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E.S. Wallace and J.E. Hubbell

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184 Thorn Hill Road
Warrendale, PA 15086-7514
(724) 776-9000

THE EFFECT OF GOLF CLUB SHAFT STIFFNESS ON GOLF PERFORMANCE VARIABLES – IMPLICATIONS FOR CLUB-FITTING.

ES Wallace[1] and JE Hubbell[2]
[1] School of Applied Medical Sciences and Sports Studies, University of Ulster, Shore Road, Newtownabbey, Co Antrim BT37 0QB, Northern Ireland.
[2] United States Golf Association, Far Hills, New Jersey 07931, USA

Abstract

The process of matching clubs with appropriate shafts to individual players is largely one of trial and error. Bending stiffness or shaft flex, mass, damping, torsional stiffness, and bend point are widely accepted as being the five main shaft properties that affect performance in golf. Considerable debate surrounds the individual and combined dynamic influence of these factors during the golf swing. The aim of this paper was to examine the effects of 5-iron clubs with shafts of different bending stiffness on selected golf performance measures. A laboratory-based experimental approach was used in the study. Eighty-four right-handed male amateur golfers gave their informed consent and participated in this investigation. Anthropometric and physical fitness measures were obtained for each subject and used in correlational analyses with shot performance measures. Objective measurements of the stance/ set-up and swing kinematics along with clubhead presentation variables were obtained for each of the golfers during swings for each of three experimental clubs. A visual inspection of body kinematics data revealed differences in shaft stiffness had no observable effect within a given subject, although obvious and expected differences were noted between subjects. While statistically significant differences were noted among shaft types for clubhead speed, solid hit factor and ball/ clubhead impact location, the actual magnitudes of these differences were considered negligible. No significant differences were noted for any of the postural variables at address due to shaft stiffness. These scientific findings lend support to conventional wisdom that shaft bending stiffness is perhaps most relevant to 'feel' of the golf club. However, the present study did not take into account other important launch conditions of the ball such as launch angle and spin rate.

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Introduction

This paper forms part of a larger laboratory-based study which was designed to examine the effects of variations in golf club parameters on the swing kinematics and dynamics of a group of amateur golfers. Specifically, bending stiffness or shaft flex was the property examined in this paper. The golf shaft is considered by many to be the most important component of the golf club (1, 2). However, different measurement techniques and methods of reporting of shaft flex generally make direct comparisons among shafts from different manufacturers difficult (3). The process of matching a club with an appropriate shaft to the particular characteristics of the individual golfer remains largely a process of trial and error, with matching done on the basis of personal preference and observation. While objective measurements of a golf shaft and an individual golfer can be easily made, there is no clear understanding of their inter-relationships during the golf swing. It has been claimed that the computer technology to measure and record the swing is far in advance of our ability to analyse and deduce from this information. This limitation must be overcome to put matching of the golfer and equipment on a sound technical footing (3). This view has been supported by Mather (4), who states that at best experimental data is accumulated and inductive reasoning is applied to hone the design for the market.

A variety of both static and dynamic tests are routinely used to quantify and categorise shaft flex, though the real value of static measurements to the actual golf swing is questionable. The dynamic properties of the shaft in the hands of the golfer are a consequence of both centrifugal and inertia forces of the rotating clubhead as well as the forces acting on the clubhead due to the golfers hand action (3). Strain gauges attached to the shaft during golf swings have determined deflection and stress levels in both the plane of the swing and perpendicular/ normal to the swing plane, with typical in-plane values found, regardless of shaft design or golfer ability. Yet photogrammetry techniques have revealed swing characteristics relating clubhead velocity and its position in swing correlate highly with handicap of players, with similar handicap players displaying similar swing patterns and a progression from poor to good (5). Later work concludes that dynamic testing appears necessary, perhaps essential, if true playing characteristics of clubs are to be found (4). They also claim that as well as propelling the ball with distance and accuracy, golf clubs ought to be matched to the player. They further state that from a knowledge of club geometry, shaft flex, head mass and mass distribution it ought to be possible to predict performance for a given swing pattern.

