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Item Type	Article
Authors	Kenny, Ian C.;Wallace, Eric S.;Otto, Steve R.
Citation	Sports Biomechanics; 8(2), 183-186
Publisher	Taylor & Francis - Routledge
Download date	2026-03-11 06:29:35
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Link to Item	<a href="https://hdl.handle.net/10344/2361">https://hdl.handle.net/10344/2361</a>

**Authors' response to "Comments on 'Influence of shaft length on golf driving performance' "**

Ian C. Kenny<sup>1</sup>, Eric S. Wallace<sup>2</sup> and Steve R. Otto<sup>3</sup>

1 Biomechanics Research Unit,  
Department of Physical Education and Sport Sciences,  
University of Limerick,  
Ireland  
Phone: +353 (0)6123 4308  
Fax: +353 (0)61202814  
E-mail: [ian.kenny@ul.ie](mailto:ian.kenny@ul.ie)

2 Sport & Exercise Sciences Research Institute, University of Ulster, Jordanstown, Co.  
Antrim, UK

3 R&A Rules Limited, St. Andrews, Fife, Scotland

The central theme of this paper was to ascertain the effect of shaft length and since this parameter cannot be changed in isolation certain decisions were made as to which characteristics of the clubs to keep controlled and which should be allowed to vary naturally with shaft length, for instance swingweight. The parameters which were controlled were mentioned in the paper together with those which were allowed to vary inherently with the shaft length. Nevertheless the results of the study, in this context, were presented in a robust and clear manner. The results of the study were presented in terms of the acquired data rather than relying on previously accepted anecdotal wisdom.

The authors wish to thank Glazier for raising a discussion related to some of the aspects of our paper. We welcome here the opportunity to comment on and clarify his three points.

### **Individual differences and the pitfalls of group-based research designs**

'Anecdotal reports' aside, data in our original paper (Kenny *et al.*, 2008) did indeed conclude that, based on group average descriptive statistics, the category one ( $0.2 \pm 2.4$  handicap) golfers studied increased average carry distance by 4.3 m when they used an extra long (XL length 1.270 m / 50") driver. This was compared to their own (Own, average length 1.156 m / 45.5") driver. Individual subject data is now shown in Table one which compliments earlier data, illustrating that for all but one golfer, using a driver longer than their own resulted in increased ball carry. The authors agree with the view expressed by Glazier which suggests that performance benefits of longer drivers are individual-specific. Indeed the original paper by Kenny *et al.* (2008) served as data to support published work by the authors describing the nature of inter- and intra-subject variability among elite golfers (Kenny *et al.*, 2008i) and subsequent single-subject analysis for the development of a subject-specific golfer-club model (Kenny *et al.*, 2008ii). Table 1 illustrates that for several golfers, the theoretical performance gains offered through the use of the longest, XL driver, could not be extracted. As was noted in the original paper, a learning effect may explain these inter-subject differences and rapid improvements for some golfers, whilst further practice time with the longer drivers may have resulted in more of the subjects driving further. It must not be ruled out, though, that some golfers may never adapt to effectively using very long drivers.

Table 1. Mean carry distance for individual subjects using drivers of different shaft length

	Subject	Club			
		Own	R	L	XL
Carry (m)	1	209.4	209.6	216.5	231.2
	2	234.2	239.4	242.8	233.2
	3	221.1	215.4	221.6	230.9
	4	221.2	219.7	221.3	221.5
	5	231.1	220.4	224.8	216.7
	6	208.7	217.0	224.4	211.2
	7	205.7	209.4	213.3	211.2

*Own = 1.156 m / 45.5"    R = 1.168 m / 46"    L = 1.219 m / 48"    XL = 1.270 m / 50"*

### Club characteristics and artefacts of increasing shaft lengths

Addressing firstly coefficient of restitution (CoR), club heads used in the original study were selected as being at the limit of 0.83 and with no more than 1.20% variance in CoR between all three club heads. This level of variance cannot account for the differences observed in the testing. Furthermore the CoR is an indication of the performance of the club for a normal impact at its centre. Even a slight variation in impact location would generate more variation than exists within these closely matched heads. It is impossible to compare this to the comments offered by Glazier as no data were presented to support his suggestions.

There are several characteristics of golf clubs which are purported to lead to changes in the performance of clubs. The intention of this work was to control as many aspects of the club's characteristics as possible, whilst accepting the inherent variation in the others. Unsubstantiated comments like "Likewise, shafts installed with correct spine alignment can purportedly produce similar increases in ball speed and also improve accuracy through more consistent ball striking" have no place within scientific discourse. Furthermore the fact that a long drive champion used a shaft with a particular flex, measured using a pseudo static method is not relevant. The strain rates attained by a higher swing speed player is likely to render a comparison with low strain rate tests at best tenuous. The comments that the shaft flexibility may have played a role in the tests reported in the paper are valuable, however there is no evidence presented that shaft flex of itself can influence performance, it is merely conjectured.

Swingweight changes were considered an acceptable parameter difference for test clubs in the present study based on the rationale that adjusting for or maintaining a uniform swingweight for the different club lengths used would have altered other crucial club parameters perceived as having a greater overall effect on shot performance and club feel. This concerns the addition of mass to the club head when adjusting for swingweight, thus altering the moment of inertia, gear, dynamic loft and perhaps most importantly the location of the club's centre of gravity. Furthermore the addition of mass to the club head will affect its CoR, which was a concern in the previous comment. These parameters, therefore playing characteristics, were matched for the test clubs assembled.

Swingweighting is one method whereby the feel of a club is adjusted and is a common industry method of achieving a matched club feel, where club adjustments are made by adding or removing mass from the club head. Previous research on swingweight has been carried out for various pieces of sports equipment including tennis rackets (Mitchell *et al.*, 2000), baseball bats (e.g. Fleisig *et al.*, 2000) and softball bats (Smith *et al.*, 2003).

Notably, Cross and Bower (2006) quantified the effects of mass and swingweight on swing speed using metal rods, recruiting 4 subjects to swing 3 rods that had the same mass but differing swingweight, and 3 rods that had different mass but identical swingweight. When swinging with maximal effort, swing speed was shown to decrease as swingweight increased, but swing speed remained constant as mass increased. In the original study by Kenny *et al.* (2008) swingweight was allowed to increase naturally with shaft length and was reported by test subjects not to have had a negative effect on perceived shot quality. Further research, though, may involve adjusting for swingweight as other club parameters are altered.

### **Role of constraints on driving technique and performance**

Task constraints are not standalone in explaining the variation in accuracy (Newell, 1986). Coupled with organismic and environmental constraints to assess the variability shown to exist for accuracy in the original paper, variability may be well explained. The authors believe, however, that the task was the dominant aspect; that the task set, that is using drivers with which the subjects were unfamiliar adequately altered the task set. Given further practice time with the drivers, subjects may have adapted further and thus accuracy at a later date could have been assessed, along with movement pattern coordination, and

discussed in terms of dynamical systems theory. The suggestions of further study offered by Glazier are indeed valid.

## Conclusions

Through the additional presentation of individual subject carry data, representing shot performance (carry), the conclusions drawn by us in the original paper are clarified and remain still. Carry distance increased as driver shaft length increased. Some subjects made substantial increases in average carry distance (21.8 m and 9 m) compared to the modest increases for the group (4.3 m) when using the extra long driver compared to their own driver. In so far as was possible and considered feasible, club parameters except length were the same for all 'test' clubs and provide a valid indication of the effect of driver length changes on shot performance for a cohort of low handicap golfers. Data here, though, does make it apparent that diminution of performance is possible and that golf studies merit single-subject analysis.

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