Abdominal muscle activation of elite male golfers with chronic low back pain

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ABSTRACT

HORTON, J. F., D. M. LINDSAY, and B. R. MACINTOSH. Abdominal muscle activation of elite male golfers with chronic low back pain. *Med. Sci. Sports Exerc.*, Vol. 33, No. 10, 2001, pp. 1647–1654. **Purpose:** The purpose of this study was twofold: 1) to determine whether elite male golfers with chronic low back pain (CLBP) exhibit different abdominal muscle activity patterns during the golf swing than asymptomatic control (AC) golfers and 2) to determine whether elite male golfers with CLBP experience greater fatigue in the abdominal muscles than AC golfers after a typical practice session. **Methods:** Surface EMG data were collected bilaterally from the rectus abdominis (RA), external oblique (EO), and internal oblique (IO) muscles. Muscle activity during the golf swing was measured using the root mean square (RMS) of the EMG signal in various phases of the golf swing. Fatigue was assessed using the median frequency (MF) and RMS of the EMG signal during a 10-s submaximal isometric contraction. Low back pain was quantified with the McGill Pain Questionnaire before and after the practice session. **Results:** No differences in the RMS of abdominal muscle activity were noted during the golf swing between AC and CLBP subjects. However, EO (lead) onset times were significantly delayed with respect to the start of the backswing in CLBP subjects. Low back pain in CLBP golfers increased significantly after the practice session. Abdominal muscle fatigue, as measured with MF or RMS, was not evident after the practice session for either AC or CLBP subjects. **Conclusion:** Abdominal muscle activity and muscle fatigue characteristics were quite similar between AC and CLBP subjects after repetitive golf swings. Despite this, it was clear that repetitive golf swings were aggravating some part of the musculoskeletal system in CLBP subjects, which resulted in increased pain in the low back area. **Key Words:** SURFACE EMG, MUSCLE FATIGUE, LUMBAR SPINE, GOLF

L ow back pain has been identified as the most common musculoskeletal problem affecting amateur and professional golfers (10,14,15,27). Surveys have shown that 63% of injuries sustained by professional golfers were to the low back area (27) as compared with 36% for amateur golfers (15). Although little is known about the exact causes of low back pain among golfers, development of such pain in amateur golfers is anecdotally attributed to poor swing mechanics, excessive practice, and poor physical conditioning (7,12,15). Professional golfers tend to exhibit more consistent swing mechanics than amateurs; however, they are especially susceptible to overuse resulting from long practice sessions and repetitive play (7,12). Overuse in association with the asymmetrical nature of the golf swing may create repetitive abnormal stresses on the lumbar spine, which might lead to injury and pain (3,11,27).

The golf swing is a very complex movement that involves a considerable amount of trunk rotation and powerful muscular contractions. Although many different muscle groups contribute to the initiation and completion of the golf swing, the abdominal muscles are known to contribute considerably to the generation of power during the acceleration phase of the golf swing (24,30). Using surface electromyo-

graphy (EMG), Pink et al. (24) and Watkins et al. (30) found the right-side abdominal oblique muscles to be particularly active during the rotation of the trunk in the acceleration and impact phases of the golf swing (in right-handed golfers). As well as involving a great deal of rotation, the golf swing also produces a significant degree of right-side lateral bending (right-handed players) during the impact phase (27). The generation of axial torque coupled with lateral bending is produced by the synergistic activity of the various trunk muscles (16). Considering the contributions of the trunk muscles in rotation and lateral bending movements and the repetitive nature of the game, it is possible that muscular fatigue could develop during a typical game or practice session. Also, Watkins et al. (30) have speculated that abdominal muscle activity patterns, which can be detected by surface EMG measurements during the golf swing, might be different in injured golfers than in the uninjured golfers.

The association between muscle deficiency and chronic low back pain (CLBP) is not clearly understood, especially in golfers. A lack of strength and endurance of the trunk muscles appears to be a significant risk factor in the development and occurrence of CLBP (8,19,25). Patients with CLBP are often advised that trunk muscle strengthening helps decrease pain by contributing to protection of the spine (29). However, McGill (17) believes that endurance of the trunk muscles may be more important than strength alone. Weakening of the trunk muscles because of fatigue is particularly relevant if the type of movement performed

involves rapid repetitive movement of the extremities (6), which typifies the game of golf.

