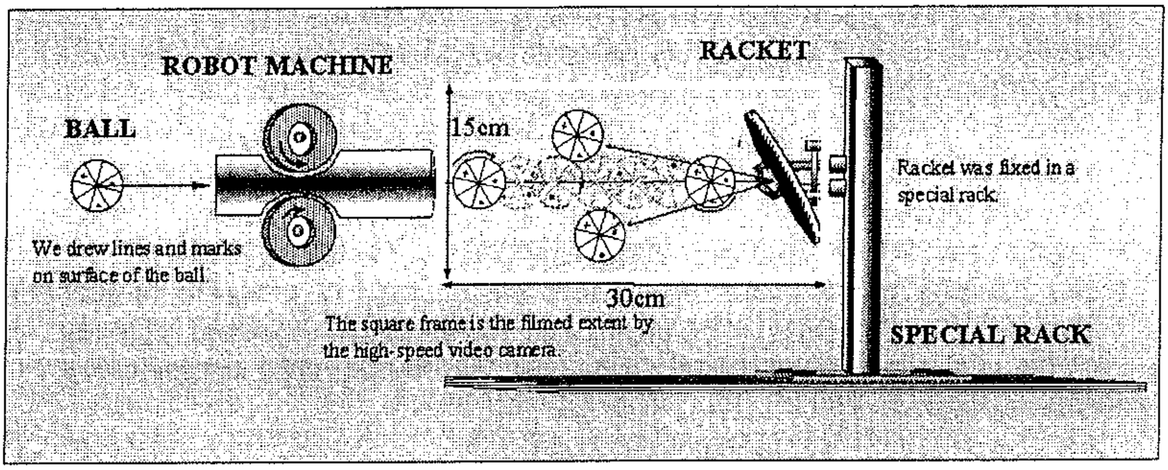


Figure1. Schematic illustration of this experimentation.

