WEIGHT TRANSFER PATTERNS BETWEEN DIFFERENT SKILL LEVELS AND CLUBS IN GOLF

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By

DEAN BROWN

Principal Supervisor: Dr Russell Best
Co-Supervisor: Kevin Ball

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ABSTRACT

This study investigates the different weight transfer patterns that exist between various handicap level golfers, and different golf clubs. Specifically, the Centre of Pressure (CP) was used to measure the weight transfer patterns of the golfers for three different golf clubs.

Thirty-eight male golfers were divided evenly into two handicap groups defined as: Low Handicap Golfers (handicap = -2 to 10) and High Handicap Golfers (handicap = 11+). Each golfer was required to bring their own driver, 3 iron and 7 iron to the testing session. Testing was conducted at Victoria University Biomechanics Laboratory, Melbourne, Australia and the laboratory was set-up to emulate a golf driving range. Thirty golf swings (10 with each club) were performed while the golfer stood on two AMTI force plates, which measured the CP position at 500 Hz. A 200 Hz camera was placed perpendicular to the line of shot and was used to obtain timing data for eight key events of the golf swing. A 50 Hz overhead camera recorded the position of the feet on the force plate. This footage was then digitised (Peak Motus) to plot the CP trace relative to the feet, which was then expressed as a percentage of movement between the feet (CP_{yt} %).

Eight repeated measures ANOVA (SPANOVA, *SPSS* definition) were conducted to investigate the within main effect (golf club comparison), between main effect (handicap comparison) and interaction effect between the two handicap groups and clubs for CP_{yt} %

at the eight golf swing events. The results showed there was a significant within main effect ($p < .03$) at four golf swing events for All Golfers ($n = 38$), two golf swing events for the Low Handicap Golfers ($n = 19$) and one golf swing event for the High Handicap Golfers ($n = 19$). The interaction effect between the handicap groups and clubs displayed a significant effect ($p < .1$) for one golf swing event. The between main effect did not reveal a significant difference between the Low Handicap Golfers and High Handicap golfers mean CP_{yt} % for the three golf clubs at the eight golf swing events. Further handicap analysis was conducted with the driver and through cluster analysis it was discovered that four distinct weight transfer patterns existed for the 38 golfers. A handicap comparison was conducted within the weight transfer patterns, however no significant differences were displayed between the Low Handicap Golfers or High Handicap Golfers mean CP_{yt} % at the eight golf swing events.

CHAPTER 1

INTRODUCTION

Golf is the most popular leisure activity undertaken by adult males in Australia (Australian Bureau of Statistics, 1999). One of the results of this popularity is the vast amount of coaching and scientific literature that has emerged, examining all elements of the game of golf. Cochran and Stobbs (1968) performed the first extensive scientific research on the golf swing and labeled their study 'The Search for the Perfect Swing'. This research examined the fundamental skills of the golf swing and provided a model of technical, physical and mental approaches for the game of golf. The scientific research that has followed has continued to build on the theories and ideas defined by Cochran and Stobbs. One area, which Cochran and Stobbs briefly researched, was the interaction between the feet and the ground during the golf swing.

Williams and Sih (1998) suggested that the interaction between the feet and the ground plays an important role by producing forces at the feet that provide a foundation for movement of the body to activate the golf swing. A number of scientific studies have investigated the interaction between the feet and ground by utilising force platforms to measure the ground reaction forces that were present during a golf swing (Williams and Cavanagh, 1983; Richards *et al.*, 1985; Koenig *et al.*, 1994). All of these studies have referred to the movement of force between the feet as 'weight transfer'. The Professional Golfers Association (PGA, 1990) has suggested that weight transfer is one of the most important fundamental skills in successfully executing a golf swing.

The primary goal of the previous weight transfer literature has been to quantify the weight transfer patterns that exist within the golf swing. More specifically, some studies have examined the weight transfer patterns of golfers with various handicaps (Richards *et al.,* 1985; Wallace *et al.,* 1990; Barrentine *et al.,* 1994; Koenig *et al.,* 1994). The assumption made in these studies was that the professional or low handicap golfers are more 'skilled' (produce superior weight transfer patterns) than the amateur or high handicap golfers. The objective of these studies was to determine if different weight transfer patterns exist between the skilled golfers (professional, low handicap) compared to the unskilled golfers (amateur, high handicap). Discrepancies were evident in the scientific literature, as some studies reported differences between the handicap groups (Barrentine *et al.,* 1994; Wallace *et al.,* 1994), while other studies have not reported any differences between the low and high handicap golfers (Richards *et al.,* 1985; Koenig *et al.,* 1994).

In conjunction with the handicap comparison, some studies have investigated the weight transfer patterns performed by golfers with various golf clubs (i.e. driver, 3 iron etc). The aim of these studies was to compare the different weight transfer styles that were present for golfers when the golf club characteristics were changed (i.e. clubface loft, club shaft length etc). Like the handicap comparison, some studies have reported the golfers performing different weight transfer patterns for various golf clubs (Cooper *et al.,* 1974; Williams and Cavanagh, 1983; Koenig *et al.,* 1994), while other studies have not reported any differences (Koslow, 1994).

Conflicting findings have been reported in the weight transfer literature for handicap comparisons and golf club comparisons. The inconsistencies from study-to-study were primarily due to the small subject numbers tested (n = 1 to 20). Additionally, the examination of the weight transfer pattern throughout the whole swing has generally been neglected with researchers opting to investigate too few golf swing events or only specific phases of the golf swing (Richards et al., 1985; Barrentine et al., 1994; Koenig et al., 1994; Koslow, 1994). This study aims to provide a more thorough investigation of the weight transfer patterns between Low Handicap Golfers and High Handicap Golfers by utilising a larger sample population (n = 38) than the majority of previous weight transfer studies. This study will also contribute to the golfing literature by providing coaches, scientists, professional and players with a clear picture of the ideal weight transfer patterns through an increased range of golf clubs and by analysing the weight transfer patterns at more golf swing events.

1.1 ABBREVIATIONS

General

CG	Centre of Gravity
HSV	High Speed Video
PGA	Professional Golfers Association
AGU	Australian Golfers Union

Force plate

CP	Centre of Pressure
CP_{yt} %	CP between the feet (front foot = 100%, back foot = 0%)
GRF	Ground Reaction Forces
FP	Force Plate
COVF	Centre of Vertical Force (as defined by Richards *et al.* 1985)
F_x	Force in the anterior/posterior direction
F_y	Force in the medial/lateral direction
F_z	Force in the vertical direction
M_x	Moment measured about X axis
M_y	Moment measured about Y axis
M_z	Moment measured about Z axis
AMTI	Advanced Mechanical Technology Incorporated

Statistical

SD	Standard Deviation
SPANOVA	Split Plot Analysis of Variance (*SPSS* version 10)
p	Significance level
η^2	Eta squared (effect size) for SPANOVA
d	Effect size for t-tests

Golf Swing Events:

AD	Address
TA	Take Away
MB	Middle of Backswing
LB	Late Backswing
TB	Top of Backswing
ED	Early Downswing
MD	Middle of Downswing
BC	Ball Contact
MF	Middle of Follow Through

CHAPTER 2

LITERATURE REVIEW

2.1 WHAT IS WEIGHT TRANSFER

Weight transfer is a golf coaching term that is used to describe the movement of weight between the feet throughout the golf swing (eg. PGA teaching manual, 1990; Newell and Foston, 1995; Norman, 1995). For these coaching texts a common weight transfer sequence is described as (Norman 1995);

- Weight is evenly balanced between the feet at AD.
- During the backswing the weight is transferred towards the back foot and remains here until the completion of the backswing.
- The downswing is initiated from the legs up and a rapid weight transfer from the back foot to the front foot is produced during this phase.
- After BC the weight transfer ceases and the golfer tries to maintain a balanced finish position.

The PGA teaching manual (1990) place large importance on weight transfer and regard it as one of the most important fundamental skills in executing a golf swing. This manual suggests that correct weight transfer must be mastered before more advanced swing instruction can occur and acquiring correct weight transfer enhances the golf swing by,

1. Providing a platform for the rotation of the body and swinging of the arms.
2. Adding impetus to the total movement.

3. Placing the body in a position to strike the ball with a clubface that is traveling in the right direction at the correct angle of approach.

Not all golf coaches agree with the PGA (1990) teaching principles of weight transfer. Cooke (1987) suggests that an overemphasis on weight transfer during the backswing can increase the likelihood of the golfer swaying too much during this phase. Cooke advocates that weight transfer should not be taught separately from the swing, instead it should become part of the backswing motion and relates to the arms and hands moving away from the body. Madonna (2001) agrees with this premise and added that the weight transfer must occur naturally and be facilitated by the swinging of the arms.

Newell and Foston (1995) agree that weight transfer should occur naturally and assert that correct weight transfer facilitates long distance hitting. The PGA teaching manual (1990) suggests that the momentum developed by the legs from weight transfer accounts for 20-30% of the golfers hitting distance. The arms, hips, trunk and wrist provide the remaining 70-80% of the distance achieved. It was unclear how these percentages were calculated but as this document is a coaching manual it can be assumed that the information is anecdotal coaching evidence. However, this statistic highlights the importance of weight transfer when executing a golf swing, especially when hitting for long distances.

2.2 CP AS A MEASURE OF WEIGHT TRANSFER

A variety of parameters have been used in the biomechanical research to assess the weight transfer patterns of a golf swing. CP movement between the feet has been investigated on three occasions (Mason *et al.,* 1991; 1995; Ball *et al.,* 2001). Mason *et al.* (1991) examined the relationship between CG movement and CP movement between the feet during the golf swing for 14 single digit handicap golfers. It was anticipated that these two parameters followed a similar trace between the feet during the golf swing. If this was found to be true, then CP could be used instead of CG to provide more readily obtained weight transfer analysis. The results showed that the medial/lateral movement (between feet movement) of the CG and CP throughout the backswing and downswing phase was similar until BC. At BC, the position of the CP was located on the medial edge of the front foot and was closer to the target than the CG. The CG was further back in the stance and was positioned in line with the ball at BC. After BC, the CG continued to move towards the front foot, while the path of the CP was inconsistent from golfer-to-golfer which resulted in no general pattern for this parameter. The primary conclusion of Mason et al. was that CP was a *good* diagnostic parameter of weight transfer although the CP and CG displayed some differences at BC. Mason *et al.* reasoning for this conclusion was related to the calculation of CG and CP. The calculation of CG was time-consuming due to the extensive experimental set-up and the digitising process involved in determining the CG of the golfer and the club (26 reflective markers placed on joint segments of the golfer and club). The calculation of CP however, was more readily obtained with the use of two Kistler force plates. Considering Mason *et al.* (1995)

conducted another golf swing study using this parameter then CP will be considered an accurate and reliable measure of weight transfer.

Another parameter used to assess the weight transfer patterns in golf was the F_z distribution between the feet. This parameter has been used more extensively (Cooper *et al.,* 1974; Williams and Cavanagh, 1983, Richards *et al.,* 1985; Koenig *et al.,* 1994; Koslow 1994) than CP or CG. In all of these studies a force plate was utilised to measure the F_z distribution between the feet. The relationship between the F_z distribution and CP during the golf swing was investigated by Ball (2001, Appendix 2A) to determine how similar these two parameters are. The F_z distribution and CP was calculated for 62 golfers at eight golf swing events (TA, MB, LB, TB, ED, MD, BC, MF). Ball found a strong relationship ($r = .999$, $p < .001$) between these two parameters and displayed a mean difference of less than 1% for the eight golf swing events. Ball concluded that the F_z distribution and CP predominately measure the same thing and suggested a comparison of these two parameters was appropriate.

2.3 HANDICAP DIFFERENCES

Golfing handicaps were implemented by golfing bodies worldwide and were usually compulsory when golfers compete in amateur competitions and tournaments. The aim of the golfing handicap is to normalise golfers so they can compete on an even playing field. The handicap is calculated by comparing the golfers average round to the par of the course and is generally an indication of playing ability. Weight transfer studies have made use of golfers handicaps to classify golfers into, two (Richards *et al.,* 1985; Wallace *et al.*, 1994) and three (Williams and Cavnagh, 1983; Barrentine *et al.*, 1994; Koenig *et al.*, 1994) handicap groups for comparison. Often in scientific golf studies, professional golfers were compared to amateur or novice golfers, or low handicap golfers were compared to high handicap golfers. In these studies it was assumed that the professional/low handicappers were more skilled than the amateur/high handicappers. The aim of these studies was to quantify the differences that exist between the groups and determine whether the difference were important for more skilled play. The problem with classifying golfers according to handicap score is that it may not be related to technical ability. A variety of swing techniques exists for golfers of the same handicap score and golfers who possess an unorthodox style may still have the ability to shoot low scores and obtain a low handicap. It seems that the handicap classification of golfers is the only viable and fair method of comparing golfers of different skill levels.

2.3.1 Weight Transfer Patterns Between the Feet

Richards *et al.* (1985) investigated the F_z distribution between the feet for 10 low handicap golfers (handicap <10) and 10 high handicap golfers (handicap >20). A force plate containing three piezoelectric transducers located in all three corners measured the F_z placed on each foot. The amount of F_z loading on each transducer allowed Richards *et al.* (1985) to calculate the center of vertical force (COVF) relative to the mid point of the front foot and the mid point of the back foot. COVF was expressed as a percentage of F_z movement between the mid point of the feet at TB and BC. Figure 2.3.1 illustrates exactly how the COVF was expressed relative to the mid point of each foot.

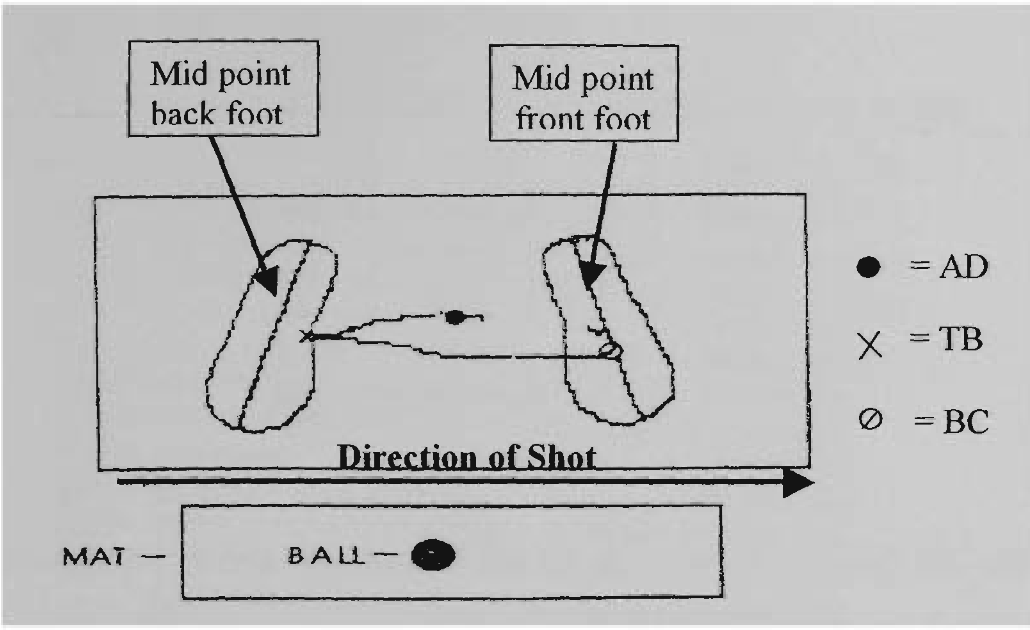


Figure 2.3.1: Richards *et al.* (1985) sample of the COVF trace throughout the swing
N.B; The force plate is rectangular in this figure, but in the study it was triangular. Also, no data was reported for this figure.

Richards *et al.* (1985) showed that the low and high handicap golfers produced different COVF percentages at TB and BC but were not significantly different (table 2.3.1.1). The maximum COVF (farthest point forward the COVF travelled towards the front foot) displayed by the low and high handicap golfers was significantly different ($p < .05$) and Richards *et al.* indicated that the maximum COVF occurred after BC for every golfer. This led Richards *et al.* to the conclusion that the follow through positions were different between the two handicap groups, whereby the low handicap golfers exhibited a larger maximum COVF than high handicap golfers. This statement however, appeared to be speculation, considering Richards *et al.* did not examine the COVF during the follow through phase or at a specific event during this phase. The small number of golf swing events investigated by Richards *et al.* severely limits this study. This study would have provided more relevant results if more golf swing events were investigated in the same manner as Wallace *et al.* (1990).

Table 2.3.1.1: COVF results for Richards *et al.* (1985)

	Low (n = 10)		High (n = 10)	
COVF %	Mean	SD	Mean	SD
TB	27.5	8.8	21.8	13.6
BC	95.6	12.1	80.9	25.2
Max*	105.4	5.6	98.1	9.1

*Significant $p < .05$

Wallace *et al.* (1990) investigated the CP distribution between the feet of one low handicap golfer (handicap = 6) and one high handicap golfer (handicap = 24), while performing ten trials standing on two Musgrave pressure sensor footplates (each plate contained 2048 sensors). The footplates measured the pressure located under each foot during the golf swing, which was expressed as a percentage of movement between the feet. This method of expressing the parameter (pressure on each foot) relative to the feet as a percentage was similar to the study of Richards *et al.* (1985), except Wallace *et al.* (1990) investigated the pressure percentage values at more events. The mean pressure percentage of the ten trials for the low and high handicap golfer was calculated at six golf swing events (AD, MB, TB, MD, BC, FT). Wallace *et al.* found that the low and high handicap golfers were significantly different ($p < .05$) in the pressure percentage for all events except TB (table 2.3.1.2).

Table 2.3.1.2: Pressure percent on the front foot for Wallace *et al.* (1990) at five golf swing events between the low and high handicap golfers

Events	Low (handicap=6)		High (handicap=24)	
	Mean	SD	Mean	SD
AD*	63.2	7.0	49.4	5.8
MB*	52.6	10.9	41.7	5.1
TB	27.3	6.3	30.7	8.6
MD*	69.2	6.4	46.6	9.6
BC*	82.2	4.2	66.5	8.3
FT*	89.8	4.5	76.6	6.0

*Significant $p < .05$

Wallace *et al.* (1990) reported a meaningful weight transfer comparison between a low and high handicap golfer but inferences about the sample populations was difficult considering only one subject was examined within each handicap group. The results from Wallace *et al.* will be treated with caution compared to other studies with a greater number of low and high handicap golfers (Williams and Cavanagh, 1983; Richards *et al.*, 1985; Koenig *et al.*, 1994). Nevertheless, the pressure distribution percentages presented by Wallace *et al.* provided a more thorough investigation of the between feet weight transfer patterns of a low and high handicap golfer because of the increased number of golf swing events utilized in the study.

The pressure distribution percentage of the low and high handicap golfer at follow through in Wallace *et al.* (1990) study supports Richards *et al.* (1985) hypothesis. Richards *et al.* suggested that low handicap golfers produced a larger F_z distribution on the front foot (105.4%) than the high handicap golfers (98.1%) during the follow through phase. Wallace *et al.* (1990) showed this was the case with the low handicap golfers producing more pressure on the front foot (89.8%) than the high handicap golfer (76.6%).

A direct comparison between these two studies is not appropriate considering Wallace *et al.* examined follow through as a specific event, while Richards *et al.* (1985) did not.

Koenig *et al.* (1994) also investigated the weight transfer patterns between the feet for golfers with a range of handicaps. No descriptive data or statistics were reported between the handicap groups, however Koenig *et al.* reported that the high handicap golfers produced much less weight shift towards the back foot than the low handicap golfers during the backswing phase. The high handicap golfers in this study maintained an even balance between their feet during the backswing phase. These findings contradict the weight transfer patterns found by Wallace *et al.* (1990) who reported a significant difference ($p < .05$) between the low and high handicap golfers at MB. At MB, the high handicap golfer exhibited a larger percentage of pressure on the back foot than the low handicap golfers. At TB only a small difference was reported between the low and high handicap golfers and they were not significantly different.

2.3.2 Handicap Comparison Between the Studies

2.3.2.1 Low Handicap Golfers

Three studies have reported the weight transfer values between the feet for low handicap golfers at specific events of the golf swing (table 2.3.2.1). Koenig *et al.* (1994) did not report any specific weight transfer values for the low handicap golfers, instead the average weight transfer pattern of the 14 golfers were reported. Both Richards *et al.* (1985) and Koenig *et al.* (1994) examined the F_z distribution, while Wallace *et al.* (1990) investigated the pressure distribution between the feet. Wallace *et al.* reported the pressure distributions for six events, while Koenig *et al.* (1994) reported three and Richards *et al.* (1985) two.

Table 2.3.2.1: Comparison of the percentage of weight placed on the front foot between low handicap golfers and an average golfer for three studies

Study	Richards *et al.* (1985)		Wallace *et al.* (1990)		Koenig *et al.* (1994)	
Parameter	COVF		Pressure distribution		F_z distribution	
n (handicap range)	10 (<10)		1 (6)		14 (0 to 15+) Average	
	Mean	SD	Mean	SD	Mean	SD
AD			63.2	7		
TA					55.0	Not reported
MB			52.6	10.9	20.0	Not reported
TB	27.5	8.8	27.3	6.3	35.0	Not reported
MD			69.2	6.4		
BC	95.6	12.1	82.2	4.2		
FT			89.8	4.5		

NB: All percentages have been calculated relative to the front foot (i.e. front foot = 100%)

Wallace *et al.* (1990) was the only study to report weight transfer data between the feet for the low handicap golfer at AD. The pressure distribution displayed by this golfer (63.2%) suggested that more weight is being placed on the front foot (table 2.3.2.1). Between AD and MB this golfer exhibits a small transfer of pressure towards the back foot and finishes with the weight evenly balanced between the feet at MB (52.6%). The weight transfer pattern from TA to MB is similar to the average golfer in Koenig's *et al.* (1994), except the average golfer has commenced the swing with less weight on the front foot. After TA the average golfer (n = 14) exhibited a larger transfer of force towards the back foot during these events and completed MB (20%) with the majority of weight placed on the back foot. The difference between the two studies at MB is just over 30%.

The discrepancy between these two studies may have been caused by the different sample sizes. Koenig *et al.* (1994) calculated the mean for the fourteen golfers, while Wallace *et al.* (1990) only investigated one golfer, who may be an extreme case.

At TB Richards *et al.* (1985) and Wallace *et al.* (1994) have reported almost identical weight transfer values for the low handicap golfers (Richards *et al.* = 27.5%, Wallace *et al.* = 27.3%), while the average golfer in Koenig *et al.* (1994) study displayed a larger percentage (35%) of weight on the front foot. The weight transfer patterns exhibited from MB to TB for the low handicap golfer in Wallace *et al.* (1990) and the average golfer in Koenig *et al.* (1994) were notable different. For Koenig *et al.* the average golfer weight transfer pattern from MB to TB was depicted by a forward shift towards the front foot resulting in a larger F_z distribution at TB than MB. The opposite weight transfer pattern occurs for the single high handicap golfer in Wallace *et al.* (1990) who displayed a backward weight transfer pattern that resulted in more weight on the back foot for TB compared to MB. These different weight transfer patterns may explain why differences were shown in the between feet percentage for these two studies at TB. Considering Wallace *et al.* had presented similar results to Richards *et al.* (1985) it could be assumed that this data was more accurate than Koenig *et al.* (1994). Furthermore, the data presented by Koenig *et al.* at TB was for the average golfer and the high handicap golfers and mid handicap golfers may have caused a larger percentage of weight to be placed on the front foot compared to Richards *et al.* (1985) and Wallace *et al.* (1990) low handicap golfers.

Wallace *et al.* (1990) has been the only between feet weight transfer study to report data for the low handicap golfer during the downswing events. The data presented for the single low handicap golfer demonstrated a large transfer of pressure from the back foot at TB to the front foot at MD. From MD to BC the single low handicap golfer continued to transfer pressure towards the front foot but the range of pressure distribution during these events (13%) was smaller than that shown from TB to MD (46.4%). The pressure distribution percentage shown at BC for the single low handicap golfer (82.5%) in Wallace *et al. was* smaller than the mean COVF displayed by the ten low handicap golfers (95.6%) in Richards *et al.* (1985, table 2.3.3.1). The low handicap golfer in Wallace *et al.* (1990) may have been an extreme case, considering the pressure distribution value was outside one standard deviation for the ten low handicap golfers in Richards *et al.* (1985).

2.3.2.2 High Handicap Golfers

Richards *et al.* (1985), Wallace *et al.* (1990) and Koslow (1994) reported between feet weight transfer data for high handicap golfers. The methods used by Richards *et al.* (1985) and Wallace *et al.* (1990) were the same for the low handicap golfers, while Koslow (1994) examined the F_z distribution of five beginner golfers at three golf swing events (table 2.3.2.2).

Table 2.3.2.2: Comparison of weight transfer results between the high handicap golfers in three different studies

Study	Richards *et al.* (1985)		Wallace *et al.* (1990)		Koslow (1994)	
Parameter	COVF		Pressure distribution		F_z distribution	
n (handicap range)	10 (>10)		1 (24)		5 (beginners)	
	Mean	SD	Mean	SD	Mean	SD
AD			49.4	5.8	47.7	Not reported
TA						
MB			41.7	5.1		
TB	21.8	13.6	30.7	8.6	26.8	Not reported
MD			46.6	9.6		
BC	80.9	25.2	66.5	4.2	62.4	Not reported
FT			76.6	4.5		

NB: All percentages have been calculated relative to the front foot (i.e. front foot = 100%)

Wallace *et al.* (1990) showed that the high handicap (49.4%) golfers address the ball with the pressure placed almost evenly between the feet. Koslow (1994) supported this finding, with the five high handicap golfers (47.7%) displaying a similar AD position to the single high handicap golfer in Wallace *et al* (1990). Comparison between the low (table 2.3.2.1) and high handicap (table 2.3.2.2) golfers at AD and TA indicated that the high handicap golfers (Wallace *et al.*, 1990; Koslow, 1994) address the ball and initiate the swing with more weight placed closer to the back foot than the low handicap golfer in Wallace *et al.* (1990).

From TA to MB the single high handicap golfer in Wallace *et al.* (1990) displayed a transfer of pressure towards the back foot, which was also demonstrated by the low handicap golfer (table 2.3.2.1). After MB the single high handicap golfer transfers more pressure towards the back foot and at TB the percentage of pressure on the front foot was greatest for this golfer (30.7%) compared to the ten high handicap golfers (21.8%) in Richards *et al.* (1985) and Koslow (1994). The values presented at TB by the three studies were spread over a range of approximately 10%, which may be attributed to the different subject numbers tested in each study. Both Richards *et al.* (1985) and Koslow (1994) sampled more than one high handicap golfer and reported mean TB positions that were more closely related than the results reported by the single high handicap golfer in Wallace *et al.* (1990).

Comparison between Richards *et al.* (1985) and Wallace *et al.* (1990) results at TB for the low and high handicap showed two different outcomes. The high handicap golfers (21.8%) in Richards *et al.* (1985) exhibited more weight on the back foot than the low handicap golfers (27.5%), while Wallace *et al.* (1990) reported more weight on the back foot for the low handicap golfer (22.8%) than the high handicap golfer (30.7%) at the same event. Both of these studies showed no significant difference between the handicap groups at TB. No other weight transfer studies have displayed between the feet data at TB for low and high handicap golfers. Further analysis is required to determine which handicap group transfers more weight towards the back foot during the backswing phase and at TB.

From TB to MD Wallace *et al.* (1990) showed that the high handicap golfer transferred pressure towards the front foot. The forward weight transfer continued for this golfer to BC (66.5%) where just over half the weight was placed on the front foot for this event. A similar result was displayed by Koslow (1994) for five beginner golfers (62.4%). The results shown by Richards *et al.* (1985) suggested that the majority of the weight is on the front foot (80.9%). The weight distribution percentage for Richards *et al.* (1985) at BC was significantly larger than Wallace *et al.* (1990) and Koslow (1994) findings.

2.4 GOLF CLUB DIFFERENCES

The emphasis of the weight transfer literature has focussed primary on handicap related differences and has often neglected the weight transfer patterns that may exist between various golf clubs. Studies that have only used one club for analysis have either opted for the driver (Wallace *et al.*, 1990; Wallace *et al.*, 1994; Mason *et al.*, 1991; Mason *et al.*, 1995) or 5 iron (Carlsoo, 1967; Richards *et al.*, 1985). Only a handful of weight transfer studies have used various golf clubs as a part of their experimental design. Barrentine *et al.* (1994) and Koslow (1994) made use of two clubs (driver, 5 iron for Barrentine *et al.*, driver, 8 iron for Koslow), while Cooper *et al.* (1974), Williams and Cavanagh (1983) and Koenig *et al.* (1994) used three clubs (driver, 3 iron and 7 iron) to investigate the weight transfer patterns. All the studies that analysed more than one club have used the F_z to examine the different weight transfer patter.

2.4.1 Weight Transfer Patterns Between the Feet

Cooper *et al.* (1974) compared the F_z distribution patterns between the feet for five low handicap university students for the driver, 3 iron and 7 iron. Cooper *et al.* found that the maximum forward shift of F_z onto the front foot occurred at different times in the swing for the driver, 3 iron and 7 iron. The driver displayed a maximum F_z on the front foot just prior to BC, while the 3 iron and 7 iron exhibited a maximum F_z on the front foot just after BC. Williams and Cavanagh (1983) reported a similar result for the driver as Cooper *et al.* (1974), however the 7 iron exhibited a peak F_z on the front foot prior to BC. Adding more inconsistency to the literature was Barrentine *et al.* (1994) who found that the driver and 5 iron displayed a peak F_z on the front foot after BC (driver .010s, 5 iron .028s). The data presented by Barrentine *et al.* would be considered more generalized to the wider golfing community due to the large number of golfers tested (n = 60). Furthermore, Barrentine *et al.* was the only study that provided descriptive data to support the claim, while Williams and Cavanagh (1983) and Cooper *et al.* (1974) only provided a qualitative assessment.

The F_z distribution between the feet for the five low handicap university golfers (Cooper *et al.* 1974) showed that the transfer of weight after BC for the 7 iron continued towards the front foot. The driver displayed a decrease in the F_z distribution for the five low handicap golfers, which resulted in less weight on the front foot. Just after BC the F_z distribution for the 7 iron (75%) was larger than the driver (50%) F_z distribution at the same instance. Visual examination of the graph shows the F_z distribution percentage for the driver is actually larger than 50%. Cooper *et al.* appears to have understated the F_z distribution percentage for this club. The instance to which Cooper *et al.* referred to, on the graph, the five low handicap golfers display a F_z distribution percentage of approximately 60%, which is still smaller than the 3 iron and 7 iron. This indicates, that just after BC the five low handicap golfers preferred to maintain a stable stance for the less lofted and longer club (i.e. driver), compared to the shorter more lofted clubs (i.e. 3

iron, 7 iron). Cooper *et al.* did not report any significant differences between these clubs because parametric tests were not performed.

Immediately after BC to the completion of the swing (end of follow through) the five low handicap golfers displayed an increase in the F_z distribution for the driver, while the 3 iron and the 7 iron maintained a similar F_z distribution during this phase. This resulted in a small F_z distribution difference between the three golf clubs at the end of follow through, with the 7 iron (80%) exhibiting the greatest amount of weight on the front foot and the driver (70%) producing the smallest. The 3 iron (approx 75%) fell in between the driver and the 7 iron.

Williams and Cavanagh (1983) suggested that the low, middle and high handicap golfers produced larger peak forces for the driver throughout the whole swing, while the 7 iron produced the least. Koenig *et al.* (1994) found a similar result and suggested that the different peak forces exhibited by the driver, 3 iron and 7 iron were the product of inertial effects. Both of these studies did not expand on this explanation and provided very little data or discussion on the comparison of weight transfer patterns exhibited by the golfers for the various golf clubs. It is clear from these two studies that further research is warranted with a larger sample population.

Koslow (1994) provided an extensive weight transfer study of 30 beginner golfers (less than ten rounds of golf). The purpose of this study was to compare the weight transfer patterns of the 30 beginner golfers for the driver and 8 iron. The experimental set-up involved a sportech swing analyser, which the golfer stood on while performing ten trials for each golf club. The mean weight transfer pattern of each golfer was analysed at three events. Koslow found that the weight transfer patterns between the driver and 8 iron were not significantly different for the beginner golfers. In addition to the club comparison, Koslow also found that three weight transfer styles were evident for the beginner golfers. Five of the 30 golfers for the driver and eight of the 30 golfers for the 8 iron displayed a 'proper weight shift'. Koslow defined a 'proper weight shift' as equally balanced weight at AD, more than 50% of weight set on the back foot at TB and more than 50% of weight on the front foot at BC. Koslow also reported an 'abbreviated weight shift' (proper weight shift at AD and TB, while BC < 50% on front foot) and 'reverse weight shift' (TB = > 50% on front foot, BC = > 50% on back foot) for the remaining golfers that were not classified into the 'proper weight shift' (table 2.4.1.1). The majority of the 30 beginner golfers were classified into the 'abbreviated' weight transfer group, which represented golfers whom do not achieve a 'proper weight transfer' early in the learning process. If this classification system was applied to the data shown by Richards *et al.* (1985), Wallace *et al.* (1990) and Koenig *et al.* (1994) for the low and average (table 2.3.2.1) and high handicap golfers (table 2.3.2.2) then they would have all been considered 'proper' weight transfer styles.

Table 2.4.1.1: Proper, Reverse and Abbreviated weight transfer styles found for 30 beginner golfers for the driver and 8 iron by Koslow (1994)

Weight Transfer Style	Club	N	Event		
			AD	TB	BC
Proper	Driver	5	47.7	26.8	62.4
	8 iron	8	48.6	29.7	61.9
Reverse	Driver	8	50.8	59.8	35.5
	8 iron	7	49.0	58.0	39.2
Abbreviated	Driver	17	48.6	39.0	43
	8 iron	15	49.7	38.0	45

N.B. Koslow (1994) values have been changed to be made relative to the front foot (i.e. front foot = 100%).

The three weight transfer styles defined by Koslow (1994) aim to provide coaches and biomechanists with an understanding of how beginner golfers move their weight throughout the golf swing. There are, however a number of experimental limitations present in Koslow's study. Firstly, only three golf swing events (AD, TB, BC) were used to identify the weight transfer styles. The large time delay between these events does not give any information of the movement patterns. Secondly, the procedure used to determine the three styles was subjective and lacked scientific merit. The 'proper' weight transfer style was constructed from previous weight transfer studies (Cooper *et al.,* 1974; Williams and Cavanagh, 1983; Richards *et al.,* 1985). The 'reverse' weight transfer style was created through anecdotal coaching literature (Frank, 1994; McGetrick, 1994) and assessment of the F_z distribution at TB and BC. The 'abbreviated' weight transfer style was produced because the majority of the beginner golfers F_z distribution did not fit the mould of the 'proper' or 'reverse' style. This qualitative method of classifying golfers into the three weight transfer groups seems simple. A more appropriate method of classifying the golfers into weight transfer groups may have been cluster analysis.

2.5 GOLF SWING EVENTS USED IN WEIGHT TRANSFER STUDIES

A six-year study conducted by Cochran and Stobbs (1968) was one of the first scientific studies to examine the underling principles governing the game of golf. This vast amount of research incorporated all aspects of the game of golf and they labelled the study 'The Search for the Perfect Swing'. The golf swing was broken down into specific segments to analyse each element of the swing. A similar approach has been incorporated in future biomechanical research of the golf swing involving kinematic and kinetic research. In these studies the golf swing was broken into specific phases and events in an attempt understand the technique that were required to perform the skill. Weight transfer studies examining the between feet movement have examined the parameters at two (Richards *et al.,* 1985), three (Koslow 1994; Koenig *et al.,* 1994), six (Wallace *et al.,* 1990) and eight (Williams and Cavanagh, 1983) events, while others have investigated the weight transfer patterns for phases of the swing (Cooper *et al.,* 1974; Mason *et al.,* 1991; 1995). The problem associated with examining the weight transfer data in phases, is that valuable data can be missed, due to large time delays. For example from MB to TB and TB to MD, the golfer moves the body through a large range of motion. To date, specific events within these phases have not been investigated. Examining the weight transfer data at more events would provide a more thorough analysis of what occurs at specific events in the golf swing (i.e. TB, MD etc), rather than the phase of the golf swing (TB to MD).

The method used to assess the events and phases of the swing have often been variable between the weight transfer studies. Cameras have been the primary source of obtaining temporal information of the golf swing and 200Hz cameras have been used previously by several studies (Cooper *et al.*, 1974; Williams and Cavanagh, 1983; Barrentine *et al.*, 1994). Those studies that have used video footage with smaller sample rates (Carlsoo, 1974; Wallace *et al.,* 1990; Kawashima *et al.*, 1994) would not have determined the position of events as accurately as the higher frequency cameras. Cooper *et al.* (1974) performed his investigation with a 200Hz camera but concluded that a 1000Hz camera would have been more appropriate for temporal analysis of the golf swing.

CHAPTER 3

AIMS

3.1 GENERAL AIM

The objective of this investigation is to analyse the weight transfer patterns of golfers incorporating the effect of two handicap groups (Low Handicap Golfers and High Handicap Golfers) while using three different golf clubs (driver, 3 iron and 7 iron). Kinetic data will be examined at specific events of the golf swing for both handicap groups and club types to determine the effect on each other.

3.2 SPECIFIC AIMS

1) To compare the mean CP_{yt} % between the driver, 3 iron and 7 iron at the eight golf swing events for All Golfers (both Low Handicap Golfers and High Handicap Golfers).

2) To compare the mean CP_{yt} % between the driver, 3 iron and 7 iron at the eight golf swing events for the Low Handicap Golfers.

3) To compare the mean CP_{yt} % between the driver, 3 iron and 7 iron at the eight golf swing events for the High Handicap Golfers.

4) To compare the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the driver at the eight golf swing events.

5) To compare the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the 3 iron at the eight golf swing events.

6) To compare the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the 7 iron at the eight golf swing events.

7) To determine the interaction effect between the two handicap groups and three golf clubs at the eight golf swing events.

3.2.1 Hypotheses

Aim 1: Null Hypothesis

No significant difference in the mean CP_{yt} % between the driver, 3 iron and 7 iron at the eight golf swing events for All Golfers (both handicap groups).

Aim 2: Null Hypothesis

No significant difference in the mean CP_{yt} % between the driver, 3 iron and 7 iron at the eight golf swing events for the Low Handicap Golfers.

Aim 3: Null Hypothesis

No significant difference between the driver, 3 iron and 7 iron mean CP_{yt} % at the eight golf swing events for the High Handicap Golfers.

Aim 4: Null Hypothesis

No significant difference between the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the driver at the eight golf swing events.

Aim 5: Null Hypothesis

No significant difference between the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the 3 iron at the eight golf swing events.

