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Speed and spin differences between the old celluloid versus new plastic table tennis balls and the effect on the kinematic responses of elite versus sub-elite players

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Abstract

This study measured 1) the speed and spin differences between the old celluloid versus new plastic table tennis balls at pre ball-table impact and post ball-table impact when projected with topspin at 7.56 $m.s^{-1}$, and investigated 2) the effect this has on the kinematic responses of 5 elite versus 5 sub-elite players' forehand topspin in response to topspin and backspin. Plastic balls were lower in both speed and spin at pre and post ball-table impact compared with celluloid balls but the magnitude of change in speed and spin for each ball material differed. During flight before impact, plastic balls lost 3.98% more speed and 1.24% more spin than celluloid balls. Post ball-table impact, plastic balls showed a greater speed increment (0.69%) and smaller spin decrement (0.19%) than celluloid balls. Differences in players' kinematic responses to the different ball materials were found only when players returned backspin shots. Players supinated their rackets more by 2.23% at ball-racket contact and produced 3.37% less ball spin when returning plastic compared with celluloid balls; an indication of an early adaptation to the lower spin rate of plastic balls. The lack of differences in kinematic response to topspin may be due to the similar changes in speed and spin of both types of balls at ball-table impact. It is not known if a higher initial ball projection velocity would evoke differences in movement responses from the players post ball-table impact but could be explored in future studies.

Keywords: *Table-Tennis, Rule Change, Human Kinematics*

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Introduction

Competitive table-tennis underwent a number of equipment changes over the last two decades that have affected game play (Takeuchi, Kobayashi, Hiruta & Yuza, 2002; Zhang & Hohmann, 2004). In the year 2000, the International Table Tennis Federation (ITTF) increased the diameter (38 mm to 40 mm) and mass (2.5 g to 2.7 g) of all competition balls. Mechanical testing revealed decreases in speed (1-2%) and spin (5-10 rps) of the 40mm compared with 38mm balls with no differences in deceleration when ejected by a machine (Iimoto, Yoshida, & Yuza, 2002; Tang, Mizoguchi, & Toyoshima, 2001). In actual game settings, rally time (3.1 s to 3.8 s) and lengths in the 1993 versus 2000 All Japan Championship competition increased for both men's (3.1 to 3.7) and women's (3.7 to 4.6) matches (Takeuchi et al., 2002).

More recently in 2014, plastic balls were introduced in all World Title and ITTF sanctioned events and the old celluloid balls were phased out due to environmental and cost concerns (ITTF, 2014). The ITTF reported that the new plastic balls were similar in weight and rebound properties as the old celluloid balls but were slightly larger in diameter and rounder (Küneth, 2017). Given the light-weight and low-density characteristics of table tennis balls, any changes in diameter and roundness to a ball are likely to affect its flight trajectory and the interactions between ball, table and racket.

The ITTF equipment committee conducted a mechanical test to investigate the horizontal and vertical rebound speed upon table impact after balls were projected onto a stationary racket with various rubber types. The plastic balls were found to have a higher vertical but lower horizontal speed than celluloid balls (Meyer & Tiefenbacher, 2012). While it is not clear what the initial conditions were and how flight characteristics were measured, Meyer and Tiefenbacher (2012) also found that velocity decreased more for the plastic than celluloid balls in flight. Inaba et al. (2017) investigated how the two balls differed pre and post ball-table impact by computing the coefficient of restitution and friction, and predicting the post impact trajectories through five velocity conditions with backspin applied. It was clear that the magnitude of differences between the two ball types depended on the initial conditions. The coefficient of restitution and friction of plastic balls were higher than celluloid balls with faster vertical and slower horizontal velocities respectively. At faster vertical speeds, akin to smashes, plastic balls were faster and rebounded higher compared with celluloid balls. At slower horizontal speeds, akin to serves, plastic balls were slower in speed and spin after table impact. It is not known if similar differences are present for topspin and sidespin shots as Inaba et al. (2017) only investigated backspin shots.

