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SKILL LEVEL OF GOLFER IMPACTS THE VARIABILITY OF EEG MEASURES UNDER DIFFERENT PRESSURE SETTINGS: A PILOT INVESTIGATION

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Introduction. Previous research has shown that the brain electrical activity of experts shows distinct differences relative to non-experts and facilitates an understanding of the neurophysiological mechanisms that underscore the performance differences between elite and amateur. Compared to novice golfers, experts demonstrate higher frontal theta power values during task performance (Reinecke et al., 2011) and an increased stability (decreased variability) in electroencephalograph (EEG) rhythms (Babiloni, et al., 2008). The frontal theta is related to working memory, is an indicator of increased attention and is associated with higher skill level during a complex task such as a golf putt (Baumeister et al., 2008). To evaluate the amounts of theta produced during task along with the variability of EEG rhythms, three different levels of golfers were recruited to go through varying pressure settings under golf putt task.

Method. The experiment was conducted at Medalist Golf Course in Hobe Sound, Florida. Participants included a professional baseball player but novice golfer, a professional golfer not on PGA listings and an expert golfer (PGA ranked #3 in Putting Leaders for 2012). Low-pressure consisted of 18 putts at predetermined locations. Moderate-pressure involved the same putt scenario except this trial would be filmed and an announcer would be describing their actions and putt results so that this footage could be used for a show on the Golf Channel. The high-pressure setting had predetermined putt positions, announcer and cameras, but in addition, each golfer worked as a team with the other golfers and for every putt made, money could be won or lost that would ultimately be donated to a charity. Multiple physiological measures were recorded including electroencephalograph (EEG), heart rate (HR), respiration rate (RR), heart rate variability (HRV), electromyography (EMG), skin conductance, and hand temperature.

Analysis. This study specifically looked at the EEG data and focused on theta but also included the frequency bands: delta, alpha and beta. EEG data was collected during each pressure scenario at FZ and PZ for the different skill level athletes under the three different pressure settings. Artifact was removed from the EEG recordings and the variance of EEG amplitude within each task was calculated. The variance and standard deviation were calculated and plotted for each subject across each condition for comparison.

Results. Results indicated trends between the skill levels of golfer as having an interaction with the variability in EEG. Our findings indicate the novice and elite golfer demonstrated low variability across multiple pressure settings while the professional, non-elite golfer demonstrated highest variability between settings. Additionally, as had been previously reported (Babiloni, 2008), our expert participant demonstrated increased levels of frontal theta during the putting task.

Discussion. The frontal theta findings were confirmed as we had expected. The new findings that are contributory to future studies is that the findings of relatively lower increased variability in EEG rhythms may be explained as the novice golfer wasn't expected to perform as well as the other two golfers and may not have felt as if he was under as much pressure as the other two. In addition, this novice golfer is a professional athlete (baseball player) and has experience in high-pressure situations. The elite golfer has mastery over the putting task in addition to experience in high-pressure situations. The professional but non-tour golfer had higher expectations to do better than the novice, and was trying to impress both his colleagues in the audience and his favorite PGA golfer who was the elite participant in the study. This may have added pressure that caused him to have increased variability in his EEG than the other two golfers. The variability in one's EEG may be an indication of how sensitive an athlete is to perceived pressure during task, such as putting. Additionally, skill level seems to be a differentiating factor but only between individuals within the same classification. This is a pilot investigation and further study is needed to test the concept of reduced EEG variability among athletes in varying pressure conditions.

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PREPARE TO SWING: GOLFERS BRAIN ACTIVITY DURING THE PREPARATION PHASE OF A FULL SWING

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Introduction. Most studies in golf examine the biomechanical markers of golf related movements. But there is only limited knowledge about the supervisor of this biomechanical output: the golfer's brain. Neurophysiological studies have been conducted using and electrophysiological approach (EEG) before and during the golf putt. Baumeister et al (2008) have demonstrated an activation of the fronto-parietal network related to the working memory due to performance and expertise, where frontal Theta power values indicate executive attention and parietal Alpha-2 spectral power were described related to somatosensory information processing. To our knowledge nothing is known about brain activity related to a golf swing. It might be possible that the described indicators of the working memory may also play a role in the preparation phase before a full golf swing.

Purpose. The aim of this pilot study is to examine changes related to EEG spectral power during the preparation phase directly before the execution of the full swing in conjunction with the activation of the fronto-parietal network. Therefore we assume that the expert golfers demonstrate an activation of this network shown by higher frontal Theta and lower parietal Alpha-2 power values compared to a resting condition.

Methods. Ten male, right-handed expert golfers (27.4 ± 7.5 years) with golf handicap of 6.3 ± 2.1 volunteered in this study were screened with a health questionnaire and had no history of neurological, cardiovascular or other major disorders, no current use of medications or drugs. The participants were asked to execute 15 golf shots with a full swing to reach a 100m target with high precision at their own pace. After this execution block (M1) they rest for two minutes in sitting position with eyes open (R1). This procedure was repeated six times (M1/R1-M7/R7). The precision of the shots was measured by the percentage of shots reaching the target within a 10m circle. EEG activity was recorded continuously using only 6 Ag/AgCl electrodes (F3, Fz, F4, P3, PZ, P4) out of 32 embedded in an elastic cap (QuickCapTM, Neuroscan, USA) in accordance with the international 10:20 system. The signals were sampled at 1000 Hz / 32 bit amplified and filtered. An impedance test (< 5 kI) ensured a sufficient signal to noise ratio before each measurement. The EEG recordings were bandbass filtered (0.5 – 40 Hz) and visually inspected for artifacts. Only artifact free 2 s epochs (2048 sample Cosine windows) before the start of the movement were used for analysis. Power spectra were calculated for each epoch and divided into Theta (4.75 – 6.75 Hz) and Alpha-2 (9.75-12.5 Hz) frequencies. For statistical analysis (ANOVA TIME x CONDITION) the average power values were log-transformed. Spectral power in each frequency was computed in each block (M1/R1-M7/R7) in each subject.

Analysis/Results. The participants reached the 100m target very precisely with 85.4 % of all balls lying within a 10m distance circle. The statistical analysis demonstrated a CONDITION effect with higher Theta values in frontal brain areas during the preparation phase compared to rest in all three frontal electrode positions (F3: $p=.017$; part. $eta^2=.579$; Fz: $p=.031$; part. $eta^2=.509$; F4: $p=.026$; part. $eta^2=.529$). Parietal Alpha-2 spectral power show significant lower values in the preparation phase 2 s before execution in P3 ($p=.043$; part. $eta^2=.523$) compared to the resting condition.

Conclusion. During the preparation directly before the execution of a full golf swing the frontoparietal network is activated demonstrated in significant higher frontal Theta and lower parietal Alpha-2 values compared to a resting condition. This finding extended the knowledge of brain activation in golf by introducing the working memory concept to the preparation period before a full swing for the first time. The activation of frontal Theta power as an indicator of focused attention and task complexity is thought to be generated in the prefrontal cortex (PFC) and the anterior cingulate cortex (ACC) an important part of the human attentional system. The results suggest that frontal EEG power may be closely related to the preparation of a swing and may provide an indicator for attentional resources which will be important for training, learning and sensorimotor control in the future. The next step should be to add novice data to the existing results to get insights of the relationship between expertise, attention and golfer´s brain activity while preparing to swing.

THE (NON) IMPACT OF CONFORMING GROOVES AS SHOWN BY MEASURED SPIN RATES IN SKILLED GOLFERS

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Introduction. On January 1st, 2010 the USGA and R&A began enforcing a new rule that limited the geometry (specifically the volume and radius) of the grooves of short irons and wedges in an effort to encourage accuracy off the tee and to discourage a growing "bomb and gouge" mentality among the professional golfing ranks. At the time, it was widely believed that the impact of 'conforming' grooves would be swift and severe. However, a comparison of ShotLink data from 2009 and 2010 PGA tour seasons revealed some rather surprising discoveries. More specifically, while very little changed in terms of driving distance or accuracy from 2009 to 2010, tour players actually improved (albeit marginally) in scrambling statistics and proximity to the hole both from the fairway and the rough. In short, the impact of new grooves was null. Explanations for these findings typically focus on the fact that tour players had advanced knowledge of the rule change and simply applied talent and practice to help them to adapt.

Purpose. The purpose of the current study was to quantify the spin rates of skilled golfers with 2 different wedges (56° and 60°) with conforming versus non-conforming grooves.

Methods. Eight university-level golfers (mean handicap 1.1) were asked to hit a series of golf shots with each wedge in an indoor laboratory setting from a launch monitor that measured impact characteristics.

Analysis/Results. The results of the study showed that the skilled players in our study were actually putting greater spin on shots using wedges with conforming grooves. These somewhat puzzling results were explained, at least partially, by supporting evidence that showed that the players were swinging the newer wedges at greater velocities.

Conclusion. It was concluded that, for yet unknown reasons, skilled players were delivering the conforming wedge to the ball with greater club head speeds, thereby imparting significantly greater backspin to the golf ball. The implications of these data are discussed from both skill acquisition and applied (i.e., club fitting) perspectives.

THE EFFECT OF A AN 8-WEEK PLYOMETRIC EXERCISE PROGRAM ON GOLF SWING KINEMATICS

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Purpose. Initial and maximal rate of force development or power is probably more important to golf performance than maximal strength (Hellström, 2009) and plyometric training is known to increase power production. Whilst physical preparation in golf has been looked at previously, studies have tended to combine general strength exercises with plyometrics (e.g. Fletcher & Hartwell, 2004) rather than specifically concentrating on the development of power; something that is suggested to be more important in highly skilled players (Hellström, 2009). The purpose of this study was to examine how plyometric training can influence golf swing kinematics.

Method. Sixteen male golfers who were plyometric naive participated in the study. Participants were randomly assigned to either the control group (n=8; hcp 3.3 ± 1.6; 24.4 ± 8.8 yrs) or experimental group (n=8; hcp 3.8 ± 1.6 [2 professionals excluded]; 21.5 ± 5.5 yrs). The control group continued with any existing exercise programme that they were performing, whilst the experimental group followed an 8-week plyometric exercise program. Training consisted of two plyometric sessions a week for eight weeks. Sessions contained the following exercises: Multi-directional Hops, Bounding, Lateral hops, Squat Jumps, Overhead Throws, Squat Ball rotational throws, Kneeling lunge Rotations, Frontal rotation throws.

All swing kinematic analysis took place on a driving range and after completion of their normal warm up routine each participant hit five 6 iron shots from a driving range mat at full speed toward a designated target at a distance on the range using a full compression ball. Three-dimensional kinematic data was collected using a Polhemus Liberty electromagnetic tracking system (Polhemus Inc., Colchester, VT, USA), sampling at 240 Hz. The target was located so that a line drawn between it and the position of the ball on the driving range mat was parallel to the x-axis of the global frame. Kinematic variables were calculated for each shot and included: maximum rate of X-factor stretch (MROS), maximum rate of X-factor recoil (MROR), maximum X-factor (mXF), X-factor stretch (XFs), peak pelvis speed ($pelvis_{peak}$), peak upper torso speed ($torso_{peak}$), peak lead arm speed (arm_{peak}), peak hand speed ($hand_{peak}$).

Results. A between groups repeated measures design approved by the University Ethics Committee was used to assess the impact of an 8-week plyometric exercise programme on golf swing kinematics. The effects of the intervention on swing kinematics were analysed using mixed factorial MANOVAs with a repeated factor of test (pre-test, post-test) and a between-groups factor of group (control, experimental). Where significant effects were found follow-up mixed factorial ANOVAs were performed to identify significant effects within individual variables along with pairwise comparisons. All data and reported as mean (95% CI) unless otherwise stated.

Table 1. Kinematic variables pre and post intervention. *significant change between pre and post testing, p<0.05)

	Power training		**Control**	
	Pre	**Post**	**Pre**	**Post**
mXF (°)	61 (56-67)*	68 (60-76)*	57 (51-63)	56 (48-64)
XFs (°)	14.9 (9.8-20.0)	17.0 (12.4-21.6)	15.5 (10.4-20.5)	13.4 (8.7-18.0)
MROS (°s^{-1})	91 (63-119)	99 (81-117)	72 (44-100)	67 (49-84)
MROR (°s^{-1})	771 (652-889)*	929 (769-1090)*	651 (533-770)	651 (490-812)
$Pelvis_{peak}$ (°s^{-1})	490 (430-550)	513 (465-561)	443 (383-503)	457 (408-505)
$Torso_{peak}$ (°s^{-1})	745 (688-802)	770 (725-815)	718 (661-774)	734 (689-779)
Arm_{peak} (°s^{-1})	868 (766-970)*	930 (840-1020)*	905 (803-1007)	908 (819-998)
$Hand_{peak}$ (°s^{-1})	1483 (1401-1565)*	1562 (1473-1651)*	1438 (1356-1520)	1404 (1315-1493)

There was a significant interaction effect between test and group for MROR, MROS, mXF, XFs (Wilk's λ=0.32 F_4=5.9, p=0.009). Follow-up ANOVAs showed the interaction to be present for MROR (F_1=5.0, p=0.04), XFs (F_1=7.2, p=0.02) and mXF (F_1=7.0, p=0.02) with pairwise comparisons showing significant increases in MROR and mXF for the experimental group post training (Table 1). There was a significant interaction effect between test and group for peak segmental speeds (Wilk's λ=0.45 F_4=3.4, p=0.049). Follow-up ANOVAs showed the interaction to be present for arm_{peak} (F_1=5.5, p=0.03) and $hand_{peak}$ (F_1=13.5, p=0.003) with pairwise comparisons showing significant increases in arm_{peak} and $hand_{peak}$ for the experimental group post training (Table 1).

Conclusion. Results show that an 8-week plyometric training intervention has significant effects on the kinematics of the golf swing of male golfers, improving variables related to driving distance (Neal & Dalgleish, 2008). One limitation of this study is that due to unforeseen difficulties during data collection there was no measure of clubhead speed. Further work examining the most suitable power training loads for golfers is required. The findings suggest that highly skilled golfers with little physical training experience may benefit from incorporating plyometric training into their physical preparation.

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PERCEPTUAL AND BIOMECHANICAL CONFLICTS IN PUTTING: UNCOUPLING OF STANCE AND PUTTER MOTION ON BREAKING PUTTS

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Purpose. Putting is recognized as a crucial element in the game of golf. Its quantitative importance to scoring is clear, and scientific advances targeting improved performance have flourished. However, the relationship between green reading and putting mechanics has received little attention. Pelz (1994) showed how golfers underestimate the break on breaking putts and described associated compensations in aim, putter alignment and swing path. We have observed apparent uncoupling of the feet from putting actions on breaking putts. Combined with poor green reading, variations in foot placement during putting contradict the notion of a repeatable putting stroke. The purpose of this study was to quantitatively analyze how golfers couple versus uncouple their feet from their putting actions on right-to-left (RTL) and left-to-right (LTR) breaking putts, to relate these actions to their estimation of break, and to propose a partial explanation for why LTR putts are considered more difficult than RTL putts, for right–handed golfers.

*Methods***.** Twenty-one proficient male golfers (ages: 20-25, USGA HCPs: 0-7) participated in the study. Each golfer performed three straight putts 6.1 m (20 ft) in length in a swing laboratory. An overhead camera captured foot placement relative to the ball-to-hole direction. Average baseline toe-line angles (TLAs) were determined for each golfer. Each golfer then putted three times each to two different holes on a putting green. These putts were also

6.1 m (20 ft) in length, incorporating moderate RTL and LTR breaks. Prior to each attempt, golfers provided an estimate of total break (EST), defined as the distance from the hole to the putt's starting velocity vector, measured at the hole perpendicular to the original ball-to-hole line. To control for putting pace, putts were considered valid if the ball reached the hole, or stopped within 0.46 m (18 in) beyond the hole. An overhead, boom-mounted video camera captured ball motion and foot placement relative to the original ball-to-hole line. EST and attempt outcomes (make, miss high, miss low) were recorded, and TLAs and initial ball projection angles (BPAs) were calculated by analyzing the overhead videos. TLAs for each golfer during breaking putts were corrected based on their straight putt TLAs. The putt's actual breaks were determined trigonometrically based on the average BPAs of the made putts. ANOVA was used to analyze differences between TLA, BPA, and EST for each putt, and ANOVA with repeated measures evaluated learning effects across the three attempts.

*Results/Analysis***.** The actual breaks of the 6.1 m (20 ft) RTL and LTR putts were 1.14 m (44.8 in) and 0.98 m (38.7 in), respectively. Perfectly struck putts were thus struck with the ball initially traveling 9.3 and 10.8 degrees above the original ball-to-hole line for RTL and LTR breaking putts, respectively. EST averaged 76.4% of the actual break for the RTL putts, and only 64% of the actual break for the LTR putts. These estimates did not statistically improve across attempts. Only 9% of RTL putts were made; 24% were missed on the high side, and 67% were missed low. For LTR putts, 19.7% of the putts were made, 21% were missed high and 59% were missed low. With LTR putts, TLA and BPA were nearly equal (averaging 9.8 and 9.7 degrees, respectively); one degree lower than the actual break. Thus, on average, golfers struck LTR putts parallel to how their toes were aligned and below the required break. TLA and BPA were statistically greater than EST, differing by 2.8 deg. For RTL putts, TLA and BPA were remarkably disparate (averaging 2.8 and 8.8 degrees, respectively). On average, these RTL putts were struck half a degree lower than needed to make the putt, while the feet were aimed 6 degrees more open than the ball's starting direction. TLAs were statistically different (less) than both estimated break (EST) and BPA. Cluster analysis exposed differences in technique.

*Conclusions***.** It appears many proficient golfers uncouple their feet from their putting stroke on RTL breaking putts, prioritizing ball starting direction with less regard to foot placement. The putter is swung dramatically away from the toe line, well above the estimated break and TLA. By contrast, the feet are placed parallel to the starting direction of the ball on LTR putts, but aligned below the required break. To make a LTR putt, the putter must be swung toward the toe-line (out to in); a potentially more difficult/uncomfortable action than the outward (in to out) swing path of the RTL putt. These findings alter our understanding of putting mechanics and should be considered in instructional settings.

ARE THE OFFICIAL WORLD GOLF RANKINGS BIASED?

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Purpose. The Official World Golf Ranking (OWGR) is a system for ranking male professional golfers who play on a number of tours worldwide, including the PGA Tour, European Tour, Japanese Tour, and others. The OWGR rankings, updated and published on a weekly basis, allow golfers who play in different tournaments on different tours and continents to be ranked against each other on a single scale. The rankings affect golfers' endorsement income, carry bragging rights, but are most important because of tournament eligibility requirements: golfers in the OWGR top 50 are automatically eligible to play in major tournaments, world golf championships and other important tournaments. These rankings are also important to tournament sponsors who seek to attract the best golfers to their events. A key issue in creating a single ranking scale is that golf scores from different tournaments are not directly comparable because of differences in course difficulty due to course length, course conditions (rough height, width of fairways, firmness of greens), weather conditions and other factors. A further complication is that pairs of golfers may never play together in the same tournaments, e.g., some Nationwide Tour golfers many never play in a European Tour event, some PGA Tour golfers may never play in a Japanese Tour event, etc. We investigate whether the OWGR system produces unbiased rankings, meaning that golfers who are similar in skill should have similar rankings independent of the tour in which they play the majority of their tournaments. (We use the term similar because skill cannot be estimated without error.) If OWGR rankings are biased, a golfer could be unfairly rewarded or penalized because of his tour affiliation.

Method. In order to estimate golfer skill, we use 18-hole scores and standard econometric methods to adjust for the relative difficulty of courses and rounds. Variations of this method, a scorebased regression method with course-round fixed effects, has been used in prior golf research in Connolly and Rendleman (2008), Broadie (2011), Brown (2011), and others. Because there is mixing of golfers in tournaments across tours, e.g., there are some PGA Tour golfers who also play in Nationwide and European Tour tournaments, and some Japanese Tour golfers who also play in PGA tournaments, etc., our score-based regression approach allows the skills of all golfers to be measured in an unbiased manner on a single scale. In contrast, the OWGR system uses weighted tournament finish positions, with the maximum weight given to majors and the weights to other tournaments based on their tour affiliation and field composition. The choice of the tournament weights in the OWGR system is subjective and has a direct impact on golfer ranks, yet there has been no systematic study of the performance of the OWGR method.

Results. We use 18-hole scoring data of all golfers participating in stroke-play tournaments from 2003 to 2010 on the major tours (PGA, Europe, Japan, Asia, Sunshine and Australasia) and from the developmental tours (Nationwide and Challenge) and compare our score-based skill rankings with OWGR rankings. We also compare the OWGR rankings with the Sagarin golf rankings published in Golfweek magazine. Our main findings, illustrated in Figure 1, indicate that the OWGR rankings are biased against PGA Tour golfers relative golfers playing on other tours. For example, the figure shows that PGA Tour golfers with skill ranks near 50 have an average OWGR rank of approximately 80. Conversely, non-PGA Tour golfers with skill ranks near 50 have an average OWGR rank of approximately 36. In short, a golfer of a given skill level is likely to be penalized in the OWGR rankings for playing on the PGA Tour and rewarded for playing elsewhere. Similarly, using the Sagarin rankings, we find that the OWGR rankings are biased against PGA Tour golfers relative to other tours. Regression analyses are presented to quantify these results and demonstrate the statistical significance of the findings.

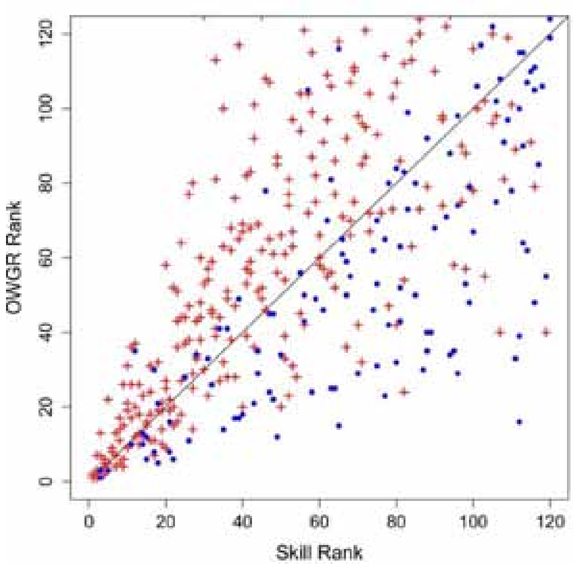

Figure 1: Score-based skill ranks versus OWGR ranks using data from 2003-2010. Each red cross represents a PGA Tour golfer in one of the two-year periods 2003-2004, 2005-2006, 2007-2008, or 2009-2010. Each blue dot represents a non-PGA Tour golfer in one of the two-year periods. A data point below the 45-degree line means that the golfer is considered to be better by the OWGR method than the score-based skill rank. A preponderance of blue dots below the 45-degree line indicates that non-PGA Tour golfers have better OWGR rankings than implied by the score-based skill rank.

