Original Article

Movement's analysis and weight transfer during the golf swing

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Abstract:

Golf swing is one of the most complicated of sport motions. The purpose of this study was complex evaluation of the golf swing, intra-individual stability of performance and relational analysis of selected parameters. To measure the kinematics of the golf swing we used 3D kinematic analyzer CODA Motion System and to measure weight transfer we used two force plates KISTLER. We evaluated selected spatial parameters of body motion and selected action force parameters (separately for left and right lower extremity). The golf swing was evaluated in eight separate events specified according to the golf club position. High intraindividual and interindividual performance stability was found during downswing phase of the golf swing in elite golf player's sample. Interindividual variability during backswing phase was higher which indicated different timing of the swing between the players. High relation between golf club velocity and weight transfer was found and indicated that subjects (elite golf players) used weight transfer toward the target throughout the swing to produce extra energy to the ball. However, differences between subjects were found in weight transfer strategy during the golf swing and are related to the golf club speed.

Key words: sport motion, biomechanics, golf players, force platform

Introduction

Golf is one of the most popular sports in the world and one of the most dynamically developing sports in Czech Republic and Central Europe. Golf swing is very complicated motion requiring coordination of all body segments and therefore is one of the most complex of sport motions (Dillman & Lange, 1994). Full golf swing is described by Wiren (1990) as motion, involving a strong rotary action of the body, producing force that is transmitted through the arms, hands and clubshaft outwardly to the clubhead and finally to the ball. Good timing of rotation movement of the shoulders and hips with correct weight transfer is the key to generate power in impact, which is indicated by club head velocity (Meister et al., 2006). Correct movement of body segments especially of the shoulders and hips in separate phases of the golf swing is very important for the effective golf swing technique. The player efforts to reach correct position of the body and the club during the backswing and in the top of the backswing to reach maximum club head velocity at impact (Adlington, 1996; Hume, Keogh, & Reid, 2005). Absolute and relative shoulders and hips rotation, where shoulders rotates more than the hips during the back swing were found important in many studies (Cochran & Stobbs, 1996; Hume et al., 2005; Cheetham, Martin, Mottram, & Laurent, 2000; McLean, 1992; Zheng, Barrentine, Fleisig, & Andrews, 2008). The angle difference between shoulders and hips is called the X-factor and was found higher at professional golfers and in players with high ball speed (McLean, 1992; Myers et al., 2008). Rotation movement during the swing is associated with weight transfer, which is a coaching term usually used to describe movement of weight between the feet (Ball & Best, 2007). It is known, that weight transfer has a great effect on success of the golf shot. It affects the angle of approach, club head address in impact and if done well gives energy to the ball (Wiren, 1990). Leadbetter (1995) describes the weight transfer during the golf swing as weight evenly balanced between the feet at address, moving towards the back foot during backswing. Just before the start of downswing, weight begins to move towards the front foot, rapidly in the early downswing phase, continuing through to the front foot at ball contact and at follow-through. In studies of the full golf swing there are usually a long iron or driver used for kinematic and or weight transfer analyses (Ball & Best, 2007; Egret, Vincent, Weber, Dujardin, & Chollet, 2003; Keogh et al., 2007; Nesbit & McGinnis, 2009), but there are no studies using middle iron. Also, there is no study describing the golf swing in both backswing and downswing phase using terms of kinetic and kinematic parameters of one elite player. The aim of the study was complex evaluation of the golf swing, intra-individual and inter-individual stability of performance and relational analysis of selected parameters in elite golf players and separately one of them.

Material & methods

Participants Four right handed male elite golf players (aged 29 ± 8 years; height 1.84 ± 0.06 m; weight 69.5 ± 10.7 kg) performed 20 golf shots with their own iron 7, hitting golf balls from synthetic grass (pro-turf artificial grass); commonly used in driving ranges; into the net placed 3.5 m away.

Methods of data collecting and processing

For statistical assessment, the 10 fastest attempts in ball contact event were used. Golfers placed each foot on separate force plates KISTLER, which were built-in in the floor. Evaluation of movement of the golfer's body and the golf club was realized by three dimensional analysis (Allard, Stokes, & Blanchi, 1995). The force plates were synchronously connected with a 3D kinematic analyzer CODA Motion System (Charmwood Dynamics Limited, Leicestershire, England). For each swing, force and kinematic data were sampled at 200 Hz. Active markers were placed on the selected points of the golfer's body and on the golf club.

