Shifting a portion of the clubshaft's mass distally: does it improve performance?

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Abstract

The purpose of this paper was to examine the claim, based on a pendular swing demonstration, that moving a portion of the mass from the grip end of a golf club to a position further down the clubshaft improves clubhead speed at impact. A two-dimensional model of a golf club was used to simulate the pendulum swing demonstration provided by a company that purportedly showed that such an optimal shifting of the club's mass increased the velocity of the clubhead at impact. Two sets of simulation experiments were performed. The first supported the video demonstration provided by the company, which showed that a club's swing-speed, while swinging under only the influence of gravitational torque, could be increased by relocating a portion of the club's mass further down the shaft. However, in the second set of experiments when an externally generated torque was applied to the grip end of the club, as would be the case for the uncocking of the wrists during the later stage of the downward swing, the relocation of mass further down the shaft proved to have a detrimental effect on the generation of clubhead speed leading up to impact. Thus, a pendulum swing, which uses only gravitational torque to drive the system, is an inappropriate test for evaluating the benefits of club design modifications intended to improve clubhead speed at impact.

Keywords: golf, simulation, clubshaft

Nomenclature

F_x, F_y	Force components acting at the rotation axis
M_T	Mass of total club
m_1	Mass of total club minus the mass of the sliding element
m_2	Mass of sliding element
$a_{x\text{cm}}$, $a_{y\text{cm}}$	Linear acceleration components of the total club's centre of mass
α	Angular acceleration of the club about an axis (z) perpendicular to the page
ω	Angular velocity of the club about an axis (z) perpendicular to the page
g	Gravitational acceleration

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Introduction

In sport, changes to equipment design are the norm. Manufacturers constantly feel pressure to change the appearance of their product as they know that such change has a significant impact on their yearly sales. Company researchers are constantly searching for new design ideas that they hope will improve the performance of their product. Some of these changes prove to be merely cosmetic, while others actually change the performance characteristics of the implement. The difficulty for the consumer is that, in most cases, all of the research evidence for the purported improvements in performance is supplied by the manufacturer. There is usually no objective third party who evaluates independently the claims made by the designer. Although there is a definite need for research accountability from equipment manufacturers, no mechanisms are presently in place. The reality, of course, is that objective evaluation takes a great deal of time and most companies cannot afford to wait until the verdict is in before moving ahead with their yearly design changes to their product. In addition, most outside researchers do not have the time, or the inclination, to examine the statements made by the manufacturers on the performance enhancement attributes of their latest product, as there is usually very little funding available for such a task.

One such example of design change from sport is the innovative idea in golf of redistributing a portion of the mass from the grip end of a club further down the clubshaft with the goal of improving clubhead speed at impact. This is indeed a novel idea, but one that appears to be counterintuitive in that redistributing mass further away from the axis of rotation will increase the moment of inertia and thus decrease angular acceleration. However, the manufacturer claimed that just the reverse happened. They reported that moving 10% of the mass from the grip end to the middle of the shaft actually produced greater clubhead acceleration during the downswing which translated into greater clubhead speed at impact. The experimental evidence that was made available to the consumer was a video clip on the company's website that compared the swing frequencies of two identical clubs swinging in a pendular fashion about an axis through the grip end. The demonstration was convincing in that for the case where the mass distributions of the two clubs were identical, they swung at exactly the same rate. However, when a portion of the mass from the grip end of one club was repositioned further down the shaft, and then released simultaneously with the other club from the same starting position and driven only by gravitational torque, it was quite noticeable that this club swung at a faster rate than the control club. The video clip conclusively demonstrated that there appeared to be something substantive behind the company's claim that this design innovation did improve clubhead speed during the downswing. However, the question not answered was whether this result was true only for conditions of gravitational torque, or was it a general result that included the effects of externally generated torques on the grip end of the clubshaft.

The purpose of this paper was to examine the premise that moving a portion of the mass from the grip end of a golf club to a position further down the clubshaft would improve clubhead speed at impact.