It has been claimed that the best method of fitting shafts to players involves matching the player's swing speed to the speed rating of a given shaft (2). Many shafts have been measured for frequency and torsional stiffness and matched to recommended swing speeds. Jackson also refers to the 'feel' of a golf shaft as a key determinant of fitting a shaft to a player, claiming torsional stiffness and frequency combine to produce a definite effect on the feel of a shaft. Wishon (6) states shaft flex has a major effect on 'feel', and goes on to describe the best feel as that which allows the golfer to swing with the most comfort and least effort and control their tempo without consciously thinking about it. Hedrick and Twigg (7) discuss the contributions of vibration measurement to the quantification of feel of a particular golf shot, and speculate that one day the design process of clubs would incorporate as much good feel as possible while eliminating uncomfortable as well as harmful vibrations. The purpose of this paper is to contribute scientific findings to assist in the overall understanding of the interaction between golfers and their clubs when shaft flex is varied within commonly manufacturered extremes.

Method

Subjects.

A total of 104 subjects volunteered to act as subjects in the series of tests that comprised this study, with 84 valid cases obtained. All subjects were male, right handed golfers with a known handicap (either USGA or R&A) and free from injuries. The physical characteristics of the golfers (n=84) are given at Table I.

Table I Physical characteristics of subjects.

	Mean (SD)	Min	Max
Age (yr)	38.35 (12.50)	18.00	68.00
Height (m)	1.77 (0.06)	1.64	1.91
Weight (kg)	81.49 (12.09)	58.90	115.60
Handicap	11.02 (8.12)	-2	28

Subjects undertook tests at either the USGA biomechanics laboratory or the biomechanics laboratory at the University of Ulster (UU). Each subject was informed of the objectives of the study, completed a set of health history and golf playing history questionnaires, and signed an Informed Consent Form as per the American College of Sports Medicine guidelines.

Experimental clubs

Two identical sets of 3 test clubs (all No. 5 Irons with steel shafts) were specifically designed and manufactured for the study by a major golf club manufacturing company. Shaft stiffness and other club parameters were measured for all clubs at the USGA Research and Test Center, and one set of 3 clubs was subsequently used at each of the two labs. Details of the club specifications are given at Tables II and III.

Table II Description of experimental golf clubs (5-irons)

Club No.	**Variable(s) manipulated**	**Description**
1	None	**Regular** flex, **regular** lie angle and **regular** length
2	Shaft flex	**Very flexible shaft**, regular lie angle and regular length
3	Shaft flex	**Very stiff shaft**, regular lie angle and regular length
10	None	**Warm-up club, each subject's** own 5-iron

Thus, **Club 1** was designated as a **'regular'** club, that is it represented a club with regular (standard) shaft flexibility, lie angle and length. This club was used as a benchmark reference against which to compare the other test clubs. **Clubs 2 and 3** were set at meaningful 'extreme' values for **shaft flexibility (stiffness)**. Thus, **Club 2** represented a **'very flexible'** shafted club, while **Club 3** represented a club with a **'very stiff'** shaft. **Club 10** was the subject's **'own club'**, the specifications of which were not ascertained. In each test session, the subject used his own club as the first club in the test series, thereby it acted as a warm-up club. Data were also obtained for this club, and were used along with the results from the test clubs for comparative analyses.

Table III Club specifications of Experimental Golf clubs (5-irons)

Club No.	Length (ins)	Loft (degrees)	Lie angle (degrees)	Dead Weight (g)	Swing Weight (g)	Shaft Freq. (cpm)
1 regular	37.25	27	60	427	587	**310**
2 v. flexible	37.25	27	60	417	583	**283**
3 v. stiff	37.25	27	60	440	588	**336**
10* own club	U	U	U	U	U	U

(*Club '10' represents each subject's 'own 5-iron', specifications of which were not measured - unknown -'U')

Procedures

Testing took place over two visits to the laboratory. On the first visit details on health background, fitness, lifestyle, manufacturer and types of current clubs used and current frequency and type of golf practice were recorded using questionnaires, and fitness tests were carried out. The measurements taken for the subjects were categorised into the following areas: physical characteristics; playing ability – handicap; anthropometry; physical fitness – strength, power, and flexibility. Height and weight were measured by a stadiometer, body fat percentage was estimated from the addition of 4 skinfolds according to Durnin and Wormseley's (8) equation, BMI was determined by body mass (kg)/ height (m) squared, and limb/ trunk lengths were determined by tape measures. The measured components of physical fitness were strength (grip, back and leg), flexibility (trunk and hips, back extension, shoulder rotation, trunk rotation), and leg power. The physical fitness measurements were largely determined by 'field tests', for example: standing broad jump mat, grip and leg and back dynamometers.