The segment model of the golfer's body was constructed from markers placed on ankles, knees, hips, shoulders, elbows, wrists and head. Golf club markers were placed on the shaft (the first one near the grip and the second one 0.1 m above leading edge). Body markers were placed on the skin on the places which represented centers of joints rotation. To evaluate the positions of selected segments of the body we specified shoulders position as the connecting line between left and right shoulder markers, hips position as the connecting line between left and right hip markers, left upper limb position as the connecting line between the left shoulder marker and left wrist marker, golf club position as the connecting line between the two shaft markers and lower limbs (left and right) position as the connecting line between the ankle and knee markers and knee and hip markers. During the golf swing performance eight critical events were specified according to the golf club position (Fig. 1): Set-up (1), Mid Backswing (2), Late Backswing (3), Top of backswing (4), Early downswing (5), Mid Downswing (6), Impact - Ball contact (7); Follow through (8). Interindividual and intraindividual stability of performance were evaluated in eight critical events of the golf swing mentioned above as variation of movement in selected segments of the body, golf club velocity and weight transfer. Parameters evaluated in this study: angle of shoulders and target line - plane XZ (S XZ), angle of shoulders and ground - plane XY (S XY), angle of hips and target line - plane XZ (H XZ), angle of hips and ground - plane XY (H XY), angle between shoulders and hips also called as X-Factor (S - H), angle of shoulders and left upper limb (S - LU), angle of left upper limb and golf club (LU - GC), angle of the right knee (RK), angle of the left knee (LK), vertical head movement (HM), relative force acting under right lower limb (RF), relative force acting under left lower limb (LF), golf club velocity (GCV). Speed of the marker placed on the shaft 0.1m above leading edge is used to describe GCV. Relative left foot force action is used in this study to describe weight transfer. RF and LF parameters were calculated as vertical force under the foot divided by player's weight.

Fig. 1. Golf swing events and axis system used in the study

To determine relation between measured variables and golf club velocity the golf swing was divided into Backswing phase specified as golf club movement between events 1 to 4 (Fig. 2) and Downswing phase specified as golf club movement between events 4 to 7 (Fig. 3) and golf swing specified as golf club movement between events 1 to 7.

Fig. 2. Frames during Backswing phase (events 1-4) with highlighted top of the backswing (event 4)

Fig. 3. Frames during Downswing phase (events 4-7) with highlighted Impact - Ball contact (event 7)

For evaluating intraindividual stability of the golf swing coefficient of variation [1] and confidence interval with probability 95% (CI₉₅) were used.

$$[CV(\%) = \frac{\sigma}{\mu} \cdot 100] \quad [1]$$

To determine relation between golf club velocity and measured variables Pearson's correlation coefficient was used. Significance was assessed at risk $p < .01$. Correlation size was evaluated: $r = 0 - .40$ small, $r = .41 - .80$ medium, $r = .81 - 1.0$ high.

Results

To describe the golf swing we used quantitative parameters measured during single golf swing of the best placed professional player (Player 1) in Czech Republic players ranking.

Event 1: Golf club starts backswing movement. Values shows close position (aims right from target) of shoulders (S HZ = -6.13°) and hips (H HZ = -3.74°) and the weight is distributed slightly to the right lower limb (RF = 0.58, LF = 0.42).

Event 2: Golf club is horizontal to the ground. Shoulders movement (S XZ) between events 1 and 2 changed to -38.44° and hips (H XZ) to -9.27°. The S – H parameter changed between events 1 and 2 from 2.39° to 29.16°. Weight is transferred to the right lower limb (RF = 0.79, LF = 0.32).

Event 3: Golf club is perpendicular to the ground. Rotation movement to backswing continued in shoulders (S XZ = -65.49°) and hips (H XZ = -34.84°). Between events 1 and 3, the angle between shoulders and hips is nearly constant (S – H = 30.65°), the LU – GC changed from 134.78° to 93.54° and the right lower limb bent from RK = 154.01° to RK = 151.05° and the left lower limb bent from LK = 156.32° to LK = 147.3°. Weight continuously transfers to the right lower limb (RF = 0.90, LF = 0.16).