Method

Model

Two- and three-segment computer simulation models of the golf swing have been used by previous authors to examine different aspects of the golf swing ranging from the timing sequence of the primary joint segments involved, to the contribution of the shaft to the club's overall performance (Milne & Davis 1992; Turner & Hills 1999). The question posed in the current study required a golf club to be swung as a simple pendulum. Because of the simplicity of the associated modelling requirements for a pendulum swing, computer simulation was selected as an appropriate experimental tool to answer the posed research question. The golf club was modelled as a two-dimensional, rigid segment that rotated about a fixed axis, perpendicular to the plane of the page (i.e. z axis), that passed through the grip end of the shaft (Fig. 1). A sliding mass-element provided the capability of repositioning mass along the shaft of the golf club model. An externally generated torque

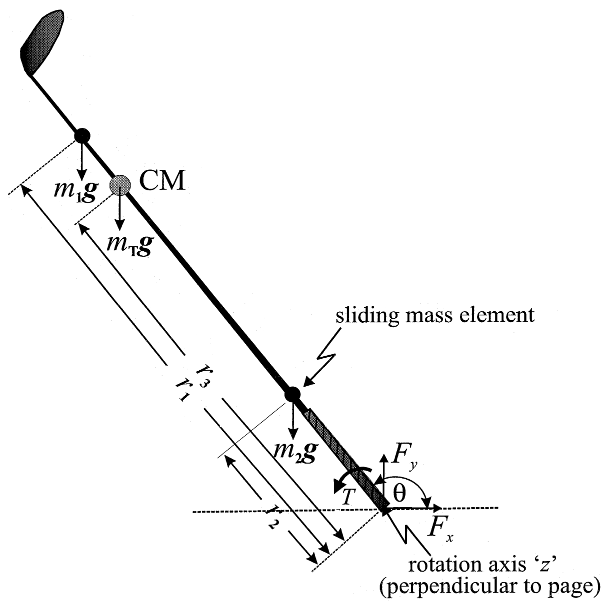

Figure 1 Two-dimensional model of the golf club used in the pendulum-swing computer simulation experiments. The club rotates about an axis perpendicular to the page, located at the grip end of the shaft.

about the grip end of the club could be activated if desired during the simulation. The profile of the torque produced by this torque-generator adhered to the force-velocity and activation constraints imposed by human muscle. The force-length property of muscle was expected to play a second order role in the outcome of the performance (Caldwell 1995) and, as such, was not included in the simulation model. The activation rate and force-velocity properties of human muscle were implemented using the calculated instantaneous isometric torque predicted from a linearized Hill model structure (Niku & Henderson 1985; Sprigings 1986) as input to the force-velocity approach described by Alexander (1990).

$$T = T_{\max}(1 - e^{-t/\tau})\frac{(\omega_{\max} - \omega)}{(\omega_{\max} + \Gamma_{\omega})} \tag{1}$$

In Eq. (1), T is the instantaneous value of torque produced by a muscle torque generator; $T_{\max}$ is the maximum isometric torque of the torque generator; $\omega_{\max}$ is the maximum angular velocity of the associated joint; ω is the instantaneous joint angular velocity; Γ is a shape factor controlling the curvature of the torque/velocity relationship; t is the elapsed time from initial torque activation and τ is the activation time constant (Sprigings 1986; Pandy *et al.* 1990). For the present study, $T_{\max}$ was set at 60 Nm, $\omega_{\max}$ was set at 60 rad s^{-1}, τ was set at 40 ms (Sprigings 1986) and Γ was assigned a value of 3.0 (Alexander 1990). The values used for r_1, m_1 and m_2 (Fig. 1) were 74 m, 0.363 kg and 0.02 kg, respectively. Although the manufacturers only claim to shift approximately 10% of the shaft's mass distally, which would be approximately 0.013 kg, it was decided to slightly increase this value to 0.02 kg to better observe whether any enhancement phenomenon, in terms of increased club speed at impact, was taking place.

