Title: The influence of weight transfer on club head speed in the golf swing

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CONTENTS

List of figures

List of Tables

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ABSTRACT

The effect of weight transfer in golf is an area that is gathering more interest as the increasing desire to hit the ball further demands a greater understanding of this variable in the golf swing. Past research into this area shows that higher skilled golfers transfer weight onto their lead leg at both higher magnitude and velocity during the downswing and at impact when compared to their lesser skilled counterparts. The purpose of this study was to investigate whether or not a transfer of weight onto the lead leg during the downswing influenced higher club head speed (CHS) using a driver. Twenty-nine male golfers were recruited (age, 36.4 ± 13.8 years; handicap, 6.1 ± 3.8) and data were collected for 10 swings each. Ground reaction force data were collected for each foot using force plates while (CHS) was collected using Trackman. Cluster analyses were used to establish two groups for comparisons in CHS. Group 1 was classified as a stable group and group 2 was classified as a front foot group. CHS data were found to be normally distributed and met all parametric assumptions. There was a trend identified for higher CHS in the front foot group. An independent samples t-test revealed a non-significant difference in mean CHS between the groups, $p > 0.05$. An indication of the findings of this study is that there is not a large effect on CHS based on weight transfer in the golf swing. Given that the large effect was not found future research should approach the area powered to detect small effects. Furthermore, a larger sample size would allow for a more refined classification of weight groups and potentially more than the 2 groups outlined in this study.

Key words: ground reaction force, driver distance

INTRODUCTION

Golf, like many sports, has evolved since its inception (11). While the majority of the game's evolution has been technology based (12), recent decades have seen the focus of the game change towards the physical aspects and requirements to perform the athletic movement of the golf swing (10,14,22). There is a growing interest in the ability to hit the ball further and with this the use of strength and conditioning (S&C) coaches for golfers has become commonplace. Past research has ensured that S&C coaches now have a detailed understanding of the biomechanics and muscle activity of the golf swing (7,12,13,22,23). Therefore, with the help of the S&C coach, players are now able to develop their bodies in the gym to hit the ball further and gain a competitive edge over their fellow competitors (9,20,24).

Research in the field of golf over the past 15 years has largely looked at muscle activation in the swing (14,23) with ample research into the importance of flexibility and mobility completed also (10,22). More recent studies, however, have investigated the importance of creating power and achieving greater distance in the game (6,15,16,17). The ability to achieve greater distance off the tee has been argued to lead to greater competitiveness (6,15,16). One of the variables in the golf swing most highly correlated (r = 0.95) to distance achieved (9) is that of club head speed (CHS). As such, many studies investigating variables affecting distance achieved in the golf swing have used CHS as the dependent variable for distance (3,15,16). There is evidence showing a relationship between handicap and CHS where higher skilled golfers produce greater CHS than their lower skilled counterparts (6). Research has also shown a positive relationship between CHS and one-rep maximum (1RM) scores in strength testing (10,20). This is an understandable relationship because of the role of strength/force in producing power (20). However, given that there is no current relationship between handicap and 1RM further investigations are required to discover why higher skilled golfers produce greater CHS than lower skilled golfers. One possible explanation for these findings is the work done in the legs during the golf swing. The golf swing is said to follow the summation of forces principle (16) and past studies have shown high correlations between ground reaction force (GRF) and CHS (r = 0.63) using a driver (15,20). Much of the available coaching literature stresses the importance of transferring weight onto the lead leg (closest to the target) as the swing progresses (2,3). Although weight transfer in the golf swing has received some attention as far back as 1985 (21) much remains unclear on the subject and results from studies already carried out are equivocal. Much of the past research in this field has focused on the relationship between weight transfer and handicap (18,19). Richards, Farrell, Kent, and Kraft (21) were able to predict handicap classification by weight transfer with an accuracy of 85%. Further investigations found differences in peak vertical force, peak lateral force, and timing of peak lateral force during the downswing between low and high handicapped golfers (18,19). Queen, Butler, Dai, and Barnes (19) established that low handicapped golfers generate a higher magnitude of force in the legs and at a faster rate when compared to higher handicapped golfers. Despite this, there is minimal research to date presenting a definitive relationship between weight transfer and CHS and this is a likely reason for why many modern coaches implement training methods that encourage a stable lower body believing that more stability in the legs during the swing will lead to greater accuracy off the tee.

The methodological approach to investigations into weight transfer was changed when Ball, Best, Dowlan, and Brown (3) established different weight transfer styles within the golf swing: namely, a front foot group and a reverse group. They argued that it was important to differentiate between these two styles before analysing any data relevant to performance measures in golf (3). Ball, Best, Dowlan, and Brown (3) was the first study to investigate the relationship between CHS and these 2 weight transfer groups. They concluded that different variables were significant to performance outcomes depending on the style (3) thereby supporting the need to establish groups before analysing performance measures.