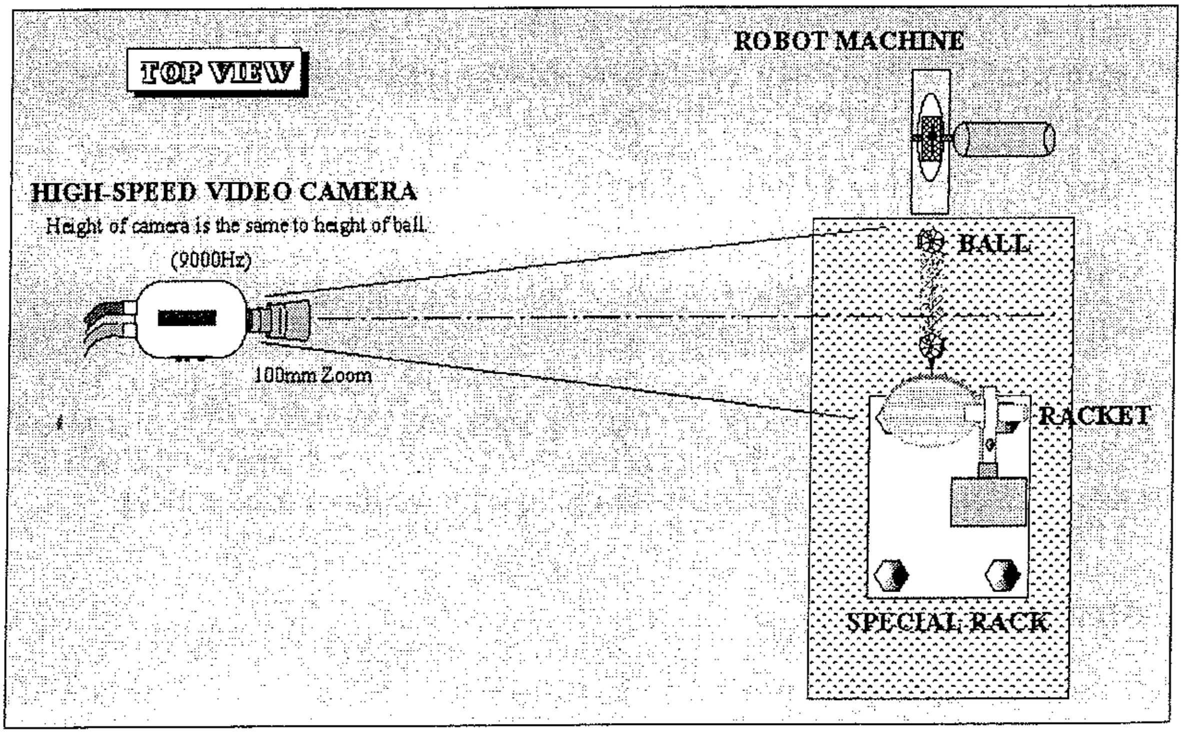
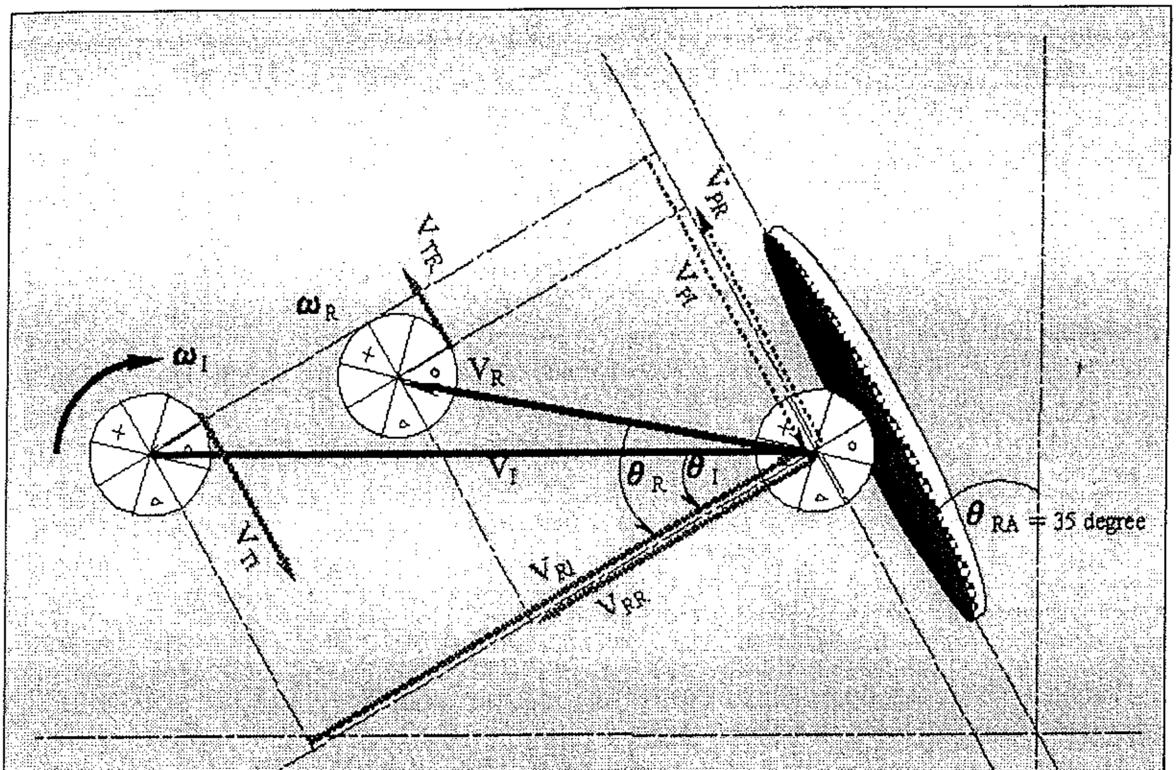


