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Electromyographic Analyses of the Erector Spinae Muscles during Golf Swings using Four Different Clubs

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Abstract

The purpose of this study was to compare the electromyography (EMG) patterns of the thoracic and lumbar regions of the erector spinae (ES) muscle during the golf swing whilst using four different golf clubs. Fifteen right-handed male golfers performed a total of twenty swings in random order using the driver, 4-iron, 7-iron and pitching-wedge. Surface EMG was recorded from the lead and trail sides of the thoracic and lumbar regions of the ES muscle (T8, L1 and L5 lateral to the spinous-process). Three-dimensional high-speed video analysis was used to identify the backswing, forward swing, acceleration, early and late follow-through phases of the golf swing. No significant differences in muscle-activation levels from the lead and trail sides of the thoracic and lumbar regions of the ES muscle were displayed between the driver, 4-iron, 7-iron and pitching-wedge ($P > 0.05$). The highest mean thoracic and lumbar ES muscle-activation levels were displayed in the forward swing (67 - 99% MVC) and acceleration (83 - 106% MVC) phases of the swing for all clubs tested. The findings from this study show that there were no significant statistical differences between the driver, 4-iron, 7-iron and pitching-wedge when examining muscle activity from the thoracic and lumbar regions of the ES muscle.

Key Words: EMG, MVC, Thoracic, Lumbar, Club Head Speed

Introduction

The golf swing is a complex movement which requires a coordinated sequence of muscle activity to efficiently transfer the power and momentum generated by the golf club (McHardy, Pollard, & Luo, 2006). The objective of any golfer is to choose the correct club in order to enable them hit the golf shot with the optimal accuracy and distance (Egret, Vincent, Weber, Dujardin, & Chollet, 2003).

Although golf is thought to be a low-impact sport, biomechanical studies show that many body parts move at high velocities and through extreme ranges of motion (ROM) during the golf swing (Cole & Grimshaw, 2008; David Lindsay & Vandervoort, 2014). As a result of these high velocities and complex movement patterns, the golf swing generates high levels of muscle activity in several areas of the body (Farber, Smith, Kvitne, Mohr, & Shin, 2009; Kao, Pink, Jobe, & Perry, 1995; Marta, Silva, Vaz, Castro, & Pezarat-correia, 2015), including the trunk muscles (Cole & Grimshaw, 2008; Horton, Lindsay, & Macintosh, 2001; Marta, Silva, Vaz, Bruno, & Pezarat-correia, 2013; Luís Silva et al., 2013; Watkins, Uppal, Perry, Pink, & Dinsay, 1996).

As previously mentioned, the trunk muscles are highly active throughout the golf swing and play a key role in trunk rotation as evidenced by research using electromyography (EMG) (Horton et al., 2001; Marta et al., 2013; Pink, Perry, & Jobe, 1993; Watkins et al., 1996). The trunk area is composed of several muscles including: erector spinae (ES), transverse abdominis (TA), rectus abdominis (RA), internal oblique (IO), external oblique (EO) and abdominal oblique (AO) (Tortora & Derrickson, 2011). During the golf swing, trunk muscles display the greatest activation levels during the forward swing and acceleration phases (Marta, Silva, António, Pezarat-correia, & Cabri, 2012; Watkins et al., 1996). A study by Pink et al. (1993) showed that the ES muscle was more active than the AO muscle on the golfer’s trail side (right side for right handed golfers) during the forward swing phase. Watkins et al. (1996) also displayed similar results that showed the trail ES muscle as being more active than the upper and lower RA muscle during the forward swing and acceleration phases. Despite these researchers only focusing on the lumbar ES muscle, it still remains unclear whether or not there is a correlation in muscle activity patterns between the other regions of the spine.

Several rehabilitation (Dolan & Adams, 1993; Larivie, Gagnon, & Loisel, 2000; Vera-Garcia, Ruiz-Pérez, Barbado, Juan-Recio, & Mcgill, 2014) and sports specific (Caldwell, Mcnair, & Williams, 2003; Grimshaw & Burden, 2000) studies have investigated muscle activity levels from thoracic and lumbar regions of the ES. The ES muscle includes the spinalis, longissimus, and iliocostalis muscles. They play a vital role in controlling flexion and rotation of the trunk (Loudon, Manske, & Reiman, 2013).

Caldwell et al. (2003) investigated muscle activity from the thoracic and lumbar regions of the ES muscle during rowing motions. These researchers found that the mean EMG amplitude significantly increased and median frequency significantly reduced during the rowing task, resulting in muscle fatigue in the three identified regions of the ES muscle. Muscle activation levels in the thoracic and lumbar regions of the ES muscle have also been investigated during a medicine-ball side-throw task (Vera-Garcia et al., 2014). These researchers reported distinct differences in muscle activity between the thoracic and lumbar regions of the ES during the backward phase of the examined movement. The medicine-ball side-throw task has similarities in movement to the golf swing. These two skills demonstrate a backward and forward phase, and require powerful trunk muscle contractions during the forward phase when performing the skill (Lindsay & Horton, 2002; Lindsay & Vandervoort, 2014).

