Customising moment of inertia of a badminton racket: Effects on performance and impact location

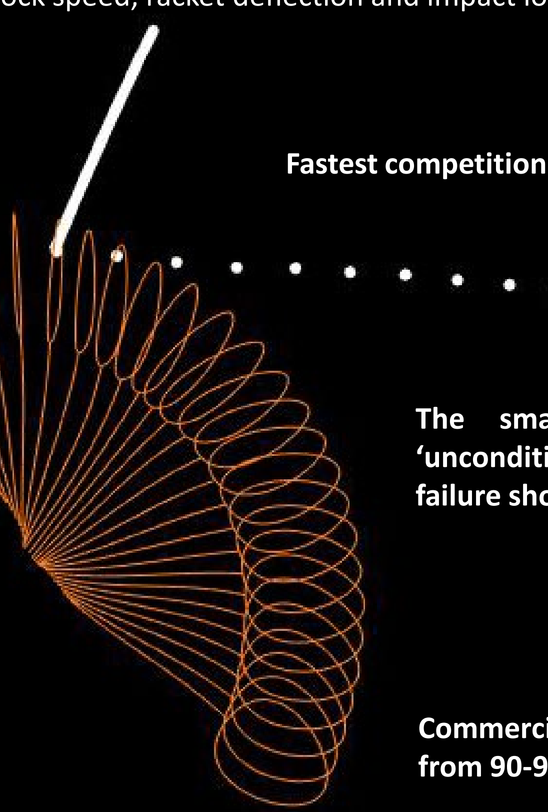
Purpose

- Investigate the role of moment of inertia (MoI) on the performance of the badminton smash,
- Current marketing suggests head-heavy (higher MoI rackets) will allow the user to produce higher shuttlecock speeds.
- Study aimed to assess the effect of MoI, defined here as the moment of inertia about an axis 9 cm from the handle end, on the following performance metrics
    - racket head speed, shuttlecock speed, racket deflection and impact location

Background

Elite players cause tip deflections ~60-70 mm at the racket head centre[1]

Fastest competition smash recorded = 426 kph[2]



Elastic component of racket head speed accounts for 4-6%[3]

The smash accounts for 54% of 'unconditional winner' and 'forced failure shots in elite competition[4].

Commercial rackets MoI typically range from 90-97 kg.cm²[3]

Hypotheses

1. ↑ in MoI = ↓ in racket head speed
2. ↑ in MoI = ↑ in longitudinal impact location to coincide with node point of 1st bending mode

Methods: Racket Preparation

Equal amount of lead tape (white, filled circles) added to 5 lightweight (72g) base frames

- minimal effect on polar MOI
- produced 5 rackets of incremental MOI, with equal mass, shaft stiffness and string tension
- Centre of mass measured using a balance board (3 scales) and taking moments about the handle end
- Knife-edge pendulum method and HSV allowed MOI calculation

Node Location:

- Modal analysis using Vicon operating at 500 Hz, to obtain fundamental mode (~50-60 Hz[7])
- MATLAB Fast Fourier Transform function determined the phase and magnitude of each marker location.
- 2nd order polynomial was fitted to the modal data to obtain node point location