Figure 2. Placement of Camera



V_I : Initial velocity of the ball before the impact(m/s)
V_R : Final velocity of the ball after the impact (m/s)
ω_I : Initial spin of the ball before the impact(rps)
ω_R : Final spin of the ball after the impact(rps)
θ_I : Incidence angle of V_I to the racket surface(deg)
θ_R : Reflection angle of V_R to the racket surface(deg)
V_{RI} : Tangental component of V_I to the racket surface (m/s)
V_{RR} : Tangental component of V_R to the racket surface (m/s)
V_{PI} : Parallel component of V_I to the racket surface (m/s)
V_{PR} : Parallel component of V_R to the racket surface (m/s)
$V_{\omega I}$: Tangental velocity of the ball surface calculated from ω_I(m/s)
$V_{\omega R}$: Tangental velocity of the ball surface calculated from ω_R(m/s)
θ_{RA} : Racket Angle from the vertical axis = 35 degree

$$\frac{V_{RR}}{V_{RI}} = \text{Normal coefficient of restitution}$$

$$\frac{V_{PR}+V_{TR}}{V_{PI}+V_{TI}} = \text{Tangential coefficient of restitution}$$

Figure 3. Methods of measurements & calculations

Table 1. Experimental condition

Class		Variables			Low	Medium	High
Laboratory condition		*Temperature*			25°C		
		Humidity			70%		
Collision condition	*40mm* (N=10)	*Velocity*	V_I	*Average*	14.2m/s	14.7m/s	14.6m/s
				(S.D.)	(0.24)	(0.37)	(0.44)
		Spin	ω_I	*Average*	5.2rps	61.1rps	122.1rps
				(S.D.)	(0.47)	(0.87)	(1.12)
		Angle	θ_I	*Average*	32.2deg	33.9deg	34.8deg
				(S.D.)	(0.48)	(0.88)	(1.35)
	38mm (N=10)	*Velocity*	V_I	*Average*	14.3m/s	14.3m/s	14.3m/s
				(S.D.)	(0.42)	(0.34)	(0.20)
		Spin	ω_I	*Average*	4.4rps	60.3rps	123.0rps
				(S.D.)	(0.46)	(1.31)	(1.76)
		Angle	θ_I	*Average*	33.0deg	32.4deg	33.7deg
				(S.D.)	(0.66)	(1.46)	(1.25)

Table 1 shows experimental conditions of the laboratory and the collision. The velocity of incidence just before impact against a racket ranged from 14.19 m/s to 14.71 m/s, with three values of spin forward, 120rps (High), 60rps (Medium) and 5rps (Low). To calculate the velocity of the ball, the distance traveled in the 50/9000 sec from just before the collision and until just after was measured on a computer's display, and the spin was measured by the time taken for one rotation.

Figure 3 illustrates parameters of measurements and calculations. They were measured at least ten times for each experimental condition.

3 Results

To examine the equality of the collision condition, we conducted analysis of variance by two-way layout design. Table 2 shows results of the analysis of variance of the collision conditions.

Figure 4 illustrates differences of initial velocity (V_I) of the balls before the impact. In table 1, the initial velocities (V_I) of the 40mm ball are Low = 14.2±0.2 4m/s, Medium = 14.7±0.37 m/s and High = 14.6±0.44 m/s, respectively (mean±S.D.). For the 38mm ball, the initial velocities are 14.3±0.42 m/s, 14.3±0.34 m/s and 14.3±0.20 m/s respectively. In the results of analysis of variance, statistical significant differences of the initial velocity (V_I) were not found under any conditions. The initial velocity is the same under all conditions. To change the rotation with the same velocity, this robot machine could not increase rotation beyond it.

Figure 5 illustrates differences of initial spin (ω_I) of the ball before the impact. In table 1, the initial spins (ω_I) of the 40mm ball are Low = 5.2±0.47 rps, Medium = 61.1±0.87 rps and High = 122.1±0.44 rps, (mean±S.D.). For the 38mm ball, the initial spins are 4.4±0.46 rps, 60.3±1.31 rps and 123.0±1.76 rps. Wu et al. (1992) have measured the ball spins of the high loops of the Chinese National Team: indicated average was 128.4 rps; the rotation of our High experimental condition is close to this value. In the results of analysis of variance, statistically significant differences of the initial rotation (ω_I) were not found between the 40mm ball and the 38mm ball; the initial spin is the same for both balls. Of course, the values of spin (High, Medium and Low), were changed intentionally. This significance level is $p<0.0001$.