The flight and rebound differences between plastic and celluloid balls could affect game play. Anecdotal accounts collected from players by Meyer & Tiefenbacher (2012) suggested that they could sense that the plastic balls have less spin and speed than celluloid balls. However, it is unknown if those players, despite "sensing" a difference, had adapted their kinematic responses when returning an incoming plastic compared with celluloid ball. Players may adjust racket path, impact height, face angle and speed in response to ball kinematics changes (Iino, Mori, & Kojima, 2008). For example, when returning heavier backspin using forehand topspin, players opened their racket face angle more (more supinated) regardless of skill levels (Iino & Kojima, 2009). The elite players, however, were reported to accelerate the racket faster than sub-elite players when using the forehand topspin to cope with heavy backspins. Considering that different ball-flight characteristics yield different responses between elite and sub-elite table tennis players, it could also be anticipated that the larger and rounder plastic versus smaller and less round celluloid balls would evoke differential responses between players of different skill levels.

This study's first aim was to 1) mechanically test for any kinematic differences between plastic versus celluloid balls when fed by a machine in topspin mode only as backspin effects have previously been reported in the literature. The second and third aims were to 2) investigate the ensuing effects that the speed and spin differences between ball materials projected in topspin and backspin have on the forehand kinematic responses of table-tennis players and 3) how these may differentiate between elite versus sub-elite players. We hypothesized that 1) plastic balls would be slower in speed and spin during flight pre ball-table impact but faster in speed and spin and achieve a higher peak height than celluloid balls post ball-table impact when projected in topspin; where vertical velocity may be higher, such that coefficient of restitution of plastic balls is higher than celluloid balls. We also hypothesized that 2a) regardless of skill and spin, players would move closer to the edge of the table, reduce their racket angle (less supinated), and strike/return the plastic balls at a higher velocity and impact height compared with celluloid balls. This should result in the plastic balls being returned at a higher velocity with less spin compared with the celluloid balls. When responding to topspin, players were hypothesized to 2b) move further away from the table, reduce their racket angle, strike the balls at a lower velocity but higher hitting height, resulting in higher ball speed but lower spin rate, in response to plastic versus celluloid balls. When responding to backspin, players were hypothesized to 2c) move nearer to the table, reduce racket angle (less supinated) and strike the balls at a higher velocity, but lower hitting height, resulting in higher ball speed but lower spin rate, in response to plastic versus celluloid balls. Lastly, we hypothesized that 3a) elite players, regardless of spin or ball type, would strike the balls with greater racket velocity and spin, and 3b) display kinematic adaptations i.e. nearer hitting location to the table at a higher hitting height with a reduced racket angle compared with sub-elite players when returning plastic balls.

Methods

Mechanical testing

Mechanical testing was performed to investigate the kinematic differences between the newer plastic versus older celluloid balls during flight. Twenty-five balls of each material were used. Both ball types were consistent in brand (Nittaku), quality (3-stars) and colour (white). The balls were weighed using a precision balance (accuracy: 0.01 g; A&D, GF-2000, Japan) and measured using a standard Vernier calliper. A ball feeder machine (Newgy Industries Inc., Gallatin, TN, USA) was used to expel the balls with topspin at a fixed speed setting 9 (7.56 ± 0.20 m.s^{-1}) at 1 s intervals to the table centre. The speed was decided after pilot testing revealed that this setting expelled the balls at a speed that was closest to actual serve speeds (Yoshida, Yamada, Tamaki, Naito, & Kaga, 2014) and the balls could consistently land on the same target area on the table. This was to ensure that differences found in the players' kinematics can be attributed more conclusively to the different ball types instead of other factors that cannot be controlled i.e. rubber, machine variability and so on. The middle 20 shots for each group of ball material were used for analysis i.e. 4th – 23rd as pilot testing indicated that the machine was less consistent when it first starts and at the end when there are fewer balls in the feeder storage. Ball kinematics were recorded at 2,000 frames per second using high speed cameras (i-SPEED, Olympus Corporation, Japan) at exit from the machine, pre and post ball-table impact (Figure 1). The first time-point when the ball exited from the ball feeder machine indicated the ball's initial kinematic properties. The ball's speed and spin towards the end of its flight were ascertained at pre ball-table impact. The ball's rebound characteristics were ascertained at post ball-table impact.