There are many variables both linked and theorised to improve golfing performance. This study aims to shed light on yet another variable – weight transfer - and its influence on CHS. An improved understanding of the variables associated with greater golf performance will prove beneficial for S&C coaches leading to a better use of training time with their athletes and having a more sport specific approach to training regimes. Therefore, the purpose of this study was to investigate the influence of weight transfer on CHS in the golf swing using the driver. The current study therefore aims to address two research questions: (1) whether or not golfers can be classified into groups based on their weight transfer patterns: H_0 = all golfers have the same weight transfer pattern and cannot be distinguished and classified based on their weight transfer profiles, and (2) is there a significant relationship between weight transfer groups and CHS: H_0 = the mean CHS for weight transfer groups will be equal.

METHODS

Quasi-Experimental Approach to the Problem

A cross-sectional study design was used to investigate the relationship between weight transfer and CHS in adult male golfers. GRF profiles were collected for both the right and left foot for each subject using two force plates. These data were used to identify and classify two groups based on weight transfer styles similar to those identified in past research (1,2) – front foot group and stable group. CHS was collected and compared across the groups to establish if there was a significant difference between weight transfer groups and mean CHS.

Subjects

Twenty-nine male right handed golfers agreed to participate in this study. The demographic and anthropometric data for the subjects are shown in Table 1. Relative to previous studies the mean handicap in this study is low. Given lower handicapped golfers have a more consistent swing (4) the variability in CHS within subjects is likely to be low which increases the measurement precision of the current study.

Table 1. Demographic and anthropometric measures of the subjects.

Characteristic	Total Sample (n = 29) Mean (*SD*)	Front Foot Group (n = 16) Mean (*SD*)	Stable Group (n = 13) Mean (*SD*)
Age (y)	37.6 (*12.5*)	35.1 (*12.1*)	40.6 (*12.7*)
Handicap	5.6 (*4.3*)	5.3 (*4.3*)	6.1 (*4.4*)
Height (m)	1.81 (*0.1*)	1.84 (*0.1*)	1.79 (*0.1*)
Weight (kg)	81.6 (*10.4*)	82.3 (*11.6*)	80.8 (*9.0*)

Required criteria for subject participation included age between 18-60, an official golfing union of Ireland handicap, and a minimum of three months without injury. Before data collection began all subjects were emailed an invitation letter, an information sheet, and a consent form for their own records which included a withdrawal slip in the event they wanted to pull out of the study. Subjects were only required to present for data collection once for approximately 30 minutes. On the day of data collection all subjects signed an informed consent form before the procedures were explained and carried out. The study design was approved by the St. Mary's University ethics review board.

Sample Size

G Power (version 3.1.9.2) was used to generate an *a priori* sample size estimation. The t-test family was selected and the statistical test was set to difference between two independent means. The following input parameters were defined as follows: The test was specified as a two-tailed test, the alpha level was set at 0.05, and power was set at 0.8 following recommendations from Field (8). A large effect size of d = 1.2 was expected, this was based on a mean difference of 6 mph with a SD of 5 mph between groups based on Trackman reports (25). These input parameters produce a sample size of 24 to be split evenly between groups.

Procedures

All testing was completed on a covered outdoor driving range bay in Dun Laoghaire golf club in County Wicklow, Ireland. Subjects performed a standardised warm-up as described in Table 2. Subjects were then given 20 warm-up shots using a driver given to them by the researcher before the recording procedure started and data for 10 shots were collected for analyses. These 20 warm-up shots served to allow the subjects get used to hitting a driver that was not their own and further to get them accustomed to hitting golf shots while standing on force plates.

The driver used was a Cobra Bio-cell head with 9.5° loft and a tour issue Miyazaki 56x shaft. Past research investigating CHS often allowed the subjects to use their own driver. This is problematic when collecting CHS data as not all drivers or clubs weigh the same due to different shaft weights, therefore, one player may be able to swing their driver at a faster speed due to having a lighter shaft weight in their particular driver and this will likely have an effect on data collected for CHS purposes. Instead, all subjects were given the same driver and informed that it did not matter to the researcher where the ball went and to swing as they normally would. All subjects were blind to the variables being examined in this study.

Table 2. Warm-up routine.

Aim	**Equipment**	**Instructions**
Raise the body's core temperature	Treadmill	Light to medium intensity jogging for 3-5 minutes
Activate the muscles in the lower body	-	Alternate Lunges x 10 repetitions per leg
Mobilise the joints	-	5 hip circles forwards and 5 hip circles backwards per side. 5 shoulder circles forwards and 5 shoulder circles backwards per side.

Weight Transfer.

GRF data were collected for each subject for both the right and left foot at seven different stages of the swing (see Table 3) using force plates (PASPORT Force Platform, PASCO, CA, USA). These data were then converted to a percentage allocation to each foot based on the total GRF of the two feet collectively. Averages were then calculated for each subject for each phase of their respective swings. For the purpose of statistical analysis only the data for one foot was used given the averages for the right and left foot at each phase of the swing added up to 100%. The left foot data were chosen.

Table 3. Phases of the swing.