Although both the abdominal and low back muscles work together to contribute to the rotation of the trunk and stability of the lumbar spine, the abdominal muscles tend to fatigue more easily than the low back muscles, especially in individuals with CLBP (28). It has been reported that alterations in trunk movement patterns occur as a result of muscular deficiencies, thus leading to an inability of the spine to withstand repetitive loads (26). The passive tissues (e.g., ligaments, bones, disks) of the spine may in turn experience abnormal stress from inappropriate muscle recruitment, thus increasing the likelihood of developing injuries in the low back (4,25). These studies have offered insight into the function of the trunk muscles in a general population of individuals with and without low back pain, but little is known about golf players.

Considering the possible relationship between trunk muscle dysfunction and low back pain in golfers, it was the purpose of this study to determine if there were differences in the magnitude and/or onset times of abdominal muscle EMG activity during maximal effort golf swings between golfers with and without CLBP. Furthermore, the influence of a typical practice session on trunk muscle fatigue and pain perception was also investigated. It was hypothesized that elite male golfers with CLBP would exhibit less abdominal muscle activity during the golf swing compared with elite male golfers without CLBP. It was also hypothesized that a typical practice session would result in greater localized abdominal muscle fatigue in elite male golfers with CLBP, and that this fatigue would lead to additional changes in muscle activity patterns.

METHODS

Subject inclusion criteria. Eighteen male professional golfers belonging to the Alberta Professional Golf Association and seven elite amateurs (<5 handicap) belonging to the Alberta Golf Association volunteered to participate in this study. All subjects completed a Physical Activity Readiness Questionnaire (PAR-Q) and gave informed consent before participating in this study. Potential subjects were initially asked to complete a general golf questionnaire regarding the location, duration, and frequency of back pain, and their playing and practicing habits. Those individuals who had "never" experienced pain in the lumbar region of their back after practicing or playing during the 6 months before completion of the questionnaire were classified as asymptomatic control (AC) subjects. Those individuals who had "always" or "often" experienced pain in the lumbar region of their back after practicing or playing for longer than 6 months before completion of the questionnaire were classified as CLBP subjects. Individuals were excluded from participating in the study if they were older than 55 yr of age or suffered from low back pain for less than 6 months. The CLBP subjects were individuals who had experienced low back pain for some time and continued to play golf in spite of this condition.

General procedures. Anthropometric measurements were made and then followed by electrode placement on the appropriate muscles. Next, a submaximal isometric contraction was performed to be used as an EMG normalizing measure. After the submaximal isometric contraction, subjects completed a severity of pain questionnaire (short-form McGill Pain Questionnaire) as outlined by Melzack (18). Subjects were then permitted to warm up for approximately 10 min to physically prepare for maximal effort shots with a driver. Subsequently, five maximal effort shots were hit with a driver while video and EMG data were collected. A typical practice session for 50 min was completed, after which five maximal effort shots were again completed while video and EMG data were collected. Immediately after the final shot with the driver, subjects performed the submaximal isometric contraction again to assess muscular fatigue and then completed the pain questionnaire again.

EMG data recording. Each subject's skin was prepared for EMG electrode placement by shaving, abrading the skin with fine-grade emery paper, and then cleaning the area thoroughly with an alcohol swab. Pairs of AgAgCl surface EMG electrodes (10 mm active diameter) (CONMED Corporation, Utica, NY) were attached to the skin approximately 25 mm apart (center to center) along the expected muscle fiber direction of the right and left rectus abdominis (RA) (3 cm lateral to umbilicus), external oblique (EO) (15 cm lateral to umbilicus at transverse level of umbilicus), and internal oblique (IO) (below external oblique and just superior to the inguinal ligament). A ground electrode was placed over the left anterior superior iliac spine. Interelectrode distance and electrode placement were consistent with procedures described by McGill (16) and Juker et al. (9). EMG signals were preamplified and conducted through a battery-powered unit (Biovision EMG System, Wehrheim, Germany) (input impedance, 10^{12} Ω; bandwidth, 10 to 1000 Hz). Amplifiers were not more than 12 cm from electrode sites and were taped to the body to minimize movement artifact in the EMG signal.

EMG normalizing procedure. Before the golf swing trials, EMG data of the three abdominal muscles were collected during a submaximal isometric contraction (double leg raise) in order to normalize the EMG data during the swing. Subjects were asked to raise their feet approximately 1 cm off the floor and hold the position as steady as possible. Electromyographic data were collected for 10 s. O'Sullivan et al. (21) have previously used the double leg raise to normalize EMG data in low back pain populations. Compared with maximal voluntary contractions, submaximal contractions are believed to be a more consistent indication of muscle activation (1). Thus, submaximal voluntary muscle contractions may be a more appropriate tool to use as a normalization standard for subjects with back pain (1).