Event 4: Determinate by the lowest golf club (shaft marker) speed in backswing (GCV = 0.128 m/s). In top of backswing club movement to the ball starts. The hips start a fast rotation to downswing (H XZ = -33.7°) and weight transfer starts to the left lower limb (RF = 0.56 LF = 0.30). The lower limbs bend (RK = 149.47°, LK = 142.22°). Shoulders rotation is at the maximum (S XZ = -87.69°). The X-factor is at the maximum (S – H = 53.99°). The angle between the left upper limb and the golf club changed to LU – GC = 47.56° and the angle between the shoulders and the left upper limb changed between events 1 to 4 from S – LU = 70.99° to S – LU = 35.74°. When the turning of the shoulders goes beyond (backswing) the rotation of the trunk and swinging of the arms carries past the turn of shoulders (followed by club), there is a full stretch in various muscle groups to generate power and high golf club speed. The player's head vertical position changed between events 1 (HM = 1430 mm) to 4 (HM = 1469 mm).

Event 5: The golf club is perpendicular to the ground. Weight is transferred to the left lower limb (RF = 0.49, LF = 0.59) and the lower limbs bend (RK = 143.17°, LK = 141.33°). The hips continue in rotation movement to downswing (H XZ = 1.88°), followed by the shoulders (S XZ = -39.65°), arms and club. The X-factor decreased (S – H = 41.52°). The parameter S – LU = 50.29° and LU – GC = 72.57° changed by following the shoulders rotation. The head vertical position is lower (HM = 1418 mm) following bending of the legs and the hips forward rotation. Golf club start to accelerate (GCV = 15.519 m/s).

Event 6: The golf club is horizontal to the ground. Weight is transferred to the left lower limb (RF = 0.43, LF = 1.09). The right lower limb starts stretching (RK = 149.47°) immediately followed by the left lower limb (LK = 145.98°). The hips continue in rotation movement (H XZ = 36.54°) followed by the shoulders (S XZ = -14.34°). The X factor increase (S – H = 50.88°). The parameter S – LU = 61.03° and parameter LU – GC = 111.71° changed because the arms carry out past-the-shoulders-turn. Head position stays nearly the same (HM = 1413 mm). The golf club continues increases velocity (GCV = 24.528 m/s).

Event 7: Determinate as the contact of the club head with the ball (impact). The weight is fully transferred to the front foot (RF = 0.39, LF = 1.41). The left lower limb continues stretch (LK = 150.25°), the right heel lose the contact with the pad and the right lower limb is bent (RK = 143.13°). The hips continue rotation movement (H XZ = 36.54°) followed by the shoulders (S XZ = 5.01°) aiming right (open position) from the target line. The X-factor energy was released to acceleration of shoulders (S – H = 34.46°). The parameter S – LU = 67.68° and parameter LU – GC = 146.39° changed during golf club acceleration to impact. Head vertical position stays nearly the same (HM = 1411 mm). The golf club velocity is at the maximum (GCV = 26.292 m/s).

Event 8: The golf club is horizontal to the ground. The weight is still on the front foot (RK = 0.30, LF = 0.91). The left lower limb continues to stretch (LK = 155.08°) and the right lower limb to bend (RK = 137.88°) following hips rotation with only the right tiptoe touching the ground. The hips (H XZ = 59.12°) and shoulders (S XZ = 40.3°) continue rotation movement to the target. The head vertical position is 1408 mm. The golf club velocity decreases (GCV = 20.942 m/s).

Table 1. Correlation between golf club velocity and observed parameters of Player 1

Player 1			HM	S XZ	S XY	H XZ	H XY	S - H	S - LU	LU - GC	RK	LK	RF	LF
Backswing	GCV	Pearson Correlation	.387	.201	.015	.280	.062	.121	.156	.154	.288	.154	.951	.847
		Sig. (2-tailed)	.020	.239	.930	.098	.720	.481	.363	.370	.088	.370	.000	.000
Downswing	GCV	Pearson Correlation	-.957	.988	.992	.988	.935	.556	-.980	.920	.301	-.756	-.600	.921
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.074	.000	.000	.000
Golf swing	GCV	Pearson Correlation	-.722	.557	.621	.797	.790	-.273	-.374	.351	.574	.004	-.454	.835
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.020	.001	.002	.000	.974	.000	.000