Aim 6: Null Hypothesis

No significant difference between the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the 7 iron at the eight golf swing events.

Aim 7: Null Hypothesis

No significant interaction effect between the two handicap groups or the three golf clubs at the eight golf swing events.

CHAPTER 4

METHODS

4.1 SUBJECTS

Thirty-eight male golfers of varying ability participated in this study. All golfers were required to have a current Australian Golfers Union (AGU) handicap, which were used to classify them into either a Low Handicap group or a High Handicap group. The Low Handicap Golfers (-2 to 10 AGU handicap) consisted of 19 golfers (mean age = 29, SD = 13) and the High Handicap Golfers (11+ AGU handicap) consisted of 19 golfers (mean age = 42, SD = 14).

The male golfers were canvassed from Victorian golf clubs. Two of the Low Handicap Golfers were training professionals and one other was considered the best amateur golfer in the state, at the time of testing. Of the 38 golfers, 3 were left-handed and the remaining 35 golfers were right handed. The laboratory was set-up to allow for both left-handed and right-handed golfers.

4.2 TASK

4.2.1 Club Selection

The golf clubs selected for testing and analysis involved a long hitting wood (Driver), long hitting iron (3-iron) and a more lofted iron (7-iron). These clubs were selected so differences in weight transfer patterns could be examined when club characteristics change; e.g. loft, length. The club selection were the same as those used in previous weight transfer studies by Cooper *et al.* (1974), Williams and Cavanagh (1983) and Koenig *et al.* (1994).

4.2.2 Testing Procedure

The Testing session took place at the Victoria University Biomechanics Laboratory, Melbourne Australia. Upon arrival to the testing session, golfers were given a tour of the laboratory and the testing procedures were explained to them. Before the commencement of the testing session, the golfers were required to complete a consent form (Appendix 1). The testing session commenced once the golfers had adequately warmed up and were familiar with the hitting environment.

The researcher requested that each golfer bring their own golf clubs to the testing session (Driver, 3 iron and 7 iron). Additionally, golfers were asked to bring along and wear their normal golfing attire (golf shoes, glove, etc) for the testing session.

All golfers were required to perform ten golf swings with each golf club, hence a total of 30 golf swings required for the testing session. To eliminate club order effect a randomised club selection was performed for each golfer (e.g. ten shots with the 7 iron, followed by ten shots with the driver, then ten shots with the 3 iron, this sequence varied for each golfer). Ten trials were performed for each club to obtain an average weight transfer pattern of the golfer for the three golf clubs. The method of obtaining an average swing has been used extensively in the weight transfer literature (Williams and Cavanagh, 1983, 4 trials per condition; Richards *et al.,* 1985, 4 trials per condition; Wallace *et al.,* 1990, 10 trials; Koenig *et al.,* 1994, 7 trials; Barrentine *et al.,* 1994, 3 trials per condition). However, the number of trials required to obtain accurate and reliable force plate data for a golf swing is unclear. A study conducted by the researcher (Brown *et al.,* 2000) found that between five to ten trials were required to obtain an average CP profile for a beginner golfer. This study lead to the conclusion that ten trials would be performed to attain the average CP profile of each golfer in this study.

For every golf swing trial, the golfers were required to stand on two force plates. The two force plates were independent of the building and were placed in the ground so the surface level of the force plates was the same level as the floor. The two force plates were separate systems placed about 15cm apart, which enabled the golfer to place one foot on each plate. Artificial grass (similar to that used at driving ranges) was placed on the force plate surface. This allowed subjects to wear their golf shoes to simulate a typical driving range setting. Ceiling to floor nylon nets were hung about three metres away from the hitting area, which wrapped around both sides to stop the ball and ensure safety (figure 4.2.2).

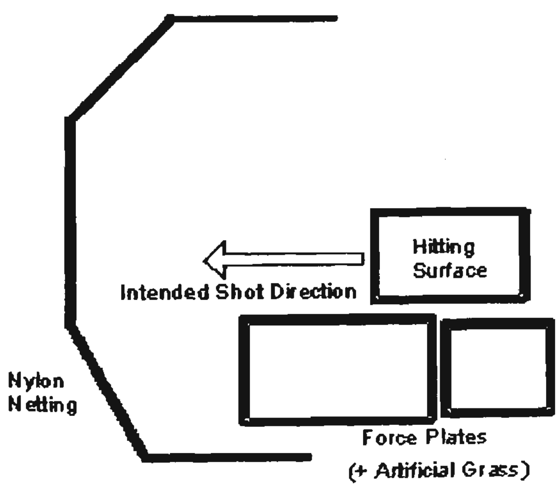


Figure 4.2.2: Force plates and surrounding nylon netting **(NB, set-up here was for a right-handed golfer)**

For each golf swing trial the ball was placed on a rubberised tee on a ProV swing analyser (Golftek Inc., Lewiston, Idaho). A selection of tee heights were provided for the golfers and they were able to choose the height that best suited their club. In most instances, the larger tees were used for the driver and the smaller tees for the 7 iron. Greg Norman Distance golf balls were used for each golf swing trail for all 38 golfers. The purpose of the ProV system was to provide the golfers with feedback on swing characteristics, but this data was not used in conjunction with weight transfer data.

Each golfer performed the 30 golf swing trials at their own pace and were requested to hit the ball as they normally would. The golfers were not given any feedback until the completion of the testing session. During the feedback session a short biomechanical assessment of the golfers swing took place. Analysis of video footage and ProV swing data was discussed in this session and each golfer was made aware that weight transfer data would be available to them at the completion of the study.

4.3 EXPERIMENTAL SET-UP

4.3.1 Force Plate

Two AMTI force plates OR6-5 (508mm x 464mm, FP 1) and LG6-4 (1200mm x 600mm, FP 2) were used to measure the GRF and moments. The force plate data was passed through an SGA6-4 (FP 1) and SGA6-3 (FP 2) AMTI amplifiers with a gain of 4000. Three dimensional forces and moments collected from the force plates were sampled via an AMLAB 16-bit ADC, at a rate of 500Hz.

A microphone located near the hitting area controlled force plate data sampling (figure 4.3.1). The sound of ball contact was detected by the microphone and activated force plate data sampling 2s prior to, and 1s after ball contact (total of 3s).

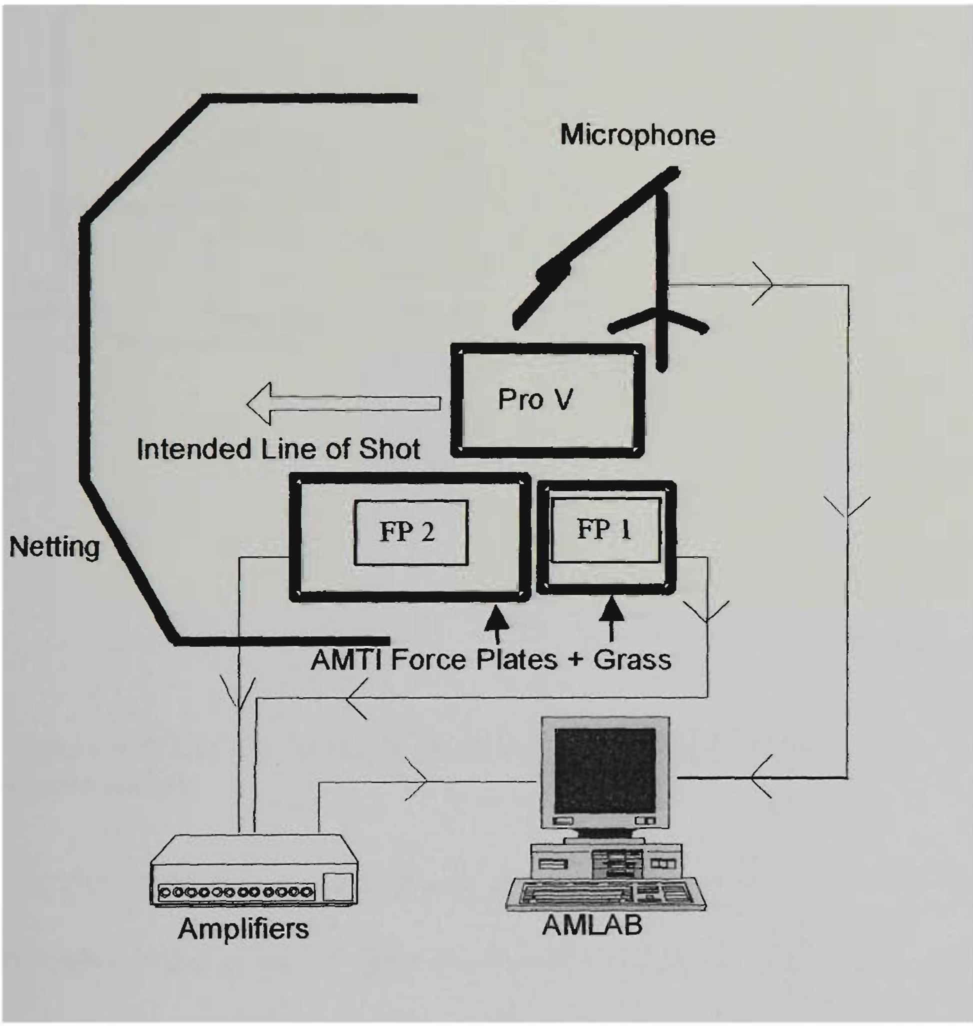


Figure 4.3.1: Force Plate set-up **(NB, set-up is for a right-handed golfer)**

4.3.2 Camera Set-Up

The camera set-up (figure 4.3.2.1) consisted of one 50Hz camera (Panasonic M15, overhead camera), a 200Hz High Speed Video camera (HSV, Peak Performance Technologies Inc., Englewood, California), two TV monitors, two VCR (for overhead and HSV cameras).

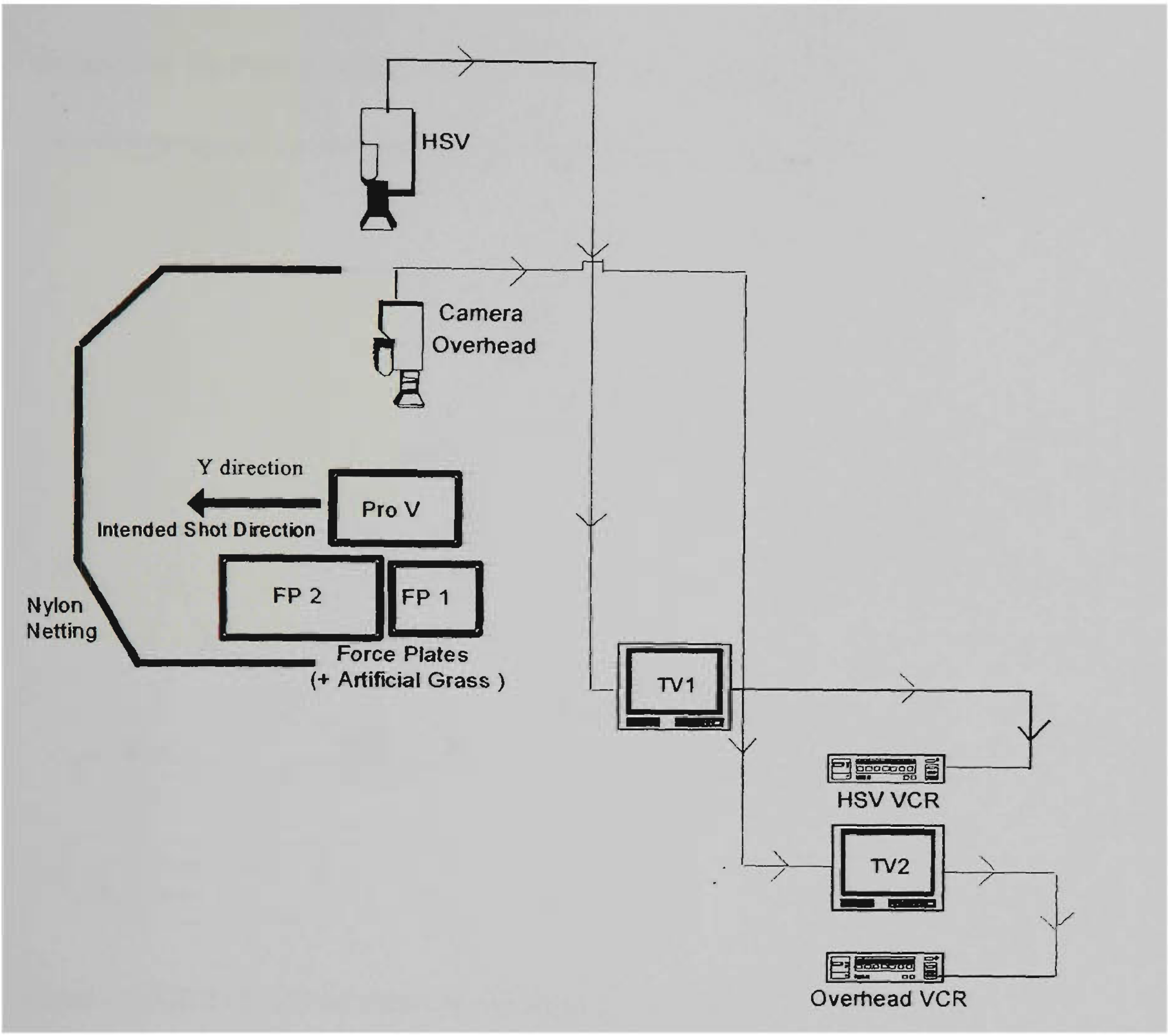


Figure 4.3.2.1: Camera set-up used in the testing session **(Note, set-up is for a right-handed golfer)**

The overhead camera (50Hz) was mounted in the roof of the laboratory approximately 4m above the ground. The overhead camera was positioned perpendicular to the intended shot direction and parallel with the AMTI force plate y direction (figure 4.3.2.2). The purpose of the overhead camera was to determine the position of the feet on the force plates. This footage was recorded on a VCR (Overhead VCR) and was later used to digitise the heel and toe position of both feet (see section 4.5.1). The overhead camera was offset so the position of the feet could be seen past the upper body. The offset nature of the overhead image gave the impression that a same sized object further away from the camera looks similar. This affected the horizontal coordinates of the toe and heels and some values needed to be decreased or increased depending on their position on the screen. The offset problem was overcome with the use of a perspective correction calculation performed by Ball (2001, Appendix 2B).

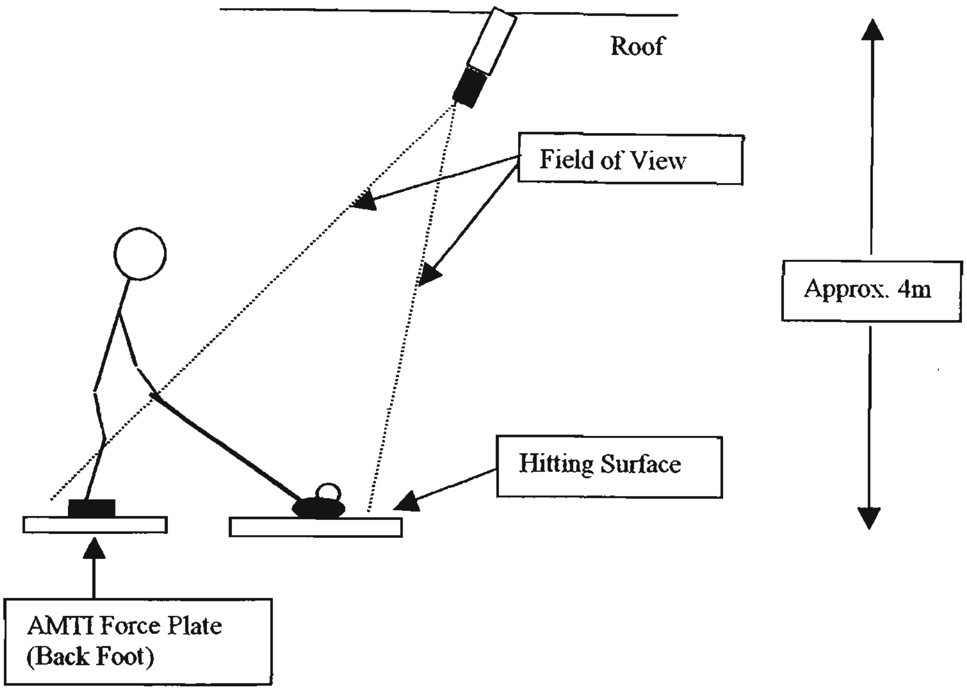


Figure 4.3.2.2: Field of view of the overhead camera

The HSV camera was placed perpendicular to the line of shot and the image of this footage was displayed on TV1. The purpose of this footage was to obtain temporal information for specific events of the swing (see section 4.5.2). Previous studies have made use of HSV (Cooper *et al.*, 1974; Williams and Cavanagh, 1983; Barrentine *et al.*, 1994) due to the explosive nature of the golf swing and Cooper *et al.* (1974) suggests that 1000Hz cameras are more appropriate but this type of equipment was not available for this study. A pilot study was conducted to compare the precision of a 50Hz camera and the 200Hz camera. Quantitative assessment of the 50Hz and the 200Hz video footage suggested that the high-speed footage was far more precise in gaining temporal data for the events of the golf swing. The complete laboratory set-up is displayed in figure 4.3.2.3 showing the major pieces of equipment utilised.

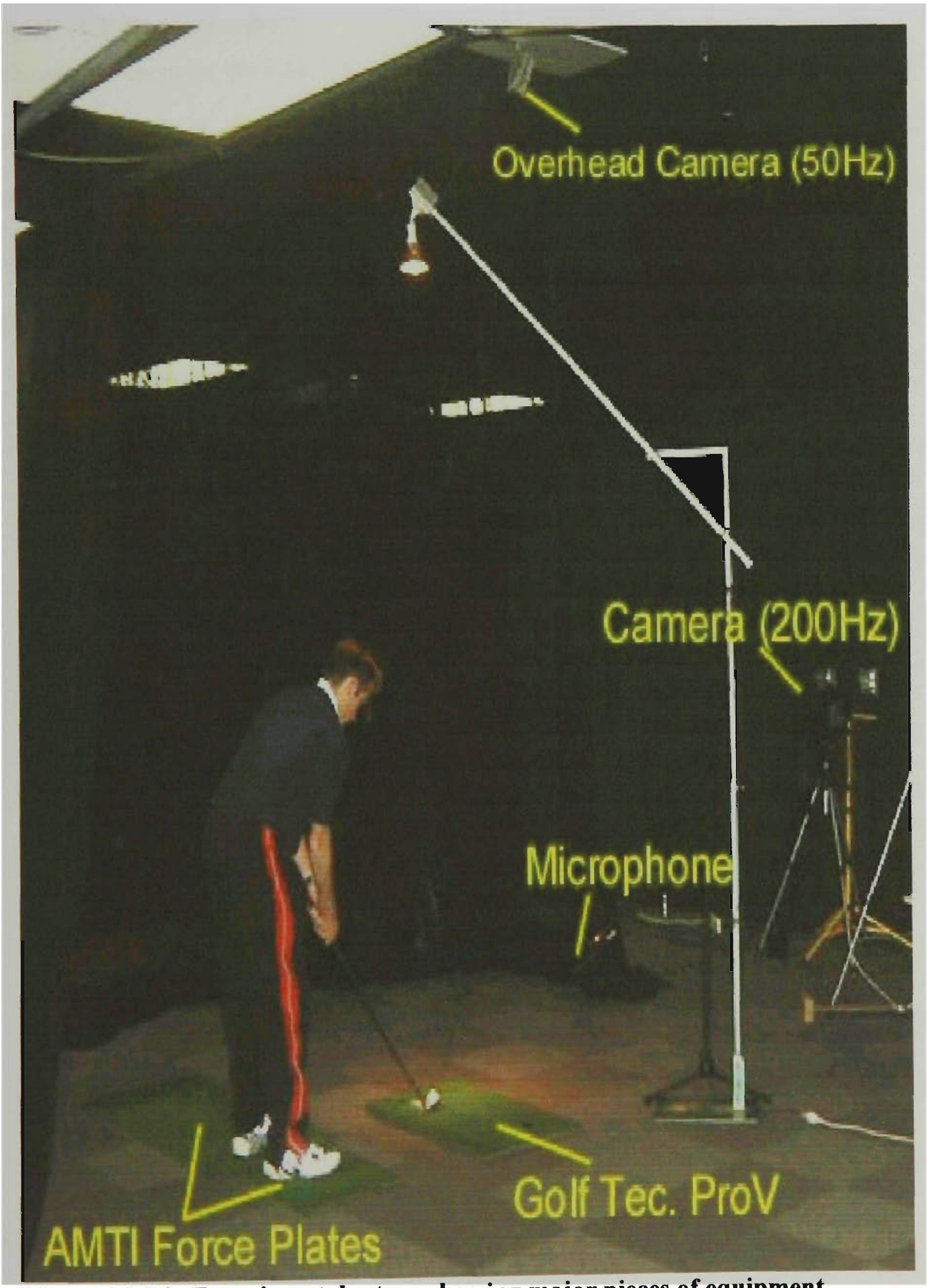


Figure 4.3.2.3: Experimental set-up showing major pieces of equipment

4.4 PARAMETERS

4.4.1 CP Displacement

Force and moment data sampled from the two AMTI force plates were used to calculate CP displacement. The AMTI force plates measures three force components along the X, Y and Z axes and three moment components about the X, Y and Z axes (figure 4.4.1, table 4.4.1a and 4.4.1b). A total of twelve force and moment channels were sampled (six for each force plate). However, not all force plate channels were required to calculate CP displacement but the definition of all forces and moments are required to understand how CP is calculated.

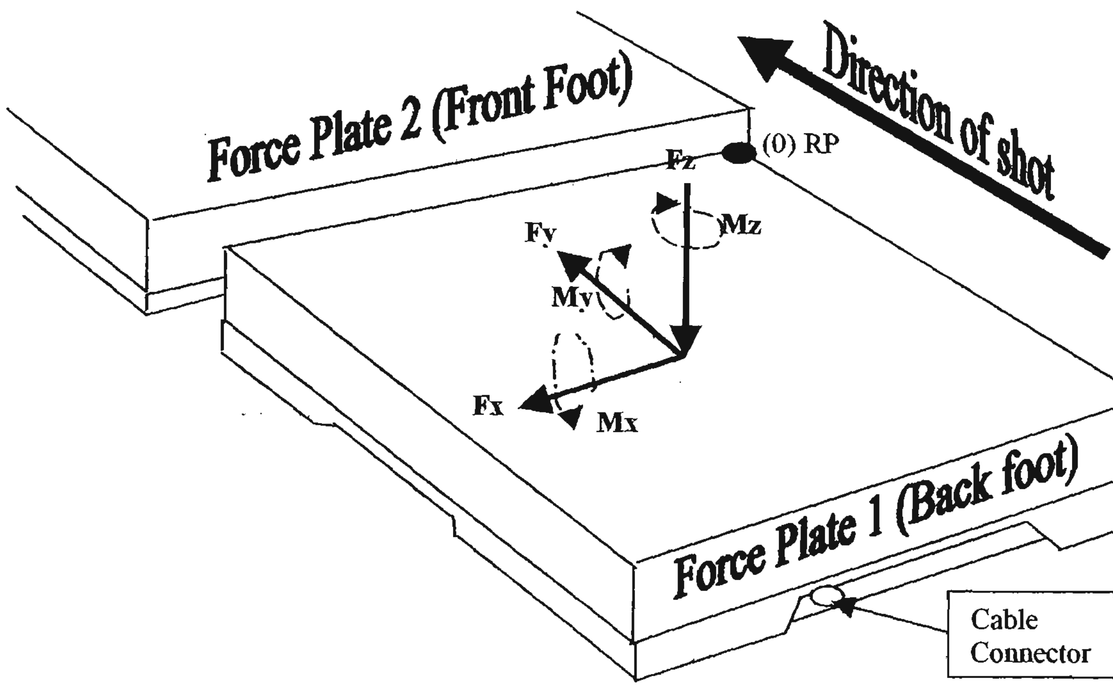


Figure 4.4.1: Forces and Moments measured by the AMTI force plates (direction of arrows indicate positive axes)

Table 4.4.1a: Forces sampled from the two AMTI force plates

Force Plate	Force direction	Abbreviation	Movement relative to target
1	Anterior/Posterior	F_{x1}	Perpendicular
1	Medial/Lateral	F_{y1}	Parallel
1	Vertical	F_{z1}	Perpendicular
2	Anterior/Posterior	F_{x2}	Perpendicular
2	Medial/Lateral	F_{y2}	Parallel
2	Vertical	F_{z2}	Perpendicular

Table 4.4.1b: Moments sampled from the two AMTI force plate

Force Plate	Measured about which axes	Abbreviation
1	F_{x1}	M_{x1}
1	F_{y1}	M_{y1}
1	F_{z1}	M_{z1}
2	F_{x2}	M_{x2}
2	F_{y2}	M_{y2}
2	F_{z2}	M_{z2}

CP displacement was measured in the medial/lateral direction, which is a CP movement parallel to the line of shot. CP movement in this plane is referred to as CP_y. CP_y was calculated for both individual force plates using the following equations, specified by AMTI.

FP 1

$$CP_{y1} = \left[\frac{(M_{x1} - (Z_{o1} \times F_{y1}))}{F_{z1}}\right]$$

FP 2

$$CP_{y2} = \left[\frac{(M_{x2} - (Z_{o2} \times F_{y2}))}{F_{z2}}\right]$$

Where,
$Z_{o1} = 0.067$

$Z_{o2} = 0.085$

Z_{o1} and Z_{o2} were known value specified by AMTI. These values are vertical distances from the transducers of the force plate to the contact surface of the force plate. The Z_{o1} and Z_{o2} values were a combination of force plate and the artificial grass and are defined above for each force plate.

CP_{y1} and CP_{y2} were calculated relative to the centre of each individual force plate (global reference). Both CP_{y1} and CP_{y2} were then transformed to be calculated relative to the front corner of force plate 1 (reference point, RP depicted in figure 4.4.1 via a black dot and RP 0,0). Once transformed, CP_{y1} and CP_{y2} were then used to calculate the combined CP between feet (CP_{yt}) using the following equation.

$$CP_{yt} = \left[\frac{(F_{z1} \times CP_{y1}) + (F_{z2} \times CP_{y2})}{F_{z1} + F_{z2}} \right]$$

$CP_{y1,2}$ and CP_{yt} were expressed in (m), but CP_{yt} was later converted to a percentage of CP movement relative to the feet (see section 4.5.1). CP_{yt} percentages were determined at eight events of the golf swing (see section 4.5.2)

4.4.2 Data Smoothing

The force plate data obtained from the 38 golfers was used in conjunction with two other studies to examine different parameters of the GRF during the golf swing. The other studies included differentiation to calculate CP velocity and hence smoothing of the raw data was deemed necessary. The method used to smooth the force plate data was the same for all three studies and this procedure was conducted by Ball (2001, Appendix 2C) and below a summary of this process is presented.

After the force plate data was amplified it was passed through a 16.4 Hz pre filter. This cut-off frequency was determined via spectral analyses of force, moment and CP data. Ball (2001) suggested no signal above 16.4 Hz was associated with the golf swing. This data was then used to calculate CP_{y1}, CP_{y2} and CP_{yt}. CP displacement values were then smoothed with a 15Hz Butterworth filter as detailed by Ball (2001), this was determined by using four methods.

1. Automatic methods for determining optimal smoothing frequency.
2. Spectral analysis
3. The effect of different smoothing cut-off frequencies on parameters of interest.
4. Observation of raw and smoothed displacement curves

4.5 DATA ANALYSIS

4.5.1 CP movement relative to the feet

The overhead camera described in the laboratory set-up (figure 4.3.2.2) was used for the purpose of determining the position of the feet on the force plates so CP_{yt} could be expressed relative to the feet. The camera was placed in a generic position and the view catered for all golfers' stance and set-up positions. The overhead footage was digitised on PEAK Motus, motion analysis software.

Using PEAK Motus the toe and heel position of the left and right foot at AD, along with the corner of FP 1 (RP figure 4.4.1) were digitised to determine the x coordinates for these points (figure 4.5.1.1). The average distance between the toe and the heel was calculated to determine the mid-point of the foot at AD. The mid-point of the foot remained a fixed position throughout the whole swing and the CP_{yt} movement was made relative to this position. The corner of FP 1 (RP) was digitised to provide a reference of alignment between the force plate data and the foot data.

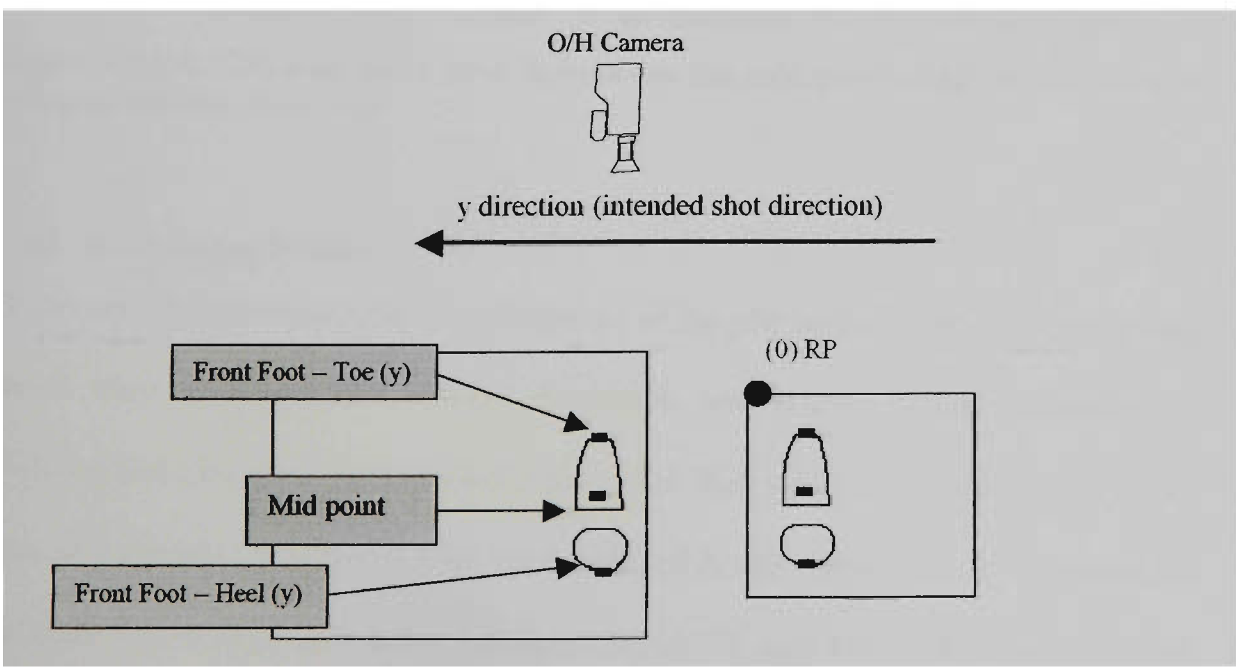
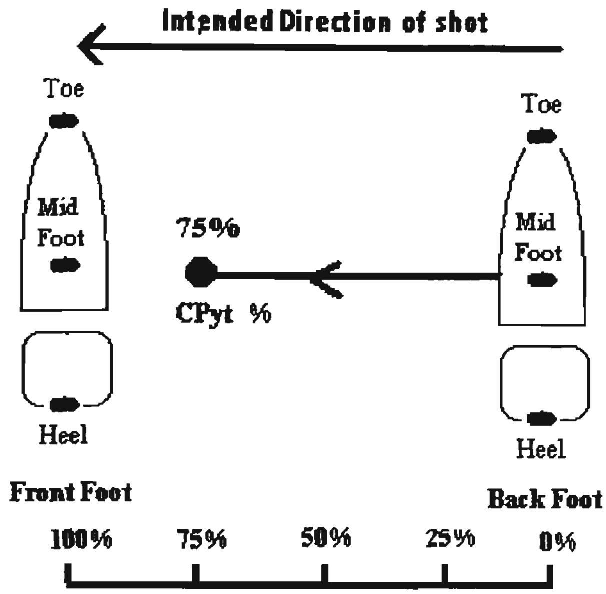


Figure 4.5.1.1: Digitised position of the toe and heel for the front and back foot and RP digitised position

CP_{yt} displacement was expressed as a percentage (CP_{yt} %) between the average distance of the left toe to heel (defined as mid foot), to the average distance of the right toe to heel (defined as mid foot). The movement of CP occurred between the front and back feet (parallel to the line of shot). When CP was placed completely on the front foot then CP_{yt} % equalled 100%. Conversely if CP was placed completely on the back foot then CP_{yt} % equalled 0%. Figure 4.5.1.2 illustrates how CP_{yt} % may be displaced between the feet at MD.



Example of CP_{yt} % at MD. CP was displaced 75% from the back foot.

Figure 4.5.1.2: CP_{yt} expressed as a % between the mid-point of the front foot and mid-point of the back foot

4.5.2 Golf Swing Events

CP_{yt} % was examined at eight specific events of the golf swing. The eight golf swing events were selected from previous kinematic and kinetic studies conducted by Williams and Cavanagh (1983); McLaughlin and Best (1994); Wallace *et, al.* (1994). Two new events (LB and ED) have been included in this study because the researcher felt there was a large time delay between MB to TB, and TB to MD. As such, this study will provide a more thorough examination of the CP movement than previous studies. Table 4.5.2 describes the golf swing events while figure 4.5.2 illustrates the golf swing events.

Table 4.5.2: Events used for analysis along with abbreviations and definitions

Event	Abbreviation	Description
Address*	AD	The clubhead and golfer is stationary. This event occurs immediately prior to TA.
Take Away	TA	The first backward movement of the clubhead to initiate the swing.
Mid-Backswing	MB	The club shaft is parallel with the horizontal plane in the backswing phase.
Late Backswing	LB	The club shaft is perpendicular to the horizontal plane in the vertical Y, Z plane during the backswing phase.
Top of Backswing	TB	The clubhead reaches its furthest point in the backswing, prior to the commencement of the downswing.
Early Downswing	ED	The club shaft is perpendicular to the horizontal plane in the vertical Y, Z plane during the downswing phase
Mid-Downswing	MD	The club shaft is parallel to the horizontal plane in the downswing phase.
Ball Contact	BC	Contact is made between the club head and the ball.
Mid-Follow Through	MF	The club shaft is parallel to the horizontal plane during the follow-through phase.

*This event was not used for analysis of CP displacement. It was only used to define the address position of the heels and toe so the CP_{yt} % could be calculated relative to this position.

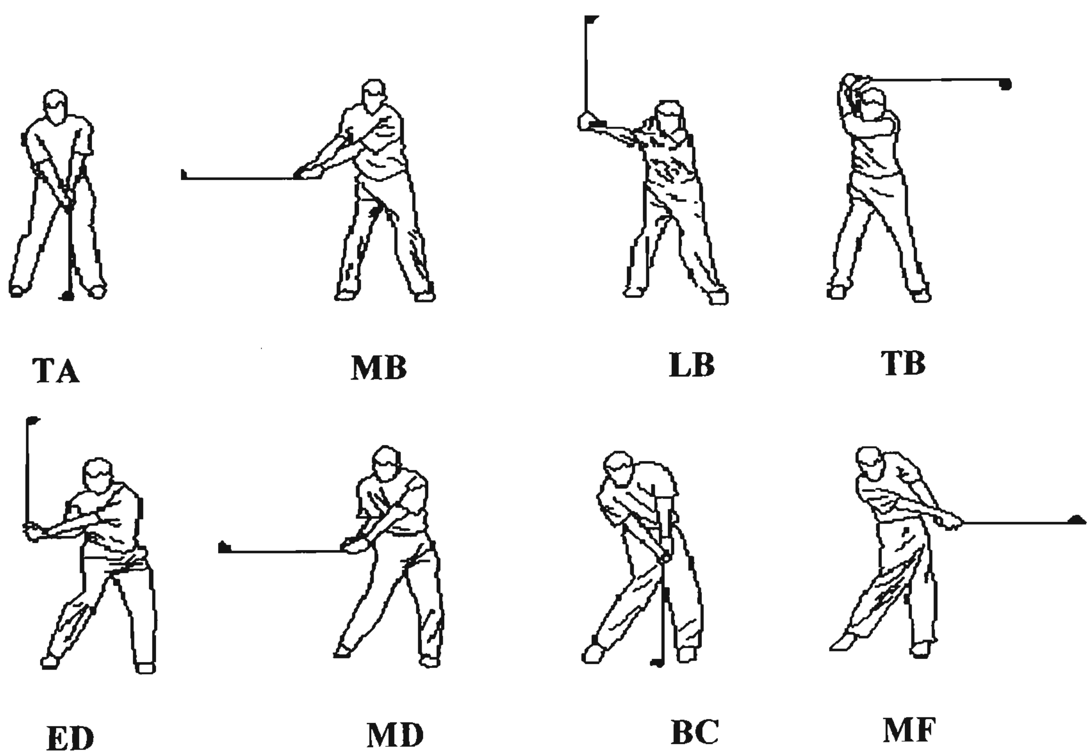


Figure 4.5.2: The eight golf swing events used for analysis

4.6 STATISTICAL ANALYSIS

Mean CP_{yt} % and standard deviation (SD) were calculated for the eight golf swing events for the driver, 3 iron and 7 iron. The mean CP_{yt} % for each golfer was combined with the golfers in the same handicap group. From this data a mean CP_{yt} % value and SD was determined for the Low Handicap Golfers and High Handicap Golfers at the eight golf swing events for the three golf clubs. A list of the independent and dependent variables are detailed below.

Independent Variables:

- Handicap group (two levels)
    1. Low Handicap
    2. High Handicap
- Clubs (three levels)
    1. Driver
    2. 3 iron
    3. 7 iron
- Events
    1. TA
    2. MB
    3. LB
    4. TB
    5. ED
    6. MD
    7. BC
    8. MF

Dependent Variable:

- CP_{yt} %

SPSS software (version 10) was used to perform 8 repeated-measure, split plot analysis of variance (SPANOVA). The SPANOVA is described by *SPSS* as an ANOVA with numerous within and between subject factors. This statistical procedure was implemented instead of a MANOVA because it allowed the variables to be analysed specifically within their independent groups. Huberty and Morris (1989) suggest that multiple ANOVA design was more appropriate than a MANOVA for statistical designs that are interested in finding how treatment variables affect each of the outcome variables. The treatment variables in this case are the handicap groups and clubs, while the outcome variable was the CP_{yt} %.

Each of the eight SPANOVA's consists of a 3x2 (clubs x handicaps) factorial design. That was, the first independent variable (Clubs) is within subject (repeated measure) in nature and has three levels, while, the second independent variable (Handicap groups), is a between subject (not repeated measure) factor with two levels (figure 4.6.1). In addition to the SPANOVA, a repeated measure ANOVA was conducted between the driver, 3 iron and 7 iron at each event for All Golfers (Low Handicap Golfers and High Handicap Golfers combination n=38, grey area of figure 4.6.1).

