SCIENCE AND GOLF V
Proceedings of the World Scientific Congress of Golf

Edited by
Debbie Crews, PhD and
Rafer Lutz, PhD

CHAPTER 4
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Comparison of Kinematic Sequence Parameters between Amateur and Professional Golfers

Phillip J. Cheetham, Advanced Motion Measurement, Inc.
Greg A. Rose, Titleist Performance Institute
Richard N. Hinrichs, Arizona State University
Robert J. Neal, Golf BioDynamics, Inc.
Robert E. Mottram, Golf Health and Performance Center
Paul D. Hurrion, Quintic Consultancy Ltd.
Peter F. Vint, United States Olympic Committee

ABSTRACT

The purpose of this study was to compare key magnitude and timing parameters of the kinematic sequence between amateur recreational players (amateurs) and PGA touring professionals (pros). It was hypothesized that the key magnitude parameters would be significantly higher in the pros than the amateurs, and that the key timing parameters would be significantly different between the two groups. A representative swing from each of 19 amateurs and 19 pros was captured using three-dimensional (3D) motion analysis techniques. Eighteen key kinematic sequence performance variables that occur during the downswing were computed from the data. Student t-test's were used to compare the group means for each parameter with an experiment-wise level of significance set at $p<0.2$, and a corresponding test-wise significance of $p<0.011$. All the magnitude variables including rotational accelerations; rotational decelerations, (except pelvis); peak rotational speeds; rotational speed gains; and linear club head speed at impact, showed a significant difference between the amateurs and pros, with the pros having greater values in every case. Although the pelvis rotational deceleration did not show a significant difference between groups, every pro did show a slowing of the pelvis before impact; not so with the amateurs. The mean of the peak times showed no significant difference between the pros and amateurs, but the standard deviations of the means for the amateurs were at least double those for the pros in each case. It was also found that the peaking order of the body segment speeds, determined from the mean timing variables, was pelvis, thorax, then arm; whereas for the amateurs it was pelvis, arm, then thorax.

Keywords: golf, swing, kinematic, sequence, rotational, speed

INTRODUCTION

A good drive in golf requires high club head speed and accurate ball contact. During the swing the golfer forms an open kinetic chain with the feet at the closed end, the club head at the open end and several body segments in between. Achieving the highest club head speed at impact is a consequence of the appropriate movements of all the segments in this chain. The sequence and timing of the body segment motions, from the larger proximal segments to the smaller distal segments, can affect both the forces applied and the distance over which these forces act (Milburn, 1982) and are therefore important in producing high club head speed. As a general principle of biomechanics, the proximal to distal sequencing has been described under several different names. Bunn (1972) described it as the "summation of speed principle". He stated that the speed of each segment should be faster than that of its predecessor. Kreighbaum and Barthels (1985) called the principle the "kinetic link" principle. They stated that the small distal segment could be made to travel fast by the sequential acceleration and deceleration of the segments. The first description of this proximal to distal sequencing in golf was by Cochran and Stobbs in 1968. They described the downswing sequence with a model using three consecutively smaller disks on a single axis connected with springs. They suggested that each spring should release on the downswing when the previous spring has imparted its energy to the system. Several recent golf studies have found evidence of proximal to distal sequencing including Sprigings and Neal (2000); Koegler (2004); and Neal (2007). There are several ways to display this sequencing such as using joint angular velocities or joint torques (Putnam, 1993), but when segmental angular velocity components are used it has been termed the "kinematic sequence" (AIM-3D Golf Manual, 2003).

Many golf instructors and fitness professionals currently use 3D analysis and the kinematic sequence to design swing and exercise training programs. Although these professionals are passionate about the value of this methodology, no research has shown that differences in the kinematic sequence parameters truly exist between amateurs and pros. The purpose of this study was therefore to compare key magnitude and timing parameters of the kinematic sequence between amateur recreational players and PGA touring professionals. It was hypothesized that the key magnitude parameters would be significantly higher in the pros than the amateurs, and that the key timing parameters would be significantly different also.