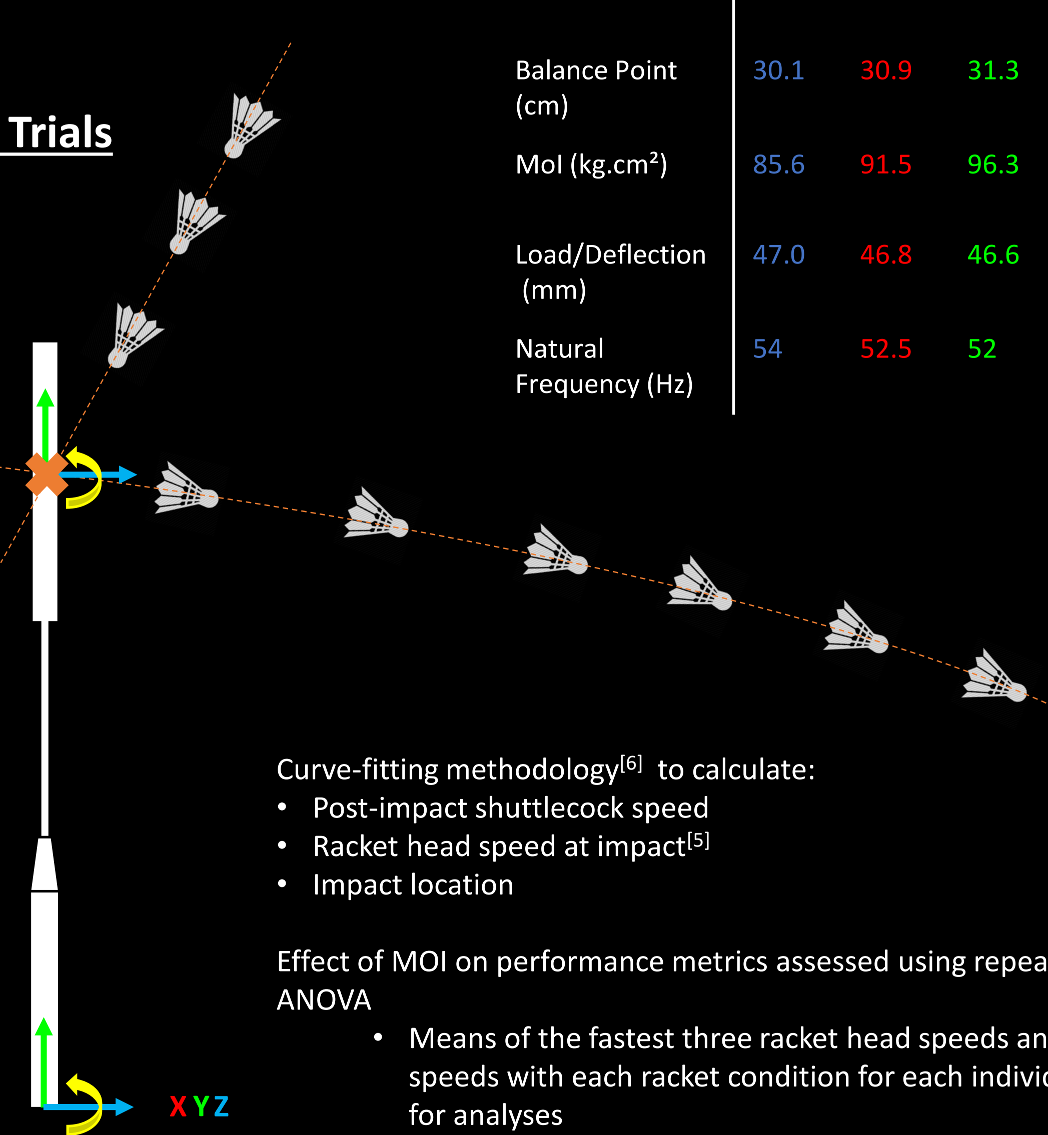
Property	Racket 1	2	3	4	5
Mass (g)	93.8	94.1	94.0	94.0	94.0
Balance Point (cm)	30.1	30.9	31.3	32.2	33.1
MoI (kg.cm²)	85.6	91.5	96.3	100.7	106.8
Load/Deflection (mm)	47.0	46.8	46.6	46.6	46.3
Natural Frequency (Hz)	54	52.5	52	51.75	51.25

Methods: Dynamic Trials

Vicon (500 Hz)

- National & international badminton players (n=20)
- Grouped into international senior males (5), national senior males (5), junior males (6) and females (4)
- 5 test rackets (+2 familiarisation rackets)
    - Randomised order
- 3 x 5 maximal smashes

Deflection defined by the transverse angle between handle and frame segments, using Euler angles