On the second visit the golf swing analyses were undertaken. Prior to each test subjects warmed up for four minutes on an exercise bicycle (Monark) or rowing ergometer (Concept II) and completed a number of directed and self selected lower and upper body stretches. Prior to the swing tests with the experimental clubs, and in addition to a general warm up, subjects were allowed to further prepare by practising with their own 5-iron club. The number of practice swings was not limited; subjects were requested to begin the test when they felt sufficiently comfortable and physically and mentally ready.

The 3 test clubs used in the present study were part of a larger set of 9 clubs which were randomly assigned to each subject. Subjects hit 3 or 10 shots with each club using a two-piece construction ball into a netted area while standing on a rubber moulded artificial grass golf mat (1.5m x 1.5m). The ball was struck off of a rubber tee situated in a GolfTek ProV analysis plate. Standardised instructions to all subjects requested them to 'hit the ball with their optimum 5 Iron swing' towards a vertical line (situated on the back wall of the net) aligned with the tee and the long axis of the GolfTek plate.

Measurement techniques

Two sets of variables were measured during the golfer's set-up and swing with each club. The first related to joint angles and feet/ ball orientation of the golfer at address and body kinematics during the swing from take-away until ball impact, and the second examined swing characteristics and ball dynamics. Body kinematics were obtained by the CODA mpx™ Motion Analysis System (UU lab) and the 3-D 5-camera Motion Analysis Corporation ™ system (USGA lab).

Clubhead speed, ball speed, clubface angle, swingpath angle, impact point, tempo, rotation, solid hit factor and spin were measured using two modified versions (one in each laboratory) of the Golftek ™ Pro-V Swing analysis system. The systems were modified, at our request, by the manufacturer to give an increase in resolution for speed of approximately 32 per cent. The ProV systems were checked for accuracy against more sophisticated systems routinely used at the USGA and were shown to be well within acceptable levels of agreement.

Data analysis

Due to the exceedingly high volume of data generated by this investigation it was necessary to apply data reduction. Thus, a 'representative swing' for each subject by each club was chosen for analysis. This representative swing was determined as the mean of the 10 swings undertaken at the UU tests, and as a freely selected swing from the 3 USGA tests.

The resulting data pertaining to the Golftek system from both laboratories were combined for further analysis, while the kinematic data obtained from each laboratory were treated separately. The quantifiable data were entered into Microsoft Excel and SPSS spreadsheets for further analyses, which included visual inspection of plots and statistical analysis. The latter involved descriptive reporting, correlations and regressions, and analysis of variance (ANOVA's).

Results

Initially, an attempt was made to gain an appreciation of the relationships between clubhead speed and the various anthropometric measures, physical characteristics, physical fitness factors and handicap. Mean data for these measures for all subjects (n=84) were entered into a multiple linear regression model as dependent variables, with clubhead speed for the regular club (club 1) entered as the dependent variable. A stepwise linear regression was performed with variables removed which were not significant ($p>.05$). This yielded only three variables as being significant predictors ($p<.05$) of clubhead speed: handicap, back strength, and leg power, with partial correlations with clubhead speed of -.59, .37, and .35 respectively. The regression equation with 95% confidence interval thus obtained was:

$$\text{CLUBHEAD SPEED} = [90.05\ (+/-\ 16.06)] - [0.898\ (+/-0\ .29)\ \text{HANDICAP}] + [0.109\ (+/-\ 0.07)\ \text{BACK STRENGTH}] + [11.82\ (+/-\ 7.75)\ \text{LEG POWER}].$$

When typical values for handicap, back strength and leg power were entered into the equation and clubhead speed was calculated, the intervals were found to be wide, thus the equation is unable to discriminate between golfers in the population for this particular club. Nonetheless, the ranked importance of these 3 variables in predicting clubhead speed is considered important and was used as a grouping basis for subjects for later analyses.

Initially, data for the complete group of subjects were collectively considered. Fig. 1 illustrates a simple linear regression for clubhead speed and handicap, where it is observed that approximately 35% of the variance in clubhead speed is accounted for by variance in handicap.