METHODS

A representative swing from each of 19 amateur and 19 professionals was chosen for this study from the swing database of the Titleist Performance Institute (Oceanside, California). A human subject exemption was obtained from the Institutional Review Board at Arizona State University because previously collected data from willing participants were used with no participant identification made public. The amateurs were chosen based upon having relatively slow swing speeds (mean club head speed of 88 mph) and the professionals chosen with "tour quality" swing speeds (mean club head speed of 109 mph). This choice was hypothesized to give a good differentiation between the swings of each group. The hardware used for 3D swing capture was a 240Hz, six-degree-of-freedom, 12-sensor electromagnetic Liberty system produced by Polhemus Inc, (Colchester, Vermont) and the software was the TPI-3D golf swing analysis system developed by Advanced Motion Measurement, Inc. (Phoenix, Arizona). The twelve sensors were attached strategically to create an accurate full-body model of the golfer. The main sensors of interest in this study were the pelvis sensor, which was attached to the sacrum by a stretch Velcro strap; the thorax sensor, which was attached at T3 using a chest harness; the lead upper arm sensor, which was attached on the posterior, distal aspect of the humerus using a stretch Velcro strap; and the club sensor which was attached securely just below the grip. Standard biomechanical modeling procedures were used to transform the sensors into "virtual sensors" at body joint centers aligned with the anatomical axes of the segment. The pelvis and thorax angular velocity vectors were computed and resolved into each local segment coordinate system. The component around the superior-inferior axis of pelvis and thorax was used to represent the rotational speed of each of these two segments. The lead upper arm was used as the third link in the sequence because of its direct attachment to the thorax and importance in the downswing. The arm and club rotate about an end point rather than a center point; hence the angular velocity component around a normal to the instantaneous swing plane was used for these two segments. No digital filtering was applied during the calculations because the electromagnetic hardware produced very clean position and orientation signals and inappropriate smoothing has been shown to distort the timing and amplitude of peaks especially near impact (Winter, 1979).

Eighteen key kinematic sequence performance variables that occur during the downswing were computed from the data, they were average rotational acceleration of pelvis, thorax, arm and club; average rotational deceleration of pelvis, thorax and arm; peak rotational speed of pelvis, thorax, arm and club; rotational speed gains from pelvis to thorax, thorax to arm, and arm to club; timing of the peak rotational speeds of pelvis, thorax and arm with respect to impact; and projected club head resultant linear speed at impact. Student's t-tests were used to detect significant differences between the pros and amateurs on these 18 performance variables. The experiment-wise level of significance was set at 0.2, and using the Bonferroni correction for multiple tests, this level gives a test-wise significance level of 0.011. These significance levels were chosen in order to balance the risks of making Type 1 and Type 2 errors.

RESULTS

Figure 1 shows the downswing phase of the kinematic sequence from one of the pros tested. The time axis starts at top of backswing and finishes at impact. The curves show the rotational speed of the pelvis, thorax, lead upper arm and club shaft. The images above the graph show the position of the golfer at each peak value.