Note: GCV – golf club velocity

Results of the relation between the club head velocity and the measured variables of Player 1 are presented in Table 1. High correlations between parameters GCV and RF ($r = .951, p < .01$) and LF ($r = -.847, p < .01$) were found during the backswing phase. High correlations between parameter GCV and movement parameters of selected body segments (S XZ: $r = .988, p < .01$; S XY: $r = .992, p < .01$; H XZ: $r = .988, p < .01$; H XY: $r = .935, p < .01$; S - LU: $r = .980, p < .01$; LU - GC: $r = .920, p < .01$), HM ($r = -.957, p < .01$), and LF ($r = .921, p < .01$) were found during the downswing phase. During the golf swing, medium correlation between parameter GCV and hips movement parameters (H XZ: $r = .797, p < .01$; H XY: $r = .790, p < .01$) and high correlation between parameters GCV and LF ($r = .835, p < .01$) were found.

Table 2. Correlation between golf club velocity and observed parameters in research group (n = 4)

Group (n = 4)			HM	S XZ	S XY	H XZ	H XY	S - H	S - LU	LU - GC	RK	LK	RF	LF
Backswing	GCV	Pearson Correlation	.115	.122	.008	.193	.050	.076	.148	.053	.003	.085	.820	.420
		Sig. (2-tailed)	.211	.184	.927	.065	.636	.471	.133	.591	.979	.422	.000	.000
Downswing	GCV	Pearson Correlation	-.152	.956	.960	.973	.902	.120	.230	.077	.376	-.646	.704	.944
		Sig. (2-tailed)	.104	.000	.000	.000	.000	.267	.022	.445	.000	.000	.000	.000
Golf swing	GCV	Pearson Correlation	-.214	.529	.576	.843	.784	.131	.186	.016	.575	-.088	.598	.864
		Sig. (2-tailed)	.001	.000	.000	.000	.000	.088	.010	.827	.000	.253	.000	.000

Note: GCV – golf club velocity

Results of the relation between parameter GCV and measured variables within the group are presented in Table 2. During the backswing phase high correlations between parameters GCV and RF ($r = .820, p < .01$) were found. High correlations between parameter GCV and shoulders movement parameters (S XZ: $r = .956, p < .01$; S XY: $r = .960, p < .01$), hips movement parameters (H XZ: $r = .973, p < .01$; H XY: $r = .902, p < .01$) and parameter LF ($r = .944, p < .01$) were found during the downswing phase. During the golf swing phase, high resp. medium correlation between parameter GCV and hips movement parameters (H XZ: $r = .843, p < .01$) and high correlation between parameters GCV and LF ($r = .864, p < .01$) were found.

Parameters GCV and LF (as best correlated measured variable with GCV) were used to describe and compare intraindividual (Player 1) and interindividual (Group) performance stability. Results of intraindividual and interindividual stability of performance in eight separated events of the swing are represented in Table 3 (GCV) and Table 4 (LF).

Table 3. Intraindividual and interindividual stability of performance - golf club velocity

Variable		1	2	3	4	5	6	7	8
Player 1	Average	0.04	6.74	10.87	0.20	15.27	24.72	26.21	20.42
	CV	0.00	3.31	5.54	12.55	3.20	1.05	1.57	2.50
	CI ₉₅	0.00	0.14	0.37	0.02	0.30	0.16	0.25	0.32
Group (n=4)	Average	0.04	7.51	8.28	0.53	13.08	22.55	24.63	18.18
	CV	0.00	10.56	24.21	61.36	12.64	7.81	5.55	11.79
	CI ₉₅	0.00	0.26	0.65	0.11	0.54	0.58	0.45	0.70

Note: CV – coefficient of variation, CV₉₅ – 95% of coefficient of variation

Results represented in Table 3 show high intraindividual stability of performance (Player 1) in golf club velocity parameter during the golf swing. The backswing phase (events 1 – 4) has higher variability (min. CV = .00%, max. CV = 12.55%) than the downswing phase and follow through (events 5-8) (min. CV: 1.05%, max. CV = 3.20%). Stability of performance within the group (interindividual stability) represented in Table 3 is lower than the performance stability of Player 1 in the backswing phase (min. CV = .00%, max. CV = 61.36%), the downswing phase and follow through (min. CV = 5.55%, max. CV = 19.15%).