Many of the aforementioned golf research reports the influence in club type for the purposes of data collection (Farber et al., 2009; Horton et al., 2001; Marta et al., 2013, 2015; Sorbie et al., 2016). Marta et al. (2015) investigated the effect of different golf clubs on lower limb muscles. These researchers reported statistical differences in muscle activation patterns of the lower limb muscles when performing golf swings with the 4-iron, 7-iron and pitching wedge. These differences were generally observed in the forward swing, acceleration and early follow-through phases of the golf swing. Marta et al. (2013) investigated EMG patterns of trunk muscles when using a long iron (4-iron) and short iron (pitching wedge). Their results showed that there were no significant differences in RA, EO and ES muscle activation levels. The researchers did, however, report that there were increased muscle activity levels when using the 4-iron when compared to the pitching wedge. Whilst this study has displayed interesting findings, it has some limitations. Firstly, the researchers only investigated the middle section of the lumbar region of the ES muscle. A study by Grimshaw & Burden, (2000) showed distinct differences between the upper and lower lumbar region of the ES muscle, as well as the thoracic region. Secondly, the researchers only investigated a long iron (4-iron) and a short iron (pitching wedge) but not the driver. Egret et al., (2003) reported kinematic changes to the golf swing when using different golf clubs. Specifically, the researchers reported that golfers rotated their hips at the top of the backswing between 41 - 63° when using the driver compared to 42 - 58° when using the pitching wedge. Furthermore, the researchers reported that the kinematic changes were clearly distinguishable between the driver and the other clubs. It is reasonable to suggest that these kinematic changes may result in a change in the thoracic and lumbar ES muscle activity when using clubs of a different length and for a different purpose. Egret et al., (2003) also reported that the club head speed (CHS) when using the driver was 1.10 times faster than that of a 5-iron and that the CHS when using the 5-iron was 1.10 times faster than the pitching wedge speed.

The purpose of the current study was to compare the EMG patterns of the thoracic and lumbar regions of the ES muscle during the five phases of the golf swing when using the driver, 4-iron, 7-iron and pitching wedge. It was hypothesized that when performing golf swings with the driver, the thoracic and lumbar regions of the ES muscle would display significantly higher muscle activation values compared to swings performed by the 4-iron, 7-iron and pitching wedge. Secondly, the study aimed to describe the CHS, ball speed (BS) and absolute carry distance (ACD) of the golf shot when using the driver, 4-iron, 7-iron and pitching wedge.

Methods

Participants

Fifteen right-handed male golfers who were physically active participated in this study (Effect size $f < 0.25$). The participants consisted of amateur golfers (Table 1). All participants were required to have had no upper extremity injuries within the past two months and have no history of lower back pain and/or persistent musculoskeletal disorders. They were also required to be currently playing golf regularly each week. All participants completed a physical readiness questionnaire, consent form and a brief questionnaire about their golfing background (handicap, experience and weekly playing capacity) before participating in the study. A golfer’s handicap is calculated from the lowest score over three round s of golf (European Golf Association, 2016). Ethics approval was granted by the XXXXXX Ethics Committee.

Table 1

Electromyography Procedure

The EMG activity was recorded using surface electrodes (AMBU, Cambridgeshire, UK) and a set of 6 Surface EMG Transmitters (Myon 320, Schwarzenberg, Switzerland). In order to reduce impedance at the interface between the skin and the surface electrode, the participant's skin was prepared by removing hair from the tested area, followed by skin abrasion and alcohol cleaning. Pairs of surface EMG electrodes were attached to the skin no more than 20mm apart (centre to centre) over the lead (left side for right handed golfers) and trail sides (right side for right handed golfers) of the ES muscle, lateral to longissimus at T8 and L1 levels, and on the multifidus at the L5 level of the spinous process. Specifically, electrodes were placed 30 mm lateral to the spinous process of the eighth thoracic vertebrae (T8) (Cheung et al., 2005; Pecos-Martín et al., 2016) and 30 mm lateral to the first lumbar vertebrae (L1) (Caldwell et al., 2003; Hermens et al., 1999). For the lower lumber region of the ES muscle, electrodes were placed on and aligned with a line from caudal tip posterior spina iliaca superior to the interspace between L1 and the second lumbar vertebrae (L2) interspace at the level of the fifth lumbar vertebrae (L5) (Grimshaw & Burden, 2000; Hermens et al., 1999).

Electromyography Normalizing Procedure

Prior to EMG recordings, participants performed a 5 minute golf specific warm-up. EMG signals during a maximum voluntary isometric contraction (MVIC) were then collected as reference for the normalization procedure. To determine the maximum EMG signal for the thoracic and lumbar regions of the ES muscle, two isometric repetitions were performed for 4 to 5 s. The MVIC was performed in the Biering-Sorensen position (prone, with the torso horizontally cantilevered over the end of a padded test bench). This position was previously used by Vera-garcia et al. (2014) when recording MVIC EMG data from the thoracic and lumbar regions of the ES muscle. Participants rested for 5 minutes between each repetition in order to avoid the effects of cumulative muscular fatigue.