Simulation process

The equations of motion for the golf club segment were written using Newtonian formulation.

$$F_x = M_T a_{x\mathrm{cm}} \tag{1}$$

$$F_y - M_T g = M_T a_{y\mathrm{cm}} \tag{2}$$

$$F_x r_3 \sin(\theta) - F_y r_3 \cos(\theta) + T = I_{\mathrm{cm}}\alpha \tag{3}$$

Using the equations of constraint for a golf club modelled as physical pendulum rotating about a fixed axis:

$$a_{x\mathrm{cm}} = -\alpha r_3 \sin(\theta) - \omega_2 r_3 \cos(\theta) \tag{4}$$

$$a_{y\mathrm{cm}} = -\alpha r_3 \cos(\theta) - \omega_2 r_3 \sin(\theta) \tag{5}$$

Substituting Eqs (1), (2), (4) and (5) into Eq. (3) resulted in an expression for α in terms of θ and parameter constants only.

$$\alpha = \frac{T - M_T g r_3 \cos(\theta)}{I_{\mathrm{cm}} + M_T r_3^2} \tag{6}$$

where: I_{cm} is the club's moment of inertia about the z axis passing through the overall centre of mass; M_T is the total combined mass of m_1 and m_2 and r_3 is the distance that the overall centre of mass of the golf club is located from the rotation axis.

Each simulation commenced with the club starting with zero angular velocity at a 50° angle (i.e. $\theta = 130°$ in Fig. 1) above a horizontal line through the axis of rotation at the grip end of the club. This starting position is consistent with the findings of Jorgensen (1994), and Neal *et al.* (1999), who reported that the muscular torque, that aids the uncocking of the wrists during the down swing, is delayed until the hands are below shoulder level, which in turn positions the club to approximately the starting position used in the simulation experiments. The initial value of angular acceleration, and subsequent value at each time step, was determined using Eq. (6). The values of θ, and ω for the next time-step were generated using a fifth order Runge–Kutta–Fehlberg subroutine with variable step size (Burden *et al.* 1981).

Programming check

A closed-form equation for the angular acceleration of the golf club at a specified angle of position was used to evaluate the accuracy of the acceleration values generated numerically during the simulation experiments.

$$\alpha = \frac{T - (m_1 + m_2)\mathbf{g}\left(\frac{m_1 r_1 + m_2 r_2}{m_1 + m_2}\right)\cos(\theta)}{I_1 + m_1 r_1^2 + I_2 + m_2 r_2^2} \tag{7}$$

where: I_1 is the moment of inertia about a 'z' axis passing through what would be the centre of mass of the club if the sliding element of mass was excluded, and I_2 is the moment of inertia about a 'z' axis passing through the sliding element's centre of mass. Values of 0.0398 kg m^2, and 0.005 kg m^2 were used for I_1 and I_2, respectively.

Simulation experiments

Two sets of simulation experiments were carried out. The first simulation experiment (SIM1) used only gravitational torque to drive the downward swing, and the second simulation experiment (SIM2) used both gravitational and muscular torque to drive the system. For both of these simulation experiments, the sliding mass element was initially positioned at the axis of rotation at the proximal end of the club and then shifted 1 cm distally along the shaft after each simulated swing. The simulation of each swing was terminated when the clubhead reached its lowest point with the shaft vertical. Because the sliding mass element was repositioned to a new location after each swing trial, r_3 was updated using Varignon's theorem. Likewise, after each trial, the moment of inertia for the golf club was updated using the parallel axis theorem.

Results

The simulation results for SIM1, where only gravitational torque was present during the downward swing, clearly showed that there was an optimal location for the sliding mass element (Fig. 2). This result was in agreement with the company's video tape demonstration which showed that repositioning a portion of the mass from the grip to a position further down the handle created a slight (0.05 m s^{-1}), but observable, increase in the swing speed of the club. For the particular mass element used in this simulation experiment, the optimal location was 0.45 m down the shaft. However, the precise distance of this optimal location will vary depending upon the magnitude of the mass element, as well as the length and mass distribution of the club itself.