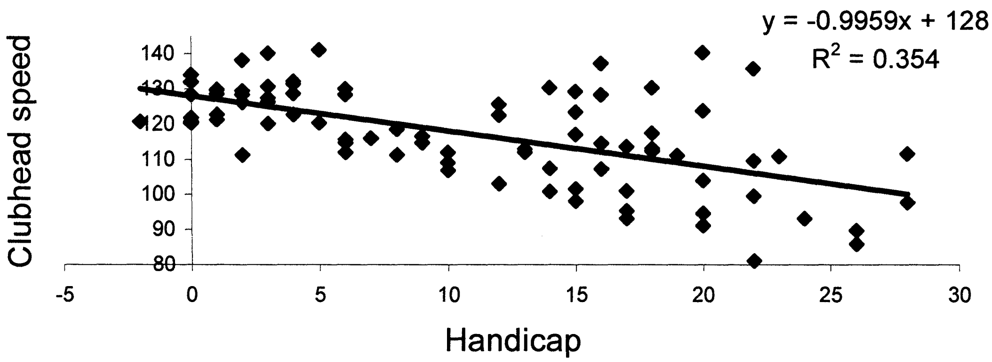

Fig. 1: Correlation of clubhead speed (ft/sec) with handicap.

Figs. 2 and 3 indicate the relationships between clubhead speed and leg power and back strength, with leg power and back strength variances shown to account for 21% and 16% respectively, of the variance in clubhead speed.

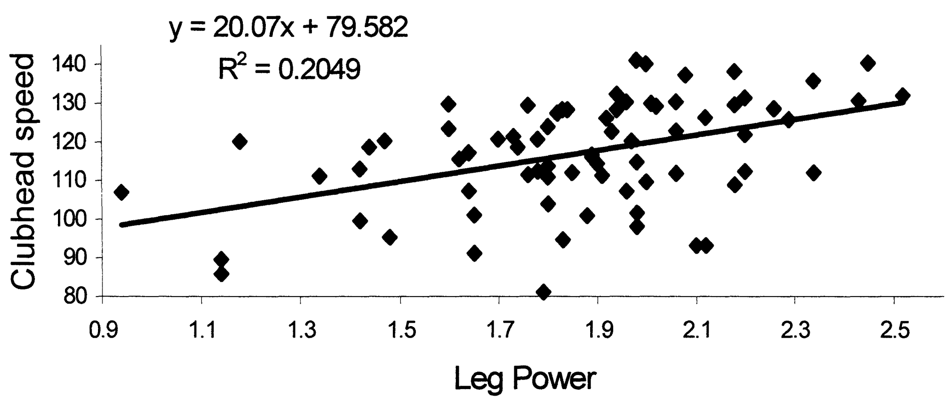

Fig. 2: Correlation of clubhead speed (ft/sec) with leg power.

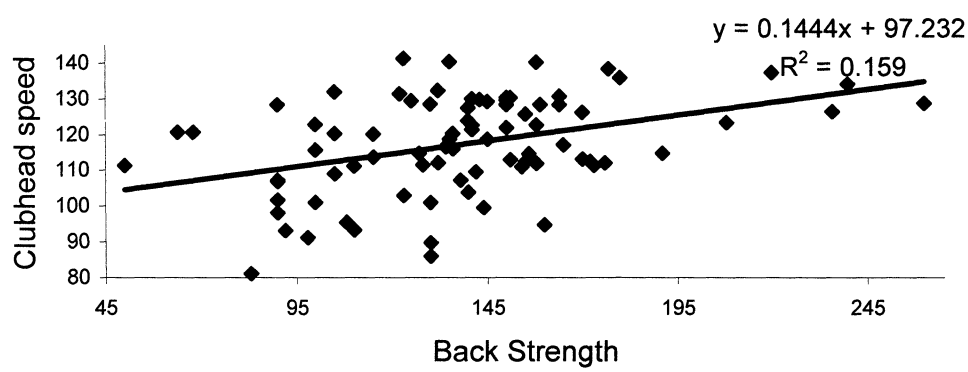

Fig. 3: Correlation of clubhead speed (ft/sec) with back strength.

