BIOLOGICAL MOVEMENT VARIABILITY DURING THE GOLF SWING

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This study quantified the level and effect of biological movement variability (BCV %) on the golf swing performance of 10 skilled and 10 unskilled golfers. Selected two-dimensional kinematic measures were obtained from each player performing ten golf swings with a five iron club. Linear regression analysis was employed to establish relationships between kinematic measures (absolute, CV%, BCV %) and club-head velocity (absolute, BCV %) using SPSS version 12.0. One-way analysis of variance (ANOVA) was used to assess the effect of handicap on all of these measures. Results revealed between-group differences in the mean, CV% and BCV% of several swing kinematic measures. Regression analysis revealed that the strongest predictive model for club-head velocity included handicap and wrist angle at address.

KEYWORDS: Coefficient of variation, standard error of the mean, biomechanics.

INTRODUCTION:

The golf swing is a complex, whole body movement that uses the kinetic chain principle to develop momentum and generate high club-head velocity to propel the ball accurately over large distances. Whilst the biomechanics of the golf swing are well described (Hume *et al.*, 2005), how the control of this motor skill can be improved and how practice conditions can influence this process is less well understood (Farrally et al., 2003). Many golf coaches and players utilise the Wiren (1990) model which discusses the laws, principles and preferences underlying optimal golf performance. While Wiren (1990) focused on the laws and principles, many coaches may have a relatively invariant view on the preferences and advocate the attainment of certain postures and positions at various phases of the golf swing, regardless of the players' age, physical abilities, club used or environmental conditions.

This (coach) approach differs to dynamical systems theory (DST). Using DST, Knight (2004) postulated that a more reliable swing may emerge by exploring different swing parameters, rather than attempting to perform each swing with absolute invariance. Such an approach may provide the player with the opportunity for observational learning on a variety of possible solutions, resulting in the coordinative adaptability for variable conditions. Such a method is employed in long jump training where the athlete is discouraged from using a stereotyped run-up pattern and is encouraged to visually adjust their running strides to adapt to variable extrinsic and intrinsic conditions (Bradshaw and Aisbett, 2006). In golf, a similar approach could involve aiming at different targets or using different clubs from one shot to another, as well as practicing in different wind conditions, with varying stance positions or fatigue levels.

Movement variability has been traditionally quantified using the coefficient of variation (CV%) (Heiderscheit, 2000). However, the CV% may include variable percentages of both technological error (e.g. from camera set-up, environmental changes during field testing, digitization) and biological movement variability (Rodano and Squadrone, 2002). A method that estimates biological variability (BCV% = CV% - SEM%) in intra-individual analysis was recently proposed by Bradshaw et al. (in press). Bradshaw et al. (in press) reported that technological error (SEM%) highly inflated traditional measures of movement variability (CV%) by up to 72% for the kinematics of a sprint start.

The purpose of this study was to quantify the magnitude of, and to examine the role of, biological movement variability on the performance of the golf swing. To achieve this, the kinematic patterns of skilled (SG) and unskilled (USG) golfers were assessed, together with performance (outcome) measures of club-head velocity and shot accuracy. It was hypothesized that the SG would have faster and more accurate golf shots than the USG, but would have a more variable swing kinematic pattern.

METHODS:

Twenty male golfers aged 18-36 years gave their informed consent to participate in the study. The golfers were divided into two equal groups; SG (age 23 ± 3 years, height 1.80 ± 0.07 m, mass 77 ± 9 kg, handicap 0.3 ± 0.5 [range 0-1]) and USG (age 28 ± 8 years, height 1.77 ± 0.07 m, mass 75 ± 12 kg, handicap 20.3 ± 2.4 [range 18-25]). Ethical approval was obtained for all testing procedures from the Auckland University of Technology Ethics Committee.

All testing was conducted at Auckland University of Technology's Golf Swing Clinic which is comprised of eight bays with an artificial grass Astroturf surface and netting. After completing a warm-up consisting of ~10 minutes of sub-maximal swings and stretches, the golfers performed ten golf shots with a five iron club. The goal of the shots was to hit a net-mounted target (positioned 15 m from the golfer) whilst maximizing ball velocity. The target was 1 m wide and 1.4 m high, with the bottom of the target placed 4.2 m above the ground to simulate the expected "average" trajectory of a 5-iron. Each swing was separated by a rest period of one minute to ensure sufficient recovery time. Three digital video cameras (Sony, PAL, 50Hz, 1/1000 s) captured overhead, frontal and right-side views of the golf swing, and were positioned 3 m, 7 m and 7 m from the golfer, respectively. Club-head velocity of the golf swing was measured using a STALKER Professional Sports radar gun (Applied Concepts, Texas) operating at a frequency of 34.7GHz, held in a 180^0 posterior position to the golfer as they performed each golf swing. The STALKER has a measuring accuracy of ± 1.6 km/hr. Target accuracy was recorded as the percentage of shots that hit the target. Video footage of the golf swing was analyzed using Silicon Coach Pro video analysis software (Dunedin, New Zealand). The kinematic measures selected for this project all had some relevance to golf swing performance, with many of these variables described by Wiren (1990). A number of temporal measures (backswing, downswing and total swing time) were also calculated.