General Procedures

After completing the golf specific warm-up and MVIC process, participants were instructed to hit twenty golf shots; five with the driver, five with the 4-iron, five with the 7-iron and five with the pitching wedge. The order in which the golf clubs were tested was randomized using a processing generator (TexFixer: www. Texfixer.com). Participants were advised to take into consideration their average distance for the four golf clubs tested within the study (Luis Silva et al., 2015). During each of the golf shots, motion analysis, EMG and golf performance data were recorded. All golf clubs were provided by Taylormade (Taylormade, Basingstoke, UK). To enable all golf shots to be hit safely, golf balls (Titleist, Cambridgeshire, UK) were hit from a high shock absorption artificial golf mat (Longridge, United Kingdom), which was placed in the centre of the laboratory, towards an enclosed golf net (Sports Net Company, United Kingdom) located 2 m from the golf mat.

Video Recording and analysis

For video collection purposes, an 8-camera Vicon Nexus Bonita (Oxford Metrics Ltd, United Kingdom) Motion Analysis System operating at 250 Hz was positioned around the golfer. The video data was synchronised with EMG using the same A/D converter. Four retro-reflective markers were secured to each of the golf clubs being tested. These markers were placed on the base of the grip, halfway down the club, the hosel of the club, and the club head (Higdon, Finch, Leib, & Dugan, 2012). This enabled the researchers to identify the different phases of the golf swing. The golf swing was divided into the following phases: (1) the backswing - from the ball address to the top of the swing; (2) the forward swing - from the top of the swing until the club is horizontal to the ground on the golfer's trail side; (3) acceleration - from the club being horizontal to the ground to the ball contact; (4) early follow-through – from the ball contact to the club being horizontal to the ground on the golfer's lead side; (5) late follow-though – from the horizontal club position to the end of the motion.

Electromyography data processing

All EMG data was sampled at 1000 Hz, digitally filtered (15 – 500 Hz) and root mean squared (RMS) values calculated. For each of the golf shots performed, the average RMS EMG signal was calculated during each phase of the golf swing. All EMG analyses were performed using the proEMG software package (Myon 320, Schwarzenberg, Switzerland). The muscle activity recorded during the golf swings performed by each participant was averaged, and then averaged again within the group, with standard deviation also being calculated.

Performance variables data recording and processing

The Voice Caddie Swing Launch Monitor SC 100 GPS (La Mirada, CA, USA) was used to calculate CHS, BS and ACD of each golf shot. The Launch Monitor was previously validated in-house against the Vicon Bonita Motion Analysis System; TrackmanTM III Golf Swing and Ball Flight Analysis System (Brighton, MI, USA). The Launch Monitor was required to be positioned 1 m directly behind the golf ball and positioned towards the target line of the golfer. After each golf shot, CHS, BS and ACD were logged using Microsoft Excel. The performance variables recorded during the golf swings performed by each participant was averaged, and then averaged again within the group, with standard deviation also being calculated.

Statistical Analysis

Normal distribution for all variables was assessed using the Shapiro-Wilk test (McCormick et al. 2014). If normal distribution ($P > 0.05$) was not granted, a log transformation was conducted on the specific data sets. Following this, a two-way repeated measures ANOVA was performed to explore the impact of the driver, 4-iron, 7-iron and pitching wedge on normalised EMG values, during the five phase of the golf swing. All performance variables were analysed for statistical significance using a one-way repeated measure ANOVA. Additionally, all calculations were performed on SPSS (version 22) and Microsoft Excel (version 2010), and $P < 0.05$ was considered significant.

Results

Comparison between clubs

The muscle activation patterns for the thoracic and lumbar regions of the ES muscle were identical for the four golf clubs tested during each phase of the golf swing. The lead and trail sides lateral to the T8, L1 and L5 of the spinous process of the ES muscle displayed no significant interactions between the clubs ($P > 0.05$). The general tendency was that the swings performed by the driver had the greatest activation levels compared to the 4-iron, 7-iron and pitching wedge, however, this was not statistically significant.

Figure 1

Comparison between phases

During the (1) backswing phase, the lead and trail sides of the ES muscle displayed 27 - 47% of muscle activation (Figure 1). The three levels of the ES muscle displayed a significant increase in muscle activation levels from the backswing to the forward swing phase ($P < 0.05$). During the (2) forward swing phase of the golf swing, the lead and trail sides of the thoracic and lumbar regions of the ES muscle displayed 67 - 99% of muscle activation. When comparing the forward swing to the acceleration phase, 4 areas of the ES muscle (lead T8, trail T8, lead L1 and lead L5) displayed significant increases in muscle activity between the two phases ($P < 0.05$). In contrast, the trail L5 ES muscle activity significantly reduced between the forward swing and the acceleration phase. No significant differences were displayed in the trail L1 between these two phases. During the (3) acceleration phase of the golf swing, the thoracic and lumbar regions of the ES muscle displayed 83 - 106% of muscle activation. Muscle activation levels reduced significantly from the acceleration phase to the early follow-through phase ($P < 0.05$) and significantly reduced again between the early follow-through and late follow-through phases ($P < 0.05$) in the lead and trail side of the thoracic and lumbar regions of the ES muscle. During the (4) early follow-through phase of the golf swing, the thoracic and lumbar regions of the ES muscle displayed 43 - 67% of muscle activation. During the (5) late follow-through phase of the golf swing, the thoracic and lumbar regions of the ES muscle displayed 27 - 43% of muscle activation.