Inferential statistics were applied to the data for all subjects to examine the effect of shaft stiffness on swing and ball variables and posture variables at address. These analyses revealed some significant differences, however the actual magnitudes were considered negligible. For example, ANOVA results for clubhead speed (CHS) across the 4 clubs yielded a statistically significant difference ($F_{3,246} = 4.60$, $p<0.01$) with Scheffe post-hoc tests indicating a statistical difference between the flexible and stiff shafted clubs. Yet when the actual mean values were examined, they were negligible (mean CHS stiff = 116.37 +/- 14.14 ft/sec, mean CHS flexible = 117.37 +/- 13.65 ft/sec).

Given the prime importance of handicap in determining clubhead speed, subjects were subdivided according to 4 handicap categories, taken as representing elite players (handicap =/<3, n=22), good players (handicap 4-11, n=20), average players (handicap 12-17, n=21), and high handicap players (handicap >18,n=21). These groupings were used for further analyses aimed at examining the relationship between clubhead speed and swing variables within players of similar ability. Fig. 4 illustrates the findings for clubhead speed for these groupings in terms of the 4 clubs used in the tests ('own' represents subject's own 5-iron, 'regular' represents the regular flex club, 'flex' represents the very flexible shafted club, and 'stiff' represents the very stiff shafted club).

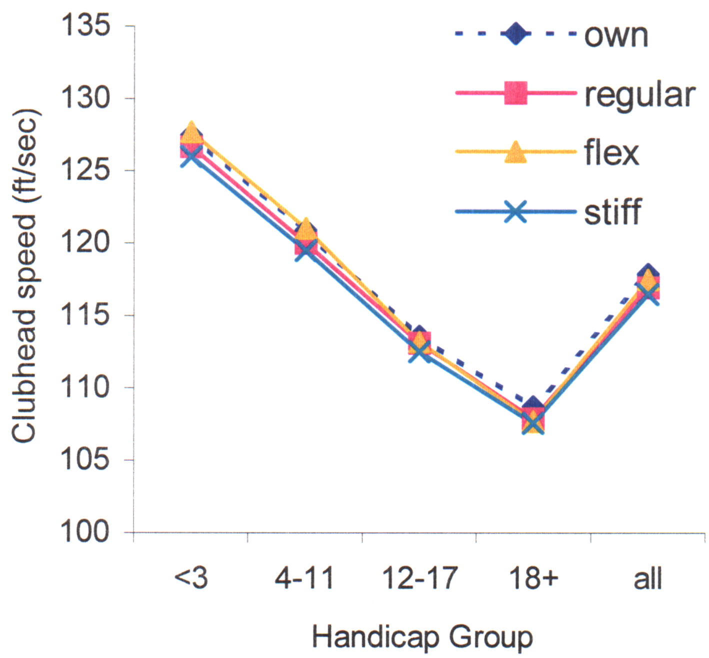

Fig. 4: Mean clubhead speeds for the 4 clubs by handicap group.

It is observed that clubhead speed decreases as handicap increases, as may be expected. Interestingly, variations in shaft stiffness had no demonstrable effect on clubhead speed in any of the handicap categories. Similar findings were observed for solid hit factor (ratio of clubhead speed to ball speed), and swing path, whereas some variations were noted for clubface angle (Fig. 5).