Conclusions. Given the importance of the OWGR rankings to professional golfers, tours and tournament sponsors, these findings suggest that the OWGR system needs to be carefully reexamined.

ACCURACY OF READING PUTTS AS A FUNCTION OF SKILL LEVEL, DIRECTION OF BREAK AND VIEWING POSITION

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Purpose. Pelz (2000) found that amateur players tend read about a third of the actual break in a putt. As a general guideline to compensate for this tendency, he recommended that players triple the amount of break they read and aim there. The purpose of this research was to replicate and extend Pelz's finding by determining the extent to which reading putts that break in two directions from nine different viewing positions affect reading accuracy for two skill levels: Low- (+3 – 15) and high- (16 – 36) handicap groups. Each group had 11 females and 25 males.

Method. The nine viewing positions included reading putts from (a) Behind Hole, (b) Behind Ball, (c) Over Ball, (d) Behind Hole then Behind Ball, (e) Behind Hole then Over Ball, (f) Behind Ball then Behind Hole, (g) Behind Ball then Over Ball, (h) Over Ball then Behind Hole, and (i) Over Ball then Behind Ball. Each participant read the direction and amount of break of 18 putts that were 15 feet in length from the viewing position to which he or she was randomly assigned. Participants were asked to read each putt such that, if missed, the ball would roll pass the hole by about 17 inches. No feedback was given about the accuracy of each read and no putts were actually stroked. Nine of the 18 putts broke right-to-left and nine broke left-to-right. The amount of break (ranged from 16 – 57 inches) and levelness of the right-to-left putts were matched to the left-to-right putts. The order in which the 18 putts were read was counterbalanced resulting in 18 different orders to which participants were randomly assigned.

Participants closed their eyes when being led by a tester from one putt to another so that they could only see the break being read from the viewing position to which they were randomly assigned. Each participant reported the amount of break read by pointing to a spot on the green, which the tester confirmed by touching the spot. The amount of break read was measured by the tester from the spot to the center of the hole. Each participant had one read per hole resulting in 18 reads. Stimpmeter readings taken at the beginning, middle and end of testing on each of the three days of testing revealed that an average green speed of 10 for each day.

Results. Reading errors were converted to z-scores to standardize and analyze the different amounts of break. Since reading accuracy between the two handicap groups failed significance ($p < .05$), they were combined. Ninety-six percent of the 1,296 putts read from the nine viewing positions were under-read by an average of 65%, which supports Pelz's finding. Also, 96% of the 648 right-to-left and 648 left-to-right breaking putts were under-read by an average of 63% and 67%, respectively, but this difference failed significance ($p > .05$). Although the low-handicap group under-read (M = -19.89 inches) by an average of 61% and the high-handicap group under-read (M = -21.53 inches) by 69%, this difference failed significance ($p > .05$).

The 2 x 2 x 9 (Handicap x Break x Viewing Position) ANOVA with repeated measures on the last two factors revealed a significant Break x Viewing Position interaction (F (8, 560) = 3.05, p = .002). Three of the nine viewing positions resulted in reading putts with significantly ($p < .05$) less average error depending on the direction of the break. Specifically, right-to-left breaking putts were read more accurately (M = -17.10 inches; SD = 14.71) when viewed from Behind Hole then Over Ball. Left-to-right breaking putts were read more accurately when viewed either from Behind Hole then Behind Ball (M = -19.79 inches; SD = 12.46) or vice versa (M = -19.98 inches; SD = 10.80). Viewing right-to-left putts from Behind Hole alone was the least accurate (M = -22.40; SD = 14.55). Emanating from these results were specific procedures for improving green reading accuracy based on the extent of one's reading error tendencies and most effective viewing position.

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THE RELEVANCE OF GOLF COURSES IN THE MEDITERRANEAN COUNTRIES. A COMPARATIVE EFFICIENCY STUDY.

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Introduction. This article presents a comparative study of most of the countries of the Mediterranean area in relation to the number of golf courses and the number of golf players. In the specialized literature we have not found any study which evaluates the use of golf courses through a specific DEA model (Banker et al., 1984). We present two complementary DEA models that allow us to compare the use of golf courses by domestic players and foreign players.

Method. To evaluate the efficiency of the use of golf courses, in a non-parametric context and with "cross-sectional" data, we have resort to the best known variable returns to scale (VRS) DEA model: the BCC model. VRS is recommended because the size of the countries considered are quite different. Output orientation is a must because inputs are exogenous variables. The list of countries compared appears below in Table 1.

The inputs and outputs used in our two models are:

Inputs: *Surface, the area of each country in millions of km^2; *Gross Domestic Product (GDP) of each country, in millions of euros; *Population of each country, in millions of persons.

Outputs: *Golf courses, number of golf courses in each country; *Golf players, number of golf players in each country; *Rounds of golf: number of rounds of golf played on an open course with at least 9 holes.

Data for inputs were obtained from the "World Economic Outlook Database," published by the International Monetary Fund (IMF, 2009). Data for outputs were obtained from publications of the KPMG (2008).

The two built models, M1 and M2, use the same three inputs listed above. "Golf courses" as an output belongs to both models. Additionally, M1 has as a second output "Golf players" while M2 incorporates "Rounds of golf". While M1 considers only domestic players, M2 considers also foreign players. Comparing both models we can deduce the relevance of foreign players in each analysed country.

Analysis/Results. As mentioned, model M1 analyses the development of golf, as a sport, in each country. Thus, the efficiency scores (see Table 1) show that only 6 out of 17 countries are efficient. As expected, the 3 major golfing countries (Spain, France and Italy) belong to this efficient subgroup. The highest potential for improvement corresponds to Turkey and, in second place, Greece. The good results obtained by Cyprus and Malta may be explained due to their former colonial dependence from the United Kingdom.

Model M2 incorporates the influence of foreign players in relation to model M1. Results are quite similar but allow us to explain the specific behaviour of certain countries. There are two countries, Spain and Bosnia-H., that get a better efficiency score in model 1 than in model 2. That means that, in comparison to the rest of the countries they can improve their attraction of foreign golf players. On the other hand, there are four countries that present the opposite behaviour. In particular Israel is attracting more foreign players than the rest of the countries.

Table 1. Efficiency score by country for the M1 and M2 models

	Country	Efficiency M2	Efficiency M1
1	Cyprus	1	1
2	Egypt	1	1
3	France	1	1
4	Malta	1	1
5	Spain	1,129	1
6	Italia	1,216	1,218
7	Slovenia	1,272	1,29
8	Morocco	2,017	2,017
9	Tunisia	2,055	2,055
10	Croatia	6,331	6,479
11	Bosnia-H.	6,647	6,433
12	Jordan	6,728	6,728
13	Israel	7,017	10,445
14	Lebanon	9,954	9,954
15	Greece	15,25	15,25
16	Turkey	15,735	15,735
17	Serbia	30,108	30,108
Average		*6,439*	*6,630*
Standard deviation		*7,812*	*7,876*

Conclusions. From a methodological point of view we have verified that the use of nonparametric models for measuring the relative efficiency of the considered sample of countries is a new approach that allows us to draw interesting conclusions.

Only 4 out of 17 of the analysed countries (Cyprus, Egypt, France and Malta) appear as fully efficient in both models. There are 12 countries (Morocco, Tunisia, Croatia, Bosnia, Jordan, Israel, Lebanon, Greece, Turkey and Serbia) that are inefficient in both models, but, as explained before the room for improvement is quite different from one country to another.

As for future research, instead of considering each country as a whole, it would be interesting to revise the different regions of each country considering their particular tourism and golf characteristics.

A BIOMECHANICAL ANALYSIS OF THE DRAW AND FADE SHOTS IN GOLF

Collinson, Andrew; University Of Lincoln

Purpose. The biomechanics of the golf swing has been well researched, especially in recent years. However, very few studies have stated the type of golf shot that subjects were asked to hit. If it has been stated then it has normally been reported that subjects were asked to hit their 'natural golf shot' or they were asked to hit a straight golf shot. However, very rarely does a golfer, especially an elite one aim to hit a golf shot dead straight. Therefore, the aim of this study was to analyse the golf swing when draw and fade shots were struck.

Method. 6 right handed male category one golfers (handicap < 5) participated in the study. Each subject was asked to hit five successful draw shots and five successful fade shots. For a shot to be deemed successful it must have moved 10-25 yards in the air (right to left for a draw and left to right for a fade) and have finished within 10 yards of the target. It must also have been struck correctly. A range of 5-Irons were used which were custom built so that subjects could use clubs that matched their own specifications for club lie and length. Analysis of the subjects was completed using 8 Raptor-4 Cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) recording at 460Hz. 44 reflective markers were used (38 on the subject, 2 on the club shaft and 4 on the club head). The resultant golf shots were analysed using a Game Changer 2 Launch Monitor (Foresight Sports, San Diego, USA) together with Ping nFlight Software (Ping Europe, Gainsborough, England). Subjects completed each trial in an indoors laboratory striking shots from a golf mat. Each subject also wore their own golf shoes.

Results and Analysis.

	Draw	***Fade***
Upper Trunk at Address (°)*	7.58	16.14
Mid Trunk at Address (°)*	5.40	14.5
Lower Trunk at Address (°)*	0.22	10.97
Foot Alignment at Address (°)*	-4.62	15.78
Ball Position (mm)*	39.45622	160.2567
Backswing Clubplane (Z) (°)*	62.38647	64.31899
Downswing Clubplane (Z) (°)*	59.9191	61.51935
Backswing Clubplane (Y) (°)*	-6.19851	5.605903
Downswing Clubplane (Y) (°)*	-4.15085	8.165127
Backswing Handplane (Z) (°)*	63.78974	68.86062
Downswing Handplane (Z) (°)	56.45186	56.34886
Backswing Handplane (Y) (°)*	4.490122	15.64294
Downswing Handplane (Y) (°)*	0.360841	13.62604
Rotated Backswing Clubplane (Y) (°)*	-7.34648	-4.84032
Rotated Downswing Clubplane (Y) (°)*	-6.40974	-2.63105
Rotated Backswing Handplane (Y) (°)*	2.452219	4.847314
Rotated Downswing Handplane (Y) (°)*	-1.52366	2.830322

* Significant difference between the draw and fade shots ($p < 0.01$)

The upper trunk, mid trunk, lower trunk and alignment of the feet were significantly more open ($p < 0.01$) for the fade shots compared to the draw shots. The position of the ball was also further forward in relation to the centre of the stance for the fade shots compared to the draw shots ($p < 0.01$).

Analysis of the plane of the club also showed significant differences between the draw and fade shots ($p < 0.01$) in the z axis (inclination angle) and also the y axis (direction angle) for both the backswing and downswing. For the downswing (from club shaft horizontal to impact) and the backswing (address to club shaft horizontal) the club head was swung on a steeper plane for the fade shots compared to the draw shots. The club head was also swung on an out to in plane for the fade shots on the backswing and downswing whereas for the draw shots the club head was swung on an in to out plane for both the backswing and downswing. Analysis of the plane of the hands indicated a significantly steeper club plane ($p < 0.01$) on the backswing for the fade shots compared to the draw shots, although this significance was not replicated in the downswing ($p > 0.01$). On the backswing and downswing the hands were swung on an out to in plane for both the draw and fade shots, however this out to in plane was more significant ($p < 0.01$) for the fade shots. Further analysis of the club and hand planes on the directional angle were made to determine whether the difference in address angles accounted for the differences in club and hand planes between the draw and fade shots. This was completed using a rotational matrix that rotated the plane of the swing to a neutral position using the original angle created by the upper trunk at address. This also revealed a significant difference ($p < 0.01$) between the fade shots compared to the draw shots in the directional angle for both the club and hands on the backswing and downswing.

Conclusion. The results from this study indicate that low handicap golfers make changes in their address positions depending on whether they are hitting draw or fade shots. The results also indicate that low handicap golfers change their club and hand planes for draw and fade shots throughout the swing even when accounting for the differences created at address.

THE EFFECT OF EMOTIONAL FREEDOM TECHNIQUES ON PERFORMANCE: PSYCHOLOGICAL, PHYSIOLOGICAL AND GOLF PUTTING

Crews, Debbie; Arizona State University; Vornbrock, Stacey; Breakthrough Performance

Introduction. Emotional Freedom Techniques (EFT), more commonly known as “tapping”, is an energy therapy that is becoming popular to enhance sports performance. This technique uses the ancient Chinese meridian system to relieve emotional stress, physiological pain, and balance the energy system. A gentle tapping procedure, using the fingertips, stimulates designated meridian end points on the face and body and opens the flow of energy in the body. Anecdotal evidence suggests that EFT may positively influence sport performance. To date, no published research exists examining the effect of EFT on sport performance.

Purpose. The purpose of this study was to determine the effect of EFT on psychological, physical, and performance characteristics among athletes, specifically golfers. Secondly, the study was designed to determine whether a dose response effect exists. It was hypothesized that psychological, physical, and performance measures would show positive change as a result of EFT training and a dose response effect would exist with specificity of training.

Method. Male volunteer athletes (N=12) participated in two days of testing (one week apart) in a controlled laboratory environment. The experimental group was 20.17 + 1.72 years old and the control group was 21.83 + 1.47 years old. The average handicap of the experimental group was 4.25 + 2.64 and the control group was 19.83 + 22.24. All participants were randomly assigned to groups. Experimental participants received EFT specific training based on the performance issue that was most important to target. Control participants followed the same testing protocol as the experimental participants, except they read "Sports Illustrated" magazine.

Psychological measures. Anxiety (trait and state), self-efficacy, focus of attention, and coping ability were assessed. The instruments included: Spielberger Trait Anxiety Scale, a 1-10 rating of state anxiety, five self-efficacy questions designed specifically for putting and The Athletic Coping Skills Inventory. The psychopysiological measure of brain activation was recorded from FP1, FP2, F3, F4, C3, C4, T3, T4, P3, P4, O2, O1.

Physical measures. Grip strength, endurance, balance, flexibility, anticipation time, acid/alkaline salivary measures, heart rate and autonomic control were recorded before and after each training intervention.

Performance measures. Performance included three measures of golf putting. First was a quality rating of the "feel" of each putt (1-10 scale, 10=high). Second was the cm error of all putts from the hole. And third was the total number of putts made.

EFT Intervention. The therapist completed a 15-minute phone interview with each experimental participant to screen participants, gather descriptive information, and determine their top three performance issues. On Day 1 the experimental participant completed the Pretest, followed by an abbreviated form of EFT training and Posttest 1. On the same day they completed a full, specific EFT training session (90 minutes) and Post 2. On Day 2 a short interview updated was followed by the third EFT training session (60 minutes) and Post 3. Control participants followed the same testing protocol and they read "Sports Illustrated" magazines.

Analysis/Results. Three separate 2x4 (Condition and Time) Multivariate Analysis of Variance (MANOVA) were used to assess differences between the experimental and control participants. Greenhouse-Geisser correction factors were used in the Analysis of Variance (ANOVA) to control for Type 1 errors. Both groups improved coping skills and putt quality ratings. Trait anxiety, self-efficacy, and heart rate showed significant improvements for the Experimental participants compared to Controls. Experimental participants demonstrated 13 high effect sizes (ES > .8) compared to three for Controls. Brain maps remained synchronized for Experimental participants compared to Controls. Selected measures showed positive effects for EFT training and dose response effects appeared only on Day 1. Experimenter bias is possible; however, there was not a consistent improvement for Day 2 results.

Conclusions. This study provides some evidence that EFT reduces anxiety among golfers and may contribute to maintaining a synchronized state and increasing self-efficacy about putting. Dose response effects are more likely to appear if the doses are given the same day rather than one week apart, or with longer EFT sessions. While this study provides selected positive effects for EFT on psychological, physical, and performance measures among sport athletes, further investigation is warranted to determine the importance of reducing anxiety vs. synchronizing the brain to produce optimal performance in sport.

THE EFFECTS OF GOLO^{SM} GOLF FITNESS USING STEP© PRINCIPLES IN IMPROVING DRIVING DISTANCE, ACCURACY, EFFICIENCY

Karen Dubrow; Dubrow's Golf Fitness and Physical Therapy

Introduction. Golf fitness has been discussed informally in golf magazines, on television, and at the range. Effects of fitness, strengthening, and stretching exercises have been formally researched by kinesiologists and biomechanists; and their research has been published. But up to the point of the execution of this study, there had been no research studies directly linking golf fitness to changes in the body directly linked to the accuracy, carry, and distance of the drive. There had been extrapolations of increased power which would increase distance, but the drive had not been tested directly. Because of existing and emerging opinions and the practice of golf fitness intervention with respect to a golfer's game, and because of the gap in the literature showing direct links of changes in the body from specific golf fitness to the actual outcome of a drive, this study is important. There were no studies looking at the specific physical needs of the individual golfer. Other studies showed responses to general exercises. Previous authors requested more studies looking at the individual golfer and his or her specific needs. This study filled that gap in the research with a research design sensitive to the individual's needs but with a methodology which could be generalized to all golfers. The purpose of this study was to determine the effects of an At- Home and an In-Clinic GoLo^{sm} Golf Fitness Program using STEP© principles in improving a golfer's driving distance, carry distance, accuracy, and efficiency of body motion during the swing.

Methods. . This study employed a double single subject research design which is sensitive to the changes occurring within an individual over time. The individual provides the control and experimental data through repetitive measurements of the individual before and during intervention. Two subjects were chosen from a selection of applicants who submitted their application to the researcher's website. The two chosen met all criteria. They had a USGA handicap of 10, were 46 and 49 years old, exercised several times per week, were sedentary in their jobs, in the same socioeconomic class, and were married. They were randomly assigned to one of the two exercise locations. Each was measured repeatedly before and during exercise intervention. Measurements were taken with Polhemus Liberty electromagnetic sensing device and JZZ Technologies E-Factor. Ball flight was measured using the FlightScope Kudu RADAR system. After baseline measurements were taken, each subject underwent a GoLo^{sm} GolfBody Screen, a Golf Body Analysis, and an Exercise Prescription using the principles of STEP©. Data were gathered over a 16 week period.

Results. Both the designed in-clinic and at-home fitness programs improved carry distance. The designed in-clinic fitness program did not significantly improve total drive distance. The identified reasons are discussed. The designed at-home fitness program significantly improved total drive distance. Both golfers' accuracy improved at carry. Neither the designed in-clinic nor the at-home fitness program improved accuracy of the drive. Several of the designed parameters of this study caused the inaccuracy which are discussed. Both the designed in-clinic and at-home fitness programs improved efficiency of body motion during the drive.

Conclusion. Both subjects showed statistically significant improvement in drive carry. The at-home subject showed statistically significant improvement in his drive. The reasons for both improvements and lack of improvement in drive distance for the in-clinic subject are discussed. Because of several elements of the study design such as which swings were measured, the use of 7 irons for driving, and no changes to previously taught "fixes" for hooks and slices, neither subject showed improvement in drive accuracy. The body motions relevant to increased power, stability, and consistency during the swing included the X-Factor and specific body "bends." Both subjects showed statistically significant improvement in these areas. GoLo^{sm} Golf Fitness coupled with STEP$^{©}$ exercises which specifically address the individual's physical needs for golf have now been shown to improve body efficiency thus improving the golfer's ability to swing consistently through improved stability and with greater power through improved rotations. Kinesiologists and biomechanists from previous research provided foundation for that which needs to occur within the body to perform a more perfect swing. The incorporation of science and clinical practice provided these golfers with longer carry and more efficient body motion. This research study filled a gap in research and provides a methodology to approach individual golfers' fitness to improve their game.

COACHES' PERSPECTIVES ON FITNESS FOR GOLF

Evans, Kerrie; Thomas, Patrick R.; Griffith University

Purpose. While there is evidence supporting the notion of being physically fit for golf, little is known about golf coaches' perceptions of the importance of fitness and its role in improving performance and preventing injury. The aim of this study was to determine the knowledge, perceptions and practices of Australian golf coaches towards physical fitness for golf.

Method. A survey about perceptions and practices related to physical fitness for golf was developed in conjunction with the Professional Golfers' Association of Australia (PGA) and Golf Australia (GA). The survey comprised four sections. Section 1 measured coaches' perspectives using 5-point Likert scales ranging either from *Strongly Disagree* to *Strongly Agree*, or from *Never* to *Always*. In Section 2, coaches were asked to estimate the percentage of their clients who experienced pain or injury affecting their golf and the percentage of those clients they referred to a health professional. Section 3 requested information about participants' education and qualifications relating to physical fitness and golf, and Section 4 obtained demographic information about coaches and their clients. After pilot testing on five teaching professionals, the Golf Fitness Survey was distributed by the PGA to its teaching members.

Analysis/Results. The sample of respondents was divided into two groups – those who agreed with the item, "I consider it very important for all of my clients to be physically fit for golf" (n = 136), and those who did not agree (n = 115) either because they disagreed (n = 85) or were undecided (n = 30). After assigning Likert-scale responses a value of 1-5, means and standard deviations were calculated and *t* tests were conducted to explore differences between the groups.

Coaches who regarded physical fitness as very important for all clients agreed significantly more than other coaches that: golf is physically demanding; flexibility, strength, endurance, aerobic fitness, balance, and stability are all very important for golf; it is easy to identify swing faults resulting from poor flexibility; their role was to identify any physical limitations affecting/impeding their clients' golf performance, give advice to clients regarding physical limitations affecting golf performance, and refer clients with a physical limitation to a health professional for a physical assessment; and it is important for older golfers and those with pain or recent injury to be cleared by a doctor or health professional prior to beginning lessons.

Coaches who agreed that physical fitness for golf is very important for all clients were also significantly more likely than other coaches to provide specific information to clients about physical fitness for golf; send clients with pain or injury to a health professional for assessment; refer clients to a physiotherapist, personal trainer, or doctor; and communicate with the health professional regarding findings and recommendations for clients.

Coaches who did not agree that physical fitness for golf is very important for all clients agreed more strongly than other coaches that fitness is more important for elite amateurs and professional golfers than other clients, and were more likely to try to improve swing mechanics of clients with physical limitations before referring them for a physical assessment. They were also marginally more confident about coaching clients with a specific disability.

Conclusions. The results of this study reveal significant differences between professional golf coaches in their perspectives of whether it is important for all clients to be physically fit for golf. Those differences are also reflected in the extent to which coaches engage with health professionals in determining effective coaching practices for their clients. The results identify significant issues that need to be addressed in ongoing professional development programs conducted for golf coaches throughout the world by organizations such as the PGA and GA.