Performance testing and practice session. After a brief warm-up, subjects hit five maximal effort shots with the driver. Electromyographic data from RA, EO, and IO muscles were collected during each of the five shots. Subjects were asked to rate each shot with the driver on a scale of 1 to 5. The shot that was perceived to be the best (most

solidly struck) by the subject was later used during data analysis. Video data were collected simultaneously to synchronize EMG data with the different phases of the golf swing. Subjects then completed a practice session, hitting golf balls into a net at a rate of one every 30 s for 50 min with various clubs (nine, seven, five, and three iron; and three wood). Each club was used for 10 min, beginning with the nine iron and finishing with the three wood. All subjects practiced in the same manner and were instructed to hit each shot with a normal full effort. After the 50-min practice session, subjects again hit five maximal effort shots with the driver. Electromyographic and video data were collected during each of these shots, and subjects rated each shot on a scale of 1 to 5.

Video data recording. Four high-speed video cameras (Falcon, 6.0 mm Computar lens, Motion Analysis Corp., Santa Rosa, CA) were used to evaluate club position throughout the golf swing and to determine the instant of ball impact. Video data were collected at 240 frames·s^{-1} to synchronize EMG data to various phases of the golf swing. Cameras were positioned in a semicircle arrangement to the side of the subject away from the direction of ball flight. Reflective markers were placed on two locations along the shaft of the driver to allow determination of specific phases of the golf swing. A 90-compression golf ball was covered with reflective tape to permit detection of the first indication of ball motion and to permit subsequent calculation of ball velocity. Video and EMG data were collected with EVa data collection software (Version 5.2, Motion Analysis Corp.).

Abdominal muscle fatigue. Electromyographic data collected during the 10-s double leg raise maneuver were used to assess muscular fatigue in the abdominal muscles by comparing before and after the practice session. It was thought that the double leg raise would offer a simple and effective means for assessing muscular fatigue in the abdominal muscles resulting from the practice session. Considering the well-being of the CLBP subjects, and to be consistent, it was decided that all subjects would perform the double leg raise maneuver for 10 s. Fatigue was assessed by comparison of median frequency (MF) and root mean square (RMS) for the postpractice double leg raise with the prepractice double leg raise.

Data Analysis

Video data analysis. All video data were analyzed using EVa software (Version 5.2, Motion Analysis Corp.). The video file, which combined data from all four cameras, was advanced one frame at a time to determine the exact time of golf club movement in the backswing direction (which was considered the start of the swing); the start of the downswing; club position parallel to the floor in the forward swing; impact; club position parallel to the floor on the follow through; and the finish position. The finish position was considered to be the point where the club was above the head and parallel to the floor. All frame numbers were converted to milliseconds to allow determination of the timing for the sequence of muscle activation.
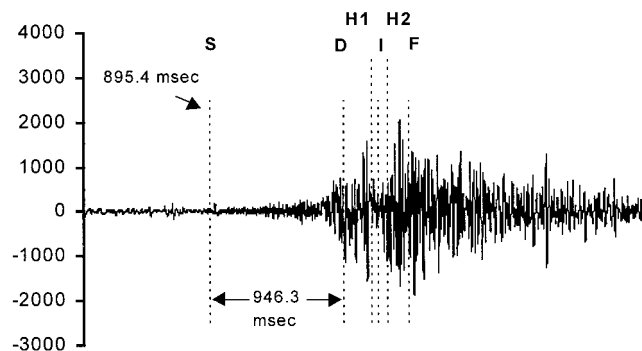

FIGURE 1—Marker settings used to calculate RMS values during various phases of the golf swing. S, start of backswing; D, start of downswing; H1, club horizontal to floor during forward swing; I, ball impact; H2, club horizontal to floor during follow-through; F, finish of swing. Duration of entire EMG signal is 4 s. EMG signal was recorded from EO (trail) muscle.

