ELECTROMYOGRAPHICAL ANALYSIS OF TRUNK MUSCLE ACTIVITIES DURING A GOLF SWING

Young-Tae Lim[1], In-Sik Shin[2], and Sang-Yeon Woo[3]
[1]Department of Physical Education, Yeungnam University, Kyungsan. [2]Department of Physical Education, Seoul National University, Seoul. [3]Division of Physical Education, Soonchunhyung University, Choongnam. Korea

The purposes of this study were to describe and compare the activation patterns of the trunk muscles during a golf swing using surface electromyographic (EMG) techniques. Five male collegiate golfers were the subjects. The golf swing was broken into five phases using the critical instants identified from video recordings. Wilcoxon signed ranks tests were used to test for significant differences ($p < .05$) in average and peak normalized EMG values between the left and right muscles for each phase. The significant bilateral differences in muscle activation were only found in the average and peak rectus abdominus (acceleration phase), external oblique (acceleration and early follow-through phases), and erector spinae (late follow-through phase). The trunk muscles were highly active in the follow-through phases which may indicate the hyperextension of the trunk, which leads to lower back injury.

KEY WORDS: surface EMG, golf swing, muscle activation pattern, lower back injury.

INTRODUCTION: The popularity and the preference of golf are based on the characteristics of this sport. Unlike other ball control sports, the rules of golf indicate that the golfer must hit a stationary ball, not a moving one. In addition, the golfers themselves are their own opponents along with the other competitors. Because of these reasons, the impressions of golf are of a non-violent, or injury-free, and mostly psychological game. Nonetheless, the rate of golf-related injuries tends to be increasing, and among them, the lower back area is potentially the most vulnerable site of both professional and amateur male golfers (McCarroll and Gioe, 1982). In the last years, nearly all of the golf studies have concentrated on the kinematics of the golf swing to develop better swing mechanics (i.e., Cochran and Stobbs, 1968; Koenig *et. al.*, 1993). Surprisingly, few studies have investigated the muscle activation patterns to examine the exact role of the trunk muscles during a golf swing (Hosea *et. al.*, 1990; Pink *et. al.*, 1993, Lim and Chow, 2000). Therefore, the purposes of this study were to describe and compare the entire electromyographical (EMG) muscle activities of the trunk during a golf swing, which can give clues for seeking the cause of a developing injury such as back pain. The characteristics of the EMG pattern in each phase were also discussed.

METHODS: Five male collegiate golfers (average handicap = 1.4) worked as the subjects. Each subject used a driver (1-wood) and wore his own golf shoes during the tests. In the same way, each subject performed 5 trials (swings) in a laboratory setting and rated his own performance using a 5-point scale (5 = excellent, 1 = poor) at the end of each trial. Eight pairs of bipolar surface EMG electrodes (Noraxon Telemyo system, AZ) placed on the skin surfaces of the following muscles on both sides of the body: (1) rectus abdominus—3 cm lateral to the umbilicus, (2) external oblique—approximately 15 cm lateral to the umbilicus, (3) erector spinae—3 cm lateral to the L4 spinous process, (4) latissimus dorsi—lateral to T9 over the muscle belly. The ground electrode was placed on the greater trochanter of the left femur. Each pair of electrodes was placed parallel to the muscle line of action. In order to enhance the quality of the signals, the skin surface was shaved and cleaved with alcohol before placing the electrodes. These electrode sites have been considered optimal for obtaining representative EMG activity patterns with minimal signal cross-talk occurring between electrode pairs when bending and twisting (Lafortune *et. al.*, 1988). To establish the maximum EMG levels of the selected muscles, each subject was asked to perform four isometric exercises with maximum effort (MVC trials) before the experimental trials. Three trials were performed for each exercise and each contraction lasted approximately 3 s. MyoResearch EMG software (Noraxon Inc, AZ) was used to record the EMG data. For each trial, the analogue signals were sampled at 1000 Hz and were collected for 5 s. Four digital camcorders (JVC DVL 9800, 60 Hz) were used to record the movement of the subject. Moreover and an event synchronization unit (Visol Inc, Korea) was used to synchronize the video and EMG recordings. The trial with the highest rating per subject was selected for analysis. For the analysis of each trial, six critical instants were identified from the video recordings: (1) ball address (BA)—initiation of backswing, (2) end of backswing (EB)—beginning of downswing, (3) middle of downswing (MD)—the club at the horizontal position during downswing, (4) ball impact (BI)—the instant of ball/driver impact, (5) middle of follow-through (MF)—the club at the horizontal position after impact, (6) end of follow-through (EF)—the instant the club stopped its motion momentarily. In order to fulfill the purpose of this study, a golf swing was divided into five phases: (1) take away—from BA to EB, (2) forward swing—from EB to MD, (3) acceleration—from MD to BI, (4) early follow-through—from BI to MF, and (5) late follow-through—from MF to EF. The raw EMG signals were filtered using a recursive digital filter (Mathlab Elliptic filter, 5th order, 10-400 Hz band pass) and full-wave rectified. The rectified EMG data were low-pass filtered (single pass, 2nd order Butterworth) at a cutoff frequency of 3 Hz. This single pass filtering generated a 53 ms phase lag that can be used to account for the electro-mechanical delay. This was compatible with the 30-90 ms contraction (delay) times reported by Buchthal and Schmalbruch (1970) for a variety of muscles. For each muscle, the maximum EMG level (EMG^{max}) obtained from MVC trials was used to normalize the EMG data collected during the experimental trials:

$$\mathbf{NEMG}_m = \frac{\mathbf{EMG}_m}{\mathbf{EMG}_m^{max}}$$

where $\mathbf{NEMG}_m$ is the normalized EMG data of the muscle m, $\mathbf{EMG}_m$ is the filtered EMG data of the muscle m during a golf swing, and $\mathbf{EMG}_m^{max}$ is the maximum EMG level of the muscle m during MVC trials. The purpose of normalization was to minimize the inter-electrode variability caused by the electrode placement, skin abrasion, flesh resistance, muscle fiber density, and electronic channel differences. Using the critical instants identified from video recordings, average and peak NEMG levels were computed for each phase. For each muscle, mean and standard deviation values were determined for the average and peak NEMG levels for each phase of a golf swing. Wilcoxon signed ranks test was used to test for significant differences ($\underline{p} < .05$) in average and peak NEMG values between the left and right muscles for each phase.

RESULTS AND DISCUSSION: Mean and standard deviation values of the average and peak NEMG levels for all muscles in the different phases of a golf swing are shown in Table 1.
Take Away Phase: The take away phase is often considered as the backswing. The purpose of the backswing is to put the golfer and the club in an optimum position to start the downswing or forward swing. The backswing begins with simultaneous backward movement of the club head and the hands, and a rotation of the trunk to the right. Over this phase, the trunk of a right-handed subject twisted in the clockwise (CW) direction (in an overhead view) and tilted to the left side. Despite this phase revealed relatively low muscle activity in all muscles (≤ 14.2% MVC), the NEMG values of the left side muscles were higher than the right side muscles except for the latissimus dorsi. The right latissimus dorsi showed higher NEMG level than the left one because the right latissimus dorsi was responsible for the shoulder rotation during the backswing. These results were not considered significant.
Forward Swing Phase: The objective of the downswing is to get the clubhead to arrive at the point of impact moving at a maximum speed in the desired direction and with the face of the club pointing in that same direction. During the forward swing phase, a golfer unwounded the upper body and twisted the trunk in the counter-clockwise (CCW) direction (in an overhead view). The hips moved to the left and the lower trunk was tilted to the right over this period. The NEMG levels for all muscles increased during this phase because the gravitational and rotational forces kept the upright body position. The NEMG values of the left side muscles were higher than the right side muscles except for the external oblique and latissimus dorsi.
Acceleration Phase: The trunk was still uncoiling and twisting in the CCW direction during the acceleration phase. Therefore, a slight lateral bending of the lower trunk to the right was still observed over this period. All the monitored muscles showed fairly high levels of NEMG activity in this phase. Among them, latissimus dorsi of both sides showed peak NEMG values of a 37% MVC or higher. It is worth pointing out that, the left external oblique also showed

relatively high activity (24% MVC). It is assumed that the left external oblique was activated to keep a controlled pace in trunk twisting as an antagonist of the right external oblique. The erector spinae on both sides showed high NEMG values (> 60% MVC). The right rectus abdominus and right external oblique showed significant higher peak NEMG levels than the corresponding muscles on the opposite side (p<. 05). Significant differences between the left and right rectus abdominus were also found in the average NEMG activity ($p < .05$). These findings indicate that the right abdominal muscles mainly functioned to twist the trunk in CCW direction.

Table 1. Mean and Standard Deviation Values of Average and Peak Normalized EMG for Different Muscles During Different Phases of a Golf Swing.

