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Badminton racket deflection, comparison between rigid versus flexible according to different strokes

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Abstract

Badminton shuttlecock generate the highest projectile velocity among all sports. To deliver a powerful stroke, the design of a badminton racket is primordial, especially the deflection on the shaft. The purpose of the study was to analyse the gain of racket deflection compares with a rigid racket during four different strokes. Eight national and international standard badminton players participated in this study and performed a drop, a clear, a smash and a full smash. Six reflective markers were affixed to the racket and were recorded with Vicon cameras capture system set. Results showed racket deflection increased racket head velocity by shaft deflection by +13.2% during a full smash and a typical time around 60 ms during which the player accelerates the racket head. The gain obtained between head velocity related to the handle by +74% during a full smash. The deflection is caused by the relation between player ability, racket mass repartition and stiffness properties of the shaft. Finding suggest players should choose a racket with their badminton stroke pattern, especially the timing of the preparation phase before the impact with the shuttlecock to obtain the higher deflection and the best energy restitution during the impact.

Keywords: performance; equipment; biomechanic; sport science; technology

41

Introduction

42 Shuttlecock generate highest projectile velocity among all sports (Phomsoupha &
43 Laffaye, 2015) and has recorded at 157 m/s by the Indian Satwiksairaj Rankireddy (Guinness
44 World Record, 2023). The speed is depended of the player expertise level whereas the
45 shuttlecock velocity ranged from 24.4 to 81.6 m/s (Phomsoupha & Laffaye, 2014). Several
46 studies have investigated power strokes as clear and smash to explain the general stroke
47 pattern (Rambely et al., 2005; Tsai, Chang, et al., 2000; Tsai, Huang, et al., 2000). To produce
48 the maximum velocity at the shuttlecock, players add velocity through a sequential proximo-
49 distal joint action (Tsai, Chang, et al., 2000). Specifically, for an overhead stroke, players
50 quickly stretch their forearm during the eccentric phase (lateral rotation of the shoulder and
51 radio-ular supination), followed by a rapid concentric action (medial rotation the shoulder
52 and radio-ular pronation) (Waddell & Gowitzke, 2000).

53 To deliver a powerful stroke, the design of a badminton racket is primordial. To
54 simplify, a racket is composed of a rigid handle and a flexible shaft (Kwan, Skipper
55 Andersen, et al., 2010). Although tennis racket technology has received much research
56 interest focusing mainly on the mass properties and geometry of racket rather than their
57 deflection (Cross & Bower, 2006). However, few studies have been conducted on the design
58 of badminton rackets (Hsieh et al., 2004). Nowadays, the innovation has a great influence on
59 badminton rackets by making them light (Singh & Yogesh, 2010). Golf club shaft has a
60 similar pattern with badminton racket shaft. Unfortunately, the golf shaft is loaded with a
61 heavy club head mass at the tip, permitted to increase the shaft deflection (Phomsoupha et al.,
62 2015a).

63 It is therefore important to examine the deflection behaviour of the badminton racket
64 to increase the racket head velocity during a stroke as a clear or a smash. Consequently, racket
65 deflection plays an important role in increasing racket head velocity (Phomsoupha & Laffaye,

66 2015). Indeed, the badminton racket is subjected to significant dynamic effect (Kwan, Cheng,
67 et al., 2010). Furthermore, the mechanism of the racket deflection influences the terminal
68 velocity of the racket head (Rasmussen et al., 2010). Small differences in racket design have
69 an influence on dynamics properties (Hsieh et al., 2004; Kwan, de Zee, et al., 2008), by
70 modifying stiffness and mass properties (Kwan, de Zee, et al., 2008; Kwan & Rasmussen,
71 2011; Montagny, 2003). To the best of our knowledge, no study has investigated the benefits
72 offered by the deflection between a rigid racket and a racket head velocity during different
73 strokes.

74 Thus, the purpose of the present study was to analyse the gain of racket deflection
75 compares with a rigid racket during four different strokes (drop, clear, smash and full smash)
76 performed by elite badminton players.