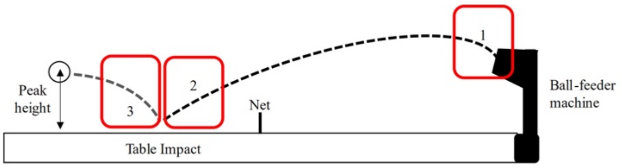

Figure 1. Mechanical Testing Set-up; red zones signify areas of data capture.

Ball spin rate was determined by measuring the time taken for an alphabet marked on the ball to move through 360 degrees or 1 revolution (Figure 2) (Inaba et al., 2017). Ball speed was measured by taking the distance travelled from the centre of the ball over 5 frames (0.0025s). Peak height post ball-table impact was measured from table surface to ball centre. All distances used were calibrated with the ball diameter at 40 mm as it is the most representative object of known dimension in the videos compared with the use of a conventional calibration pole. The authors acknowledge that there may be slight <1mm difference between ball materials that could affect the calibration but the ball's diameter still presented the best option for calibration as it is in the plane of movement. Videos were analysed using an open source video analysis software (Kinovea, version 0.8.15).

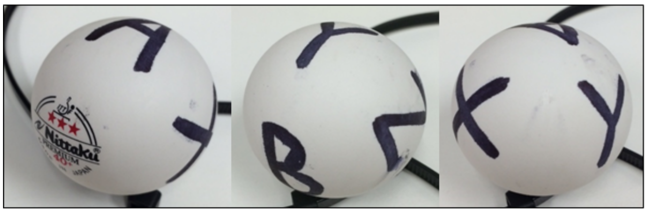

Figure 2. Alphabet markings on all balls used

A simple means comparison was performed rather than statistical analysis as the purpose was not to find any statistical difference but to assess if flight characteristics differed between the two ball types.

Human testing

Participants

Five elite players from the national table-tennis team (age: 22.2 ± 4.2 years; playing experience: 18.3 ± 5.2 years; ITTF ranking: 64.4 ± 86.6; gender: 5 female) and five sub-elite players from the national youth intermediate training squad (age: 16.6 ± 2.5 years; playing experience 12.8 ± 5.4 years; ITTF ranking: 593 ± 390; gender: 4 males, 1 female) participated in the study. All players used the shake-hand grip and were offensive players except for one elite player who was a defensive chopper. None of the players had any injuries and had not started training with the plastic balls at the time of testing. Ethics approval was obtained by the Human Research Ethics Committee at the Singapore Sport Institute. Informed written consent was obtained from all players prior to testing.

Apparatus

The same ball feeder machine was used to project balls in topspin and backspin respectively at speed setting 9 (7.56 ± 0.20 m.s^{-1}) at 1 s intervals to the players' forehand hitting position. These settings were similar to those used for the mechanical tests. Players had to respond using forehand topspin technique directed to a target area (0.3 x 0.3 m) straight down the table (Figure 3).