Phase	**Definition**
Address	Club head behind the ball before initiation of the swing
Mid Backswing	Club shaft parallel to the ground pointing away from the target
Top Backswing	Moment just before the body or club (whichever is first) starts moving back towards the target
Mid Downswing	Club shaft parallel to the ground pointing away from the target
Impact	Club makes impact with the ball
Mid Follow-through	Club shaft parallel to the ground pointing towards the target
Finish	Swing is completed

The classification criteria for top of the backswing in previous investigations was determined by the club shaft, a possible flaw in past research. The potential flaw in this classification involves the x-factor described in detail by Hume, Keogh, and Reid (12). This is the process whereby the hips begin the movement towards the target while the arms and club continue their backswing. This results in a greater stretch of the upper extremity muscles leading to larger elastic energy storage which ultimately delivers more power to the golf ball at impact (12). Therefore, in order to increase power in the golf swing, the hips and legs begin their movement towards the target while the arms continue to move away from the target creating this x-factor stretch (12). This is particularly important in weight transfer studies as weight will begin to shift onto the lead leg before the club head or hands reach their end position. As such, it is more appropriate to classify the top of the backswing as the point just before the hips (or the golf club in the event the hips do not lead the beginning of the downswing) move towards the target.

This gives a more complete representation of the magnitude of weight transfer for the front foot group.

CHS

CHS was collected using a Trackman 3e (Trackman, Scottsdale, AZ, USA) which was placed approximately 2 metres behind the subject. Trackman uses 2 different radar beams to detect information related to CHS and other measures related to the golf swing. Reliability data for these measures were most recently published in (26). These data were generated using a robotic arm which could systematically provide reliable data for measurement and calibration purposes. Within the current study, the absolute reliability of CHS was found to have a 95% CI of 1.5 mph around the true mean. Test-retest reliability was found to have a 95% CI of 0.4 mph. Both of these reliabilities are considered excellent. Previous testing of products similar to trackman has shown that accuracy within 2-3 mph is the industry standard for CHS tracking (27). Therefore, the measurement of CHS can be considered accurate and reliable enough for the current study.

The Trackman was connected via wireless internet to an iPad. The iPad was used to adjust the focal point of the Trackman camera so that the ball was positioned in the middle of camera's line of view. With this setup the Trackman automatically records and stores the information for each swing. Once 10 swings were recorded the trackman automatically generated a group sample report for all 10 shots detailing the CHS for each shot. Each report was sent and stored via email for each participant.

Motion Capture

Motion capture data were collected with an iPhone 5 (Apple iPhone, Version 9.3.2) using Hudl technique which is a slow motion video recording app. This app runs at 60 frames per second on the iPhone 5 allowing each phase of the swing to be determined to within 0.016 seconds. The iPhone was positioned approximately 2 metres in front of the subject to allow for a clear and full view of all phases of the swing.

Data Collection

Upon completion of the warm-up, subjects were given specific instructions regarding the recording process. Two force plates were positioned to suit the subjects' normal stance for their driver shot. The force plates were connected directly to the laptop positioned approximately 2 metres behind the subject to allow for ample room to swing. The video recorder would be turned on and left recording for the duration of the data collection for each subject. The Trackman would also be turned on at this point and would automatically collect the required data for each swing. The force plates were set to record at 1000 Hz for a duration of 12 seconds. Subjects were then instructed that once the force plates started recording they must tap the right force plate with the head of the driver and then proceed to hit their shot. The tap on the right force plate acted as a reference point both on the video recorder and the GRF data from the force plates. Using the video recordings it was possible to determine timestamps which showed how long after the tap each phase of the swing occurred. The tap also produced an identifiable spike in GRF data corresponding to the force plate under the right foot. The timestamps established from motion capture analysis with the video recorder were then used to determine the times for each stage of the swing within the GRF data gathered by the force plates. This allowed for the exact GRF data for both feet at all stages of the swing to be collected.

Statistical Analyses

A K-Means cluster analysis was used to establish and classify groups for this study. Descriptive statistics were run for CHS and showed that the data were normally distributed. An Independent-samples t-test was then run to establish if there was a significant difference in mean CHS between the two groups. The level of significance for all tests was set at $p \leq 0.05$. All statistics were performed using the IBM Statistical Package for the Social Sciences (IBM SPSS for Windows, Version 22.0. Armonk, NY: IBM Corp).

RESULTS

The descriptive statistics for CHS demonstrated a normal distribution for these data as shown by Figure 1. The distance between the lowest and highest CHS was 21. The mean ($\overline{x}$ = 101.5 mph, *SD* = 5.5 mph) and the median (M = 102.2 mph) were almost the same giving strength to the normal distribution of the data. The 5% trimmed mean was the same as the whole mean showing that there was no problems within the data set caused by outliers.

