Using Principal Components Analysis to Determine Differences in 3D Loading Patterns Between Beginner and Collegiate Level Golfers

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Traditionally, golf research and instruction have focused on the kinematics of the golf swing; while relatively little attention has been paid to the three-dimensional (3D) golf ground reaction forces (GRF). These GRF profiles are waveforms representing the change in these forces throughout the golf swing. If they are just represented by a few discreet variables, much of the variability is lost. Therefore, this study used Principal Components Analysis (PCA) to determine 3D GRF differences between the golf swing of 23 beginners and 18 NCAA collegiate golfers. Six GRF waveforms were analyzed (3D GRFs for the lead/trail legs) and each waveform required 5 principal component (PC) scores to represent at least 90% of variability in the curves. Of the 30 PC scores analyzed, 6 of them were found to be significantly different between the Collegiate and Beginner golfer. The differences which represented the most variability occurred in the vertical forces, but there were also key differences in the shearing forces. GRF data could potentially help in developing better golf instructional techniques.

Keywords: golf swing, kinetics, ground reaction forces, biomechanics.

The sport of golf is a popular way of keeping individuals of all ages active throughout their lifetime. In 2003, it was estimated that there were 55 million golfers worldwide (Farrally et al., 2003) and with the inclusion of golf as an Olympic
sport in 2016, it can be hypothesized that the number of people taking up the game will increase in the near future. If participation rates do in fact increase, it will be important that better instructional techniques are developed so that those who take up the game can have a better chance of improving. If individuals experience success within the game, they will be more likely to continue their participation in the activity (Bandura, 1986; McAuley, 1993). Since it has been shown that walking 18 holes of golf consistently exceeds the 10,000 steps per day generally recommended as part of a general physical activity plan (Kobriger, Smith, Hollman, & Smith, 2006), having more people playing the game and reaping the associated health benefits would have several positive effects throughout society. Thus, an important aspect of keeping individuals active in golf is to provide evidence-based instructional strategies that not only optimize their learning of the golf swing but also optimize their performance on the course. The motor learning and control literature provides a variety of evidence-based instructional strategies to help golf instructors effectively teach the golf swing. These concepts include methods of delivering instruction and feedback (Wu, Porter, & Brown, 2012; Wulf & Prinz, 2001), methods to design practice (Wu & Magill, 2011; Magill & Hall, 1990), and principles on using technology for instruction (McCullagh & Weiss, 2001; Magill, 2001).

Traditionally, golf swing research and instructional techniques have focused on the kinematics of the swing (Hume, Keogh, & Reid, 2005; Lindsay, Mantrop, & Vandervoort, 2008) while relatively little attention has been paid to the three-dimensional (3D) ground reaction forces (GRF) which produce these movements. One study has reported 3D GRFs and found differences between golfers of three different skill levels: professionals, low handicap, and high handicaps (Barrentine, Fleisig, & Johnson, 1994). This study found differences in the 3D GRF loading patterns between golfers of different skill levels; however, the variables used to make these comparisons were predefined parameters taken from the GRF curves (peaks forces and time to peak). These GRF profiles are waveforms representing the change in these 3D forces throughout the golf swing, and if these curves are just represented by a few subjective predefined parameters, much of the variability in the entire curve is not accounted for and differences between skill level groups may not be detected.

A statistical technique that can be used to analyze entire waveforms is Principal Components Analysis (PCA). This data reduction technique has been used in the analysis of various other biomechanical waveforms. PCA has been able to differentiate between healthy and pathological gait patterns (Deluzio & Astephen, 2007; Deluzio, Wyss, Zee, Costigan, & Sorbie, 1997), to track the changes in gait patterns and clinical status following joint replacement surgery (Deluzio, Wyss, Costigan, Sorbie, & Zee, 1999), to identify faulty lifting patterns (Wrigley, Albert, Deluzio, & Stevenson, 2005, 2006), to determine the effectiveness of a personal lifting device (Sadler, Graham, & Stevenson, 2011), and to determine the differences between young and older adult movement patterns (Reid, Graham, & Costigan, 2010). However, to date it has not been used to analyze any biomechanical data related to golfing technique. PCA provides a small set of uncorrelated, objectively selected variables ranked in order of importance that can be used to test differences in groups using standard statistical tests (Deluzio et al., 1997). Some advantages of using PCA over randomly selecting curve parameters is that PCA variables are objective and not subjectively selected by the researchers, the resulting PCA scores...
are independent of each other and not correlated as many curve parameters would be, PCA scores are ranked in terms of their importance (the amount of variability they explain in the entire data set) whereas random curve parameters would not give you this information. Therefore, this paper will use PCA to determine the differences in 3D GRFs during the golf swing between a group of Beginner and a group of Collegiate golfers.

