CONTRIBUTIONS TO CLUB VELOCITY IN GOLF SWINGS TO SUBMAXIMAL AND MAXIMAL SHOT DISTANCES

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The contribution of joint rotations to endpoint velocity was investigated in golf shots to submaximal and maximal shot distances using a 41degrees of freedom (DOF) kinematic model. A subset of 16 DOFs was found to explain 97%-99% of endpoint velocity regulation at club–ball contact. The largest contributors, for both groups at every shot condition, were pelvis and torso twist rotation among the most proximal DOFs, elbow pronation/supination and wrist flexion/extension among DOFs in the left arm, and shoulder internal/external rotation and wrist flexion/extension among DOFs in the right arm. The contributions from pelvis obliquity, left wrist flexion/extension, left wrist ulnar/radial deviation and right shoulder flexion/extension differed significantly between the advanced and intermediate group.

KEY WORDS: golf, joint contributions, speed-regulation.

INTRODUCTION: The control of endpoint movement in a variety of single-limb multijoint coordination tasks, have received much attention in the literature. In throwing and striking tasks, a precise control of endpoint velocity at ball release or impact is essential for performance. Study of the contributions from various joint rotations to endpoint velocity has provided some insight into this control, in single-limb tasks such as the overarm throw and the tennis serve (Gordon & Dapena, 2006; Hirashima, Kudo, Watarai, & Ohtsuki, 2007). In a multijoint bimanual striking task, where the coupling of the hands requires not only intra-limb coordination but also inter-limb coordination, we may expect kinematics to differ in important ways. Golf, which for the absolute majority of players is a bimanual multijoint striking task, has generally been analyzed as a single-limb task ignoring the right arm.
The purpose here was to assess the contributions to endpoint velocity from pelvis, the trunk and two bilateral open kinematic chains corresponding to the left and right arm, in golf swings to submaximal and maximal shot distances.

METHODS: A total of 20 right handed golf players volunteered to take part in the study, 10 male tournament professionals (age 29 ±6 y, 1.81 ±0.06 m, 80 ±5 kg), and 10 male amateurs (30 ±9 y, 1.83 ±0.06 m, 77 ±7 kg, handicap 21 ±5 strokes). The individuals in these two groups are hereafter referred to as advanced and intermediate players, respectively.
They performed 3 golf shots with a wedge at each of 3 test conditions: (1) partial shots to a target located at a distance of 25m; (2) partial shots to a target located at a distance of 55m; and (3) full-swing shots in the same direction for maximal distance. Test condition 1, 2 and 3 is hereafter referred to as slow, medium and fast test condition, respectively.
Spatiotemporal data of pelvis, upper torso, upper arms, hands and club were collected with an electromagnetic motion capture system (Polhemus Liberty) at 120 Hz. 26 virtual landmarks were digitized in order to define segment lengths, orientation of local frames and joint axes. A model consisting of pelvis, the trunk and two bilateral open kinematic chains corresponding to the left and right arm was used. Each chain consisted of upper arm, forearm, hand and club segments. The model was constrained to 41 DOFs (6DOF pelvis-lab,

3DOF trunk-pelvis, 6DOF shoulder joints, 2DOF elbow joints, 2DOF wrist joints, and 6DOF club-hand).
The state of the model is the set of angular/linear joint positions and corresponding velocities. The state was estimated from motion data using a fixed- interval smoothing extended Kalman filter (Anderson & Moore, 1979; Halvorsen, Johnston, Back, Stokes, & Lanshammar, 2008). The contribution from each joint angular/linear velocity to the velocity of the endpoint (the club-head) was calculated as follows. At each sampled instance of time, the contribution from the angular velocity of a given degree of freedom was calculated assuming the rest of the joints in the kinematic model to be momentarily fixed. The single remaining angular velocity gives a certain velocity at the endpoint. Adding these endpoint velocities contributed from all the degrees of freedom sums up to the actual velocity of the endpoint. Differences in contributions from each DOF at estimated impact (club–ball contact) were analyzed in separate repeated-measures ANOVAs with test condition as within-subject factor. To reveal differences between advanced and intermediate players, group was used as between-subject factor. Pair-wise comparisons were conducted using Tukey HSD tests. Significance level was set at $p<0.05$.

RESULTS: The endpoint velocity for the 41 DOF model at impact were 14.7 ±1.7, 21.6 ±1.9 and 30.0 ±2.5 m/s for the slow, medium and fast test condition, respectively. For a subset of 16 DOFs, repeated-measures ANOVAs showed a main effect of test condition on contributions to endpoint velocity. These 16 DOFs are listed together with their corresponding contributions at estimated impact in Table 1. The contributions from this subset of 16 DOFs ranged between 97% and 99% of the mean change in endpoint velocities between test conditions.