EMG data analysis. All EMG data were sampled at 2400 Hz and bandpass filtered between 10 and 240 Hz (fourth-order Butterworth digital filter). Although EMG and video data were collected during each of the five shots with the driver, only one trial was chosen for EMG data analysis. The best-rated shot (as indicated by the subject) was used as long as the EMG signals were free of movement artifact. If the EMG signal associated with the best-rated shot appeared to be distorted with artifact, then the next-best-rated shot was used for data analysis. The magnitude of these EMG signals was normalized relative to the submaximal signal collected during the leg raise, as previously described. Right and left sides were referred to as "trail" and "lead" sides, respectively, in right-handed golfers ("lead" and "trail," respectively, in left-handed golfers).

Root mean square calculation. Electromyographic signals of the submaximal isometric contraction (double leg raise) were analyzed in the same manner for all subjects. To avoid artifacts of the filtering process, a 2000-ms selection of each EMG signal was chosen beginning at 1000 ms. The magnitude of muscle activity during different phases of the golf swing was calculated with Kintrak (versions 5.2 and 6.0, University of Calgary, Calgary, Alberta, Canada). The RMS for each of the three phases (phase 1, start of backswing to start of downswing; phase 2, start of downswing to impact; phase 3, impact to finish) was calculated in millivolts. RMS values were also calculated during the impact phase (horizontal 1 to horizontal 2). Markers were manually set on EMG signals according to the previously determined video times (Fig. 1).

Determination of abdominal muscle activity onset times during the golf swing. Using nonrectified EMG signals, onset times of individual abdominal muscles were determined using Kintrak (version 5.2 and 6.0). Onset times were calculated as 7 SD above the mean of a 200-ms segment (one twentieth of the whole sample) where the quietest activity in the signal occurred (Fig. 2). Use of 7 SD consistently selected times when substantial EMG activity occurred (i.e., related to the golf swing). Onset times for each muscle were expressed relative to specific times during
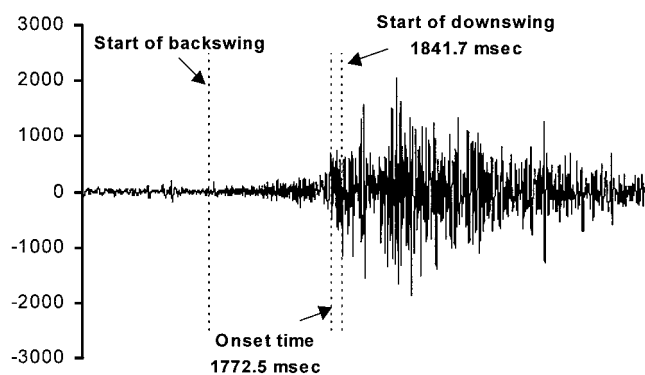
FIGURE 2—Onset time selection. Example of computer program (Kintrak) calculation of muscle activity onset time. Onset time was calculated as 7 SD above the mean of a 200-ms segment (one twentieth of the whole sample) where the quietest activity in the signal occurred. The entire EMG signal was 4 s in duration. EMG signal was recorded from EO (trail) muscle.

the golf swing, which were determined from the video data analysis.

Abdominal muscle fatigue. The 10-s submaximal isometric contraction (double leg raise) was used to assess muscular fatigue in the abdominal muscles after the practice session. The MF of the EMG signal in the first three segments (1.25 s in duration) was calculated (Kintrak, version 5.2) to give an indication of muscular fatigue after versus before the practice session. In a pilot study with healthy subjects, the submaximal isometric exercise (double leg raise) was difficult to sustain for 30 s; therefore, the duration of this maneuver was predetermined to last only 10 s. This duration was considered to be sufficient, since it is commonly observed that the spectral shift of the EMG signal is most dramatic near the beginning of a sustained contraction (13). RMS was also calculated to determine if the magnitude of muscle activation was increased, indicating possible muscular fatigue. The RMS of the 10-s submaximal isometric contraction after practice was compared to the RMS before practice. Whereas the MF of the EMG signal is known to decrease over time during a fatiguing contraction, the RMS of the EMG signal is known to increase throughout a fatiguing contraction (2).

Low back pain severity measurement. Subjects were required to complete a severity of pain questionnaire (short-form McGill Pain Questionnaire) as outlined by Melzack (18) before and immediately after the practice session. Within the McGill Pain Questionnaire is a visual analog scale (VAS). The VAS is a 100-mm line with "no pain" being represented as 0 and the "worst possible pain" represented as 100. Subjects were asked to identify their level of pain on the VAS by making a tick mark with a pencil on the line. The VAS scores for each subject were then determined with a ruler to assess pain intensity.