COMPARATIVE PERFORMANCE ANALYSIS OF PGA TOUR AND ONTARIO UNIVERSITY GOLFERS

Fitzsimmons, Charles R. S.; Carron, Albert V.; University of Western Ontario

Purpose. There has been a general lack of studies that specifically analyze the performance parameters associated with success in amateur and professional golfers in a comparable situation. Perhaps the best study to compare amateurs and professionals was conducted by Pelz, Pelz, Evans and Bracey (2008); however, 4 holes of amateur play were compared to season long averages from PGA tour players. Furthermore, the Pelz et al. study involved amateurs with a wide range of skill levels, with only a limited comparison between the average scores of elite amateurs (U.S. Amateur competitors) and the PGA tour players. A question that arises from comparative studies of amateur and professional golfer is what areas of the game (i.e., driving, iron play, putting or scrambling) separates the elite amateur (e.g., University/College golfer) from the average PGA tour professional. Unfortunately there have been few studies conducted with elite amateurs. Perhaps the best study on elite amateurs was conducted by Callan and Thomas (2004), who examined NCAA Division I golfers over a university season, but even this study did not compare the collegiate results to those of professionals. With this in mind, the present study was undertaken to achieve three main purposes: 1) build a model to predict scoring average for a total sample of professional and elite amateur collegiate golfers using stepwise regression, 2) test the model to predict scoring average for professional and collegiate golfers independently using hierarchical regression and 3) analyze the absolute performance differences between the professionals and collegians.

*Methods***.** The total sample comprised of 123 male golfers; 82 professionals and 41 Ontario collegians. Both samples played two tournament rounds at the South Course of Angus Glen Golf Club; the professionals during the 2002 PGA tour Canadian Open and the collegians during the 2010 Ontario University Association championship.

Analysis/ Results. The results from the stepwise regression showed that for the total sample greens in regulation (GIR) percentage, putts per round, scrambling percentage and driving accuracy percentage, in that order, predicted 92% of the variance in scoring average. However, the results from the two independent hierarchical regression analyses showed that for both the professional and the collegian subsamples only GIR percentage, putts per round and scrambling percentage, in that order, added explained variance for scoring average, accounting for 80% and 81% respectively. There was no interaction between the type of golfer (i.e., professional vs. collegian) and the four performance indices, thus showing the same predictors were equally salient for both subsamples. Possibly not surprisingly, professionals were significantly better than the collegians in all four performance indices included in the model to predict scoring average. Furthermore, the difference in GIR percentage, putts per round and scrambling percentage was able to account for a 6.5 shots lower per round scoring average for professionals compared to the collegians. Importantly, in all analyses only GIR percentage and putts per round were able to account for virtually identical amounts of the variance in scoring average.

Conclusions. The most important implication is that whether a golfer is a male professional or amateur, he should improve his iron play then putting skill to dramatically reduce his scoring average. However, he should also remember that scrambling percentage did have a small but significant effect on scoring average that could be the difference between winning and coming second in a tournament. Another implication is that golfers, especially at elite levels, should keep records of performance statistics, such as GIR percentage and putts per round, to provide an objective analysis of their shot making strengths and weaknesses. Ultimately, having knowledge of performance statistics will allow a player to focus their practice and improve their game with maximum efficiency.

DESCRIBING THE EPIDEMIOLOGY OF FEMALE GOLFING INJURIES

Fradkin, Andrea J.; Bloomsburg University

Introduction. Injuries are an unfortunate consequence of sports participation, and have been estimated to cost billions of dollars annually. Injury studies are important to accurately determine the extent, nature, and location of injuries so appropriate intervention strategies can be developed. Few epidemiological studies have illustrated the extent of golfing injuries, as most research focuses on sports perceived as more aggressive or demanding. Golf is a popular sport enjoyed by millions of people worldwide. However, the tendency for players to be older and often not in good physical condition contributes to its injury risk.

*Purpose***.** To determine the 12-month injury history of female golfers, including medical treatment sought and the impact of the injury. Also, to investigate differences in the epidemiology of the injuries by age, handicap, experience, and participation.

Methods. Female golfers over 18 years, who played golf once a week, and had a registered handicap, completed a questionnaire documenting their 12-month injury status and associated golfing demographics. The definition of injury was "damage to the body that occurred as a result of competing, training, and / or participating in a golfing activity". The outcome of interest was whether an injury was reported in the previous 12-months. Chi-square analyses examined associations between variables and injury outcome, and multivariate logistic regression identified independent injury predictors. The Hosmer and Lemeshow statistic determined model goodness of fit.

Results. There were 2376 respondents with a median age of 53.2 years. The median handicap was 14.6, and golfers had been playing a median of 11.7 years. The average golfer played a median 9.2 hours a week, and practiced a median 1.9 hours per week. Over the 12-month period 874 injuries were reported (36.8%), with the majority of injuries sustained during play (75.7%). The most common injury sites were the shoulder (24.7%), lower back (22.7%), elbow (17.0%), and wrist (14.1%). Strains were the most frequent type of injury (41.8%), followed by stiffness (13.8%) and inflammation (9.9%). The most common mechanism of injury (excluding those unsure) was overuse (29.2%), followed by a technical error (23.3%). Over half the injuries were serious enough to require treatment from a healthcare professional (55.3%), and the professional visited most frequently was a physical therapist (31.5%). The most common injury sequelae were an inability to play (33.6%), an altered swing (32.2%), and a decreased performance (29.6%), and 642 (73.5%) of the injured golfers reported the injury impacted their performance or participation. Over two-thirds of the injured golfers missed participation time due to their injury, and 110 of the injured golfers (12.6%) needed time away from school or work. Chi-square analysis showed that golfers' handicaps ($\chi 2$ 4 = 22.274, $p \leq 0.001$), hours of play ($\chi 2$ 8 = 37.803, $p \leq 0.001$), hours of practice ($\chi 2$ 8 = 2 χ.013, $p \leq 0.001$), and experience level ($\chi 2$ 9 = 31.172, $p \leq 0.001$) were significantly associated with their injury status. Handicap, hours of play, and experience level were found to be significant independent predictors of injury. Golfers with lower handicaps were more likely to sustain an injury than those with higher handicaps, while those who played more golf were at an increased risk of injury. Finally, more experienced golfers were more likely to be injured than those who had been playing fewer years. The Hosmer and Lemeshow test was not significant ($p = 0.925$) indicating acceptable goodness of fit.

Conclusion. This is one of the few studies to investigate injuries specific to female golfers, as well as exploring the treatment sought and impact of golf-related injuries on participation, performance, and life. This study confirms the common occurrence of golf injuries and the impact these injuries have on injured golfers. Golfers with lower handicaps were more likely sustain an injury than those with higher handicaps, potentially due to the increased exposure time required to obtain lower handicaps.

This is further supported as hours per week of golf play and practice (exposure time) were also found to be significant predictors of injury, as was experience level. As more people continue to participate in golf, the risk of sustaining an injury is likely to increase, thus the need for proven preventive strategies. As overuse injuries and strains are the most common injuries sustained, it is possible these could be avoided if adequate preventive measures are implemented. As warming-up has been shown to reduce injury risk, future studies should focus upon the best way to promote warm-up to golfers. Other preventive strategies also need to be investigated in relation to specific characteristics of female golfers to attempt to reduce the injury risk.

IS THERE A LINK BETWEEN GOLF PLAYING SURFACE AND INJURY RISK? A BIOMECHANICAL PERSPECTIVE

Fradkin, Andrea J.; Bloomsburg University; Smoliga, James M.; High Point University

Introduction. Golf is a very popular sport worldwide, and although golf is not considered a strenuous sport, approximately 35% of recreational golfers sustain an injury each year. The most frequently injured sites are the lower back, shoulder, elbow, wrist, and knee. There are many different surfaces that golfers can play and / or practice on, however no one has investigated the different accelerations placed upon the body while swinging a golf club on these different surfaces. There is also no published scientific literature that has investigated the effect surface may have on golf injuries.

Purpose. To analyze and compare accelerations exerted on different areas of the body during a golf swing on three commonly used surfaces in golf: natural grass, sand, and artificial turf.

Methods. Fifteen golfers with a registered handicap completed a standardized warm-up routine prior to performing three swings on each surface using a 5-iron club in a randomly assigned order. Four Microstrain G-link wireless accelerometers were attached to an elastic resistance band with Velcro, and this band was wrapped around the participant's limbs and also secured with Velcro. This allowed the golfer to swing naturally, yet kept the accelerometers in place with minimal extraneous movement. One accelerometer was placed on each of the golfer's left and right forearms, as well as one on each of the left and right tibial surfaces. As the golf swing has considerable rotational movement associated with it, the orientation of the accelerometers was constantly changing throughout the swing. As a result, examining individual channels of data would not provide accurate information about Anterior-Posterior, Medial-Lateral, or Superior-Inferior accelerations. Therefore, resultant accelerations were calculated to quantify total acceleration experienced by each segment. A repeated-measures MANOVA was performed to determine within-subjects effects, and a univariate ANOVA was undertaken to determine surface differences for each body location. Further examination using pair-wise comparisons were performed to determine acceleration differences for each surface.

Results. The overall reliability and precision data on each surface and body location were high (ICC range: 0.70 –0.95), with only two exceptions: the lead leg on artificial turf (0.42) and the trail leg on sand (0.27). Accelerations in the lead arm were significantly higher on natural grass compared to artificial turf ($p = 0.022$), and natural grass compared to sand ($p = 0.034$). Although not significant, accelerations in the trail arm were higher on natural grass compared to artificial turf ($p = 0.057$). There were also significantly higher accelerations in the lead leg on natural grass compared to artificial turf ($p = 0.017$), and natural grass compared to sand ($p = 0.009$). Accelerations in the trail leg were also significantly higher on natural grass compared to sand ($p = 0.038$). Resultant accelerations were also significantly smaller in the legs compared to the arms across all conditions ($p \leq 0.001$).

Conclusion. These results suggest that the amount of golf play and / or practice on natural grass should be limited, especially in golfers recovering from, or those predisposed to, injury. This is because natural grass consistently produced the greatest total accelerations, suggesting that body segments may be subjected to greater forces which may increase the risk of injury, or re-injury. The acceleration variations between the arms and legs are likely due to the roles of these limbs throughout the golf swing. The arms help to generate force throughout the swing, and control accuracy of club head at impact. Therefore, they tend to have a much greater role and produce larger accelerations than the legs. The legs primarily act as stabilizers and contribute to consistency in the swing. Accelerations were significantly greater on the lead side compared to the trail side which is expected as the lead side is more involved throughout the golf swing. However, this is a major concern as the literature shows that the lead side sustains significantly more injuries. The high degree of reliability shown throughout the study suggests that all the golfers had consistent swings and conditions. As the golfers had consistent swings, the accelerations would have been similar if all surfaces were equal. As this was not the case, the swings were not the limiting factor, so it is likely that the stability of the surface was. The surface may have caused the legs to become less stable, which in turn may have affected the accelerations of both the arms and legs. These data suggest further research should be performed to examine how playing and practice surfaces relate to golf injuries.

HOW DRIVING DISTANCE AND DRIVING ACCURACY ARE CHANGING ON THE PGA AND CHAMPIONS TOURS

Friar, John; Habibullah, Mohamed; Wiseman, Frederick; Northeastern University

Purpose. The unanswered question of which is more important to a professional golfer – the distance or the accuracy of their drive has been of interest for a long period of time. Wiseman, Habibullah and Friar (2011) investigated this question by studying the performances of PGA and Champions Tour members for the 2006 to 2009 seasons. Their research was guided by the fact that past attempts to answer this question failed to take into consideration that the answer might depend on the type of hole (par 4 or par 5) and the specific tour (PGA or Champions). Their analysis clearly revealed that the answer did, in fact, vary by both type of hole and by tour. Specifically, for PGA Tour golfers, distance was more important on par 5 holes, but accuracy was more important on par 4 holes. However, on the Champions Tour, distance was more important than accuracy on both par 4 and par 5 holes. In this paper, the authors update the results of this previous study by extending the analysis to include both the 2010 and the recently completed 2011 seasons for golfers on both tours.

Methods and Results. Statistical data for this study were obtained from the PGA Tour website (www.pgatour.com) and the results indicate that small, but subtle differences were taking place on both tours. During the last thirty years, there has been a negative relationship between distance and accuracy. However, the data indicate that this relationship has grown stronger in recent years on both tours. For example, the correlation between distance and accuracy was equal to $r=-.57$ in 2009 on the PGA Tour, but was equal to $r=-.66$ in 2011, the strongest level in over 30 years. A similar trend existed for the growing strength of the relationship on the Champions Tour as the correlation went from $r = -.37$ in 2009 to $r = -.51$ in 2011. This suggests that the benefit that professional golfers obtain by driving the ball longer distances is partially offset by a decline in accuracy.

The strength of the relationship between each of the two driving measures on par 4 and par 5 holes with scoring average on each type of hole for members of each tour was obtained. For PGA Tour members on par 4 holes, the correlation between distance and scoring average was virtually non-existent as the R^2 value for each of the three years was less than 2%. However, the strength of the relationship was stronger for accuracy and scoring average, although the data from 2010 and 2011 indicated that there was a weakening in the strength of this relationship.

For PGA Tour members on par 5 holes, the results were virtually identical over the last three tour seasons as there continued to be a relatively strong negative correlation between distance and scoring average as big hitters were able to reach long par 5 holes in two shots, thus yielding a larger number of birdie and eagle opportunities. However, on these holes, accuracy had virtually no relationship to scoring average with R^2 values all less than 2%.

The updated findings for the Champions Tour highlighted the growing strength of the relationship between distance and scoring average on par 5 holes as R^2=.40 in 2011 compared to R^2=.29 in both 2009 and 2010. This compares to R^2 values close to zero between driving accuracy and scoring average on par 5 holes in each of the last three years.

For par 4 holes on the Champions Tour, the data indicated that both distance and accuracy were important with distance being more important, although in 2011, the R^2 values between each of the measures with scoring average were virtually identical. Further analyses were conducted to determine the relative importance of the two driving measures and three additional statistical measures, (greens in regulation, sand saves and putting average) on overall performance on par 4 and par 5 holes. The results indicated that the drive was of far greater importance for golfers on the Champions Tour than it was for golfers on the PGA Tour.

Conclusions. These results indicated the growing strength of the negative relationship between driving distance and driving accuracy. They also indicated that on par 5 holes, on both tours, the distance of the drive is far more important than its accuracy. However, on par 4 holes, accuracy is more important than distance on the PGA Tour, but on the Champions Tour, both are important. In summary, the findings highlighted the necessity for a well-rounded game on the PGA Tour where all shots are critical, but to be successful on the Champions Tour, a key factor is being able to drive the ball a long distance.

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PSYCHOLOGICAL CHARACTERISTICS OF TOURING GOLF PROFESSIONALS

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Purpose. The aims of this research were to examine the relationship between dispositional optimism, sport confidence, and golf performance using self-report psychological measures and objective performance data from touring golf professionals. This research also examined the cognitive styles of the professional golfers using a revised Your Information Processing Preferences Scale (YIPPS-R) instrument that included verbal, visual, and kinesthetic subscales. The rationale for collecting data on the cognitive styles of touring golf professionals was to guide the development of psychological skills training (PST) programs, specifically addressing the issue of whether these programs should be tailored to individuals' cognitive styles. Additionally, the current research aimed to determine the dispositional optimism and sport confidence levels of touring golf professionals with a view to developing PST programs for elite amateur or trainee professional golfers who aspire to become professional tour players. Given the limited information available on touring golf professionals' psychological characteristics, the current research contributes to understanding of this important topic.

Method. One hundred touring golf professionals participated in the research. The golfers were playing on a national (e.g., PGA Tour Australasia) or an international tour (e.g., European PGA Tour). The sample consisted of male professional players aged from 22 to 54 years ($M = 31.8$, $SD = 6.8$). The breakdown of primary tour membership was: 12% U.S., 7% Europe, 19% Nationwide, 6% Japan, 5% Asia, 38% Australasia, 1% Canada, and 9% Von Nida.

The players completed a questionnaire that included demographic information, questions regarding factors that influence their performance and satisfaction levels with various aspects of their golf life, and the following psychological measures: (1) Life Orientation Test-Revised (LOT-R; Scheier et al., 1994), (2) Sport Confidence Inventory (SCI; Vealey & Knight, 2003), (3) Carolina Sport Confidence Inventory (CSCI; Manzo et al., 2001), and (4) Your Information Processing Preferences Scale-Revised (YIPPS-R). Objective measures of golf performance for the relevant tournaments were obtained from the Internet.

Approvals to conduct the study and approach the players were obtained from the relevant Institutional Ethics Committee and PGA Tour Australasia, respectively. Players who provided informed consent completed the questionnaires at four tournaments organized by the PGA Tour Australasia between November 2004 and February 2005 (Australian Open, PGA Championships, Masters, & Jacob's Creek Open).

Analysis/Results. Analysis of LOT-R responses revealed that the sample of touring golf professionals ($M = 16.11$, $SD = 3.09$) were higher than average ($M = 14.33$, $SD = 4.28$) on dispositional optimism, $t_{(2147)} = 5.33$, $p < .001$. Discriminant function analysis determined that golf professionals playing on international tours reported higher scores on each of the SCI scales than golf professionals playing on Australian tours, $\chi^2_{(6)} = 15.65$, $p = .02$.

Players reported that preparation had greater influence on their tournament performance than other factors. They were also more satisfied with family support and health than with their finances and level of performance. Satisfaction with performance was linked to their average score relative to par, $\tau = -.45$, $p < .001$, and their dispositional optimism, $\tau = .16$, $p = .04$. Players' performance relative to par was also related to confidence in their physical skills and abilities, $\tau = -.16$, $p = .03$.

Total scores on each of the three subscales of the YIPPS-R were used to classify each participant as having low, moderate, or high preference for verbal, visual, and kinesthetic information. Two important findings emerged from analysis of the YIPPS-R data. First, no participants reported a distinct preference for one cognitive style to the exclusion of the others. Second, there were not many players with low scores on any of the subscales.

Conclusions. This research has provided useful insights into the psychological characteristics of touring golf professionals, adding to the knowledge about expertise in golf and enhancing service delivery in this specific sport (Dosil, 2006; Ravizza, 1988, 2001; Weinberg & Williams, 2010). The above average scores on dispositional optimism as well as the higher scores for international tour players on the sport confidence scale measuring belief in physical skills training suggest that these characteristics should be targeted in PST programs. The lack of a dominant cognitive style in professional tour players indicates that PST programs do not need to be tailored to each participant's specific cognitive preference. Rather, the programs need to incorporate components that cater for all three cognitive preferences, particularly hands-on practical components. Overall, these findings from the largest known touring golf professional sample inform the design and implementation of PST programs for elite golfers striving to become touring golf professionals.

THE EFFECT OF GOLFER BIAS ON PERCEIVED DRIVER PERFORMANCE: A DESIGNED EXPERIMENTAL STUDY

Garrison, Teena; Hale, Brendon; Lacy Jr., Thomas E.; Mississippi State University

The influence of golfer bias on perceived driver performance was evaluated using a carefully conducted experimental design. Two sets of skilled golfers were required to hit a series of shots with each of three premium drivers. Prior to testing, members of the first (experimental) set of golfers were told that one driver was rated particularly high, one marginal, and one poor by accomplished golfers, where the club ratings that each golfer received were randomly assigned. The golfers hit a series of shots indoors where initial golf ball launch parameters were measured using the Foresight GC2 launch monitor measurement system. The dispersion of impacts across the clubface was characterized using pressure sensitive impact tape on each shot. Standard analysis of variance techniques were used to assess the significance of the regression models, individual model terms, and model lack-of-fit. In addition, the inherent variability associated with various types of experimental measurements was evaluated. The golfers were also required to play at least one round of golf using each of the drivers. After testing, golfers answered a series of qualitative questions regarding each driver's characteristics and performance. The golfer's perception of driver performance was compared to measured launch monitor data. This process was repeated for a second (control) set of golfers that received no initial biasing regarding driver ratings. Employing the methodology outlined here, it may be possible to assess the effect of club marketing, player psychology, and inherent biases on player outcomes and performance.

STRATEGIC DECISION-MAKING IN GOLF: A QUALITATIVE EXPLORATION OF THE EXPERIENCE AND MEANING OF AGGRESSIVE PLAY

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Purpose. The purpose of this study was to gain a better understanding of the experience and meaning of strategic decision making in golf. Extant research suggests that a majority of amateur golfers implement inappropriate strategies as a result of positive illusions (Kirschenbaum & O'Connor, 1999). However, these data cannot be generalized to the more highly skilled professional.

Method. Qualitative methods, informed by existential and phenomenological practices, were used to study the experience of aggressive (high risk/high reward) decisions for three professional golfers. This approach was selected as qualitative methodologies are posited especially useful when little is known about a specific phenomenon (McKague & Verheof, 2003). In addition, existential phenomenology is particularly useful in investigating lived experiences and is similar to techniques employed in applied sports psychology consulting (Fifer, Henschen, Gould, & Ravizza, 2008). To implement this approach, 3 golfers who had been playing for an average of 3.9 years on sub-PGA professional tours (e.g. Canadian, Hooters, and Gateway) were recruited to participate. Three participants provide the minimal data required for thematic analysis (Pollio, Henely, & Thompson, 1997). Each interview

began with the question, “Can you tell me about a time in which you have taken an aggressive approach while playing competitively and describe your experience?” Follow up probes were used as needed to gain greater clarity and depth of the experience.

Analysis. Data analysis consisted of an interpretive analysis informed by Hermeneutic procedures and recommendations from Colaizzi (1978), and Cote et al., (1993). The interviews were recorded and transcribed verbatim. The interviews were decontextualized into smaller chunks of information. These chunks were labeled with meaning statements. The meaning statements were then grouped and labeled as larger, categories of meaning. These, in turn, were further combined into a smaller number of common components of meaning. It is these components of meaning that are used to describe the experience of the golfers.

Results. Following analysis, 32 categories of meaning statements emerged, which were organized within five, larger common components: (a) assessment (b) affect (c) conservative alternative (d) competitive environment and (e) commitment. In summary, for these golfers, strategic decision-making can be described as an informed choice guided by experiences of both positive and negative affect, which were associated with the opportunity to experience optimal performance or to demonstrate superior skill relative to their opponents. As such, it appears that personal meaning, affective states, and perceptions of the competitive environment influence the golfers strategic decisions beyond what is explained by expected utility models.

Conclusions. Expected utility models state that a “rational” individual should and will invariably choose an option that maximizes utility (von Neumann & Morgenstern, 1944). In this vein, “smart golf” strategies (Kirschenbaum, O’Connor, & Owens, 1999; Kirshenbaum, Owens, & O’Conner, 1998) have been suggested to maximize performance. However, expected utility models consistently fail to predict individual decisions that often deviate from normative statistics (Starmer, 2000).