77

78

Methods

Participants

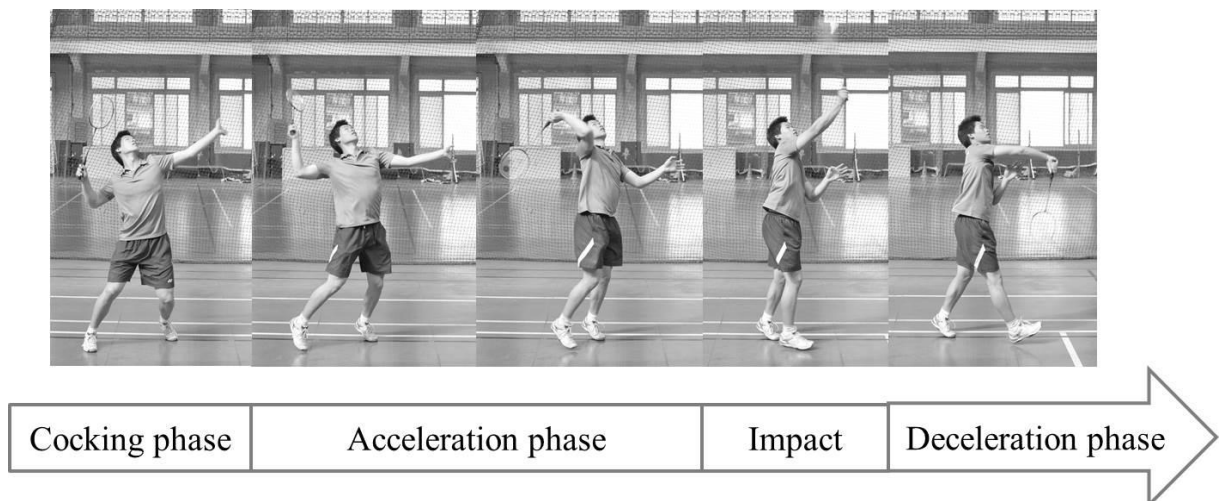
80 Eight participants realised in this study (age 23.3 ± 3.1 years; body mass 76.3 ± 8.3 kg;
81 height 179.2 ± 8.3 mm; amount of training undergone 16.1 ± 4.5 years) with national and
82 international experience participated in this study. All participants were healthy and in good
83 physical condition and reported no injuries at the time of the study. They were fully informed
84 about the protocol before participating in this study and they signed an informed consent
85 form. Ethical approval was granted by the university Human Ethics Committee and followed
86 principles of the Declaration of Helsinki.

87

Design & Procedures

89 After a general warm-up of 10 minutes, participants were allowed to perform as many
90 practice movements as needed to familiarize themselves with the testing requirement under

91 coached supervision. The racket used during the test was identical for all participants (Yonex
92 Astrox 88D Pro; 88g; 680 mm). Four conditions were included during each session slow
93 compared as a drop, medium compared as a clear, fast compared as a smash and very fast
94 compared as a full smash. Each condition was repeated 10 times within a counter-balance
95 order. The timing of stroke is obtained by the beginning of the movement (acceleration phase)
96 and the impact between the racket with the shuttlecock (figure 1). A shuttlecock is attached to
97 the duct ceiling by using a wire and adjusted from the participant.
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Figure 1: Different phases during a badminton stroke

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102 *Analysis*

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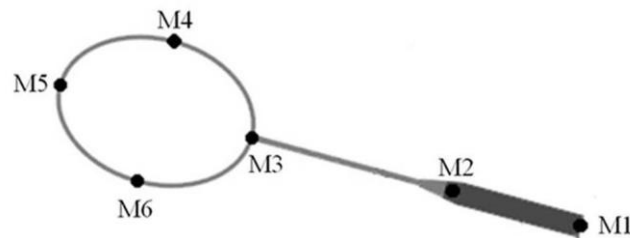
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The experimental setup consisted of a nine-camera Vicon V8i motion capture system set at a frequency of 500 Hz (Vicon Peak, Oxford, UK). For kinematic analysis, six reflective markers of 14 mm in diameter were affixed to specific anatomical landmarks (Plug-In Gait Marker Set, Vicon Peak) for each participant. The markers were fixed to the dominant side, as follows: (a) angulus acromialis; (b) medial and lateral humeral epicondyles; (c) radial and ulnar styloid processes; and (d) 2nd metacarpal heads, as recommended by the International Society of Biomechanics (Wu et al., 2005).

110 The global x-axis was defined in the anteroposterior, the z-axis vertically and the y-
111 axis laterally, whereas the xy-plane was identical to the court. The orientation of the humerus,
112 radius, ulna and hand segments was determined by the longitudinal z-axis, the mediolateral y-
113 axis, and the perpendicular anteroposterior x-axis, as described in detail by (Wu et al., 2005).
114 All calculations were performed using Matlab R2023a software (The Math Works Inc,
115 Natick, MA, USA). Only the arm holding the racket was analysed.