Performance Variables

The ACD of the driver was 1.40 m greater than that of the 4-iron (190.11 ± 18.32 m vs. 135.53 ± 9.11 m) ($P < 0.05$). The ACD of the 4-iron was 1.12 m greater than that of the 7-iron (135.53 ± 9.11 m vs. 121.31 ± 10.20 m) ($P < 0.05$) and the 7-iron was 1.27 m greater than that of the pitching wedge (121.31 ± 10.20 m vs. 95.27 ± 6.05 m) ($P < 0.05$).

The CHS (Figure 2) of the driver was 1.10 km/h greater than that of the 4-iron (150.63 ± 5.98 km/h vs. 136.94 ± 4.05 km/h) ($P < 0.05$). The CHS of the 4-iron was 1.06 km/h greater than that of the 7-iron (136.94 ± 4.05 km/h vs. 129.54 ± 4.84 km/h) ($P < 0.05$) and the 7-iron was 1.16 km/h greater than that of the pitching wedge (129.54 ± 4.84 km/h vs. 111.70 ± 5.82 km/h) ($P < 0.05$).

The BS (Figure 2) of the driver was 1.22 km/h greater than that of the 4-iron (208.27 ± 11.92 km/h vs. 170.60 ± 7.12 km/h) ($P < 0.05$). The BS of the 4-iron was 1.07 km/h greater than that of the 7-iron (170.60 ± 7.12 km/h vs. 159.52 ± 9.48 km/h) ($P < 0.05$) and the 7-iron was 1.22 km/h greater than that of the pitching wedge (159.52 ± 9.48 km/h vs. 131.13 ± 6.49 km/h) ($P < 0.05$).

Figure 2

Discussion

The aim of this study was to compare and describe the EMG patterns of thoracic and lumbar regions of the ES muscle during the five phases of the golf swing when using the driver, 4-iron, 7-iron and pitching wedge. It was hypothesized that when performing golf swings with the driver, the thoracic and lumbar regions of the ES muscle would display significantly higher muscle activation values compared to swings performed by the 4-iron, 7-iron and pitching wedge. The study also aimed to describe the changes in performance variables when using the driver, 4-iron, 7-iron and pitching wedge.

The results from the current study show that the lead and trail sides of the thoracic and lumbar regions of the ES muscle activation patterns were identical for the driver, 4-iron, 7-iron and pitching wedge during each of the five phases of the golf swing, therefore, rejecting the initial hypothesis. Similarly, Marta et al. (2013) reported that EMG muscle activity from the trunk muscles, including the ES muscle lateral to the third lumbar vertebrae, did not change when using a 4-iron compared to a pitching wedge. Additionally, the current study showed that in many cases the longer club generated greater muscle activation levels, however, this was not statically significant. Marta et al. (2013) displayed similar findings by stating that muscle activation levels increased when using the 4-iron in comparison to the pitching wedge. The current research also investigated the use of the driver and 7-iron clubs and reported that the muscle activity produced when using the driver did not significantly change in comparison to the iron and pitching wedge clubs. Egret et al., (2003) reported that the shoulder joint rotation angles and stance are clearly distinguishable between the driver swing and the pitching wedge. However, it seems unlikely that these kinematic changes have an effect on muscle activation levels from the thoracic and lumbar regions of the ES muscle on both the lead and trail sides.

Contrary to the findings of the current study and Marta et al. (2013), Marta et al. (2015) displayed significant changes in muscle activity in the lower limb muscles when examining the 4-iron, 7-iron and pitching wedge. These contrasting results are likely to be a result of different muscles being examined within the study. Specifically, the significant changes observed in the study conducted by Marta et al. (2015) could be associated with the hip extensor muscles requiring greater activation levels when the shaft length and CHS increases. Keogh et al. (2009) have also shown CHS is significantly correlated with lower-body strength.

With reference to the five phases of the golf swing, the current study displays distinct differences in muscle activation between these five phases. These findings are similar to Marta et al., (2013), where the authors reported differences between the phases of the golf swing when examining the lumbar region of the ES muscle. The results from the current study show that in most cases the trail thoracic and lumbar regions of the ES muscle are more active than the lead side during the backswing, especially when using the driver. This may be a result of amateur golfers displaying significantly more left side bend at the top of the backswing in comparison to higher skilled golfers (McTeigue, Lamb, Mottram, & Pirozzolo, 1994). A golfer displaying this significant left side bend at the top of the backswing can be one of the main factors contributing to lower back pain (McTeigue et al., 1994). It is suggested, therefore, that coaches attempt to amend this error in the swing in order to reduce injury risk to the trail side of the thoracic and lumbar regions of the ES muscle, especially when performing swings with the driver.