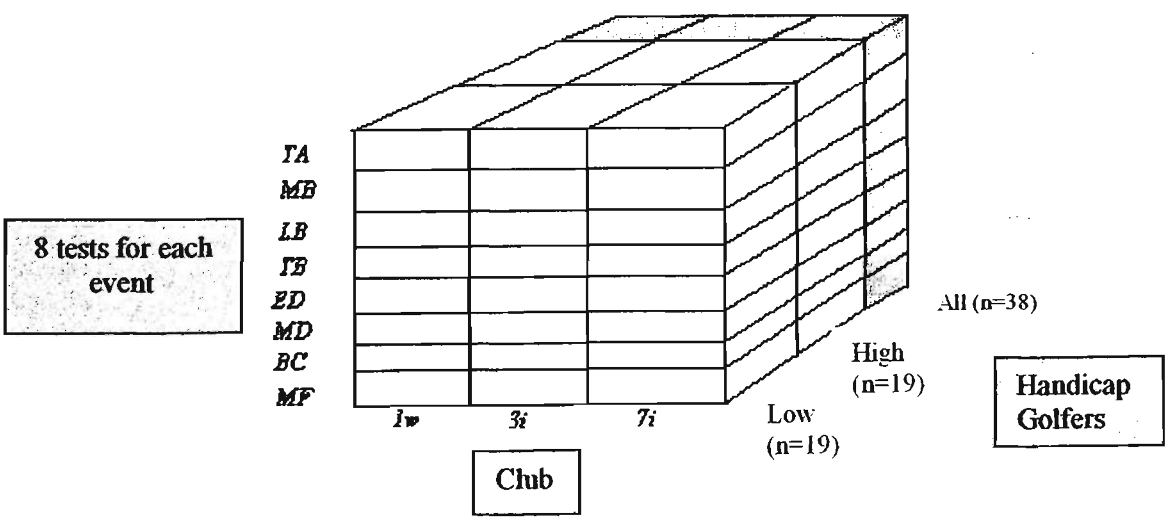


Figure 4.6.1: SPANOVA design employed to analyse the dependent variable (CP_{yt} %)

There were five assumptions underlying the SPANOVA. All five of these assumptions were tested and the following recommendations were made by *SPSS* if the assumptions were violated.

1. Random Selection – Subjects were randomly sampled from the golfing population.
2. Normality – *SPSS* suggests that each population score should have a normal distribution. This assumption was examined by visual inspection of the data and also Shapiro-Wilks test of normality.
3. Homogeneity of Variance – *SPSS* recommends that the population scores should have homogeneous variances. This was examined with Levene's test of equal variance between the groups. If the F ratio was greater than 3 then the assumption had been violated. If this test was violated then a more conservative alpha level must be used.
4. Sphericity – *SPSS* suggests that the variance of the population scores for any two groups should be the same as the variance of any other two population scores. This assumption was tested using Mauchly's test of sphericity. If this was violated (Mauchly's test is significant $p < .05$) then the Huynh-Feldt was used to assess the SPANOVA. *SPSS* uses the Huynh-Feldt method as part of the statistical procedure.
5. Homogeneity of Intercorrelations – This assumption is defined by *SPSS* as the intercorrelation among the various levels of repeated measures factors, which should be consistent from level-to-level of the between subject factors. This assumption is tested with the Box's M statistic. No recommendations are made by *SPSS* if this test is violated and in fact this test was not violated.

(N.B: For the repeated measure ANOVA assumptions 1 to 4 are followed)

The effect of type I and type II errors were considered when investigating the p value for the within (clubs), between (handicap groups) and interaction effect for each SPANOVA. All p values are reported for each test and a significant difference was evident when $p < .1$. This value has been selected over the traditional $p < .05$ conventions, for theoretical and statistical reasons. Firstly, small subject numbers in each group ($n = 19$). Franks and Huck (1986) recommend that less rigorous significant levels be set when there are limited sample size, as in this case. Secondly, previous weight transfer studies appear to neglect the chance of type II errors (Richards *et al.,* 1983; Wallace *et al.,* 1990; Koslow *et al.,* 1994; Barrentine *et al.* 1994; Kawashima *et al.,* 1994). This statistical procedure may have seen several studies disregard results because of stringent significance levels and small power.

In addition to the SPANOVA and repeated measure ANOVA, statistical power and effect size (η^2 = eta squared, also known as R^2) were examined. Speed and Anderson (2000) recommend the use and interpretation of effect size and power to support the significance levels provided by the parametric tests. The use of statistical power and effect size coupled with the $p < .1$ significance level will provide information on the degree of separation between the groups, the effect, and recommendations for further analysis. Cohen (1988) conventions were used to assess η^2 (small >.01, medium >.06, large >.14) and power (small >.3, medium >.5 and large >.8).

SPSS software (version 10) does not incorporate a post-hoc test for the SPANOVA. This posed a problem when the SPANOVA showed a significant main effect ($p < .1$) for the within or between subject effect. Therefore the following t-tests were conducted if a significant main effect was displayed;

Within subject effect *(golf club comparison)* = Paired samples t-test.

Between subject effect *(handicap comparison)* = Independent samples t-test.

For both the paired samples t-test and independent samples t-test, the effect of a type I errors was also monitored with the use of a bonferroni adjustment (also known as an error wise adjustment). Speed and Anderson (2000) recommend the use of this procedure when multiple tests are being conducted. This procedure was only conducted if a significant main effect was displayed. The bonferroni adjustments involved calculating a new alpha level, and in this case the new alpha level was set at $p = .03$, that is the number of tests (3) divided by the significance level set (.1). For example a significant post-hoc difference was only shown if $p < .03$. In addition to the post-hoc tests, the effect size (d) was calculated between the pairs to measure the effect of the means and Cohen's (1988) conventions were used to define a small ($d > .2$), medium ($d > .5$) and large ($d > .8$) effect size.

4.7 RELIABILITY OF THE CP_{yt} % CALCULATED AT THE EIGHT GOLF SWING EVENTS

There were three primary sources that contribute to the error associated with the CP_{yt} % at the eight golf swing events (figure 4.7). For each source, a number of potential factors influenced the validity and reliability of their measurement (table 4.7).

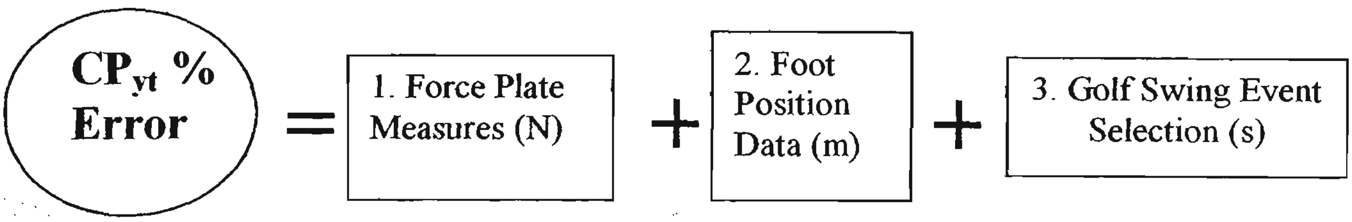


Figure 4.7: The three sources that contribute to the CP_{yt} % error at the eight golf swing events

Table 4.7: Potential factors that influence the error of each system

Source of Error	Validity	Reliability
Force Plate (N)	*1.* Sample rate of the force plate (500Hz). *2.* Accuracy of the 12 force plate channels. *3.* Force Plate distortion.	*1.* Consistency of the 12 force plate channels when sampling on separate occasions.
Foot Position Data (m)	*1.* Sample rate of the camera (50Hz). *2.* Position of the camera *3.* Accuracy of the digitised position of the toe and heels of the feet relative to the FP	*1.* Consistency of the tester at digitising the same toe and heel position of the feet on separate occasions.
Golf Swing Event Selection (s)	*1.* Sampling rate of the camera (200Hz). *2.* Accuracy of the tester at selecting the golf swing events.	*1.* Consistency of the tester at selecting the same golf swing event on separate occasions.

Calculating the validity and reliability of each system is not a difficult task. However, combining these systems to calculate the validity and reliability of the three systems (CP_{yt} %) is made difficult because each system measures different units. Additionally, no gold standard existed, which made it impossible to determine the validity of the complete system (CP_{yt} %). For these reasons, a reliability analysis was conducted to determine the consistency of the CP_{yt} % on separate occasion. The researcher hypothesized that the calculation of the digitised foot position data and the golf swing event selection provided the greatest sources of error due to the manual process involved in calculating these sources. The data obtained from the force plate was considered reliable and accurate because of the high resolution and minimal human error involved in the calculation of this source.

4.7.1 Aim

The objective of this investigation was to determine how reliable the tester was at calculating the CP_{yt} % at the eight golf swing events on two separate days for a single trial of a Low Handicap Golfer.

4.7.2 Method

A single driver trial for a young (age = 23) Low Handicap Golfer (AGU = 4) was used to calculate the CP_{yt} % at the eight golf swing events. The CP_{yt} % was calculated according to the procedures outlined in section 4.5.1 (digitised position of the feet) and section 4.5.2 (temporal information of the golf swing events). The CP_{yt} % at the eight golf swing events was determined on five separate occasions on day one and five separate occasions on day-two (NB: the force plate data does not change because the same trial is used). A mean CP_{yt} % for day one and day two was calculated and the change in the mean CP_{yt} % between these two days was used to assess the reliability of the tester at calculating the CP_{yt} % at the eight golf swing events. Hopkins (2000) methods of assess reliability was applied, which involved calculating the Total Error Measurement (TEM) to examine the typical error associated with the change in the mean from Day One to Day Two at the eight golf swing events. In addition to the TEM, the limits of agreement was reported, which represents the 95% likely range of differences between the two days and the upper limit of the TEM (TEM + limits of agreement).

4.7.3 Results

From Day One to Day Two an increase in the mean CP_{yt} % was displayed for all eight golf swing events (table 4.7.3). However, the change in the mean CP_{yt} % and TEM was small for all eight golf swing events (mean = 0.3%), which suggests that the tester is consistent at reproducing the CP_{yt} % from day one to day two. Events TA (0.5%) and MB (0.4%) exhibited the largest TEM for the eight golf swing events but considering the deviation was less than half a percent it was concluded that the error was minor. MB (1.3%) and MF (1.3%) displayed the largest TEM upper limit, while the mean TEM upper limit for the eight golf swing events was 1.1%. This suggests that significant mean CP_{yt} % differences of less than 1.1% for the golf club comparison or handicap comparison should be disregarded due to the error associated with the CP_{yt} % calculation for the eight golf swing events.

Table 4.7.3: Comparison between day 1 and 2 showing the reliability data for the change in the mean and the total error of measurement

Events	Day 1		Day 2		Change in the Mean	TEM		
	Mean	*SD*	*Mean*	*SD*	*%*	*%*	*Limits of agreement (%)*	*Upper Limit (%)*
TA	47.8	0.2	48.4	0.2	0.6	0.5	0.6	1.1
MB	19.2	0.3	19.6	0.2	0.4	0.4	0.9	1.3
LB	22.2	0.3	22.4	0.2	0.2	0.3	0.9	1.2
TB	23	0.2	23.3	0.2	0.3	0.3	0.6	0.9
ED	62.6	0.6	62.7	0.6	0.1	0.2	0.7	0.9
MD	79.9	0.3	80	0.3	0.1	0.3	0.7	1
BC	93.1	0.5	93.2	0.4	0.1	0.3	0.9	1.2
MF	95.7	0.5	95.9	0.4	0.2	0.3	1	1.3
Mean for the eight golf swing events					0.3	0.3	0.8	1.1

4.7.4 Conclusion

This analysis has showed that the tester can consistently reproduce to the CP_{yt} % on separate days for the same trial to 0.3% for the eight golf swing events. This indicates that the experimental procedures involved in calculating the CP_{yt} % at the eight golf swing events (temporal data, digitised feet position) is reliable. However, the TEM mean upper limit for all eight golf swing events indicates that a mean CP_{yt} % difference of less than 1.1% for the golf club comparison or handicap comparison should be treated with caution.

CHAPTER 5

RESULTS

5.1 GOLF CLUB COMPARISON

5.1.1 All Golfers

For the driver, 3 iron and 7 iron All Golfers (n = 38) initiated the golf swing (TA) with the mean CP_{yt}% at just larger than 50% (figure 5.1.1.1). From TA to MB, and MB to LB All Golfers exhibited a decrease in the mean CP_{yt} % (table 5.1.1.1), which lead to the majority of the weight, as indicated by the mean CP_{yt} % being placed on the back foot. The mean CP_{yt} % difference between the three golf clubs at MB and LB appears to be small. Following LB, the mean CP_{yt} % increased for the driver to TB, while the 3 iron and 7 iron maintain a similar mean CP_{yt} % between these events. At TB, All Golfers displayed a similar mean CP_{yt} % for all three golf clubs with just over 75% of the CP_{yt} % placed on the back foot. From TB, All Golfers displayed a large increase in the mean CP_{yt} % for the three golf clubs and at ED a small mean CP_{yt} % differences were evident between the three golf clubs. At ED, the largest mean CP_{yt} % was produced for the driver, while the 7 iron produced the smallest mean CP_{yt} %. Between ED to MD All Golfers mean CP_{yt} % continued to increase for all three golf clubs with the 7 iron displaying the largest increase during this phase, but producing the smallest mean CP_{yt} % at MD. From MD to BC All Golfers displayed a small increase in the mean CP_{yt} % and at BC the 3 iron displayed the largest mean CP_{yt} % and the driver produced the smallest mean CP_{yt} %. After BC, the driver displayed a larger decrease in the mean CP_{yt} % than the 3 iron, while the 7 iron maintained a similar mean CP_{yt} %. This resulted in the 7 iron producing the largest mean CP_{yt} % at MF and the driver exhihiting the smallest mean CP_{yt} %.

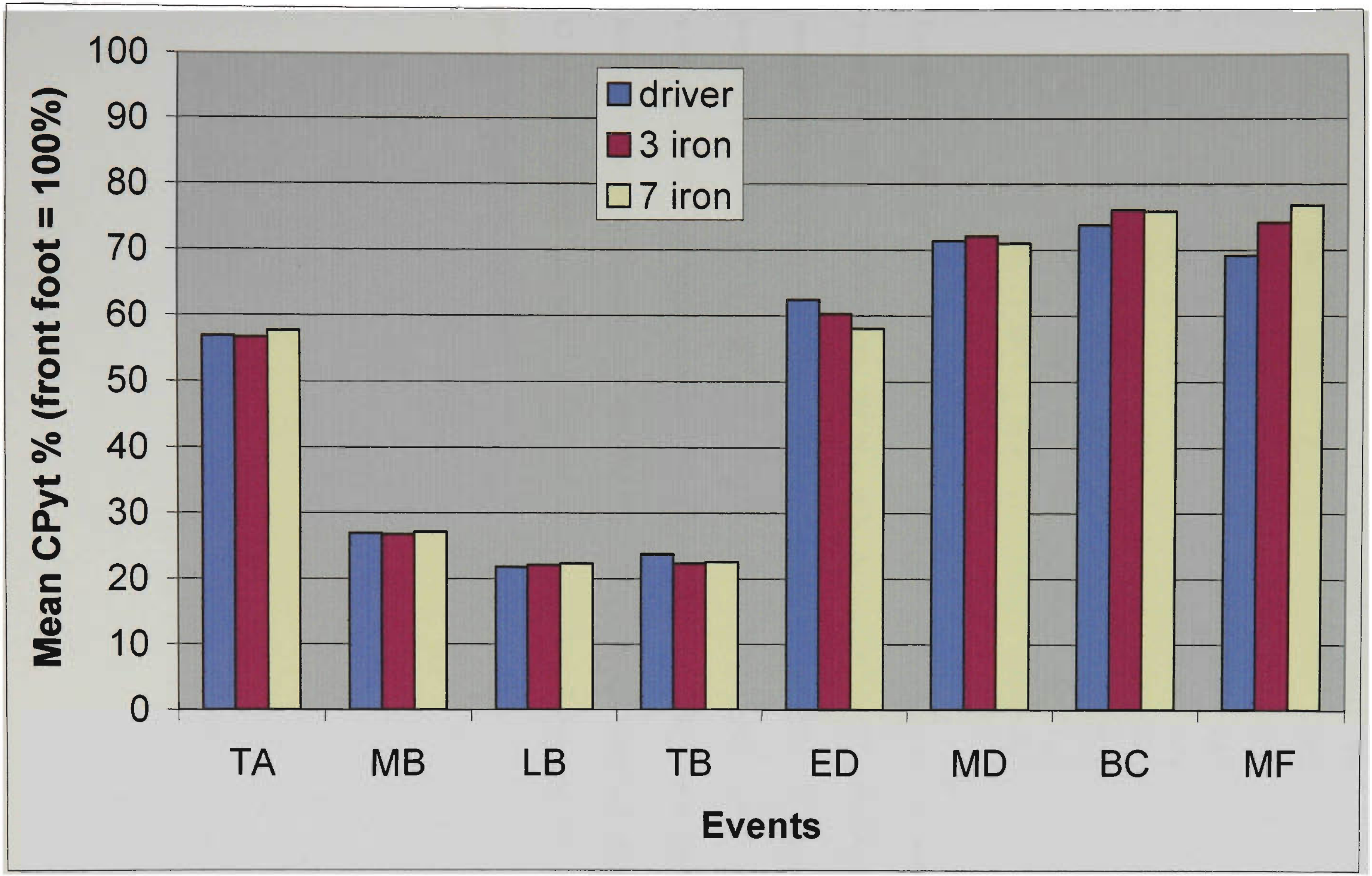


Figure 5.1.1.1: Mean CP_{yt} % for the three golf clubs at the eight golf swing events for All Golfers (n = 38)
N.B: Individual mean CP_{yt} % traces with SD bars for the driver, 3 iron and 7 iron are displayed in appendix 4A for this group.

Table 5.1.1.1: Mean CP_{yt} % and *SD* for the driver, 3 iron and 7 iron for All Golfers (n = 38)

Event	Driver		3 iron		7 iron	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
TA	56.9	*6.1*	56.8	*6.4*	57.7	*5.5*
MB	26.9	*10.1*	26.7	*9.9*	27.1	*9.6*
LB	21.8	*11.2*	22.1	*10.7*	22.3	*11.2*
TB	23.8	*12.2*	22.3	*11.9*	22.6	*12.6*
ED	62.5	*12.5*	60.3	*14.4*	58.1	*14.7*
MD	71.4	*11.3*	72.1	*11.3*	71.0	*11.8*
BC	73.8	*15.4*	76.1	*13.9*	75.8	*14.1*
MF	69.2	*20.0*	74.2	*17.9*	76.8	*16.4*

Events TB, ED, BC and MF displayed a significant main effect ($p < .1$) between the mean CP_{yt} % for All Golfers for the three golf clubs (table 5.1.1.2). Post-hoc analysis revealed that the driver and 3 iron were significantly different ($p < .03$) at all of these events (TB $p = .026$, ED $p = .021$, BC $p = .023$, MF $p = .001$) while the driver and 7 iron were also significantly different at ED ($p < .001$) and MF ($p < .001$). Furthermore, the 3 iron and 7 iron were significantly different at ED ($p < .002$). Comparison of the mean CP_{yt} % at TA, MB, LB, MD for All Golfers for the driver, 3 iron and 7 iron did not produce a significant main effect

Table 5.1.1.2: Club comparison for All Golfers (n = 38) at the eight golf swing events

Events	SPANOVA				Post-hoc paired samples t-test								
					Driver – 3 iron			Driver – 7 iron			3 iron - 7 iron		
	Sphericity Assumed	p	Effect Size (η^2)	Power	Mean CP_{yt} % difference	p	Effect Size (d)	Mean CP_{yt} % difference	p	Effect Size (d)	Mean CP_{yt} % difference	p	Effect Size (d)
TA	Yes	.387	.026	.319									
MB	Yes	.802	.006	.150									
LB	Yes	.734	.009	.170									
TB	No	.082*	.070	.606	1.5	**.026**	.124	1.2	.162	.098	-0.3	.563	.027
ED	No	.000*	.258	.995	2.2	**.021**	.175	4.4	**.000**	.352	2.2	**.002**	.153
MD	No	.330	.030	.324									
BC	No	.074*	.074	.622	-2.3	**.023**	.149	-2.0	.117	.133	0.2	.763	.017
MF	No	.000*	.281	.999	-5.0	**.001**	.248	-7.6	**.000**	.378	-2.6	.040	.145

*Significant at p < .1

Significant at p < .03 (Bonferroni adjustment)

5.1.2 Low Handicap Golfers

The Low Handicap Golfers (n = 19) displayed a similar mean CP_{yt} % pattern for the driver, 3 iron and 7 iron throughout the entire golf swing. Minor mean CP_{yt} % differences between the three golf clubs were displayed at ED, BC and MF (figure 5.1.2.1). The Low Handicap Golfers exhibited almost identical mean CP_{yt} % at TA, MB and LB for all three golf clubs (table 5.1.2.1). From LB to TB the Low Handicap Golfers displayed a small increase in the mean CP_{yt} % for the three golf clubs and at TB the driver and 7 iron exhibited a slightly larger mean CP_{yt} % than the 3 iron. The Low Handicap Golfers exhibited a large increase in the mean CP_{yt} % from TB to ED for all three golf clubs and at ED the Low Handicap Golfers displayed the largest mean CP_{yt} % for the driver and the smallest mean CP_{yt} % for the 7 iron. The increase in the mean CP_{yt} % continued from ED to MD and at MD a similar mean CP_{yt} % was displayed for the three golf clubs. The increase in the mean CP_{yt} % was small from MD to BC and resulted in the 3 iron and 7 iron producing a slightly larger mean CP_{yt} % than the driver at BC. MD. The Low Handicap Golfers displayed a decrease in the mean CP_{yt} % from BC to MF for the driver and 3 iron, while the 7 iron maintained a constant mean CP_{yt} % during this phase. This resulted in the driver exhibiting the smallest mean CP_{yt} % at MF, while the 7 iron displayed the largest.

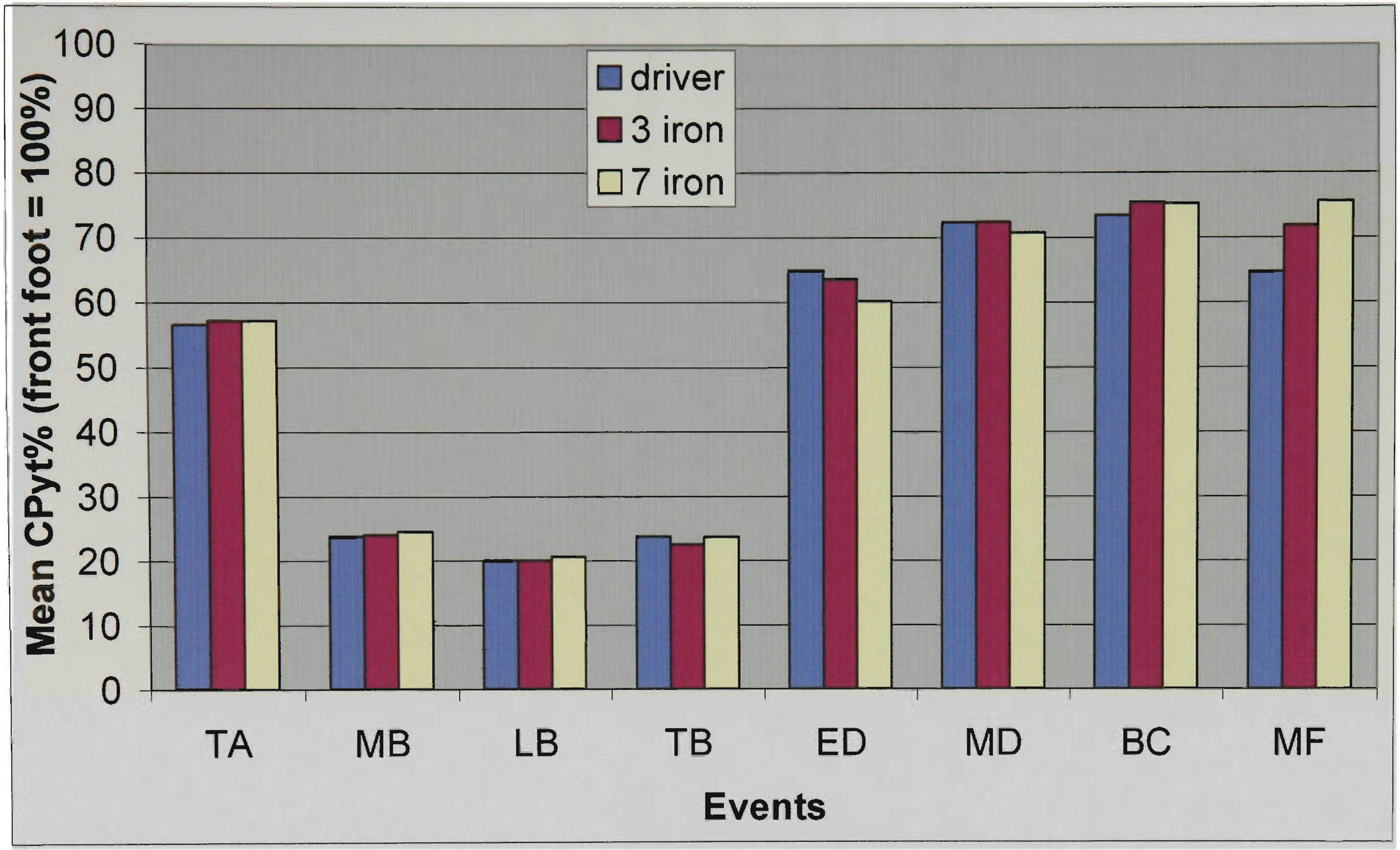


Figure 5.1.2.1: Mean CP_{yt} % for the three golf clubs at the eight golf swing events for the Low Handicap Golfers (n = 19)
N.B: Individual mean CP_{yt} % traces with SD bars for the driver, 3 iron and 7 iron are displayed in appendix 4B for this group.

Table 5.1.2.1: Mean CP_{yt} % and *SD* for the driver, 3 iron and 7 iron for the Low Handicap Golfers (n = 19)

Event	Driver		3 iron		7 iron	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
TA	56.6	*4.7*	57.2	*4.5*	57.2	*4.3*
MB	23.8	*8.0*	24.0	*7.7*	24.5	*8.1*
LB	20.0	*8.6*	20.1	*7.6*	20.6	*7.8*
TB	23.8	*10.4*	22.5	*11.0*	23.7	*11.9*
ED	65.0	*12.9*	63.6	*14.1*	60.2	*14.9*
MD	72.3	*11.9*	72.4	*12.5*	70.8	*13.1*
BC	73.4	*17.9*	75.4	*16.1*	75.2	*15.4*
MF	64.7	*21.5*	71.8	*18.7*	75.6	*15.6*

At ED and MF the Low Handicap Golfers produced a significant main effect ($p < .1$) between the three golf clubs mean CP_{yt} % (table 5.1.2.2). Post-hoc analysis showed that driver and 7 iron ($p = .002$) the 3 iron and 7 iron ($p = .001$) were significantly different ($p < .03$) at ED. Additionally, the driver and 3 iron ($p = .001$) the driver and 7 iron ($p = .001$) and 3 iron and 7 iron ($p = .025$) were significantly different at MF. For the other golf swing events (TA, MB, LB, TB, MD and BC) no significant main effect was displayed between the three golf clubs mean CP_{yt} %.

Table 5.1.2.2: Club comparison for the Low Handicap Golfers (n = 19) at the eight swing events

Event	SPANOVA				Post-hoc paired samples t-test								
					Driver – 3 iron			Driver – 7 iron			3 iron - 7 iron		
	Sphericity Assumed	p	Effect Size (η^2)	Power	Mean CP_{yt} % difference	p	Effect Size (d)	Mean CP_{yt} % difference	p	Effect Size (d)	Mean CP_{yt} % difference	p	Effect Size (d)
TA	Yes	.410	.048	.196									
MB	Yes	.520	.036	.153									
LB	Yes	.654	.023	.114									
TB	No	.246	.075	.291									
ED	No	<.001*	.383	.987	1.4	.109	.110	4.8	**.002**	.323	3.4	**.001**	.240
MD	No	.201	.085	.330									
BC	No	.387	.051	.206									
MF	No	<.001*	.452	.998	-7.2	**.001**	.335	-10.9	**.001**	.702	-3.7	**.025**	.201

*Significant at p < .1

Significant at p < .03 (Bonferroni adjustment)

5.1.3 High Handicap Golfers

The mean CP_{yt} % trace of the High Handicap Golfers (n = 19) for the driver, 3 iron and 7 iron from TA to LB followed a similar pattern (figure 5.1.3.1). At TA, MB, LB the High Handicap Golfers produced similar mean CP_{yt} % for all three golf clubs (table 5.1.3.1). Between LB to TB the High Handicap Golfers displayed an increase in the mean CP_{yt} % for the 3 iron and 7 iron, while the driver maintained a stable mean CP_{yt} % between these events. At TB a small mean CP_{yt} % difference was shown between the three golf clubs with the driver exhibiting the largest mean CP_{yt} % and the 7 iron displaying the smallest. From TB to ED the High Handicap Golfers displayed a large increase in the mean CP_{yt} % for all three golf clubs. At ED, the High Handicap Golfers displayed a larger mean CP_{yt} % for the driver, compared to the 3 iron and 7 iron. From ED to MD the High Handicap Golfers continued to increase the mean CP_{yt} % and at MD a larger mean CP_{yt} % was displayed for the 3 iron and 7 iron compared to the driver. A small increase in the mean CP_{yt} % was shown for all three golf clubs from MD to BC and at BC the driver exhibited the smallest mean CP_{yt} %, while the 3 iron and 7 iron produced a similar mean CP_{yt} %. After BC the High Handicap Golfers maintained a similar mean CP_{yt} % for the 3 iron and 7 iron till MF. While the driver displayed a small decrease in the mean CP_{yt} % from BC to MF, which resulted in the smallest mean CP_{yt} % for the driver compared to the 3 iron and 7 iron.

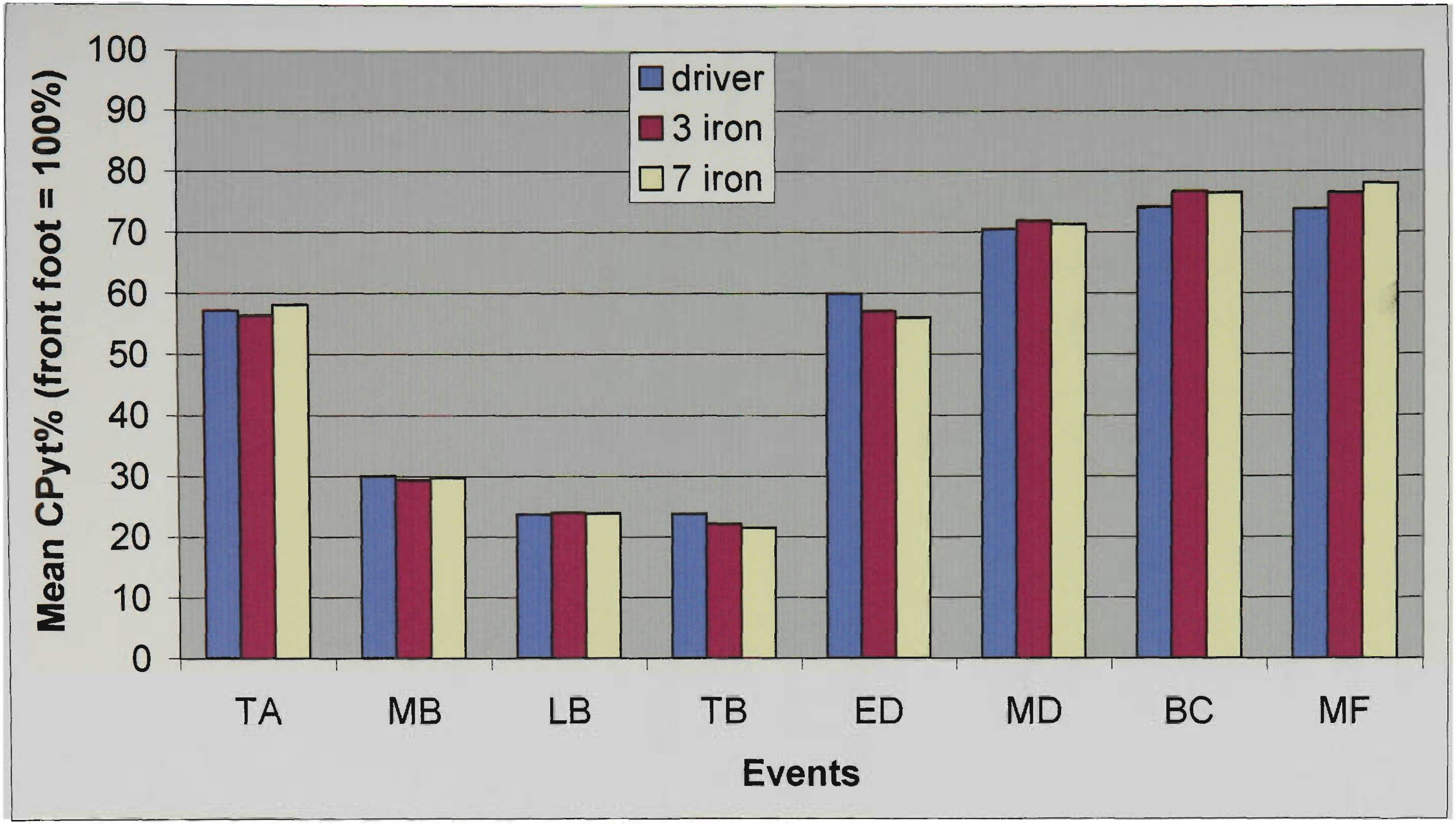


Figure 5.1.3.1: Mean CP_{yt} % for the three golf clubs at the eight golf swing events for the High Handicap Golfers (n = 19)
N.B: Individual mean CP_{yt} % traces with SD bars for the driver, 3 iron and 7 iron are displayed in appendix 4C for this group.

Table 5.1.3.1: Mean CP_{yt} % and *SD* for the driver, 3 iron and 7 iron for the High Handicap Golfers (n = 19)

Event	Driver		3 iron		7 iron	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
TA	57.2	*7.3*	56.4	*7.9*	58.1	*6.6*
MB	30.0	*11.0*	29.4	*11.2*	29.7	*10.6*
LB	23.7	*13.4*	24.0	*13.0*	23.9	*13.8*
TB	23.8	*14.1*	22.1	*13.1*	21.5	*13.5*
ED	60.0	*11.9*	57.1	*14.2*	56.0	*14.6*
MD	70.5	*10.8*	71.8	*10.4*	71.3	*10.8*
BC	74.1	*13.0*	76.7	*11.5*	76.4	*13.0*
MF	73.8	*17.8*	76.5	*17.3*	78.0	*17.6*

The golf club comparison for the High Handicap Golfers at ED has shown a significant main effect ($p < .1$) and the post-hoc analysis revealed that the driver and 7 iron were significantly different at this event ($p = .021$, table 5.1.3.2). The High Handicap Golfers did not display a significant main effect between the three golf clubs at the remaining seven golf swing events (TA, MB, LB, TB, MD and BC).

Table 5.1.3.2: Club comparison for the High Handicap Golfers (n = 19) at the eight swing events

Event	SPANOVA				Post-hoc paired samples t-test								
					Driver – 3 iron			Driver – 7 iron			3 iron - 7 iron		
	Sphericity Assumed	p	Effect Size (η^2)	Power	Mean CP_{yt} % difference	p	Effect size (d)	Mean CP_{yt} % difference	p	Effect size (d)	Mean CP_{yt} % difference	p	Effect size (d)
TA	Yes	.406	.049	.197									
MB	Yes	.852	.009	.073									
LB	Yes	.915	.005	.063									
TB	No	.104	.118	.455									
ED	No	.021*	.193	.713	3.0	.084	.249	4.0	**.021**	.335	1.0	.280	.072
MD	No	.454	.043	.177									
BC	No	.141	.103	.398									
MF	No	.131	.107	.411									

*Significant at p < .1

Significant at p < .03 (Bonferroni adjustment)

5.2 COMPARISON OF CP_{yt} % BETWEEN LOW HANDICAP GOLFERS AND HIGH HANDICAP GOLFERS

Examination of the within handicap group comparison between the golf clubs (section 5.1.2 and 5.1.3) displayed that the mean CP_{yt} % pattern for the Low Handicap Golfers and High Handicap Golfers was similar for the eight golf swings events for the three golf clubs.

5.2.1 Driver

The Low Handicap Golfers and High Handicap Golfers commence the golf swing (TA) with a similar mean CP_{yt} % for the driver (table 5.2.1.1). At MB and LB the Low Handicap Golfers produced a smaller mean CP_{yt} % than the High Handicap Golfers for this club. From LB to TB the Low Handicap Golfers exhibited a small increase in the mean CP_{yt} %, while the High Handicap Golfers maintain a similar mean CP_{yt} % between the events (figure 5.2.1.1). This resulted in a similar mean CP_{yt} % at TB between the two handicap groups. Following TB both handicap groups display a large increase in the mean CP_{yt} % and at ED a larger mean CP_{yt} % is exhibited by the Low Handicap Golfers for the driver compared to the High Handicap Golfers. From ED to BC both handicap groups displayed a small increase in the mean CP_{yt} % and at MD the Low Handicap Golfers displayed a slightly larger mean CP_{yt} %. Conversely, at BC the High Handicap golfers displayed a larger mean CP_{yt} %. From BC to MF the Low Handicap Golfers displayed a large decrease in the mean CP_{yt} %, resulting in a smaller mean CP_{yt} % at MF than the High Handicap Golfers.