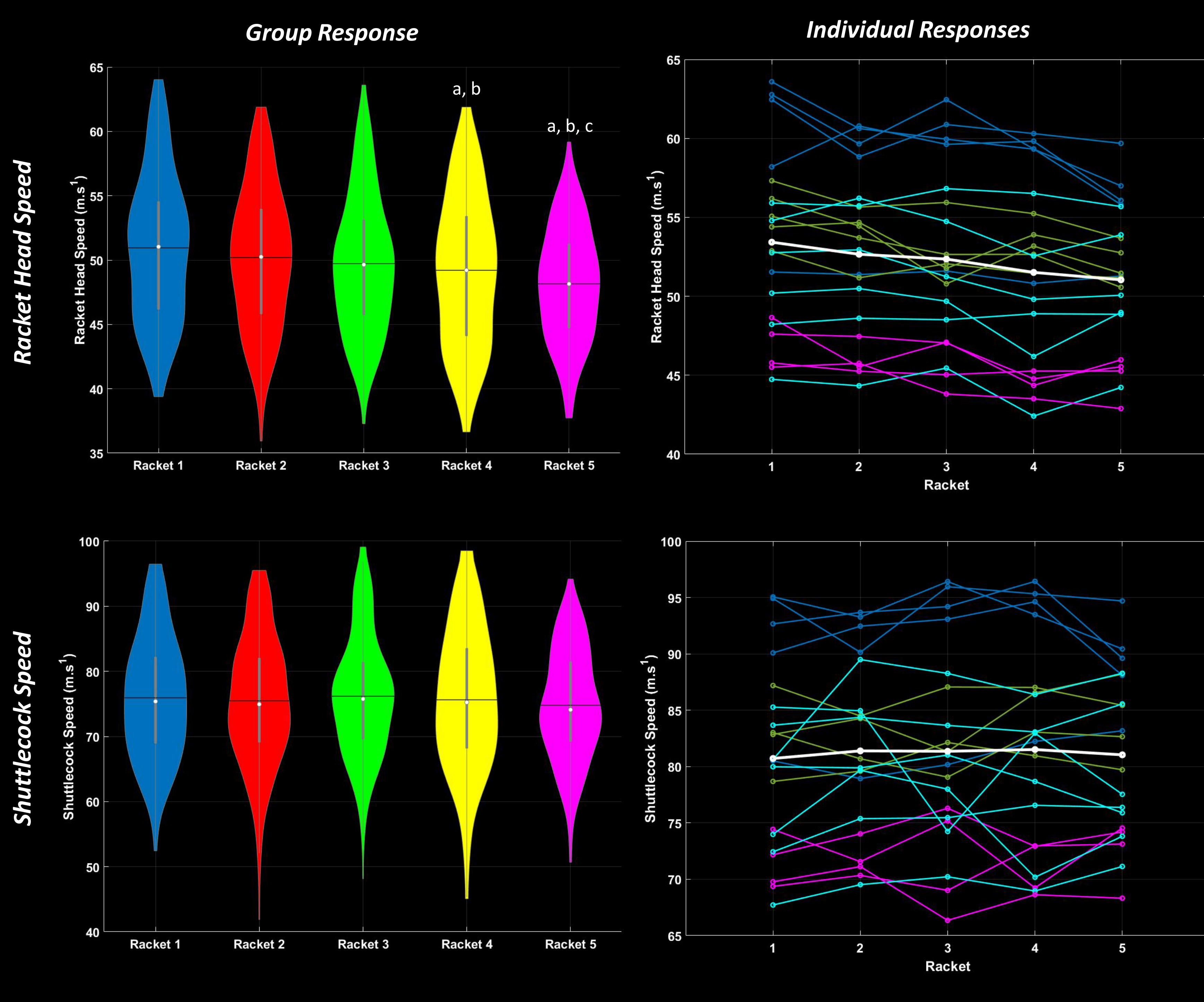
Curve-fitting methodology[6] to calculate:

- Post-impact shuttlecock speed
- Racket head speed at impact[5]
- Impact location

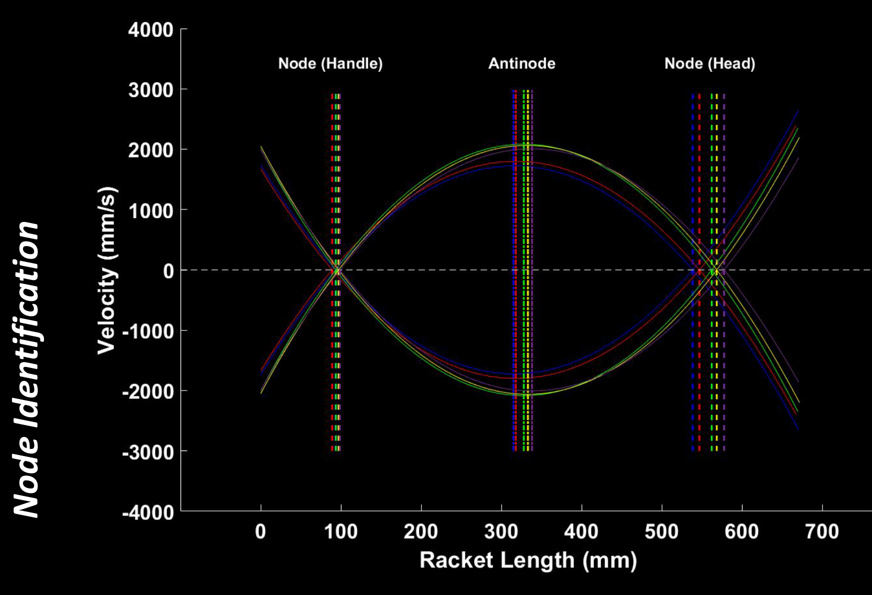
Effect of MOI on performance metrics assessed using repeated measures ANOVA

- Means of the fastest three racket head speeds and shuttlecock speeds with each racket condition for each individual were used for analyses

Results & Discussion



Violin plots of racket head speed and shuttlecock speed, representing the mean, median, IQR, distribution and kernel density; a, b, c refer to Bonferroni post-hoc tests significantly different to Rackets 1, 2, 3, respectively (p<0.05)



↑ in MoI caused a ↓ in racket head speed (p<0.05)