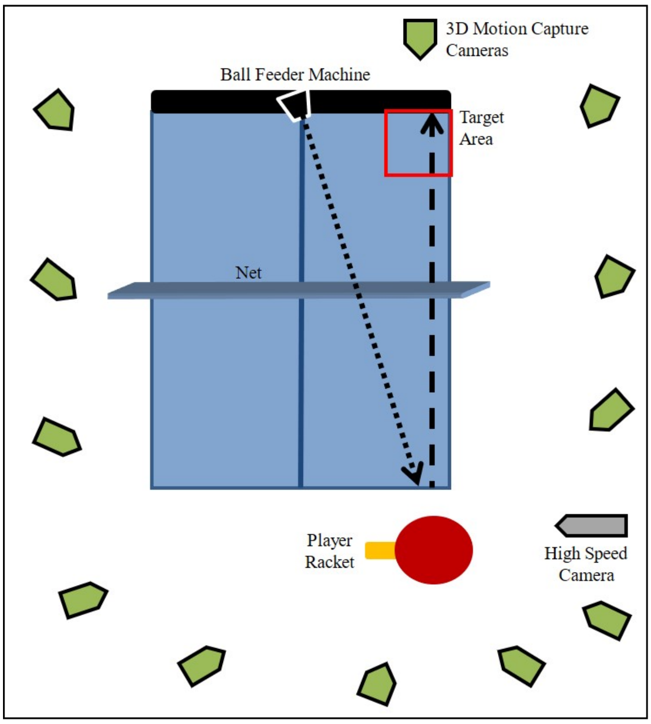

Figure 3. Experimental Set-Up

A 12-camera three-dimensional motion capture system (VICON MX series., Oxford, UK) captured the forehand topspin technique performed by the players at 500 Hz. Reflective spherical markers of 14 mm diameter were attached to the bilateral anterior superior iliac spines and bilateral posterior superior iliac spines (Figure 4) to define mid-pelvis of the players. This allowed the measurement of horizontal and vertical distances at racket-ball impact from the hitting side of the table-tennis table whereby the playing area was defined by four markers. Players used their own racket, where four reflective markers were attached to the lateral aspects, top and bottom of the racket to measure racket kinematics and racket-ball impact angle. The three-dimensional coordinates were expressed as a right-handed orthogonal reference frame fixed on the table (Z was vertical and pointed upwards, Y was horizontal and pointed to the centre of the target, while X was perpendicular to Y and Z). Selected racket kinematics, ball impact angle, ball impact height, and the perpendicular distances between players' mid-pelvis to the table at ball impact were computed and analysed. The high-speed camera was placed at point of racket-ball impact to record the ball speed and spin after racket impact.

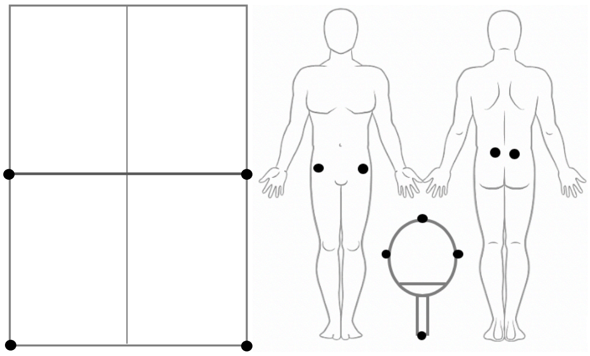

Figure 4. Reflective marker placement on subject, racket and table

Procedure

Players were informed of the task procedures and marked up before performing five minutes of self-selected physical warm-up. Thereafter, each player underwent familiarisation whereby they had to perform forehand topspin at maximum strength to return 15 plastic and 15 celluloid balls that were delivered in topspin and backspin to the target area.

Upon completion of the familiarisation process, players rested for five minutes before actual testing. The four conditions of celluloid-topspin, celluloid-backspin, plastic-topspin and plastic-backspin were randomised and counter-balanced to avoid any sequence effects. Instructions were reiterated to hit each shot at maximum strength to the target area. Players were blinded to the ball type but not the spin that they had to return. Each player then performed 15 shots across four conditions totalling 60 shots. Before each set, LED lights were used to synchronise the high-speed camera and 3D motion capture system. Players rested for 2 minutes between sets while the ball-feeder machine was replenished with new balls.