Methods

Participants

Participants were recruited for two groups: 18 Collegiate golfers (9 male/9 female, age = 19.6 ± 1.3 years, height = 1.71 m ± 0.10 m, mass = 69.6 ± 8.9 kg), 23 Beginner golfers (10 male/13 female, age = 22.9 ± 1.9 years, height = 1.71 ± 0.10 m, mass = 72.9 ± 16.7 kg). All collegiate golfers were members of an NCAA division I golf team, while all Beginner golfers were undergraduate kinesiology students who had never played a round of golf or received a formal golf lesson. All participants signed a letter of informed consent approved by the University’s Research Ethics Board before participation in the study.

Instrumentation

Kinematic data from retro-reflective markers placed on the club-head and ball were tracked using a 9 camera Qualisys (Gothenburg, Sweden) Oqus 300 motion capture system. This allowed for the phases of the swing to be identified. Participants also stood with each foot on a separate AMTI (Newton, MA, USA) force platform which was covered with artificial grass. Footwear was standardized by having all participants wear standard athletic footwear as none of the Beginner golfers owned spiked golf shoes. Golf shots were also hit parallel to one of the principal axes of each plate so that forces could be analyzed in the laboratory global coordinate system. 3D GRF data were named relative to the anatomical directions of the golfer (vertical [Vert], anterior-posterior [AP], medial-lateral [ML]) and were collected for each foot at 2400 Hz while marker data were simultaneously collected at 240 Hz using Qualisys Track Manager (QTM) software (Gothenburg, Sweden).

Protocol

Each participant was asked to hit 5 golf shots with a 5-iron into a net while standing with each foot on a separate force platform. All golfers were right handed so their left foot was the lead foot (LF) and their right foot was the trail foot (TF).

Data Processing

Club and ball kinematic data were used to crop 3D GRF data so that only data from take-away (defined as the instant the club began to move away from the ball) until ball contact (the moment the ball was struck) were analyzed. Data were then time normalized from 0 to 100% (with 100% being ball contact) and the data for each GRF curve (Vert, AP, ML) and foot (LF, TF) for all 5 swings were averaged together to give 6 waveforms for each participant. This gave a representation of
their “average” force pattern, as has been done in the study of the biomechanics of several other movement patterns (Reid et al., 2010; Sadler et al., 2011). GRF data were also amplitude normalized to body weight (BW) units by dividing the GRF (in Newtons) by the participant’s body weight (in Newtons).

**Design and Analysis**

Principal components analysis (PCA) was used to reduce the size of the data set. Our PCA model used an n x p matrix of data where n = number of participants and p = are the variables representing the waveform. Our data set for each of the 6 waveforms consisted of p = 100 variables (time normalized to 100% of swing) for all n = 41 participants, giving a matrix of 4100 data points/waveform. PCA was then used on one curve at a time to apply a mathematical orthogonal transformation that converts the data into new uncorrelated variables called principal components (PCs) which are arranged in decreasing order of the amount of variance they explain from the entire original data set (Deluzio et al., 1999; Deluzio et al., 1997). The PCA model is a transformation matrix that creates weighting factors for each PC score so that it can be determined which variables (or phases of the golf swing) contribute most to each PC score. These weighting factors help identify the phases of the swing that are most highly weighted in accounting for the variability in the entire data set (force curve for all participants) represented by that particular PC score. Each participant’s curve was then scored against the mean curve for the entire data set, and the degree to which each participant’s curve differs from the mean curve is multiplied by the weighting factor for each variable (% of the swing) (Deluzio & Astephen, 2007). Therefore, the further the participants curve was from the mean curve in the areas that were most highly weighted, the larger the magnitude of their PC score.

PC scores create new variables that are a subset of uncorrelated, objectively selected curve parameters ranked in order of importance (amount of variability they represent in the entire data set) that can then be tested using regular statistical procedures for group differences (Collegiate vs. Beginners). To provide meaning to PC scores that were significantly different between groups, the weighting factor was first examined to see which phases of the swing were most highly weighted in that particular score. Following this, force plate waveforms from individual participants that corresponded to high and low PC scores (on opposite ends of the spectrum for that particular PC score) were examined, as has been done previously (Astephen, Deluzio, Caldwell, Dunbar, & Hubley-Kozey, 2008; Reid et al., 2010).