Table 2. Analysis of variance on V_I, ω_I, θ_I before the impact

Initial velocity of the ball before the impact (V_I)

source of variation	*sum of square*	*df*	*mean square*	*computed F*	*P value*
Ball	0.467	1	0.467	3.873	0.0542
Rotation	0.771	2	0.385	3.197	<0.05
Ball × Rotation	0.685	2	0.343	2.842	0.0671
Error	6.510	54	0.121		

Initial spin of the ball before the impact(ω_I)

source of variation	*sum of square*	*df*	*mean square*	*computed F*	*P value*
Ball	0.913	1	0.913	0.756	0.3885
Rotation	138741.672	2	69370.836	57399.719	<0.0001
Ball × Rotation	8.978	2	4.489	3.714	0.0308
Error	65.262	54	1.209		

Incidence angle of V_I to the racket surface (θ_I)

source of variation	*sum of square*	*df*	*mean square*	*computed F*	*P value*
Ball	4.870	1	4.870	4.209	<0.05
Rotation	27.601	2	13.801	11.927	<0.0001
Ball × Rotation	14.995	2	7.497	6.480	<0.01
Error	62.482	54	1.157		

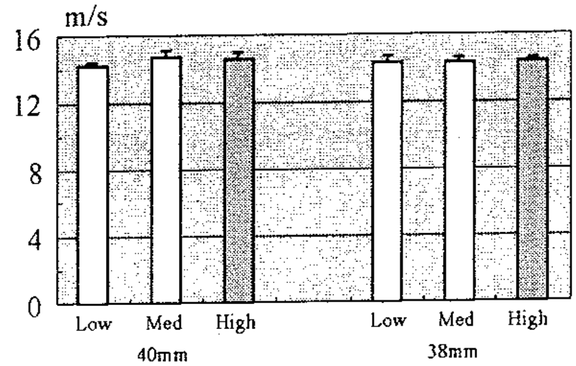


Figure 4. Initial velocity of the ball before the impact

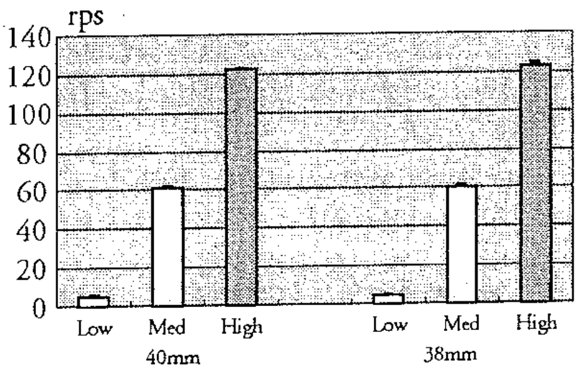


Figure 5. Initial spin of the ball before the impact

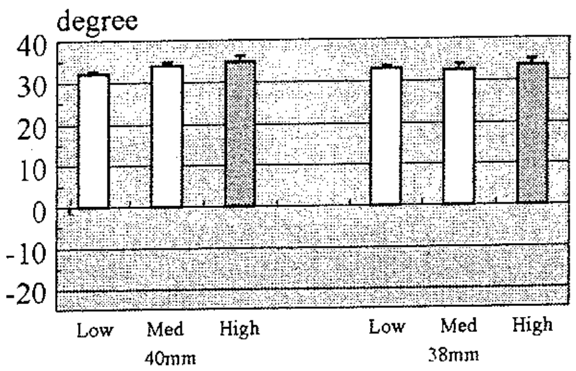


Figure 6. Incidence angle of VI to the racket surface

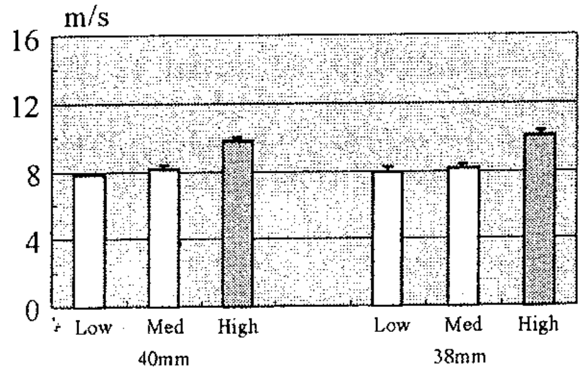


Figure 7. Final velocity of the ball after the impact

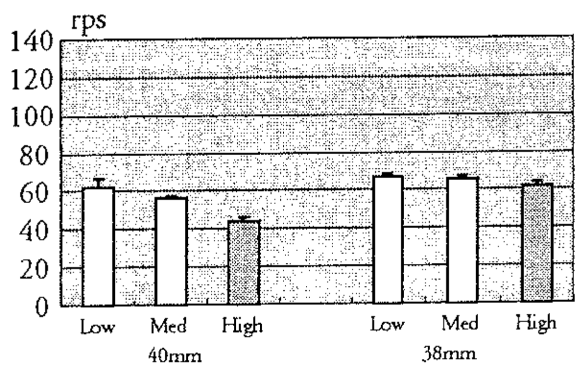


Figure 8. Final Spin of the ball after the impact

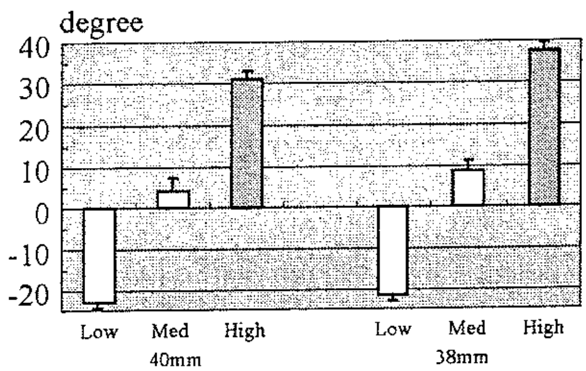


Figure 9. Reflection angle of VR to the racket surface

Table 3. Measured value after the impact

Variables			*Low*	*Medium*	*High*
40mm (N=10)	*Velocity* V_R	*Average*	7.7m/s	8.1m/s	9.7m/s
		(S.D.)	(0.17)	(0.23)	(0.20)
	Spin ω_R	*Average*	62.4rps	55.8rps	44.2rps
		(S.D.)	(3.81)	(1.27)	(1.49)
	Angle θ_R	*Average*	-22.9deg	4.1deg	31.3deg
		(S.D.)	(1.50)	(3.12)	(1.76)