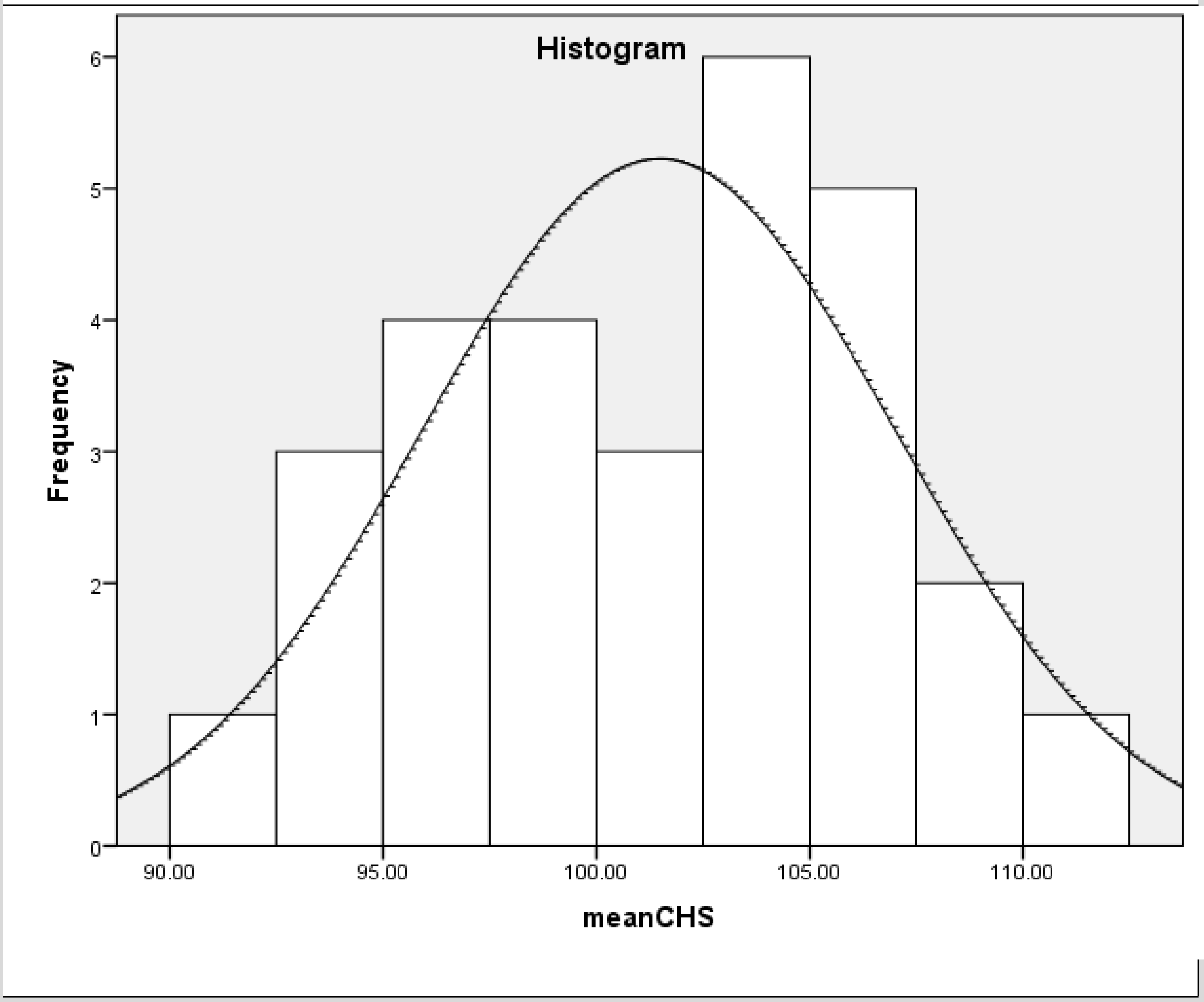

Figure 1. Histogram showing a normal distribution for CHS data.

Lastly, the Skewness and Kurtosis values are between +1 and -1 which means the data obey normal distribution mathematically as well as visually. This was formally confirmed by the Shapiro Wilk's test ($p > 0.05$). Full descriptives for these individual outcome measures are reported in Appendix 1.

The first step of the K-Means cluster analysis was run to generate three groups based on weight transfer style – it was expected to see a stable group and two different styles of weight transfer groups. All seven phases of the swing were included for classification criteria at this point. The results for a 3 cluster analysis showed that all subjects reasonably belonged to their respective cluster group. However, the distance between final cluster centers showed little difference between two of the cluster groups generated (see Appendix 2). The weak support for 3 groups at this stage of analysis would argue for the creation of 2 groups within the data collected rather than the proposed 3 groups. In addition to weak classification, the ANOVA table for the different phases of the swing showed non-significant ($p > 0.05$) values for 2 phases (address and mid backswing). It would appear that these phases of the swing are not useful for classification purposes.