116 Six reflective markers were affixed to the racket, as proposed by Kwan et al. (2008b)
117 in their model: (e) racket handle, bottom and top of the handle; (f) racket shaft, top of the
118 shaft; and (g) racket head, left, right and top of the head (figure 2). To calculate the joint
119 positions, a 3D model (Plug-In Gait Marker Set, Vicon Peak) was used by David et al. (1991).
120 The reflective markers placed on the racket weighed 1.2 - 2.4 g each, increasing total mass by
121 12.4 g (14%). Static and dynamic calibrations were conducted to set up the global reference
122 system and calibration volume. The accuracy of 3D calibration was 0.2 mm.



123
124 Figure 2: Reflective markers affixed to the racket

125
126 To compare the racket head velocity to a virtual stiff racket velocity, a virtual marker
127 was built using the two markers on the racket handle. This new marker is at the same position
128 as the marker on the top of the head when the racket is not deflected but stay aligned with the
129 handle when it is accelerated, allowing to create a virtual stiff racket. Deflection is obtained
130 by calculating the distance between the real marker and the virtual marker.

131 The kinematics data was calculated by Vicon Nexus 1.8 software (Vicon Motion
132 System Limited, Oxford, UK). Racket deflection was calculated between the head racket real
133 marker and the head racket virtual marker on the global system.

134

135 *Statistical analysis*

136 All statistical analyses were performed using Statistica 10 software (StatSoft Inc.,
137 Tulsa, OK). Mean and standard deviations of the variables were calculated for descriptive
138 statistics. Assumptions of normality were verified using the Shapiro-Wilk W Test. Groups of
139 variables were used for statistical analysis: (a) velocity between handle, shaft and head racket
140 (m/s); (b) maximal velocity (m/s) (head and virtual marker); (c) maximal racket deflection
141 (mm); and (d) wrist acceleration (m/s²). Where the ANOVA was significant, a Bonferroni
142 post hoc test and power test (1- β) were performed. For all statistical analyses, significance
143 was set at $p < 0.05$ and effect size (I^2) was defined as small for $I^2 > 0.01$; medium $I^2 > 0.09$;
144 and large for $I^2 > 0.25$ (Cohen, 1988). Lastly, Spearman correlation coefficients were
145 calculated to determine the relationship between selected variables.

146

147

147 **Results**

148 Racket deflection increased each part of the racket point from the racket handle to the head of
149 the racket ($p < 0.001$); except for the drop shot ($p > 0.05$) (Table 1). The gain obtained
150 between the head velocity related to the handle by +39% during a drop, by +62% during a
151 clear, by +67% during a smash and by +74% during a full smash.

152

153 Table 1: Velocity on handle, shaft and head racket during four different strokes.

Conditions	Racket handle (m/s)	Racket shaft (m/s)	Racket head (m/s)	p-value*	η^2 *	1- β *
Drop (slow)	5.6 \pm 2.7	5.8 \pm 2.3	6.3 \pm 1.9	> 0.05	0.199	0.527

Clear (medium)	7.9 ± 2.9	13.2 ± 3.4	20.9 ± 4.1	< 0.001	0.714	0.989
Smash (fast)	11.2 ± 2.3	24.2 ± 6.5	34.6 ± 3.4	< 0.001	0.836	0.992
Full Smash (very fast)	12.8 ± 1.7	34.6 ± 3.6	49.2 ± 5.1	< 0.001	0.946	0.993

154 * p-value: significant differences for values lower than 0.05; * η^2 : Effect size; *1- β : Power-
155 test.

156

157 Racket deflection increased racket head compared to the virtual racket ($p < 0.001$); except for
158 the drop and the clear ($p > 0.05$) (Table 2).

159

160 Table 2: Velocity on head racket and virtual during four different strokes.

Conditions	Racket head (m/s)	Virtual racket (m/s)	p-value*	η^2 *	1- β *
Drop (slow)	6.3 ± 1.9	6.2 ± 1.9	> 0.05	< 0.001	0.050
Clear (medium)	20.9 ± 4.1	18.5 ± 3.5	> 0.05	0.022	0.262
Smash (fast)	34.6 ± 3.4	31.7 ± 4.6	< 0.001	0.198	0.984
Full Smash (very fast)	49.2 ± 5.1	41.4 ± 4.1	< 0.001	0.438	0.998

161 * p-value: significant differences for values lower than 0.05; * η^2 : Effect size; *1- β : Power-
162 test.

163

164 All results of maximal velocity of the racket and the virtual racket, gain, maximal
165 racket deflection and wrist acceleration were showed in Table 3.