PCA is a powerful analysis tool as the majority of the variance in the entire data set can be explained by the first few PC scores. The number of PCs needed to adequately represent a data set can be determined based on the amount of variance they explain. For this current study, additional PC scores were included in the analysis until at least 90% of the variance in the entire data set was explained, as had been done previously (Deluzio & Astephen, 2007; Reid et al., 2010). This resulted in five PC scores being included for all six PCA models. Participant PC scores were then divided up based on group (Collegiate vs. Beginner) and independent sample t tests were run on the five PC scores per curve to determine differences between groups. Critical p-values were adjusted using a Bonferroni adjustment for the five t tests performed per force curve (p < .05/5 comparisons = p < .01).
Results

The Beginner golfers spent an average of 73.6% (1.03 ± 0.33 s) of their swing in the backswing and 26.4% (0.37 ± 0.11 s) in the downswing. The Collegiate golfers spent an average of 77.2% (0.95 ± 0.20 s) in the backswing and 22.8% (0.28 ± 0.05 s) in the downswing.

The results of the PC analysis of the GRF data are shown in Table 1 along with the percent variation in the entire data set represented by each PC score. There were significant differences (p < .01) between the Beginner and Collegiate golfers in 6 of the 30 PC scores that were tested.

Table 1  Principal Component Scores and Percent Variation Explained for the Collegiate and Beginner Golfers across All Ground Reaction Force Curves.

<table>
<thead>
<tr>
<th>Force Measure</th>
<th>PC</th>
<th>Variance Explained (%)</th>
<th>PC Score (mean ± SD)</th>
<th>Collegiate</th>
<th>Beginner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vert Force</td>
<td>1</td>
<td>45.6</td>
<td>0.86 ± 0.61</td>
<td>-0.67 ± 0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>21.5</td>
<td>0.24 ± 0.65</td>
<td>-0.19 ± 0.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>16.6</td>
<td>-0.05 ± 0.68</td>
<td>0.04 ± 0.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6.9</td>
<td>-0.02 ± 0.43</td>
<td>0.02 ± 0.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.8</td>
<td>0.03 ± 0.25</td>
<td>-0.02 ± 0.38</td>
<td></td>
</tr>
<tr>
<td>AP Force</td>
<td>1</td>
<td>41.1</td>
<td>0.09 ± 0.26</td>
<td>-0.07 ± 0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>23.5</td>
<td>-0.11 ± 0.17</td>
<td>0.08 ± 0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>13.6</td>
<td>0.06 ± 0.11</td>
<td>-0.04 ± 0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8.4</td>
<td>-0.02 ± 0.12</td>
<td>0.02 ± 0.09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.2</td>
<td>0.01 ± 0.10</td>
<td>-0.01 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>ML Force</td>
<td>1</td>
<td>34.0</td>
<td>-0.04 ± 0.21</td>
<td>0.04 ± 0.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>29.9</td>
<td>0.14 ± 0.14</td>
<td>-0.11 ± 0.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>14.1</td>
<td>0.02 ± 0.13</td>
<td>-0.02 ± 0.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>7.7</td>
<td>-0.02 ± 0.12</td>
<td>0.02 ± 0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.1</td>
<td>0.01 ± 0.08</td>
<td>-0.01 ± 0.10</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
For LF Vert Force PC1, LF AP Force PC2 and TF ML Force PC1, the Collegiate golfers had a positive score while the Beginners had a negative score; whereas, for the LF AP Force PC2, LF ML Force PC3 and TF Vert Force PC1, the Collegiate golfers had a negative score while the Beginners had a positive score.

Figure 1 shows the PC weighting factors, along with force curves corresponding with individual participants who scored high and low for that particular PC score. These force curves were the individuals force curves for participants who were furthest from the mean curve in opposite directions for the phases of the swing that were most highly weighted by the weighting factor for that PC score. For both the LF and TF Vertical PC1 weighting factors (Figure 1a & 1b), the majority of the swing is positively weighted but both become negative just before ball contact. Since the Collegiate golfers had a positive (high) PC1 score for the LF Vert, they tended to have more weight on their LF throughout the swing but also had it

Table 1 (continued)