Variables and data processing

Five successful shots performed between the 3rd and 13th balls in each condition for each player were analysed to circumvent the inconsistency of the ball-feeder machine as mentioned earlier. The racket-ball impact frame was determined through synchronisation with the high-speed camera. At the impact frame, coordinates of the medial and lateral sides of the racket and pelvis were selected to calculate racket and pelvis centres. Hitting height from table was calculated from the z-coordinate of the racket centre, while racket-ball impact distance from the table was calculated from the y-coordinates of the pelvis centre and table. Racket speed was calculated by taking the displacement of one frame after racket-ball impact. Racket face angle was measured by using the y and z components of the two markers on the sides of the racket (Figure 5). Both S1 and S2 markers were projected in the YZ plane then an angle between the vector from S1' to S2' and Y axis in the global coordinate was defined as racket face angle.

$$\text{Assuming } x = 0,\ \tan\theta = \frac{z_1 - z_2}{y_1 - y_2}$$

$$\theta = \tan^{-1}\frac{z_1 - z_2}{y_1 - y_2}$$

The resulting displacement–time data of each marker was filtered using a Singular Spectrum Analysis. Optimal window sizes were chosen by comparing the residuals of the difference between filtered and unfiltered signals at several window lengths. Ball speed post racket-ball impact was measured by manual digitisation of the ball centre 5 frames after racket impact through the high-speed footages and the resulting displacement-time data of the ball centre were smoothed by using the simple moving average. Ball spin post racket-ball impact was also calculated by using high-speed footages by measuring the number of frames for the alphabet at point of racket-ball impact to complete 1 revolution, similar to the mechanical testing method that was previously described.

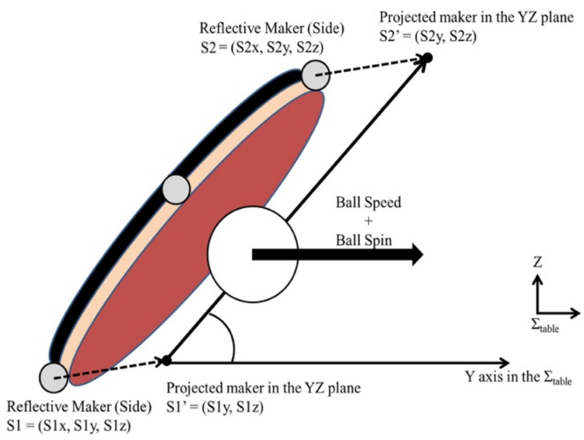

Figure 5. Racket angle calculation

All six variables from the human testing (racket speed and angle, hitting height and distance from table, ball speed and spin) were analysed using a 2 (ball types) x 2 (ball spin) x 2 (skill) mixed model analysis of variance (ANOVA). Main effects and interactions were subjected to Bonferroni post hoc tests and effect sizes were calculated using partial eta squared (ηp^2) for omnibus comparisons. The level for significance was set at $p < 0.05$. Trends were reported when $0.05 < p < 0.08$. Small, medium and large effect sizes were defined as less than 0.2, between 0.2 to 0.5 and above 0.8 respectively (Cohen, 1988).

Results

Mechanical testing

Plastic balls were slightly heavier (0.006 g) and wider (0.7 mm) than celluloid balls (Table 1). Plastic balls had slower speed and spin during flight pre and post ball-table impact compared with celluloid balls (Table 2). During flight prior to ball-table impact, the decrease in speed (3.98%) and spin (1.24%) from that at machine exit was greater for plastic than celluloid balls. Post ball-table impact, plastic balls recorded marginally slightly faster speed increment (0.69%) and smaller spin decrement (0.19%) than celluloid balls. The peak height achieved by the plastic ball post ball-table impact was 1.1cm lower than the celluloid ball.

Table 1.

Physical properties of balls.

	Plastic	**Celluloid**
Mass (g)	2.754 (0.02)	2.748 (0.01)
Diameter (mm)	40.40 (0.06)	39.82 (0.04)

Table 2.