Ball velocity measurement. Ball velocity was calculated in Matlab (The Math Works, Inc., Natick, MA) using a finite difference method. This velocity was calculated for a three-dimensional ball movement and subsequently converted from $cm \cdot s^{-1}$ to $km \cdot h^{-1}$.

RESULTS

Demographic and descriptive information. Eight AC subjects (eight professionals) (age, 29.4 ± 2.0 yr; weight, 81.7 ± 2.4 kg; height, 1.80 ± 0.01 m; BMI, 25.3 ± 0.6; mean $\pm$ SEM) and 17 CLBP subjects (10 professionals, 7 elite amateurs) (age, 36.1 ± 2.7 yr; weight, 81.8 ± 2.2 kg; height, 1.80 ± 0.01 m; BMI, 25.4 ± 0.6) participated in this study.

Abdominal muscle activity during the golf swing. Normalized EMG activity of all abdominal muscles is shown with the same scale for ease of comparison (Fig. 3). The magnitudes of abdominal muscle activity during all parts of the golf swing were found to be very similar between AC and CLBP subjects at both the beginning and end of the 50-min practice session (P values ranged from 0.657 to 0.970). All abdominal muscles, with the exception of EO (lead), displayed the same pattern of relative EMG activity during the golf swing. The pattern of muscle activity typically involved an increase in activity from phase 1 to phase 2 followed by a decrease in activity to phase 3. External oblique (lead) muscle tended to have a constant amount of activity during the different phases of the golf swing (Fig. 3).

Abdominal muscle activity onset times during the swing. Tables 1 and 2 show onset times for the EO and IO muscles during the golf swing. These oblique muscles were selected for analysis because they are the main abdominal muscles responsible for axial rotation movements. ANOVA revealed no significant interaction ($P > 0.28$) and no main effect of practice ($P > 0.60$) for EO onset time relative to the start of the backswing. There was, however, a significant group effect ($P < 0.006$) (Table 1). ANOVA revealed no significant effects (no interaction ($P > 0.90$) and no main effect ($P > 0.20$)) for onset time of IO abdominal muscle activity relative to the start of the backswing (Table 1). Analysis of the onset times for EO (trail) and IO (lead) muscle activation relative to the start of the downswing revealed no significant differences ($P > 0.19$) (Table 2).
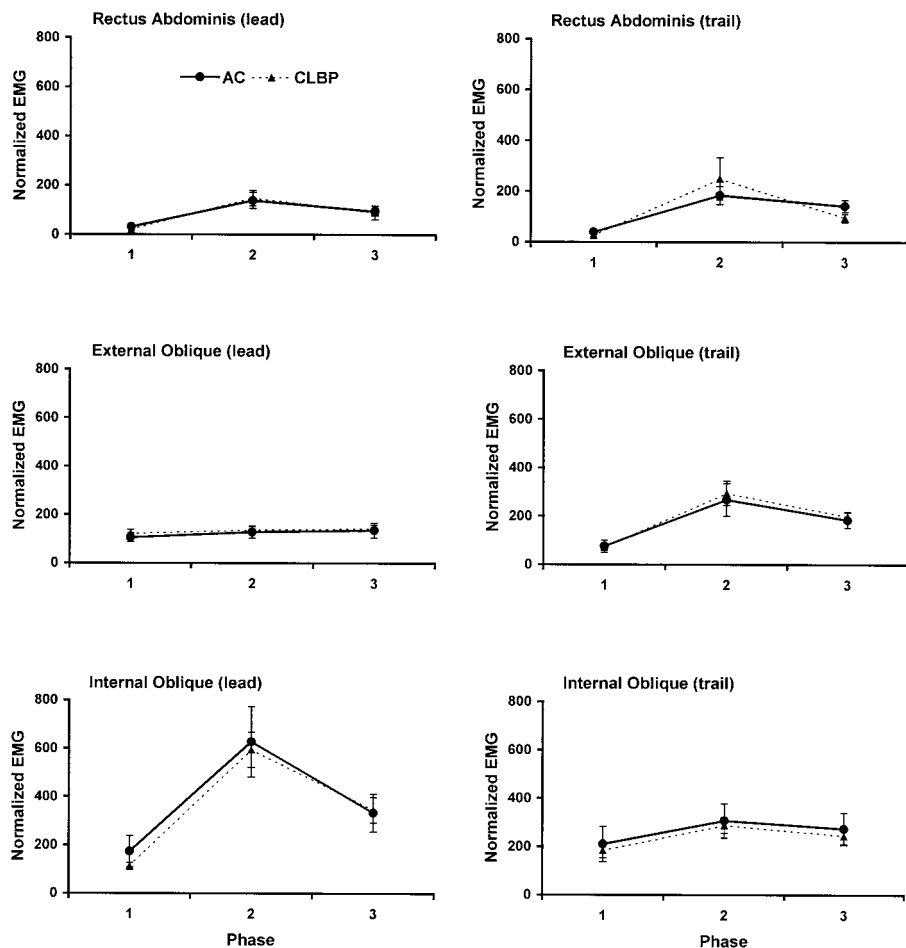
FIGURE 3—Abdominal muscle EMG activity throughout the golf swing for AC and CLBP subjects. Phase 1, start of backswing to start of downswing; phase 2, start of downswing to impact; phase 3, impact to finish. Magnitude of activity is expressed as percent of submaximal (double leg raise) RMS.