During the forward swing and acceleration phases, the thoracic and lumbar regions of the ES muscle were at their most active in comparison to the other phases of the golf swing. These finding are in accordance with previous research examining the ES muscle during the golf swing phases (Marta et al., (2013). In the majority of cases, the trail side of the lumbar region of the ES muscle was more active during the forward swing, which is to be expected based on trunk biomechanics of the golf swing (Marta et al., 2013) and the ES muscle counteracting gravity during this phase. Similarly, Marta et al., (2013) also reported greater muscle activation levels from the lumbar region of the ES muscle on the trail side during the forward swing phase. Furthermore, Bulbulian et al., (2001) found that amateur golfers demonstrate significantly less left side bend during the forward swing phase which may also result in amateur golfers displaying greater muscle activation in the trail side of the thoracic and lumbar regions of the ES muscle.

During the acceleration phase, the thoracic and lumbar regions of the ES muscle displayed greater activation levels on the lead side compared to the trail side, especially when using the driver. Although the acceleration phase is one of the shortest phases of the golf swing, the lumbar spine is exposed to high levels of stress. During this phase, the leftward shift of the hip and the counter-clockwise direction rotation of the trunk area on the frontal view may result in the higher activation levels of the lead side in comparison to the trail side (Lim, Chow, & Chae, 2012). These higher activation levels on the lead side are in agreement with previous research investigating the ES muscle during the golf swing (Marta et al., 2013). Due to the high levels of muscle activation levels displayed in both the forward swing and acceleration phases, it is essential for golf coaches to incorporate correct swing techniques in their instruction, as well as ensuring the golfers having good physical conditioning of the lower back area.

During the early and late follow-through phases, activations levels from the thoracic and lumbar regions of the ES muscle reduced as the golfer came close to completion of the swing. The muscle activation levels reduced from the early follow-through phase to the late follow-through phase. These muscle activation reductions in the final two phases of the golf swing are similar to the results in previous research examining the lumbar region of the ES muscle (Marta et al., 2013). The ES muscle on the lead and trail sides showed higher activation values when using the driver compared to the three irons tested, however, these were not statistically significant. These changes between the driver and irons may have been caused by the increased spinal rotation required to complete the driver swing (Gluck, Bendo, & Spivak, 2008) or the increased length of the driver in comparison to the iron clubs (Egret et al., 2003). The current study displayed high variation in the ES activation levels, which may be attributed to the high variability in different swing techniques used by the study participants. Furthermore, this large within-subject variability can be expected when using EMG techniques to evaluate muscle activity (Hashemi Oskouei, Paulin, & Carman, 2013).

In addition to muscle activation levels, this study also investigated the performance variables between the four clubs tested. The results of the study confirm that the ACD, CHS and BS increases when the shaft length increases and the loft of the club decreases. The CHS has been previously investigated with regards to performance variables when using different clubs. Nagao & Sawada. (1973) showed that CHS when using the driver was 1.34 times faster compared to the CHS whilst using the 9-iron. These results are similar to the current study in that the researchers found that the driver swing was 1.35 times faster than that of a pitching wedge, which has a shorter shaft length than a 9-iron and is, therefore, expected to produce a slower CHS. Egret et al., (2003) also reported a CHS of 161.5 km/h when using the driver and 146.7 km/h when using the 5-iron. These results are higher than those reported in the current study (150.63 ± 5.98). This increase may be due to the higher skill level of the golfers who participated in the study conducted by Egret et al., (2003) (mean handicap: 0.4 ± 1.1). Participants in the current study had a higher mean handicap of 15.2 ± 5.4, indicating a lower skill level of golfers in this study than that of Egret et al., (2003). To our current knowledge, BS and ACD have not yet been investigated in relation to using different clubs. The BS has, however, been investigated with regards to upper torso and pelvic rotation (Myers et al., 2008). These researchers showed a mean BS of 200 km/h for golfers with a mean handicap of 15.1 and a BS of 236 km/h for golfers with a mean handicap of 7.8. As the current study tested golfers with a mean handicap of 11.3 and a mean BS of 214 km/h when using the driver, the results in this study are very similar to research published by Myers and colleagues.

The results of this study can help clinicians and golf coaches to have a better understanding of the thoracic and lumbar regions of the ES muscle contribution when using golf clubs with a different shaft length and loft. The current study may also help these clinicians and coaches have a better understanding of the golf swing in terms of muscle activation patterns from the thoracic and lumbar regions of the ES muscle with respect to the phases of the golf swing. The results could help to develop thoracic and lumbar ES specific intervention programmes to prevent injuries. The current study has displayed high activation levels in both the thoracic and lumbar regions of the ES muscle. Inadequate trunk strength and stability may leave golfers more susceptible to developing injuries in relation to lower back pain.

The current study was conducted within a laboratory, therefore ACD had to be calculated from the CHS and BS and may not give a true reflection of the distance of each shot. This may be seen as a limitation of the study. Additionally, only right-handed golfers participated in the current study, therefore the results may not be applicable to left handed-golfers. Furthermore, the results of the current study may not be applicable to females due to an all-male cohort participating in the study.