Mechanical testing data

	Plastic	**Celluloid**
1. Exit from machine		
Initial Speed ($m.s^{-1}$)	7.56 (0.04)	7.56 (0.06)
Initial Spin (rps)	60.67 (0.18)	62.57 (0.18)
2. Before ball-table impact		
Speed ($m.s^{-1}$)	5.53 (0.17)	5.83 (0.13)
Spin (rps)	57.25 (0.25)	59.82 (0.50)
Flight phase (time-point 1 to 2)		
Speed difference ($m.s^{-1}$)	- 2.03	- 1.73
Spin difference (rps)	- 3.42	- 2.75
3. Post ball-table impact		
Speed ($m.s^{-1}$)	6.27 (0.11)	6.57 (0.14)
Spin (rps)	46.30 (0.41)	48.27 (0.57)
Ball-table impact (time-point 2 to 3)		
Speed difference ($m.s^{-1}$)	+ 0.74	+ 0.74
Spin difference (rps)	- 10.95	- 11.55

Peak height after impact		
Height (cm)	24.9 (1.5)	26.0 (1.5)

Human testing

Table 3 and 4 show the mean data for variables and the statistical output respectively from the human testing. There were trends with a large effect size whereby ball material affected the kinematics of the players but only when returning backspin shots ($p = 0.058$, $\eta p^2 = 0.94$). At racket-ball impact, players supinated the racket face by 2.09% more ($p = 0.032$) and produced 3.26% less spin ($p = 0.01$) after racket-ball impact when returning plastic compared with celluloid balls.

Spin types, independent of ball material, affected the kinematic responses of the players ($p = 0.02$, $\eta p^2 = 0.97$). When returning backspin compared with topspin, players contacted the ball 63.2% closer to the table ($p < 0.01$, $\eta p^2 = 0.85$) while producing 8.5% higher racket speed ($p = 0.06$, $\eta p^2 = 0.39$). Between skill levels, elite players supinated their racket face by about 17% more ($p = 0.048$, $\eta p^2 = 0.41$) than the sub-elites when hitting forehand topspin regardless of ball material and spin.

Table 3.
Mean data for variables of forehand topspin

	Celluloid Ball						**Plastic Ball**					
	Backspin			**Topspin**			**Backspin**			**Topspin**		
Variables	**All**	**Elite**	**Sub-Elite**	**All**	**Elite**	**Sub-Elite**	**All**	**Elite**	**Sub-Elite**	**All**	**Elite**	**Sub-Elite**
Racket Speed ($m.s^{-1}$)	15.3 ± 0.84	15.0 ± 0.99	15.6 ± 0.62	14.1 ± 2.2	13.1 ± 2.8	15.0 ± 1.0	15.1 ± 0.68	14.8 ± 0.65	15.4 ± 0.60	14.0 ± 2.1	13.0 ± 2.6	15.0 ± 0.83
Hitting Location (m)	0.46 ± 0.33	0.33 ± 0.07	0.60 ± 0.44	1.00 ± 0.26	1.11 ± 0.22	0.89 ± 0.32	0.30 ± 0.07	0.26 ± 0.03	0.35 ± 0.08	0.99 ± 0.26	1.06 ± 0.19	0.92 ± 0.32
Hitting Height (m)	0.23 ± 0.04	0.23 ± 0.06	0.23 ± 0.29	0.25 ± 0.07	0.28 ± 0.05	0.21 ± 0.07	0.22 ± 0.04	0.22 ± 0.04	0.22 ± 0.05	0.22 ± 0.04	0.24 ± 0.04	0.21 ± 0.05
Racket Face Angle (°)	71.7 ± 7.35	75.9 ± 3.85	67.6 ± 8.00	68.1 ± 19.3	78.5 ± 23.0	57.7 ± 5.9	73.3 ± 7.53	77.1 ± 3.13	69.4 ± 8.97	68.0 ± 18.0	76.8 ± 22.2	59.1 ± 6.58
Ball Speed ($m.s^{-1}$)	15.6 ± 1.70	16.5 ± 1.45	14.8 ± 1.64	16.5 ± 3.20	17.0 ± 4.48	16.0 ± 1.53	15.5 ± 1.95	16.3 ± 1.42	14.8 ± 2.30	16.8 ± 3.36	17.1 ± 4.78	16.4 ± 1.47
Ball Spin Rate (rps)	113.5 ± 11.3	113.6 ± 8.21	113.4 ± 14.1	113.6 ± 13.6	106.3 ± 14.6	120.9 ± 8.20	109.8 ± 9.03	109.1 ± 7.66	110.4 ± 10.7	113.9 ± 18.4	104.4 ± 22.3	123.4 ± 6.45

Hitting height and locations are distances away from the table

Table 4.

