

MORPHOMETRIC ANALYSIS TO DETERMINE HOW THE SHAPE OF TENNIS RACKETS HAS DEVELOPED

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When studying sports equipment mechanics, object shapes are often simplified; for example, implements like rackets are often modelled as beams [1]. Such beam models cannot account for differences in racket shape that could influence mechanics, such as asymmetry and variations in head width. Indeed, the shape of lawn tennis rackets has changed considerably since the origins of the game in the 1870s [2], with implications for player performance and injury risk [3]. Nineteenth century rackets were wooden and often had small, asymmetric heads. From the 1900s to 1960s, rackets tended to be wooden with small, symmetrical heads. A period of rapid development in racket design began in the 1960s, as engineers trialled different materials and experimented with new shapes. In response to these developments, the International Tennis Federation started limiting the size of tennis rackets in the 1980s, with current limits on overall length and width set at 73.7 and 31.7 cm, respectively [4]. Most high-end tennis rackets are now made from fibre-polymer composites, and tend to be lighter and stiffer [1] and have larger heads than their wooden predecessors.

Finite element models can capture the shape of an object, with the potential to investigate the possible associations between racket design, performance and injury risk. However, developing geometrically-faithful finite element models of tennis rackets is time consuming, so it is inefficient to apply this technique to many samples. The aim of this work was to quantify how tennis racket shape has changed since the 1870s, with a view to informing efficient shape modelling strategies. Five-hundred and twenty-five rackets, dating from 1874 to 2017, were characterised at various collections, including the Wimbledon Lawn Tennis Museum, the International Tennis Federation and HEAD Sports [1].

We applied statistical shape modelling, in the form of two-dimensional morphometric analysis [5] (Fig. 1), to describe how tennis racket shape has changed over time. A principal component analysis was conducted on silhouette outlines to summarise racket shapes. The first principal component (PC1) captured 87% of the variation in racket shape. A pairwise Pearson's correlation test indicated that head width and length were both strongly correlated to PC1 ($r > 0.80$). PC1 was also correlated to the Polar ($r = 0.862$, $p < 0.001$) and Transverse ($r = -0.506$, $p < 0.001$)

moments of inertia. Racket age and material had a medium ($p < 0.001$, $\eta^2 p = 0.074$) and small ($p = 0.015$, $\eta^2 p = 0.017$) effect on PC1, respectively.

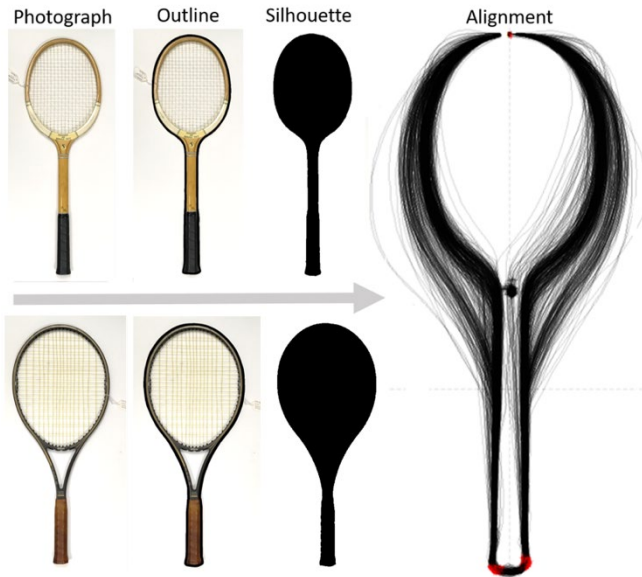


Fig. 1: Image processing examples for shape analysis (Slazenger PM and Wilson Pro Select rackets). All rackets were photographed from above. Matlab was used to make an outline and fill for a silhouette image. All silhouette images were then inputted to the R Package Momocs [4] and aligned via a Procrustes alignment on three coordinates (red points).

Our results indicate that the age of a tennis racket has a larger effect on its shape than the material it is made from, suggesting that developments in racket design over time have been somewhat gradual and incremental in nature. As PC1 captured almost 90% of the variation in the shape of racket silhouettes, the techniques presented here could be applied to identify representative or “mean” shapes when modelling rackets of varying age.

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