166

167 Table 3: Virtual and real racket velocity, deflection racket, wrist velocity and acceleration
168 during four different strokes.

Condition	Drop (slow)	Clear (medium)	Smash (fast)	Full smash (very fast)	p-value*	η^2 *	1- β *
Maximal velocity	6.3 ± 1.9	20.9 ± 4.1	34.6 ± 3.4	49.2 ± 5.1	< 0.001	0.921	0.975

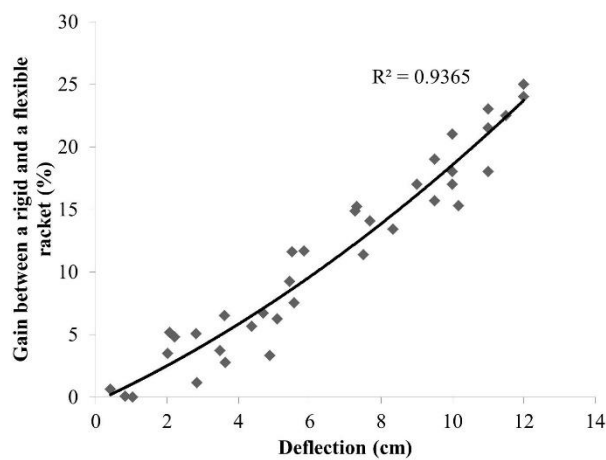
racket head							
(m/s)							
Maximal velocity	6.2 ± 1.9	18.5 ± 3.5	31.7 ± 4.6	41.4 ± 4.1	< 0.001	0.931	0.984
virtual head racket							
(m/s)							
Gain (%)	0.2	3.8	6.3	13.2	< 0.001	0.828	0.993
Maximal racket deflection	0.8 ± 0.3	2.6 ± 0.6	4.6 ± 0.8	8.4 ± 1.2	< 0.001	0.832	0.952
(cm)							
Wrist acceleration	3.4 ± 0.7	10.2 ± 4.8	15.6 ± 0.8	23.1 ± 1.5	< 0.001	0.607	0.931
(m/s ²)							
Timing (ms)	73.7 ± 5.4	64.8 ± 2.8	60.1 ± 2.7	58.5 ± 3.1	< 0.001	0.665	0.954

169 * p-value: significant differences for values lower than 0.05; * η^2 : Effect size; *1- β : Power-
 170 test.

171

172 A strong correlation was found between maximal racket deflection and gain obtained
 173 by the deflection ($r = 0.933$; $p > 0.001$) (figure 3), and maximal deflection and maximal racket
 174 velocity ($r = 0.954$; $p < 0.001$) (figure 4).

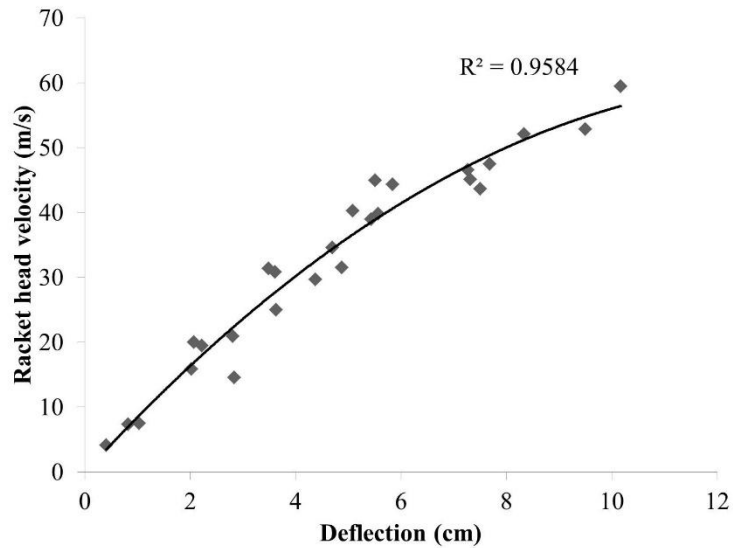
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176

177 Figure 3: Correlation between rigid and flexible racket and deflection ($p > 0.001$)

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179

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Figure 4: Correlation between racket head velocity and deflection ($p > 0.001$)

181

182

Discussion

183

The aim of the study was to analyse to compare the velocity gain of the racket deflection

184

compared with a rigid one during four different strokes (drop, clear, smash and full smash)

185

performed by elite badminton players. In this experimentation, we compared the gain

186

obtained from a flexible racket with a rigid racket (a virtual stiff racket) to analyse the gain on

187

racket velocity. Simulate a new marker allows to be a new useful tool for analysing stroke

188

dynamics with a flexible racket. Starting from this virtual stiff racket, information about the

189

deflection during a stroke was extracted and could be compared between the type of stroke

190

and players.