On the other hand the simulation results for SIM2, where both gravitational and muscular

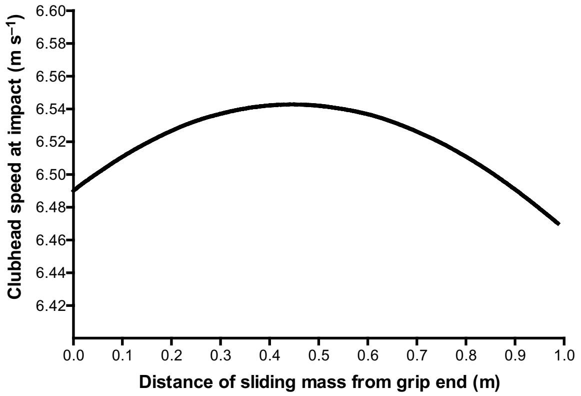

Figure 2 Optimal location of the sliding element of mass for a simulated golf club swinging only under the influence of gravitational torque.

torque were used to swing the club, showed no sign of any improvement of clubhead speed at impact as a result of shifting the mass element distally along the shaft (Fig. 3). On the contrary, the further the mass element was shifted down the shaft, the slower was the clubhead speed at the impact position. This finding is a significant departure from the results achieved under the conditions of SIM1 where it was observed that shifting a portion of the shaft's mass approximately halfway down the shaft improved swing speed performance. The results from SIM2 revealed that any shifting of the club's mass distally down the shaft reduces the magnitude of impact velocity that can be achieved when wrist torque is applied to the club. The torque profile produced by the muscle actuator at the grip end of the golf club for SIM2 was observed to be consistent with a model that adhered to the activation and force-velocity properties of muscle (Fig. 4).

The angular acceleration values used in the simulations were compared at selected swing-angles with those generated from the theoretical closed-form equation and found to be within 0.02% of each other. The angular acceleration from the closed-form equation was plotted against the distance of the sliding mass element from the grip end. When only gravitational torque was present during the descent, there was an optimal location for the element of mass that resulted in the greatest angular acceleration of the club (Fig. 5). However, as was the case for SIM1 in the simulation experiments, this was only true when gravitational force provided the external torque accelerating the club. When a representative muscular torque was added to the closed-form equation, the further down the shaft the element of mass was shifted, the lower was the angular acceleration value (Fig. 6).

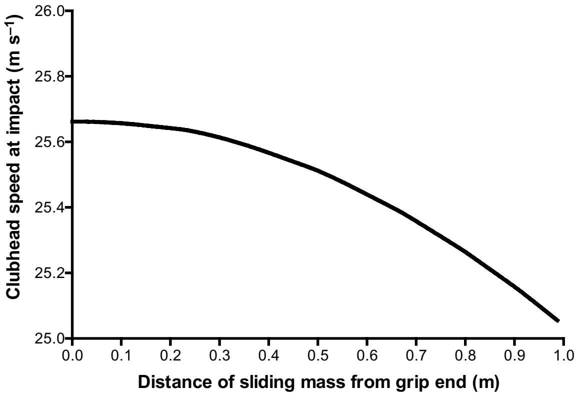

Figure 3 Optimal location of the sliding element of mass for a simulated golf club swinging under the influence of both gravitational force and an externally generated muscular torque about the proximal end of the club.

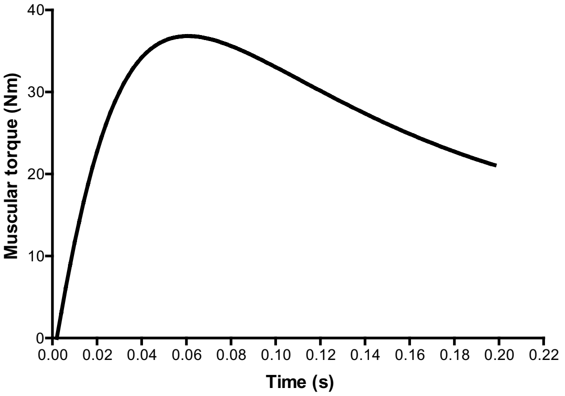

Figure 4 Profile of the muscular torque used to accelerate the golf club during the simulation experiments SIM2.

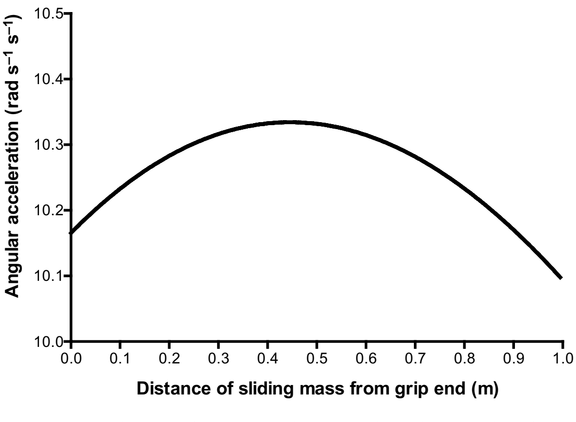

Figure 5 Angular acceleration values produced from the closed-form equation (using only gravitational torque) for each incremental shift of the sliding mass element along the club's shaft. For this plot, the clubhead was positioned at an angle of 20° (i.e. $\theta = 160°$ in Fig. 1) above a horizontal line through the axis of rotation at the grip end.