Instead, individuals use both non-statistical and statistical principles in developing probabilistic judgments (Ginossar & Trope, 1987). Results from the present study support this more nuanced interpretation. They indicate that golfers make decisions resulting from biases or through the use of decision heuristics that are not governed by a sole desire to shoot the lowest possible score. Unlike amateurs, this does not appear to be due to an exaggerate set of positive expectations. Instead, it appears to be directed by personal biases for an aggressive style of play, as well as negative perceptions of conservative play, which they feel offers relatively little reward for well-executed performances. Findings from this study will contribute to the fields understanding of strategic decision-making and be useful to applied practices of sports psychology consulting and golf coaching. Consistent with hermeneutics, the in-depth details of the individual’s descriptions are useful in both creating understanding and for stimulating conversation (Wilson & Hutchinson, 1991). As a result, findings from this study may be used to guide future research and the development of individualized intervention techniques.

PGA TOUR GOLFERS SHORT GAME FROM DIFFERENT LIES AND DISTANCES

Hellström, John; Swedish Golf Federation

Purpose. A good short game is important to get a low scoring average.[1] Luke Donald, ranked no1 in adjusted scoring average[1] 2011, had the following one-putt percentage: 0.0–1.5m: 98%, 1.5–3.0m: 66%, 3.0–4.6m: 28% (see http://www.pgatour.com). The short game is the only part outside the green that players can hit the ball close enough to regularly one-putt.[2] Club, swing and aim selection depend on the player's perceived risk, rewards and odds to succeed.[3] The lie of the ball and the distance to the target will affect that tactical decision. The purpose is therefore to investigate the effect of lie from different starting distances on the finishing distance to hole after the shot. Also, normative data may be used when creating needs and gap profiles to steer training.

Method. The 30 best PGA Tour players were selected based on lowest adjusted scoring average 2011. PGA Tour and ShotLink collected the data. Friedman's test was used to compare finishing distance between three lies, from three starting distances. Each player's median values for finishing distance were used so each individual affected the group statistics equally. Lies were divided into three categories: fairway, rough and bunker. Starting distances were divided into three intervals; 0.0–9.9m, 10.0–19.9m and 20.0–29.9m. Significance level was set to $p<0.05$. Wilcoxon with Bonferroni correction ($p<0.017$) was used post-hoc to compare individual pairs.

Results. **0.0-9.9m:** There was a statistically significant difference in finishing distance depending on lie, χ^2 (2, N=30) = 49.933, p = 0.000. Median (IQR[2]) distances to the hole after shot from fairway, rough and bunker were 0.70m (0.65–0.81m), 1.14m (1.07–1.32m) and 1.99m (1.56–2.57m). There were significant increases in finishing distance from fairway to rough (Z=-4.682, p=0.000), fairway to bunker (Z = -4.762, p = 0.000), and rough to bunker (Z = -4.587, P=0.000).

10.0-19.9m: There was a statistically significant difference in finishing distance depending on lie, χ^2 (2, N=30)=42.200, p=0.000. Median (IQR) distances to hole after shot from fairway, rough and bunker were 1.38m (1.24–1.63m), 2.15m (1.93–2.42m) and 2.15m (1.96–2.26m). There were significant increases in finishing distance from fairway to rough (Z=-4.639, p=0.000) and fairway to bunker (Z=-4.783, p=0.000), but not between rough and bunker (Z=-0.360, p=0.719).

20.0-29.9m: There was a statistically significant difference in finishing distance depending on lie, χ^2 (2, N=30)=20.067, p=0.000. Median (IQR) distances to hole after shot from fairway, rough and bunker were 2.19m (1.84–2.55m), 2.91m (2.55–3.15m) and 2.88m (2.34–3.38m). There were significant increases in finishing distance from fairway to rough (Z=-3.569, p=0.000) and fairway to bunker (Z=-3.394, p=0.001), but not between rough and bunker (Z=-0.051, p=0.959).

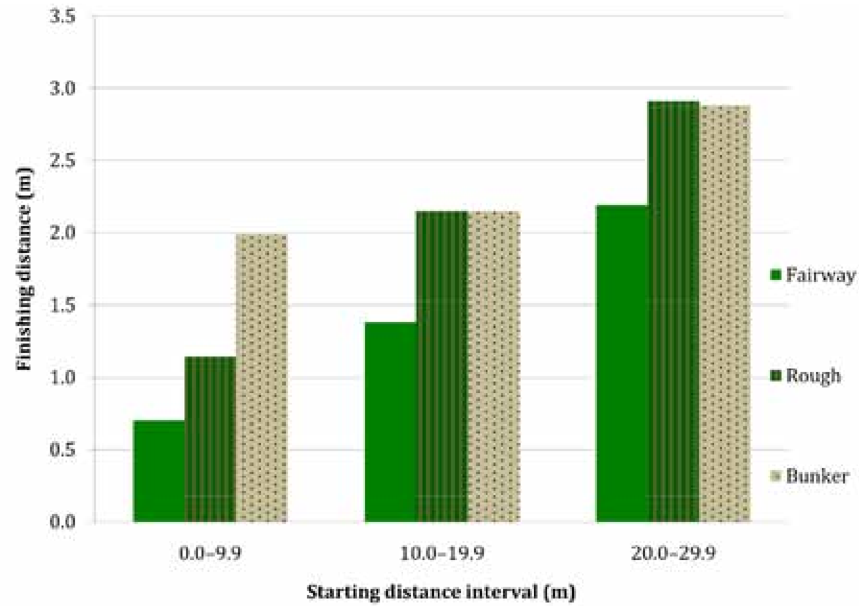

Figure 1. Median finishing distance depending on starting distance and lie.

Conclusion. Hitting from fairway will probably get the ball closer to hole than swinging from rough or bunker, when the same starting distance is compared.

Even a slight reduction in finishing distance will improve chances of one-putting substantially, from all rough and bunker lies that are within 30m of the pin.

For this category of players, it may be better to practice more from fairway lies between 10–30m, than from inside 10m where they regularly end up within 1m to one-putt repeatedly.

The median finishing distance from fairways 20.0–29.9m was only 20cm further away from the hole than bunkers from 0.0–9.9m. Bunker shots from 10.0–19.9m finished only 16cm further away from the hole than bunker shots from 0.0–9.9m (see Figure 1).

It is not only amateur players that have problems when hitting from bunkers.[4] World-class players finish significantly further away from the hole when hitting from bunker compared to rough (85cm difference) when being close to the hole (0.0–9.9m). It therefore seems tactically wise to avoid short bunker shots.

Notes.

1. The weighted scoring average takes the stroke average of the field into account.

2. Interquartile range (Q_3–Q_1)

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A GOLFER'S PERCEPTION OF THEIR SWING PERFORMANCE IS INFLUENCED BY BALL CONTACT RATHER THAN UPPER BODY KINEMATICS

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Introduction. Performing an efficient and effective swing consistently is critical to successful golf performance. For this reason, much research has been devoted to analyzing the mechanics of the golf swing. In particular, the pattern and speed of movement of the thorax, pelvis and hand segments have been examined in an effort to identify variables thought to reflect skilled performance. However, for individual golfers, a precise understanding of the kinematics underpinning an optimal swing may not be necessary. It has been suggested that golfers rely more on the 'feel' of a shot rather than on a conscious awareness of specific segmental movement or timing. To date, very little research has examined whether kinematic variables influence a golfer's perception of how well they perform a full golf swing. Therefore, the purpose of the present study was to examine whether upper body kinematics influence a golfer's perception of their swing performance for shots with a driver.

Methods. Eighteen male and two female golfers (mean ± SD; age 35 ± 9 years, height 1.77 ± 9 m, mass 86 ± 17 kg, handicap 4 ± 5 strokes) participated in the study. A five sensor Polhemus Liberty electro-magnetic tracking system (Polhemus Inc., Colchester, VT, USA) operating at 240 Hz was used to record three-dimensional motion of the upper body during five driver swings. All swings were collected by the same operator, under similar weather conditions, at an outdoor driving range. In addition to collecting club and ball speed using a Trackman radar system (Trackman A/S, Vedbaek, Denmark), self-reported ratings of swing performance were recorded after each shot using a 10-point ordinal scale (i.e. 1 = very poor, 10 = excellent). Angular displacements and speeds of the pelvis, thorax, upper arm and hand were calculated using standard biomechanical principles in conjunction with Golf BioDynamics software, version 1.0.1 (Golf BioDynamics Pty Ltd., Brisbane, Australia). The variables of interest extracted for statistical analysis were X-Factor (at top of backswing), X-Factor stretch, and the magnitude and timing of segment speed for the pelvis, thorax, upper arm and hand. Group means for all dependent variables were analyzed using independent samples t-test with Bonferroni corrections (SPSS for Windows 17.0; SPSS, Chicago, IL, USA). The level of significance was set at $p < 0.05$.

Results. Swings were divided into tertiles, corresponding with low, average, and high ball speed groups. Comparison between the low ball speed group (mean ± SD; 134.4 ± 8.0 mph) and high ball speed group (160.1 ± 6.2 mph) revealed that X-Factor stretch (low vs. high; -6.8 ± 1.9 vs. -8.8 ± 2.7 deg), and thorax (672 ± 87 vs. 791 ± 80 deg/s), arm (895 ± 119 vs. 1018 ± 161 deg/s) and hand speed (1555 ± 133 vs. 1729 ± 94 deg/s) were significantly greater for the high ball speed group. No differences for self-perceived rating of swing performance, 'smash factor' (calculated by dividing ball speed by club speed) or percentage of swings with a proximal to distal pattern of motion were observed between groups. Swings were also divided into tertiles based on self-perceived rating of swing performance. Comparison between the lowest (3.3 ± 1.4) and highest (8.7 ± 0.8) rated swing groups, revealed that smash factor (lowest vs. highest; 1.44 ± 0.05 vs. 1.48 ± 0.02) was significantly greater for the high group. No other differences in upper body kinematics or club or ball speeds were observed between the groups.

Conclusions. As expected, high ball speeds were evident in those golfers who produced high upper body segment speeds. For shots with a driver, a golfer's perception of how well they performed the swing was indirectly related to ball contact (i.e. smash factor) rather than on specific segmental motion, speed or timing. These findings have a number of implications. For golf coaches, the results may be intuitive - that is, enhancing a golfer's ability to sense or feel ball contact rather than on their ability to produce specific movement patterns may be more effective for improving performance. However, further validation of these results with respect to other performance measures is required. Specifically, it would be of interest to determine if the same relationship holds true with respect to the location of ball contact and the accuracy outcome of each shot.

GENDER DIFFERENCES IN FULL SWING KINEMATICS FOLLOWING PROLONGED PUTTING PRACTICE

Horan, Sean A.; Evans, Kerrie; Kavanagh, Justin J.; Griffith University

Background. The kinematics of the golf swing are typically examined following a simple warm up routine or brief familiarization session, which may not be reflective of the movement patterns adopted over extended periods of play or practice. Recent investigations have examined the effect of prolonged sport-specific tasks on the performance of multi-segment movements, and revealed that movement patterns can adapt over time to ensure that performance is maintained. Therefore, it is critical for the design of future golf studies to determine if golf swing kinematics are altered following golf-specific interventions. Surprisingly, it is unknown if kinematics of the full swing are altered following prolonged practice, or if prolonged practice affects males and females differently. The aims of this study were (i) to determine if 40 minutes of putting practice alters thorax and pelvis kinematics during the full swing, and (ii) determine if males and females are affected differently.

Methods. An 8 × camera motion analysis system (Vicon Motion Systems, Oxford, UK) operating at 500Hz, was used to capture three-dimensional thorax and pelvis motion during the driver swing of 19 male (mean ± SD; age = 26 ± 7 years, hcp = 0.6 ± 1.1) and 17 female (age = 24 ± 7 years, hcp = 1.4 ± 1.7) golfers before and after a 40 minute practice putting task. Forty minutes was chosen based on self-reported practice times and previously reported data. The putting task involved hitting putts along a mat to a hole from a range of self-selected distances, with subjects free to walk around the putting area but required not to sit or rest at any point during the 40 minute session. While the number of putts for each participant was not specifically recorded, one of the authors (SH) supervised all participants to ensure that the putting task was performed at a similar intensity and similar putt frequency. Segment kinematics were calculated using a customized kinematic model written using BodyBuilder v3.6 software (Vicon Motion Systems, Oxford, UK). Angular displacement at address, top of backswing and ball contact for the pelvis, thorax, and pelvis-thorax interaction were calculated. The magnitude of peak angular velocity and repeatability of continuous segment angular velocities using coefficient of multiple determination (CMD) were also calculated. As gender differences exist in thorax and pelvis angular displacement and velocity for male and female skilled golfers, change scores (post- minus pre-intervention) for each dependent variable formed the basis of the statistical analysis. One-way ANOVA (SPSS for Windows 17.0, SPSS, Chicago, IL) was subsequently used to test for gender differences in change scores.

Results. Female golfers had less pelvis and thorax anterior-posterior tilt at address (pelvis: $p = 0.01$; thorax: $p < 0.001$), less thorax and thorax-pelvis axial rotation at top of backswing (thorax: $p < 0.001$; thorax-pelvis: $p < 0.001$), and less pelvis and thorax axial rotation (pelvis: $p < 0.001$; thorax: $p = 0.002$) and pelvis lateral tilt ($p = 0.02$) at ball contact following the putting task. Analysis of peak angular velocities revealed females had significantly lower thorax-pelvis lateral tilt velocity following putting. For repeatability analysis, females exhibited significantly lower CMDs for thorax and thorax-pelvis axial rotation velocity, while males exhibited significantly lower CMDs for thorax-pelvis axial rotation velocity only following the putting intervention.

Conclusions. The results of this study suggest that a prolonged practice putting intervention affects females' thorax and pelvis orientation angles and velocities to a greater extent than males. Interestingly, clubhead speed for both males and females was unaffected by the intervention, suggesting different coordination strategies may be employed where unfatigued muscles of the arms, or less fatigued muscles of the trunk are recruited to complete the goal-directed task. The practical implications of these results are that golfers and golf instructors should carefully consider the duration of training or instruction sessions, particularly when working with different genders. While more rigorous investigation is warranted, endurance training programs aimed at improving a golfer's ability to manage static golf postures may also be of benefit to skilled golfers.

THE COMPARISON OF A 'TRACKMAN' RADAR LAUNCH MONITOR AND HIGH SPEED CAMERAS

Hurrion, Paul; Twogood, Rory; Quintic Consultancy Limited

Purpose. The purpose of the study was to compare and hopefully explain, understand and interpret the apparent discrepancies between ball flight viewed by the naked eye and that reported by a market leading 'radar tacking' system, 'Trackman'. In addition, this study aimed to further investigate the club data reported (measured and predicated) by the 'Trackman' system. Two high-speed video cameras (10,000 fps) were used to calculate the key kinematic parameters measured by 'Trackman' to discover if there were significant differences between any of these parameters. To fully understand observations of ball flight, accurate measurement of impact conditions are required to establish the swing mechanics which have created this impact conditions (Cochran, A. & Stobbs, J.). Radar technology has been used for a number of years to provide ball flight data. Only recently has the equipment attempted to measure the impact conditions of the club which can provide the basis for coaching the golf swing. Golf professionals are using radar systems as a coaching tool to measure ball flight, but without fully understand and having accurate measurement parameters for the club impact data and how the centre of gravity of each club impacts the results.

Method. Forty Driver swings were made by one golfer (scratch handicap) with both the 'Trackman' and the two high speed cameras recording simultaneously. The club was a Titleist 975d 9.5 degree loft, Aldila VS Proto S80 shaft. Two Phantom v1210 high speed cameras (image resolution of 1200 x 680) with a sampling rate of 10,000 frames per second (fps) were used to collect the data. A shutter speed of 15,000Hz was used to prevent blurring of the club head. The first camera was placed at 90° to the path of the golf ball, 10cm above the height of the ground. The second camera was placed directly overhead of the path of the golf ball, 80cm above the ground. 'Trackman' was set-up according to manufactures guidelines, directly along the ball to target line. A calibration procedure for both systems was performed prior to data collection. After processing, each camera view was analyzed using a personal computer running Quintic Biomechanics v17 video software. Each video was calibrated in the horizontal and vertical plane using a known calibration measurement. All forty swings were digitized at a rate of 10,000Hz. The driver head was digitized and tracked using automatic tracking Quintic Biomechanics v17 with specific markers placed upon the club head. A two-sided paired t-test was used to compare the differences from the individual shots each parameter and investigate if any were significantly different. The level of significance was set at $p<0.05$. For each driver swing, digitization of the club head began 50 frames prior to contact with the golf ball and continued 50 frames past impact. For each swing the corresponding 'radar tracking data' were recorded and saved for analysis.

Analysis.

	Trackman		High-Speed Video				
Parameter	**Mean**	**±SE**	**Mean**	**±SE**	**Difference**	**±SE**	**P value**
Club Head Speed (mph) [1]	107.8	0.4	110.7	0.5	3.00	0.36	p<0.005**
Ball Speed (mph) [2]	158.8	0.6	158.0	0.6	0.85	0.17	p<0.005**
Horizontal Launch Angle (°)	2.0	0.5	1.9	0.4	0.10	0.22	NSD
Vertical Launch Angle (°)	10.6	0.3	10.7	0.3	-0.12	0.12	NSD
Attack Angle (°) [3]	-0.7	0.3	0.1	0.4	-0.66	0.37	p<0.05*
Dynamic Loft : Roll (°) [1]	11.6	0.2	15.9	0.5	-3.94	0.46	p<0.005**
Face Angle : Bulge (°) [1]	2.3	0.6	2.8	0.5	-0.84	0.49	p<0.05*
Club Path (°) [3]	1.8	0.3	0.3	0.3	1.19	0.23	p<0.005**

[1]Calculated at first frame of contact [2]Calculated 10 frames after impact [3]Club Path / Attack Angle (Horizontal / Vertical movement of the club through impact); $p<0.05$* $p<0.005$** NSD = No Significant Differences

As a result of the experimental data collected during this research, the 'Trackman' ball flight information (both horizontal, and vertical launch angles) were found to have no significant difference when compared to the high-speed video analysis. However, club head and ball speed were found to have significant difference at the $p<0.005$ level. When analyzing the club head data, attack angle and face angle were found to have significant difference at the $p<0.005$ level. Dynamic loft and club path were found to be of significance difference ($p<0.005$ level).

Conclusions. The use of 'radar tracking' systems have become a simple and common way to teach golf, every golfer can instantly review the information provided by the computer after each swing. However, it is the authors' opinion that in many cases the individual has no appreciation of how the data is recorded, calculated and most importantly the terminology used to explain the key parameters measure. If a PGA Professional / Coach are using the club parameters report by such radar tracking systems for coaching purposes, they may in all likelihood be giving incorrect information to their student if they are solely relying on this technology.

Radar technology has been used for a number of years to provide ball flight data. This study further supports the accuracy and use of such technology to measure ball flight. However, as previously stated, this equipment has only recently stated to attempt to measure the impact conditions of the club. Until such time as this equipment can accurately measure the ball impact location on the face of the club, allow in its calculation for the club head centre of gravity, the model used to predict club face angle and dynamic loft for example should only be used as a guide for teaching professionals. Furthermore, this study again highlights the need for consistent language and clear description of parameters measured for scientists, club manufactures and coaches alike. Face angle can change by over 6 degrees whilst the club head is still in contact with the ball. Angle of Attack can change by 1.0 degrees during impact... which measurement is correct? Or more importantly which one should we all be using?

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I PUTT WELL WHEN NO ONE IS WATCHING: THE INFLUENCE OF SOCIAL PRESSURE WHILE PUTTING

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Purpose. Pressure associated with competing in a variety of sports has been linked to performance decrements. Although this phenomenon (sometimes labeled 'choking under pressure') has been studied for several decades, a number of complexities in regards to what personal variables contribute to such decrements have arisen (e.g., Baumeister & Showers, 1986; Beilock & Carr, 2001; Clark, 2002; Masters, 1992; Oxendine, 1970). Golf putting is a fine-motor skill that is highly susceptible to diminished execution under competitive pressure. Social evaluation and threats to social status have both been implicated in inducing a stress response (Dickerson & Kemeny, 2004). When a golfer is performing under pressure, the presence of an observing audience often elicits feelings of self-focus, which may lead to an increase of conscious control of efforts to enhance performance (Wicklund & Duval, 1971). Exactly *how* pressure influences the various aspects of the putting stroke is not entirely understood, despite recent studies that have attempted to measure the kinematic effects of stress under pressure (e.g., Cooke, Kavussanu, McIntyre, & Ring, 2010; Tanaka & Sekiya, 2010). As such, in two studies we explored the linear and interactive associations between state anxiety and golf putting performance under differing conditions of stress. We assessed golf putting performance under "lower-stress" (i.e., baseline) and "higher-stress" conditions using a high-speed infrared camera to measure the putting strokes of golfers.

Methods. In study 1, 35 amateur golfers (4 females, 31 males) who were members of a private golf practice facility in Ottawa, Ontario (M_{age} = 53.97 yrs). All golfers possessed a valid *Golf Canada* Handicap ($M_{handicap}$ = 13.62, ranging from 0.0 to 30.0). In study 2, 17 low-handicap golfers ($M_{handicap}$ = 1.69, range = 0.0 to 7.0; all male) participated (M_{age} = 29.58 yrs).

Golfers completed a demographic questionnaire and the *Competitive State Anxiety Inventory 2-Revised* (CSAI-2; Cox, Martens, & Russell, 2003), to assess both cognitive and somatic anxiety.

To assess putting performance, golfers had their putters outfitted with a putting motion analysis system called the TOMI® (Pure Motion, Inc., Southlake, TX). The TOMI® uses a high-speed infrared camera to capture a number of different real-time parameters of the putting stroke (e.g., alignment, stroke time, impact position, etc.). Furthermore, the number of putts holed was collected to serve as an alternate measure of performance.

In the *low-stress condition*, golfers were asked to hit a series of 5 (study 1) or 10 putts (study 2) to a hole 6 feet away, while being told that the system needed to be calibrated. These putts served as their baseline results. For the *high-stress condition*, golfers were then told that next series of putts were to be a part of a competition, in which results would be posted for everyone to see. For study 1, a golf professional was summoned to view the putting stroke and to provide feedback as to the 'correctness' of the stroke, with the entire process video-recorded to add an additional element of evaluation. For study 2, participants were told that NCAA division I golf coaches would be evaluating the video tape to learn how golfers react under pressure.

Analysis/Results. In both studies, hierarchical linear modeling (HLM) was used to test the hypotheses at both levels of analysis, namely the between- and the within-person levels of analysis. Overall, results indicated that regardless of skill level all golfers tended to have less putter head rotation, quicker back strokes, and quicker forward strokes in the stress condition compared to baseline. Furthermore, the stress manipulation was significantly associated with quicker back swing times, but only for those with high levels of state anxiety. Lastly, golfers with low levels of anxiety holed significantly more putts in the high stress condition whereas the putting performance of golfers with high anxiety did not significantly differ across conditions.