<table>
<thead>
<tr>
<th>Force Measure</th>
<th>PC</th>
<th>Variance Explained (%)</th>
<th>PC Score (mean ± SD)</th>
<th>Collegiate</th>
<th>Beginner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trail Foot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vert Force</td>
<td>1‡</td>
<td>49.3</td>
<td>-0.65 ± 0.75</td>
<td>0.51 ± 0.76</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>18.5</td>
<td>0.25 ± 0.49</td>
<td>-0.19 ± 0.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>12.4</td>
<td>-0.11 ± 0.57</td>
<td>0.09 ± 0.37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9.0</td>
<td>-0.07 ± 0.27</td>
<td>0.06 ± 0.48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.3</td>
<td>0.02 ± 0.27</td>
<td>-0.02 ± 0.29</td>
<td></td>
</tr>
<tr>
<td>AP Force</td>
<td>1</td>
<td>44.4</td>
<td>0.11 ± 0.19</td>
<td>-0.09 ± 0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>18.7</td>
<td>0.05 ± 0.12</td>
<td>-0.04 ± 0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>17.1</td>
<td>-0.07 ± 0.10</td>
<td>0.05 ± 0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8.6</td>
<td>0.02 ± 0.10</td>
<td>-0.01 ± 0.08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5.0</td>
<td>-0.02 ± 0.07</td>
<td>0.01 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>ML Force</td>
<td>1‡</td>
<td>47.6</td>
<td>0.02 ± 0.12</td>
<td>-0.01 ± 0.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>18.7</td>
<td>0.05 ± 0.15</td>
<td>-0.04 ± 0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3‡</td>
<td>14.5</td>
<td>-0.02 ± 0.13</td>
<td>0.01 ± 0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6.2</td>
<td>-0.07 ± 0.07</td>
<td>0.05 ± 0.09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.5</td>
<td>-0.01 ± 0.09</td>
<td>0.01 ± 0.06</td>
<td></td>
</tr>
</tbody>
</table>

-‡ = significant difference in PC scores between the Collegiate and Beginner golfers (p < 0.01)
- PC = principal component, Vert = vertical, AP = anterior-posterior, ML = medial-lateral
Figure 1 — Principal component (PC) weighting factors for all PC Scores that were significantly different between the Collegiate and Beginner golfers. Each graph also has individual force waveforms for one participant who scored high (positive PC score) and one who scored low (negative PC score) for that particular variable.
Figure 1 — (continued)
Figure 1 — (continued)
drop significantly before ball contact. The Collegiate golfers also had a negative (low) PC1 score for the TF Vert, indicating that they had less weight on their TF throughout the swing but that it increased just before ball contact.

For the LF AP Force PC2, the weighting factor is negative throughout the backswing and positive throughout the downswing (Figure 1c). Since the Collegiate golfers had a negative (low) PC2 score for this measure, this means they are creating more of a positive AP shear force (anteriorly directed) during the backswing and a negative AP shear force (posteriorly directed) during the downswing with their LF than the Beginners.

The TF ML force PC1 has a positive weighting factor throughout the swing that increases into the late backswing and then decreases quickly leading into ball contact (Figure 1d). Since the Collegiate golfers had a positive (high) PC1 score, this means they displayed more positive ML force in the TF (force directed toward the target) throughout the swing than did the Beginner golfers. In addition, for the TF ML force PC3, the weighting factor is negative during the early downswing and quickly reverses to a large positive value just before ball contact (Figure 1e). Since the Collegiate golfers had a negative (low) PC3 score for this measure, they would tend to have a positively directed ML force (directed toward the target) during the early downswing and then a negatively directed ML force (directed away from the target) just before ball contact.

Finally, the LF ML force PC2 has a weighting factor that has three distinct phases to it; a positive weighting for the first half of the swing (early backswing), a negative weight for the late backswing and early downswing, then another positive weighting leading into ball contact (Figure 1f). Since the Collegiate golfers had a positive (high) PC2, as compared with the Beginner golfers, they had less negative ML force (directed away from the target) during the backswing, more positive ML force (directed toward the target) during the late back swing and early down swing, and less negative ML force (directed away from the target) during the late downswing leading into ball contact.