Low back pain severity. Fifty-three percent of the golfers with CLBP identified a central or bilateral pain distribution. A further 35% indicated pain on the trail side (right side of a right-handed golfer), whereas the remaining 12% listed a lead side low back pain location. A significant increase in severity of low back pain was found for CLBP individuals after the 50-min practice session ($P = 0.006$). Average VAS scores for CLBP subjects were 23.5 ± 6.1 before the practice session and 34.4 ± 5.6 after the practice session. Asymptomatic control subjects did not experience any degree of low back pain before or after the 50-min practice session.

Abdominal muscle fatigue after practice session. No significant differences were found for abdominal muscle EMG MF during the double leg raise maneuver after the practice session in either AC or CLBP subjects ($P > 0.22$) (Table 3). No significant differences were found for abdom-

inal muscle EMG RMS during the double leg raise maneuver after the practice session in either AC or CLBP subjects ($P > 0.27$) (Table 3). Ball velocity also did not significantly change ($P > 0.87$) as a result of the practice session for AC subjects (241.9 ± 2.9 km·h^{-1} before practice vs 242.2 ± 2.9 km·h^{-1} after practice) or CLBP subjects (235.3 ± 5.6 km·h^{-1} before practice vs 234.7 ± 4.6 km·h^{-1} after practice).

DISCUSSION

Abdominal muscle activity during the golf swing. The results of this study did not support the hypothesis that elite male golfers with CLBP exhibit less abdominal muscle activity than AC subjects during a maximal effort golf swing with the driver. Although this hypothesis was not supported, the observations regarding abdominal muscle activity in elite male golfers with and without CLBP provided useful information that can be applied to future studies.

TABLE 1. Abdominal muscle activity onset times[a] relative to the start of the backswing.

	EO (Lead) Before[b]	EO (Lead) After[b]	IO (Trail) Before	IO (Trail) After
AC	-16.6 ± 27.4	-41.7 ± 16.4	13.8 ± 81.4	73.2 ± 124.1
CLBP	55.5 ± 19.4	67.2 ± 22.3	22.4 ± 38.7	85.0 ± 65.9

[a] Onset times (ms) of the EO and IO muscles before and after the practice session are presented relative to the first movement of the golf club in the backswing (start of backswing).
[b] There was a significant group effect between AC and CLBP subjects in EO (lead) onset time relative to the start of the backswing ($P = 0.006$).

TABLE 2. Abdominal muscle activity onset times[a] relative to start of downswing.

	EO (Trail) Before	EO (Trail) After	IO (Lead) Before	IO (Lead) After
AC	-63.2 ± 37.9	-55.1 ± 30.4	-84.9 ± 16.5	-69.0 ± 32.1
CLBP	-94.8 ± 61.3	-73.1 ± 54.7	-38.8 ± 11.7	-53.8 ± 17.3

[a] Onset times (ms) of the EO and IO muscles before and after the practice session are presented relative to the first movement of the golf club in the downswing direction (start of downswing).