Table 5.2.1.1: Mean CP_{yt} % for the Low Handicap Golfers and High Handicap Golfers for the driver at the eight golf swing events

Event	Low Handicap Golfers (n = 19)		High Handicap Golfers (n = 19)	
	Mean	*SD*	Mean	*SD*
TA	56.6	*4.8*	57.2	*7.3*
MB	23.8	*8.1*	30.0	*11.0*
LB	20.0	*8.6*	23.7	*13.4*
TB	23.8	*10.4*	23.8	*14.1*
ED	65.0	*12.9*	60.0	*11.9*
MD	72.3	*11.9*	70.5	*10.8*
BC	73.4	*17.9*	74.1	*13.0*
MF	64.7	*21.5*	73.8	*17.8*

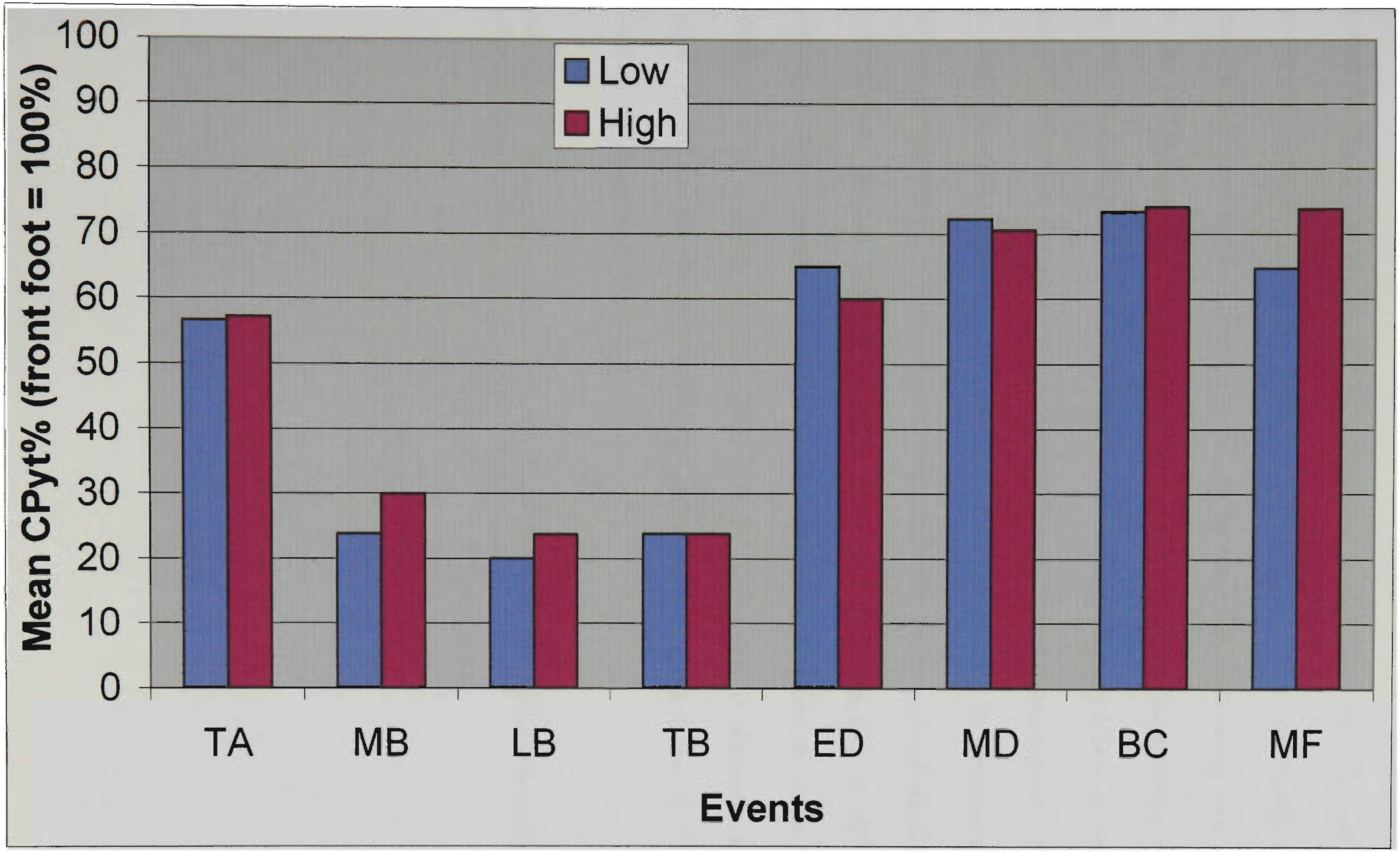


Figure 5.2.1: Mean CP_{yt} % for the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) at the eight golf swing events for the driver

5.2.2 3 iron

The mean CP_{yt} % trace displayed by the Low Handicap Golfers and High Handicap Golfers for the 3 iron (figure 5.2.2) was similar to the mean CP_{yt} % trace displayed between the handicap groups for the driver (figure 5.2.1). The Low Handicap Golfers handicap golfer exhibited smaller mean CP_{yt} % for two of the backswing events (MB and LB) but at TB the mean CP_{yt} % were almost identical between the handicap groups for the 3 iron (table 5.2.2.1). After TB, both handicap groups display a large increase in the mean CP_{yt} % and at ED the Low Handicap Golfers exhibited a larger mean CP_{yt} % than the High Handicap Golfers. The increase in the mean CP_{yt} % continues for both handicap groups during the early downswing and at MD the Low Handicap Golfers and High Handicap Golfers displayed a similar mean CP_{yt} %. From MD to MF the High Handicap Golfers display an increase in the mean CP_{yt} %, while the Low Handicap Golfers show an increase until BC, then after BC a decrease in the mean CP_{yt} % is evident. At BC and MF the High Handicap Golfers exhibit a larger mean CP_{yt} % than the Low Handicap Golfers for the 3 iron.

Table 5.2.2.1: Mean CP_{yt} % for the Low Handicap Golfers and High Handicap Golfers for the 3 iron at the eight golf swing events

Event	Low Handicap Golfers (n = 19)		High Handicap Golfers (n = 19)	
	Mean	*SD*	Mean	*SD*
TA	57.2	*4.5*	56.4	*7.9*
MB	24.0	*7.7*	29.4	*11.2*
LB	20.1	*7.6*	24.0	*13.0*
TB	22.5	*11.0*	22.1	*13.1*
ED	63.6	*14.1*	57.1	*14.2*
MD	72.4	*12.5*	71.8	*10.4*
BC	75.4	*16.1*	76.7	*11.5*
MF	71.8	*18.7*	76.5	*17.3*

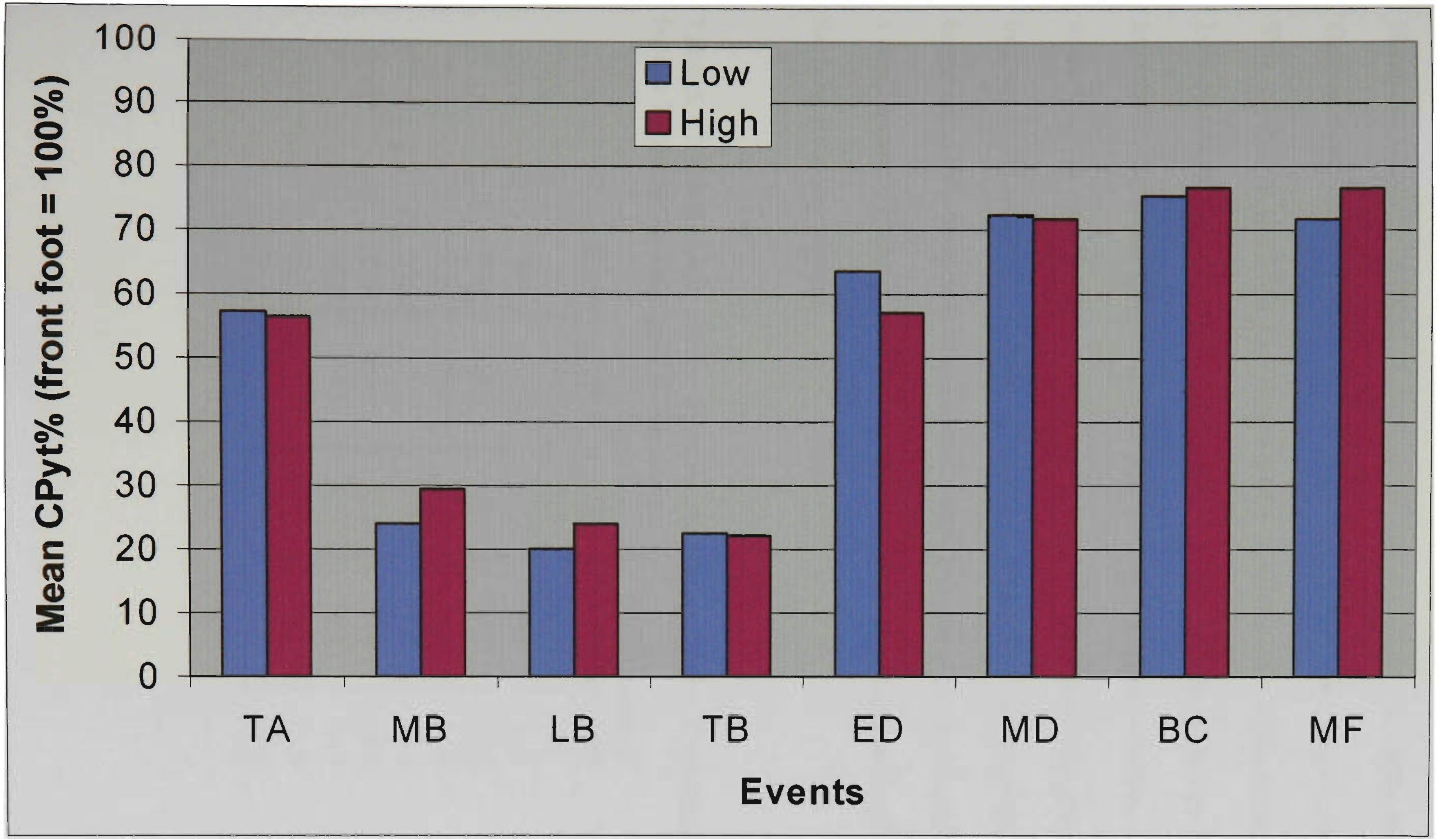


Figure 5.2.2: Mean CP_{yt} % for the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) at the eight golf swing events for the 3 iron

5.2.3 7 iron

The Low Handicap Golfers displayed a smaller mean CP_{yt} % at TA, MB and LB for the 7 iron compared to the High Handicap golfers (table 5.2.3.1). From LB to TB the Low Handicap Golfers exhibited an increase in the mean CP_{yt} %, while the High Handicap Golfers displayed a decrease in the mean CP_{yt} % between these events (figure 5.2.3). This resulted in the High Handicap Golfers exhibiting a smaller mean CP_{yt} % than the Low Handicap Golfers at TB. Following TB, both handicap groups displayed a large increase in the mean CP_{yt} % and at ED the Low Handicap Golfers exhibited a larger mean CP_{yt} % than the High Handicap Golfers. Both handicap groups displayed an increase in the mean CP_{yt} % from ED to BC, with the High Handicap Golfers producing a larger mean CP_{yt} % at both MD and BC. After BC, the High Handicap Golfers displayed a small increase in the mean CP_{yt} %, which resulted in a larger mean CP_{yt} % at MF than the Low Handicap Golfers.

Table 5.2.3.1: Mean CP_{yt} % for the Low Handicap Golfers High Handicap Golfers for the 7 iron at the eight golf swing events

Event	Low Handicap Golfers (n = 19)		High Handicap Golfers (n = 19)	
	Mean	*SD*	Mean	*SD*
TA	57.2	*4.3*	58.1	*6.6*
MB	24.5	*8.1*	29.7	*10.6*
LB	20.6	*7.8*	23.9	*13.8*
TB	23.7	*11.9*	21.5	*13.5*
ED	60.2	*14.9*	56.0	*14.6*
MD	70.8	*13.1*	71.3	*10.8*
BC	75.2	*15.4*	76.4	*13.0*
MF	75.6	*15.6*	78.0	*17.6*

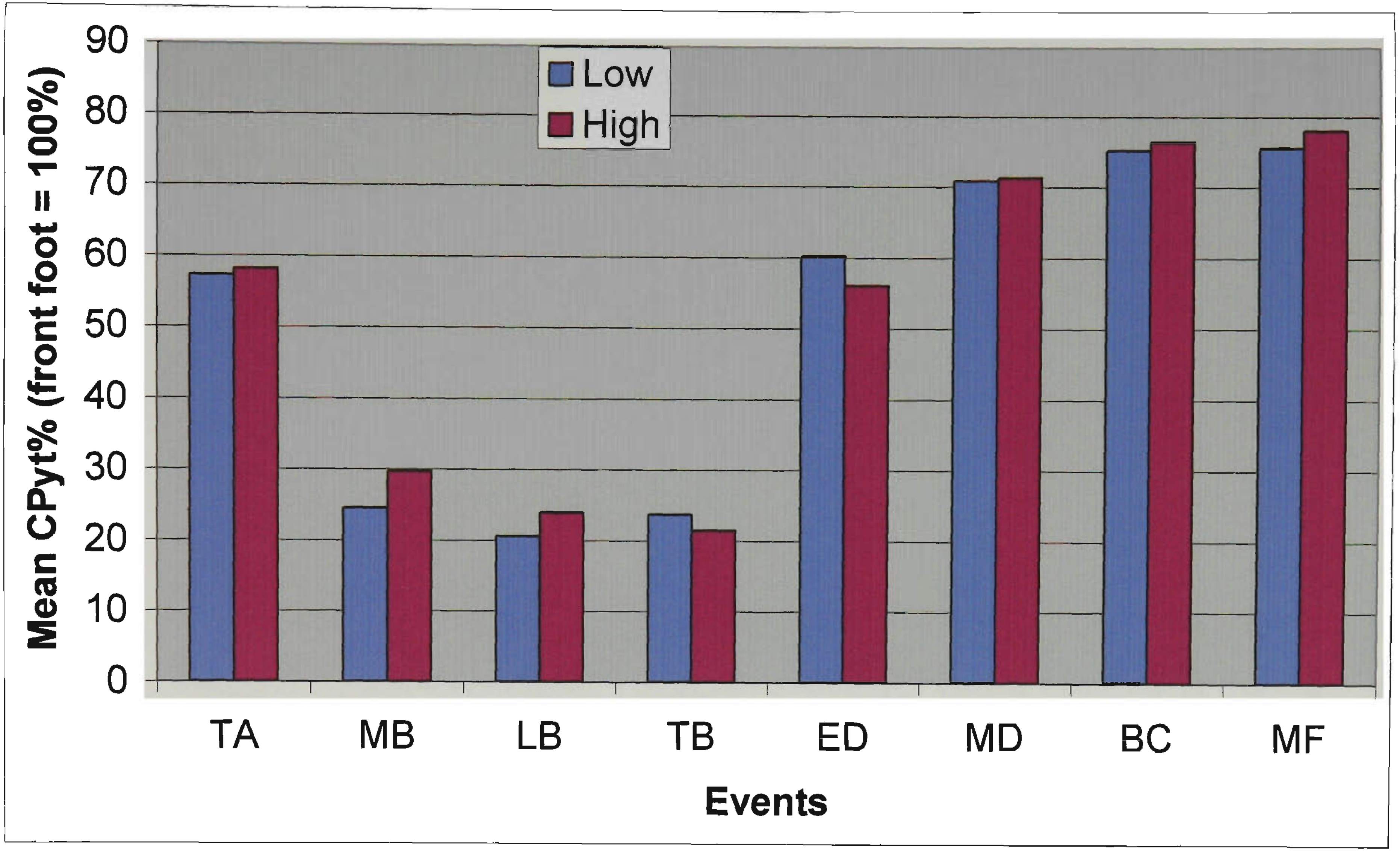


Figure 5.2.3: Mean CP_{yt} % for the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) at the eight golf swing events for the 7 iron

At MB the Low Handicap Golfers and High Handicap Golfers produced a significant main effect ($p = .070$) between the mean CP_{yt} % for the driver, 3 iron and 7 iron (table 5.2). Post-hoc analysis revealed no significant difference between the Low Handicap Golfers High Handicap Golfers for the three golf clubs at this event. For the remaining seven golf swing events (TA, LB, TB, ED, MD, BC and MF) no significant main effect were shown between the mean CP_{yt} % for the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the driver, 3 iron and 7 iron.

Table 5.2: SPANOVA results for the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) for the three clubs at the eight swing events and post-hoc test

Event	SPANOVA			Post-hoc independent samples t-test								
				Driver			3 iron			7 iron		
	P	Effect Size (η^2)	Power	Mean CP_{yt} % diff.	p	Effect Size (d)	Mean CP_{yt} % diff.	p	Effect Size (d)	Mean CP_{yt} % diff.	p	Effect Size (d)
TA	.884	.001	.104									
MB	.070*	.088	.575	-6.3	.053	.778	-5.4	.092	.703	-5.2	.098	.643
LB	.310	.029	.267									
TB	.835	.001	.107									
ED	.239	.038	.321									
MD	.855	.001	.106									
BC	.817	.002	.109									
MF	.347	.025	.244									

*Significant ($p < .1$)

Significant ($p < .03$) (Bionferroni adjustment)

5.3 INTERACTION EFFECT

MF was the only event to displayed a significant interaction effect ($p < .1$) between the Low Handicap Golfers and High Handicap Golfers for the driver, 3 iron and 7 iron (table 5.3). The remaining seven events (TA, MB, LB, TB, ED, MD and BC) did not provide a significant interaction effect between the handicap groups or golf clubs.

Table 5.3: Interaction effect between the Low Handicap Golfers High Handicap Golfers for the driver, 3 iron and 7 iron at the eight swing events

Event	p	Effect Size (η^2)	Power
TA	.419	.024	.301
MB	.686	.01	.186
LB	.84	.005	.139
TB	.256	.037	.383
ED	.383	.025	.293
MD	.265	.036	.372
BC	.920	.001	.111
MF	.075*	.072	.628

*Significant at $p < .1$

CHAPTER 6

DISCUSSION

6.1 GOLF CLUB COMPARISON

Table 6.1 is a summary of the findings for All Golfers (n = 38), the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) for the golf club comparison at the eight golf swing events. All Golfers provided seven significant differences between the three golf clubs at four of the eight golf swing events while the Low Handicap Golfers provided five and the High Handicap Golfers displayed one.

Table 6.1: Summary of the significant results for the golf club comparison within each group

	All Golfers (n = 38)			Low Handicap Golfers (n=19)			High Handicap Golfers (n=19)			
Events	D-3i	D-7i	3i-7i	D-3i	D-7i	3i-7i	D-3i	D-7i	3i-7i	Total
TA										0
MB										0
LB										0
TB	✓									1
ED	✓	✓	✓		✓	✓		✓		6
MD										0
BC	✓									1
MF	✓	✓		✓	✓	✓				5
Total	7			5			1			13

✓ denotes a significant difference (p < .03) between the clubs, NB. D = Driver, 3i = 3 iron, 7i = 7 iron

6.1.1 TA, MB and LB

All Golfers (n = 38), the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) displayed no significant difference between the three clubs at TA, MB and LB. In support of this finding was Koslow (1994) who reported no significant difference between the F_z distribution percentages for the driver and the 8 iron at AD for five beginner golfers who possessed a 'proper' weight transfer style. The golfers in Koslow's study produced a smaller F_z distribution for the driver, than the Low Handicap Golfers, High Handicap Golfers and All Golfers mean CP_{yt} % at TA (table 6.1.1.1). The different values displayed between the studies, at TA, maybe related to the playing ability and experience of the golfers tested. Koslow's golfers were inexperienced beginners (i.e. < 10 rounds of golf), while the golfers in this study are all experienced and all possess AGU handicaps.

Table 6.1.1.1: Comparison between the results displayed at TA for this study compared to Koslow (1994) results at AD for the driver

Event/Golfers	This Study		Koslow (1994)	
	TA		Beginner Golfers (n = 5) at AD	
	Mean	SD	Mean	SD
All Golfers (n = 38)	56.9	6.1	47.7	N/A
Low Handicap Golfers (n = 19)	56.6	4.8		
High Handicap Golfers (n = 19)	57.2	7.3		

NB: AD and TA are very similar events therefore comparison is appropriate between the studies.

Furthermore, Williams and Cavanagh (1983) and Koenig *et al.* (1994) were in support of low, mid and high handicap golfers producing similar weight transfer patterns for the driver, 3 iron and 7 iron during the backswing phase. The problem with these two studies is no data was report to support their claim or to provide a comparison between the studies.

At TA, MB and LB, the effect size (η^2) conventions ranged from less-than-small to small for all three groups (table 6.1.1.2). This resulted in a small power for each group at the three golf swing events and indicated that greater subject numbers are required within each handicap group to provide a significant main effect. The importance of a larger sample population is displayed at TA for All Golfers compared to the Low Handicap Golfers and High Handicap Golfers. At this event, All Golfers exhibit a smaller effect size (η^2) than the Low Handicap Golfers and High Handicap Golfers. However, the power displayed by All Golfers was larger than the Low Handicap Golfers and High Handicap Golfers. The reason for this statistical difference is that All Golfers had twice as many subject (n = 38) for the golf club analysis compared to the individual handicap groups (n = 19).

Table 6.1.1.2: Effect size and power data for the Low Handicap Golfer, High Handicap Golfer and All Golfers at TA, MB, LB

	All Golfers (n = 38)			Low Handicap Golfers (n = 19)			High Handicap Golfers (n = 19)		
Event	Effect Size (η^2)	Convention	Power	Effect Size (η^2)	Convention	Power	Effect Size (η^2)	Convention	Power
TA	.026	small	.319	.048	small	.196	.049	small	.197
MB	.006	< small	.150	.036	small	.153	.009	< small	.073
LB	.009	< small	.170	.023	small	.114	.005	< small	.063

Post-hoc power analysis was conducted using Cohen's (1988) power tables to determine the number of subjects required to obtain a larger power (0.8 at p = .01, table 6.1.4) if the effect size remained the same (η^2). For All Golfers and the High Handicap Golfers the n required at MB and LB was calculated because the effect size conventions were below small and this type of analysis would not be appropriate.

Table 6.1.1.3: n required in each group to provide a power of .8 for the main effect between the three golf clubs at TA, MB and LB for p = 0.1

Event	All Golfers (n = 38)	Low Handicap Golfers (n = 19)	High Handicap Golfers (n = 19)
TA	120	42	42
MB		64	
LB		250	

6.1.2 TB and BC

At TB, All Golfers were the only group to produce a significant main effect. Post-hoc examination revealed that the mean CP_{yt} % for the driver and 3 iron were significantly different (p = .026, table 6.1). For this group a larger mean CP_{yt} % was displayed for the driver (23.8%) compared to the 3 iron (22.3%). This established that more weight, as indicated by mean CP_{yt} %, was placed on the back foot for the 3 iron at TB compared to the driver. The mean CP_{yt} % difference between the driver and 3 iron, at TB, was relatively small (1.5%) and may not be considered a practical difference in the real world. What constitutes a practical difference is unknown. However, the researcher suspects a mean CP_{yt} % difference of 4% or greater would translate to a practical difference considering the SD is not too large.

A small effect size (d = .124) has been displayed between these two clubs, which indicates only a small mean separation has occurred and provides more uncertainty to the significance of this result. However, the number of subjects tested (n = 38) has influenced the significant difference by producing a medium power (.606). Examination of the previous literature may help in determining if the small significant mean CP_{yt} % difference displayed between the driver and 3 iron for All Golfers is appropriate.

Koslow (1994) contradicts the findings of this study by reporting no significant difference between the F_z distribution percentages for the driver (26.8%) and 8 iron (29.7%) at TB. Although, it may not be appropriate to compare this study with Koslow (1994) due to the different golf clubs used (i.e. driver and 3 iron, driver and 8 iron). Nevertheless, the smaller sample population investigated by Koslow (1994) may be the reason why no significant difference between the driver (n = 5) and the 8 iron (n = 8) were not reported at TB. No other between the feet weight transfer study has reported data specifically at TB between various golf clubs so comparison can not be made. Therefore a significant difference has been displayed between the driver and 3 iron but the importance of this difference in the real-world is uncertain.

Like TB, All Golfers were the only group to provide a significant main effect at BC between the three golf clubs. The driver and the 3 iron were again significantly different at this event (table 6.1, p = .023). For All Golfers the 3 iron (76.1%) exhibited a larger mean CP_{yt} % than the driver (73.8%) at BC indicating more weight is placed towards the front foot for the 3 iron. The mean CP_{yt} % displayed by both of these clubs was similar to that reported by Cooper *et al.* (1974) who showed that the approximate F_z distribution between the feet for the driver, 3 iron and 7 iron was 75:25 (front foot:back foot). Cooper *et al.* did not perform any statistical comparisons between the clubs, so the significance of this finding can not be substantiated with previous literature.

The mean CP_{yt} % difference exhibited by All Golfers between the driver and 3 iron, at BC, was not large (2.3%), which resulted in a small effect size (d = .149). However, due to the large sample population for the All Golfers group (n = 38) a medium power was displayed (.622). Previous studies (Williams and Cavanagh, 1983; Koenig *et al.,* 1994; Koslow, 1994) may not have displayed significant differences for the golfers weight transfer patterns for various golf clubs at BC because of small sample populations.

For the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) no significant main effect was evident at TB or BC (table 6.1). Comparison of the effect size data and power between All Golfers and the individual handicap groups (Low Handicap Golfers and High Handicap Golfers) at TB and BC provides a statistical reason as to why this occurred. For TB and BC the Low Handicap Golfers and High Handicap Golfers displayed a larger effect size than All Golfers (except for Low Handicap Golfers at BC). However, a smaller power was exhibited by the individual handicap groups at TB and BC compared to All Golfers (table 6.1.2.1). An example of this is displayed at TB where a large effect size is exhibited by the High Handicap Golfers, yet a small power is displayed. Conversely, All Golfers exhibit a medium effect and power at TB and a significant difference is shown. The statistical difference between the groups highlights the importance of a large sample population.

Table 6.1.2.1: Effect size (η^2) and power data for all three groups at TB and BC

	TB		BC	
Group	Effect Size η^2	Power	Effect Size η^2	Power
All Golfers (n = 38)	.070	.606	.074	.622
Low Handicap Golfers (n = 19)	.075	.291	.051	.206
High Handicap Golfers (n = 19)	.118	.455	.103	.398

It can be concluded that an increase in the number of Low Handicap Golfers and High Handicap Golfers within each handicap group may increase the power and lead to a significant difference between the clubs at TB and BC. Post-hoc power analysis showed that an additional seven High Handicap Golfers and 17 Low Handicap Golfers would be required at TB and BC to produce a large power (0.8) and increase the likelihood of finding a significant difference at $p < .1$ (table 6.1.2.2).

Table 6.1.2.2: n required for the Low Handicap Golfers and High Handicap Golfers to provide a power of .8 between the three golf clubs at TB and BC for p = 0.1

Event	Low Handicap Golfers (n = 19)	High Handicap Golfers (n = 19)
TB	42	25
BC	42	25

6.1.3 ED

For all three groups a significant difference ($p < .03$) was evident between the driver and 7 iron at ED. Furthermore, the driver and 3 iron for All Golfers, and the 3 iron and 7 iron for the Low Handicap Golfers and All Golfers produced a significant difference ($p < .03$, table 6.1.3.1) at this event. For all three groups the largest mean CP_{yt} % was displayed by the driver at ED, while the 7 iron exhibited the smallest mean CP_{yt} %. This indicates that the golf clubs with the longer shafts and the smaller club face angle (loft) to the ground (driver, 3 iron) produced more weight on the front foot than the club with a shorter shaft and a larger loft angle (7 iron). Previous researchers (Cooper *et al.*, 1974; Williams and Cavanagh, 1983; Koenig *et al.*, 1994; Koslow, 1994) have not examined the weight transfer values at ED and the results presented in this study indicate that valuable information has been overlooked.

Table 6.1.3.1: Mean CP_{yt} % and SD for all three groups at ED for the driver, 3 iron and 7 iron and the significance levels. ***Significant at ($p < .03$)**

Group	Driver		3 iron		7 iron		Driver - 3 iron		Driver – 7 iron		3 iron - 7 iron	
	Mean	SD	Mean	SD	Mean	SD	Mean diff.	p	Mean diff.	P	Mean diff.	p
All Golfers (n = 38)	62.5	12.5	60.3	14.4	58.1	14.7	2.2	.021*	4.4	.000*	2.2	.002*
Low Handicap Golfers (n = 19)	65.0	12.9	63.6	14.1	60.2	14.9	1.4	.109	4.8	.002*	3.4	.001*
High Handicap Golfers (n = 19)	60.0	11.9	57.1	14.2	56.0	14.6	3.0	.084	4.0	.021*	1.0	.280

At ED, the Low Handicap Golfers and High Handicap Golfers did not produce a significant difference between the driver and 3 iron. Additionally, the High Handicap

Golfers did not display a significant difference between the 3 iron and 7 iron at ED. Once again, the larger subjects numbers in All Golfers (n = 38) contributed to the significant difference between the driver and 3 iron compared to the smaller subject numbers within the High Handicap group (n = 19). All Golfers displayed a smaller mean CP_{yt} % difference and effect size than the High Handicap golfers, yet the High Handicap Golfers exhibited a larger p value (table 6.1.3.2). By doubling the number of golfers within the Low Handicap Group and the High Handicap Group will enhance the likelihood of achieving a significant difference between those clubs that did not produce a significant difference.

Table 6.1.3.2: Comparison between All Golfers (n = 38) and High Handicap Golfers (n = 19) effect size (d), p value and mean CP_{yt} % data between the driver and the 3 iron at ED

Group	Mean CP_{yt} % difference	p	Effect Size (d)
All Golfers (n = 38)	2.2	.021*	.175
High Handicap Golfers (n = 19)	3.0	.084	.249

*Significant at $p < .03$

The larger mean CP_{yt} % exhibited by the driver at ED compared to the 7 iron, for all three groups may have been related to the pattern of CP movement produced from TB and ED. This phenomenon was examined and the results displayed that all three groups displayed the largest mean CP_{yt} % movement for the driver during this phase and the smallest mean CP_{yt} % movement for the 7 iron. The mean CP_{yt} % movement for the driver was significantly different ($p < .03$) to the mean CP_{yt} % movement for the 7 iron for All Golfers and the Low Handicap Golfers (table 6.1.3.3). Moreover, All Golfers and the Low Handicap Golfers exhibited a significant difference between the 3 iron and 7 iron mean CP_{yt} % movement during this phase. Conversely no significant differences were displayed between the three golf clubs mean CP_{yt} % movement for the High Handicap golfers or between the driver and 3 iron for All Golfers and the Low Handicap Golfers.

Table 6.1.3.3: Mean CP_{yt} % movement and paired samples t-test for all three groups from TB to ED for the driver, 3 iron and 7 iron

Group	Descriptive			Paired Samples t-test		
	Driver	3 iron	7 iron	Driver - 3 iron	Driver - 7 iron	3 iron - 7 iron
All Golfers (n = 38)	38.7	38	35.5	.283	.001*	.002*
Low Handicap Golfers (n = 19)	41.2	41.1	36.5	.906	.004*	.000*
High Handicap Golfers (n = 19)	36.2	35	34.5	.519	.148	.519

*Significant at $p < .03$ (Bonferroni)

The larger mean CP_{yt} % displayed by the three groups at ED for the driver and 3 iron compared to the 7 iron is the product of the mean CP_{yt} % movement from TB to ED. The golf clubs with the longer shafts (driver, 3 iron) move the CP_{yt} % through a larger range during this phase (TB to ED), which results in a more weight closer to the front foot than the shorter club (7 iron) at ED.

6.1.4 MD

At MD the Low Handicap Golfers, High Handicap Golfers and All Golfers produced a similar result with no significant main effects shown between the three clubs at this event (table 6.1). Both the High Handicap Golfers (η^2 = .043) and All Golfers (η^2 = .030) displayed a small effect size at MD between the three golf clubs, while the Low Handicap Golfers (η^2 = .085) exhibited a medium effect size. The small and medium effect sizes for the three groups contributed to the non-significant difference. The small subject numbers in each group results in a small power shown by all three groups (All Golfers = .324, Low Handicap Golfers Handicap Golfers = .330, High Handicap Golfers = .117). Once again, All Golfers have displayed a good power compared to the Low Handicap Golfers and High Handicap Golfers considering the effect size was small for All Golfers. This result has highlighted the importance for more subject numbers within each handicap group. Post-hoc analysis showed that 64 golfers are required for All Golfers and the High Handicap Golfers, while the Low Handicap Golfers only require 29 subjects to produce a large power (0.8) and increase the probability of producing a significant difference at $p < .1$ (table 6.1.4.1). However, the relatively small mean CP_{yt} % difference between the clubs at MD for all three handicap groups may not be considered a valuable difference in the real-world and increasing the number of subject would not be recommended.

Table 6.1.4.1: n required to provide a large power (0.8) and the mean CP_{yt} % difference between the clubs for the three groups at MD

Group	N required	Driver - 3iron	Driver - 7 iron	3 iron - 7 iron
All Golfers (n = 38)	64	0.7	0.4	1.1
Low Handicap Golfers (n = 19)	29	0.1	1.6	1.6
High Handicap Golfers (n = 19)	64	1.3	0.8	0.5

The non-significant finding at MD was unusual, particularly for All Golfers, considering the events either side of MD (ED and BC) reported a significant difference between the driver and the 3 iron. This lead to and examination of the mean CP_{yt} % movement during ED to MD for all three groups. The results showed that the Low Handicap Golfers, High

Handicap Golfers and All Golfers exhibited the largest increase in the mean CP_{yt} % for the 7 iron, then followed by the 3 iron and lastly the driver (table 6.1.4.2). This pattern has been reversed from the previous phase (TB to ED), where the driver showed the largest increase in the mean CP_{yt} % and the 7 iron displayed the least. For All Golfers and the High Handicap golfers a significant difference ($p < .03$) was displayed between the driver and 3 iron, and the driver and 7 iron. Additionally, All Golfers also displayed a significant difference ($p < .03$) between the 3 iron and 7 iron mean CP_{yt} % movement during this phase. Alternatively, the Low Handicap Golfers did not produce a significant difference between the mean CP_{yt} % movement for the three golf clubs during ED to MD.

Table 6.1.4.2: Mean CP_{yt} % movement and paired samples t-test for all groups between ED to MD for the driver, 3 iron and 7 iron

Group	Descrptive			Paired Samples t-tes		
	Driver	3 iron	7 iron	Driver - 3 iron	Driver - 7 iron	3 iron - 7 iron
All Golfers (n = 38)	8.9	11.8	12.9	.003*	.000*	.026*
Low Handicap Golfers (n = 19)	7.3	8.8	10.6	.129	.031	.074
High Handicap Golfers (n = 19)	10.5	14.7	15.3	.011*	.004*	.157

*Significant at $p < .03$ (Bonferroni)

The transition phases from TB to ED and ED to MD displayed a mean CP_{yt} % pattern for all three groups. From TB to ED the longer clubs (driver and 3 iron) exhibited a larger mean CP_{yt} % movement than the shorter club (7 iron) for all three groups. Conversely, from ED to MD the shorter clubs (7 iron and 3 iron) exhibited a larger increase in the mean CP_{yt} % compared to the longer clubs (driver and 3 iron). This effect may be due to the inertial characteristics (length, weight etc) of the golf clubs. Koenig *et al.* (1994) suggested that the inertial characteristics of the driver, 3 iron and 7 iron produced later peak F_x, F_y, F_z forces during the downswing phase with the driver displaying the largest peak forces and the 7 iron producing the least. The inertial characteristics of the golf clubs may have caused the Low Handicap Golfers, High Handicap Golfers and All Golfers to display a different weight transfer pattern from TB ED and ED to MD.

6.1.5 MF

At MF the Low Handicap Golfers showed a significant difference between all three clubs, while All Golfers produced a significant difference between the driver and 7 iron, and the driver and 3 iron (table 6.1). For all three golf clubs the 7 iron displayed the largest mean CP_{yt} % for these two groups (Low Handicap Golfers = 75.6%, All Golfers = 76.8%) and the driver (Low Handicap Golfers = 64.7%, All Golfers = 69.2%) produced the smallest mean CP_{yt} %. This finding supports the results presented by Cooper *et al.* (1974) who found that the 7 iron (approximately 75%) and 3 iron (approximately 70%) placed more weight closer to the front foot than the driver (approximately 50%). The mean CP_{yt} % displayed by the Low Handicap Golfers and All Golfers for the 3 iron and 7 iron were similar to the F_z distribution displayed by Cooper *et al.* (table 6.1.5.1). The F_z distribution produced by the driver was different to the mean CP_{yt} % exhibited by the Low Handicap Golfers and All Golfers. For both groups the driver displayed a decrease in the mean CP_{yt} % from BC to MF, but this was not as extreme as what Cooper *et al.* has described. Cooper *et al.* has actually over estimated the F_z distribution of the driver when in fact, visual examination of the graph presented by Cooper *et al.* showed the value was closer to 60%. From this study and Cooper *et al.* a similar pattern has emerged, which indicates that the shorter and more lofted clubs exhibit a larger percentage of weight on the front foot than the longer and less lofted clubs at MF.

Table 6.1.5.1: Comparison between the mean CP_{yt} % from this study and F_z distribution from Cooper *et al.* (1974) at MF for the driver, 3 iron and 7 iron

	This Study		Cooper *et al.* (1974)
Golf Club	All Golfers (n = 38)	Low Handicap Golfers (n = 19)	Low Handicap Golfers (n = 5)
	Mean CP_{yt} %	Mean CP_{yt} %	F_z Distribution (approx)
Driver	69.2	64.6	50
3 iron	74.2	71.8	70
7 iron	76.8	75.6	75

No significant main effect was shown between the three clubs at MF for the High Handicap Golfers because the effect size was medium (η^2 = .107) and the power was small (.411). The medium effect size indicates some differences may exist between the three golf clubs. However the small power suggests that an increase in subject number (n = 25) is required to provide a significant difference. Furthermore, the High Handicap Golfers exhibited the same mean CP_{yt} % pattern, between the three golf clubs, that was displayed by the Low Handicap Golfers and All Golfers. The 7 iron (78.0%) displayed the largest mean CP_{yt} % and the driver (73.8%) exhibited the smallest mean CP_{yt} %, while the 3 iron (76.5%) produced a mean CP_{yt} % that fell between these two golf clubs.

Additionally, the mean CP_{yt} % movement from BC to MF has influenced the results at MF between the golf clubs for the three groups. All Golfers and the Low Handicap

Golfers displayed as significant difference ($p < .03$) between the driver and 3 iron, and the driver and 7 iron for the CP_{yt} % movement between BC to MF (table 6.1.5.2). For both of these groups the driver exhibited a larger decrease in the mean CP_{yt} % from BC to MF than the 3 iron, while the 7 iron displayed a small increase in the mean CP_{yt} % between these events. For the High Handicap Golfers, a non-significant difference was evident between the three golf clubs at MF because the CP_{yt} % movement from BC to MF was not significantly different. Furthermore, All Golfers and the Low Handicap Golfers did not exhibit a significant difference between the 3 iron and 7 iron, although the p values were quite small for both groups.

Table 6.1.5.2: Mean CP_{yt} % movement and paired samples t-test for the three groups between BC and MF for the driver, 3 iron and 7 iron

Group	Descriptive			Paired samples t-test		
	Driver	3 iron	7 iron	Driver - 3 iron	Driver - 7 iron	3 iron - 7 iron
All Golfers (n = 38)	-4.6	-1.9	1	.013*	.002*	.038
Low Handicap Golfers (n = 19)	-8.7	-3.6	0.4	.007*	.002*	.031
High Handicap Golfers (n = 19)	-0.3	-0.2	1.6	.548	.241	.361

*Significant at $p < .03$ (Bonferonni)

N.B: A negative value indicates a decrease in the mean CP_{yt} % from BC to MF.