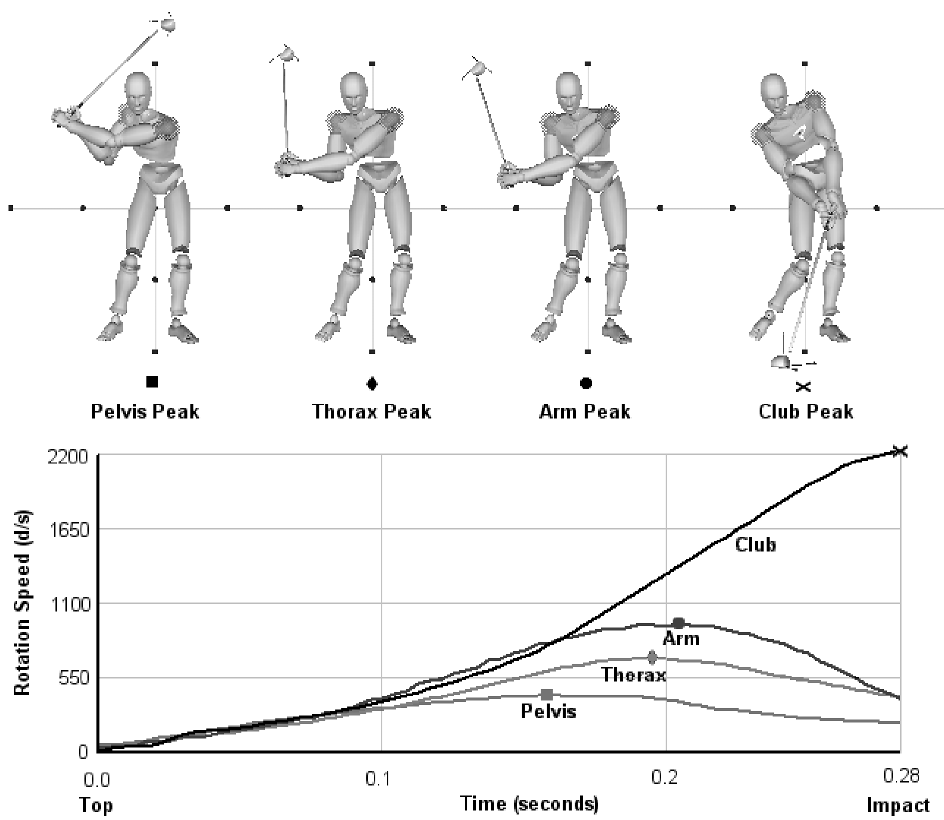

Figure 1 Segmental rotational speeds in the downswing with peak locations indicated

The resulting kinematic sequence statistics are presented in Table 1. As hypothesized, all average rotational accelerations and decelerations (with the exception of the pelvis); maximum rotational speeds; and rotational speed gains showed a significant difference between the amateurs and pros at the chosen level of significance; the pros having greater values in every case. The means of pelvis average rotational deceleration, contrary to our hypothesis, showed no significant difference between pros and amateurs at this significance level, but the pros did show a larger mean pelvis deceleration value than the amateurs. The means for the time of peak rotational speed before impact, contrary to our hypothesis, showed no significant difference between the pros and amateurs, but interestingly the standard deviations of the means of the amateurs were at least double those of the pros in each case. Finally, the linear club head speed mean value for the pros was significantly larger than that for the amateurs.

Table 1 Kinematic sequence statistics

Parameter	Segment	Units	Pros		Amateurs		T Test
			Mean	SD	Mean	SD	
Average Rotational Acceleration	Pelvis	kd/s^2	2.1	0.4	1.5	0.4	0.000 *
	Thorax	kd/s^2	3.3	0.5	2.3	0.5	0.000 *
	Arm	kd/s^2	5.1	0.8	3.3	0.9	0.000 *
	Club	kd/s^2	8.8	1.1	6.0	1.1	0.000 *
Average Rotational Deceleration	Pelvis	kd/s^2	2.0	0.7	1.6	1.0	0.026
	Thorax	kd/s^2	2.6	1.1	1.6	1.1	0.007 *
	Arm	kd/s^2	7.0	1.2	3.0	1.5	0.000 *
Maximum Rotational Speed	Pelvis	d/s	477	53	395	68	0.000 *
	Thorax	d/s	727	61	583	84	0.000 *
	Arm	d/s	980	68	763	95	0.000 *
	Club	d/s	2254	68	1790	111	0.000 *
Rotational Speed Gain	Pelvis to Thorax	d/s	250	42	188	72	0.003 *
	Thorax to Arm	d/s	253	59	185	76	0.005 *
	Arm to Club	d/s	1274	65	1027	147	0.000 *
Time of Peak Rotational Speed before Impact	Pelvis	ms	87	19	78	38	0.124
	Thorax	ms	68	14	59	29	0.147
	Arm	ms	65	8	64	23	0.821
Linear Speed at Impact	Club Head	mph	109	3	88	5	0.000 *

Note. * indicates significant difference between means at an experiment-wise $p<0.2$ (and test-wise $p< 0.011$). kd/s^2 is thousands of degrees per second squared.