**Discussion**

The purpose of this study was to determine the differences in 3D GRF loading patterns between a group of Collegiate golfers and a group of Beginner golfers using PCA. This analysis revealed several differences in these 3D loading patterns that help expand on the work conducted by Barrentine et al. (1994), where only pre-defined parameters were used to select variables off of these waveforms. The main difference between the two groups in the LF vertical force involved the Collegiate players keeping more weight on their lead foot throughout the backswing and also having this force peak earlier before ball contact than the Beginners. It has been suggested that for the general biomechanical foundation of striking or throwing skills, a proximal to distal sequencing of joint rotations creates the most effective results (Putnam, 1993). This has also been shown to be true specifically for golf swings (Cheetham et al., 2008; Tinmark, Hellstrom, Halvorsen, & Thorstensson, 2010). To initiate this process and allow time for the proximal to distal sequencing to occur, it can by hypothesized that one would need to transfer the body weight onto the front foot well in advance of ball contact, as was done by the Collegiate golfers. As can be seen in Figure 1 (a), the Beginner golfers have their peak LF vert
force peaking much closer to ball impact, which may not provide enough time for this sequencing to occur before impact. This concept may also help describe the differences seen in the TF vert forces as well.

The Beginners tended to have much more weight on the TF throughout the late part of the backswing and early part of the downswing, whereas the Collegiate players unloaded the TF much earlier. Having too much weight on the TF late in the backswing and early in the downswing may not give enough time to transfer this weight to the front foot and initiate the sequence of events that needs to occur before ball contact. Therefore, it seems that the more effective vertical force patterns involve transferring the weight off of the back foot and onto the front foot early in the downswing, to allow time for the proper sequencing of body rotations to occur.

The difference in the AP force on the LF had the Collegiate players producing much more anteriorly directed GRF during the early part of the backswing and posteriorly directed GRF during the early part of the downswing. It has been suggested that the GRFs produced during the golf swing are used to create the coupled forces (Hellstrom, 2009) or the resultant moment needed to produce the rotations of the body segments required for an efficient swing, and our data supports this theory. These rotations created with AP GRFS may also help initiate the sequence of segmental rotations needed for an effective golf swing (Cheetham et al., 2008; Tinmark et al., 2010). Examples of these force couples are shown for the backswing (producing right rotation for a right handed player) and downswing (producing left rotation for a right handed player) in Figure 2.

Figure 2 — Animations showing how the Anterior-Posterior components of the GRFs create the force couples needed to create right rotation during the backswing (left) and left rotation during the downswing (right).
It is also interesting that an effective swing appears to have the posteriorly directed AP forces in the LF peaking in the early part of the downswing, when the LF vertical force is also peaking. Having the LF vert force peak at the same time as this posterior AP force may increase the effectiveness of the AP shear force in producing rotations by also increasing the normal force between the LF and the ground.

There were several differences in the ML forces between the Collegiate and Beginner golfers. The TF ML force resulted in two PC scores being significantly different between groups. For the PC1 score, the Collegiate players tended to produce a force that was directed toward the target throughout the swing but also peaked close to the top of the backswing or change of direction in the swing (Figure 1d). Interestingly, the Beginner golfers tended to have a very small amount of positive force (directed toward the target) and actually had this force become negative (directed away from the target) early in the downswing. Koslow (1994) identified common weight shifting patterns of Beginner golfers and labeled one style as a “reverse pivot”. This pattern can be thought of as producing momentum directed away from the target as they approach ball contact. It can be hypothesized that this “reverse pivot” would be created by the negative ML force (directed away from the target) seen in the Beginner golfers in the early downswing. The TF ML force PC3 demonstrates that the Collegiate golfers create forward momentum through a large positive ML force (directed toward the target) during the early part of the downswing that subsequently needs to be stopped by negative ML force (directed away from the target) before ball contact (Figure 1e). It can be hypothesized that this deceleration of the forward momentum would be created by the ML forces rapid shift toward negative values just before ball contact in the Collegiate players.

In other athletic movements, this deceleration has been shown to initiate the transfer of momentum from the ground up (Morriss & Bartlett, 1996; Morriss, Bartlett, & Navarro, 2001) and it may also help in avoiding a common swing error that has been described as too much lateral slide of the body or “sway” (Leadbetter, 1990). A similar pattern is seen in the difference in LF ML force PC2, as the Collegiate golfers tended to produce a positive ML force (directed toward the target) in the early part of the downswing which is reversed to a negative force (directed away from the target) just before impact (Figure 1f). The Beginner players tended to have this LF ML force directed away from the target (negative) throughout the transition and downswing and never produced the large positive force (directed toward the target). Animations showing the ML forces directed toward the target at the top of the backswing for both feet, and away from the target just before ball contact are shown in Figure 3. Therefore, it seems that the most effective ML force patterns have the forces directed toward the target during the early part of the downswing to create some forward momentum that is then stopped by ML forces which are directed away from the target just before impact.