Statistical outputs of main effects

Results	**df, df error**	**F**	**Significance (*p*-value)**	**Partial Eta Squared**
Ball Material	1, 8	3.22	0.18	0.866
Ball Spin	1, 8	17.2	0.02*	0.972
Racket Speed	1, 8	5.05	0.06**	0.387
Hitting Location	1, 8	46.59	< 0.01*	0.853
Hitting Height	1, 8	0.45	0.52	0.053
Racket Angle	1, 8	0.69	0.43	0.079
Ball Speed	1, 8	1.16	0.31	0.127
Ball Spin Rate	1, 8	< 0.01	0.97	< 0.01
Skill				
Racket Speed	1, 8	2.52	0.15	0.239
Hitting Location	1, 8	< 0.01	0.98	0.000
Hitting Height	1, 8	1.47	0.26	0.155
Racket Angle	1, 8	5.50	0.048*	0.408
Ball Speed	1, 8	0.74	0.41	0.085
Ball Spin Rate	1, 8	3.05	0.12	0.276
Ball Spin * Ball Material	1, 8	8.06	0.06**	0.942
Ball Spin * Skill	1, 8	0.55	0.76	0.524
Ball Spin * Ball Material * Skill	1, 8	1	0.55	0.667
Ball Material * Skill	1, 8	0.528	0.77	0.513

*: $p < 0.05$ (significant result)

**: $p \leq 0.06$ (close to significant result)

Discussion

Celluloid table-tennis balls were switched to slightly larger plastic balls in the latest equipment rule change by the ITTF. Given the light-weight and low-density characteristics of table tennis balls, any changes in material, diameter and roundness to a ball is likely to affect its flight trajectory and the interactions between ball, table, racket and players' responses. This study aimed 1) to mechanically test for kinematic differences between plastic and celluloid balls when fed in topspin by a machine, 2) investigate the ensuing effects these may have when projected with both topspin and backspin on the forehand kinematic responses of table-tennis players and 3) how these may differ between elite versus sub-elite players. Hypothesis 1 was supported as plastic balls were slower in speed and spin than celluloid balls pre ball-table impact, but from pre to post ball-table impact, the speed increment was slighter faster and spin decrement was smaller for plastic than celluloid balls when projected in topspin. Hypothesis 2a and 2b were not supported as there were no kinematic differences found when players responded to the plastic versus celluloid balls in topspin. Hypothesis 2c was partially supported as players did produce less spin but supinated the racket more instead of less on plastic compared with celluloid balls when returning backspin shots. Hypothesis 3a was partially supported as elite players did not strike the balls with greater velocity nor spin but with a more supinated racket angle. Hypothesis 3b was not supported as the elite players did not display kinematic adaptations to the plastic balls when compared with sub-elite players.

The mechanical testing revealed kinematic differences between the plastic and celluloid balls during flight pre and post ball-table impact when projected with topspin. During flight pre ball-table impact, plastic balls recorded lower speed and spin compared with celluloid balls. This might be due to the increased diameter and weight of the plastic ball that in turn, increases the air drag experienced (Nagurka, 2003). While plastic balls did not record higher speed and spin post ball-table impact as hypothesized, the slight percentage increment in speed and smaller decrement in spin of plastic balls upon impact are still in line with previous theoretical prediction of a higher coefficient of restitution (Inaba et al., 2017). Based on the prediction of Inaba et al. (2017), a higher initial velocity may be able to elicit bigger differences between plastic and celluloid balls. The equipment used in the current study could only reliably project the balls at a speed of 7.56 m.s^{-1} which may reflect the average velocity of a serve but not the forehand topspin at 17 m.s^{-1} (Iino & Kojima, 2009). Future studies may include projections across a range of velocities to extend our understanding of the differences between the plastic versus celluloid balls.