Conclusion

The results of the current study indicate that there are no significant differences in the thoracic and lumbar regions of the ES muscle activation levels between golf swings performed with the driver, 4-iron, 7-iron and pitching wedge, therefore it seems unlikely that the risk of injury to the lower back area will increase when performing swings with the driver compared to the iron clubs. Furthermore, the results of the current study display distinct differences in muscle activation levels when examining the five phases. Finally, the greatest thoracic and lumbar ES muscle activation levels were observed during the forward swing and acceleration phase of the golf swing. The outcome of this study provides clinicians and coaches with useful physiological parameters that could highlight some of the potential underlying mechanisms associated with the development of lower back pain.

References

Bulbulian, R., Ball, K. A., & Seaman, D. R. (2001). The short golf backswing: Effects on performance and spinal health implications. *Journal of Manipulative and Physiological Therapeutics*, *24*(9), 569–575. http://doi.org/10.1067/mmt.2001.118982

Caldwell, J. S., Mcnair, P. J., & Williams, M. (2003). The effects of repetitive motion on lumbar flexion and erector spinae muscle activity in rowers. *Clinical Biomechanics*, *18*(8), 704–711. http://doi.org/10.1016/S0268-0033(03)00117-7

Cheung, J., Halbertsma, J. P. K., Veldhuizen, A. G., Sluiter, W. J., Maurits, N. M., Cool, J. C., & Van Horn, J. R. (2005). A preliminary study on electromyographic analysis of the paraspinal musculature in idiopathic scoliosis. *European Spine Journal*, *14*(2), 130–137. http://doi.org/10.1007/s00586-004-0780-7

Cole, M. H., & Grimshaw, P. N. (2008). Electromyography of the trunk and abdominal muscles in golfers with and without low back pain. *Journal of Science and Medicine in Sport*, *11*(2), 174–181. http://doi.org/10.1016/j.jsams.2007.02.006

Dolan, P., & Adams, M. . (1993). The relationship between EMG activity and extensor moment generation in the erector spinae muscles during bending and lifting activities. *Journal of Biomechanics*, *26*(5), 513–522.

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*(6), 465–470. http://doi.org/10.1055/s-2003-41175

European Golf Association. (2016). *Handicap System 2016 – 2019*.

Farber, A. J., Smith, J. S., Kvitne, R. S., Mohr, K. J., & Shin, S. S. (2009). Electromyographic analysis of forearm muscles in professional and amateur golfers. *The American Journal of Sports Medicine*, *37*(2), 396–401. http://doi.org/10.1177/0363546508325154

Gluck, G. S., Bendo, J. A., & Spivak, J. M. (2008). The lumbar spine and low back pain in golf: a literature review of swing biomechanics and injury prevention. *Spine Journal*, *8*(5), 778–788. http://doi.org/10.1016/j.spinee.2007.07.388

Grimshaw, P. N., & Burden, A. M. (2000). Case report: reduction of low back pain in a professional golfer. *Medicine and Science in Sports and Exercise*, *32*(7), 1667–1673. http://doi.org/10.1097/00005768-200010000-00001

Hashemi Oskouei, A., Paulin, M. G., & Carman, A. B. (2013). Intra-session and inter-day reliability of forearm surface EMG during varying hand grip forces. *Journal of Electromyography and Kinesiology*, *23*(1), 216–222. http://doi.org/10.1016/j.jelekin.2012.08.011

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., … Hägg, G. (1999). European Recommendations for Surface ElectroMyoGraphy. *Seniam*, 8–11. http://doi.org/10.1016/S1050-6411(00)00027-4

Higdon, N. R., Finch, W. H., Leib, D., & Dugan, E. L. (2012). Effects of fatigue on golf performance. *Sports Biomechanics*, *11*(2), 190–196. http://doi.org/10.1080/14763141.2011.638386

Horton, J., Lindsay, D., & Macintosh, B. (2001). Abdominal muscle activation of elite male golfers with chronic low back pain. *Medicine & Science in Sports & Exercise*, (29), 1647–1654.

Kao, J., Pink, M., Jobe, F., & Perry, J. (1995). Electromyographic analysis of the scapular muscles during a golf swing. *The American Journal of Sports Medicine*, *23*(1), 19–23.

Larivie, C., Gagnon, D., & Loisel, P. (2000). The comparison of trunk muscles EMG activation between subjects with and without chronic low back pain during flexion – extension and lateral bending tasks. *Journal of Electromyography and Kinesiology*, *10*(2), 79–91.

Lim, Y.-T., Chow, J. W., & Chae, W.-S. (2012). Lumbar spinal loads and muscle activity during a golf swing. *Sports Biomechanics*, *11*(2), 197–211. http://doi.org/10.1080/14763141.2012.670662

Lindsay, D., & Horton, J. (2002). Comparison of spine motion in elite golfers with and without low back pain. *Journal of Sports Sciences*, *20*(8), 599–605. http://doi.org/10.1080/026404102320183158

Lindsay, D., & Vandervoort, A. (2014). Golf-related low back pain: a review of causative factors and prevention strategies. *Asian Journal of Sports Medicine*, *5*(4), 1–8. http://doi.org/10.5812/asjsm.24289

Loudon, J., Manske, R., & Reiman, M. (2013). *Clinical Mechanics and Kinesiology* (1st ed.). Human Kinetics.