While characterizing 3D GRF patterns within the golf swing are critical to understanding the forces that produce the motion of the golf swing, instructors need to use evidence-based instructional strategies to convey this information to their students. While advocating for evidence-based instructional strategies appears like a logical approach, often while trying to teach motor skills, practitioners fail to use evidence-based instruction. This may seem like a mistake of novice instructors or coaches, but recent findings have illustrated a significant lack of evidence-based instructional methods at the elite level of coaching (Porter, Wu, and Partridge, 2010). To successfully
implement findings from biomechanical research, an instructor must consider motor learning concepts that enable players to successfully acquire movement patterns. One such concept that is critical to performance and learning is termed focus of attention. Coaches can modify a player’s attentional focus with the use of verbal instructions or verbal cues. The manner in which a player focuses one’s attention plays a critical role in skill acquisition. According to the attentional focus research, coaches should structure their verbal instructions in a manner that directs golfers’ attention to the effects of their movements (external focus of attention) rather than providing instructions that direct attention to specific body parts (internal focus of attention) (Wulf & Prinz, 2001).

With respect to the findings of this study, specifically the propensity of novices to produce a negative ML force away from the target, an external focus of attention can be fostered by verbally cueing the golfer to “stay over the ball during the backswing” rather than “keep your weight on your front leg during the backswing”. While this may seem like a subtle difference, the performance and learning effects are profound. That is, instructions that orient one’s attention to the effect of movements elicit significantly better performance, and learning, than instructions that direct players to focus on aspects of the body. Research findings within the motor behavior domain have demonstrated the advantage of an external

Figure 3 — Animations showing how the Medial-Lateral components of the ground reaction forces (GRFs) directed toward the target in the transition/early downswing (left) and directed away from the target just before ball contact (right).
focus over an internal focus of attention in a wide range of motor tasks (Al-Abood, Bennet, Hernandez, Ashford, & Davids, 2002; Marchant, Greig, & Scott, 2009; Wu, Porter, & Brown, 2012; Wulf, 2008; Wulf, Lauterbach, & Toole, 1999). In addition, the performance and learning advantage has been demonstrated in novice and experienced golfers (Wulf & Su, 2007).

With the emergence of technology in golf, gathering detailed information such as the forces associated with the golf swing has become much easier. From a learning perspective, golf coaches and players must be mindful with how they use this information (termed augmented feedback). If these GRFs, and the information they provide, are used improperly, acquisition of the desired movement patterns can be significantly hindered. When utilizing augmented feedback, coaches must consider how much information to provide to golfers. Augmented feedback should be provided in such a way that it enhances the sensory information of the golfer by providing less feedback rather than more (Magill, 2001, 2011; Salmoni, Schmidt, & Walter, 1984). When golfers are provided too much augmented feedback, they become reliant on the technology for solutions and become unable to use their own task-intrinsic feedback because they have not learned how to interpret their own sensory information. In short, coaches should be careful when attempting to apply the information contained in this manuscript and not attempt to provide too much feedback to their students.

Although this study discovered several interesting differences in 3D GRF loading patterns between Collegiate and Beginner golfers, it also has several limitations. One limitation is that it did not examine the GRFs associated with the follow-through phase of the golf swing. In addition, the Collegiate players did not wear their normal golf shoes so that footwear could be standardized between groups, and this may have had an effect on their swings. An interesting future comparison would be between low and high handicap regular golfers. This would remove the extreme gap in skill level between our two groups and also allow both groups to wear their normal golf shoes for testing. It may also be useful to separate participants based on performance criteria, such as ball flight characteristics, and not on preestablished criteria (experience level or handicap). Unfortunately, the collection of 3D Doppler radar ball flight kinematics was not possible for all participants in this study, so this information was not included in the current manuscript. Future research can also develop simpler curve parameters to examine golf swing GRF data based on our PCA analysis, as the information here can help focus the selection of curve parameters much better.

This paper focused only on determining differences 3D GRF data that may be useful in developing new golf instructional techniques, which could then be tested to determine their effectiveness in improving performance. This data could also be useful in several other areas such as in improving advanced club fitting techniques, creating better golf training programs and developing golf injury prevention strategies. Further research should attempt to combine kinematics and kinetic variables to determine the optimal joint moments and muscular activation strategies needed to produce a safe and effective golf swing. In addition, correlating GRF patterns to the resulting kinematics of the swing and ball flight parameters could help us better understand this complicated movement so that golf participation rates can be increased and more people can enjoy the benefits of this lifelong game.
References