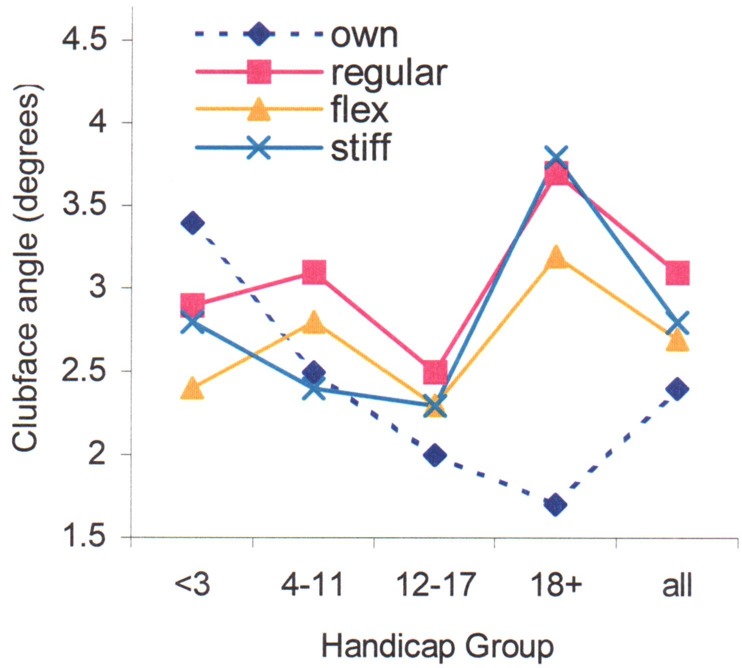

Fig. 5: Mean clubface angles for the 4 clubs by handicap group.

The positive mean values for clubface angle for all handicap groups for all 4 clubs indicates an open clubface at impact. The clubface orientation in conjunction with the swingpath determines the direction of initial ball flight and the side spin properties. It was found that the elite players had the highest positive values for swingpath (indicating an in-out path), with the magnitude of this variable decreasing as handicap increased for the top three handicap groups (Fig. 6). However, little effect of shaft stiffness is observed for any of the groups.

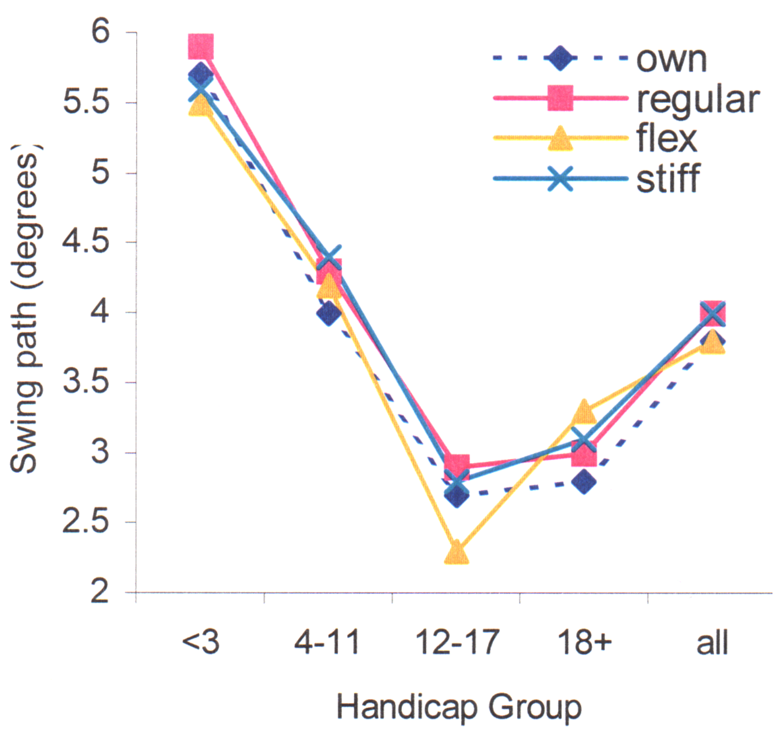

Fig. 6: Mean swingpath angles for the 4 clubs by handicap group.