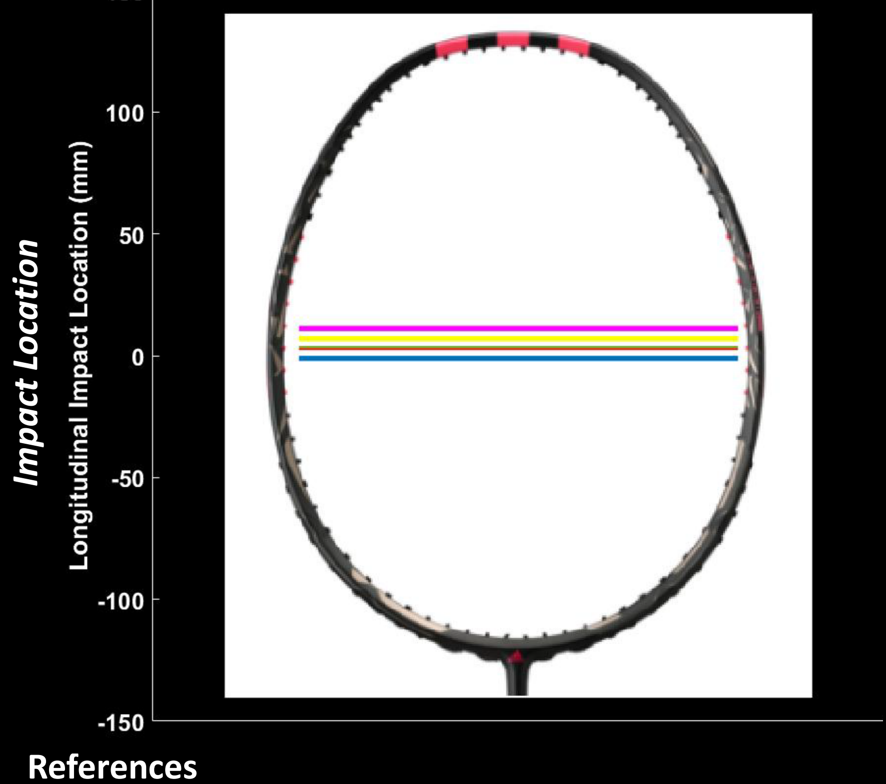
- lowest MoI racket was not always the fastest racket for each individual perhaps due to familiarity
- linear trend not evident for all individuals

✗ MoI had no significant effects on shuttlecock speed despite the reduction in racket head speed at the racket head centre

- Possibly due to the increase in longitudinal impact location (p<0.05), causing a greater racket head speed at the impact location.

Elite senior males > National senior males > Junior males > Females

- Racket head speed
- Shuttlecock speed



Corresponding increase in longitudinal impact location and node location

- The nodal 'sweet spot' has been identified as a location that players aim for in tennis, to minimise vibrotactile sensation during play[8].

Recommendations for racket designers to produce a racket where node and maximum COR location coincide

- Greater shuttlecock speed and feeling

Greater mass added nearer to the tip caused a ↓ in natural frequency and greater pre-impact deflections (p<0.05)

Future Work

1. Identify optimal racket for an individual based on MoI only
2. Link subjective shot feeling to impact location in relation to node location
3. Perform study over a longer period of time to assess whether allowing an adaptation period to a particular racket specification changes the response to MoI perturbations

References

[1] Kwan *et al.* (2010). Measurement of badminton racket deflection during a stroke. *Sports Engineering, 12,* 143-153
[2] Guinness World Records. (2017). Fastest badminton hit in competition (male). Retrieved June 19, 2019, from https://www.guinnessworldrecords.com/world-records/fastest-badminton-hit-in-competition-(male)/
[3] Kwan, M., Rasmussen, J. (2010). The importance of being elastic: Deflection of a badminton racket during a stroke. *Journal of Sports Sciences, 28*(5), 505-511
[4] Tong, Y., M., Hong, Y. (2000) The playing pattern of world's top single badminton players. *18th International Symposium on Biomechanics in Sports.* Hong Kong, China
[5] Kwan *et al.* (2011). Investigation of high-speed racket kinematics by motion capture. *Sports Engineering, 13*(2), 57-63.
[6] McErlain-Naylor *et al.* (2015). Determining instantaneous shuttlecock velocity: overcoming the effects of a low ballistics coefficient. *Proceedings of the 14th ITTF Sports Science Congress and 5th World Racquet Sports Congress*. Suzhou, China
[7] Gawande *et al.* (2017). Failure investigation of badminton racket using modal analysis. *International Journal for Scientific Research and Development, 5*(2), 1849-1856.
[8] Choppin *et al.* (2011). Impact characteristics of the ball and racket during play at the Wimbledon qualifying tournament. *Sports Engineering, 13,* 163-170.

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