6.2 HANDICAP COMPARISON

Table 6.2.1 is a summary of the results for the handicap comparison and the mean CP_{yt} % difference between the handicap groups for the three golf clubs.

Table 6.2: Mean CP_{yt} % differences between the two handicap groups for the driver, 3 iron and 7 iron at the eight golf swing events and significant findings

	Mean CP_{yt} % difference between the handicap groups for each golf club			Significant main effect ($p < .1$)	Clubs that showed a significant handicap difference ($p < .03$)
	Driver	3 iron	7 iron		
TA	-0.6	0.8	-0.9	No ($p = .884$)	
MB	-6.2	-5.4	-5.2	Yes ($p = .070$)	None
LB	-3.7	-3.9	-3.3	No ($p = .310$)	
TB	0.0	0.4	2.2	No ($p = .835$)	
ED	5.0	6.5	4.2	No ($p = .239$)	
MD	1.8	0.6	-0.5	No ($p = .855$)	
BC	-0.7	-1.3	-1.2	No ($p = .817$)	
MF	-9.1	-4.7	-2.4	No ($p = .347$)	

+ Mean CP_{yt} % difference = Low Handicap Golfers show a larger mean CP_{yt} %
- Mean CP_{yt} % difference = High Handicap Golfers show a larger mean CP_{yt} %

6.2.1 TA

At TA no significant main effect was displayed between the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the three golf clubs (table 6.2). The mean CP_{yt}% for the Low Handicap Golfers and High Handicap Golfers at TA were just over 50%, which indicates that slightly more weight is placed towards the front foot (table 6.2.1). This result supports the findings of Koenig *et al.* (1994) who found the typical golfer (the average of 14 low, mid and high handicap golfers) initiated the swing with the F_z distribution of 55:45 (front foot:back foot). Due to the small mean CP_{yt} % difference between the handicap groups (table 6.2) a below small effect size ($\eta^2 = .001$) has been displayed at TA. This indicates that the effect is not worth pursuing due to the large number of golfers required (n > 1000) within each group to provide a large power. Furthermore, a mean CP_{yt} % difference of less than 1.0% would not be considered a practical difference and it can be concluded that the Low Handicap Golfers and High Handicap Golfers produce similar mean CP_{yt} % at TA for the driver, 3 iron and 7 iron.

Table 6.2.1: Mean CP_{yt} % at TA for the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) for the three golf clubs

Club	Low Handicap Golfer (n = 19)	High Handicap Golfers (n = 19)
Driver	56.6	57.2
3 iron	57.2	56.4
7 iron	57.2	58.1

6.2.2 MB

At MB a significant main effect ($p < .1$) was reported between the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the driver, 3 iron and 7 iron. Post-hoc analysis displayed that the Low Handicap Golfers and High Handicap Golfers were not significantly different at this event for the three golf clubs. The reason no significant differences were shown is because the significance level was adjusted from the SPANOVA ($p < .1$) to the independent samples t-test ($p < .03$) to allow for the bonferroni correction.

The handicap comparison for the driver showed the lowest p value ($p = .053$) at MB however, it was above the significance level ($p < .03$). While the post-hoc test showed no significant difference between the handicap groups for the three golf clubs, the Low

Handicap Golfers produced a smaller mean CP_{yt} % for all three clubs (table 6.2). This suggests that the Low Handicap Golfers produced more weight on the back foot than the High Handicap Golfers for the driver, 3 iron and 7 iron. This does not support the finding of Wallace *et al.* (1990) who showed the High Handicap Golfers placed significantly ($p < .05$) more weight, as indicated by the CP distribution between the feet, on the back foot at MB (58.3%) than the Low Handicap Golfers (47.4%). However, as Wallace *et al.* only used one low handicap golfer and one high handicap golfer, the generalisability of the data is poor. Certainly the larger subject numbers in this study provided stronger results which are more generalisable.

The mean CP_{yt} % difference between the Low Handicap Golfers and High Handicap Golfers for the three golf clubs at MB (table 6.2) appears to be substantial considering the golf club comparison displayed mean CP_{yt} % differences that were smaller that produced significant differences. For example, the golf club comparison for the Low Handicap Golfers exhibited a significant difference ($p = .001$) between the 3 iron and 7 iron at ED when the mean CP_{yt} % differences between these two clubs was 3.4%. At MB the mean CP_{yt} % difference between the handicap groups for the three golf clubs (table 6.2) were larger than the mean CP_{yt} % difference between the 3 iron and 7 iron at ED. However, no significant difference were shown between the handicap groups for the individual clubs. A medium effect size ($\eta^2 = .088$) was displayed for the main effect, while the post-hoc effect size between the handicap groups for the driver, 3 iron and 7 iron was also medium (table 6.2.2). The medium effect size indicates that the mean CP_{yt} % difference between the handicap groups is good, but a larger effect size may have produced a significant difference between the handicap groups. Post-hoc power analysis (table 6.2.2) displayed that driver required four more golfers, the 3 iron required an additional seven and the 7 iron required 11 more golfers in each handicap group to produce a large power (0.8), given the effect size remains the same.

Table 6.2.2: Effect size and p value between the Low Handicap Golfers and High Handicap Golfers for the three golf clubs at MB and the n required to display a large power (0.8)

	Effect Size (d)	P	n required
Driver	.778	.053	23
3 iron	.703	.092	26
7 iron	.643	.098	30

6.2.3 LB

No significant main effect ($p = .310$) was displayed at LB between the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the three golf clubs. However, LB displayed a similar mean CP_{yt} % pattern as MB, with the Low Handicap Golfers exhibiting a smaller mean CP_{yt} % than the High Handicap Golfer for all three golf clubs (table 6.2.3). The mean CP_{yt} % difference between the handicap groups for the driver, 3 iron and 7 iron appears to be substantial and the small effect size ($\eta^2 = .029$) indicates further analysis may be warranted. A post-hoc power analysis indicated that an additional 31 golfers are required for the 3 iron and 61 golfers for the driver and 7 iron to produce a large power (table 6.2.3).

Table 6.2.3: Mean CP_{yt} % and effect size for the Low and High Handicap Golfer for the three clubs and the n required to produce a large power (0.8)

Club	Descriptive				
	Low Handicap Golfers (n = 19)	High Handicap Golfers (n = 19)	mean CP_{yt} % diff	Effect Size η^2	n required
Driver	20.0	23.7	-3.7		80
3 iron	20.1	24.0	-3.9	.029	50
7 iron	20.6	23.9	-3.3		80

6.2.4 TB

At TB no significant main effect (p = .835) was displayed between the Low Handicap Golfers and High Handicap Golfers mean CP_{yt} % for the three golf clubs. This finding is supported by Richards *et al.* (1985) and Wallace *et al.* (1990) who both found no significant difference between the Low Handicap Golfers and High Handicap Golfers at TB. However, the mean CP_{yt} % displayed by the Low Handicap Golfers for the three golf clubs was smaller than the percentages displayed by Richards *et al.* (1985) and Wallace *et al.* (1990) (table 6.2.4). The mean CP_{yt} % exhibited by the High Handicap Golfers for all three clubs was similar to Richards *et al.* findings, but was smaller than Wallace *et al.* (1990). Different subject numbers, different golf clubs and different methods of assessing TB may have lead to the inconsistencies between all three studies.

Table 6.2.4: Comparison of the weight transfer values at TB between this study, Richards *et al.* (1985) and Wallace *et al.* (1990)

Study	Club	Parameter	n in each group	Low Handicap Golfers	High Handicap Golfers	Difference Low - High
This Study	Driver	Mean CP_{yt} %	19	23.8	23.8	0.0
	3 iron	Mean CP_{yt} %	19	22.5	22.1	0.4
	7 iron	Mean CP_{yt} %	19	23.7	21.5	2.2
Richards *et al.* (1985)	5 iron	COVF	10	27.5	21.8	5.7
Wallace *et al.* (1990)	Driver	CP Distribution	1	27.3	30.7	-3.4

The effect size (η^2 = .001) at TB was below small, which indicates that a minor mean separation has occurred between the handicap groups. Furthermore, the small mean CP_{yt} % difference between the handicap groups suggests that the Low Handicap Golfers and High Handicap Golfers produce similar mean CP_{yt} % at TB. Therefore additional post-hoc power analysis would not be appropriate at this event.

6.2.5 ED

At ED no significant main effect (p = .239) was reported between the handicap groups mean CP_{yt} % for the three golf clubs (table 6.2). The mean CP_{yt} % difference between the handicap groups appears to be quite good for the driver, 3 iron and 7 iron, but a small effect size has been displayed (table 6.2.5). The small effect size was generated because a large SD is displayed for the two handicap groups for all three golf clubs. The large SD displayed at ED indicates a large range of CP_{yt} % values were produced by golfers within the same handicap group. The SD for both handicap groups were two to three times larger than the between-handicap group difference for all three golf clubs. The large within-handicap group variability combined with the small between-handicap group difference has contributed to a small effect size ($\eta^2 = .038$). This in turn influenced a small power (.321), which indicates that larger subjects numbers are required to provide a significant main effect at ED. If the effect size ($\eta^2 = .038$) remained the same then 880 golfers are required in each handicap group for the driver and 3 iron, while 140 for the 7 iron to produce a large power. A study of that magnitude may not be feasible or practical due to time constraints.

Table 6.2.5: Mean CP_{yt} %, SD, mean CP_{yt} % difference and the effect size for the Low Handicap Golfers and High Handicap golfers for the three golf clubs at ED and the n required for a large power (0.8)

Club	Low Handicap Golfers (n = 19)		High Handicap Golfers (n = 19)		Mean CP_{yt} % Diff..	Effect Size η^2	Post-hoc power analysis
	Mean	SD	Mean	SD			N required for a large power
Driver	65.0	*12.9*	60.0	*11.9*	5.0		880
3 iron	63.6	*14.1*	57.1	*14.2*	6.5	.038	880
7 iron	60.2	*14.9*	56.0	*14.6*	4.2		140

6.2.6 MD and BC

Both MD (p = .855) and BC (p = .817) displayed no significant difference between the handicap groups mean CP_{yt} % for the three golf clubs. However, the mean CP_{yt} % difference between the handicap groups for the three clubs at BC displays a pattern with the High Handicap Golfers exhibiting a slightly larger mean CP_{yt} % than the Low Handicap Golfers for the driver, 3 iron and 7 iron (figure 6.2.6).

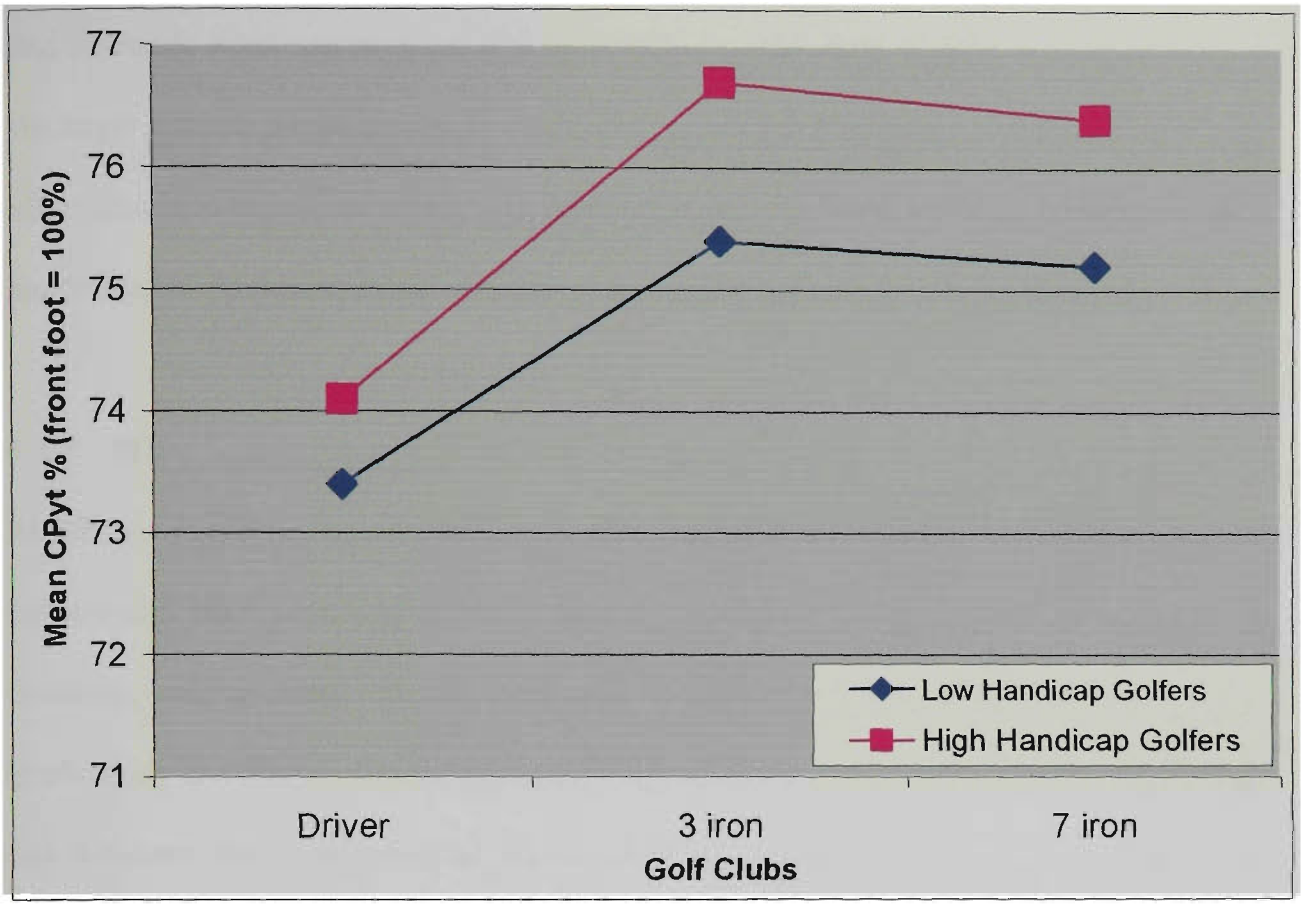


Figure 6.2.6: Mean CP_{yt} % pattern between the Low Handicap Golfers and High Handicap golfers for the three golf clubs at BC

The findings at BC contradicts the previous literature with both Richards *et al.* (1985) and Wallace *et al.* (1990) showing the Low Handicap Golfers (Richards *et al.* = 95.6%, Wallace *et al.* = 82.2%) placed more weight towards the front foot than the High Handicap Golfers (Richards *et al.* = 80.9%, Wallace *et al.* = 66.5%) at BC. Although different weight transfer values were displayed between this study and Richards *et al.* (1985) a common result has been produced between the studies. That is, no significant difference is displayed between the low and high handicap golfers weight transfer values at BC. Conversely, Wallace *et al.* (1994) displayed a significant ($p < .05$) difference between the low and high handicap golfers at BC. As previously discussed, this study and Richards *et al.* are more readily generalised to the wider golfing community due to the larger subject numbers tested. The small mean CP_{yt} % difference and the below small effect size between the handicap groups for the driver, 3 iron and 7 iron at MD ($\eta^2 = .001$) and BC ($\eta^2 = .002$) indicates the handicap groups are not different at these events.

6.2.7 MF

At MF, no significant main effect (p = .347) was displayed between the Low Handicap Golfers and High Handicap Golfer mean CP_{yt} % for the three golf clubs (table 6.2). However, a large mean CP_{yt} % difference is displayed between the handicap groups (particularly for the driver), yet no significant difference (table 6.2.7). The small effect size indicates that a large within-handicap group variability exists. MF displays the largest SD for both handicap groups for the driver, 3 iron and 7 iron compared to the other seven golf swing events. This finding supports Williams and Cavanagh (1983) statement that the follow-through phase is the most variable event throughout the golf swing. Obviously, the large with-handicap group variability and small between-handicap group difference has contributed to the non-significant main effect at MF (this is discussed further in section 6.4).

Table 6.2.7: Descriptive statistics, p value, effect size and power for the Low Handicap Golfers and High Handicap golfers for the three golf clubs at MF

	Low Handicap Golfers (n = 19)		High Handicap Golfers (n = 19)		Mean CPyt % Diff..	p	Effect Size	Power
	Mean	*SD*	Mean	*SD*				
Driver	64.7	*21.5*	73.8	*17.8*	9.1			
3 iron	71.8	*18.7*	76.5	*17.3*	4.7	.347	.025	.244
7 iron	75.6	*15.6*	78.0	*17.6*	2.4			

6.3 INTERACTION EFFECT

MF was the only event to display a significant interaction effect ($p = .075$) between the Low Handicap Golfers and High Handicap Golfers and for the driver, 3 iron and 7 iron. The significant interaction effect displayed at MF suggests that the mean CP_{yt} % exhibited were dependent on the handicap group and the golf club used. For MF the between-handicap group difference displayed that the High Handicap Golfers produced a larger mean CP_{yt} % than the Low Handicap Golfers for all three golf clubs. Furthermore, within each handicap group the mean CP_{yt} % produced was dependent on the club used. For both handicap groups the 7 iron exhibiting the largest mean CP_{yt} %, then followed by the 3 iron and finally the driver (figure 6.3.1). In the golfing weight transfer literature, Barrentine *et al.* (1994) has been the only other study to report interaction effects between-handicap group and golf clubs used. The results reported by Barrentine *et al.* don't relate specifically to this study because the interactions found were all kinematic variables, except for the shear force on the back foot in the anterior-to-posterior direction (heel-to-toe direction).

Figure 6.3.1: Interaction effect between the Low Handicap Golfers and High Handicap Golfers for the driver, 3 iron and 7 iron at MF

Graphical examination of the remaining seven events (appendix 5), that did not produce a significant interaction effect, showed that ED displayed a similar pattern between the handicap groups and clubs as MF. For this event, the Low Handicap Golfers displayed a larger mean CP_{yt} % than the High Handicap Golfers for all three golf clubs. A within-handicap group pattern also existed, even though no significance was exhibited with driver displaying the largest CP_{yt} %, then followed by the 3 iron and finally the 7 iron (figure 6.3.2). No significant interaction effect was shown at this event because the between-handicap group difference and within-handicap group club comparison was not large enough, which was indicated by the small effect size ($\eta^2 = .025$). Also, the large SD experienced within each handicap group for the three golf clubs contributed to the small effect size. The other six events did not display significant interaction because of these reasons too (table 5.3).

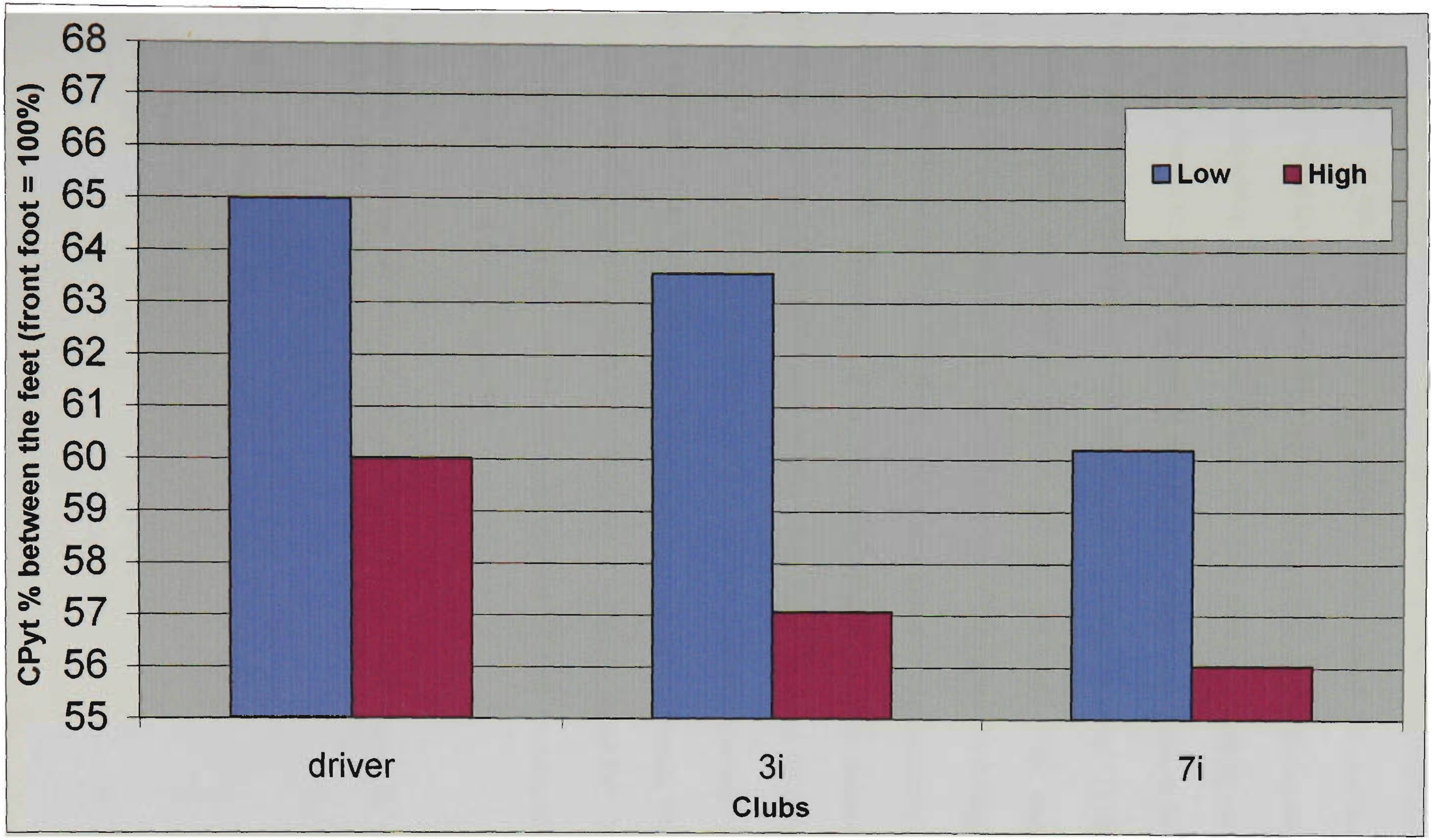


Figure 6.3.2: Interaction effect between the Low Handicap Golfers and High Handicap Golfers for the driver, 3 iron and 7 iron at ED

6.4 VARIABILITY WITHIN THE LOW HANDICAP GOLFERS AND HIGH HANDICAP GOLFERS

Both the Low Handicap Golfers and High Handicap Golfers exhibited a large SD for all three clubs at the eight golf swing events. This caused the within-handicap group difference to be larger than the between-handicap group difference at all eight golf swing events. Resulting in a reduced effect size (η^2) which influenced the non-significant finding between the handicap groups at each golf swing event (table 5.2). A large within-handicap group variance was also displayed by Richards *et al.* (1985) for the High Handicap Golfers at TB (13.6) and BC (25.2). Richards *et al.* suggested that this produced the non-significant finding in that study. Comparing the within-handicap group variance between the High Handicap Golfers, in this study to Richards *et al.* displays a similar SD at TB. However, at BC the within-handicap group variance for the High Handicap Golfers (this study) was smaller than Richards *et al.* high handicap golfers (table 6.4.1). Conversely, the Low Handicap Golfers exhibited a smaller SD for the three golf clubs at TB to Richards *et al.* High Handicap Golfers. Though, the Low Handicap Golfers (this study) produced a larger SD for the three golf clubs at BC. Furthermore, the Low Handicap Golfers (this study) displayed a larger SD than the Low Handicap Golfers for Richards *et al.* at both TB and BC.

Table 6.4.1: SD for the Low Handicap Golfers and High Handicap golfers for the three golf clubs at TB and BC compared to Richards *et al.* (1985)

	This Study						Richards et al. (1985)	
Events	Low Handicap Golfers(n = 19)			High Handicap Golfers (n = 19)			Low Handicap Golfers (n = 10)	High Handicap Golfers (n = 10)
	driver	3 iron	7 iron	driver	3 iron	7 iron	5 iron	5 iron
TB	10.4	11	11.9	14.1	13.1	13.5	8.8	13.6
BC	17.9	16.1	15.4	13	11.5	13	12.2	25.2

The large variability exhibited within each handicap group for the eight golf swing events suggested that a wide range of CP_{yt} % are being produced by golfers of similar handicap scores. Table 6.4.2 displays the range of CP_{yt} % displayed at each event for the Low Handicap Golfers and High Handicap Golfers for the driver. A large range of values have been displayed at all eight golf swing events. Surprisingly, MB also displayed a large range of CP_{yt} % for both the Low Handicap Golfers and High Handicap Golfers when a significant main effect was evident at this event. The significant main effect was displayed at MB because the mean CP_{yt} % difference between the Low Handicap Golfers and High Handicap Golfers was large (6.2%) and the within-handicap SD was relatively small compared to the other seven golf swing events. The large within-handicap group variability and range for each event may indicate different weight transfer styles exist.

Table 6.4.2: The mean, SD and range for the Low Handicap Golfers (n = 19) and High Handicap Golfers (n = 19) for the driver at the eight golf swing events

Events	Low (n = 19)			High (n = 19)		
	Mean	SD	**Range**	Mean	SD	**Range**
TA	56.6	4.8	**19.7**	57.2	7.3	**29.6**
MB	23.8	8.1	**32.1**	30.0	11	**35.3**
LB	20.0	8.6	**28.0**	23.7	13.4	**48.7**
TB	23.8	10.4	**39.1**	23.8	14.1	**48.1**
ED	65.0	12.9	**51.7**	60.0	11.9	**47.1**
MD	72.3	11.9	**42.4**	70.5	10.8	**43.2**
BC	73.4	17.9	**67.9**	74.1	13	**43.5**
MF	64.7	21.5	**70.1**	73.8	17.8	**68.3**

Three previous weight transfer studies have reported different weight transfer styles exist for the low, high and beginner golfers tested. Koslow (1994) found three weight transfer styles for 30 beginner golfers and these styles were labeled 'proper', 'reverse', 'abbreviated'. Neal (1998) reported two weight transfer styles for low handicap golfers and he labeled the styles 'traditional' and 'rotational'. While more recently, Ball *et al.* (2002) found two weight transfer styles for low handicap golfers and high handicap golfers and labeled them as 'front foot' and 'reverse' weight transfer styles.

Given the large within-handicap group SD, it was decided to examine if different weight transfer styles exist for the 38 golfers tested. This will be investigated via a cluster analysis (chapter 7). Providing the cluster analysis finds a meaningful and valid cluster solution then a handicap comparison will be conducted to determine if the Low Handicap Golfers and High Handicap Golfers within the same weight transfer patterns differ in their mean CP_{yt} % at the eight golf swing events for the driver. Due to time constraints, this analysis has been limited to the driver.

CHAPTER 7

CLUSTER ANALYSIS

7.1 AIM OF THE CLUSTER ANALYSIS

The purpose of the cluster analysis was to classify the 38 golfers into cluster groups according to their CP_{yt} % at the eight golf swing events for the driver. Provided a significant and valid cluster solution is found then a handicap comparison will be conducted. The handicap comparison will compare the mean CP_{yt} % for the Low Handicap Golfer and High Handicap Golfers for the driver at the eight golf swing events.

7.2 METHOD

The cluster analysis was performed for the 38 golfers using *SPSS* (version 10) software. Each golfer's mean CP_{yt} % (ten trials) for the eight golf swing events (appendix 3) was used to classify the golfers into the cluster groups. A hierarchical cluster analysis was performed using the between-groups linkage method to calculate the clusters and the squared euclidean distance was used to determine the proximity measures. A combination of three techniques were used to determine the most appropriate cluster solution. Large jumps in the agglomeration schedule (coefficient junp) and the separation of golfers from groups in the dendrogram as recommended by SPSS, were combined with the C Index stopping rule (Milligan and Cooper, 1985) to examine the best cluster solution. Once the best cluster solution was determined, it was then validated using a point biserial correlation as recommended by Miligan and Cooper. Providing the cluster solution was valid and significant, then a handicap comparison was conducted within the cluster solutions using the methods described throughout chapters four, five and six.

7.3 THE CLUSTER GROUPS

The four-cluster solution displayed the best results according to the agglomeration schedule, the C Index (table 7.3) and the dendrogram (figure 7.3). For the agglomeration schedule the four-cluster solution produced the largest coefficient jump, while the C Index also displayed that the four-cluster solution was the best result exhibiting larger values than the two, three and five cluster solutions. The dendrogram is not the best statistical procedure of selecting the number of clusters, but it is effective in determining when golfers form the cluster groups. The dendrogam clearly displays when the two, three and four cluster solutions are formed and labels the golfers (cases) that belong to each group. From the dendrogram and the cluster membership, in table 7.3, it is evident that a large percentage of the golfers are classified into one group for the two ($n = 32$), three ($n = 30$) and four ($n = 29$) cluster solutions, while a smaller number of golfers ($n=6$) are classified into another group for the same cluster solutions. This small cluster group ($n = 6$) maintains the same number of golfers throughout the two, three and four-cluster solutions, but as the three and four-cluster groups are formed, golfers are taken from the larger group in the two-cluster solution ($n=32$) to form the third ($n=2$) and finally fourth ($n=1$) cluster group. Both the agglomeration schedule and the C Index displayed that the four-cluster solution is the most appropriate number of cluster groups. The validation of the four-cluster solution exhibited a significant ($p < .001$) point biserial correlation ($r = .63$), which indicates that four weight transfer styles are valid solutions for the 38 golfers.

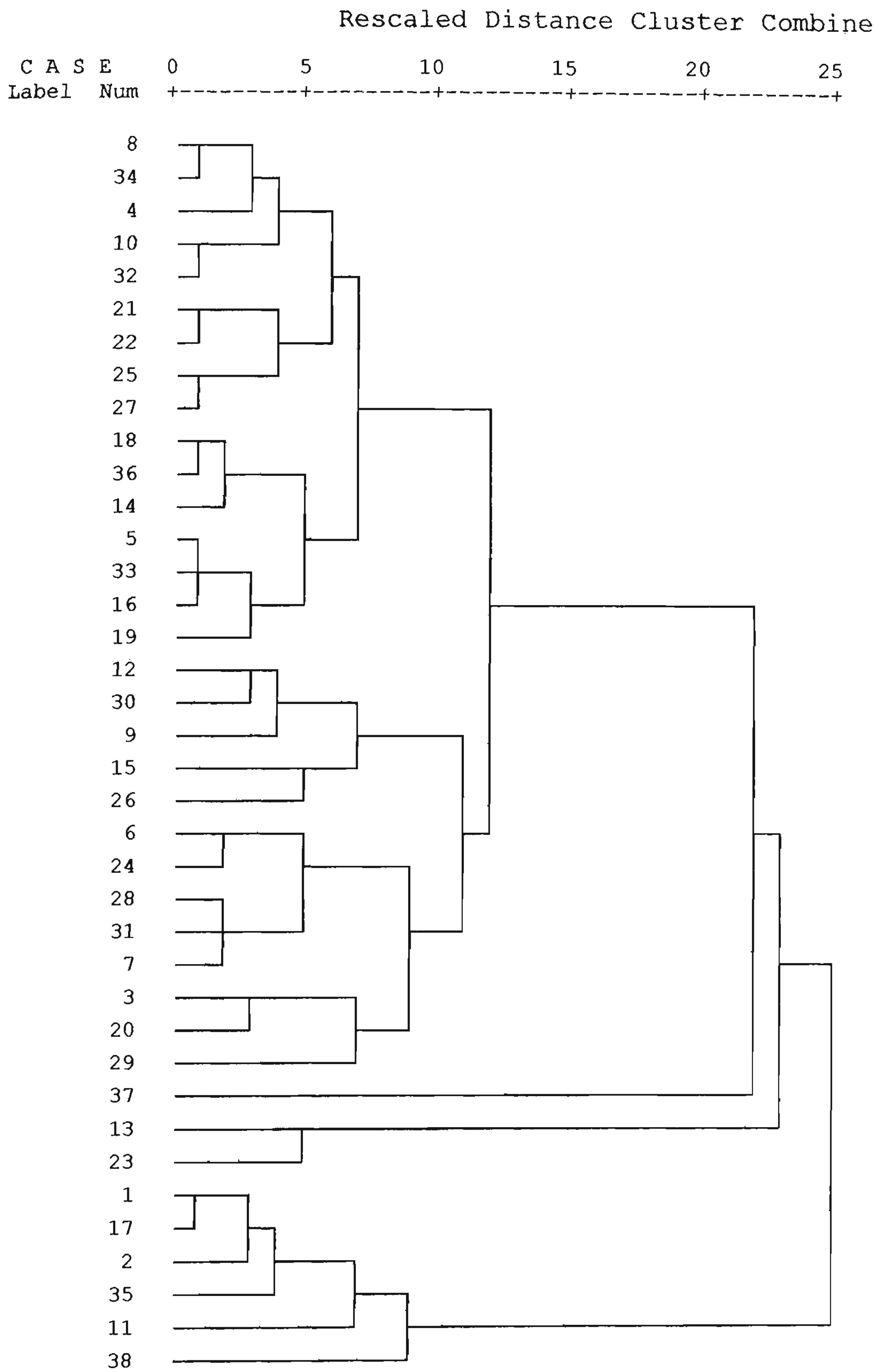
Table 7.3: Assessment of the best cluster solution using the coefficient jump and C Index and the validation of the cluster group using the point biserial correlation

Assessment of the best cluster solution					Validation
Cluster Solutions	**N in Each Group**	**Coefficient** (agglomeration schedule)	**Coefficient Jump** (change in the coefficient from solution-to-solution)	**C Index**	**Point Biserial Correlation**
2	6, 32	4268	445	251	
3	6, 30, 2	3823	190	279	
4	6, 29, 2, 1	3633	1989	306	0.63*
5	6, 9, 16, 5, 2	1644	1	114	
		1643			

*Significant at $p < .001$

Figure 7.3: Results from the dendrogram showing when cases (golfers) form the cluster groups

Dendrogram using Average Linkage (Between Groups)



7.4 THE FOUR WEIGHT TRANSFER STYLES

The four-cluster groups were labeled according to the mean CP_{yt} % at the eight golf swing events (table 7.4) and the weight transfer pattern exhibited from event-to-event (figure 7.4).

Table 7.4: Mean CP_{yt} % and SD for the four-cluster groups for the driver at the eight golf swing events

Events	Typical (n = 29)		Back foot (n = 6)		Late Translation (n = 2)		Irregular (n = 1)
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean
TA	56.8	*5.9*	55.8	*5.3*	53.8	*3.2*	71.3
MB	25.6	*10.2*	29.4	*5.9*	28.8	*15.1*	44.8
LB	20.7	*10.1*	27.2	*8.0*	7.4	*3.7*	51.5
TB	21.8	*9.3*	33.8	*14.5*	8.0	*0.7*	53.4
ED	65.0	*10.4*	62.6	*9.1*	30.4	*1.4*	54.0
MD	75.6	*8.8*	60.0	*3.4*	48.0	*3.2*	64.0
BC	79.7	*10.9*	48.3	*7.4*	62.7	*6.9*	76.7
MF	75.8	*15.4*	36.7	*8.8*	69.4	*13.0*	73.5

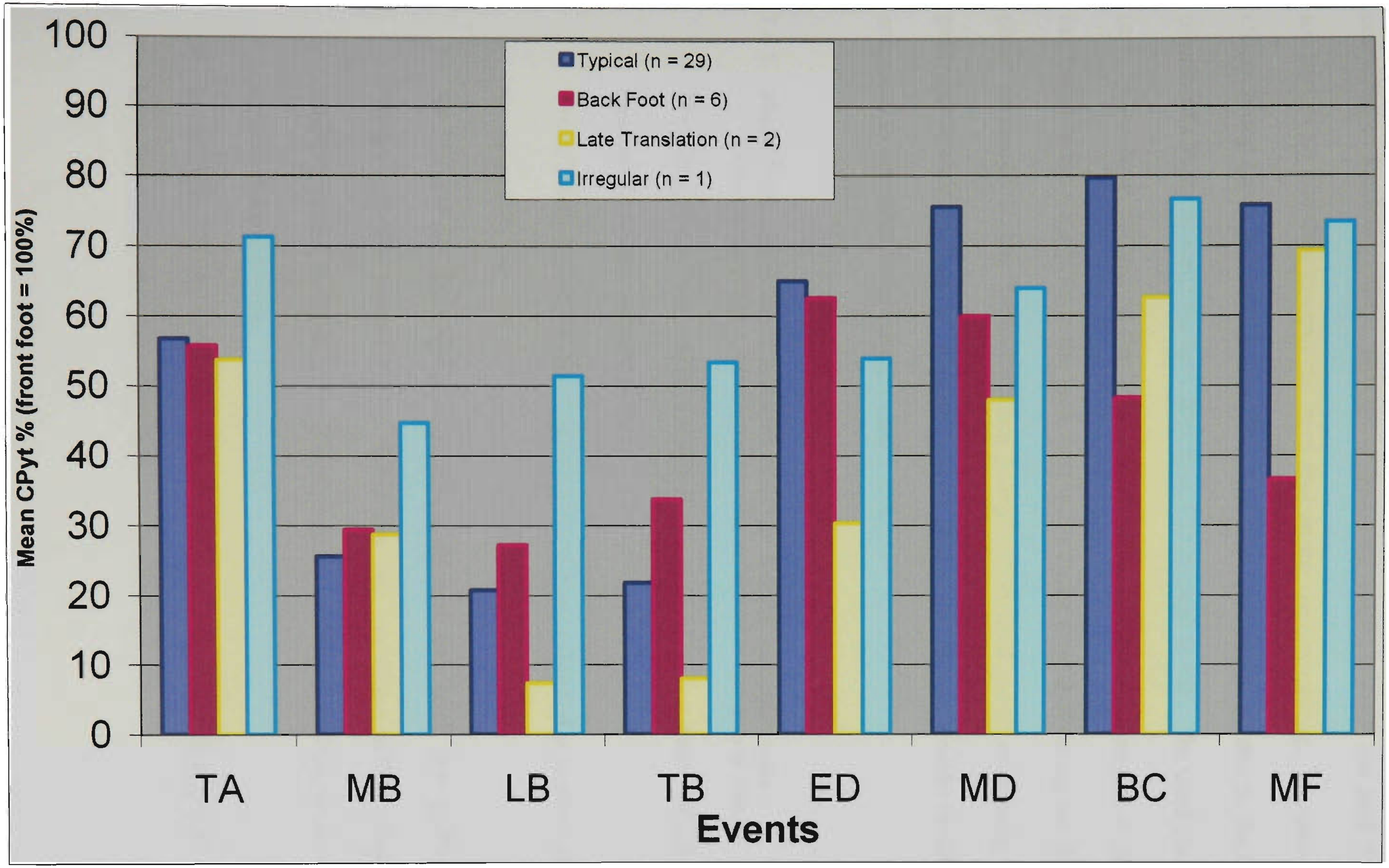


Figure 7.4: Mean CP_{yt} % for the four-cluster groups for the driver at the eight golf swing events

The large cluster group (n=29) has been labeled the 'typical golfers group' because they display a weight transfer pattern that is considered normal or typical for most golfers, according to Koslow (1994). This group transfers weight towards the back foot during the backswing and then towards the front foot during the downswing. The second largest cluster group (n=6) has been labeled the 'back foot golfers group' due to the distinctive transfer of CP_{yt} % towards the back foot from ED through to MF. The third cluster group (n = 2) has been defined as the 'late translation golfers group' because of the smaller increasing in the CP_{yt} % from the back foot at TB to the front foot during the downswing phase compared to the 'typical golfers group'. The final group containing only one golfer has been labeled as the 'irregular golfer' due to his unusual weight transfer pattern compared to the other three weight transfer styles.