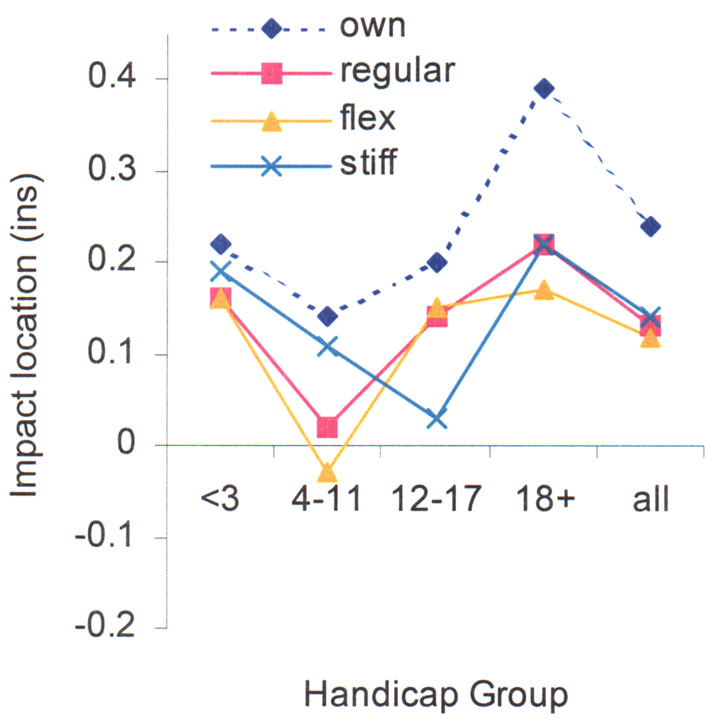

Fig. 7: Mean clubhead/ ball impact locations for the 4 clubs by handicap group.

The effect of shaft stiffness is minimal on the ball impact location (Fig. 7) for the elite group, whereas some variation, albeit inconsistent, occurs in the other groups.

Similar plots were produced and inspected for body kinematics at ball address, an example of which is illustrated in Fig. 8.

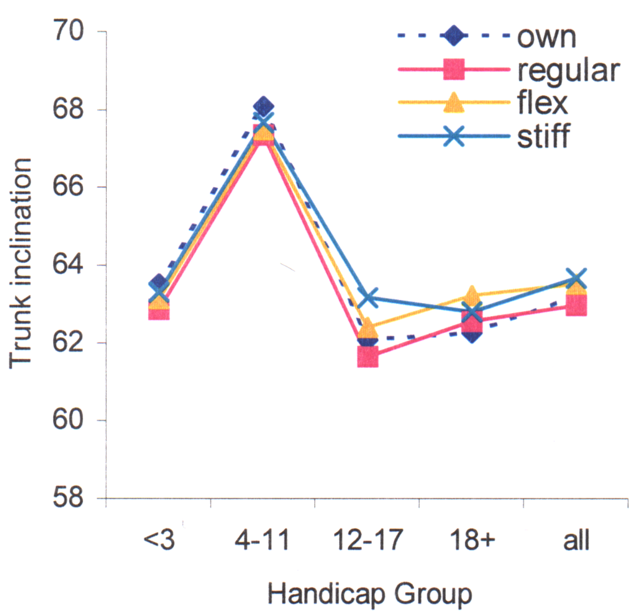

Fig. 8: Mean trunk inclination angles for the 4 clubs by handicap group.

As for many of the swing variables reported above, shaft flex had no demonstrable effect for any group on the trunk-to-ground inclination angles at ball address/ set-up position. Similar observations at set-up were noted for the angles between the trunk and the arm, the arm angles with respect to the horizontal, and the hip joint angles. There was a tendency for the ball to be moved back in the stance for the stiff club compared to the flexible club for most handicap groups.

Body kinematics during the golf swings revealed high consistency rates within each elite subject tested for the clubs with different shaft stiffness.

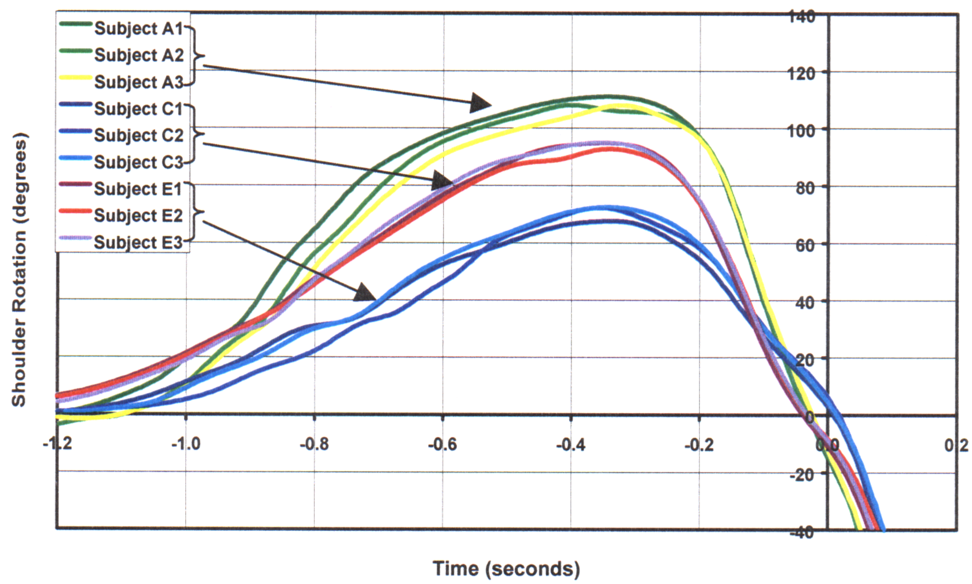

Fig. 9: Shoulder rotation comparisons for the 3 test clubs.