	Take Away		**Forward Swing**		**Acceleration**		**Early Follow-through**		**Late Follow-through**	
Muscle	Ave	Peak	Ave	Peak	Ave	Peak	Ave	Peak	Ave	Peak
Left rectus	3.2	10.7	14.1	23.0	11.5*	14.9*	15.5	17.6	17.1	42.9
adbominus	(2.9)	(16.6)	(20.1)	(26.0)	(5.2)	(7.4)	(12.0)	(14.2)	(12.2)	(28.9)
Right rectus	2.2	3.3	8.6	19.5	19.5*	22.4*	23.1	25.6	11.9	31.3
adbominus	(0.7)	(0.7)	(5.7)	(8.9)	(10.4)	(11.0)	(8.9)	(9.9)	(5.0)	(5.4)
Left external	6.2	14.2	10.2	23.3	21.6	24.1*	23.7*	26.1*	30.2	61.1
Oblique	(3.7)	(8.9)	(5.0)	(9.8)	(12.4)	(12.5)	(12.0)	(11.4)	(13.1)	(30.0)
Right external	5.4	9.1	15.1	38.0	45.9	55.9*	62.6*	69.3*	29.4	78.3
Oblique	(0.6)	(0.9)	(9.3)	(23.9)	(20.7)	(21.0)	(18.2)	(16.4)	(9.9)	(10.7)
Left latissimus	4.7	6.4	15.1	36.1	34.9	37.0	29.3	34.1	14.8	31.1
Dorsi	(2.9)	(3.7)	(6.4)	(18.5)	(20.4)	(20.2)	(14.8)	(18.7)	(5.5)	(6.4)
Right latissimus	5.7	13.3	16.2	46.0	44.8	48.9	38.8	43.7	14.9	47.1
Dorsi	(6.2)	(11.8)	(14.7)	(27.3)	(29.5)	(30.8)	(28.7)	(31.2)	(13.8)	(31.8)
Left erector	6.1	12.6	20.4	63.9	55.3	62.0	43.1*	53.1	6.5*	32.4*
Spinae	(2.6)	(6.9)	(16.0)	(30.3)	(28.5)	(24.6)	(23.9)	(28.3)	(3.2)	(17.9)
Right erector	4.0	9.6	17.3	50.4	54.2	60.1	57.1*	62.6	21.6*	67.1*
Spinae	(1.9)	(4.5)	(6.5)	(23.7)	(28.8)	(29.5)	(26.8)	(28.2)	(5.9)	(22.7)

Note. Units are in % MVC and the values enclosed in parentheses represent standard deviations.
Significant difference between left and right muscles at * $p < .05$.

Early Follow-through Phase: The follow-through consists of a gradual slowing down of the body and club movements after the moment of impact. Nevertheless, the momentum of the swing with a driver made the lower trunk twist in the CCW direction and the trunk started to face forward parallel to the line of IM. Although this phase occurred after the ball/driver impact, the NEMG levels of all muscles were still high and were comparable to the values seen in the acceleration phase. It is interesting to notice that, the average NEMG activities of both left and right rectus abdominus, left and right external oblique, and right erector spinae were 4%, 4%, 2%, 17%, and 3% MVC greater than the corresponding values for the acceleration phase, respectively. Significant differences between the left and right external oblique were found in the average and peak NEMG activity ($p< .05$). The right erector spinae also showed a higher average NEMG level than the corresponding muscle on the opposite side ($p < .05$). It is clear that the right external oblique was still activated to rotate the trunk in CCW direction and higher activation of the right erector spinae implies that the trunk was tilted to the right.

Late Follow-through Phase: throughout during this phase, the trunk was fully twisted in the CCW direction and faced toward the target parallel to the line of IM. The muscle activity in the late follow-through phase was still notable, and rectus abdominus, external oblique, and right erector spinae showed the highest peak NEMG values in this phase. The average NEMG values of the left rectus abdominus and left external oblique were actually increasing in comparison to the previous phase. It seemed that the oblique muscles were still active to twist the trunk in the CCW direction while the rectus abdominus were activated to resist the hyperextension of the trunk at the early stage of this phase. Consequently, the trunk muscles served to decelerate the twisting, as opposed to the acceleration observed impact. The right erector spinae showed a significant higher average and peak NEMG level than the corresponding muscle on the opposite side ($p < .05$). These values were considerably higher than those reported in the literature (Pink *et. al.*, 1993). The findings in this phase are a clear result of the trunk tilting to the right.

CONCLUSION: The high and consistent level of NEMG, with various patterns of muscle activation, revealed that repetitions of a golf swing have a predisposition to produce lower back injury with accumulated fatigue in these muscles. Unlike the previous reports, this study indicated that the trunk muscles were still very active in the follow-through phases. These high muscle tensions may indicate that the golfers were not capable of performing optimum swing patterns because the trunk muscle activations in the follow-through phase were at a low level. The hyperextension and leaning of the trunk, which caused imbalanced high activation of the erector spinae, could be critical factors in causing lower back pain. Therefore, to reduce the risk of back injury with minimum level of muscle activity, the follow-throw phase must be finished in the straight 'I' position. It may sacrifice slightly the ball flight distance but it will greatly reduce the risk of back injury.

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