Table 1: Mean ±SD contributions to endpoint linear velocity (m/s) for each of 16 DOFs and for each of 3 test conditions at estimated impact. Values for both groups are combined (n=20). Bold text refers to an interaction between test condition and group.

	Test condition		
DOF	Slow	Medium	Fast
Pelvis mediolateral tilt	**1.0 ±0.6**	**1.4 ±0.9**	**1.8 ±1.3**
Pelvis twist rotation	1.7 ±0.7	2.5 ±1.0	3.5 ±1.2
Trunk twist rotation	3.3 ±1.0	4.6 ±1.6	5.5 ±2.8
L Shoulder flexion/extension	0.6 ±0.6	1.1 ±0.9	1.8 ±1.2
L Shoulder abduction/adduction	-0.4 ±0.9	-0.3 ±1.4	0.9 ±2.2
L Shoulder external rotation	1.2 ±0.9	1.9 ±1.2	2.7 ±1.4
L Elbow pronation/supination	2.7 ±0.8	4.4 ±1.4	5.2 ±1.7
L Wrist flexion/extension	**2.3 ±0.9**	**2.9 ±1.1**	**3.8 ±1.4**
L Wrist ulnar/radial deviation	**0.3 ±0.4**	**0.4 ±0.7**	**0.9 ±1.1**
L Grip yaw	0.9 ±0.6	1.6 ±0.6	2.6 ±0.9
R Shoulder flexion/extension	**0.4 ±0.4**	**0.6 ±0.6**	**1.1 ±0.8**
R Shoulder abduction/adduction	0.8 ±0.9	1.3 ±1.5	1.8 ±2.1
R Shoulder internal rotation	2.7 ±1.0	5.2 ±1.7	8.7 ±2.7
R Elbow flexion/extension	-0.9 ±0.6	-1.5 ±1.0	-2.0 ±1.6
R Wrist flexion/extension	2.9 ±1.3	4.5 ±1.8	6.8 ±2.8
R Wrist ulnar/radial deviation	0.2 ±0.7	0.4 ±1.1	0.9 ±1.6

An interaction effect between test condition and group was revealed in 4 DOFs: pelvis mediolateral tilt; left wrist flexion/extension; left wrist ulnar/radial deviation; and right shoulder flexion/extension (denoted with bold text in Table 1). For pelvis mediolateral tilt and left wrist flexion/extension, pair-wise comparisons revealed significant differences between test conditions only for the intermediate group ($p<0.05$). In contrast, for left wrist ulnar/radial deviation and right shoulder flexion/extension, pair-wise comparisons revealed significant differences between test conditions only for the advanced group ($p<0.05$).

DISCUSSION: In this study, we investigated the contribution to endpoint velocity from the pelvis, trunk and two bilateral open kinematic chains corresponding to the left and right arm, in both advanced and intermediate golf swings to submaximal and maximal shot distances. The results for both groups combined, showed that a major part of endpoint velocity regulation at impact can be explained by the scaling of a subset of 16 DOFs. The role of the remaining DOFs might be to fulfil task goals other than those related to club velocity regulation.

The largest contributors among the most proximal DOFs are pelvis and torso twist rotation. Among DOFs in the left arm, elbow pronation/supination and wrist flexion/extension contributed the most, whereas the shoulder internal/external rotation and wrist flexion/extension contributed the most among DOFs in the right arm. Interestingly, the right elbow extension gives a negative contribution to endpoint velocity at both submaximal and maximal shot distances. This appears at first glance to be suboptimal. In single-limb multijoint coordination tasks such as the overarm throw and the tennis serve (Gordon & Dapena, 2006; Hirashima, et al., 2007). right elbow extension is a major contributor to endpoint velocity. Possibly, as a consequence of the two-handed grip and the mechanical coupling of the arms, right elbow extension plays a different role in golf. Comparing our results with the contributions to endpoint velocity in skilled golf players that use only one arm due to disability, may give further insight into the control of two-handed striking tasks.

The results also revealed differences in contributions between advanced and intermediate players. The finding that contributions from left wrist flexion/extension did not differ between test conditions in the advanced group was somewhat surprising. This indicates a higher percentage contribution from the left wrist flexion/extension in partial shots than in full-swing shots. Considering the request for precise control of submaximal endpoint velocity in the slow and medium speed conditions, the opposite could be expected.

CONCLUSION: Results indicate that a major part of endpoint velocity regulation can be explained by the scaling of a small set of contributing DOFs. However, the individual DOFs included in this set differ with skill level.

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