TABLE 3. Mean MF and RMS values before and after practice.[a]

	RA (Lead)	RA (Trail)	EO (Lead)	EO (Trail)	IO (Lead)	IO (Trail)
Mean MF values for AC subjects (N = 8)						
Before[b]	90.5 ± 7.8	83.4 ± 5.2	67.7 ± 4.1	59.6 ± 4.1	92.2 ± 10.3	92.2 ± 9.7
After	88.3 ± 6.9	84.3 ± 5.4	67.3 ± 3.9	60.2 ± 2.9	89.9 ± 9.1	93.4 ± 9.2
Mean RMS values for AC subjects (N = 8)						
Before	0.13 ± 0.06	0.09 ± 0.04	0.12 ± 0.02	0.14 ± 0.03	0.07 ± 0.01	0.08 ± 0.02
After	0.14 ± 0.06	0.11 ± 0.05	0.15 ± 0.03	0.17 ± 0.03	0.08 ± 0.01	0.08 ± 0.02
Mean MF values for CLBP subjects (N = 17)						
Before	79.2 ± 3.7	81.8 ± 4.4	68.9 ± 2.7	65.1 ± 2.5	77.1 ± 5.4	78.1 ± 5.6
After	80.2 ± 3.6	81.5 ± 4.4	70.2 ± 2.6	66.6 ± 2.6	73.2 ± 4.4	80.9 ± 6.9
Mean RMS values for CLBP subjects (N = 17)						
Before	0.08 ± 0.01	0.09 ± 0.01	0.07 ± 0.01	0.09 ± 0.01	0.06 ± 0.01	0.08 ± 0.01
After	0.09 ± 0.01	0.11 ± 0.02	0.09 ± 0.01	0.10 ± 0.01	0.08 ± 0.01	0.09 ± 0.01

[a] P values ranged between 0.219 and 0.926.
[b] Before and after refer to measurements obtained before and after the practice session.

Only two studies have previously used EMG to investigate trunk muscle activity patterns in male golfers (24,30). Pink et al. (24) were the first to investigate trunk muscle activity during the golf swing using amateur players, and Watkins et al. (30) conducted a similar study with professional golfers. Both studies concluded that the abdominal muscles (particularly on the trail side) were very active during what they considered the forward swing, acceleration, and early follow-through phases. Watkins et al. (30) believed the trunk muscles were important as stabilizers of the lumbar spine during the golf swing and speculated that trunk muscle activity patterns might be different in injured golfers than in uninjured golfers.

Unlike the present study, neither Pink et al. (24) nor Watkins et al. (30) differentiated between the different abdominal oblique muscles on the same side of the body. Since EO and IO muscles have distinctly different fiber orientations and functions, it is useful to distinguish between the two. Juker et al. (9) recently demonstrated independent muscle activity from IO and EO using surface EMG. The same electrode placement was used in the present study as that described by Juker et al. (9).

The present study showed that it is possible to measure EO and IO muscles independently during the golf swing. This can be seen in Figure 4, where it is clear that EO (lead) and IO (lead) EMG signals are distinctly different. The predominant activity of the lead EO during the backswing is consistent with the fiber orientation and function of this muscle (right axial rotation). Conversely, the fiber orientation of the lead IO is more suited to the downswing direction (left axial rotation). One would expect the two signals to be similar if the two different sets of electrodes were monitoring activity from the same muscle.

Abdominal muscle activity onset times during the golf swing. Although results from this study did not show any difference in the magnitude of abdominal muscle activity between golfers with and without CLBP, differences were evident for the timing of these contractions. Specifically, EO lead was activated significantly earlier in AC golfers compared with CLBP subjects (P = 0.006). Although not significant, earlier activation of the IO (trail) and EO (trail) was also evident in the AC players. Differences in abdominal muscle onset times among subjects with and without low back pain have been investigated previously. Hodges and Richardson (5) found that during sharp upper limb movements, the transverse abdominis (TrA) and IO contracted not only before any of the other trunk muscles but even before the agonist upper limb muscles. Furthermore, contractions of the TrA and IO muscles were delayed in subjects with low back pain (6). The authors suggested that the preemptive contractions of the deeper abdominal muscles such as TrA and IO provided enhanced stability to the lumbar spine, thus protecting it from possible injury. Although it is difficult to draw a strong association between Hodges and Richardson's findings and the current experiment, abdominal muscle activation appeared to be delayed in the swings of CLBP golfers, which may be reflective of abnormal neuromuscular control.