7.4.1 Main Points of interest between the four weight transfer styles

(N.B. refer to table 7.4.1 and figure 7.4.1 for values and weight transfer styles)

- The 'irregular golfer' initiates the golf swing (TA) with a larger CP_{yt} % than the three other weight transfer groups.
- From TA to MB all four-weight transfer groups exhibited a similar decrease in the mean CP_{yt} %.
- At LB and TB the 'typical golfers group' and the 'back foot golfers group' display a similar mean CP_{yt} %. While the 'late translation golfers' displayed the smallest mean CP_{yt} % and the 'irregular golfers exhibited the largest mean CP_{yt} % at both of these events.
- From TB to ED the 'typical golfers group' and 'back foot golfers group' display a large increase in the mean CP_{yt} %.

- From ED to BC the 'typical golfers group', the 'late translation golfers group' and the 'irregular golfer' display an increase in the mean CP_{yt} %. While the 'back foot golfers group' display a decrease in the mean CP_{yt} %.
- At MF the 'typical golfers group' the 'late translation golfers group' and the 'irregular golfer' display similar mean CP_{yt} %, while the 'back foot golfers group' produced a mean CP_{yt} % at MF that was extremely smaller.

7.4.2 Assessment of the four weight transfer styles

The 'typical golfers group' weight transfer pattern was the most common weight transfer style with 76% (n = 29) of the 38 golfers making up this group. The 'typical golfers group' weight transfer pattern has been described and found previously by Koslow (1994), who referred to this weight transfer style as 'proper' and Neal (1998), who referred to this movement as the traditional 'left-to-right' weight transfer pattern. The other main weight transfer pattern to become apparent for six of the 38 golfers is the 'back foot golfers group' weight transfer pattern. Only a small percentage (16%) of golfers displayed this style but from the two-cluster solution to the five-cluster solution this group remained the same. This indicated that this group was unlike the remaining 32 golfers due to their unique transfer of weight towards the back foot from ED to MF.

The 'late translation golfers group' weight transfer pattern was formed for the three-cluster solution and the two golfers that created this group were taken from the 'typical golfers group' in the two-cluster solution. It is apparent why they were taken from this group due to the same general weight transfer pattern (decrease in mean CP_{yt} % from TA to TB, increase in mean CP_{yt} % from TB to MF). However, the mean CP_{yt} % displayed at LB, TB, ED and MD were smaller than the 'typical golfers group', which resulted in the formation of this weight transfer group.

The 'irregular golfer', who created the fourth cluster group, was also taken from the 'typical golfers group'. Examination of the mean CP_{yt} % at ED, MD, BC and MF display the similarities between these two groups. Yet, the mean CP_{yt} % at TA, MB, LB and TB were completely different between these two weight transfer styles. Furthermore, examination of the age and AGU handicap of the 'irregular golfer', compared to the three other weight transfer groups, suggests he may be an outlier (figure 7.4). The age and AGU handicap of this golfer is well above the mean age and mean AGU handicap of the 'typical golfers group', 'back foot golfers group' and 'late translation golfers group' golfers. This may indicate the age and lack of skill for this golfer has contributed to the different weight transfer style compared to the other 37 golfers. Further analysis is required to determine if this weight transfer pattern really exists.

Table 7.4.2: Mean AGU, age and number of golfers in the 'Typical', 'Back Foot', 'Late Translation' and 'Irregular' golfer groups

	Typical		Back Foot		Late Translation		Irregular	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N	29		6		2		1	
AGU	11	7	11	13	10	5	30	
Age (years)	35	15	34	16	43	9	57	

7.5 COMPARISON OF THE CP_{yt} % BETWEEN THE LOW HANDICAP GOLFERS AND HIGH HANDICAP GOLFERS FOR THE 'TYPICAL GOLFERS GROUP'

Comparison between the Low Handicap Golfers and High Handicap Golfers was only conducted for the 'typical golfers group'. A handicap comparison was not performed for the other groups due to the small subject numbers (i.e. 'back foot golfers group' n = 6). The handicap comparison for the 'typical golfers group' showed that there were 14 Low Handicap Golfers and 15 High Handicap Golfers. Both handicap groups produced a similar weight transfer pattern for the driver (figure 7.5), although small mean CP_{yt} % differences were noted at MB, LB, ED, MD, BC and MF. For the two backswing events (MB and LB) the Low Handicap Golfers displayed a smaller mean CP_{yt} % than the High Handicap Golfers. Conversely at ED, MD and BC the High Handicap Golfers displayed a smaller mean CP_{yt} % than the Low Handicap Golfers. After BC the two handicap groups exhibited different weight transfer patterns with the Low Handicap Golfers exhibiting a larger decrease in the mean CP_{yt} % and completed the swing (MF) with a smaller mean CP_{yt} % than the High Handicap Golfers.

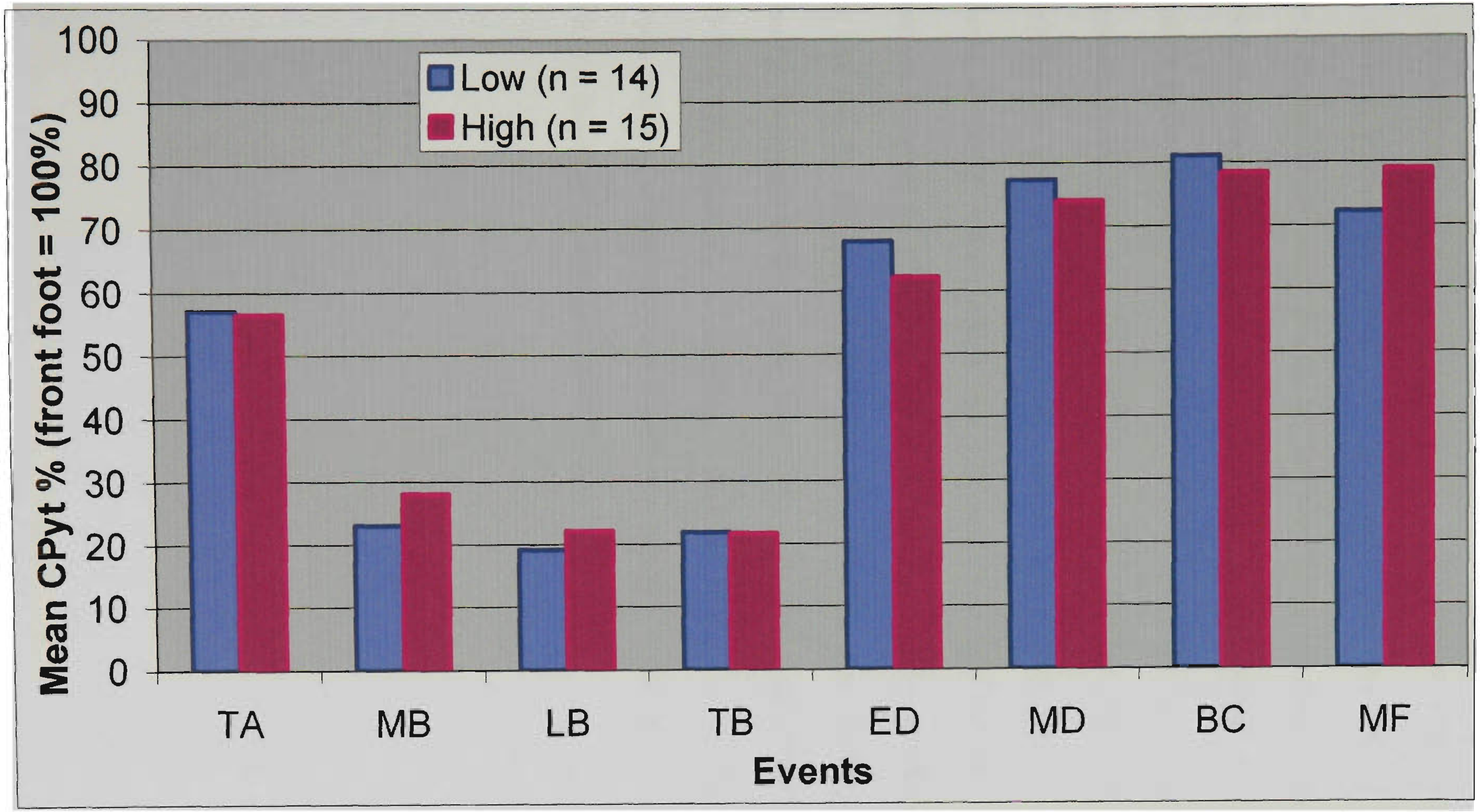


Figure 7.5: Mean CP_{yt} % trace of the 'typical golfers group' Low Handicap Golfers (n = 14) and High Handicap Golfers (n = 15) for the eight golf swing events for the driver

The independent samples t-test displayed no significant difference between the 'typical' Low Handicap Golfers (n = 14) and 'typical' High Handicap Golfers mean CP_{yt} % at the eight golf swing events for the driver (table 7.5.1). The reason no significant differences were shown is because the 'typical' Low Handicap Golfers and 'typical' High Handicap Golfers are almost the same groups as the SPANOVA handicap groups, except nine golfers have been taken out of the analysis ('back foot golfers group' n = 6, 'late translation golfers group' n = 2, 'irregular golfer' n = 1). The statistical information that is important in this analysis is the p values, effect size (d) and the n required (for a large power) for the 'typical' Low Handicap Golfers and 'typical' High Handicap Golfers compared to the p values, effect size (d) and the n required for the SPANOVA comparison between the 19 Low Handicap Golfers and 19 High Handicap Golfers. The effect size (d) for the 'typical' Low Handicap Golfers and 'typical High Handicap Golfers has increased for five (TB to MF) of the eight golf swing events compared to the SPANOVA effect size (d). Conversely, a decrease in the p value and n required was displayed for four events between the cluster analysis handicap comparison and the SPANOVA handicap comparison (table 7.5.1).

Table 7.5.1: Results of the independent samples t-test and comparison between the 'typical' Low Handicap Golfers and 'typical' High Handicap Golfers to the SPANOVA for the p value, effect size and n required to produce a large power (0.8)

Event	Independent Samples t-test for 'typical golfers group'				SPANOVA				Cluster – SPANOVA		
	p (two-tailed)	Effect Size (d)	Conven.	N	p (two-tailed)	Effect Size (d)	Conven.	n	p	(d)	n
TA	.832	.070	< Small	>1000	.745	.137	< Small	>1000	.087	-.070	Same
MB	.206	.438	Small	85	.053	.778	Medium	23	.153	-.34	62
LB	.424	.265	< Small	300	.319	.430	Small	80	.105	-.170	220
TB	.946	.020	< Small	>1000	.991	.005	< Small	>1000	-.050	.015	Same
ED	.144	.564	Medium	57	.224	.387	Small	80	-.080	.177	-23
MD	.299	.405	Small	100	.613	.158	< Small	>500	-.310	.247	-400
BC	.509	.290	< Small	180	.895	.037	< Small	>1000	-.390	.253	-820
MF	.250	.475	Small	70	.163	.424	Small	80	.087	.051	-10

ED, MD and BC displayed the largest increase in the effect size for the cluster analysis handicap comparison compared to the SPANOVA handicap comparison. At ED the increase in the effect size has seen the convention go from small (d = .387) to medium (d = .564), while MD shifted from a below small effect size (d = .158) to a small effect size (d = .405). For BC, the effect size did not change conventions although a small (d = .290) effect size was almost produced. The increased effect size for these events was produced because of a larger between-handicap group mean CP_{yt} % difference and a smaller within-handicap group variability for the cluster analysis handicap comparison compared to the SPANOVA handicap comparison (table 7.5.2). This resulted in a smaller p value, for all three events, and in turn reduced the n required to produce a large power for the cluster analysis handicap comparison compared to the SPANOVA handicap comparison (table 7.5.1).

Table 7.5.2: Comparison of the Mean CP_{yt} % difference for the handicap groups for the cluster analysis and SPANOVA at ED, MD and BC

Event	Cluster Analysis					SPANOVA					Cluster - SPANOVA
	Low (n = 14)		High (n = 15)		Mean CP_{yt} % Diff.	Low (n = 19)		High (n = 19)		Mean CP_{yt} % Diff.	Mean CP_{yt} % Diff.
	Mean	*SD*	Mean	*SD*		Mean	*SD*	Mean	*SD*		
ED	68.9	*10.3*	62.2	*10.1*	**6.7**	65.0	*13.9*	60.0	*12.9*	**5.0**	**1.7**
MD	77.4	*9.1*	74.0	*8.4*	**3.4**	72.3	*12.9*	71.5	*11.8*	**0.8**	**2.6**
BC	81.1	*13.5*	78.4	*9.3*	**2.7**	73.4	*18.9*	74.1	*13.0*	**0.7**	**2.0**

A minor increase in the effect size (d) between the cluster analysis handicap comparison and the SPANOVA handicap comparison was displayed for TB (.015) and MF (.051). For TB (d = .020) a below-small effect size has been maintained, while a small effect size was preserved at MF (d = .475) between the cluster analysis handicap comparison compared to the SPANOVA handicap comparison (table 7.5.1). The below-small effect size at TB indicates that the mean CP_{yt} % effect between the handicap groups is not worth examining further, considering over 1000 golfers are required within each handicap group to produce a large power. However, the small increase in the effect size for MF has seen the number of golfers required (n = 70) reduce by ten to provide a large power. The p value for the cluster analysis handicap comparison (p = .250) at MF is larger than the p value for the SPANOVA handicap comparison (p = .163). This may be due to the reduced number of golfers in the cluster analysis compared to the SPANOVA handicap comparison.

For TA, LB and MB the effect size for the SPANOVA handicap comparison was larger than the effect size for the cluster analysis handicap comparison (table 7.5.3). The effect size convention for TA remained the same (< small), while both MB and LB exhibited a change in the effect size conventions. MB went from a medium effect size (SPANOVA) to a small effect size (cluster analysis) and LB changed from a small effect size (SPANOVA) to a below small effect size (cluster analysis). For MB and LB the effect size conventions have changed because the handicap mean CP_{yt} % difference has reduced, yet the within-handicap group SD has remained the same (table 7.5.3). The reduced effect size has seen the number of golfers required for a large power increase for MB (n = 85), LB (n = 300) and TA (n = > 1000). Further analysis involving the mean CP_{yt} % difference between the handicap groups at TA and LB would not be recommended due to the below small effect. However, MB has displayed a large mean CP_{yt} % difference between the handicap groups and by increasing the sample population the difference may become more apparent.

Table 7.5.3: Comparison of the Mean CP_{yt} % difference for the handicap groups for the cluster analysis and SPANOVA at TA, MB and LB

Event	Cluster Analysis						SPANOVA						Cluster - SPANOVA
	Low (n = 14)		High (n = 15)		Mean CP_{yt} % Diff.	Effect Size (d)	Low (n = 19)		High (n = 19)		Mean CP_{yt} % Diff.	Effect Size (d)	Mean CP_{yt} % Diff.
	Mean	*SD*	Mean	*SD*			Mean	*SD*	Mean	*SD*			
TA	57.1	*5.5*	57.6	*7.1*	**0.5**	.070	57.6	*5.8*	57.2	*7.3*	**0.4**	.137	**0.1**
MB	23.1	*9.7*	28	*11.2*	**4.9**	.438	24.8	*8.1*	30	*11*	**5.2**	.778	**-0.3**
LB	19.1	*8*	22.2	*12.7*	**3.1**	.265	20	*9.6*	24.7	*13.4*	**4.7**	.430	**-1.6**

7.6 SUMMARY OF THE CLUSTER ANALYSIS

The cluster analysis has displayed four weight transfer styles. This indicates that a screening process must take place prior to weight transfer analysis studies to classify the golfers accordingly. The handicap comparison, in this analysis, has displayed no significant difference between the 'typical' Low Handicap Golfers or 'typical' High Handicap Golfers mean CP_{yt} % for the eight golf swing events for the driver. However, positive results were displayed due to the increased effect size for five of the golf swing events. This was a direct relationship to an increased between-handicap group mean CP_{yt} % difference and a decreased within-handicap group variance. Additional analysis involving a larger sample population (n = 50 to 80) within each handicap group for the 'typical golfers group' may increase the likelihood of finding a significant difference at the eight golf swing events for the driver.

The non-significant difference between the handicap groups for the 'typical golfers group' does not mean that handicap differences do not exist within the remaining three weight transfer groups. This facet needs to be examined with more subject numbers to perform a more statistically powerful analysis.

CHAPTER 8

PRACTICAL IMPLICATIONS

It is clear from the golf coaching literature that weight transfer is not fully understood. Controversies and misconceptions exist across the golf coaching texts as to what weight transfer actually is, and its role in the golf swing. However, it is apparent that golf coaches agree an ideal weight transfer pattern should be performed to produce optimal performance outcomes. Norman (1995) describes the sequence as;

- Weight is evenly balanced between the feet at AD.
- During the backswing the weight is transferred towards the back foot and remains here until the completion of the backswing.
- The downswing is initiated from the legs up and a rapid weight transfer from the back foot to the front foot is produced during this phase.
- After BC the weight transfer ceases and the golfer tries to maintain a balanced finish position.

However, no scientific study has proved that this style or any style produces the best performance outcomes. It is evident from this study and previous studies (eg. Koslow 1994) that golfers of like and different handicaps produce varying weight transfer patterns. No study to date has proved that one weight transfer style (particularly the ideal weight transfer style as described in the coaching literature) produces better performance outcomes than other weight transfer patterns, such as those found in this study - Back Foot, Late Translation and Irregular styles - and those found by Koslow (1994) - Reverse and Abbreviated styles). This would suggest, in this instance, that coaching is based on anecdotal evidence and further investigation is warranted.

It is also unclear from the golf coaching literature about the importance of weight transfer and whether it should be taught as a fundamental skill of the swing. The Professional Golfers Association (1990) suggest it should and recommend weight transfer should be mastered prior to learning more advanced swing mechanics. However, Cooke (1987) and Madonna (2001) suggests weight transfer should not be taught; instead it should be a natural occurrence of the golf swing. Data presented in this thesis does not answer this question, however in speculating it would suggest weight transfer is occurring naturally and is not forced. This conclusion has been made because weight transfer style appeared to be independent of handicap, plus the golfers tested were mostly amateurs who were not receiving regular tuition from golf coaches). Further investigation is warranted to examine weight transfer and its relationship to swing mechanics. This study did not focus on the mechanics of the swing and will not speculate any further for this reason

The golf coaching literature places a strong focus on swing mechanics and kinematic cues (Cooke 1987; Madonna 2001; Newell and Foston 1995) and often neglect weight transfer. In all of these coaching texts a large emphasis is placed on the golfer's body position and golf club position throughout different phases of the swing, while little or no emphasis is placed on how the golfer should transfer weight throughout the golf swing. Again, this lack of quantitative description of weight transfer may be due to the fact that golf coaches don't fully understand the mechanics or the role of weight transfer in the golf swing.

The data presented in this thesis provides the golf coach with increased knowledge to better understand weight transfer patterns within the golf swing. Golfers of varying handicaps can produce like or different weight transfer patterns. It is unclear if these weight transfer patterns are a function of swing mechanics, coaching or anatomical/physical factors. However, by being aware of the different weight transfer patterns that golfers produce, coaches may be able to translate into a greater understanding of how the swing mechanics and weight transfer are related in the golf swing. This increased knowledge may allow golf coaches to provide the golfer with adequate information to adjust his/her technique allowing him/her to hit the ball with optimal outcomes. More research is required in this area, especially coupling swing mechanics with weight transfer patterns.

CHAPTER 9

CONCLUSIONS

All Golfers, regardless of handicap, displayed a difference in weight transfer patterns during the downswing and follow-through events for the driver, 3 iron and 7 iron. For the remaining events during take-away and the backswing phases, All Golfers exhibited weight transfer patterns that were similar for the three golf clubs. At events ED and MF All Golfers produced a mean CP_{yt} % sequence between the driver, 3 iron and 7 iron. At ED, All Golfers produced larger mean CP_{yt} % for the longer shafted golf clubs compared to the shorter shafted golf clubs (driver > 3iron > 7 iron). Conversely, at MF, All Golfers displayed a larger mean CP_{yt} % for the shorter shafted golf clubs (7 iron and 3 iron) compared to the longer shafted golf clubs (driver, 3iron). This result indicates that the length of the golf club contributes to the golfers weight transfer pattern during the latter phases of the golf swing (i.e. downswing, follow through).

In examining the weight transfer patterns of the Low Handicap Golfers compared to the High Handicap Golfers, it was revealed there was no significant difference in any weight transfer parameter. This was due to a large within-handicap group variance and a small between-handicap group difference, which resulted in medium, small and less-than-small effect sizes conventions for the eight golf swing events. This warranted further investigation, a cluster analysis, which found four valid weight transfer styles for the 38 golfers. The four groups were, 1. 'Typical Golfers group' (n = 29), 2. 'Back Foot Golfers group' (n = 6), 3. 'Slow Translation Golfers group' (n = 2), 4. 'Irregular golfer' (n = 1).

These four weight transfer styles were not dependent on handicap level suggesting that a golfer's scoring ability does not influence the way they transfer weight during the golf swing. From this result it was hypothesized that the four weight transfer styles produced by the golfers could be a function of swing mechanics or previous coaching. Establishing the four weight transfer styles raised several other issues that were not encompassed in the original aims. Due to time constraints some of these issues could not be addressed and a number of recommendations have been made for future weight transfer studies to address these issues:

- Classification of golfers into weight transfer styles is required prior to handicap comparison and golf club comparison;
- Larger sample population required to investigate the handicap comparison within the 'back foot golfers group', 'slow translation golfers group' and 'irregular golfer' weight transfer styles.
- Examine the weight transfer patterns at more swing events. For example, the addition of ED, not used in previous studies, provided valuable information. However examination of the data indicated that potentially important information may still be missed between some events (especially where large movements occur in and around TB, ED and MD). The addition of events between TB, ED and MD may provide a more thorough examination of the weight transfer patterns between different handicap golfers for various golf clubs and within the weight transfer styles.

- The research has examined the between-feet weight transfer patterns of the golf swing. However, throughout the golf swing a golfer also exhibits movement in an anterior/posterior direction or heel-to-toe movement. In addition to the previous recommendations this parameter should also be examined to give the golf coach, professional and player a holistic view of the weight transfer patterns exhibited throughout the golf swing.

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APPENDIX 1

Consent form for participants

Victoria University of Technology

Consent Form for Club Golfers Involved in Research

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study into the weight transfer patterns of golf. The aim of this study is to compare the weight transfer patterns of golfers with varying ability. You will be asked to come along to the Biomechanics laboratory at Victoria University to undertake golf swing testing. Upon completion of testing you will be given a biomechanical analysis of your golf swing and weight transfer. Data obtained from all subjects will be used to determine an ideal weight transfer pattern for the golf swing.

CERTIFICATION BY SUBJECT

I,

of

certify that I am at least 18 years old and that I am voluntarily giving my consent to participate in the experiment entitled:

Weight Transfer Patterns Between Different Skill Levels and Clubs in Golf.

being conducted at Victoria University of Technology by:
Dean Brown

I certify that the objectives of the experiment, together with any risks to me associated with the procedures listed hereunder to be carried out in the experiment, have been fully explained to me by:
Dean Brown

and that I freely consent to participation involving the use on me of these procedures.

Procedures:

> **After adequate warm up, I will perform 30 golf shots from the hitting area set up for this purpose in the laboratory. During each swing, a force plate located below the floor will measure my weight transfer and the swing will be videoed. All data will be kept confidential and can only be accessed by the researchers (Dean Brown, Kevin Ball and Dr Russell Best).**

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this experiment at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: ....

Witness other than the experimenter: **Date:....................**

....

Any queries about your participation in this project may be directed to the researcher (Dean Brown: ph. 9248 1133 or 0402 123 531). If you have any queries or complaints about the way you have been treated, you may contact the Secretary, University Human Research Ethics Committee, Victoria University of Technology, PO Box 14428 MC, Melbourne, 8001 (telephone no: 03-9688 4710).

APPENDIX 2

<u>Personal communication from Kevin Ball</u>

Appendix 2A - Comparison of Fz% and CP

The aim of this examination was to compare Fz% under each foot and CPy% between the feet. Both measures have been used to indicate weight position and transfer in golf studies.

Sixty-two golfers performed 10 swings with the driver while standing on two force plates; one under each foot. CPy% between the feet and Fz% under each foot was quantified at eight swing events. CPy% and Fz% means were calculated at each of the swing events for comparison and correlations were performed on this data. Correlations were also performed between CPy% and Fz% data for each individual, with a mean correlation also obtained.

Observation of the group mean CPy% and Fz% data across the eight swing events indicated very similar patterns and values (table 1 and figure 1). This was supported by strong correlation coefficients between mean CPy% and Fz% on a group basis ($r = 0.999$, $p<0.001$, N=62). As well, weight position at the eight different swing events was similar, with a mean absolute difference of 1.5%. CPy% returned slightly lower values during backswing (MB, LB and TB) and slightly higher values during downswing (ED, MD and BC) and in follow through (MF).

Table 1: Group means for CPy% and Fz% at eight swing events (N=62)

	TA	MB	LB	TB	ED	MD	BC	MF
CPy%	57	28	22	23	63	70	71	66
Fz%	57	29	24	26	62	68	69	64

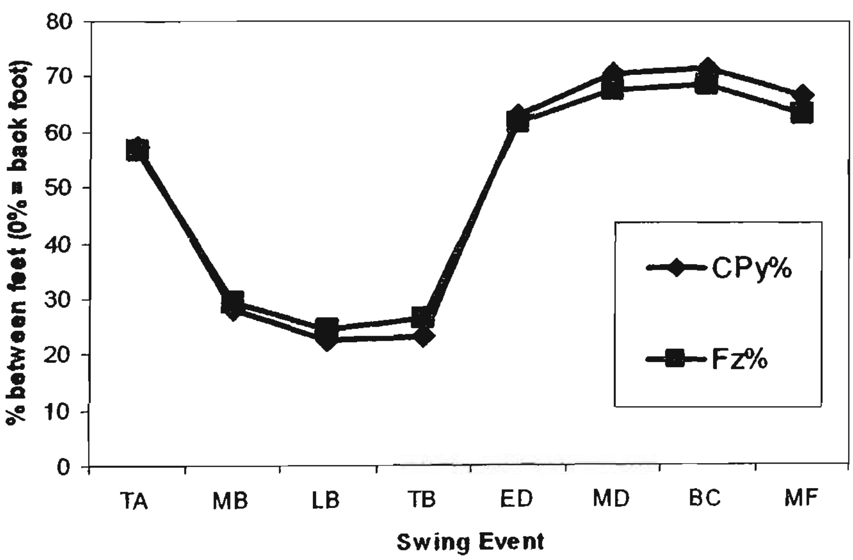


Figure 2.3: Comparison of CPy% and Fz% between the feet during the golf swing (mean values at each event; N=62 golfers).

CPy% and Fz% measures also showed strong similarities on an individual basis. The mean correlation for all individuals between CPy% and Fz% was r=0.996 (range r=1.000 – 0.947; all significant at p<0.001). There were a number of golfers who showed large differences (>5%) at certain events, particularly at TB and MF where horizontal forces were high.

As the correlations between CPy% and Fz% were strong for this group, statistical analyses involving either measure would be expected to be similar. This means that statistical analyses for studies using either measure can be compared with confidence that the type of measure is not influencing the data. For example the correlations between clubhead speed and CPy% range (r=** p=**) and clubhead speed and Fz% () were very similar.

As mean differences between CPy% and Fz% values were generally low (≤3% on a group basis) comparison of CPy% and Fz% values may also be performed when examining group-based data. However, as some individuals produced large (>5%) differences, the comparisons on an individual basis are likely to hold more error and should be treated with caution.

Perspective Correction
Kevin Ball

Horizontal screen coordinates (parallel to the line of shot)

As the overhead video camera image was required to be offset to see the feet for digitizing, a perspective correction was required for horizontal screen coordinates (coordinates parallel to the line of shot). This was performed using an adaptation of the method presented by Begg *et al.* (1990).

To calibrate and calculate the required perspective correction, a rectangular calibration board (0.96 x 0.72 m) was used. Prior to testing, the board was positioned over the hitting area, encompassing the position of the force plates, feet and ball position at TA. The top left corner of the calibration board was positioned over the top left corner of the left force plate. The axes of the calibration board were aligned with the force plate axes.

The video image of the calibration board was recorded. The four corners of the calibration board were digitized from this image using Peak Motus. This was repeated four times to reduce digitizing error, with the mean of the four trials used to represent the coordinates of the four corners.

Referring to figure 2, extending the two sides (line A-B and line C-D) of the calibration device defined the vanishing point (VP; the point at which the two 'parallel' sides intersect).

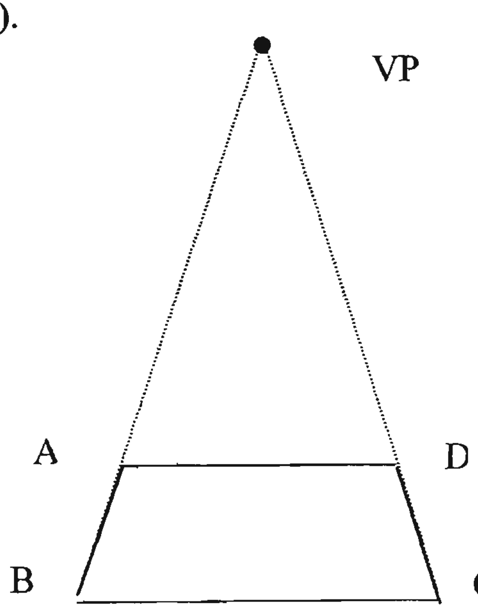


Figure 2: Location of the vanishing point (VP) using the sides of the calibration board.

The coordinates of A, B, C and D were shifted such that the middle of the calibration board was (0,0). The vertical coordinate of VP was then established using equation (2).

$$\frac{u-u1}{u1-u2}=\frac{v-v1}{v1-v2} \qquad (1)$$

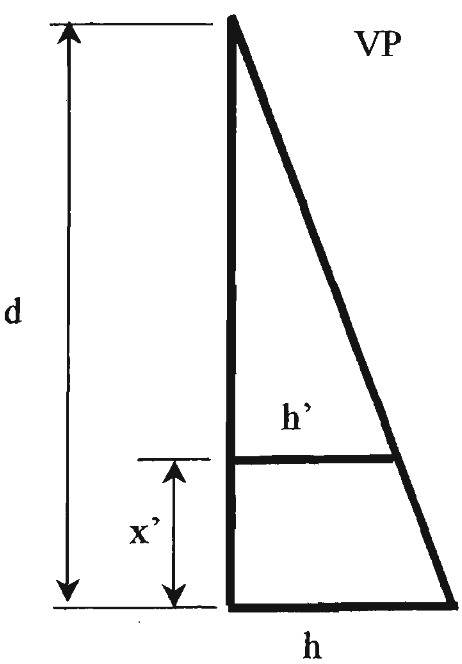
where u = horizontal screen coordinate at VP
u1 = horizontal screen coordinate at A
u2 = horizontal screen coordinate at B
v = vertical screen coordinate at VP
v1 = vertical screen coordinate at A
v2 = vertical screen coordinate at B

As the calibration device was in the centre of the screen with its vertical axis aligned with the vertical axis of the video, the horizontal coordinate of VP will be at the horizontal position on the screen; u = 0 (Note: only one side of the calibration board required to establish v in this case, as u = 0).

Rearranging (1)

$$v=\left(\frac{u-u1}{u1-u2}\right)\times(v1-v2)+v1 \qquad (2)$$

Referring to figure 2, using VP, perspective adjustment was made using the simple geometrical relationship:



Perspective Equation*

h' = h (1 – x'/d)

** Obtained from the relationship of the smaller and larger triangle i.e. the ratio of the large triangle d:h will be the same as the ratio of the small triangle (d-x'):h'*

Figure 3: Geometrical relationship and equation used to adjust points due to perspective error.

Assessment of error in perspective adjustment

To assess the horizontal axis error of the adjustment and calibration system for the foot digitising system, 26 points with known coordinates were digitised using Peak MOTUS. The digitised and known locations were then compared to establish mean and maximum errors produced by the system.

Mean differences between measured and true coordinates were 1.25 mm with the maximum difference of 2.9 mm (table 1).

Table 1: Comparison of known and digitised measures: horizontal screen axis. All measures in mm.

	Known Measure	Digitised Measure	Difference
1	0	0.0	0
2	239	238.7	0.3
3	479	479.7	0.7
4	720.5	720.9	0.4
5	117	115.8	1.2
6	355	352.9	2.1
7	598.5	596.7	1.8
8	0	-0.4	0.4
9	238	236.2	1.8
10	478	479.5	1.5
11	720	718.4	1.6
12	118	118.4	0.4
13	599	597.8	1.2
14	0	1.7	1.7
15	236	238.2	2.2
16	720	720.3	0.3
17	117	119.9	2.9
18	597	599.5	2.5
19	0	1.7	1.7
20	238	238.1	0.1
21	478	478.9	0.9
22	720	721.8	1.8
23	118	117.9	0.1
24	358	360.5	2.5
25	600	601.1	1.1
Mean			**1.25**

Vertical screen coordinates (perpendicular to the line of shot)

As there was no offset to the vertical axis of the image, no perspective adjustment was required. This was confirmed by larger errors produced when perspective adjustment was attempted on vertical screen coordinates compared to when a simple scaling procedure was used. The most accurate data was obtained when two scaling factors were used: one for the feet and one for the ball position. The two scaling factor points were located near the area where the feet were

positioned by each golfer and were approximately 0.35 m apart. For the ball, as the distance of the ball was measured relative to the front foot toe, two points, one in the area that the front foot was positioned by each golfer and one near where the ball was positioned were digitized. Comparison with 8 known measures indicated a mean error of 1.1 mm, with the maximum error of 2.2 mm (table 2).

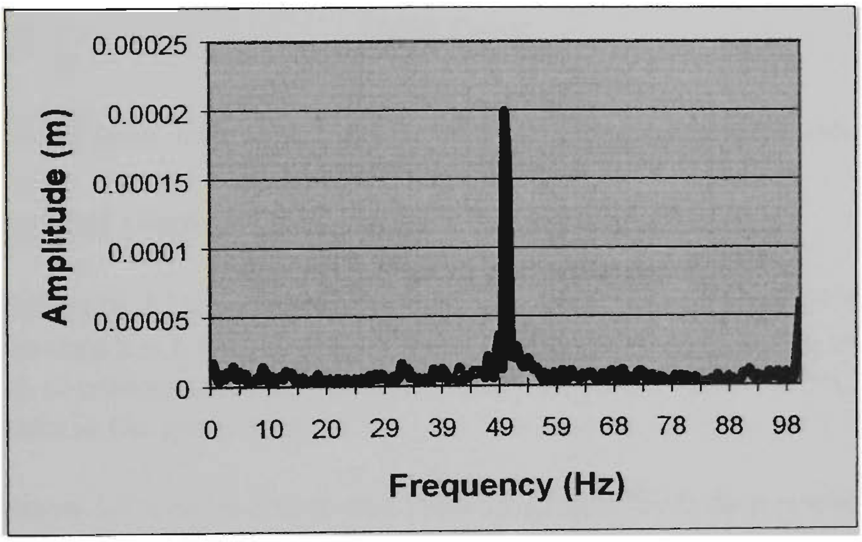
Table 2: Comparison of known and digitised measures: vertical screen axis.
All measures in mm.

	Known Measure	Digitised Measure	Difference
Feet	121.0	120.0	1.0
	119.8	120.0	0.2
	239.6	242.0	2.4
	242.0	242.0	0.0
	242.2	242.0	0.1
	244.4	242.0	2.4
	361.8	360.0	1.8
	360.6	360.0	0.6
Mean			**1.1**
Ball	960.0	962.0	2.0
	960.0	962.0	2.0
	964.6	962.0	2.6
	964.6	962.0	2.6
Mean			**2.3**

Note: These error values were not used to indicate overall error in the foot digitizing process as it was considered more appropriate to indicate error based on actual testing processes.

Appendix 2C - Smoothing

Observation of the raw force plate data for golf swings and for static loading situations (weights placed on force plate) indicated a high frequency noise existed in force and moment data. Figure 1 shows a spectral analysis of CP when the force plate was loaded with a 750 N weight, showing a relatively large 50 Hz spike with low amplitude noise across the frequency spectrum which was slightly larger amplitude between approximately 30 Hz and 60 Hz. Figures 2 and 3 show an example CP displacement and velocity graph from a



golf swing with this noise evident. All curves have been examined from address (approximately 0.25 s before TA) to mid follow through.

Figure : Spectral analysis of CP with a 750 N weight placed on the force plate

Note: Calculation on 1024 samples (2.048 s at 500 Hz). Unusual time interval due to the FFT calculation requiring a value which is a power of 2. Changing the sample rate would have been inconsistent with the testing sample rate and may have produced different results.

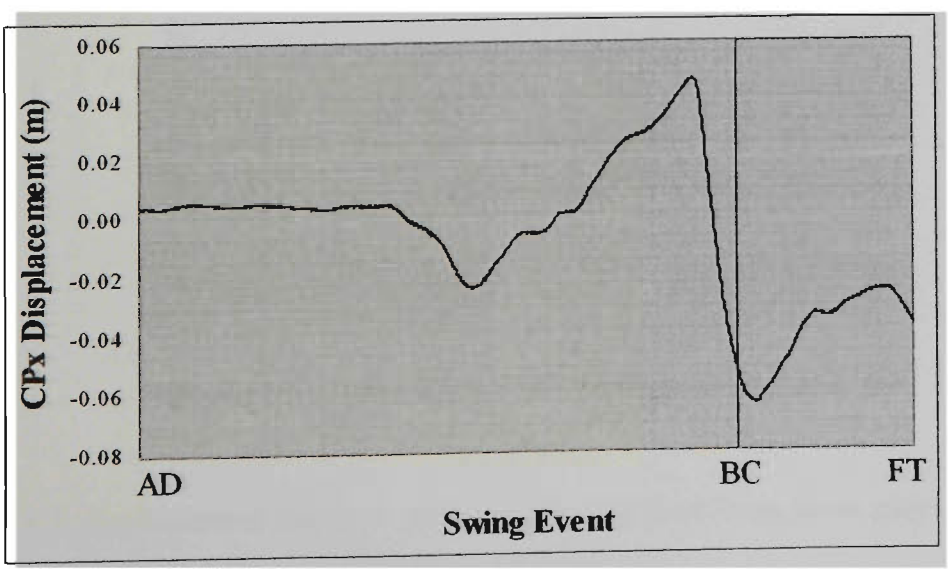


Figure 1: Raw CP curve from a golf swing with low amplitude, high frequency noise evident.