38mm (N=10)	*Velocity* V_R	*Average*	7.9m/s	8.1m/s	10.1m/s
		(S.D.)	(0.27)	(0.17)	(0.24)
	Spin ω_R	*Average*	66.6rps	65.4rps	61.3rps
		(S.D.)	(1.82)	(2.62)	(2.99)
	Angle θ_R	*Average*	-21.6deg	8.5deg	37.7deg
		(S.D.)	(1.47)	(1.46)	(1.97)

Figure 6 illustrates differences of incidence angle (θ_I) of the ball before the impact. In table 1, the incident angles (θ_I) of the 40mm ball are Low = 32.2±0.48°, Medium = 33.9±0.88° and High = 34.8±1.35°, respectively (mean±S.D.). For the 38mm ball, the incident angles are 33.0±0.66°, 32.4±1.46° and 33.7±1.25° respectively. In the results of analysis of variance, statistically significant differences in the incidence angle (θ_I) were found between the two balls (significance level $p<0.05$), and also in rotation (significance level $p<0.0001$). The Fisher's post-hoc test indicated that the angle is greater than for other conditions. This result originates because our robot machine was not new. But the difference of angle is only an average of 2.4°. We considered that not to be an important difference.

Table 3 shows results that measured Vr, Wr and Or after the impact. Table 4 shows the values of variance of each parameter after the impact.

Figure 7 illustrates differences of final velocity (V_R) of the ball after the impact. In table 3, the final velocities (V_R) of the 40mm ball are Low = 7.7±0.17 m/s, Medium = 8.1±0.23 m/s and High = 9.7±0.20 m/s, respectively (mean±S.D.). For the 38mm ball, the final velocities are 7.9±0.27 m/s, 8.1±0.23 m/s and 9.7±0.20 m/s in turn. In the result of analysis of variance, small statistically significant differences of the final velocity (V_R) were found between the two balls (significance level $p<0.05$). The final velocity increased as rotation increased.