Quantifying kinematic adaptations of players' responses to the new plastic versus old celluloid balls in light of its initial condition is important (Inaba et al., 2017) as it could present coaches and athletes with information to be strategic in technique and tactics modification (Hodges, 1993). Despite reported kinematic differences between celluloid and plastic balls (Inaba et al., 2017; Küneth, 2017; Meyer & Tiefenbacher, 2012), both elite and sub-elite players did not differentiate their forehand topspin return except in response to backspin shots whereby rackets were more supinated. The increased racket face angle resulted in less spin when returning the plastic compared with celluloid balls. First, the lack of kinematic differences when returning topspin could be associated with the mechanical testing result in this study where the change in speed and spin were similar at ball-table impact between the two ball materials. This means that both ball materials would have travelled towards the players with similar kinematic properties since the time from ball-table impact to players' racket-ball contact is short. Second, it could be possible that players responded differently to the plastic versus celluloid ball only in backspin because the plastic balls were likely slower and have less spin from a higher coefficient of friction due to the slower projected speed akin to serves; 6 m.s^{-1} (Inaba et al., 2017). As such, players were able to supinate their racket more in response to the slower speed and spin, and thus produced less ball spin, perhaps with the intention to impart more force in the horizontal direction with less possibility of the balls going into the net or out of the table. Additionally, players did contact the plastic balls nearer to the table than celluloid balls by 0.16 m (34.7%) although this was not significant. Again, it is possible that if the range of projection velocities and spin rates increased, clearer kinematic adaptations can be elicited by maximising the effect of the coefficients of restitution and friction (Inaba et al., 2017).

Differences in kinematic responses of the players were found when they responded to the two ball spins regardless of ball types. When returning backspin versus topspin shots, players contacted the balls closer to the table and produced higher racket speed. Balls projected with backspin have a shorter trajectory due to the Magnus effect which explains the closer contact distance to the table. Previous research reported that when returning backhands against backspin versus topspin, the racket upward velocity at impact was higher for the former (Iino et al., 2008), similar to the higher racket speed in this study. Players potentially had to overcome the backspin by imparting greater speed to the ball to ensure that it crosses the net.

Racket and ball speed did not differentiate elite from sub-elite players in this study, which may be due to the sufficient time between each shot to generate their ideal racket speed. Iino and Kojima (2009) also did not find differences in racket speed between more well-trained versus less well-trained players but reported that advanced players required less time for racket acceleration despite covering a greater displacement which was in part contributed by a lower trunk axial rotation. Hence if time constraint similar to an actual game was present in this study, more kinematic differences may be found.

Conclusion

This study assessed not only the differences in flight and rebound characteristics of the old celluloid versus new plastic balls when projected in topspin, but also the kinematic responses of elite versus sub-elite players' when performing forehand returns to backspin and topspin of both ball types. Plastic balls when projected with topspin at 7.56 $m.s^{-1}$, displayed similar trends to previously computed predictions (Inaba et al., 2017); slower in speed and spin in flight and slightly less change from initial properties at ball-table impact compared with celluloid balls. Kinematic differences in response to the different ball materials were found only when players returned backspin shots. Players supinated their racket more by 2.23% at ball-racket contact and produced 3.37% less ball spin when returning plastic compared with celluloid balls; an indication of an early adaptation to the lower spin rate of plastic balls by supinating the racket face more. The lack of movement difference in response to topspin may be due to the almost similar kinematic change of both balls at ball-table impact. A future study should be conducted whereby a range of ball projection velocities and response time could be included to better replicate the possible scenarios in an actual table-tennis game. This could be tied in with a performance analysis study to find out if actual game statistics have changed with the introduction of plastic balls. This study provides an early insight into the kinematic adaptations table tennis players have in response to the new plastic balls and could be used for the foundation of future studies and also for more targeted training.

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