Conclusion. State anxiety likely exacerbates the detrimental effect of induced stress by impeding the expected tendency to improve across putts in a laboratory setting. Although all golfers had shorter back stroke times during the stress condition, this effect was particularly pronounced for those endorsing high state anxiety scores. It appears as though higher levels of anxiety disrupt the natural flow of the putting stroke ever so slightly – just enough to perhaps be the difference between squaring the putter face at impact, or leaving it open. Results from these studies may help both beginner and elite golfers by making them aware of the kinematic impact of social pressure, and their own individual reactions to this pressure when playing competitively.

APPLYING SIMPLE AND ACUTE KINEMATIC ALTERATIONS TO ELICIT CHANGE IN GOLF CLUB SPEED AND ANGLE

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This research was supported by a grant from: Eaton Corp., Golf Pride Grips

Purpose. Golf is perceived as a complex movement, requiring 10,000[8] hours of practice to elicit elite performance. Are there any simple changes to swing kinematics which can produce quick improvement in club parameters? The purpose of this study was to measure alteration in the club speed and angle of approach; as well as in acute swing kinematics during interventions using either a popular teaching method[1] based on swing 'rhythm' or a less-known one[2] based on arm kinematic changes, during a single session.

Method. Two swing methods - 'rhythm' and 'position' were assigned randomly to 16 right-handed participants - 2 female, 14 male. During the session, swings were monitored using 53 retroreflective markers and 6-camera near-infrared video motion capture. Ten pre-intervention shots were recorded. Participants were then trained by the author (17 years teaching experience; familiarity with both methods); made 10-15 practice shots; then made 10 recorded post-intervention shots.

The intervention for the 'rhythm' group required the subject to swing to a rhythm[2] of 'one and' during the backswing, and 'two' during the downswing. The intervention for the 'position' group[2] - to induce an increase in backswing arc width - required the subject to keep the right elbow extended and the right wrist neutral for as long as comfortably possible during the backswing; while simultaneously swinging the arms and club shaft in a straight line towards the participant's right foot.

The surface markers of the trials were connected together and then tracked (EVART software) and edited to produce three-dimensional coordinates as a function of the swing. The average of all trackable 'good' shots, from both the pre- and post-intervention sessions was used for analysis. 'Good' shots were those which both the golf instructor and subject agreed were of good quality. Based on the position-time data collected, specific angles and distances were noted at four particular break-points during the swing (Table 2). Clubhead speed at impact was calculated. Three sets of variables were measured to quantify changes a) rhythm, b) position c) outcome (club speed and angle).

Statistical analysis included an independent t-test to determine if significant differences ($p<0.05$) existed between the variables for the two groups at the outset of the investigation (Table 1.). A dependent t test was performed to detect kinematic changes, including clubhead's angle of approach, as a consequence of the intervention. A non-parametric chi square test was performed to compare clubhead speed results between the two groups.

Results. There was no significant difference between groups (Table 1.). There were no significant changes in the rhythm variables for either group. The position group showed several statistically significant kinematic changes (Table 2.). The angle of approach of the clubhead to the ball reduced significantly for the position group. There was no significant change in the angle of approach for the rhythm group. Results for clubhead speed indicated that there was a significant increase for the position group from what was expected. No change was observed for the rhythm group.

Conclusions. This study was the first to compare two swing methods for efficacy in improving club parameters during acute swing alterations. The comparison served to rule out improvement taking place from random, undirected practice. The study was able to show an improvement in clubhead speed for the 'position' intervention in a small time frame. The 'position' method, requiring an extended right elbow and neutral wrist during backswing, was successful because 'wide' arms produce a longer lever for greater swing velocity. An 'inside' backswing path is more likely to promote the desired 'in-to-out' downswing path. Only the arms are required to move during backswing takeaway, with no requirement for torso rotation, so the arms and body remain in synchronization, and the downswing is more likely to commence in sequential order - lower body first - for greater power production. Keeping both arms 'as straight as possible' keeps the backswing 'shallow' and allows the downswing to be similarly shallow. Less wrist-cock (bend) prevents the club from being taken too far past its position of maximum gravitational potential energy, thus harnessing gravity to help initiate the downswing. A final benefit of the recommended 'inside' movement of the position method is that it moves the right shoulder away from the ball during the backswing, thus reducing the chances of the upper right side of the body starting the downswing.

The 'position' method was able to shallow-out the downswing arc, which should lead to greater trajectory, and thus greater carry distance. Two limitations of the study are that there was no follow-up to assess retention of the kinematic changes, and that all 10 swings 'before' and 'after' were not always trackable. It can be concluded that it is possible to increase clubhead speed; reduce the angle of approach of the club to the ball; and make kinematic changes, in a short time interval, in a diverse range of club golfers.

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Table 1. *Pre-intervention results*

Group Position (1) Rhythm (2)	Age	Inches Height	Lbs Weight	Years Playing	Per week Play Frequency	Per week Practice Frequency	Hndicp Current	Hndicp Lowest
2	68	66	163	9	3	0	-30.1	-27
2	30	66	205	26	1	0	-3.4	-1.2
2	44	75	185	30	2	6	-12	-5
2	61	72	170	35	2	1	-19	-19
2	51	71	230	13	2	3	-7.6	-7.6
2	35	72	220	20	1	1	-11.6	-10.9
2	61	72	160	50	1	0	-18	-18
2	73	68	180	30	3	0	-15	-15
1	49	71	240	6	5	1	-10.9	-10.9
1	75	70	150	67	7	0	-8.9	-5
1	36	71	198	5	3	1	-15	-12
1	68	73	178	30	7	0	-23	-20
1	54	63	160	10	1	0	-18	-11
1	63	74	230	15	3	0	-18	-14
1	39	74	200	4	3	2	-15	-15
1	49	70	170	39	1	2	+ 2	+ 4
Mean	53	70	187	25	3	1	13.6	10.9
Std Dev	15	3	29	17	2	2	6.6	6.8

Table 2. *Means and Standard Deviations of Kinematic Variables for Positions and Rhythm Groups*

	Position Group		**Rhythm Group**	
	Before †	After †	Before †	After †
BS-DS Ratio (sec)	3.53 + 0.92	3.28 + 1.17	2.96 + 0.75	3.01 + 0.36
Right hand-forearm angle(deg) 90BS °	54.40 + 9.41	44.68 + 12.77 *	46.14 + 14.64	48.17 + 15.95
Left hand-forearm angle(deg) 90BS	37.54 + 8.80	30.71 + 7.70 *	34.07 + 13.98	31.92 + 8.86
Left hand-forearm angle(deg) ToBS	61.86 + 17.48	49.80 + 15.74 *	59.43 + 24.45	58.50 + 23.45
Right upper vs. fore-arm angle(deg) 90BS	51.50 + 7.15	43.31 + 12.80 *	45.48 + 10.73	48.51 + 7.55
Right upper vs. forearm angle(deg) Impact	33.63 + 4.92	29.90 + 5.71 *	34.49 + 15.09	34.91 + 13.81
Right hand to heel line angle(deg) ToBS	29.42 + 50.20	-8.45 + 46.51 *	24.60 + 84.87	-29.72 + 115.35
Left hand to heel line angle(deg) ToBS	133.79 + 63.71	84.13 + 63.01 *	118.30 + 85.19	59.53 + 114.90
Angle of Approach (deg)	37.8 + 3.14	36.24 + 2.77 *	38.27 + 2.27	38.0 + 1.99

Note. BS = Backswing, DS = Downswing; 90BS = club shaft horizontal, Backswing; ToBS = Top of Backswing

† Values are presented as the means + SDs

* Significantly different from 'before' group ($p < 0.05$, using paired t test

DECOMPOSITION OF THE CLUBHEAD VELOCITY: CONTRIBUTIONS OF THE JOINT/SEGMENT MOTIONS IN GOLF DRIVES

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Purpose. A golf drive is a complex three-dimensional motion involving multiple segments and joints and coordinated motions of these joints/segments are important for a successful drive. The golfer's body forms a kinematic chain and the clubhead motion can be decomposed to component motions of the member joints/segments of the chain. Contributions of the component joint/segment motions can thus be assessed based on the decomposed velocities. The purpose of this study was to assess the contributions of key joint and segments of the kinematic chain to the clubhead velocity and to identify the sequencing pattern of the joint/segment motions.

Methods. Fourteen healthy male golfers participated in this study: mass = 83.8 ± 11.1 kg, height = 180.5 ± 5.3 cm, age = 32.8 ± 10.7 years, and handicap = -0.5 ± 2.0. A 250-Hz 10-camera motion capture system was used in an indoor motion analysis laboratory to capture the trajectories of the reflective markers attached on golfer's body and club. A total of 65 reflective markers were used in a series of static trials and motion trials. Practice foam balls were used in the motion trials and five successful drives were collected for each golfer.

A kinematic chain consisting of 7 segments (pelvis, trunk, left shoulder girdle, left upper arm, left ulna, left radius, and left hand/club), linked at L4/L5, mid-shoulder, left shoulder, left elbow, and left wrist, was defined. The mid-hip (proximal) and the clubhead (distal) were used as the end points of the chain. The clubhead velocity was decomposed to the component velocities due to the motions of the pelvis segment (translation and rotation) and the joints. All velocity values were normalized to the body height of the golfer (in BH/s).

The 'functional swing plane' (FSP) was identified by numerically fitting the clubhead trajectory to a plane using a least square method in the execution phase (mid downswing to mid follow-through). The clubhead trajectory of the downswing (top of backswing to impact) was then projected to the FSP to obtain the projected trajectory. The moving FSP reference frame was defined based on the projected trajectory: normal (perpendicular to the FSP)-tangential (along the tangential line of the projected trajectory)-radial (projected clubhead to the instantaneous center-of-rotation). The decomposed velocities were transformed to the swing plane reference frame.

Analysis/Results. The average impact velocity of the clubhead was 44.37 ± 3.28 m/s. The joint/segment contributions reached their peak values in the sequence of L4/L5 (at 52% of the downswing), shoulder (77%), wrist (89%), pelvis (89%), and forearm (97%). The velocity contribution decreased after the peak value in all joints/segments except the L4/L5 joint which was characterized by a gradual increase in the velocity contribution throughout the downswing (Table 1). The wrist was characterized by the largest peak contribution, contribution at impact, and peak-to-impact difference (Table 1). The forearm, shoulder, and pelvis revealed similar maximum contributions with the shoulder showing the largest velocity decrease from the peak value. The elbow extension, shoulder elevation, and pelvis translation revealed negligible peak contributions. At impact, about 53.7% of the tangential clubhead velocity came from the motions of the wrist (flexion/extension and deviation) and forearm (pronation/supination). The elbow/shoulder complex and the L4/L5 motions showed contributions similar to that of pelvis rotation (~15%).

Values in BH/s. CH = clubhead velocity; FA = forearm (pronation/supination); SG = shoulder girdle (elevation/depression); Pelvis-R & Pelvis-T = rotation and translation of the pelvis, respectively. For the relative contributions, the tangential clubhead velocity at impact was used as 100%.

Conclusions. A tendency of proximal-to-distal sequencing of peak velocity contribution (L4/L5, shoulder, and wrist) was observed with exceptions: the forearm pronation/supination and pelvis rotation reached their peak contributions at the end while the L4/L5 joint showed a gradual increase in velocity contribution after the initial peak contribution. The wrist joint motion was identified as the main contributor followed by the forearm motion and over 50% of the clubhead velocity at impact was associated with the wrist/forearm motion.

TABLE 1. Tangential Velocity Contribution (BH/s)

		CH	Wrist	FA	Elbow	Shoulder	SG	L4/L5	Pelvis-R	Pelvis-T
Peak Contribution	Mean	25.04	10.96	4.82	-	4.26	-	2.58	4.44	-
	(SD)	(1.97)	(1.70)	(2.46)		(1.16)		(0.59)	(0.84)	
	Relative	101.7%	44.5%	19.6%		17.3%		10.5%	18.0%	
Contribution at Impact	Mean	24.63	8.58	4.66	1.38	2.47	-0.11	3.74	3.82	-0.05
	(SD)	(2.11)	(2.22)	(1.90)	(2.73)	(2.56)	(0.26)	(1.17)	(0.83)	(0.08)
	Relative	***100%***	34.8%	18.9%	5.6%	10.0%	-0.5%	15.2%	15.5%	-0.2%
Peak-Impact Difference	Mean	-0.41	-2.38	-0.16	-	-1.79	-	+1.16	-0.63	-

THE EFFECT OF DRIVER LOFT, MASS, AND SHAFT LENGTH ON INITIAL GOLF BALL LAUNCH CONDITIONS: A DESIGNED EXPERIMENTAL STUDY

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The influence of golf driver loft, mass, and shaft length on initial golf ball launch conditions was investigated using empirically-based response surfaces. A series of carefully selected player tests were used to isolate the coupled influence of club mass and shaft length on initial ball velocity, spin rates, launch angle, and dispersion of impacts across the clubface. The ranges of selected club masses and shaft lengths were typical of those found in currently available drivers. Initial golf ball launch parameters were measured using the Foresight GC2 launch monitor measurement system. The dispersion of impacts across the clubface was characterized using pressure sensitive impact tape on each shot. Standard analysis of variance techniques were used to assess the significance of the regression models, individual model terms, and model lack-of-fit. In addition, the inherent variability associated with various types of experimental measurements was evaluated. Response surface characterizations of the quality of driver impacts can provide an essential tool in player swing analysis and club fitting. Employing the methodology outlined here, it may be possible to tailor golf club designs in order to obtain enhanced golf ball launch characteristics for a range of golfers. Such efforts may facilitate golf club design by establishing relationships between mass and configuration parameters that lead to improved driver performance.

QUALITATIVE CHANGES IN COORDINATION BETWEEN GOLF SWINGS

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Purpose. Much of conventional golf biomechanics research looks to describe the motion of the golf swing and characterize the movement in terms of discrete variables. The discrete variables of interest are selected by a) identifying maxima and minima (e.g. maximum hip rotation) or, b) the value of a variable at a critical event (e.g. vertical head displacement at the top of the backswing). This method of data reduction allows for statistical analysis to be done but ignores the interaction of (biomechanical) components of the swing. The human motor system is particularly adept at making online compensatory movements to achieve a desirable performance outcome. Therefore, it is likely that important characteristics of the swing, critical for movement control, do not occur at convenient events (such as the top of the backswing), thus making it important to analyze the evolution of coordination throughout the entire swing. More recently, the sequencing of key variables has been introduced to the swing analyst's toolbox, and although the coordination of the movement system's interacting parts are considered, it is still an over simplification of the movement in order to provide quantitative feedback.

Qualitative techniques (e.g. angle-angle diagrams, phase plane portraits and self-organizing maps) have been used to describe sports techniques as 'patterns of motion'. In doing so, the transitions between critical events and the coupling of two or more variables can be described and analyzed. The purpose of this research is to analyze the temporal changes in coordination associated with certain imposed constraints on the swing. The imposed constraints in this study involve hitting shots with different clubs (driver and 5-iron) and swing speeds ('comfortable' and 'hard').

Method. Two players from the German Golf Association (DGV), one on the adult squad and one on the junior squad, took part in one data collection session each. Each player performed twelve shots into an indoor golf net. Six of the twelve shots were performed with a 5-iron and six with the driver. Of the six shots played with each club, three were 'comfortable swings' and three were 'hard swings'. Data were collected with five Genie HM640 cameras (Teledyne Dalsa, Waterloo, Canada) with a sampling rate of 300 Hz. A three-dimensional model was constructed using Simi Motion software (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany). Variables created for analysis were: torso rotation, hip rotation, left and right (l/r) elbow angle, ulnar deviation (wrist cock), pelvic tilt, spine angle and l/r knee angle. Raw angular displacement data were filtered using a second order Butterworth filter with a cut-off frequency of 10 Hz. A dual direction low pass filter was then applied to remove the effects of phase shifting. Derivatives of the joint angles were calculated using the raw data sampling rate and movement times. Performance outcome was recorded using a FlightScope launch monitor (EDH, Stellenbosch, South Africa).

Results. Angle-angle diagrams show the coupling between two variables and the phase plane diagrams show an angle relative to its angular velocity. Of note, tight coupling was found between torso and hip rotation, hip rotation and pelvic tilt, and torso rotation and trailing elbow angle for both players. Left and right elbow flexion-extension was surprisingly loosely coupled for both players, considering their presumably critical role through impact and release. Although generally tightly coupled, there was more obvious in-phase movement during the transition from backswing to downswing for the junior player's 5-iron shots—this is indicative of reduced 'X-factor stretch'. Pelvic tilt was surprisingly robust, according to the phase plane portraits, given its relatively small range of motion. Most of the variability within each player was between clubs rather than swing speed conditions. Characteristics unique to each player were also identified. In particular, the junior player tended to keep his leading elbow slightly flexed through impact and release compared to the adult player. This was qualitatively obvious from the angle-angle diagrams showing the coupling of the leading elbow angle and any other variable.

Conclusions. The angle-angle diagrams were useful for identifying changes in coordination between shots, both according to topological equivalence and by the number of changes in coordination during the swing. The phase plane portraits were useful to visualize the variability in angular velocity throughout the changing posture of the swing. The qualitative analysis techniques can be useful for coaches given modern motion capture technology offered by many swing analysis facilities. These techniques build on previous methods (e.g. sequencing), which have focused on severely reducing the data set, which represents the movement pattern of the golf swing.

PHYSIOLOGICAL REACTIVITY AND PERFORMANCE OUTCOMES UNDER HIGH PRESSURE IN GOLFERS OF VARIED SKILL LEVELS: A PILOT INVESTIGATION

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Introduction: Perceived pressure generally increases sympathetic autonomic nervous system (ANS) arousal (Ito et al., 2011) and cortical activity (Baumeister, Reinecke, Liesen, & Weiss, 2008). It is thought that this response represents perceived pressure and results in negative performance outcomes (Markman, Maddox, & Worthy, 2006; Shelley-Tremblay, Shugrue, & Kline, 2006). Yet skill level may influence physiological reactivity to pressure and less reactivity may impact success rate. It is important to understand this dynamic because it relates to performance enhancement among all skill levels.

Method: Three male participants, a professional athlete but novice golfer, a club professional aspiring to become a Professional Golf Association (PGA) tour player, and a champion PGA tour professional, completed a baseline segment followed by a series of putting tasks designed to increase perceived pressure. Concurrently, physiological measures including electroencephalograph (EEG), heart rate (HR), respiration rate (RR), heart rate variability (HRV), electromyography (EMG), skin conductance, and hand temperature were assessed. Participants ranged in age from 21 to 26 years. The highest-pressure task was achieved by requiring participants to choose a length of putt that would result in either gaining or losing as little as $3,000 or as much as $20,000 for a national children's charity depending on making or missing the putt, respectively. Data collection was completed on a practice putting green at the Medalist Golf Club in Hobe Sound, Florida. Percent change in physiological reactivity of each player was calculated separately for all measures, mentioned previously, based on the difference between measures during the baseline and the highest-pressure tasks. Performance was defined dichotomously based on putting success (miss/make) during the highest-pressure task. Correlation analyses were conducted to determine if skill level was related to physiological reactivity. Subsequently, percent change in reactivity was correlated with putting success to ascertain if decreased reactivity is related to improved performance. This was not a deception study; the charity earned $13,000 of a potential $25,000.

Results: The current study found a curvilinear relationship between increased skill level and physiological reactivity; specifically, the highest skilled player generally had the lowest level of reactivity and the novice golfer moderately responded, while the club professional demonstrated the highest level of physiological response. Additionally, reduced physiological reactivity is positively correlated to performance, the less the player responded physically to pressure the more likely they were to make the putt.

Discussion: The current study found that the expert golfer had reduced physiological reactivity to pressure compared to less skilled players and also performed better. These findings imply that professionals in any arena may experience less reactive physiology under stressful circumstances, which is likely to coincide with better performance. Reduced physiological reactivity may represent less anxiety *or* advanced coping skills for adapting to anxiety, since high levels of anxiety have been correlated to poor performance (Markman et al., 2006; Shelley-Tremblay, et al., 2006). Professionals are more frequently exposed to higher-pressure situations with the expectation to perform well and therefore are more practiced at coping with physiological reactions to pressure (Harung et al., 2011; Milton, Solodkin, Hluštík, & Small, 2007). Broadly, this notion indicates that training physiology is likely beneficial and may help less skilled individuals improve performance. This study was limited in sample size, thus future research is needed to confirm this conclusion.

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USING PRINCIPAL COMPONENTS ANALYSIS TO DETERMINE DIFFERENCES IN 3D LOADING PATTERNS BETWEEN BEGINNER AND COLLEGIATE LEVEL GOLFERS

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Purpose. Traditionally, golf research and instructional techniques have focused on the kinematics of the golf swing [1], while relatively little attention has been paid to the three dimensional (3D) ground reaction forces (GRFs) which produce these movements. One study has reported 3D GRFs and found differences between golfers of different skill levels; however, this study simply took discreet variables (peaks and time to peak) from the GRF curves [2]. 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 discreet variables, much of the variability in them is lost. A statistical technique that can be used to analyze the entire waveform is Principal Component Analysis (PCA). This technique has been used in the biomechanical analysis of other movements. It has been used to differentiate between healthy and pathological gait patterns [3], to identify faulty lifting patterns [4], and to determine the differences between young and older adult movement patterns [5]. Therefore, this study will use PCA to determine the differences in 3D GRFs between a group of skilled and beginner golfers.

Methods. Participants were recruited for two groups: 18 Collegiate golfers (9 male, 9 female, age = 19.6 ± 1.3 years), 23 Beginner golfers (10 male, 13 female, age = 22.9 ± 1.9 years). All collegiate golfers were members of an NCAA division I golf team, while all beginner golfers had never played a round of golf or received a formal golf lesson. Each subject was asked to hit 5 shots with a 5-iron into a net while standing with each foot on a separate AMTI (Newton, Mass) force platform so that 3D GRF data (vertical (V), anterior-posterior (AP), medial-lateral (ML)) could be collected separately for each foot. All golfers were right handed so their left foot was the lead foot (LF) and their right foot was the trail foot (TF). Retro-reflective markers placed on the club-head and ball were tracked with a 9 camera Qualisys (Sweden) motion tracking system to allow for the phases of the swing to be identified.