Table 4. Analysis of variance on V_R, ω_R, θ_R after the impact

Final velocity of the ball after the impact(V_R)

source of variation	*sum of square*	*df*	*mean square*	*computed F*	*P value*
Ball	0.416	1	0.416	8.836	<0.05
Rotation	51.030	2	25.515	541.462	<0.0001
Ball x Rotation	0.198	2	0.099	2.103	0.132
Error	2.545	54	0.047		

Final spin of the ball after the impact(ω_R)

source of variation	*sum of square*	*df*	*mean square*	*computed F*	*P value*
Ball	1580.936	1	1580.936	273.891	<0.0001
Rotation	1442.135	2	721.068	124.922	<0.0001
Ball x Rotation	425.016	2	212.508	36.816	<0.0001
Error	311.695	54	5.772		

Reflection angle of V_R to the racket surface(θ_R)

source of variation	*sum of square*	*df*	*mean square*	*computed F*	*P value*
Ball	245.660	1	245.660	52.714	<0.0001
Rotation	32210.189	2	16105.095	3455.830	<0.0001
Ball x Rotation	66.650	2	33.325	7.151	<0.001
Error	251.654	54	4.660		

Figure 8 illustrates differences of final spin (ω_R) of the ball after the impact. In table 3, the final spins (ω_R) of the 40mm ball are Low = 62.4±3.81 rps, Medium = 55.8±1.27 rps and High = 44.2±1.49 rps, respectively (mean±S.D.). For the 38mm ball, the final spin are 66.6±1.82 rps, 65.4±2.62 rps and 61.3±2.99 rps respectively. In the result of analysis of variance, statistically significant differences in the final spin (ω_R) were found at all factors (all significance levels $p<0.0001$). The final spin of 40mm ball is less than that of 38mm ball. As the initial spin before the impact was increased, the final spin after the impact showed progressively larger differences between the 40mm and 38mm balls. The characteristic of the spin differs between the 40mm and the 38mm ball. Therefore, it is expected that it will be more difficult for players to spin the 40mm ball than the 38mm ball.

Figure 9 illustrates differences of the reflection angles (θ_R) of the ball after the impact. In table 3, the reflection angle (θ_R) of the 40mm ball are Low = −22.9±1.50°, Medium = 4.1±3.12° and High = 31.3±1.76°, respectively (mean±S.D.). For the 38mm ball, the final angles are −21.6±1.47°, 8.5±1.46° and 37.7±1.97° respectively. In the result of analysis of variance, statistically significant differences of the reflection angle (θ_R) were found at all conditions (all significance levels p<0.0001). The reflection angle of the 40mm ball is lower than for the 38mm ball. From this result, we considered that the amount of spin has influence.

Table 5. Calculated value of coefficients

	Variables		*Low*	*Medium*	*High*
40mm (N=10)	***Coefficient of restitution***	***Average***	0.59	0.66	0.70
		(S.D.)	(0.01)	(0.02)	(0.01)
	Tangential coefficient of restitution	***Average***	0.62	0.48	0.45
		(S.D.)	(0.06)	(0.03)	(0.02)
38mm (N=10)	***Coefficient of restitution***	***Average***	0.61	0.67	0.67
		(S.D.)	(0.02)	(0.02)	(0.01)
	Tangential coefficient of restitution	***Average***	0.64	0.59	0.60
		(S.D.)	(0.05)	(0.04)	(0.03)

Table 6. Analysis of variance on the coefficient of restitution and the tangential coefficient of restitution

Coefficient of restitution

source of variation	*sum of square*	*df*	*mean square*	*computed F*	*P value*
Ball	0.00005	1	0.00005	0.213	0.646
Rotation	0.069	2	0.035	134.653	<0.0001
Ball × Rotation	0.006	2	0.003	12.150	<0.0001
Error	0.014	54	0.0003		