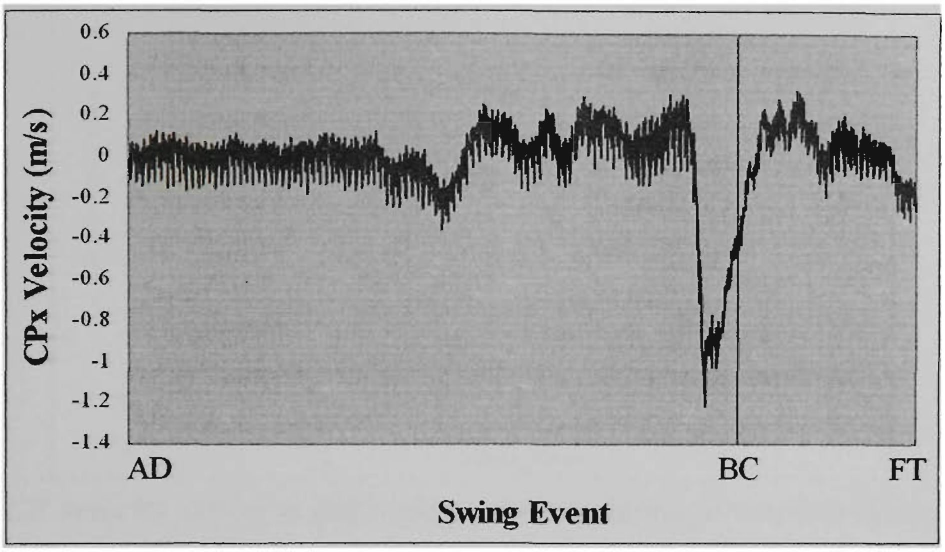


Figure 2: Raw CP Velocity from a golf swing with high frequency noise evident.

Force and moment data

A low pass pre-filter (16.4 Hz) was inserted into the AMLAB software. While no frequency domain data has been presented in the literature for weight transfer in the golf swing, it was considered that no frequencies above 16 Hz would be expected in weight transfer data in the golf swing.

Figures 3 and 4 show CP displacement and velocity graphs from data smoothed with the 16.4 Hz pre-filter. Noise still existed in the data even after pre-filtering at 16.4 Hz. Spectral analysis indicated that some of this noise was 50 Hz, indicating that noise was added after the pre-filtering but before the data was stored. This researcher assumed the source of this noise was the ADC board. Changing the pre-filter had little effect on this noise. As such, it was decided that smoothing the CP displacement data was required.

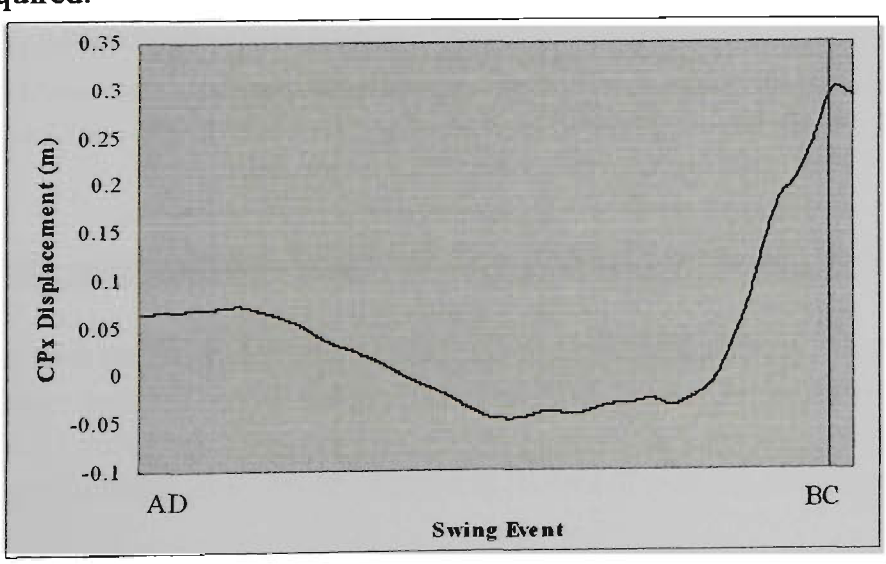


Figure 3: CP displacement during a golf swing calculated from force plate data pre filtered at 16.4 Hz.

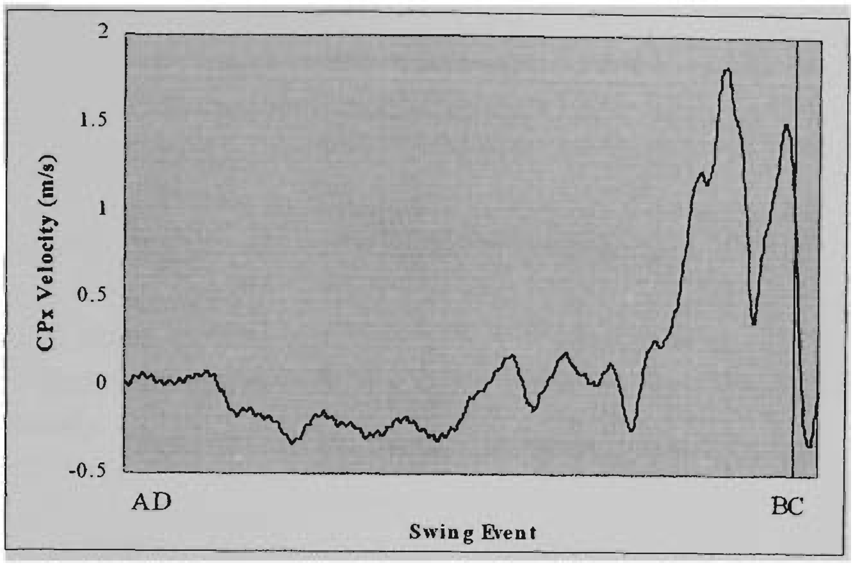


Figure 4: CP velocity during a golf swing calculated from force plate data pre filtered at 16.4 Hz.

CP Displacement

To decide on an appropriate smoothing cut-off frequency for CP displacement and velocity, a combination of methods was used to gather information on the data. These were:

1. Automatic methods for determining optimal smoothing frequency.
2. The effect of different smoothing cut-off frequencies on parameters of interest.
3. Observation of raw and smoothed data curves (displacement and speed)

Ball et al. (2001) recommended a combination of the above methods as well as spectral analysis for thorough assessment of smoothing requirements. However, as the golf swing is non-stationary, accurate spectral analysis would have required the use of wavelets. Wavelet software was unavailable to this researcher at the time of deciding upon a smoothing cut-off frequency and development of this software was considered beyond the scope of this study. As well, no frequency domain data for the golf swing exists in the literature so the decision of smoothing cut-off frequency was made based on methods 1-3 only.

<u>1. Automatic methods for determining optimal smoothing frequency</u>

Three automated methods for calculating an optimal smoothing cut-off frequency were applied to CP data; Challis (1999), Yu *et al.*, (1999) and Winter (1990). Table 1 reports the mean cut-off frequencies returned by each of the methods (5 golf swing trials from randomly selected golfers examined).

Table 1: Cut-off frequencies found by different methods to be optimal.

	Displacement	
	CPx	CPy
Challis (1999)	14.0	15.2
Yu et al. (1999)	24.8	24.9
Winter (1990)	14.0	15.0

The Challis (1999) method and the Winter (1990) method produced similar cut-offs for both CPy and CPx. The Yu et al. (1999) method returned larger values than the Challis (1999) and Winter (1990) methods of approximately 25 Hz, due to the large sample rate in this study (500Hz; The Yu method is largely sample rate based).

2. The effect of different smoothing cut-off frequencies on parameters of interest.

Inspection of parameters of interest (CPx%, CPy% at events, maximums and minimums) indicated that for most parameters, minimal change existed using cut-off frequencies from 15-25 Hz. At 10 Hz, some change was evident and at 5 Hz the change was relatively large for some parameters. Figure 5 shows an example of the effect of different smoothing cut-off frequencies on the values of CPy% maximum and CPy% minimum for a single trial. At 10 Hz, CPy% maximum began to change more considerably than for the higher frequencies, indicating that the smoothing is influencing values and that signal as well as noise may be being eliminated. It should be noted, though, that the differences are in practical terms still small (less than CPy%=1% change). For other parameters (e.g. velocity) this change was more considerable. These figures were chosen to show the point at which the smoothing cut-off began to increase in effect on parameters.

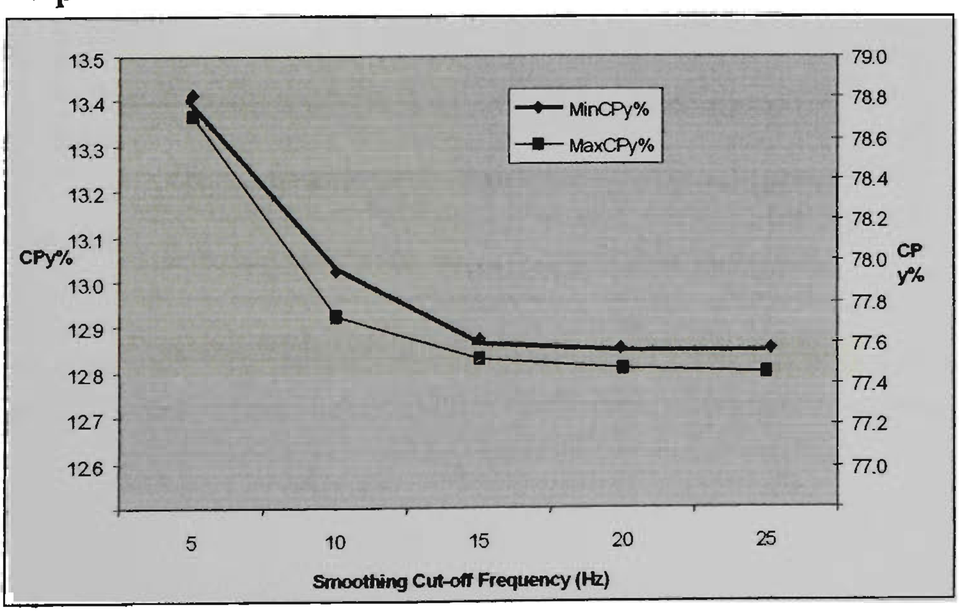


Figure 5: Effects of different cut-off frequencies on parameters of interest (CPy% maximum and CPy% minimum)

3. Observation of raw and smoothed data curves (displacement and velocity)

Figures 6 and 7 show raw and smoothed CP displacement and velocity curves for a single trial across the whole swing from address to mid follow through. The same data is presented again for downswing only (TB – MF) to enable better inspection of the changes due to smoothing. Inspection of displacement curves smoothed at a range of frequencies from 5 Hz to 30 Hz indicated that little change existed between raw and smoothed data from 15-30 Hz. Slight changes were noted on the later stages of downswing at 5 Hz and 10 Hz, which were more particularly noticeable in velocity data at the peaks. This supported the findings of parameter changes from the previous section.

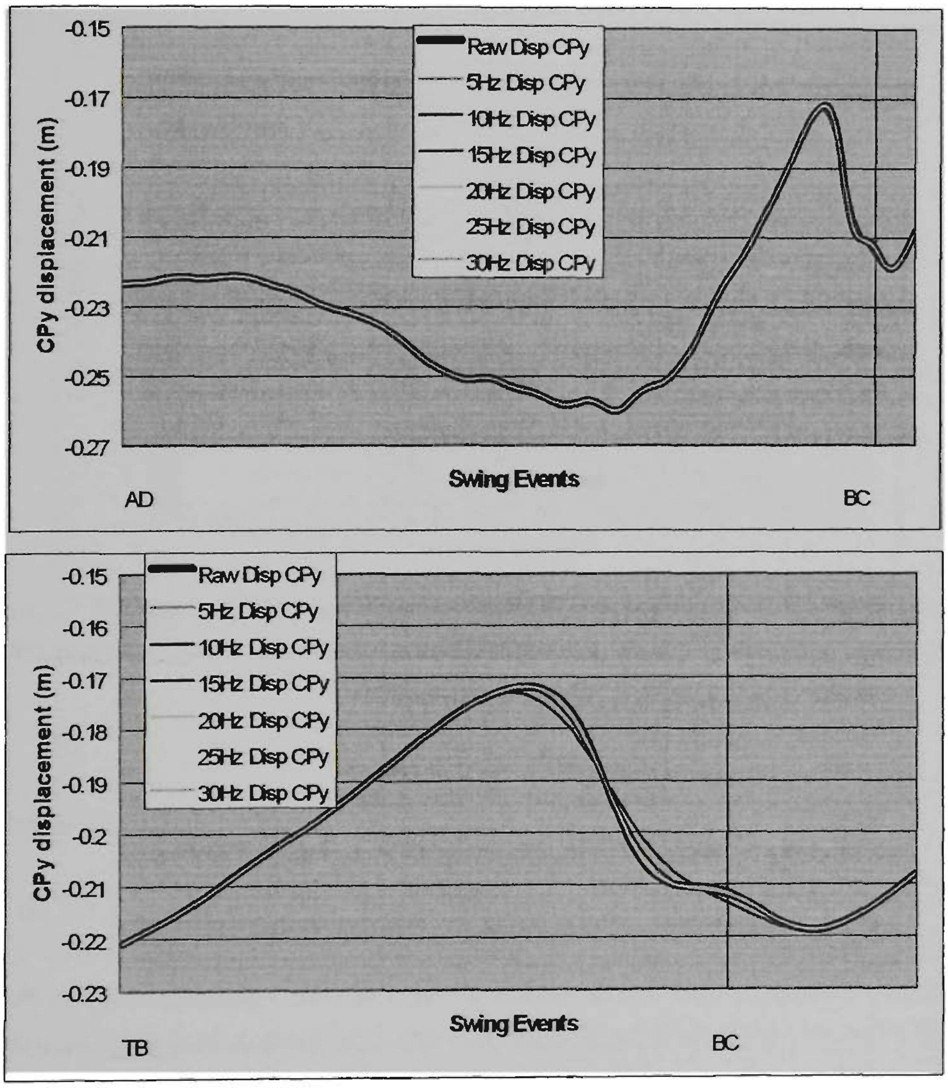


Figure 6: Example CP displacement data: raw and smoothed at different cut-off frequencies (same curve with second graph focusing on downswing).

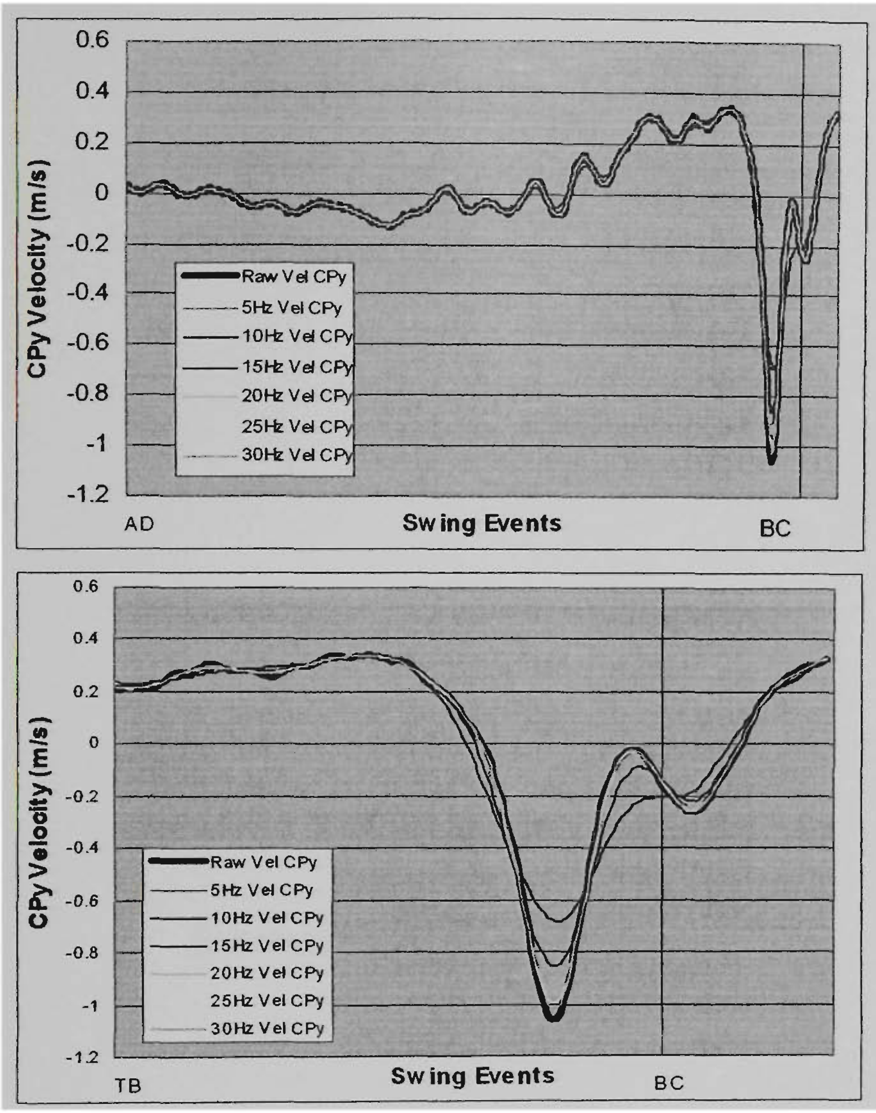


Figure 7: Example CP velocity data: raw and smoothed at different cut-off frequencies (same curve with second graph focusing on downswing).

Smoothing summary

A cut-off of 15 Hz was decided upon for both CP displacement and velocity data. This was chosen as it was indicated by 2 of the 3 automatic methods and was the lowest smoothing cut-off before parameters were altered considerably. Observation of raw and smoothed curves indicated that this cut-off eliminated high frequency noise without affecting the underlying pattern of the curves to any extent. No distinction was made between CPy and CPx. Although it might be expected that there would be differences in the nature of the movement between axes, there was no consistent trend from the analysis to indicate that there was a case for treating them separately.

APPENDIX 3

Summary sheets for the 38 golfers

Driver

Golfer	AGU Handicap	Age	Handicap Group	Mean CP_{yt} %							
				TA	MB	LB	TB	ED	MD	BC	MF
1	-2	24	Low	55.2	30.2	30.4	31.7	50.1	56.8	52.2	35.5
2	-2	22	Low	45.6	31.0	29.3	40.9	66.6	62.6	50.3	28.8
3	1	19	Low	55.0	29.2	17.2	26.8	44.7	63.6	78.8	64.1
4	4	23	Low	55.5	26.1	17.3	22.0	75.1	92.6	101.9	83.8
5	4	20	Low	65.2	26.8	20.9	24.6	68.5	75.8	80.2	73.0
6	4	24	Low	55.2	15.0	3.2	16.9	56.6	71.7	75.7	81.7
7	4	20	Low	55.9	17.2	15.9	25.7	56.6	60.2	59.3	58.3
8	4	23	Low	47.9	19.7	23.6	25.5	67.7	79.5	90.9	93.6
9	5	26	Low	55.0	20.6	18.9	3.4	72.9	69.0	64.3	59.5
10	5	20	Low	55.6	26.8	11.2	10.6	65.7	82.9	97.2	98.9
11	6	19	Low	60.4	19.8	20.3	42.5	75.5	61.2	34.0	40.0
12	6	21	Low	53.2	41.0	30.6	15.6	76.2	73.7	67.0	53.8
13	6	36	Low	56.1	18.1	4.9	8.5	31.4	50.2	67.6	78.6
14	6	32	Low	63.1	9.0	9.5	37.5	78.0	85.8	96.8	83.4
15	7	63	Low	62.6	26.9	31.3	27.9	61.8	84.9	78.0	37.2
16	7	18	Low	56.6	34.2	28.8	29.4	75.7	79.6	82.5	70.7
17	7	53	Low	58.3	28.8	27.3	21.2	60.0	59.8	55.4	33.1
18	8	50	Low	60.1	11.6	16.7	23.9	68.5	79.0	82.8	76.6
19	10	33	Low	58.1	19.6	22.4	17.0	83.1	85.7	80.0	77.9
Mean	5	29		56.6	23.8	20.0	23.8	65.0	72.3	73.4	64.7
SD	3	13		4.7	8.1	8.6	10.4	12.9	11.9	17.9	21.5
20	11	20	High	51.5	27.2	25.8	37.5	44.1	71.4	82.5	82.1
21	11	26	High	57.9	33.8	30.7	21.0	76.4	79.2	88.4	95.0
22	12	46	High	57.3	38.3	33.6	5.3	71.6	78.9	88.3	98.4
23	13	49	High	51.5	39.4	10.0	7.6	29.4	45.7	57.8	60.2
24	13	52	High	54.8	11.8	2.9	8.4	67.6	77.1	75.7	66.4
25	13	59	High	56.8	37.0	30.8	18.6	57.2	81.8	83.2	86.7
26	14	59	High	53.8	38.7	37.7	35.4	58.6	76.4	77.9	59.8
27	14	46	High	51.2	43.2	35.9	15.9	53.6	66.6	78.2	85.8
28	16	59	High	68.4	19.9	7.8	20.1	56.1	59.7	64.3	72.0
29	16	32	High	51.6	37.6	33.3	32.8	68.9	60.1	65.7	82.3
30	18	49	High	65.3	25.6	24.1	27.1	76.5	71.2	65.7	52.3
31	20	45	High	55.5	15.9	4.6	10.7	46.6	63.6	66.5	67.3
32	22	22	High	59.1	34.9	13.4	14.1	56.6	79.0	88.2	94.3
33	22	22	High	54.5	32.8	22.5	20.0	61.4	75.1	77.7	67.4
34	22	22	High	41.7	13.7	16.2	22.7	68.1	89.0	92.3	93.2
35	24	28	High	58.1	28.5	16.6	13.7	67.4	64.1	48.8	30.0
36	27	48	High	69.5	9.4	13.1	35.5	70.4	80.6	81.0	82.2
37	30	57	High	71.3	44.8	51.5	53.4	54.0	64.0	76.7	73.5
38	30	56	High	57.2	38.0	39.3	52.6	55.7	55.3	48.9	52.6
Mean	18	42		57.2	30.0	23.7	23.8	60.0	70.5	74.1	73.8
SD	6	15		7.3	11.0	13.4	14.1	11.9	10.8	13.0	17.8

3 iron

Golfer	AGU Handicap	Age	Handicap Group	Mean CP_{yt} %							
				TA	MB	LB	TB	ED	MD	BC	MF
1	-2	24	Low	57.2	30.9	30.3	34.4	45.3	52.0	49.8	37.5
2	-2	22	Low	48.4	30.5	28.5	40.1	65.4	68.1	60.4	45.8
3	1	19	Low	57.6	26.2	16.7	27.5	41.7	63.4	75.3	71.9
4	4	23	Low	57.0	25.3	15.9	20.5	78.5	92.1	99.6	94.6
5	4	20	Low	67.5	29.1	20.0	20.7	65.3	76.0	82.1	80.7
6	4	24	Low	55.4	17.8	6.9	11.8	54.8	71.8	82.1	90.4
7	4	20	Low	59.4	17.4	16.7	27.4	61.0	65.2	65.1	74.6
8	4	23	Low	49.6	23.4	27.0	27.4	73.4	83.6	91.6	94.2
9	5	26	Low	54.4	21.4	21.9	6.1	68.5	63.4	62.2	60.1
10	5	20	Low	55.8	26.2	11.4	10.5	63.1	82.1	96.5	100.4
11	6	19	Low	64.0	25.3	25.7	45.7	76.2	67.1	51.2	48.5
12	6	21	Low	55.5	39.2	26.5	10.8	78.0	72.5	63.5	57.7
13	6	36	Low	53.6	18.6	7.9	8.1	27.3	45.7	62.6	74.6
14	6	32	Low	62.1	5.8	7.6	32.9	76.3	86.6	96.9	89.3
15	7	63	Low	61.5	26.3	22.6	19.1	55.3	83.9	93.5	68.4
16	7	18	Low	56.6	33.0	29.6	28.9	70.0	75.7	79.6	77.6
17	7	53	Low	57.5	25.2	21.3	16.3	62.5	61.8	57.0	43.4
18	8	50	Low	56.1	11.0	19.1	21.3	62.2	74.1	78.8	74.1
19	10	33	Low								
Mean	5	29		57.2	24.0	19.8	22.7	62.5	71.4	74.9	71.3
SD	3	13		4.6	7.9	7.6	11.2	13.7	12.0	16.4	19.0
20	11	20	High	54.4	30.4	29.7	41.3	38.6	67.1	81.2	85.0
21	11	26	High	59.5	33.5	33.0	16.5	80.0	85.3	93.5	97.5
22	12	46	High	59.3	40.9	37.5	9.2	78.7	85.2	91.6	100.2
23	13	49	High	58.4	32.8	11.0	9.0	33.5	53.1	68.2	73.0
24	13	52	High	52.8	12.9	6.2	11.5	66.6	77.7	72.0	61.8
25	13	59	High	59.7	31.4	23.8	14.3	56.9	82.5	82.5	83.0
26	14	59	High	53.5	35.3	34.7	20.7	40.1	75.1	84.1	82.6
27	14	46	High	52.3	38.5	33.5	18.0	53.2	71.3	84.8	92.9
28	16	59	High	70.7	12.3	5.0	15.1	47.3	55.9	62.4	73.8
29	16	32	High	52.2	36.3	33.7	27.0	72.5	67.3	79.3	89.8
30	18	49	High	67.5	23.2	23.1	27.7	78.3	75.3	70.4	59.3
31	20	45	High	55.0	14.7	3.3	8.9	41.5	62.7	64.6	60.4
32	22	22	High	61.3	39.7	16.4	15.7	56.4	79.1	88.4	93.7
33	22	22	High	57.6	36.1	22.8	17.6	59.1	78.5	83.9	78.7
34	22	22	High	43.5	13.6	15.3	17.2	49.3	82.3	89.1	93.3
35	24	28	High	54.4	32.0	22.2	17.3	69.4	70.5	59.0	34.4
36	27	48	High	56.3	10.2	14.0	29.8	61.1	78.5	74.5	66.6
37	30	57	High	66.9	41.3	49.6	54.0	52.4	62.4	74.7	75.1
38	30	56	High	36.3	43.7	41.3	48.6	49.0	53.9	53.0	52.8
Mean	18	42		56.4	29.4	24.0	22.1	57.0	71.8	76.7	76.5
SD	6	15		7.9	11.2	13.0	13.1	14.2	10.4	11.5	17.3

7 iron

Golfer	AGU Handicap	Age	Handicap Group	Mean CP_{yt} %							
				TA	MB	LB	TB	ED	MD	BC	MF
1	-2	24	Low	57.1	31.3	31.7	35.2	44.2	51.3	50.8	44.0
2	-2	22	Low	53.0	37.2	34.3	48.9	61.3	71.8	69.6	62.0
3	1	19	Low	56.7	23.9	17.0	28.1	30.6	55.2	68.3	73.4
4	4	23	Low	57.2	19.9	12.8	26.0	79.0	92.0	99.0	100.3
5	4	20	Low	64.0	29.1	20.3	19.1	59.2	71.9	77.8	79.7
6	4	24	Low	54.2	18.6	8.5	10.8	49.7	69.3	82.3	87.9
7	4	20	Low	59.4	17.4	17.0	31.4	63.7	67.4	66.3	73.3
8	4	23	Low	49.2	23.9	25.9	22.4	71.6	83.2	90.1	91.3
9	5	26	Low	57.1	22.0	22.7	7.5	62.1	60.1	60.5	62.4
10	5	20	Low	55.8	28.8	13.8	12.3	58.1	78.3	93.3	101.0
11	6	19	Low	62.9	26.1	22.8	45.4	75.2	65.6	51.4	51.6
12	6	21	Low	54.5	37.4	25.2	12.2	66.4	63.9	58.8	62.2
13	6	36	Low	53.0	15.5	5.9	7.0	26.6	43.7	62.1	76.0
14	6	32	Low	65.8	10.0	12.2	34.4	73.3	84.7	94.0	91.3
15	7	63	Low	63.0	27.5	23.8	20.6	50.7	84.5	95.1	68.5
16	7	18	Low	54.5	33.8	29.4	29.3	69.2	74.5	78.5	81.7
17	7	53	Low	59.1	29.7	24.9	17.5	61.8	64.1	63.1	67.8
18	8	50	Low	56.1	9.4	16.5	19.4	58.2	72.8	78.0	73.1
19	10	33	Low	54.2	24.6	26.9	21.8	82.7	90.7	89.5	88.6
Mean	5	29		57.2	24.5	20.6	23.7	60.2	70.8	75.2	75.6
SD	3	13		4.3	8.1	7.8	11.9	14.9	13.1	15.4	15.6
20	11	20	High	53.8	26.2	26.4	36.5	35.6	60.3	74.3	82.5
21	11	26	High	58.0	34.7	34.5	18.4	82.3	89.5	98.1	97.4
22	12	46	High	60.7	41.2	34.8	9.5	72.7	81.4	88.0	98.9
23	13	49	High	58.0	39.8	11.8	11.5	33.6	55.2	71.9	76.4
24	13	52	High	59.2	12.2	2.5	6.3	63.2	76.2	75.0	69.5
25	13	59	High	55.3	32.3	25.6	15.1	54.0	85.0	89.0	93.6
26	14	59	High	58.0	33.4	31.9	16.1	36.8	77.6	91.3	87.7
27	14	46	High	52.4	40.7	40.0	20.4	55.9	73.7	86.2	92.0
28	16	59	High	72.9	12.3	3.4	9.9	45.5	55.1	60.8	63.6
29	16	32	High	50.0	34.2	34.2	34.5	70.3	60.3	66.6	74.2
30	18	49	High	66.6	29.0	23.8	24.4	78.1	77.5	74.3	73.3
31	20	45	High	56.5	14.4	3.3	8.4	36.0	64.3	62.5	56.6
32	22	22	High	60.8	29.1	9.7	10.8	54.7	78.5	85.8	93.4
33	22	22	High	58.3	30.7	19.6	16.6	50.2	71.9	79.1	77.6
34	22	22	High	43.1	10.7	14.3	19.0	58.2	84.2	89.0	95.0
35	24	28	High	55.7	32.7	24.3	18.4	68.3	63.7	46.7	25.3
36	27	48	High	56.9	25.4	22.2	31.6	64.5	78.5	78.3	80.0
37	30	57	High	68.7	43.4	50.2	55.6	53.9	61.3	74.1	75.6
38	30	56	High	59.5	42.0	41.7	46.1	50.8	60.0	61.1	68.3
Mean	18	42		58.1	29.7	23.9	21.5	56.0	71.3	76.4	78.0
SD	6	15		6.6	10.5	13.8	13.5	14.6	10.8	13.0	17.6

APPENDIX 4

Individual graphs for all golfers group (n = 38), low handicap golfer (n = 19) and high handicap golfer (n = 19) for the driver, 3 iron and 7 iron.

Appendix 4A – All Golfers (n = 38)

Mean CP_{yt} % for the three golf clubs at the eight golf swing events.

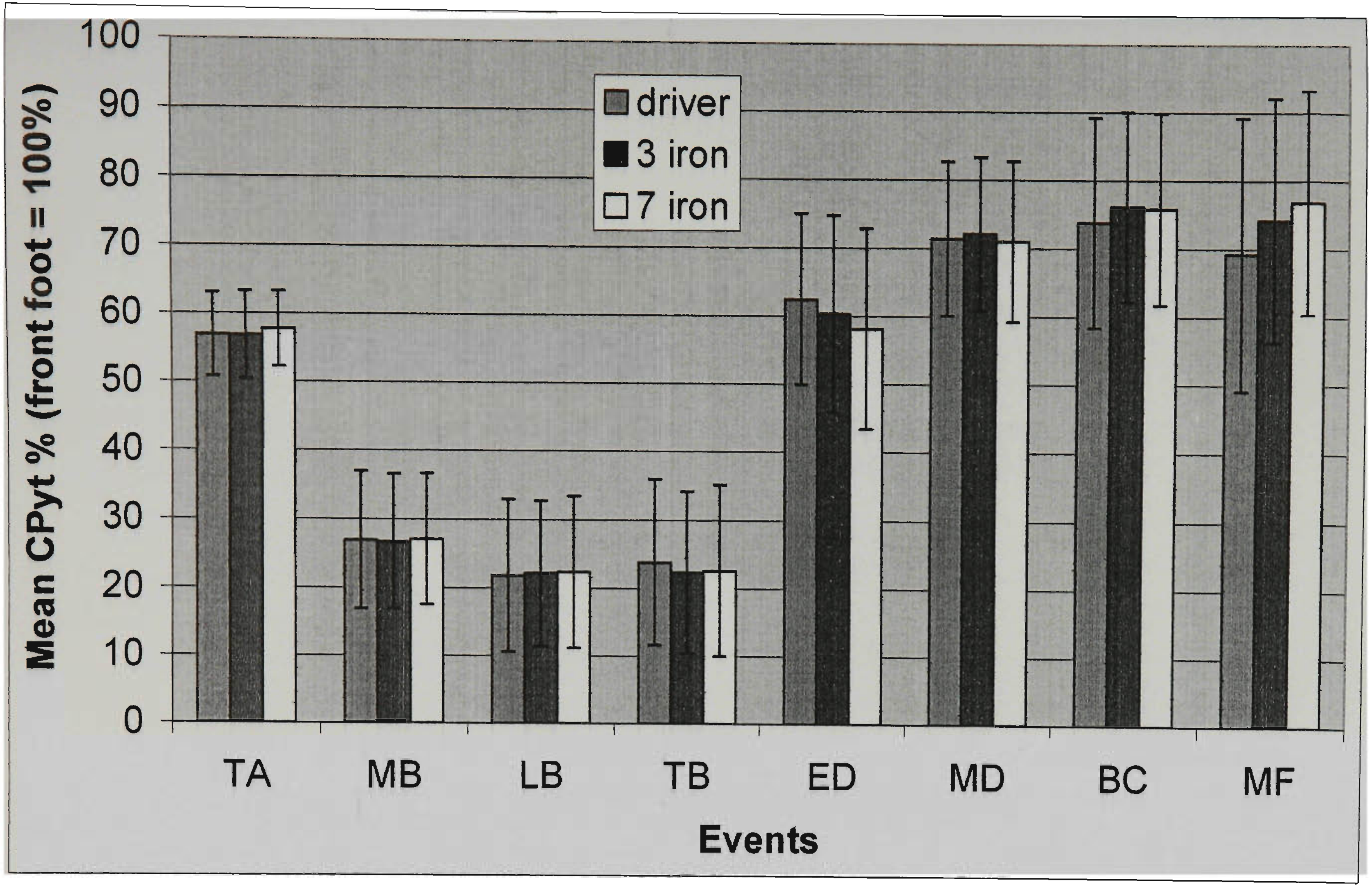


Figure 4A: Mean CP_{yt} % for all golfers (n = 38) at the eight golf swing events for the driver, 3 iron and 7 iron

Appendix 4B – Low Handicap Golfer (n = 19)

Mean CP_{yt} % for the three golf clubs at the eight golf swing events.

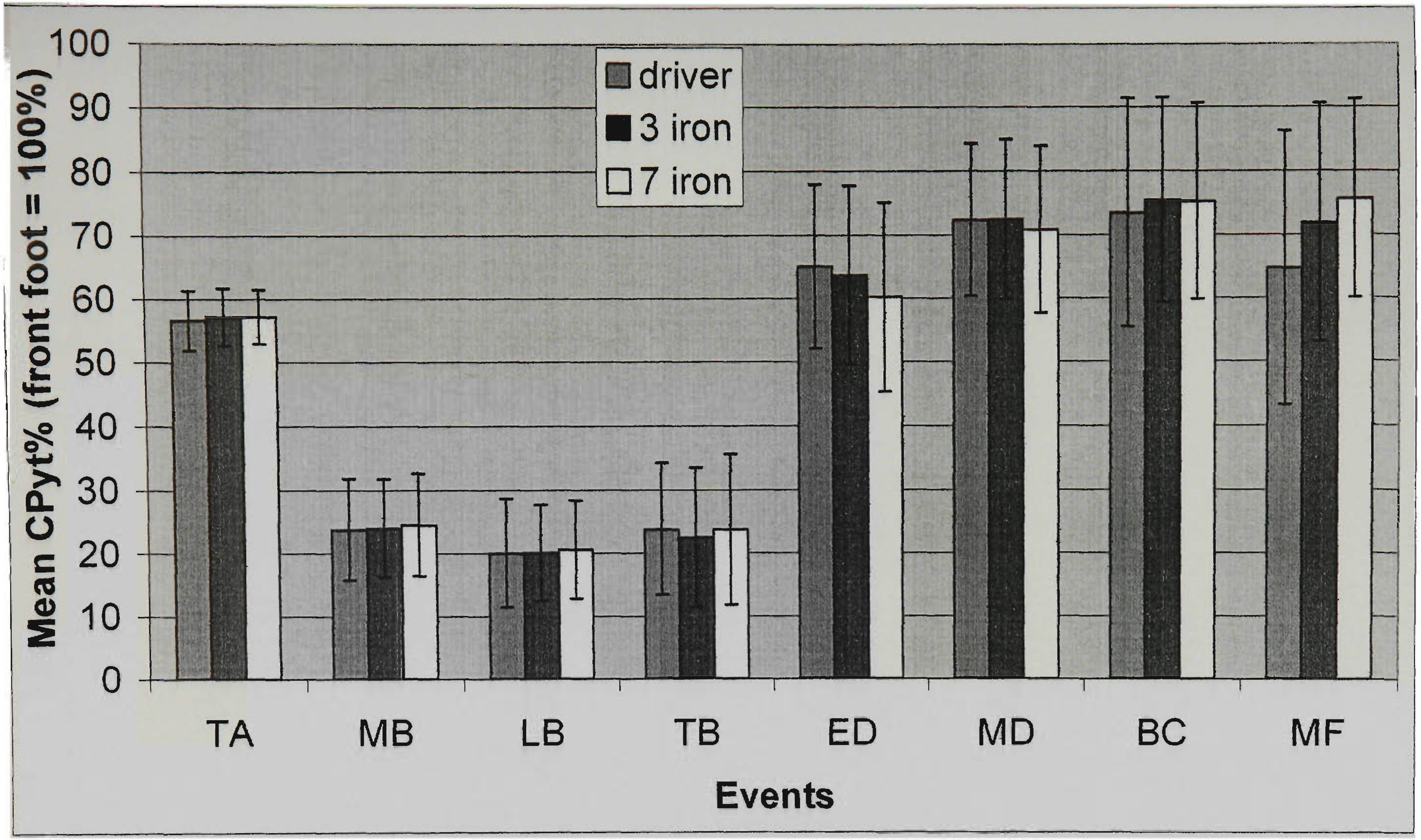


Figure 4B: Mean CP_{yt} % for the low handicap golfers (n = 19) at the eight golf swing events for the driver, 3 iron an 7 iron

Appendix 4C – High Handicap Golfers (n = 19)

Mean CP_{yt} % for the three golf clubs at the eight golf swing events.