Table 4. Intraindividual and interindividual stability of performance – Left foot force action

Variable		1	2	3	4	5	6	7	8
Player 1	Average	0.47	0.32	0.16	0.33	0.57	1.02	1.34	0.95
	CV	0.87	5.45	8.93	4.98	4.25	5.36	5.18	5.85
	CI₉₅	0.00	0.01	0.01	0.01	0.02	0.04	0.05	0.04
Group (n=4)	Average	0.48	0.33	0.18	0.25	0.70	1.07	1.26	0.86
	CV	3.10	13.39	22.36	29.35	19.15	6.24	6.16	13.90
	CI₉₅	0.01	0.02	0.02	0.03	0.05	0.03	0.03	0.04

Note: CV – coefficient of variation, CV₉₅ – 95% of coefficient of variation

Intraindividual and interindividual performance stability of weight transfer represented in this study as relative left foot force action is represented in Table 4. Intraindividual stability of performance (Player 1) during the downswing phase and follow through (event 5 - 8) (min. CV = 0.87%, max. CV = 8.93%) is higher than in the backswing phase (events 1 – 4) (min. CV = 4.25%, max. CV = 5.85%). Interindividual stability of performance (within the group) is lower in the backswing phase (event 1- 4) (min. CV = 3.10%, max. CV = 29.35%) than the downswing phase and follow through (min. CV = 6.16%, max. CV = 19.15%).

Fig. 4. Correlation between parameters GCV and LF (Player 1)

Fig.5. Correlation between parameters GCV and LF (Group, n = 4)

The correlation between parameters GCV and LF is shown in Figure 4 (Player 1) and Figure 5 (Group, $n = 4$). The differences in weight transfer during the swing (events 1 – 8) between Player 1 and average of other three elite golf players (Group, $n = 4$) are shown in Figure 6.

Fig. 6. Mean LF at swing events for the Player 1 and the Group ($n=4$)

Figure 6 shows similar weight transfer of Player 1 and Group ($n = 4$) between events 1 and 3. In event 3 Player 1 starts weight transfer to the left (front) foot and fluently continues until event 7 (Impact – Ball contact) where he produces higher LS than the Group. Weight transfer within the Group to the left (front) foot starts between event 3 and 4 and is rapidly rising until event 6. Group produces lower LS at Impact – ball contact (event 7) than Player 1.

Discussion

Complex analysis of single golf swing and follow-up evaluation of measured quantitative data during the golf swings of all subjects were done. Based on measured objective quantitative data, we were able to compare stability of performance within and between subjects. Best placed professional player (Player 1) in Czech Republic players ranking in the group had both the highest intraindividual stability and the highest golf club velocity in the group. Correlation of measured parameters with the golf club velocity within and between subjects was done to identify the most related parameter. Left lower limb vertical force was evaluated as the best related parameter between subjects and also showed differences in weight transfer during the golf swing between Player 1 and the other players. Results showed that weight transfer during the swing is important to achieve better results (higher golf club velocity at impact) and with regard to players individuality (golf swing technique) we can recommend specific balance exercises. Effect of these exercises on results of the golf swing (higher golf club velocity) evaluated as changes in weight distribution during the golf swing will be subject of further studies. Results and high amount of objective data suggest use of kinematic analysis in applied coaching to monitor the high skill golfers' performance growth and swing technique corrections.

Player 1 single golf swing quantitative parameters were used for complex evaluation and description of the elite golf swing. Swing Biomechanics data was correlated to golf club velocity within and between subjects (Table 1, 2). These data suggests the importance of the torque action of shoulders and hips especially during the downswing phase to reach high club head velocity at ball contact. Similar results in correlating torque of body with club head velocity presents Meister et al. (2006). Vertical force to the ground which is given by the left lower limb and its high correlation to the club head velocity (Table 1, 2) indicated that all subjects used weight transfer toward the target throughout the swing which is recommended in coaching literature to produce extra energy to the ball (Wiren, 1990).

Group ($n = 4$) data presented in Table 4 shows the continuance of the weight transfer recommended in coaching literature (Leadbetter, 1995) with regard to balanced position at Set-up ($LF = 0.48$), moving to the right foot until the Top of the backswing ($LF = 0.25$) and in the downswing phase moving to the left foot with highest peak of vertical force under the left foot at Impact ($LF = 1.26$), and correspond with results presented in Ball and Best (2007).