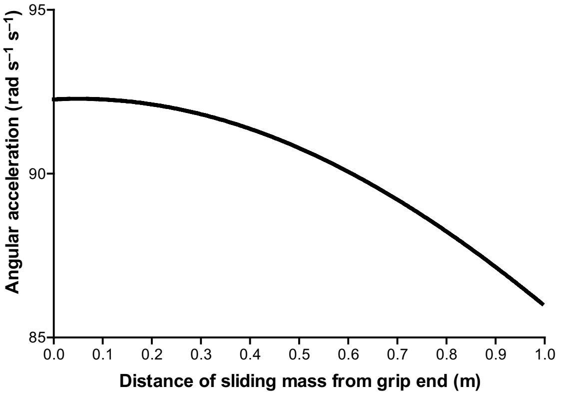

Figure 6 Angular acceleration values produced from the closed-form equation (using both gravitational and muscular torques) for each incremental shift of the sliding mass element along the club's shaft. The applied muscular torque was set at 20 Nm, and the club shaft was positioned at an angle of 20° (i.e. $\theta = 160°$ in Fig. 1) above a horizontal line through the axis of rotation at the grip end.

Discussion

The intent of this paper was to examine the premise that moving a portion of the mass from the grip end of a golf club to a position further down the clubshaft would improve clubhead speed at impact. The pursuit of improving clubhead speed at impact by modifying club design is a reasonable goal for any club manufacturer. It has previously been shown (Cochran & Stobbs 1968) that clubhead speed at impact is the primary determinant of a golf ball's speed leaving the clubface.

The results from the simulation experiments, SIM1 and SIM2, revealed that the conclusion reached on the optimal position of the element of mass along the club's shaft was dependent on whether the club's downswing acted strictly under the influence of gravitational torque, or whether it was also under the influence of an external torque at the grip end. The suggestion that the downward swing of a golf club acts only under the influence of gravitational torque is unsupported in the literature. The works of Vaughan (1981) and Neal *et al.* (1999) have shown, using reverse dynamics, that the uncocking of the wrist during the later stage of the downward swing is a product of both gravitational and muscular torque. Values in excess of 40 Nm for muscular wrist torque during the downswing have been reported by Neal *et al.* (1999). In SIM2, the applied muscular torque reached a maximum value of approximately 37 Nm which was well within the torque generating capabilities of a good golfer.

The results from the closed-form equation support the conclusions reached using simulated impact velocities. That is, the shifting of mass further down the club's shaft reduces the clubhead speed at impact when muscular torque is actively employed at the grip end of the club. As in any simulation experiment, a number of simplifying approximations to the true world were made which might bias the conclusions reached. For example, only one pattern of muscular external torque was applied. The simulation model only shifted a single small element of mass along the shaft, whereas in practice the real shaft's shifting of mass was done in the form of a gradual series of tapers. In addition, it may be argued that the simulation model used in these computer experiments does not take into consideration any positive changes in flex characteristics that might be introduced by the extrusion process necessary to shift a portion of the club's mass further down the shaft. However, any enhanced flex characteristics of the shaft were certainly not promoted during the company's pendulum swing experiments as the reason for the increase in clubhead speed. The company's video evidence of enhanced performance attributable to the redistribution of mass further down the club's shaft was based solely on their pendulum swing experiment. The results shown in this paper dispute the use of a gravity based pendulum-swing experiment being used to ascertain whether shifting a portion of the club's mass further down the shaft will benefit the golfer by producing higher clubhead speeds at impact. Clearly, any valid test for assessing whether a modification in club design produces improvement in clubhead speed at impact must include the influence of an external torque applied to the grip end of the club.

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