Subsequently, a K-Means cluster analysis was run specifying 2 groups. The cluster analysis was also run without the non-significant address and mid backswing phases. In the second cluster analysis, the final cluster centers showed a moderate difference between the 2 groups. The resulting ANOVA table showed significant values ($p < 0.05$) for classification for three of the five phases in the swing. The Top backswing phase and the finish phase were non-significant for the purpose of group classification. A final K-Means cluster analysis was run excluding the non-significant finish phase. Top backswing was retained as a predictor for classification because both groups presented a similar weight pattern at the top backswing phase (see Figure 2). This is important to highlight given the different classification criteria for top backswing in this study compared to past research. It demonstrates that both groups have similar weight patterns during the backswing. What is therefore important for the purpose of establishing a relationship between weight transfer and CHS is what happens during the downswing (after the top backswing phase). Two groups were then identified based on the results in Figure 2.

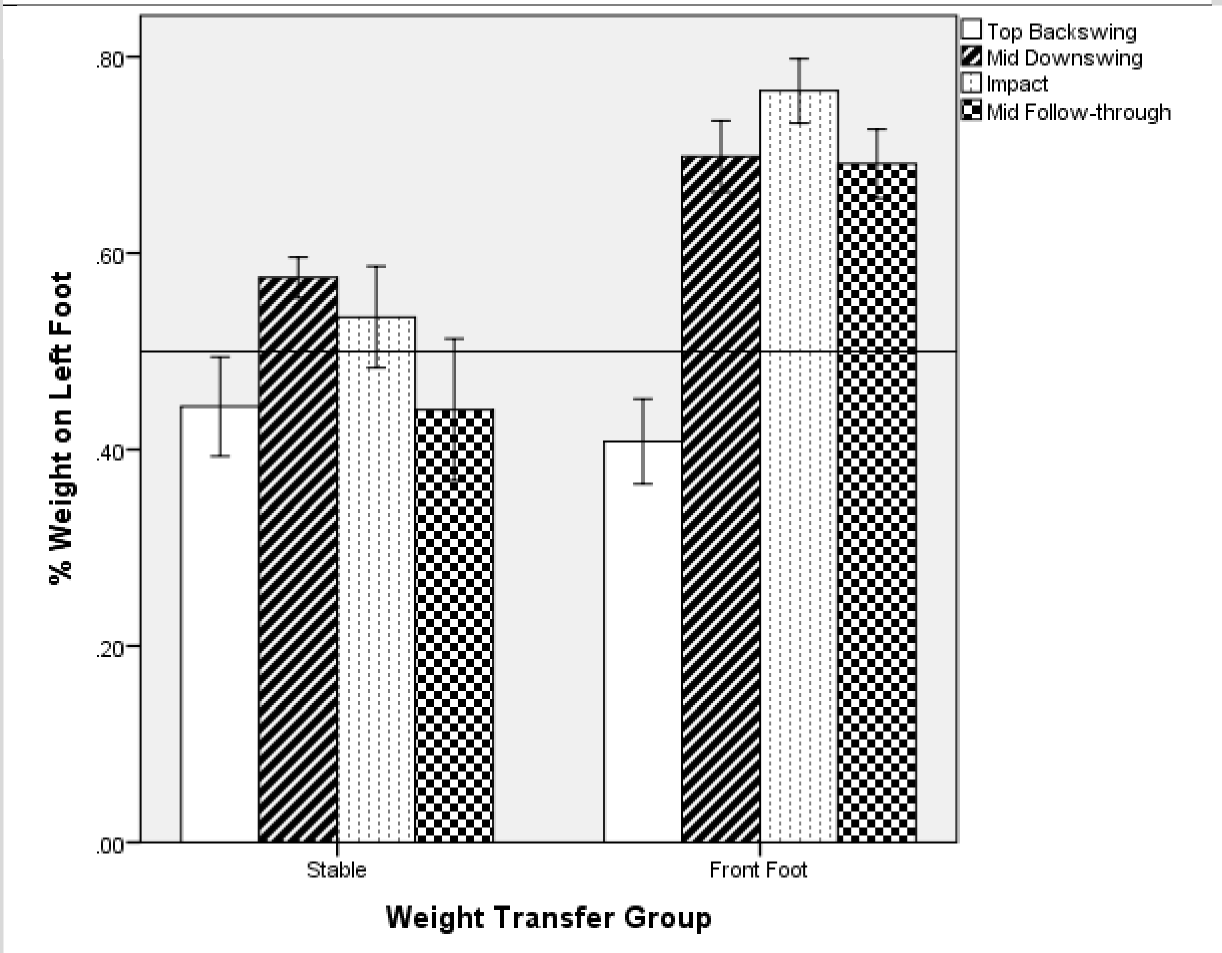

Figure 2. Percentage Weight on Left Foot During Swing (error bars represent ± 2 standard errors).

It is evident from Figure 2 that group 1 (stable) does not transfer weight during the represented phases of the downswing. In contrast, group 2 (front foot) shows a large spike in GRF data for the left foot through each phase of the downswing. Figure 2 and the corresponding ANOVA values for significance for the phases of the downswing (see Appendix 3) demonstrate that subjects can be classified into the front foot group or the stable group based on their weight transfer style. This evidence rejects the first null hypothesis that subjects cannot be grouped based on weight transfer style in the golf swing.