DISCUSSION

For best energy transfer and maximum club head speed in the downswing, the theory of proximal to distal sequencing (Putnam, 1993) requires several attributes to be evident in a golfer's kinematic sequence; all segments should accelerate then decelerate before impact (except the club which should peak exactly at impact); the peaking order should be pelvis, thorax, arm, club; and each peak should be larger and later than the previous one. Figure 1 exemplifies these traits.

Practitioners that use graphs of this type in their analysis of swing efficiency have intuitively known that good speed and acceleration values for the larger proximal body segments are very important. They believe that high club head speed should be generated by the whole body and not just the arms and wrists. This study proves this to be the case, certainly when comparing slower amateur swings to faster pro swings. In fact all the magnitude parameters tested, except pelvis deceleration proved to be significantly larger in the pros than the amateurs. Although pelvis deceleration did not show a significant difference between groups, the mean value was larger for the pros than the amateurs and pelvis deceleration prior to impact was evident in every pro swing but not in every amateur swing. This suggests that pelvis deceleration before impact is still a desirable trait of a fast swing.

It may at first be surprising that there was no significant difference in the means for the timing variables, however on closer examination the main difference lies in the size of the standard deviations. The large values for the amateurs suggest that the amateurs are very inconsistent in their timing. The pros however are all clustered more tightly around their mean, suggesting that as a group they tend to have more similar timing profiles than the amateurs. This suggests that consistent timing of the sequence peaks is very important in a fast swing. As previously stated proximal to distal sequencing theory suggests that this sequence should be pelvis, thorax, arm and club; the data of the pros support this theory. The fact that, for the amateurs, the mean arm peak time is before the mean thorax peak time suggests that they tend to use their arms earlier in the downswing than the pros. Generally speaking the results show that the amateurs tend to have poorer coordination, weaker power production, and inefficient energy transfer from segment to segment than the pros.

APPLICATION

The use of 3D motion analysis provides the ability to look at dynamics that the naked-eye can not see. A good instructor can see positional aspects of the swing at stationary points such as address and top of backswing, but 3D analysis allows the instructor to critically review timing, speed and acceleration variations in all parts of the swing that would otherwise not be seen.

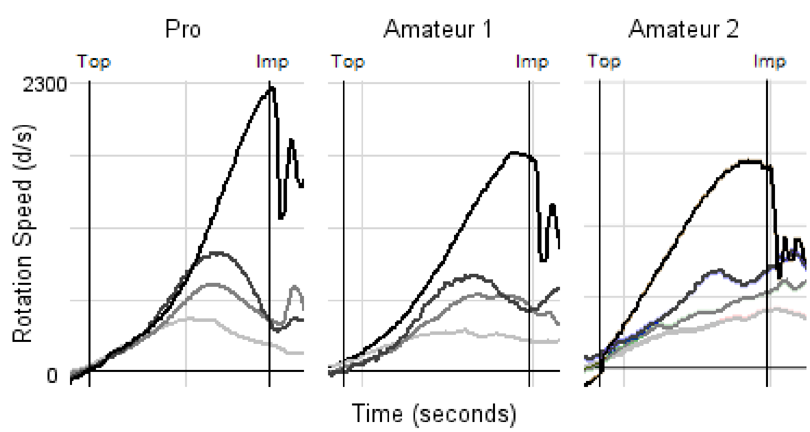

Figure 2 Three example downswing sequences

Note. Curves from bottom to top are pelvis, thorax, lead arm and club

On reviewing Figure 2 it can be seen that the Pro graph shows smooth accelerations and decelerations, each curve peaking higher and later than the previous one, with the club peaking at impact. The Amateur 1 graph shows poorer accelerations and decelerations, lower speeds and the arm peaks before the thorax. The Amateur 2 graph shows no overall decelerations of the pelvis and thorax before impact. Both amateurs cast the club; it races ahead of the body segments, peaks too soon and decelerates slightly before impact. The pro does not cast the club; the arm and the club track each other very closely until the club races ahead at the wrist release point later in the downswing.

When combined with physical screening, this 3D analysis technique allows the instructor and fitness trainer to design training programs based specifically on the physical characteristics of the individual golfer. The swing instructor can design more focused swing drills and the fitness trainer can design specific strength and power development exercises.

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