Marta, S., Silva, L., António, M., Pezarat-correia, P., & Cabri, J. (2012). Electromyography variables during the golf swing : A literature review. *Journal of Electromyography and Kinesiology*, *22*, 803–813. http://doi.org/10.1016/j.jelekin.2012.04.002

Marta, S., Silva, L., Vaz, J., Bruno, P., & Pezarat-correia, P. (2013). Electromyographic analysis of trunk muscles during the golf swing performed with two different llubs. *International Journal of Sports Science & Coaching*, *8*(4), 779–787.

Marta, S., Silva, L., Vaz, J. R., Castro, M. A., & Pezarat-correia, P. (2015). Electromyographic analysis of lower limb muscles during the golf swing performed with three different clubs. *Journal of Sports Sciences*, *38*(8), 713–720. http://doi.org/10.1080/02640414.2015.1069376

McHardy, A., Pollard, H., & Luo, K. (2006). Golf injuries: A review of the literature. *Sports Medicine*, *36*(2), 171–187.

McTeigue, M., Lamb, S., Mottram, R., & Pirozzolo, F. (1994). Spine and hip motion analysis during the golf swing. In *Proceedings of the World Scientific Congress of Golf* (pp. 50–58). London.

Myers, J., Lephart, S., Tsai, Y.-S., 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*(2), 181–188. http://doi.org/10.1080/02640410701373543

Nagao, N., & Sawada, Y. (1973). A kinematic analysis in golf swing concerning driver shot and No. 9 iron shot. *The Journal of Sports Medicine and Physical Fitness*, *13*, 4–16.

Pecos-Martín, D., de Melo Aroeira, A. E., Verás Silva, R. L., Martínez de Tejada Pozo, G., Rodríguez Solano, L. M., Plaza-Manzano, G., … Falla, D. (2016). Immediate effects of thoracic spinal mobilisation on erector spinae muscle activity and pain in patients with thoracic spine pain: A preliminary randomised controlled trial. *Physiotherapy*, 1–8. http://doi.org/10.1016/j.physio.2015.10.016

Pink, M., Perry, J., & Jobe, F. W. (1993). Electromyographic analysis of the trunk in golfers. *The*

American Journal of Sports Medicine, *21*(3), 385–388. http://doi.org/10.1177/036354659302100310

Silva, L., Marta, S., Vaz, J., Fernandes, O., Castro, M. A., & Pezarat-Correia, P. (2013). Trunk muscle activation during golf swing: Baseline and threshold. *Journal of Electromyography and Kinesiology*, *23*(5), 1174–1182. http://doi.org/10.1016/j.jelekin.2013.05.007

Silva, L., Vaz, J. R., Castro, M. A., Serranho, P., Cabri, J., & Pezarat-Correia, P. (2015). Recurrence quantification analysis and support vector machines for golf handicap and low back pain EMG classification. *Journal of Electromyography and Kinesiology*, *25*(4), 637–647. http://doi.org/10.1016/j.jelekin.2015.04.008

Sorbie, G. G., Hunter, H. S., Fergal, F. M., Gu, Y., Baker, J. S., & Ugbolue, U. C. (2016). An electromyographic study of the effect of hand grip sizes on forearm muscle activity and golf performance. *Research in Sports Medicine*, *24*(3), 207–218.

Tortora, G., & Derrickson, B. (2011). *Principles of Anatomy & Physiology* (13th ed.). Wiley & Sons, Inc.

Vera-Garcia, F. J., Ruiz-Pérez, I., Barbado, D., Juan-Recio, C., & Mcgill, S. M. (2014). Trunk and shoulder EMG and lumbar kinematics of medicine-ball side throw and sie catch and throw. *European Journal of Human Movement*, *33*, 93–109.

Watkins, R., Uppal, G., Perry, J., Pink, M., & Dinsay, J. (1996). Dynamic electromyographic analysis of trunk musculature in professional golfers. *The American Journal of Sports Medicine*, *24*(4), 535–538.

Table 1: Participants demographics (n=15)

Demographics	**Mean ± SD**	**Range**
Height (m)	1.84 ± 0.1	(1.66 - 1.95)
Body mass (kg)	78.9 ± 11.2	(53.6 - 92.8)
Age (years)	24.9 ± 4.1	(20 - 36.0)
Handicap	15.2 ± 5.4	(10 - 22)
Experience	10.1 ± 4.4	(7-18)