Although force production was not measured in this study, it is important to note there is an inherent delay between the onset of the EMG signal and the onset of the corresponding force. This is typically called electromechan-
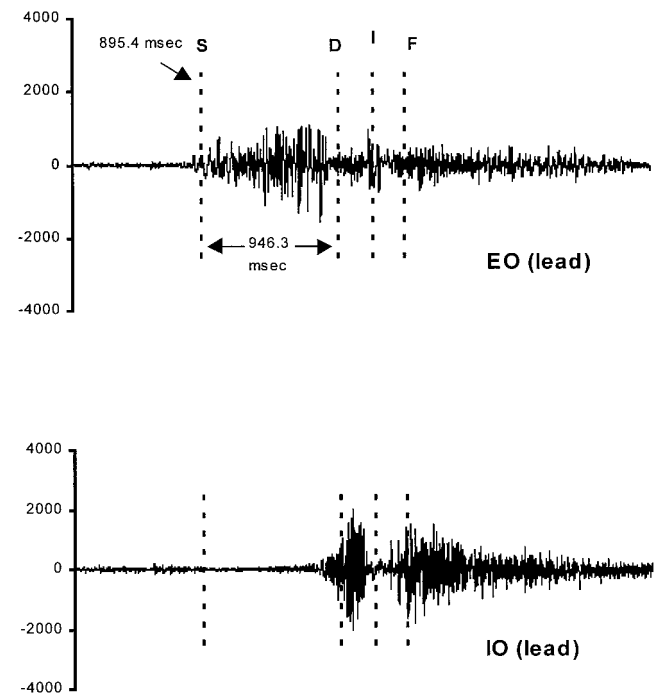

FIGURE 4—EMG signals of EO (lead) and IO (lead) muscle activity during the golf swing. S, start of backswing; D, start of downswing; I, ball impact; F, finish.

ical delay (EMD). The EMD is approximately 40 ms (31). Assuming this is a constant parameter and should not vary between AC and CLBP groups, the differences observed in EMG signal onset times in this study should represent a difference in the time of muscle mechanical response.

Abdominal muscle fatigue after the practice session. Given the important functional contribution of the trunk muscles during the golf swing, there is a need for coordination and control by the central nervous system in recruiting these muscles over a long period of time. Trunk muscle coordination may be compromised by muscle fatigue and result in decreased trunk stability and increased injury risk (20). Measuring changes in the EMG power frequency spectrum is a common method for assessing muscular fatigue (19,22,23,25). Surface EMG measurements of the median frequency are noninvasive and independent of the subject's effort level (19). Indices of muscle performance that are derived from spectral parameters of the surface EMG signal may provide a more objective measure of muscle performance than purely mechanical indices (25).

Results from this study showed that a 50-min practice session did not appear to influence abdominal muscle fatigue as measured with MF or RMS for both CLBP and AC subjects (Table 3). Furthermore, the onset and magnitudes of abdominal muscle activity during the golf swing as well as ball velocity did not significantly change in either group after the practice session. It would seem likely that if muscular fatigue had developed as a result of the practice session, alterations in the EMG signal and/or ball velocity would have been observed. The hypothesis that abdominal muscles fatigue during a typical practice session was not supported in this case. It is possible that either the practice session did not sufficiently challenge the trunk muscles (resulting in minimal fatigue) or the methods used for assessing abdominal muscle fatigue could not detect this fatigue.

Severity of low back pain after practice session. Although neither abdominal muscle fatigue nor patterns of abdominal muscle activity during a golf swing were affected by the practice session, it is important to note that severity of low back pain did increase as a result of the practice

session in CLBP subjects. These findings would indicate repetitive golf swings are aggravating some part of the musculoskeletal system, which results in increased pain in the lumbar region of the back.

CONCLUSION

The present study showed that activation patterns of the different parts of the abdominal musculature during the golf swing were consistent with that which would be expected, considering the fiber orientation of the oblique muscles and the direction of the rotational movement. Significant differences in EO (lead) muscle activity onset times between AC and CLBP subjects may suggest inappropriate recruitment of these abdominal muscles in CLBP subjects during the golf swing. Because EMG measurements were made on subjects who had existing chronic low back pain, it could not be concluded whether differences in abdominal muscle activity between AC and CLBP subjects were a cause or a result of the pain. A prospective long-term study would be necessary to determine if abdominal muscle activity is affected by or contributes to the onset of low back pain.

Although muscular fatigue was not detected in the abdominal muscles after the practice session, low back pain did significantly increase in CLBP subjects after practicing for 50 min. Future studies should investigate other methods of assessing trunk muscle endurance or other possible causes of low back pain among golfers. It would also be appropriate to investigate the effects of playing 18 holes of golf rather than a typical practice session on the development of low back pain. It may be that walking 18 holes while carrying golf clubs, and repeated bending while putting combined with repetitive swings, could potentially cause a greater increase in low back pain and possibly more apparent muscle fatigue.

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