3D GRF data were cropped so that only data from take-away until ball contact was analyzed. Data were then time normalized from 0-100% (with 100% being ball contact) and the data for each GRF curve (V, AP,ML) and foot (LF, TF) for all 5 swings were averaged together to give 6 waveforms for each subject. PCA models for each of the 6 waveforms were created with the data from all 41 subjects using the technique previously described [6]. Each subject's curve was then scored against these models to create principal component (PC) scores. The number of PC scores included in the analysis ensured that at least 90% of the variance in curves was accounted for [3,5]. This resulted in 5 PC scores being included for all 6 PCA models. Subject PC scores were then divided up based on group (Collegiate vs. Beginner) and independent sample t-tests were run on the 5 PC scores per curve to determine differences between groups. Critical p-value was adjusted for the 5 t-tests performed per force curve ($p<0.01$).

*Analysis/Results***.** Differences in PC scores between the collegiate and beginner golfers are shown in Table 1.

Table 1. Significantly different PC Scores between Collegiate and Beginner golfers and the percent variation explained.

Limb	GRF Curve	PC Score	Variation
	V	PC1	46%
LF	ML	PC2	30%
	AP	PC2	24%
	V	PC1	49%
TF	AP	PC1	44%
	AP	PC3	17%

The differences in both the LF and TF vertical forces has to do more with the timing of the weight shift from the TF to the LF and not so much with the % body weight on each foot at set-up or ball contact. The collegiate golfers tend to have much less weight shift onto the TF during the backswing and also initiate the weight shift towards the front foot much earlier, prior to ball contact.

The differences in the ML GRFs involves the beginners producing much more LF medially directed GRF (force directed away from the target) during the backswing and at ball contact; while the collegiate golfers have a clear laterally directed GRF (force directed towards the target) in the early part of the downswing.

The experts produced greater AP GRFs during both the backswing and downswing. These forces create force couples needed to produce body rotations essential to an efficient golf swing.

Conclusions. Golf swing kinetic information (GRFs) provides some useful information that can be used to develop better drills/instructional techniques and track improvement/ give feedback.

WRIST KINEMATICS DURING THE GOLF SWING: IS FLEXION OR ULNAR DEVIATION MORE IMPORTANT?

Sweeney, Matthew; Australian Catholic University; Mills, Peter; Griffith University; Alderson, Jacqueline; Elliott, Bruce; University of Western Australia

Purpose. Despite the reported importance of movement at the wrist (Springings & McKenzie 2002; Chu et al., 2010) there remains a lack of clarity around the relative importance of wrist flexion/extension and ulnar/radial deviation. A recent forward kinematic approach (Mills, 2007; Sweeney et al., 2011) has the potential to shed light on the relative importance of these two degrees of freedom. Of particular interest are the anatomical movements possible at the trail wrist, as anecdotal evidence has suggested this side of the body provides the majority of power to the club (Hume et al., 2005).

The aim of the current study is to assess the individual influences of flexion and ulnar deviation of the right wrist in producing club-head velocity in the golf drive.

Methods. Ten highly skilled male golfers were recruited for the study, with an average handicap, height and mass of 3.0 (±1.8), 1.81m (±0.09) and 78.1kg (±8.9), respectively. After a 5 minute warm-up, each participant hit 4 drives into a net situated 5 m in front of them. Participants were asked to use the natural technique that they would employ for a straight drive on the golf course.

Each swing was recorded using a 12 camera Vicon (Oxford, UK) MX system operating at 400Hz. Kinematics of the golfer and club were collected using methods outlined by Sweeney et al., (2011).

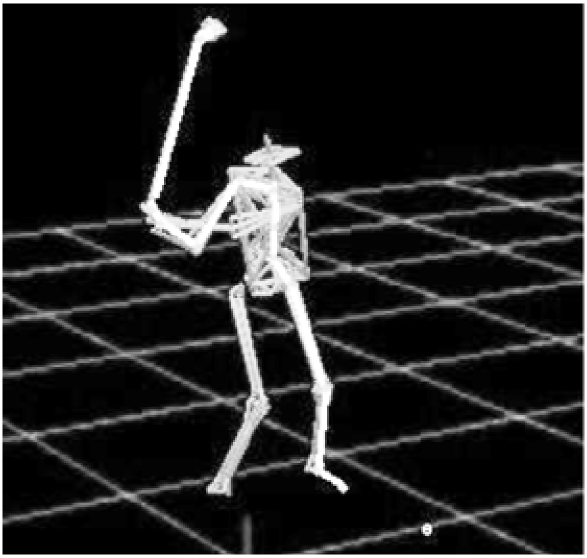

Figure 1: Segments of the Forward Kinematic Model highlighted

A three dimensional Forward Kinematic Model (FKM) was developed to allow the calculation of club-head position and orientation, given the position and orientation of the initial segment, as well as the subsequent segment angles and joint positions (relative to Anatomical Coordinate Systems) for the rest of the kinematic chain. The FKM consisted of 36 Degrees of Freedom (DOF), from the 12 segments defined as a part of the original kinematic data. The general equation was:

$$^{G}P_{CF} = {}^{G}P_{1} + \sum_{i=1}^{N} {}^{i}P_{i}\ {}^{G}_{i}R_{zyx}(\alpha,\beta,\chi)$$

Where:

$^{G}P_{CF}$ = position of the centre of the club-face in the global coordinate system,

$^{G}P_{1}$ = position of the lead foot (initial segment)

$^{i}P_{i}$ = position of the endpoint of segment *i* defined within segment *i*'s ACS

$^{G}_{i}R_{zyx}$ (α,β,χ) = the rotation matrix defining the orientation of segment *I* composed via sequential rotations about the z-, x- and y-axes of segment *i* by the angles α, β, χ (corresponding to the medio-lateral, anterior-posterior and vertical axis).

Validation of the FKM was performed by evaluating club-face position and resultant velocity produced by the FKM, in comparison to the empirical data across each trial to produce a RMS error. Using the FKM, two conditions were then imposed for each trial collected across all participants, assessing the effect of restricting flexion/extension or ulnar/radial deviation at the trail wrist. This was achieved by replacing the specific DOF with that which was achieved at the first frame of downswing, whilst keeping the kinematics across the other 35 degrees of freedom the same as the empirical data. Dependent samples t-tests ($p<.05$) were used to assess whether each experimental condition produced significantly different resultant velocity to the original FKM data at impact.

Results. With respect to predicting club-head velocity, the FKM had an average RMS error of under 0.001 ms^{-1}. The influence of imposing both conditions on the swing were fairly consistent across all players and can be seen in a representative trial (Figure 2).

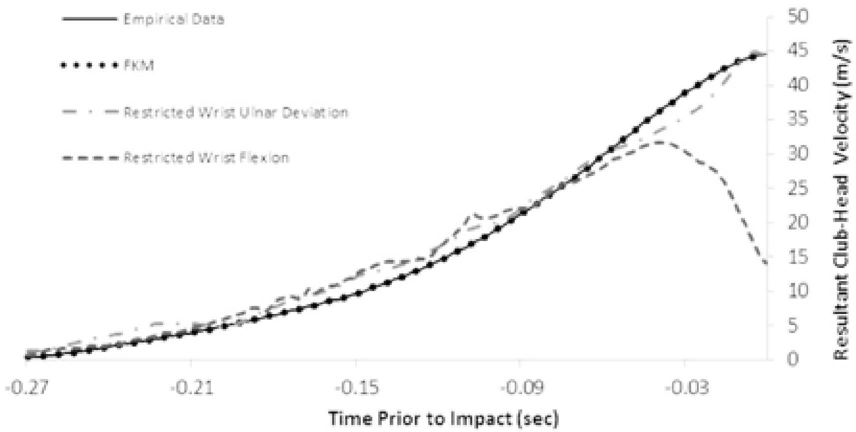

Figure 2: Resultant club-head velocity across each condition from a representative trial

Average impact club-head velocities across each trial, for each player for the FKM data and two imposed conditions, are presented in Table 1. Restricting flexion of the wrist resulted in a significant reduction of velocity at impact, while restricting wrist ulnar deviation, did not result in any significant change in club-head velocity at impact.

Table 1

Average impact club-head velocity (ms^{-1}) across each condition.

	Original FKM	Restricted Wrist Flexion	Restricted Wrist Ulnar Deviation
Resultant Impact Club-Head Velocity	45.2 (±2.7)	20.3 (±5.7)*	45.3 (±3.2)

* sig <0.05

Conclusions. The results support that of previous research, indicating that the wrist plays a vital role in producing power in the golf swing (Springings & McKenzie 2002; Chu et al., 2010). Further to this, the present study suggests that the swing is a product of wrist flexion and not ulnar deviation. While the current investigation has shown a dramatic influence on performance by the trail wrist, future research should address the importance of other DOFs that may influence the planar 'wrist-uncocking' action. These DOFs include movements at the lead wrist as well as rotation around the long axis of both upper arms and forearms.

While radial/ulnar deviation at the wrist may play a role in controlling the club-head through the swing, to maximise performance in the golf drive coaches should ensure players get the most out of flexion of their wrists. Failing to do so could cost a player over 50% of their potential club-head velocity at impact.

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AMPLIFYING BODY SPEED: STRETCH-SHORTENING AT THE LEAD SHOULDER?

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Purpose. Many research papers have investigated the inter-segmental coordination between the pelvis and the upper torso (UT), the X-Factor, during the golf swing. While the results have not always been statistically consistent, the general consensus among coaches is that the X-Factor is a key biomechanical variable used to describe the golf swing. No published research has investigated another key interaction between segments, the upper torso and lead arm. Golf coaches have talked about the relative movement of these two segments of the body and believe that the *connection* between the two segments is important for a sound golf swing. This paper provides a platform that allows one to investigate the relationship between the lead arm and UT during the transition and downswing and gain insight into a stretch-shortening phenomenon that occurs in the muscles that surround the posterior aspects of the lead shoulder.

Method. Two groups of highly skilled amateur golfers from Germany were the cohorts for the study. The golfers were from the Junior National Boys' (Group 1) and Men's (Group 2) teams. Three dimensional (3D) kinematic data were collected using the Golf BioDynamics System while ball flight and club head delivery information were collected using the TrackMan radar device. In the GBD system, local anatomically relevant coordinate systems for seven segments (club, lead hand, lead forearm, lead arm, head, UT and pelvis) were defined and tracked in real time at a sampling rate of 240 Hz. For the purposes of this study, the shoulder joint refers to the collection of joints that permit the articulation of the lead arm with the UT. Timing sequence graphs were generated for each player as they hit drivers ($n = 5$) for maximum distance but still with control. The interval from the top of the backswing (TOB) defined as the point in time when the pelvis rotational velocity changed direction between backswing and downswing and 20 samples beyond impact was used as the epoch of interest. The axial component of the angular velocity of the UT and the angular velocity component of the lead arm, normal to the plane of best fit for the lead arm (between the points where the club was parallel with the ground pre and post-impact) were plotted during this interval. The section of this graph that was of most interest was the region between the changes of direction of the UT and lead arm (transition) and the point where the lead arm angular velocity exceeded the UT (if that occurred).

Analysis/Results. When the velocity of the UT is greater than the lead arm, the structures on the posterior portion of the lead shoulder are being stretched (the tissues include the posterior deltoid, triceps brachii and latissimus dorsi). This "stretch" can be calculated as the area between the two velocity curves during the period of time when the velocity of the UT exceeds the lead arm. Once the velocity of the lead arm exceeds the UT, energy can flow from the UT to the lead arm. Thus the "gain" in velocity from UT to lead arm is a gross measure of how much energy flowed from the proximal to the distal segment during this interaction. The gain in speed and the amount of stretch at the lead arm were correlated with club head speed and ball speed. ANOVA was also used to determine if there were differences between the groups. Preliminary results show a significant positive ($p < .05$) correlation between the speed gained from UT to lead arm and club head speed. The correlation between the amount of stretch and club head speed was not significant. ANOVA showed that there was a significant difference in the amount of stretch and the speed gain with the Group 2 data returning higher mean values then Group 1.

Conclusions. Anecdotally the interaction between the lead arm and UT seems to be extremely important in the transfer of energy from the proximal segments (pelvis and UT) to the distal ones (arm and ultimately to the club). The amount of stretch at the lead shoulder and the possible use of a stretchshortening cycle to increase the work done by these muscles seem to be a strategy that is beneficial both physiologically and mechanically. The method described above is crucial to describing the correct coordination between the lead arm and UT segments as well as providing insight into possible physiological limitations of the golfer such as lack of strength and/or flexibility in the key muscle groups of the upper back and lead shoulder.

HOW ACCURATE ARE DOPPLER RADAR BALL TRACKERS AT MEASURING BALL DISTANCE?

Noffal, Guillermo J.; Lynn, Scott K.; California State University, Fullerton ; Vandervoort, Anthony A.; University of Western Ontario

Purpose. Improvements in technology have taken many sports to a level of competition unlike anything seen before. Better engineered equipment and more accurate sports measurement systems have resulted in improvements in both how games are played as well as how games are watched. In golf, there have been many modifications to balls and clubs which have led to increased driving distances. These improvements have forced championship courses to elongate holes in order to maintain a high degree of difficulty for the professional golfer. An interesting addition to those watching golf on TV is the display of ball trajectory emanating from flight measurement equipment. These devices use a sophisticated phased array Doppler radar to measure the ball flight (Figure 1). The same technology is used in military applications for the purpose of tracking projectiles and missiles. The radar continuously transmits radio signals (emitting an extremely low amount of microwave energy – 200 times less than a cellular phone) that experience a change in frequency, when they bounce off a moving object. This change in frequency is then translated into a velocity. By using multiple receivers the system is able to measure the exact 3D positions during the entire ball flight.

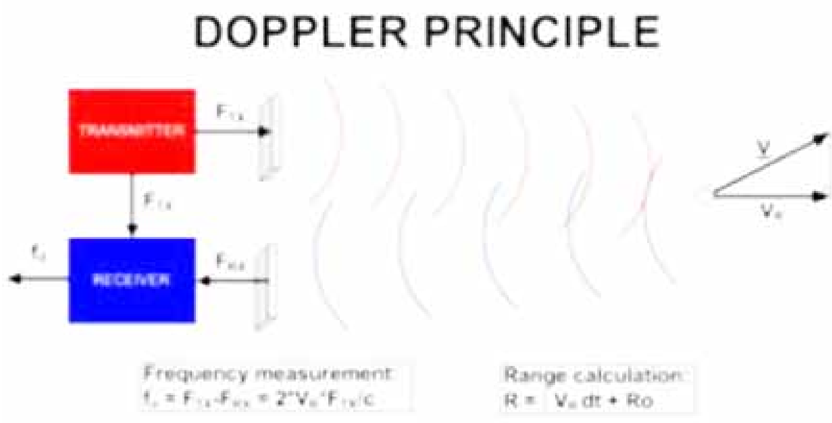


Figure 1. Technology used by 3D ball trackers.

Although visually appealing to those watching golf, ball tracking devices are able to measure a number of variables related to the flight of the golf ball, including real time tracking, ball speed, both vertical and horizontal launch angles, sidespin, and backspin. These variables are helping players receive useful immediate feedback while both indoors and outdoors, thus expediting improvements during swing modifications and also helping those living in cold environments remain active. Two of the better known Doppler radar ball trackers currently available in the market are TrackMan™ (Denmark) and FlightScope® (South Africa). Although both claim a high degree of accuracy associated with their products, no scientific evidence is currently available to support their claims. Therefore the purpose of this study was to compare distances provided by these devices to those measured on the field by a person.

Methods. In order to achieve consistency in distances achieved for multiple trials a servo driven robot was used. A driver and 5-iron were used to hit three shots each with three different intended directions (straight, fade, draw) and at two different club head speeds to approximate distances of 300 and 250 yards (274.3 and 228.6 meters respectively) for the driver and 190 and 170 yards (173.7 to 155.4 meters) for the 5-iron. Thus the analysis included a total of 18 (3 trials x 3 directions x 2 speeds) distances for each club of interest. Both carry and total distances were assessed in this study.

Four one-way ANOVAs were carried out to compare ball distance values between FlightScope, TrackMan and field measurements. A critical alpha level of 0.05 was used.

Analysis/Results. A significant difference ($p < 0.05$) amongst groups was found for 5-iron total with post-hoc findings that FlightScope and TrackMan were significantly different from each other but neither was significantly different from the measured distance. No significant group difference were found for 5-iron carry, driver carry or driver total.

Table 1. Mean and standard deviations for distances (in meters)

	Driver carry	Driver total	5-iron carry	5-iron total *
FlightScope	231.9 (24.7)	239.9 (24.4)	162.4 (5.7)	164.4 (5.7) [A]
TrackMan	234.0 (25.5)	253.8 (23.9)	157.4 (6.3)	157.6 (5.5) [B]
Measured	237.1 (25.1)	245.8 (25.0)	159.7 (6.9)	161.0 (5.6) [A,B]

* = main effect with letters representing post hoc test results.

Conclusions. Although no significant difference in ball distances were found between the FlightScope and the actual measured distance it can be seen that under estimation errors of 2.2% and 2.4% were found for the driver carry and driver total distances respectively. These errors equate to 5.7 yards (5.2 meters) and 6.4 yards (5.9 meters) respectively.

The shorter distances achieved with the 5-iron yield reduced estimation errors for the Flight-Scope of 1.6% and 2.1% for carry and total distances respectively. Note however that while both values were under estimations for the driver, the 5-iron values were actually both over estimations when compared to measured distances.

Similarly, although no significant difference in ball distances were found between the TrackMan and the actual measured distance, it was found that an under estimation error of 1.3% and an over estimation error of 3.2% were seen for the driver carry and driver total distance respectively. These errors equate to 3.4 yards (3.1 meters) and to 8.7 yards (8 meters) respectively.

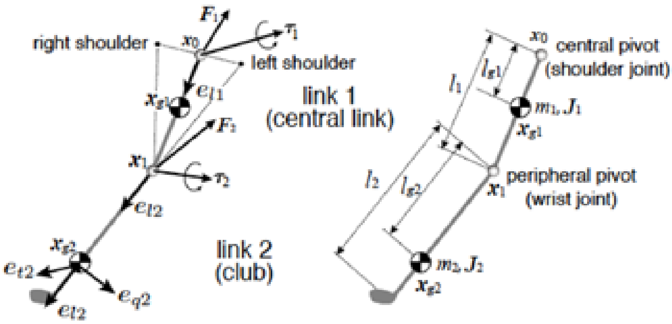
TrackMan distances with the 5-iron yielded under estimations errors of 1.4% and 2.1% for carry and total distances respectively. These errors equate to 2.3 yards (2.1 meters) and 3.4 yards (3.1 meters) respectively. Finally, advances in technology through the availability of accurate ball trackers are another tool providing golfers with immediate feedback which can be used to further enhance their performance.

ENERGY TRANSFER THROUGH THE INTERNAL FORCE IN THE GOLF SWING

Ohta, Ken; Ohgi, Yuji; Keio University; Shibuya, Kazuhiro; Seiko Epson Corporation

Introduction. Distance is required in golf swing. In order to hit a shot of maximum distance, swing linear velocity at impact phase must be maximum. Since dynamics of club and arm dominates the overall behavior of the swing, the dynamical mechanism of the arm and the club must be clarified for understanding the mechanism to produce the maximum velocity of the club. As a step toward understanding the mechanism, we investigated how non-muscular (e.g. centrifugal and gravity) forces of the each link generates, absorbs, and transfers mechanical energy in order to produce the maximum velocity. This was accomplished using the multi-body power analysis derived entirely from dynamical equations of a three-dimensional double pendulum with moving pivot model.

Many sports demand that maximum speed produced at the end of the distal segment in a sequential movement and is typically known as the kinematic chain principle (Feltner & Dapena, 1989). Golf swing is one of the typical sequential movements of human body. This paper focus specifically on the swing movements performed with an upper extremity, with the goal of manipulating a club with a certain speed. The simplest description of the golf swing is in terms of two phases (Pickering & Vickers, 1999). In the first phase shoulder torque delivers energy to arms and club and wrist torque is required to constrain a 'wrist-cock'angle. In the second phase non-muscular forces dominantly act to accelerate the club since wrist joint torque cannot supply enough energy to accelerate the club through the peripheral pivot. During the second phase the wrist-cock angle is no longer constrained, commonly referred to as the release of the club, or wrist 'uncocking'. The purpose of this study was to investigate how non-muscular forces coordinate golf swing movement. We elucidate how energy produced by muscles is delivered to the club through the synergistic action of non-muscular forces and this is derived from analyses of a multi-power analysis of the arm and the club motion.



To analyze the golf swing, a three-dimensional double pendulum model was employed (Fig. 1). The 3D double pendulum has rigid bodies supported by fixed, frictionless pivots. Both supporting pivots allows three degrees of rotational freedom of the pendulum. The position vector of a moving central pivot joint between the shoulders is denoted by $\boldsymbol{x}0$. $\boldsymbol{x}1$, $\boldsymbol{x}g1$, $\boldsymbol{x}g2$ denote the position vector of the peripheral pivot, center of mass of central link (link1) and center of mass of club (link2), respectively. $m1$, $m2$ denote mass of each the center arm and the club. $\boldsymbol{J}1$, $\boldsymbol{J}2$ 1denote inertia matrix of each the center arm and the club. $l1$, $l2$ denote length of each the center arm and the club. $lg1$, $lg2$ denote length between each pivot and center of mass.

Rate of mechanical energy change

Acceleration mechanism of the club can be discussed using first derivative of mechanical energy (power). The mechanical energy for each segment is given by $E_1 = T_1 + U_1, E_2 = T_2 + U_2$, where $T_1 = ½\, \mathrm{m}_1\, x^T{}_{g1}\, x_{g1} + ½\, \omega^T{}_1\, J_1\omega_1, U_1 = -m_1 g^T x_{g1}$, $T_2 = ½\, m_2{}^{\cdot} x^T{}_{g2}\, x_{g2} + ½\, \omega^T{}_2\, J_2\omega_2, U_2 = -m_2 g^T{}_{xg2}$.

Rate of energy change for the club

Differentiating the club mechanical energy $E2 = T2 + U2$, we get another form of the club power

$$\dot{E}_2 = m_2 \dot{x}^T_{g2} \ddot{x}_{g2} + \dot{\omega}^T_2 J_2 \omega_2 - m_2 g^T \dot{x}_{g2} = m_2(\ddot{x}_{g2} - g)^T \dot{x}_{g2} + \omega^T_2 J_2 \dot{\omega}_2$$

$$= F^T_2 \dot{x}_1 + F^T_2 (\omega 2 \times l_{g2} e_{l2}) + \tau^T_2 \omega_2 - (l_{g2} e_{l2} \times F_2)^T \omega_2 - (\omega_2 \times J_2 \omega_2)^T \omega_2$$

$$= F^T_2 \dot{x}_1 + \tau^T_2 \omega_2$$

Note that the first term of Eq. (3) denotes the power transferred by means of the internal force and the second term denotes the power produced/absorbed by the muscle (external force).