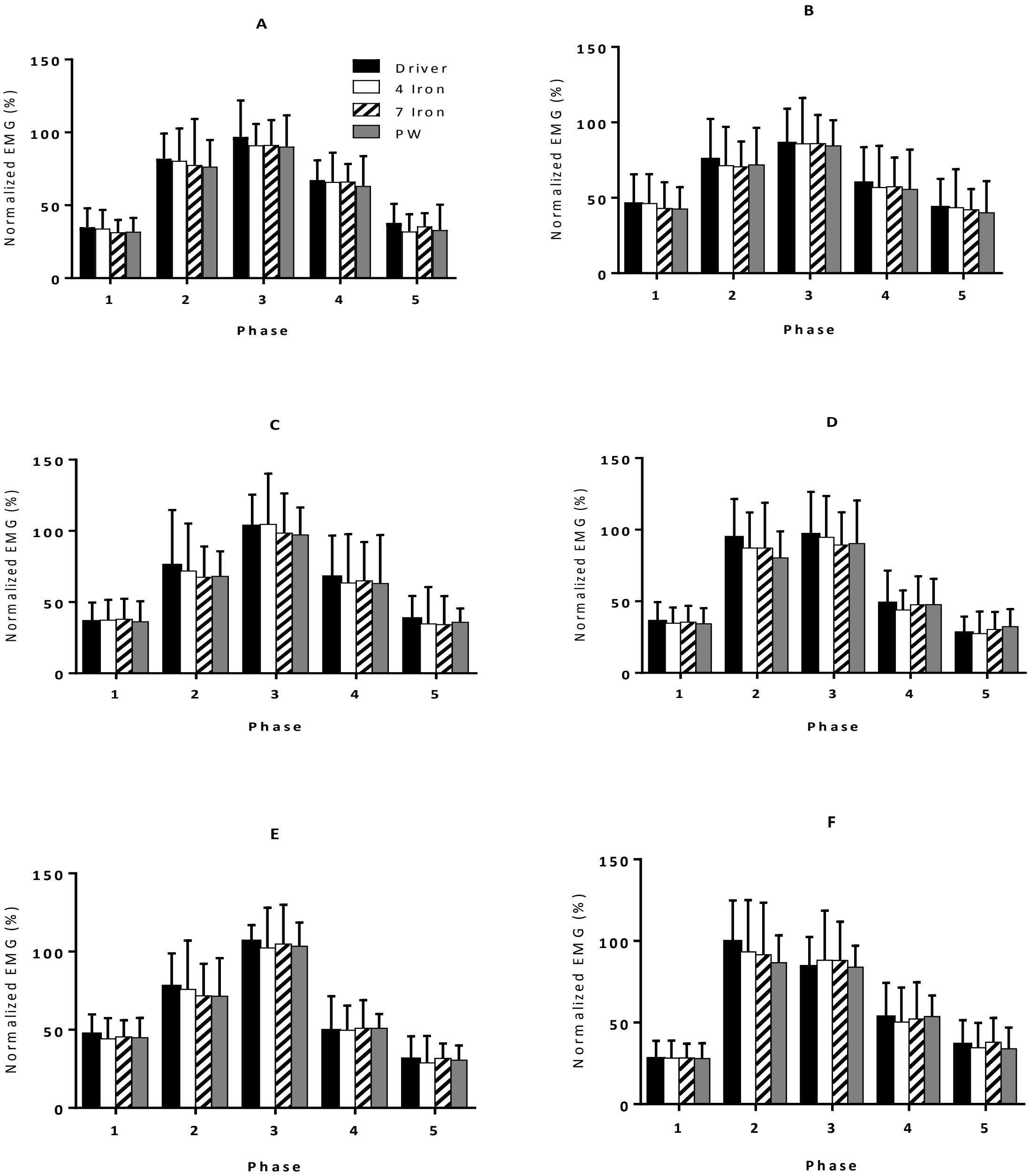

Figure 1. Muscle activity for the erector spinae (A) left T8 ES, (B) right T8 ES, (C) left L1 ES, (D) right L1 ES, (E) left L5 ES, and (F) right L5 ES throughout the 5 phases of the golf swing whilst using the driver, 4-iron, 7-iron and pitching wedge (PW). (1) backswing, (2) forward swing, (3) acceleration, (4) early follow-through and (5) late follow-through phases.

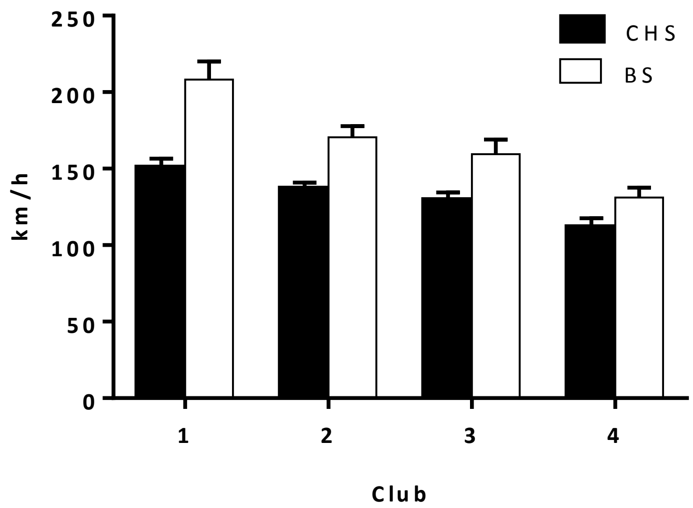

Figure 2. Mean club head speed (CHS) and ball speed (BS) of the 15 participants using the (1) driver, (2) 4-iron, (3) 7-iron, (4) pitching wedge (Mean ± Standard Deviation).