191

The average values of the flexible racket head velocity (44.3 ± 17.6 m/s) are very

192

similar to the experimentally obtained values reported from 40 m/s to 50 m/s during a smash

193

in previous study (Kwan, Skipper Andersen, et al., 2010). The maximal head racket velocity

194

was obtained during a full smash stroke (49.2 ± 5.1 m/s). However, these values are higher

195

than those found in other study with 37.5 m/s (Rambely et al., 2005). This difference could be

196

due to a lower sampling rate (50 Hz) on their study.

197 Racket deflection showed a significant change in racket head velocity and was
198 influenced by shaft deflection by +13.2% during a full smash. Assuming consistent stroke
199 condition, it has been estimated that this could lead to an increase in racket head velocity of
200 approximately +24% during a full smash (Phomsoupha et al., 2015). A rigid racket showed
201 lower velocity than flexible one according to the kind of strokes, except for the drop and clear
202 where there is a low deflection (Table 2). A totally rigid racket produces a slightly highest
203 velocity at head than handle during a translation movement due to the lever effect (Kwan, de
204 Zee, et al., 2008), however, the head velocity could be increased during a rotational
205 movement. The racket properties have a great influence during a stroke and particularly
206 the racket's deflection by providing about 4-6% through the elastic energy (Kwan &
207 Rasmussen, 2010).

208 Maximum deflection of the racket head in our study ranged between 4.1 and 102.2
209 mm during a drop to a full smash, which is higher than the values found in earlier studies,
210 where deflection ranged from 38.5 to 56.2 mm for a smash (Kwan, Skipper Andersen, et al.,
211 2010). This disparity can be explained, firstly, by differences in racket properties in our study;
212 the racket used was more flexible. In addition, our study was performed with human players
213 and they realised a complete stroke, whereas the earlier study used a rotational actuator with a
214 rotational movement. In addition, by storing and releasing more strain energy with a greater
215 flexibility, this results in a higher racket velocity (Phomsoupha et al., 2015). A similar pattern
216 has found with golf club, the effect of deflection amplified club head speed (Worobets &
217 Stefanyshyn, 2012). The correlation between racket head velocity and the gain showed the
218 influence of elastic deformation to increase the final velocity (figure 4). It seems to be
219 important to obtain a high deformation to produce a high velocity to transfer it to the
220 shuttlecock.

221 To obtain the maximum benefit from deflection, impact between the racket and the
222 shuttlecock should occur when racket deflection returns to its original position (± 0.05 s). In
223 this way, the maximal advantage of racket elasticity can be obtained at the contact with the
224 shuttlecock (Kwan & Rasmussen, 2010). For a given player, lighter strokes as drop shot were
225 characterized by a lower deflection peak and a hard stroke as smash by a high deflection peak.
226 The peak deflection and timing values are depending of each player (Table 3). A maximal
227 head velocity is generated that is higher than the maximal velocity of the handle, due to the
228 elastic deformation.

229 Additionally, our study showed different acceleration phase according to the type of
230 strokes. The optimal timing is obtained during a smash (60.1 ± 2.7) and a full smash ($58.5 \pm$
231 3.1 ms). The timing seems to be constant whereas the peak deflection is depending of the
232 players. The consistency of impact timing in all strokes indicates that players coordinate their
233 stroke to allow the benefit from the deflection (Kwan & Rasmussen, 2010). Furthermore,
234 Phomsoupha et al. (2015) showed expert have better used the deflection than novices by the
235 fact the typical time during which the player accelerates the racket head is around 60 ms and
236 could theoretically increase by +80% racket head velocity. Thus, players take advantage of
237 the elastic effect of deflection to increase the racket velocity during the acceleration phase
238 (Kwan, de Zee, et al., 2008; Smith et al., 1996).

239 The drop showed the lowest racket head velocity as compared of the full smash. To
240 produce the power needed, players take advantage of adding velocity with a sequential
241 proximo-distal joint action. The rapid sequence constituted a stretch-shorten cycle to increase
242 the efficiency of the force production. Higher force is generated by a high acceleration of the
243 wrist (Phomsoupha & Laffaye, 2014). When the arm, especially at the end of the wrist
244 movement, is accelerated, the head moves with a delay, resulting in a deflection of the shaft
245 due to elastic deformation (Phomsoupha et al., 2015). Thus, elastic energy stored in racket

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