Shoulder rotations during the swings of three subjects with the three test clubs are shown in Fig. 9, where it is observed that within any given subject there is little variation imposed on the shoulder angular kinematics as a consequence of shaft flex. Ball impact is given as time zero, with data recorded during 1.2s of the backswing and immediately subsequent to impact.

Discussion

The shaft is widely regarded as the key performance component of the golf club and the need to match the golf shaft to the individual golfer's swing is generally recognised. There appears to be no sound objective method to achieve this matching, and thus methods to do so have remained largely subjective and based on time-consuming trial-and-error processes. Wishon (6) who approaches the task from the perspective of the golfer has advocated one practical solution to the problem. Thus, the player is asked what they want to change in order to improve their game, and this determines which of a set of 20 club specifications have the power to bring about those changes. In this regard, shaft flex is purported to have a major effect on feel, a medium effect on distance and only a minor effect on accuracy and trajectory. The 'feel' of a club, while difficult to quantify, has been featured in a number of research papers as an important aspect of the fitting process. Given the current lack of clear understanding of clubfitting principles and

processes, there is recognition of the need for research which combines the biomechanics of the swing and the matching of the golfer most accurately to his equipment (4, 9).
The present study was an attempt to address this issue, with shaft flex used as the independent variable. A number of key features of the golfer and his swing were selected as dependent variables and used in the analyses. The three test clubs were matched for key properties with the exception of shaft flex, with an extremely stiff shaft, an extremely flexible shaft and a regular flex shaft produced and fitted to the three test clubs. Each subject's own 5-iron served as a warm-up club and was also added to the analyses.

The scatter plot data sets for clubhead speed with handicap, leg power and back strength, tend to show linear relationships, albeit with wide variability and with a number of outliers. Nonetheless, each of these variables is considered to be an important determinant of clubhead speed. It is recognised that a number of other factors, which may be classified into the broad areas of motor skill, physical and mental characteristics, and psychological skills determine a player's handicap. However, handicap, which is a unique feature of the active golfer, has been shown to be the best predictor of clubhead speed. The other two features of back strength and leg power indicate the importance of these physical fitness dimensions in attaining high clubhead speeds.

The findings that shaft stiffness had minimal effect on clubhead speed for any of the different handicap groupings suggests that matching shaft stiffness on the basis of handicap alone is futile. However, other subtle differences between handicap groups for the various measures were observed. The small and inconsistent effect of shaft stiffness on both clubface angle presentation and swingpath angle across handicap groups suggests that shaft stiffness is not a key factor in determining these variables. Similar findings were noted for ball impact location leading to the same conclusion regarding shaft stiffness effect on clubhead/ ball impact location. The lack of any significant alteration in the set-up kinematics of all the groups, with the exception of ball position in the stance of the elite players, also suggests the lack of an effect of shaft stiffness on the set-up of the golfer at ball address. It is noteworthy, however, that the elite players tended to show least variation in all of the dependent measures suggesting that they have a greater capacity to repeat their golf swings irrespective of the shaft stiffness.

In conclusion, since clubhead speed failed to discriminate among clubs with shafts of different stiffness, we would strongly suggest the need for caution in using clubhead speed as a key measure in matching players to their equipment. Furthermore, the highly consistent ball striking and body kinematics observed across the clubs leads to the same cautionary note. These findings lend support to previously published works which have stated that shaft stiffness does not have a major effect on distance or accuracy, and is perhaps more related to feel. However, the context and limitations of the present study must be considered in any recommendations regarding clubfitting. Firstly, there was no measure of launch angle or spin rate, which along with clubhead speed are determinants of carry distance. Secondly, although 5-iron clubs are routinely used in clubfitting practices, this study was only concerned with this mid range iron which is not generally hit in an attempt to maximise distance in the first instance.

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