Individual athlete means ($\overline{\mathrm{X}}$), standard deviations (SD), standard error of the mean (SEM% = $\left[\left(\mathrm{SD}/\sqrt{n}\right)/\overline{\mathrm{X}}\right]\times 100$ where n = the number of samples), and coefficient of variations (CV% = SD/$\overline{\mathrm{X}}$ x 100) were calculated for all kinematic measures. True biological movement variability was calculated as BCV% = CV% - SEM% (Bradshaw *et al.*, in press). As this proposed calculation assumes that firstly, all of the data is normally distributed, the critical appraisal approach was used to determine if each golfers' data was normally distributed according to a set number of criteria following the recommendations of Peat and Barton (2005). Individual data that breached these criterions were excluded from further analysis. One-way analysis of variance (ANOVA) was used to identify the effect of skill level (skilled, unskilled) on golf swing kinematics and club-head velocity. Multiple stepwise linear regression analyses were employed to establish relationships between measures of BCV% and club-head velocity or club-head velocity BCV%. Statistical significance was set at $p < 0.05$ for all analyses.

RESULTS:

Skilled golfers had significantly greater club-head velocity (135.5 ± 3.7 vs 119.0 ± 6.6 km/hr) and target accuracy (86 vs 40%) but significantly less variability in club-head velocity (BCV% = 1.66 ± 0.53) than USG (BCV% = 2.53 ± 0.90%). Compared to USG, SG completed the backswing and total swing in significantly less time, had a greater (more extended) wrist angle and a more horizontal (flexed) trunk position at address as well as a greater (more extended) wrist and elbow angle at ball contact. Group means and variability measures are displayed in Table 1. Regression analysis revealed that the strongest predictive model (Equation 1) for club-head velocity included handicap and the wrist angle at address. Further, the best predictive linear model (Equation 2) for the variability in club-head velocity included handicap, body mass and the variability in the distance between the ball and the front foot at address. However, whilst this model provided some insight on potential causes of club-head velocity variability, the standard error of estimate of 10.59% indicated that this linear model was only moderately valid.

Equation 1: Club-Head Velocity (km/hr) = 270.454 – (0.796 x Handicap) – (778.756 x Wrist Angle at address).
[p = 0.003, r^2 = 0.818, SEE (km/hr) = 3.501, SEE (%) = 2.751].

Equation 2: Club-Head Velocity BCV (%) = (0.100 x Handicap) – (0.028 x Mass) – (0.275 x Ball Position with respect to front foot at address BCV %) + 4.625.
[p = 0.001, r^2 = 0.972, SEE (%) = 0.225, SEE (%) = 10.59]

Table 1. Group means, traditional coefficient of variation (CV %) and biological coefficient of variation (BCV %) measurements for selected kinematic variables.

	Skilled Golfers				Unskilled Golfers			
	Mean	SD	CV(%)	BCV(%)	Mean	SD	CV(%)	BCV(%)
Temporal								
Backswing time (s)	0.80*	0.12	3.4	2.3	1.04	0.25	5.1	3.5
Downswing time (s)	0.29	0.03	5.8	2.3	0.34	0.05	4.7	1.4
Total swing time (s)	1.07*	0.14	2.3	1.6	1.35	0.24	3.3	2.3
Ball Address								
Foot width (m)	0.51	0.06	2.0*	1.4*	0.55	0.05	2.7	1.9
Ball to lead foot (m)	0.19	0.03	4.4	3.0	0.23	0.05	6.0	4.1
Lead wrist angle (^{o})	172.2*	3.8	1.1	0.7	168.6	3.5	1.4	1.0
Trunk angle (^{o})	33.2*	4.0	2.3*	1.5*	24.1	5.5	5.8	4.0
Half Backswing								
Lead wrist angle (^{o})	98.7	10.6	2.6*	1.8*	96.5	30.7	6.8	4.6
Trail Forearm (^{o})	25.0	6.2	5.7*	3.9*	18.0	11.4	17.6	12.0
Top of Backswing								
Lead arm angle (^{o})	35.7	18.5	9.1	6.2	44.6	26.2	9.7	6.6
Trunk rotation (^{o})	99.3	10.8	2.3	1.5	100.5	19.3	3.0	2.1
Ball Contact								
Lead wrist angle (^{o})	175.3*	5.3	3.2	2.2	169.4	6.2	3.1	2.1
Lead elbow angle (^{o})	182.1*	4.6	1.8	1.2	174.5	9.0	1.7	1.1

* Significant ($p < 0.05$) between-group difference.