Rate of energy change for the central link

Differentiating the arm mechanical energy $E1 = T1 + U1$, we obtain the arm power

$$\dot{E}_1 = m_1 \dot{x}^T_{g1} \ddot{x}_{g1} + \dot{\omega}^T_1 J_1 \omega_1 - m_1 g^T \dot{x}_{g1} = m_1(\ddot{x}_{g1} - g)^T \dot{x}_{g1} + \omega^T_1 J_1 \dot{\omega}_1$$

$$= F^T_1 \dot{x}_0 - F^T_2 \dot{x}_1 + \tau^T_1 \omega_1 - \tau^T_2 \omega_1$$

Note that the second term of Eq. (5) denotes the power transferred by means of the internal force and the other terms denote the power produced/absorbed by external force.

Internal force as energy pipeline

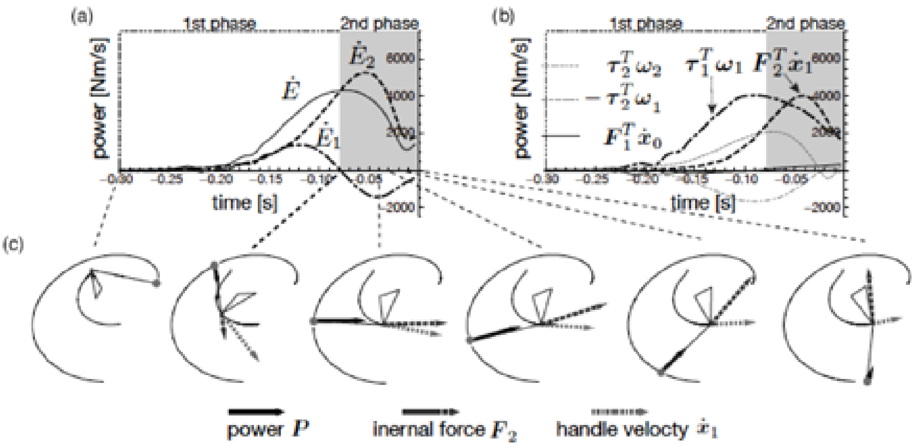
From Eq. (3) and (5), we obtain the net power of the entire system

$$\dot{E} = \dot{E}_1 + \dot{E}_2 = \boldsymbol{F}^T_1 \dot{\boldsymbol{x}}_0 + \tau^T_1 \omega_1 + \tau^T_2 (\omega_2 - \omega_1)$$

This equation means that these external force $\boldsymbol{F}1$, τ 1, τ 2 can affect the net power and produce/absorb the net energy of the entire system. It should be emphasized that the term $\boldsymbol{F}T2\,\dot{\boldsymbol{x}}1$ is canceled in the net power $\dot{E}$ although it is shown in both $\dot{E}1$, $\dot{E}2$. This indicates the internal force $\boldsymbol{F}2$ transfers the energy and works as an energy pipeline among the adjacent segments, although it does not affect the entire energy. Despite playing the most important roll in the system, the internal force $\boldsymbol{F}2$ cannot be expressed in minimum coordinates set such as Lagrange equations since the internal force does not affect the mechanical energy of the entire system. Only redundant coordinates formulation such as Newton-Euler equations can explicitly express the effect of the internal force among segments.

Experiment and analysis. One right-handed male golfer participated in this study and executed a series of drives. His arm and club motions were recorded by motion capture system (Vicon MX system) at 500 Hz. The data were analyzed between top of downswing (-0.3 s) and impact (0.0 s).

Fig. 2(a) shows the rate of mechanical energy change $\dot{E}1$, $\dot{E}2$, $\dot{E}$ and Fig. 2(b) shows the mechanical energy change distributions due to torques and forces acting on each segments. In this study we define two phases in the downswing. The phase is determined by the sign of $\dot{E}1$ and if $\dot{E}1 > 0$ the phase is the earlier of the two. Note that the energy of central link was decreasing in the 2nd phase, even though supplying the energy from the shoulder joint during the downswing ($\tau T1\ \omega 1 > 0$, see Fig. 2(b)). This indicates the supplied energy from the shoulder pass through the energy pipeline between segments. The power $\boldsymbol{F}T2\ \dot{}\ 1$ can be written in the vectorial formulation, although the power are scalar quantities. An augmented power can be defined $\boldsymbol{P} \equiv [t2P, l2P, q2P]T$ in accordance with this argument. Fig. 2(c) shows stick pictures of the club and the central link, augmented powers $[t2P, l2P, q2P]T$, internal force vectors $\boldsymbol{F}2$ and hand velocity vectors $\dot{\boldsymbol{x}}1$. The power reveals peak value under the condition of angle between the club and the central link is nearly 90 deg, since the internal force vectors $\boldsymbol{F}2$ nearly face the longitudinal axial direction $\boldsymbol{e}l2$ and the hand velocity vectors $\dot{\boldsymbol{x}}1$ nearly face perpendicular direction to the central link (link 1). This indicates that the transferred energy through the internal force $\boldsymbol{F}T2\ \dot{\boldsymbol{x}}\ 1$ is decreasing, although the internal force $\boldsymbol{F}2$ shows maximum value at the end of second phase.



Conclusion. Many analysis have been studied previously to define how each muscle force acts to accelerate each segment. However, the non-muscular force, which means the dynamics of the club and the arm, govern the natural swing movement pattern. In this study, we investigated how the non-muscular forces generate, absorb, and transfer energy in order to produce the maximum swing velocity of the club. In the first phase of the downswing, the energy was supplied from the shoulder joint and this energy accelerate the arm rotational movement. Following a phase delay, angular velocity and the centrifugal force of the central link reaches the maximum value and this induce the acceleration of the club movement. This phase delay causes the kinematic chain in the link structure of the arm and the club. This research may go some way to explaining the mechanics of the kinetic chain principle. While this may be so, it is outside the scope of the current research which was to develop a model to explain energy transfer. However, the authors encourage further discussion and investigation on this concept.

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OPTIMAL REDESIGN OF THE PGA TOUR EXEMPTION RULES

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Purpose. This paper investigates how best to reconfigure the end-of-season tour exemption rules used by the PGATOUR, the Nationwide Tour (NW), and Q-School so as to enhance competitiveness. Presently, at the end of each season, the top 125 players on the PGA TOUR money list, the top 25 players on the NW money list, and the top 25 finishers (and ties) from Q-School receive full PGA TOUR exemption status in the subsequent year. The remainder of the players receive limited exemption on either the PGA TOUR, the NW tour or miss out altogether. This may be regarded as a variant of relegation and promotion (RP) – a concept used in European sports leagues to maintain the competitive quality of the league by replacing weaker teams in upper tiers with stronger teams from lower tiers at the end of each season. As the PGA TOUR, NW, Q-School exemption structure has evolved over time, these end-of-season RP rules have remained mostly unchanged and may not be optimal for achieving the PGA TOUR objective of providing the highest possible level of professional golf competition.

Method. To investigate and optimize these RP rules, a mathematical model of the PGATOUR, NW, and Q-School was developed using empirical data. Players were represented by their age, a probabilistic model of their career skill level performance trajectory and the expected number of tournaments they compete in. Based on their skill level at the start of the season, a round by round tournament scoring distribution was empirically derived. A complete season on each tour was simulated to obtain end of season money lists which were the basis for moving players between tours under a range of RP rules. For each RP rule, 20 replicates of 1000 seasons were simulated. The relative quality of the RP rules is compared on basis of the number (or percentage) of players correctly assigned to PGA TOUR and NW based on their skill level.

Results. The paper shows that PGA TOUR competitiveness is maximized when the top 145 players on the PGA TOUR money list retain full PGA TOUR status, the top 35 players on the NW money list are promoted to the PGA TOUR, and Q-School does not promote players directly into the PGA TOUR. Further, if only 125 PGA players retained full exemption status each year, it would still be optimal not to provide PGA TOUR exemption for any Q-School qualifiers.

Conclusions. The results of this analysis suggest that the current PGA TOUR exemption rules do not ensure that the top players compete on the PGA TOUR each season. A similar conclusion has been reached by other researchers and PGA TOUR management. Consequently several alternatives have been proposed. This research provides an analytical framework for investigating these and other end of season promotion and relegation strategies and Q-School. It can also be used to improve competitiveness on other professional golf tours as well.

Acknowledgement. This paper extends general work on relegation and promotion by Puterman and Wang (JQAS, Issue 2, Article 7, 2011). We acknowledge Ken Lovell from the PGA TOUR for his contributions and discussions regarding this research.

USE OF BALL LINE AS AN AID IN PUTTING

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Introduction. To successfully putt a golf ball in the hole, the ball must be hit in the right direction with right speed. However, the surroundings of the green and the stance on the ball can create an illusion. When addressing the putt, players must stand to the left or right of the line between the ball and the hole. This stance puts the player in an unnatural position to read the green because the head is positioned either to the left or to the right of the line and facing perpendicular to the line. Sam Snead who suffered from the yips, having an innovative mind, started putting croquet style by placing the ball between the legs so that the head was directly behind the ball and facing the hole. However, the USGA (United Stated Golf Association) banned this technique of straddling the line of putt but Snead quickly found a way to sidestep the new rule and putted with his feet together to the side of the line while still facing towards the hole. When standing sideways to the ball, it becomes very difficult to see the veridical line of putt to the target and players often misread the direction (e.g., Johnston, Benton, & Nishida, 2003). A conventional technique to overcome misreading the direction is the logo alignment aid (Farnsworth, 1997) where the player stands behind the ball and positions the ball so that its logo or a marked elongated line on the ball is aligned with the true line between the ball and the hole. The purpose of the study was to determine if a line on the ball aids putting success.

Method. Eleven expert players (9 Males & 2 Females, handicap index < 3) hit 20 putts, either with or without using a line on the ball, 4 m away from the hole. A video camera was positioned 3 m above the ground slightly behind the ball to capture the putter head angle at address and at impact. Players wore PLATO goggles which occluded their vision immediately after ball contact.

Results. When using a line on the ball, players overall were accurate in aligning the line towards the target (Mean = 0.3 degrees left of target). However, there was a large standard deviation between players (sd = 2.9 degrees) indicating an individual difference. In regards to aligning the putter head at address and at impact, there was no significant difference between the two putting conditions ($p > .05$).

Conclusion. Results remain inconclusive due to small sample size but it appears a line on the ball does not aid expert players putting performance. It will be interesting to determine if this persists among novices.

THE GOLFER'S BRAIN ACTIVITY DURING PUTTING PERFORMANCE AND REST IN LABORATORY AND FIELD CONDITIONS

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Introduction. Neurophysiological aspects of goal-directed movements, motor learning and skilled performance in sports and exercise sciences have become more important during the past years. To date, several investigations exist using Electroencephalography (EEG) to provide reliable data concerning cortical activation patterns during golf putting (Crews & Landers 1993; Baumeister et al. 2008, Babiloni et al. 2008). However, they all took place under laboratory and therefore well-controlled testing conditions. Findings from other research areas of sports and exercise sciences suggest that data from laboratory examinations are similar to field conditions but can't be transferred unevaluated (Meyer et al. 2003; Riley et al. 2008). Hence, it appears to be necessary to investigate whether neurocognitive patterns measured in laboratory conditions are comparable to field conditions and if the EEG tool is able to deliver reliable data in a real sports environment likewise. In this pilot study we aim to examine whether EEG is able to demonstrate cortical activation patterns between putting performance and rest. Secondly, the purpose was to investigate whether cortical activation patterns obtained by EEG differ between laboratory and field conditions.

Method. Eleven male students from the University of Paderborn (25.6 ± 0.8 years; 80.9 ± 5.4 kg; 185.3 ± 6.7 cm) volunteered in this study. They were recruited from the affiliated golf club (handicap of 28.4 ± 11.9). They were asked to putt golf balls towards a target hole on a standardized green carpet inside the laboratory and on an ordinary green outside the laboratory for 2 minutes each followed by a 2 minutes resting period after each putting heat. Cortical activity was recorded continuously at 17 electrode positions (CATEEM, MediSyst, Linden, Germany) during putting and resting in accordance with the international 10:20 system. Electrode positions F7, F8, O1 and O2 were excluded from analysis because of movement artifacts. After automatic and visual inspection artifact free EEG data were Fast Fourier transformed to determine power at different frequencies: Theta (4.75 – 6.75 Hz), Alpha-1 (7 - 8.5 Hz), Alpha-2 (9.75 - 12.5 Hz) and Beta-1 (12.75 – 18.5 Hz). To reduce data volume electrode positions were averaged over brain areas (frontal: F3, Fz, F4; central: C3, Cz, C4; parietal: P3, Pz, P4; temporal: T3, T4, T5, T6) and power values were logtransformed. To demonstrate differences in the described parameters an ANOVA (LOAD x CONDITION) was performed as well as paired T-Tests in case of appearing main effects were calculated for each brain area and frequency band.

Analysis/Results. EEG parameters demonstrated LOAD effect for overall Theta (F1, part. eta²temporal Alpha-2 (F1,10=12.409; p part. eta²=.554) and Beta-1 at frontal and temporal brain areas (F1,10 cortical activation during performance was confirmed post hoc for both conditions (field: p lab: p Statistical main effects for CONDITION occurred only for Theta at frontal (F1,10=5.392; p eta²=.350) and temporal (F1,10=7.309; p²=.422) brain areas. Post hoc tests revealed significant higher theta values during the field compared to the lab performance.

Conclusion. First of all, we established a stable EEG based testing situation which is proofed by systematic cortical activation effects during performance situations compared to rest. Furthermore, our study revealed similar cortical activation patterns for the field and the laboratory putting condition. However, the results are not exactly equivalent which is indicated by the significant higher frontal and temporal Theta values during the field condition. EEG Theta power especially in frontal brain areas is often related to attentional processes. Here, higher Theta values may be associated with a brain state of higher executive attention related to cognitive demand (Smith et al. 1999; Baumeister et al. 2011). This might indicate an increased sensory complexity in the field condition due to sensory disturbances like noise or lightning conditions. Even though both conditions seemed to be comparable altered cognitive demand needs to be addressed when evaluating neurophysiological aspects of golf performance in a standardized lab condition. Provided that equipment is both portable and wireless we also suggest to monitor training or skill acquisition processes under field and therefore realistic conditions.

OPTIMAL KINETIC SEQUENCING DURING THE DOWNSWING

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Purpose. There is strong evidence to suggest that a proximal-to-distal kinematic sequence of movements is optimal in the downswing. This sequence is specified by the velocity of the torso peaking before the lead arm, which peaks before the velocity of the club. However, less in known about the underlying kinetic sequence, and specifically the contribution from muscular torques. This is may be because inverse dynamic methods do not distinguish between the torque contribution from passive structures such as ligaments, and the torque due to muscular effort at a joint. The inherent errors in the inverse dynamic method also cloud the issue. Understanding the optimal kinetic sequence is important for golf instructors attempting to effect a change in their students. The optimal kinetics, in terms of joint torques, are directly related to what the golfer should attempting in the downswing. For example, should the golfer contract the muscles that produce wrist ulnar deviation before, or after, those muscles that produce abduction of the lead shoulder, and what affect will this have on clubhead speed. Therefore, the purpose of this study was to determine the optimal kinetic sequence in the downswing and quantify the effect of altering this sequence. It was hypothesized that altering the optimal kinetic sequence would meaningfully reduce clubhead speed at impact.

*Method***.** A 3D, 6-segment (torso, lead arm, and 4 club segments) forward dynamics model of a golfer was developed to represent the four primary motions executed in the downswing: torso rotation, horizontal abduction at the lead shoulder, ulnar deviation at the lead wrist, and longitudinal rotation about the lead arm. The arm was constrained to rotate in a plane that was 20 steeper than the torso. The club segments were connected with rotational spring-damper elements that permitted the shaft to bend. Autolev was used to generate the dynamical equations of motion into FORTRAN code according to Kane's Method. Four torque generators that adhered to the activation rates and force-velocity properties of muscle powered the model. A genetic algorithm was employed to determined the best activation pattern (start and stop times) of the four muscle torque generators in order to maximize clubhead speed whilst maintaining a square clubface at impact. Five simulations with differing constraints on the kinetic sequence (start times of the torque generators) were optimized.

Results.

Sim	Club Speed (m/s)	Constraints on the start times of the torque generators
1	52.6	No constraints
2	49.6	Shoulder abductor had to start on or before torso rotator
3	47.9	Wrist ulnar deviator had to start on or before torso rotator
4	50.6	Wrist ulnar deviator had to start on or before shoulder abductor
5	50.1	Arm external rotator had to start on or before shoulder abductor

Sim1, with no constraints on the torque activation patterns, demonstrated a proximal-to-distal kinetic sequence and generated the highest clubhead speed at impact (52.6 m/s). In terms of the percentage of the downswing, the torque generators were activated in the order of torso (0%), shoulder abductor (30%), external rotator (60%), and ulnar deviator (71%). In all optimized simulations the most proximal torque generator, the torso rotator, was initiated at t=0 s. In the simulations in which a more distal torque generator was constrained to start at any time on, or before, a more proximal torque generator, the optimal solution was one in which the distal torque generator was delayed as long as possible. For example, in Sim4, the ulnar deviator was activated simultaneously with the shoulder abductor, and in Sim5, the external rotator was activated simultaneously with the shoulder abductor. The simulation, which forced the greatest disruption to the proximal to distal kinetic sequencing, Sim3, resulted in the slowest clubhead at impact (47.9 m/s). Despite forcing variations in the kinetic sequence, alterations in the timing of the *unconstrained* torque generators resulted in every simulation following the same *kinematic* sequence in terms of the timing in the peaks of the linear speed of each segment. For example, in Sim5, the linear speed of the shoulder peaked at 54% of the downswing, the wrist at 71%, and the club at 96%. Similarly, in Sim3, the linear speed of the shoulder peaked at 53% of the downswing, the wrist at 67%, and the club at 96%.

Conclusion. A proximal-to-distal kinetic sequence was found to generate the highest clubhead speed; however, suboptimal kinetic sequences still resulted in viable golf swings. These findings suggest that golf instructors should be instructing their students in such a way that promotes a proximal-to-distal muscular activation pattern.

UNDERSTANDING PUTTING DISTANCE PERCEPTIONS AND GOALS

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Introduction. At the professional level only scores under par usually win tournaments and to score under par, professionals need to sink putts. According to Richard & Tierney (1998) for World Class Players, the probability of 1-putt from 15 feet is 25 percent. At just under 8 feet, World Class Players have a 50 percent chance of making one putt (Broadie, 2008). In 2011, the PGA Tour introduced a new putting measurement "Strokes Gained Putting". While the distance of the ball from the hole varies for every stroke, players recognize three putting distances: short, medium and long with three probability performance outcomes of 1, 2 or 3 putts. The purpose of this study was to use quantitative and qualitative measures to define more accurately the meaning of three accepted putting distances: short, medium, and long.

Method. This study was conducted during the months of April, May, July, August, September, November and December, 2011 where the author acted either as a caddy, coach or spectator at the following tour events: China Open, Beijing CLPGA, Evian Masters, Omega European Master, Wuhan CLPGA Challenge, Sanya Ladies Open, Shanghai Masters, WGC HSBC Shanghai, Australian Open, UBS Hong Kong Open, Dubai World Championship, Dubai Omega Lady Masters.

The author monitored all shots played during at least 18 holes played by the following tour players: Sergio Garcia, Paige Mackenzie, Bradley Dredge, HaiYing Zhang, Florentyna Parker, John Daly, Jim Furyk, Kegaan Bradley, Seung-Yul Noh, Kevin Na, Zhang Lian Wei, Wu Ah Shun, Mark Wilson, Stuart Appleby, Jon Senden, Anders Hansen, Anthony Brown, Christian Cevaer, Stephen Dodd, Nicolas Kahn, Melissa Reid, Maria Verchenova, Michelle Wie.

To understand more about their playing strategies and decisions, the author also conducted individual interviews with ten PGA tour players, among them World N.1 (12.2011). Luke Donald The author conducted further research by asking three questions from five playing abilities categories: a.) Amateurs (n=26), b.) Coaches (n =17), c.) Tour Caddies (n=21), d.) Experts (n =13), e.) Tour Players (n=24), Includes World N.2 (12.2011) Lee Westwood and his Caddy Billy Foster.

The three questions were: 1.) Until what distance do you consider a putt to be a short putt? Past this distance it's a medium putt. 2.) Until what distance do you consider a putt to be a medium-length putt? Past this distance it' a long putt. 3.) Additional comments?

Results.

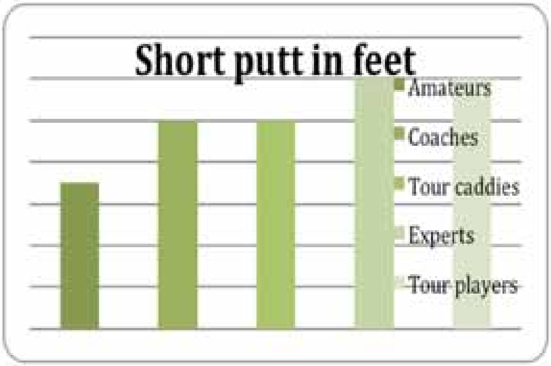

Figure 1: Short putt in feet.

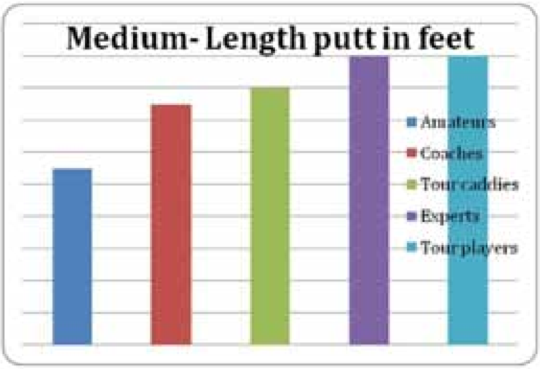

Figure 2: Medium putt in feet.

As shown in Figure 1: Tour pros and experts used the same average definitions/perceptions for short and medium putts with a short putt being defined as up to 6 feet and medium putts being defined as up to 18 feet. Amateurs define a short putt as a ball that "must" go in versus a tour pro definition as a ball that "should" go in. Most surprise came from the tour caddies who did not have the same answers/definitions as their respective tour players (Figure 1& 2).

It is also noted that among more than 80 stats options, the PGA tour Putting statistics (ShotLink) does not cover those several distances as shown in the results of this study. Does not cover: total of one putts 2-6 feet, inside 6 feet, from 2 feet, inside 2 feet, three putts over 18 feet, putting from 18 feet, putting from 6 to 18 feet.