The assumptions for normality were met for the data in this study. Therefore, an independent-samples t-test was run to establish if there was a significant difference in CHS between the two groups. The results showed that the stable group (n=13) had a mean of 100 mph with a *SD* of 5.7 mph, and the front foot group (n = 16) had a mean of 102.2 mph and *SD* of 5.5 mph. Levene's test supported that there were no significant differences in the variances of the 2 groups, F (27) 0.13, $p > 0.05$. This allows an assumption of equal variances across groups to be made. The observed mean CHS difference between groups was 1.6 mph. This is a small difference and was found to be non-significant, t (27) = 0.782, $p > 0.05$. This was confirmed by consulting the 95% confidence interval (CI) which showed that there was a zero between the lower and upper bounds [-2.6, 5.9]. Based on this data the second null hypothesis that CHS for both groups will be equal cannot be rejected.

DISCUSSION

The purpose of this study was to investigate the relationship between weight transfer and CHS in experienced male golfers using the driver. Past research (6,7,9,24) has already established a high correlation (r = 0.95) between CHS and golf performance for both low and high handicapped golfers and overall distance achieved. Furthermore, golf coaching literature stresses the importance of a good weight transfer pattern that begins with a weight shift onto the trail leg on the backswing and a transfer of weight onto the lead leg during the downswing and into impact (2,3). Despite this, there is a distinct lack of research investigating this area of the golf game. The present study aimed to further educate S&C coaches surrounding the influence of their current (and future) training methods with their golfing athletes and whether or not they can employ a more effective methodology in the gym for increasing their athletes' CHS and thereby distance achieved off the tee.

More recent studies investigating the effect of weight transfer in the golf swing have emphasised the importance of first classifying the style of weight transfer for each subject before analysing any performance measures (1,2,3). These past studies have used a front foot group where weight is transferred onto the lead leg through the downswing and impact, and a reverse group where weight is transferred onto the trail leg during these same phases of the golf swing. The present study, however, attempted to establish 3 groups to determine a more detailed understanding of the relationship between weight transfer and CHS. Given a principle aim of the present study was to examine whether or not coaches should encourage a transfer of weight onto the lead leg during the downswing or not, it was hoped to identify and classify a stable group within the data. The rationale for this surrounds the modern coaching methods employed, particularly in the amateur game, where a stable lower body is encouraged throughout the golf swing. Many S&C coaches therefore train their athletes to rotate their upper body around a stable lower body believing this to have a positive effect on accuracy. However, the literature to date does not allow for a full understanding of the effects on distance achieved (or lost) when encouraging a stable lower body using the driver hence the use of a two-tailed t-test used in the present study. For the remaining subjects it was hoped to divide them into two weight transfer groups so that a more detailed understanding of the style of weight transfer would be delivered. For example, past research has identified both a front foot group (1,2,3) where weight is transferred onto the lead leg at some point during the downswing, and a normal or right-to-left style of weight transfer (1) where weight is first shifted onto the trail leg before returning to the front foot during the downswing. However, the results of the cluster analysis showed that the creation of 3 such groups within the data collected for this study was not possible as the final cluster centers for 2 of the groups were too close to be reasonably considered different styles of weight transfer. The cluster analysis was then narrowed to specify 2 groups. The classification from the resulting 2 groups presented notable between-groups differences and the within-group data were consistent. This gave a reasonable level of confidence that there was a real difference between the groups. These groups were then named as the stable group (group 1) based on classification criteria already outlined and the front foot group (group 2) based on criteria identified in past research. The K-Means cluster analysis, therefore, allowed the first hypothesis of the present study to be tested and showed that subjects can be classified based on their weight transfer style in the golf swing. As a result, the null hypothesis for the first research question addressed in the present study was rejected.

A notable difference between the current investigation and past literature is in the methods used to group and classify the weight transfer styles. Ball and Best (1) used a hierarchical cluster analysis approach to establish the groups used in their study – front foot and reverse. The disadvantage with a hierarchical method is the mathematical approach to determining classification criteria for groups. Instead, the present study used multiple K-Means cluster analyses to allow for certain phases of the swing to be gradually excluded based on their non-significant values ($p > 0.05$) for classification criteria (address, mid backswing, top backswing, and finish). This method allowed for the direct testing of 2 clustering structures based on the theory outlined in this study. This could prove beneficial as a new starting point for future investigations given that the current study identified the 3 key phases of the swing (mid downswing, impact, and mid follow-through) for determining weight transfer classification within normally distributed data. Furthermore, these 3 phases are continuous from the top backswing instead of 3 random phases across the swing. This is consequential for S&C coaches looking to increase CHS with their golfers as it identifies a true relationship between the trend found in the results and the groups established in this study. The K-Means approach also provides a visual representation of what happens during the swing for the groups identified in the cluster analysis. This allows for the expertise of the researcher to be used during the classification process. Compare this to the hierarchical method where this process is completed by SPSS arriving at a mathematically rather than theoretically derived set of clusters. Therefore, in hierarchical analysis the expertise of the researcher is less influential on the outcome measures.