DISCUSSION:

A number of findings in the present study were expected. For example, it appears that the heightened performance (accuracy and velocity) of the SG than USG may reflect between-group differences in the mean durations of the swing phases (particularly the backswing) as well as trunk and upper limb positions and angles at ball address and ball contact (Hume *et al.*, 2005). Consistent with Fradkin et al. (2004), results of the first regression analysis indicated that handicap and club-head velocity are highly related in a homogeneous group of golfers. Further, the second regression analysis indicated that golfers with high handicap (i.e. USG) have more trial-to-trial variability in their club-head velocity than SG.

The SG had significantly less variability (for a number of variables) than USG at ball address and at the half-backswing position. Such a result appeared to be in contrast to that of DST where high levels of movement variability have been shown to be advantageous during locomotion and jumping tasks (Heiderscheit, 2000; Tillman *et al.*, 2005; Bradshaw *et al.*, in press). However, these results which implied the need to minimize variance at locations other than the critical point of ball contact, is consistent with the lay and scientific golf literature. It is apparent that many coaching books (and coaches) advocate or infer, that at certain points of the golf swing e.g. ball address and top of backswing that golfers need to adopt relatively invariant positions. This viewpoint also has some support from a recent review of the golf literature (Penner, 2003) where it was stated that the position of the club-head at the top of the backswing and its trajectory during the first 100 ms of the downswing were strong determinants of the remaining downswing trajectory and that of the nature of the contact with the ball. This high level of determinacy between the positions at the top of the backswing and early downswing to overall performance may reflect the fact that when the wrist begins to uncock (~100 ms into the downswing), the club-head passively and rapidly rotates around the wrist joint, thereby limiting the degree of active control of the club-head during this phase.

These findings also appear consistent with some of the views expressed by Knight (2004), who while advocating the DST approach as a tool for skills acquisition in golf, highlighted the fact that until more is known regarding what features of the golf swing are critical and require low variance, that not all coaching should be based on the DST model. Therefore, future studies in this area should examine the manner in which the trajectory of the club-head and relevant body segments change from swing to swing and how this affects performance. Such an approach will provide greater insight into which features are critical and require low variance compared to which variables are non-critical and can therefore be performed in a more flexible, variant manner and still maximize golf swing performance. Such information could augment the theoretical understanding of skill acquisition as well as improve golf coaching standards and playing performance throughout the world.

CONCLUSION:

Whilst DST states that high levels of variability in joint coordination patterns provide the performer with the adaptability and flexibility to perform a motor task successfully in a range of situations, SG exhibited lower levels of variability than USG at certain positions of the golf swing i.e. ball address and top of the backswing. This suggests that golfers need to exhibit relatively low levels of variance at these key positions if they wish to be consistently successful. However, as the manner in which the golfers obtained these positions was not evaluated in this study, future research should examine if this relative invariance in swing kinematics also requires a relatively invariant trajectory of the club-head and body segments.

REFERENCES:

Bradshaw, E. J., and Aisbett, B. (2006). Visual guidance during competition performance and run-through training in long jumping. *Sports Biomechanics,* 5, 1-14.

Bradshaw, E. J., Maulder, P. S., and Keogh, J. W. L. (in press). Movement coordination and biological variability during the sprint start: performance enhancement or hindrance? *Sport Biomechanics,*

Farrally, M. R., Cochran, A. J., Crews, D. J., Hurdzan, M. J., Price, R. J., Snow, J. T., and Thomas, P. R. (2003). Golf science research at the beginning of the twenty-first century. *Journal of Sport Sciences,* 21, 753-765.

Fradkin, A. J., Sherman, C. A., and Finch, C. F. (2004). How well does club head speed correlate with golf handicaps? *Journal of Science and Medicine in Sport,* 7, 465-472.

Heiderscheit, B. C. (2000). Movement variability as a clinical measure for locomotion. *Journal of Applied Biomechanics,* 16, 419-427.

Hume, P. A., Keogh, J., and Reid, D. (2005). The role of biomechanics in maximising distance and accuracy of golf shots. *Sports Medicine,* 35, 429-449.

Knight, C. A. (2004). Neuromotor issues in the learning and control of golf skill. *Research Quarterly for Exercise and Sport,* 75, 9-15.

Peat, J., and Barton, B. (2005). *Medical statistics: A guide to data analysis and critical appraisal*. Carlton: Blackwell Publishing.

Penner, A. R. (2003). The physics of golf. *Reports on Progress in Physics,* 66, 131-171.

Rodano, R., and Squadrone, R. (2002). Stability of selected lower limb joint kinetic parameters during vertical jump. *Journal of Applied Biomechanics,* 18, 83-89.

Tillman, M. D., Hass, C. J., Chow, J. W., and Brunt, D. (2005). Lower extremity coupling parameters during locomotion and landings. *Journal of Applied Biomechanics,* 21, 359-370.

Wiren, G. (1990). Laws, principles and preferences - a teaching model. In A. J. Cochran (Ed.), *Science and Golf I: Proceedings of the First World Scientific Congress of Golf* (pp. 3-13). London: E & FN Spon.