The research also noticed that the definition of "tap-in" putts was used to define 2 feet and less. This definition was highlighted by tour pro Dustin Johnson after his second round 66 at the 2011 Australian Open where he comments "Today I missed a few short ones. Most of the birdies I made were tap-ins or three to four footers"

Discussion. The main purpose of this study was to better understand short, medium and long putts definition using quantitative and qualitative measures. It was important to know what the players are trying to do when facing variable distances and to define with better accuracy the meaning of "short putt" because this is where players need to be successful to save par and make birdies. Once players are within 2 feet of the hole some consider/call it a "tap-in" rather than "short" putt. Thus, a recommendation to describe putting distances would be to add "tap-in" to short, medium and long putt definitions.

THE ANATOMY OF AN EFFECTIVE GOLF INSTRUCTION ARTICLE

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Purpose. Traditionally, golf instruction occurs between a student and teacher on the lesson tee. Many golfers, however, acquire the largest amount of their instructional information from trade publications such as *Golf Digest, GOLF Magazine*, and others. Usually, leading (or "well-known") golf professionals in the industry contribute to trade magazines and other outlets for instructional articles, little or no research is available identifying the elements of an effective instructional article. The purpose of this study was, therefore, to determine the elements of an effective golf instruction article.

Method. Fifty volunteer amateur golfers were recruited from three locations: a) a public driving range, b) a private country club, and c) a public golf course. The golfers first completed a demographic questionnaire and informed consent. They were then asked to review six *GOLF Magazine* articles. The six articles were chosen from 10 articles recommended by the editors of *GOLF Magazine* for inclusion in this study. The editors were asked to select the "10 Best Articles" from *GOLF Magazine* published in the previous two years**.** The researchers then selected the six articles they believed represented the greatest diversity in the variables of interest (i.e., head, deck, copy, graphics/overlay, photos, author, artwork, color, type). The participants were asked to review the articles and rank order them from the article they would *most likely read* to the article they would *least likely read*. After the rankings have been recorded, the participants were interviewed regarding their rankings and preferences. Data analysis included a quantitative calculation of the articles most and least likely to be read, and a qualitative analysis intended to identify the readers' rationale for their preferences.

Results/Discussion. There were two sides of the qualitative analysis, the positive and the negative. Self-improvement or self-help was by far the largest motivational factor in identifying an article as *most likely to be read*. Over 75% of the participants were concerned about becoming a better player. The article's title, alone, received the most weight in deciding whether or not it would be read. Participants noted that clarity of the topic and the size of the title were eye catchers. Illustrations, such as the use of sequencing pictures, were the second most frequent comment. When the participants did read the deck, especially in *"Hand Me Downs*" by Hunki Yun, it played a significant role in their decision. Fundamentals were another topic of interest to a large majority of participants. The short game articles were important to several, especially those who have played a considerable amount of golf. Participants also commented that color was important—green was the color used in the top three articles. Recognition of a tour professional as the author or photographic model was a factor for some participants. Negative comments were few but insightful. The prevailing reason that a participant ranked an article as *not likely to be read* was because it failed to address an area of concern for the participant. Unclear titles were another reason for not reading an article. Participants reported that photographs that did not authentically connect with the text/title were less useful, and that cartoons or figure illustrations were less effective than photographs.

Acknowledgement. This study was funded by a grant from *GOLF Magazine*.

A NEW BIOMECHANICAL-MEDICAL BASED SWING-MODEL IN ORDER TO REDUCE BODY LOAD DURING SWING AND IMPACT

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Purpose. The increased incidence of injured golfers seen in our clinic led to looking for ways to reduce the loads on the injured parts of the human body. Therefore, the purpose of our research was to examine ways to reduce the load to the body during the golf swing and produce a medical (orthopedic) based biomechanical model for a golf swing. For example, one of the first insert irons on the market (1992) developed by the first author to help reduce the impact forces measured on the hands at ball strike. Many biomechanical swing models are concerned with biomechanical rigid-body-interactions, mostly two-dimensional, and partial-body-models. With this kind of model explanations of real effects on injured body segments are hardly possible.

Methods. First a conglomeration of available information about muscle action, body movements during a golf swing were obtained. Therefore, a model of normal movement during a normal golf swing of a normal, uninjured golfer was explored. The standard muscle action and the standard movement of the different body parts are known in a standard golfers' swing now. The drawback was that the data is based on very few individuals. The next steps was the implementation which body parts were loaded during the swing and may occur as a problem to injured patients. We first focused on the spine and lower body parts due to the data of our own analysis of 49.3 percent problems in this area in German golfers. Future research will be the biomechanical analysis of the upper body parts. The first most loaded parts indicated were the spine, the hips, knees and the feet focusing on the patients with spine and lower body problems.

Analysis and Results. Results from a German representative population of golfers revealed that 36.6 percent of the golfers suffer from back problems and 13 percent from lower body problems. The upper extremity was involved in 23.7 percent. From these data a swing set-up and a swing performance were created so that the injured parts of the body may reveal less stress and forces during the golf swing. This suggested a new way to swing and create a follow through with the torso and the hips more as a union. The first step was to create a uniform swing concept, which could be adapted to the injured and handicapped part of the patient body and then to test the model.

Biomechanical Golf swing analysis using the Albavision 3D/4D Motion System (also in use for the Olympic games 2008 in Bejing) revealed that ground reaction forces and force distributions of the feet were quite different than the standard golf swing and have in some areas of the foot significant lowering of the peak-forces, e.g. the big-toe of the right foot. (#s)

Another very important fact of the new medical-biomechanically optimized golf swing is that in spine patients the so-called X-factor is reduced and the leg- and foot-position is realigned (#s). The result is that the precision of the ball flight is significantly improved (#s) and the force distributions of the feet has move significantly to lower averages with less peak-values in the spine injured patients (#s).

The new medical and biomechanical based swing alterations of handicapped people and injured patients resulted in a lowering of body loads and a lowering of complaints during and after golf.

Conclusions. More scientific research should be conducted to explain also the reduction in upper body complaints and reveal results also in more detail in 3-D/4-D analysis using a complete body model of the golfer, which was already implemented for research. Recent results show that this kind of analysis is also evident for the analysis of world class golfers as well as of high handicap golfers having injuries or complaints during or after golf play.

NUMERICAL INVESTIGATION OF NEAR-WALL FLOW OVER A GOLF BALL

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Purpose. The current work presents an investigation of the flow over a golf ball using simulation. The drag on the golf ball drops dramatically compared to a smooth sphere at typical drive velocities, producing what is commonly known as the “drag-crisis”. The mechanism of drag reduction is directly related to the dimples. Since the dimples lead to drag reduction, understanding the flow near the wall (in the dimpled and non-dimpled regions) will illuminate the effect of the geometric details of the dimples. The present work presents an investigation of flow near the golf ball which are related directly to geometric details of the dimples.

Method . Numerical simulation is applied in this work, in which the governing equations for air flow are solved in large models (surpassing 1 billion points) on a supercomputer. Results are presented for conditions which corresponds to a typical drive velocity. A golf ball comprised of approximately 300 spherical dimples is used in this study.

Analysis/Results. Flow visualizations reveal local separation and reattachment within the dimples. Time-averaged statistics reveal physical patterns and local trends in the dimples.

Conclusions . The mechanism of drag reduction due to the dimples is characterized by development of the flow over a golf ball. Flow structures form near the leading edge of the dimples and energize the flow, often causing reattachment. This pattern of local separation followed by reattachment produces transition in the flow, ultimately leading to drag reduction. This work advances understanding of the relationship between geometric details of dimples and the coherent flow structures which are generated by them. The overarching purpose is the application of these ideas for optimizing the aerodynamic performance of golf balls.

IS WIRELESS ELECTROMYOGRAPHY RELIABLE FOR STUDYING THE GOLF SWING IN A HETEROGENEOUS GROUP OF GOLFERS?

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Introduction. The golf swing is a complex movement requiring a coordinated sequence of muscle activity to efficiently transfer power generated from the swing. While many studies have investigated muscle activity patterns throughout the golf swing, the majority of available data were collected before wireless electromyography (EMG) was available. Wireless EMG reduces movement artifact and allows golfers to swing more naturally, potentially improving accuracy and reliability of EMG data and enabling a more precise study of the golf swing.

Purpose. To quantify the reliability of wireless EMG and describe muscle activation patterns throughout three phases of the golf swing (backswing, downswing, and through-swing).

Methods. Eight right-handed, male golfers were fitted with an eight channel wireless EMG system. Electrode sites were identified and prepared according to SENIAM standards, and disposable, self-adhesive electrodes were attached to the skin. Golfers completed five swings with a 5-iron club and EMG data were collected at 2000Hz from the right pectoralis major (PM_{right}), latissimus dorsi (LD_{right}), external oblique (EO_{right}), and erector spinae (ES_{right}), and left vastus lateralis (VL_{left}), biceps femoris (BF_{left}), external oblique (EO_{left}), and erector spinae (ES_{left}). High definition video of each swing was simultaneously recorded. Key event times from each swing were identified and manually synchronized to EMG data, and integrated EMG (iEMG) from each muscle was then computed. Two-way random single (2,1) and average (2,k) intraclass correlation coefficients (ICC) were computed to quantify reliability. Mean iEMG data from each swing stage was normalized to iEMG of the entire swing.

Results. The overall average ICC measures during the backswing were very high ($\geq$0.900) for all muscles except PM_{right} (0.648), while single ICC measures varied widely, ranging from 0.315 (PM_{right}) to 0.993 (ES_{left}). During the downswing, average ICC measures were very high for all muscles except VL_{left} (0.887), BF_{left} (0.867), and ES_{left} (0.834), and single ICC measures ranged from 0.556 (ES_{left}) to 0.885 (EO_{right}). Average ICC measures for all muscles were very high during the through-swing with the exception of ES_{left} (0.880), and single ICC measures ranged from 0.648 (ES_{left}) to 0.963 (EO_{right}). EO_{left} was the most active muscle throughout the backswing (0.043 ± 0.022mV·s), followed by ES_{left} (0.034 ± 0.021mV·s), LD_{right} (0.031 ± 0.021mV·s), and ES_{right} (0.031 ± 0.010mV·s). During the downswing, PM_{right} was the most active muscle (0.043 ± 0.018mV·s), followed by EO_{right} (0.037 ± 0.029mV·s), VL_{left} (0.035 ± 0.010mV·s), and ES_{right} (0.033 ± 0.014mV·s). EO_{right} (0.038 ±

0.031mV·s) was the most active muscle during the through-swing, followed by PM_{right} (0.036 ± 0.018mV·s), and VL_{left} (0.031 ± 0.016mV·s).

Conclusions. The reliability measures suggest that EMG data collected throughout the golf swing should be averaged across multiple swings. Furthermore, EMG data were shown to be reliable when manually synchronized with video footage, thus, hardware synchronization with high-speed, three-dimensional motion capture may further improve reliability by minimizing human error in differentiating between swing phases. These reliability values reflect a heterogeneous group of golfers and therefore may not be applicable to novice golfers who would likely have more variability within individual swings. These data were consistent with previous literature in regard to the most active muscles throughout the phases of the golf swing. The backswing begins when club movement starts through to the top of the backswing and is the least strenuous phase. The external oblique and erector spinae muscles are most active in this phase as they aid trunk rotation and maintain posture, while LD_{right} contributes to power generation through adduction, medial rotation, and extension of the humerus. The downswing phase requires the greatest conversion of muscular power to club-head acceleration. ES_{right} and EO_{right} muscle activity indicates their importance to generate rotational power to drive the ball, while VL_{left} is highly active due to providing a solid base for subsequent trunk rotation. In the through-swing phase, muscle activity decreases as the golfer nears the end of the swing, and a number of muscles are eccentrically loaded to aid deceleration of the body and club. EO_{right} activity is most likely high due to continuous axial rotation of trunk, and the stability and mobility role the external obliques have in this phase of the swing. PM_{right} continues to be a driving force for power generation, while VL_{left} activity is likely due to this muscle acting as a stabilizer. The relatively high and constant activity in many of the muscles demonstrates the importance of these muscles, as well as the potential for these muscles to fatigue, suggesting that golfers should undertake warm-up and conditioning programs to attempt to keep their bodies in optimal physical condition to participate healthily in golf.

ANALYZING THE PGA TOUR SHOTLINK™ DATABASE USING THE ISOPAR METHOD

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Introduction. Conventional performance indicators used in golf rely on classifications of shots based on the distance to the hole. These indicators ignore the unique factors which make up the difficulty of each shot. Furthermore, these indicators do not take into account that a shot is a single event within a chain of events, the sequence of shots taken on a hole. Hence, the starting conditions of a shot are determined by the ending conditions of its previous shot. The aim of the project was to develop new performance indicators which are independent from the other shots played on the hole. For example, putting performance is partly a measure of approach shot performance since better played approaches tend to leave easier putts. Because of the analogy to isobars in meteorology, the method is called the ISOPAR method and the so-called ISOPAR lines are lines of equal average number of strokes which are needed to hole out. The method allows us, not only to analyze the performance of individual shots, but also to visualize difficult areas on a hole.

Method. Our research group has been given access to the ShotLink database which includes data from PGA TOUR tournaments since 2003. The ISOPAR method relies on ball locations on a hole and the corresponding number of required shots to hole out. The method smoothes the number of remaining shots using an exponential smoothing algorithm and interpolates the smoothed representation of the performance of the field for all possible ball locations on a hole by means of a spline interpolation.

Results. The output of the ISOPAR method allows us to visualize the difficulty of a hole which is shown on an ISOPAR map. Furthermore, the ISOPAR method allows some new measures of performance of individual shots without imposing a distance based classification upon them. In order to do performance analysis we distinguish between five different shot types: Tee shots, fairway shots, approach shots, around the green shots and putts. To demonstrate the potential for performance analysis of the method we have taken the Arnold Palmer Invitational in 2008 from the PGA TOUR's ShotLink database (n=26,873). First, the performance indicator Shot Quality (SQ) represents the quality of a shot played and is calculated as the difference between ISOPAR values before and after the shot. Tiger Woods sunk a memorable putt on the 72nd hole to win the tournament. This putt had a SQ of 1.83 and was ranked as 58th best putt (n=11,104) of the tournament.

The average SQ at a hole is always 1 as we have proven using tournament data. This allows the definition of a second performance indicator: Shots Saved. Shots Saved is the difference between the SQ of a shot and the average and describes how any player gains advantage on the rest of the field. For instance, Tiger's putt was 0.83 better than the average. Hence, he performed a shot for which the average of the field would have had to take 0.83 shots more than Woods.

A third performance indicator describes the quality of a shot within one of the shot types: normalized Shot Quality (SQnorm). SQnorm is the difference between a player's shot and the average performance of the field for this shot type which is, as an artifact of the method, not exactly 1. For instance, Tiger's winning putt had a SQnorm of 0.89.

Using these performance indicators a player's performance in tournament(s) or round(s) can be analyzed. In this tournament Woods performed relatively consistently and above average on tee shots and putting in all rounds; whereas his performance in the other shot types was more variable between rounds.

Conclusion. The ISOPAR method provides a variety of tools for the analysis of the quality of golf strokes and the difficulty of golf holes. ISOPAR maps allow the visualization of the difficulty of a hole. Furthermore, the method gives two measures of performance for individual shots, SQ and SQnorm, which are independent of distance to the hole and, therefore, measure the quality of each shot independently. Another performance indicator, shots saved, shows the contribution of each shot to the overall performance of a player with respect to the performance of the field. These performance indicators allow a wealth of new statistics on general properties of the game as well as statements on the performance of individual players.

EFFECTS OF AN ATTENTIONAL FOCUS ROUTINE ON PUTTING TECHNIQUE

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Purpose. Two experiments were conducted to investigate how covert and overt manipulations of participants' attentional focus affected their putting performance (Neumann & Thomas, 2011; Thomas, Neumann, & Hooper, 2007, 2008). Feedback on individual and group putting performances in the experiments was then used to develop attentional focus putting routines for each participant. The purpose of this study was to determine whether there was any improvement in golf coaches' ratings of participants' putting technique after they had practiced using those attentional focus routines.

Method. The 16 participants (4 females, 12 males) had competed at national or international competitions as elite amateur or professional golfers. Females' (*M* =23.25 yrs, *SD* = 2.2) handicaps ranged from 0 to 8 (*M* = 3.5, *SD* = 3.4); males' (*M* =25.4 yrs, *SD* = 6.3) handicaps ranged from -2 to 4 (*M* = 0.83. *SD* = 2.0). All participants completed six blocks of 20 putts in a multiple-baseline design.

Half the blocks counted towards a putting competition and were recorded for coaches' analysis, both procedures intended to put pressure on participants. Half of the sample received previous putting performance feedback and a recommended attentional focus routine after completing two blocks of putts (one recorded), and the other half after four blocks of putts (two recorded). Participants completed the remaining blocks after practicing the routine for approximately one week (*M* = 7.5 days, *SD* = 5.50). All blocks included 10 short (1.8 m) and 10 long (6.0 m) putts, five from each distance being straight and the other five breaking putts. The order of pressure/no pressure blocks was counterbalanced across participants, and the sequence of four types of putts within each block was randomized Two professional golf coaches rated participants' technique on 24 putts – the first, third and fifth putts of each type (e.g., short straight) in the first block of putts recorded before and after the routines were practiced. The digital recording of each putt was edited to occlude information about how far the ball finished from the hole. Coaches rated the six putts of each type one after the other, but the sequence was randomized across participants and coaches did not know which putts were taken before or after training. The coaches independently rated each putt from 1 *very po*or to 5 *very good* on five criteria – Face angle on backswing, Accelerating through the ball, Face angle past impact, Swing path, and Angle of attack.

Analysis/Results. Average ratings across the three putts of each type before and after routine training were calculated separately for each coach. Significant correlations indicated high inter-rater reliability, so average ratings for the two coaches were analyzed. Because ratings on the five technique criteria were correlated, Multivariate ANOVA with repeated measures on time, length, and slope was conducted, and Univariate ANOVAs were used to examine significant effects for each criterion. The multivariate effect for Time was significant, F (5, 11) = 3.57, p = .037, λ = .38. Coaches' ratings were higher on all five criteria after participants practiced the routine, with significant improvements in swing path, F (1, 15) = 13.70, p = .002, and angle of attack, F (1, 15) = 4.68, p = .047. The multivariate effect for Length of putt was also significant, F (5, 11) = 3.72, p = .032, λ = .37. Coaches rated participants' angle of attack more highly on short putts, F (1, 15) = 8.89, p = .009. The Length x Slope interaction was significant, multivariate F (5, 11) = 3.59, p = .036, λ = .38. Participants accelerated through the ball more on short straight putts than short breaking putts, but this was reversed for long putts, F (1, 15) = 5.26, p = .037. Putter face angle past impact was also rated more highly for short straight putts than short breaking putts, but this too was reversed for long putts, F (1, 15) = 5.80, p = .029. Similarly, participants' swing path was rated more highly for short straight putts than short breaking putts, but it was also higher for long breaking putts than long straight putts, F (1, 15) = 14.40, p = .002.

Conclusions. Our previous research has shown how attentional focus strategies affect golf putting performance. The results of this study indicate that feedback on those performance effects can be used to develop attentional focus routines, which when practiced, can lead to significant improvements in putting technique. Stronger effects are likely if golfers have not already developed an attentional preshot routine for putting.

DEVELOPING ELITE PERFORMERS: PARTICIPANT PROFILING PGA ASSISTANT PRO'S IN THE UK

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Introduction. The purpose of this longitudinal study is to explore the sporting history and profile of those people who train as PGA Professionals within the PGA of GB&I, in order to better understand the process and social variables that can impact upon the development of elite golfers. Through existing talent development models - such as Long Term Athlete Development (Balyi, 2002) and the Development Model of Sports Participation (Côté & Hay, 2002; Côté & Fraser-Thomas, 2007) - it is evident that there is a plethora of literature that purports to explain the development of elite performers through biological and psychological processes. However, until the development of the 'Bio-Psycho-Social' model of participant development (Bailey et al, 2010), little attention has been played to the social variables that can impact upon this. The traditional performance development literature has historically focussed upon bio-psycho explanations for performance; however, it is clear that this ignores the underpinning social history of the performer. This paper argues that understanding this 'missing link' is as fundamental as applying biological and psychological characteristics to player development. It therefore seeks to review and analyse key social characteristics in order to identify the developmental history of elite young golfers in the UK.

Method. A questionnaire survey has been conducted annually (2009, 2010 and 2011*) on Year 1 Assistant Professionals from the PGA of GB&I (n=590). The survey uses questions around retrospective recall to explore the participant's history and background in sport from the ages of 5 until 18. Questions revolve around their family background; sporting history (sampling, specialising and investing behaviour); deliberate play and practice; number (and level) of sports played at each year until 18; and also questions around age started playing golf, month of birth (Relative Age Effect); and also educational background. Once completed, the questionnaires were scanned and data uploaded onto Access from where they were interpreted and examined in context. From this data, a sub sample (n=51) who played at International level at the age of 18 was highlighted and differences between the Elite and International players was explored. The issues were then linked to existing theoretical and empirical knowledge of sports participation within the UK (to highlight the importance of the cultural context of participation).

Results. A selection of the findings indicate that within this sample of Assistant Professionals there was a significant over-representation of those from a biological two parent family (92%) compared to the national average (60%) (this was also reflected with the International performers at 90%); that 69.5% of the overall sample had parents who also played the game (92.6% of International performers); and that 61% of the International sample were 'youngest' children within their family structure. Data also highlighted that with secondary education, there was a significant over-representation of those educated at a Selective Grammar school (19.4% from the International sample and 10.9% from the main sample respectively) and Fee Paying school (32.3% and 22.2%) is reflected by the general population (national averages are: State: 85%; Fee Paying: 12% and Selective Grammar: 4%). Around issues of sampling and specialising, only 55% of the International sample were Investing in golf at 18 (average age of 15), whilst the other 45% were playing at least one other sport (particularly: soccer, snooker, badminton and table tennis) at an organised level whilst competing at that level. This then leads to a debate over the value and focus of early specialisation behaviour of young golfers in the UK. Many of these findings concur with the similar (but smaller sample) of Hayman et al, (2011).

Conclusion. To conclude, the data provides some significant empirical evidence that can influence our understanding of golfing performance, and can help develop policy. Sociologically it is evident that success appears to be largely dependent upon a cohesive family unit, the participation of parents, and educational opportunity. These first two sets of data from this longitudinal study suggests that there are certain social characteristics are more likely to help mediate success in young golfers – and more importantly that the existing models of player development need some social context to them. In particular, it also highlights the importance of understanding a player's social background in order to help develop pathways that are appropriate for their future sporting behaviour and for policy makers and strategists to consider a more bio-psycho-social focus for talent development. The study emphasises the value of understanding the golfer as a social being with a life history, as much as a body for physiological and psychological development (Bailey, et al 2010).

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