Tangential coefficient of restitution

source of variation	*sum of square*	*df*	*mean square*	*computed F*	*P value*
Ball	0.127	1	0.127	73.042	<0.0001
Rotation	0.144	2	0.072	41.526	<0.0001
Ball × Rotation	0.042	2	0.021	12.219	<0.0001
Error	0.094	54	0.002		

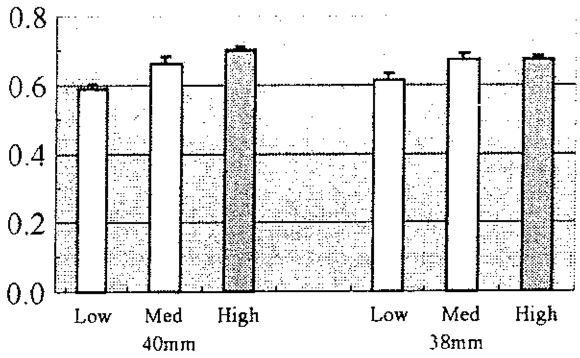


Figure 10. Coefficient of restitution

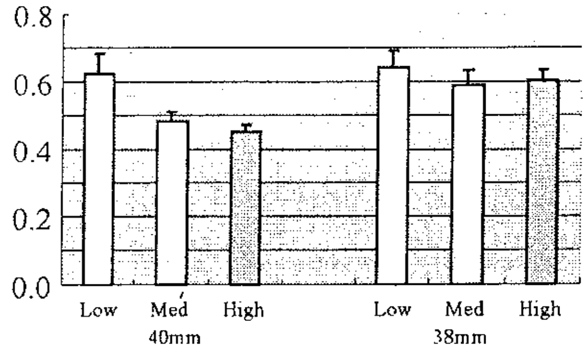


Figure 11. Tangential coefficient of restitution

Table 5 shows the calculated normal and tangential coefficients of restitution. Table 6 shows results of analysis of variance of the normal and tangential coefficients of restitution.

Figure 10 illustrates differences of the coefficient of restitution. In table 6, the coefficients of restitution of the 40mm ball are Low = 0.59±0.01, Medium = 0.66±0.02 and High = 0.70±0.01, respectively (mean±S.D.). For the 38mm ball, the coefficients of restitution are 0.61±0.02, 0.67±0.02 and 0.67±0.01 in turn. In the analysis of variance, statistically significant differences of the coefficients of restitution were not found between the two balls. The coefficients of restitution indicated tendency to decrease as the rotation increased. These significance levels were $p < 0.0001$ (between High and Low), $p < 0.01$ (between High and Medium) and $p < 0.0001$ (between Medium and Low). However, the coefficient of restitution showed little difference between the two balls under each condition; this difference is not important.

Figure 11 illustrates differences in the tangential coefficients of restitution. Tiefenbacher and Durey (1994) proposed the usefulness of the tangential coefficient of restitution, and Araki (1996) gave its mathematical definition. It can range between –1 and +1. The tangential coefficient of restitution is +1 when the ball slips perfectly. However it has a negative value when the ball with topspin rebounds with topspin. We calculated from measured values the absolute value of the tangential coefficient of restitution that Araki et al. defined. In table 6, the tangential coefficients of restitution of the 40mm ball are Low = 0.62±0.06, Medium = 0.48±0.03 and High = 0.45±0.02, respectively (mean±S.D.). For the 38mm ball, the tangential coefficient of restitution are 0.64±0.05, 0.59±0.04 and 0.60±0.03 respectively. In the analysis of variance, statistically significant differences of the tangential coefficient of restitution were found at all conditions. The tangential coefficient of restitution tended to decrease as the rotation increased. This tendency is stronger with the 40mm ball than with the 38mm ball.

4 Conclusions

When the ball spin is low, the rebound characteristics of 40mm and 38mm balls are not very different, but as the spin is increased, the two balls begin to show differences. At the prescribed collisional speed of about 14m/s, the tangential coefficient of restitution of 40mm balls shows more significant decrease than it does for 38mm balls. In our opinion this suggests that in order to impart equal amounts of spin, combined with an appropriate change in the racket angle a player must have a faster swing with 40mm balls than with 38mm balls.

5 References

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