Similar to past research (1,18,19), this study collected GRF data for both feet at various phases of the swing. One notable difference in this study when compared to past methods is the distinction of where the backswing finishes (top backswing). While past research has used the highest point of the club head or hands to indicate the top backswing this study found it more appropriate to consider the x-factor in the golf swing which means the lower body will start to move towards the target while the upper body still moves away from the target. This is hugely consequential given that, especially with any front foot subjects, the weight transfer onto the lead leg will initiate before the club head or hands reach the top of the backswing. Therefore, the magnitude of weight transfer in previous studies may have been undervalued leading to a misrepresentation of the data and thereby results. Within the present study the repeated use of K-Means cluster analysis allowed for a precise classification of groups with notable differences in final cluster centers and significant ANOVA values for the represented phases of the downswing.

The present study found a non-significant difference in CHS between groups. This is consistent with results from the only previous study known to the researcher which investigated weight transfer using CHS as the dependent variable (3). Despite these results, there was a trend for increased CHS for the front foot group where the front foot group had a mean CHS of 1.6 mph faster than the mean CHS for the stable group. Given this trend is found within data that is normally distributed, it warrants the need for further research. An indication of the findings of this study is that there is not a large effect on CHS based on weight transfer in the golf swing. A post-hoc power analysis revealed a very small effect size of 0.3 and showed that a sample of 170 participants per group would be sufficient to detect an effect of this size. Future research should therefore approach the area powered to detect such small effects using these guidelines. Furthermore, a larger sample size would allow for a more refined classification of weight groups and potentially more than the 2 groups outlined in this study. A larger sample size will also reduce the overall standard error allowing for smaller effects to be detected and a more precise 95% CI which is needed to reject the null hypothesis and apply the results to a larger population. In addition to a larger sample size, future research should employ a true experimental design using an intervention which would train participants to use a specific weight transfer style and apply a repeated measures design. The purpose of this would be to better assign causality to the link between weight transfer and CHS. The repeated measures design is also said to be more efficient than the independent groups design allowing for small effects to be detected with a lower total sample size (8). The design of such future studies could involve randomly assigning participants to different coaching strategies of stability versus weight transfer and studying the longitudinal trends in CHS. The results of such a study could inform S&C coaches as to the best practice training method to achieve greater CHS with their golfers.

The first limitation of the present study was the non-probability convenience sampling method used to choose the participants. Therefore, the sample used may not be a true reflection of the population. This method was chosen given there was no funding contributed towards the completion of this research and participants were recruited based on contact details that had already been established before the commencement of this study. A related consequence of this is the quasi-experimental design where participants were not purposefully assigned to groups. Instead, their performance data assigned them to their group retrospectively. It was not certain, therefore, when the sample size was collected that there would be enough participants to meet the requirements of power analysis. A second limitation of the present study was the use of a standardised driver to be used by all subjects. Although rationale for this method was provided in this study it should be noted that such a method may influence the true swing of the subjects given that they would likely not feel completely comfortable with a driver that is not theirs despite having 20 warm-up shots. A third limitation of the present study was the sample size being too small to allow for control variables such as age, height, and weight. For example, it is generally accepted that ageing has an inverse relationship with muscle mass and strength (5). As such, it is likely that CHS in older golfers is lower than their younger counterparts irrespective of whether or not they transfer their weight during the swing. This could prove beneficial to ageing golfers who, as they age and their ability to hit the ball as far reduces, could counteract these effect if consistent results were revealed by future studies investigating weight transfer. Similarly, the influence of height and weight – if controlled for- could reveal meaningful information regarding their effect on weight transfer and CHS. Future investigations into weight transfer in golf with larger sample sizes should control for these variables

There are many variables in the golf swing to consider and it was hoped that this study would show that weight transfer is one such variable that can be identified and used to increase CHS and thereby increase distance achieved off the tee. However, the results of this study were non-significant. The mean difference in CHS between groups was small but showed a trend for increased CHS for the front foot group. Furthermore, Trackman reports show a trend that for every 1 mph gained in swing speed amateur golfers can gain an average of 2.29 yards (25). Further research into this area will provide S&C coaches with a better understanding of the variables investigated in this study and help to mould more sport specific training methods with their athletes. Given the increasing interest in hitting the ball further, these trends will be of interest to golfers looking to achieve greater competitiveness through extra distance off the tee.

PRACTICAL APPLICATIONS

The results of this study indicate that there is no statistically significant relationship between weight transfer and CHS in the golf swing. A trend was identified to warrant further investigations into this area. It is possible that future research into weight transfer styles powered to detect smaller effects within the data could provide S&C coaches with information to influence the strategies they employ with their golfing athletes in the gym in order to gain extra distance off the tee.

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APPENDICES

Appendix 1. Full descriptives for individual outcome measures for CHS.