Conclusions

The results of our study demonstrated high intraindividual performance stability during the golf swing. The variation within the group (interindividual stability) is obvious (Table 3, 4). These data suggest high stability of performance during the swing within the group of elite golf players, particularly in the downswing phase. The backswing phase had higher variability in golf club velocity parameter (Table 3) which indicated different timing of the swing between the players. Higher variability in relative left foot force action parameter (Table 4) indicated a different strategy of weight transfer during backswing within the group. Comparison of weight transfer between Player 1 and the Group ($n = 4$) shown in Figure 6 and higher GCV of Player 1 (Table 3)

indicated a high relation between GCV and a weight transfer strategy. That could be direction of future research if differences in golf swing techniques with different clubs are considered and a larger sample is measured.

High intraindividual and interindividual performance stability was found during downswing phase of the golf swing in elite golf player's sample. Interindividual variability during backswing phase was higher. The method of measurement allows us to conduct the exact and objective analysis of the golf swing performance based on quantitative data. In other words, based on these objective quantitative data, we are able to evaluate the golf swing realization from a quality point of view. Intraindividual stability of performance can be evaluated and patterns of movement during the swing can be found. These found patterns of movement must respect the individuality of the swing technique to be applied in teaching processes.

References

- Adlington, G. S. (1996). Proper swing technique and biomechanics of golf. *Clinics in Sports Medicine*, 15(1), 9-26.
- Allard, P., Stokes, I., & Blanchi, J. (1995). *Three-Dimensional Analysis of Human Movement*. Champaign: Human Kinetics.
- Ball, K., & Best, R. (2007). Different centre of pressure patterns within the golf stroke I: Cluster analysis. *Journal of Sports Sciences*, 25(7), 757-770.
- Cochran, A. J., & Stobbs, J. (1996). *The Search for the Perfect Swing: The Proven Scientific Approach to Fundamentally Improve Your Game*: Triumph Books.
- Dillman, C. J., & Lange, G. W. (1994). *How has biomechanics contributed to the understanding of the golf swing?* Paper presented at the World Scientific Congress of Golf, St. Andrews, Scotland.
- Egret, C. I., Vincent, O., Weber, J., Dujardin, F. H., & Chollet, D. (2003). Analysis of 3D Kinematics Concerning Three Different Clubs in Golf Swing. *International Journal of Sports Medicine*(24), 465-469.
- Hume, P. A., Keogh, J., & Reid, D. (2005). The role of biomechanics in maximising distance and accuracy of golf shots. *Sports Medicine*, 35(5), 429-449.
- Cheetham, P. J., Martin, P. E., Mottram, R. E., & Laurent, B. F. S. (2000). *The importance of stretching the X Factor in the golf downswing*. Paper presented at the International Congress on Sport Science Medicine and Physical Education, Brisbane, Australia.
- Keogh, J., Bradshaw, E., Hume, P., Maulder, P., Marnewick, M., & Nortje, J. (2007). Biological Movement Variability During the Golf Swing. In H. Menzel & M. Chagas (Eds.), *25 International Symposium on Biomechanics in Sports* Ouro Preto - Brazil.
- McLean, J. (1992). Widen the gap. *Golf Magazine*, 34(12), 49.
- Meister, D., Schroeder, J., Butler, E., Twist, K., Ladd, A., & Rose, J. (2006). *Kinematic and Kinetic Analysis of the elite golf swing*. Paper presented at the 24. th Annual International Symposium On Biomechanics In Sports, Salzburg.
- Myers, J., Lephart, S., Tsai, Y., Sell, T., Smoliga, J., & Jolly, J. (2008). The role of upper torso and pelvis rotation in driving performance during the golf swing. *Journal of Sports Sciences*, 26(181-188).
- Nesbit, S. M., & McGinnis, R. (2009). Kinematic analyses of the golf swing hub path and its role in golfer/club kinetic transfer. *Journal of Sports Science and Medicine*(8), 235-246.
- Richards, J., Farrell, J., Kent, M., & Kraft, J. (1985). Weight transfer patterns during the golf swing. *Research Quarterly for Exercise and Sport*, 56, 361-365.
- Wren, G. (1990). *Teaching manual*. Palm Beach Gardens: Greenstone Roberts Advertising.
- Zheng, N., Barrentine, S. W., Fleisig, G. S., & Andrews, J. R. (2008). Kinematic analysis of swing in Pro and amateur golfers. *International Journal of Sports Medicine*, 29(6), 487-493.