		Statistic
Mean		101.5
SD		5.5
95% CI for	Lower Bound	99.4
	Upper Bound	103.6
5% Trimmed Mean		101.5
Range		21.3
Skewness		-.103
Kurtosis		-.709

Appendix 2. Distances between final cluster centers for the 3 group cluster analysis.

Cluster	**1**	**2**	**3**
1		.384	.262
2	.384		.390
3	.262	.390	

Appendix 3. ANOVA values for cluster analysis using 3 groups.

	F	**Sig.**
Top Backswing	1.162	.291
Mid Downswing	30.859	.000
Impact	61.279	.000
Mid Follow-through	43.679	.000

Appendix 4. Signed ethics application

St Mary's University Twickenham London

Approval Sheet

Name of applicant: Mark O'Grady

Name of supervisor: Dan Cleather

Programme of study: S&C MSc

Title of project: The influence of weight transfer patterns on club-head speed in the golf swing

Supervisors, please complete section 1 or 2. If approved at level 1, please forward a copy of this Approval Sheet to the School Ethics Representative for their records.

SECTION 1

Approved at Level 1
Signature of supervisor (for student applications
Date: 22/1/16

SECTION 2

Refer to School Ethics Representative for consideration at Level 2 or Level 3

Signature of supervisor...

Date...

SECTION 3

To be completed by School Ethics Representative

Approved at Level 2

Signature of School Ethics Representative: J Hill
Date 02/03/16

Appendix 5. Information sheet

St Mary's University Twickenham London

Participant information sheet.

Section A: The Research Project

1. The purpose of this study is to analyse a mechanical variable in the golf swing using the driver and establish a correlation value to greater competitive golf. If a high correlation value is achieved then it is hoped to give both swing coaches and S&C coaches valuable information that may influence their strategies with their golfers.

2. This is an invitation letter to participate in a research study for golfers.

3. The research and data collection are being organised by Mark O'Grady and Dr. Daniel Cleather

4. The study's results will be presented as Mark O'Grady's independent project as part of his MSc in St. Mary's university, London.

5. This study is being funded by the researcher Mark O'Grady

6. Contact Mark: 134242@live.stmarys.ac.uk or Dr. Dan Cleather: daniel.cleather@stmarys.ac.uk

Section B: Your Participation in the Research Project

1. You have been invited to take part in this study given that you are a golfer with a valid handicap aged between 18-60 and injury free for the last 3 months.

2. You have the right to refuse to take part in this study

3. You have the right to withdraw from this study at any time. You will be given a withdrawal form before the study commences which you can fill out and give to the researcher if you wish to withdraw.

4. If you are happy to participate, the study will require you to be present in Dun Laoghaire golf club for approx. 1 hour. You will be asked to perform a brief warm-up and you will be allowed to hit 20 practice balls before your recorded swings commence. Swings will be performed on two force plates, one under each foot with a Trackman approx. 2 metres behind you recorded your swing data. Once your swings have been recorded you are finished and free to leave.

5. The risks involved are minimal, the environment is safe and you will only be asked to perform your usual golf swing with rest between shots.

6. Agreement to participate in this research will not compromise your legal rights if something goes wrong.

7. In order to avoid fatigue it is explicitly requested that participants do not play golf the morning of data collection.

8. All participant information and data collected for participants will be stored on a private laptop and shared only with the supervisor of this study in St Mary's university, Dr. Dan Cleather daniel.cleather@stmarys.ac.uk

9. Upon completion of this study, participants will be given their respective results from the research project. The feedback they receive is hoped to benefit their understanding of the game and their swing. They are also free to take their data to their swing and/or S&C coach which may well have an influence on the respective strategies of these coaches.

10. Participants will be asked to give up a few hours of their time on one day only for this study. This includes travel to and from Dun Laoghaire golf club and 1 hour in the golf academy where the warm-up will be conducted and the swings will be recorded.

11. Your participation in this project will be kept confidential.

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP TOGETHER WITH A COPY OF YOUR CONSENT FORM

Appendix 6. Consent form

St Mary's University Twickenham London

Name of Participant: ________________________________

Title of the project: N/A

Main investigator and contact details: Mark O'Grady: 134242@live.stmarys.ac.uk

Members of the research team: Dr. Dan Cleather: daniel.cleather@stmarys.ac.uk

1. I agree to take part in the above research. I have read the Participant Information Sheet which is attached to this form. I understand what my role will be in this research, and all my questions have been answered to my satisfaction.
2. I understand that I am free to withdraw from the research at any time, for any reason and without prejudice.
3. I have been informed that the confidentiality of the information I provide will be safeguarded.
4. I am free to ask any questions at any time before and during the study.
5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of participant (print)..

Signed.. Date..

If you wish to withdraw from the research, please complete the form below and return to the main investigator named above.

Title of Project: ________________________________

I WISH TO WITHDRAW FROM THIS STUDY

Name: ________________________________

Signed: ________________________ Date: ________________