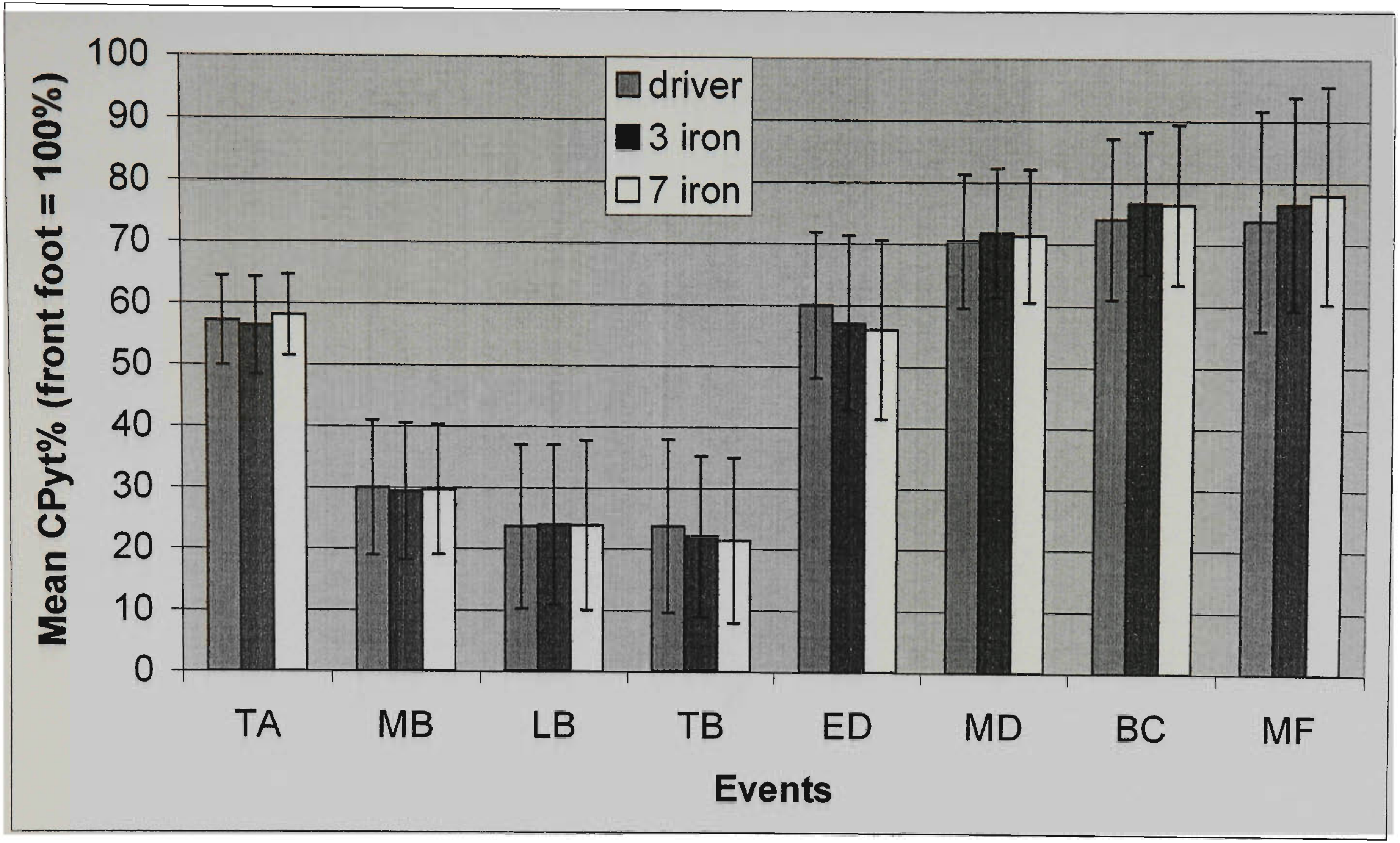


Figure 4C: Mean CP_{yt} % for the High Handicap golfers (n = 19) at the eight golf swing events for the driver, 3 iron and 7 iron

APPENDIX 5

Interaction effect for golf swing events TA to BC.

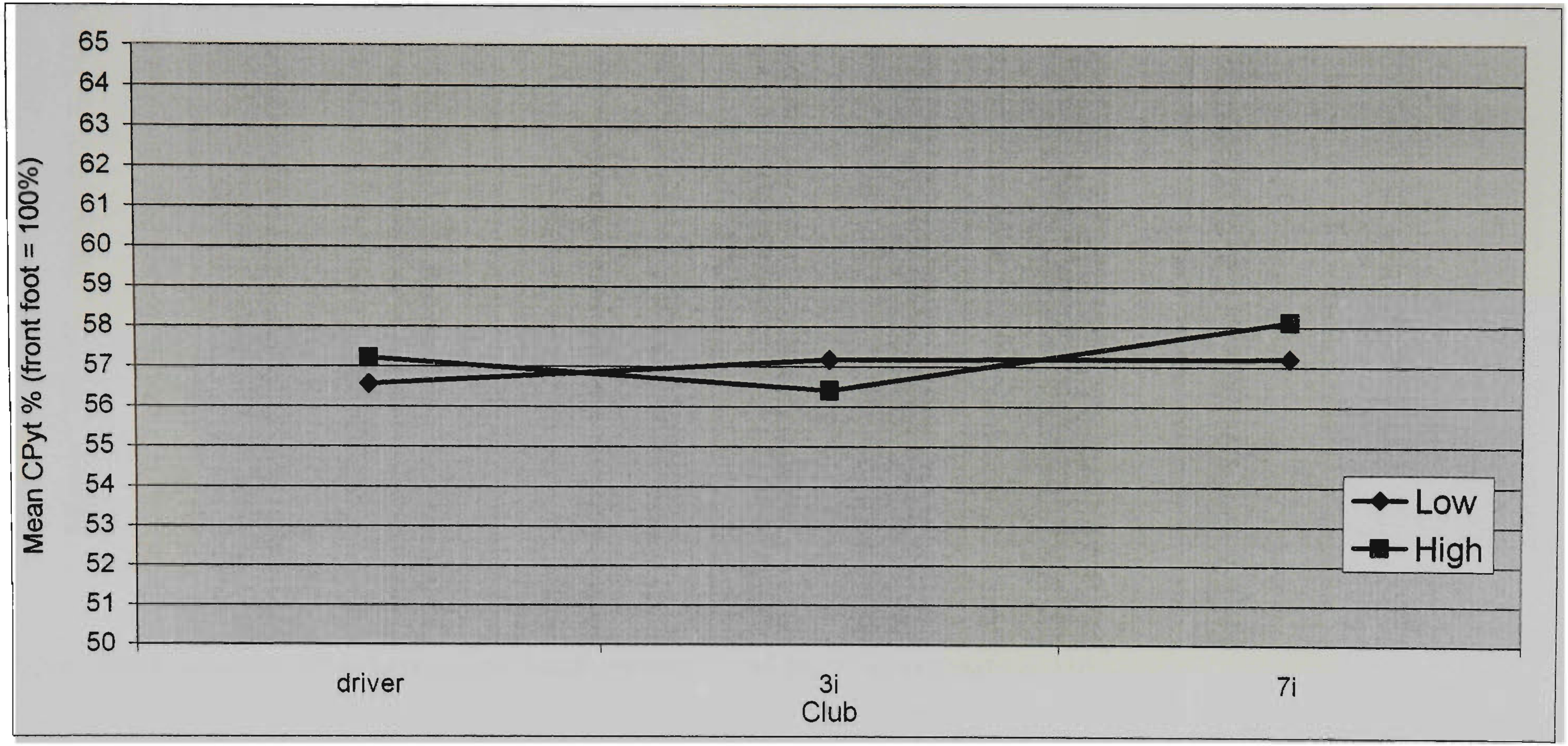


Figure 5.A: Interaction effect between the handicap groups and the three golf clubs at TA

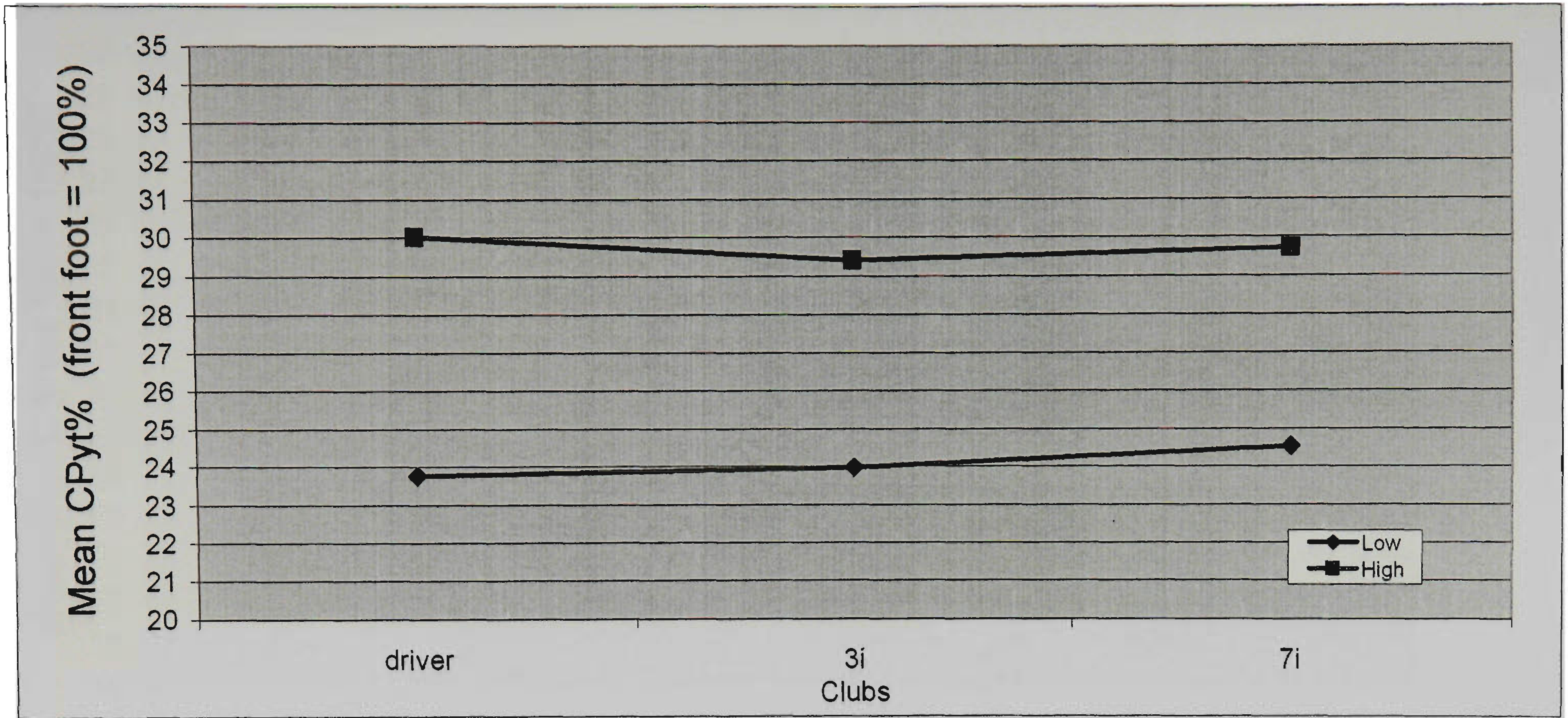


Figure 5.B: Interaction effect between the handicap groups and the three golf clubs at MB

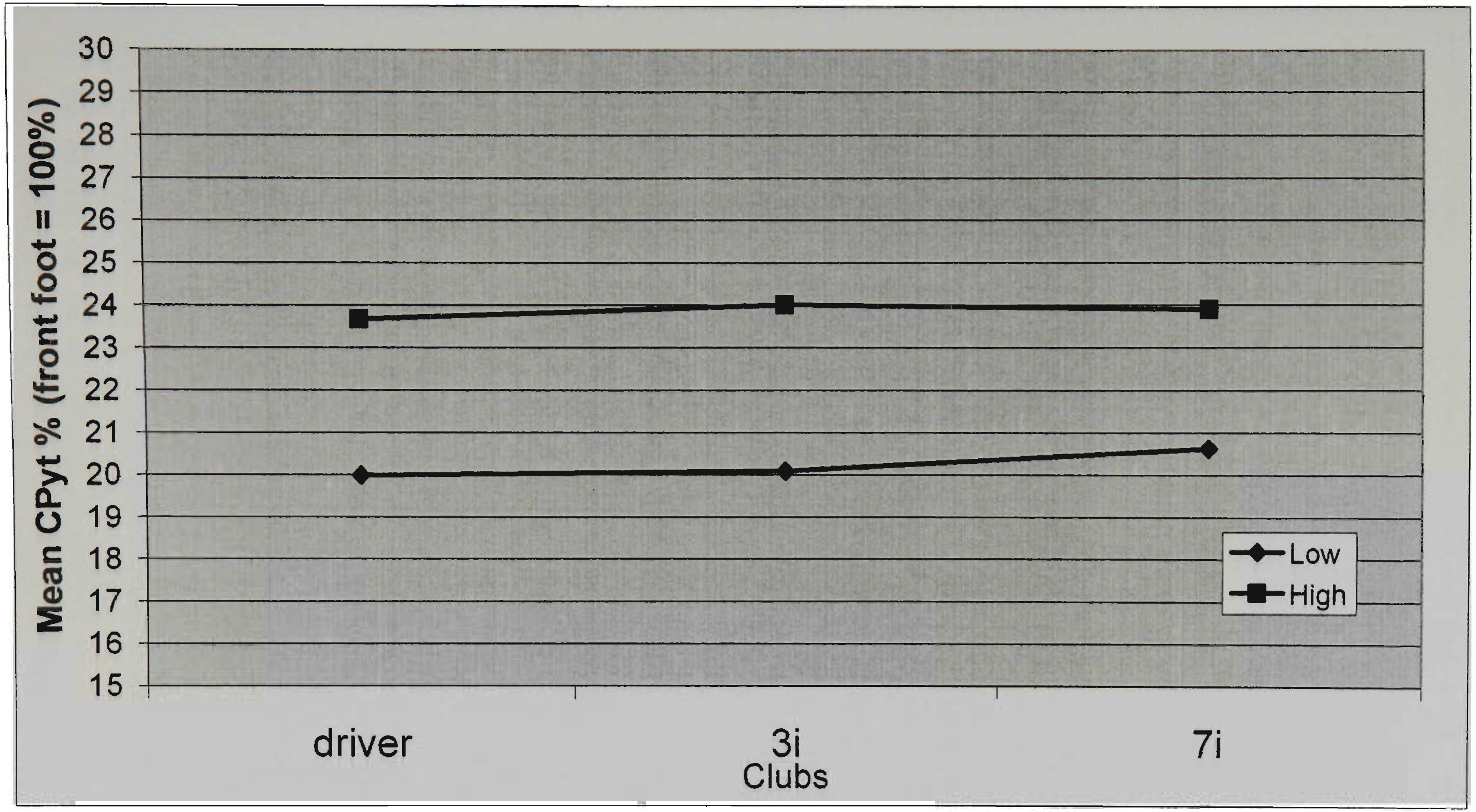


Figure 5.C: Interaction effect between the handicap groups and the three golf clubs at LB

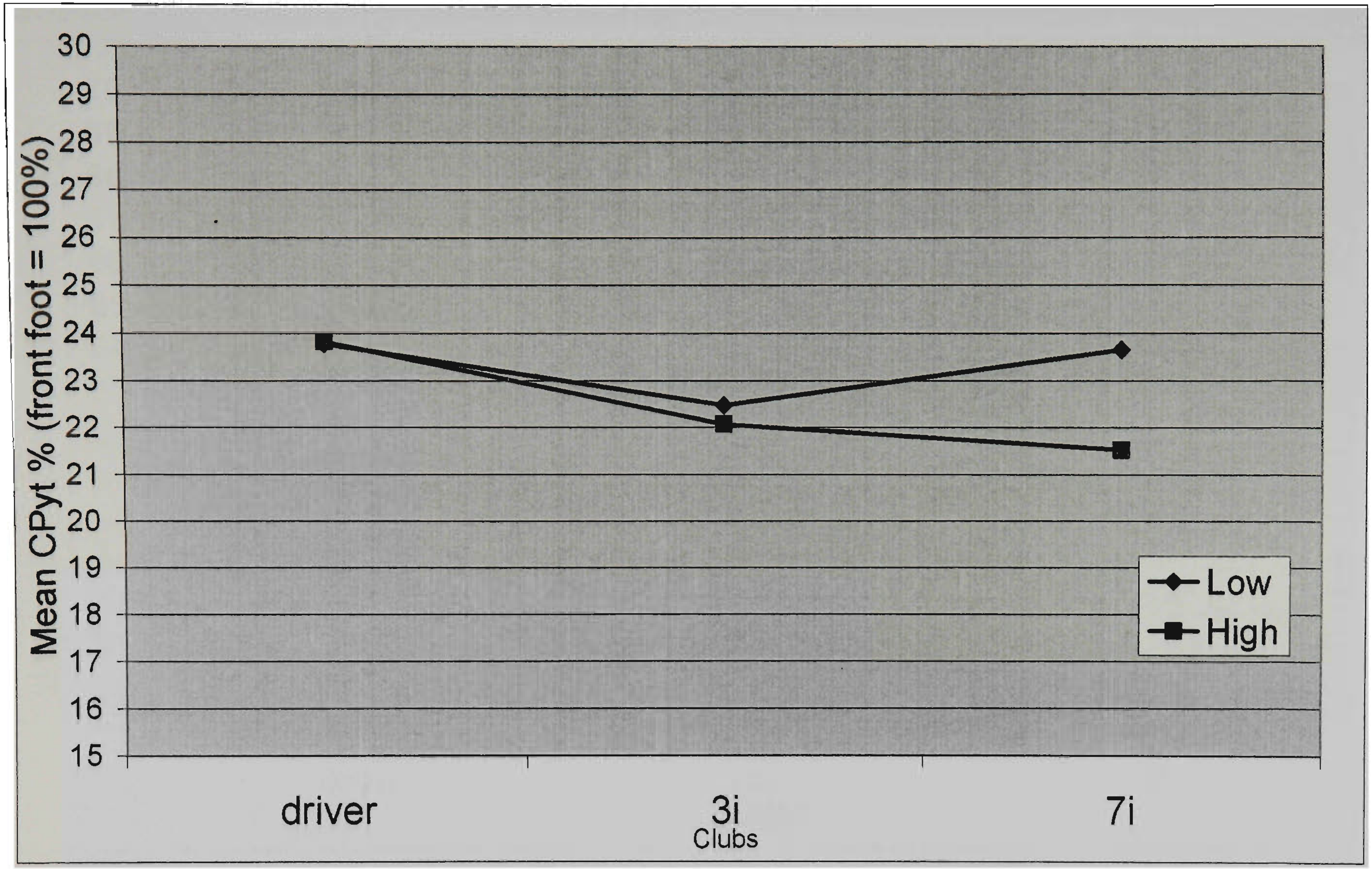


Figure 5.D: Interaction effect between the handicap groups and the three golf clubs at TB

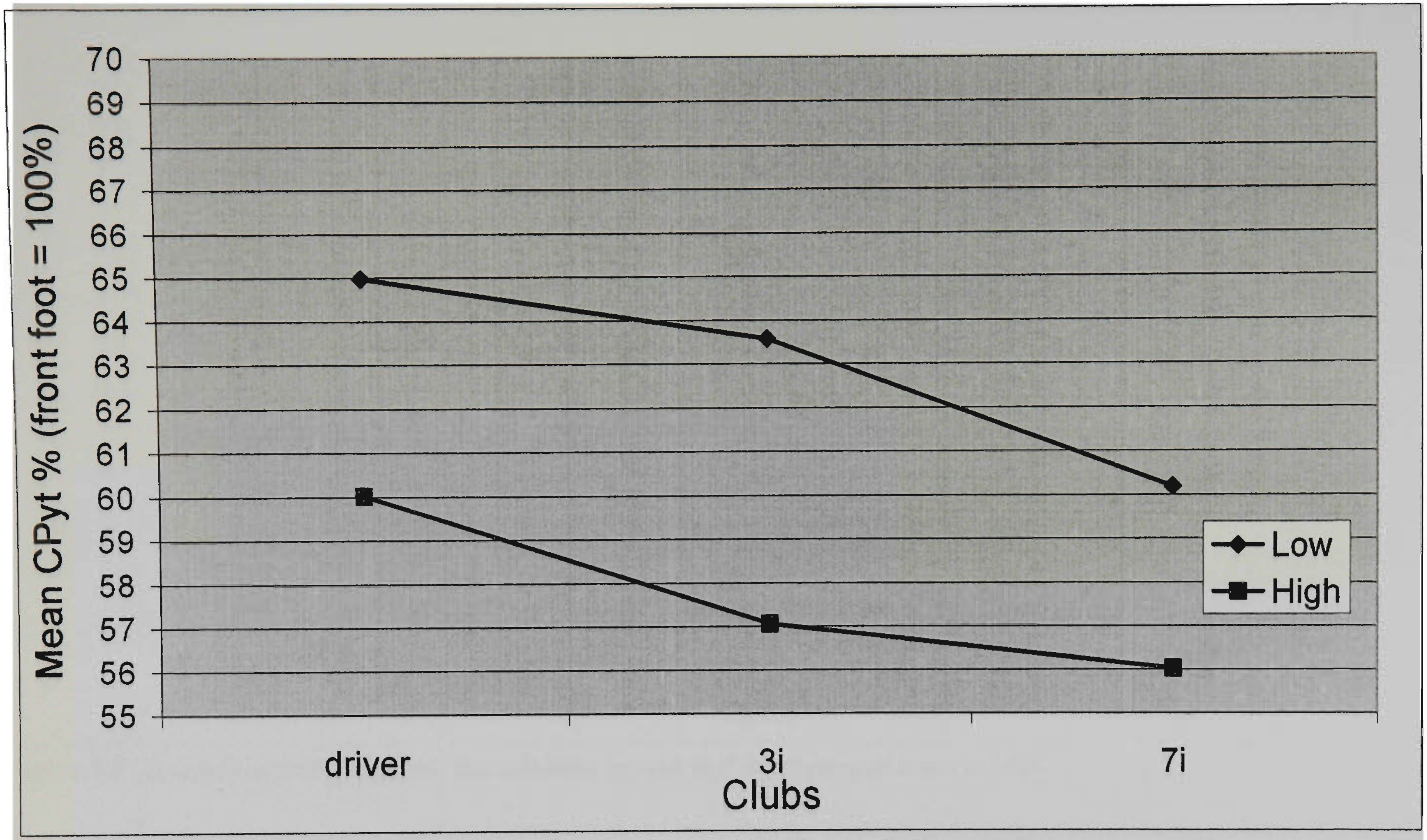


Figure 5.E: Interaction effect between the handicap groups and the three golf clubs at ED

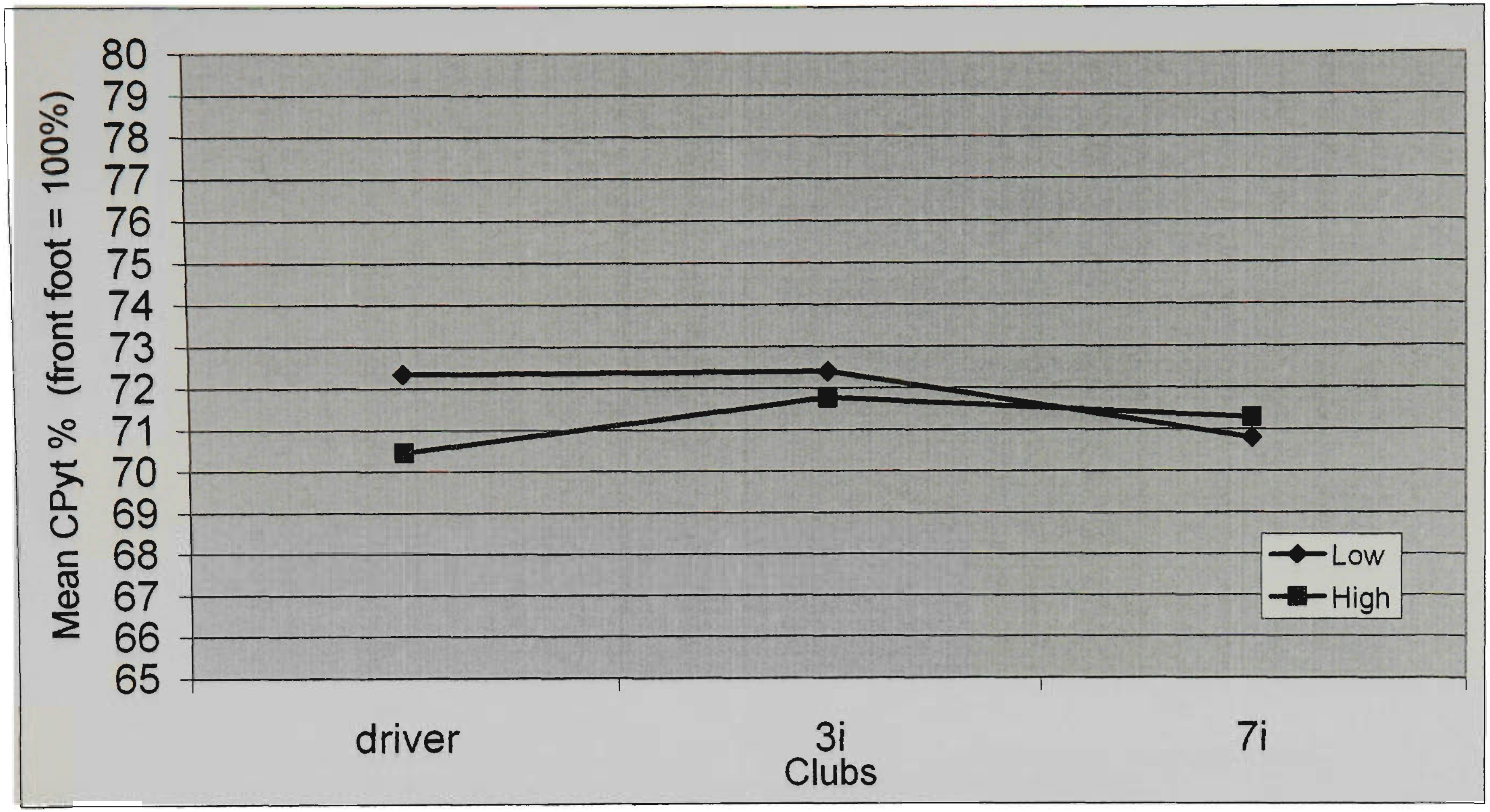


Figure 5.F: Interaction effect between the handicap groups and the three golf clubs at MD

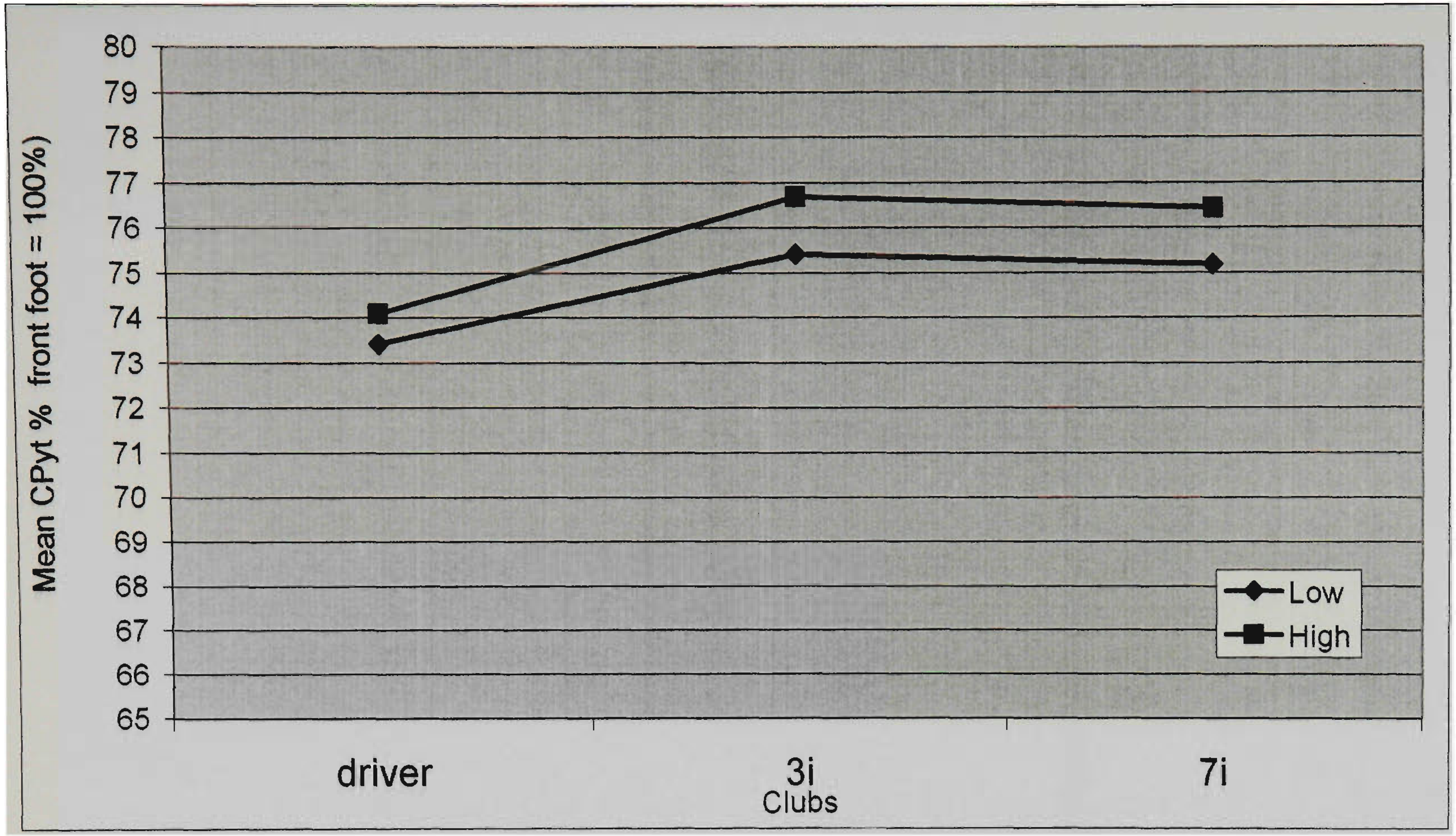


Figure 5.G: Interaction effect between the handicap groups and the three golf clubs at BC

APPENDIX 6

SPANOVA and t-test results for the eight golf swing events.

TA

SPANOVA

	Test	Type III Sum of Squares	Df	Mean Square	F	Sig.	Effect Size (η^2)	Noncent. Parameter	Power
Within effect	Sphericity Assumed	17.169	2	8.585	0.963	0.387	0.026	1.927	0.319
	Huynh-Feldt	17.169	1.936	8.868	0.963	0.384	0.026	1.865	0.315
Between effect		1.999	1	1.999	0.022	0.884	0.001	0.022	0.104
Interaction effect	Sphericity Assumed	15.706	2	7.853	0.881	0.419	0.024	1.762	0.301
	Huynh-Feldt	15.706	1.936	8.113	0.881	0.416	0.024	1.706	0.297

MB

SPANOVA

	Test	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size (η^2)	Noncent. Parameter	Power
Within effect	Sphericity Assumed	3.568	2	1.784	0.221	0.802	0.006	0.442	0.150
	Huynh-Feldt	3.568	1.926	1.852	0.221	0.794	0.006	0.426	0.149
Between effect		901.682	1.000	901.682	3.493	0.070	0.088	3.493	0.575
Interaction effect	Sphericity Assumed	6.111	2	3.055	0.378	0.686	0.010	0.757	0.186
	Huynh-Feldt	6.111	1.926	3.173	0.378	0.678	0.010	0.729	0.184

Independent Samples t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
Club		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Difference	Lower	Upper
driver	Equal variance assumed	2.688	0.110	-1.998	36	0.053	-6.265	3.135	-12.623	0.094
	Equal variance not assumed			-1.998	32.922	0.054	-6.265	3.135	-12.643	0.114
3 iron	Equal variance assumed	4.670	0.037	-1.736	36	0.091	-5.426	3.125	-11.763	0.911
	Equal variance not assumed			-1.736	31.892	0.092	-5.426	3.125	-11.791	0.940
7 iron	Equal variance assumed	1.098	0.302	-1.701	36	0.098	-5.184	3.047	-11.363	0.996
	Equal variance not assumed			-1.701	33.695	0.098	-5.184	3.047	-11.378	1.010

LB

SPANOVA

	Sorce	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size (η^2)	Noncent. Parameter	Power
Within effect	Sphericity Assumed	3.570	2	1.785	0.310	0.734	0.009	0.620	0.170
	Huynh-Feldt	3.570	2	1.785	0.310	0.734	0.009	0.620	0.170
Between effect		375.671	1	375.671	1.059	0.310	0.029	1.059	0.267
Interaction effect	Sphericity Assumed	2.012	2	1.006	0.175	0.840	0.005	0.349	0.139
	Huynh-Feldt	2.012	2	1.006	0.175	0.840	0.005	0.349	0.139

TB

SPANOVA

	Sorce	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size (η^2)	Noncent. Parameter	Power
Within effect	Sphericity Assumed	49.003	2	24.502	2.727	0.072	0.070	5.455	0.650
	Huynh-Feldt	49.003	1.681	29.147	2.727	0.082	0.070	4.585	0.606
Between effect		19.562	1	19.562	0.044	0.835	0.001	0.044	0.107
Interaction effect	Sphericity Assumed	24.912	2	12.456	1.387	0.257	0.037	2.773	0.410
	Huynh-Feldt	24.912	1.681	14.818	1.387	0.256	0.037	2.331	0.383

Paired Samples t-test

	Mean	Std. Deviation	Std. Error Mean	98.5% Confidence Interval of the Difference				
				Lower	Upper	t.	df	Sig.
Driver top-back - 3iron top-back	1.521	4.035	0.655	-0.149	3.192	2.324	37	0.026
Driver top-back - 7iron top-back	1.206	5.205	0.844	-0.949	3.36	1.428	37	0.162
3iron top-back - 7iron top-back	-0.316	3.329	0.54	-1.693	1.062	-0.584	37	0.563

ED

SPANOVA

	Sorce	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size (η^2)	Noncent. Parameter	Power
Within effect	Sphericity Assumed	366.814	2	183.407	12.537	0.000	0.258	25.074	0.998

	Huynh-Feldt	366.814	1.670	219.609	12.537	0.000	0.258	20.940	0.995
Between effect		775.571	1	775.571	1.432	0.239	0.038	1.432	0.321
Interaction effect	Sphericity Assumed	27.401	2	13.701	0.937	0.397	0.025	1.873	0.313
	Huynh-Feldt	27.401	1.670	16.405	0.937	0.383	0.025	1.564	0.293

Paired Samples t-test

	Mean	Std. Deviation	Std. Error Mean	98.5% Confidence Interval of the Difference				
				Lower	Upper	t	df	Sig. (2-tailed)
Driver early down - 3iron early down	2.19125	5.6116	0.91032	-0.1312	4.51373	2.40712	37	0.02118
Driver early down - 7iron early down	4.39385	6.3437	1.02908	1.76838	7.01933	4.26967	37	0.00013
3iron early down - 7iron early down	2.2026	3.9866	0.64671	0.55266	3.85254	3.40585	37	0.0016

MD

SPANOVA

	Sorce	Type III Sum of Squares	Df	Mean Square	F	Sig.	Effect Size (η^2)	Noncent. Parameter	Power
Within effect	Sphericity Assumed	21.837	2	10.919	1.098	0.339	0.030	2.196	0.349
	Huynh-Feldt	21.837	1.641	13.306	1.098	0.330	0.030	1.802	0.324
Between effect		13.011	1	13.011	0.034	0.855	0.001	0.034	0.106
Interaction effect	Sphericity Assumed	26.814	2	13.407	1.348	0.266	0.036	2.696	0.402
	Huynh-Feldt	26.814	1.641	16.339	1.348	0.265	0.036	2.212	0.372

BC

SPANOVA

	Sorce	Type III Sum of Squares	Df	Mean Square	F	Sig.	Effect Size (η^2)	Noncent. Parameter	Power
Within effect	Sphericity Assumed	119.665	2	59.832	2.879	0.063	0.074	5.758	0.672
	Huynh-Feldt	119.665	1.646	72.684	2.879	0.074	0.074	4.740	0.622
Between effect		32.667	1	32.667	0.054	0.817	0.002	0.054	0.109
Interaction effect	Sphericity Assumed	2.229	2	1.115	0.054	0.948	0.001	0.107	0.112
	Huynh-Feldt	2.229	1.646	1.354	0.054	0.920	0.001	0.088	0.111

Paired Samples t-test

	Mean	Std. Deviation	Std. Error Mean	98.5% Confidence Interval of the Difference				
				Lower	Upper	t	df	Sig. (2-tailed)
driver ball contact - 3iron ball contact	-2.285	5.951	0.965	-4.748	0.178	-2.367	37	0.023
driver ball contact - 7iron ball contact	-2.041	7.846	1.273	-5.288	1.206	-1.604	37	0.117
3iron ball contact - 7iron ball contact	0.244	4.953	0.803	-1.806	2.294	0.303	37	0.763

MF

SPANOVA

	Sorce	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size (η^2)	Noncent. Parameter	Power
Within effect	Sphericity Assumed	1120.611	2	560.306	14.102	0.000	0.281	28.204	0.999
	Huynh-Feldt	1120.611	1.757	637.636	14.102	0.000	0.281	24.783	0.999
Between effect		826.559	1	826.559	0.909	0.347	0.025	0.909	0.244
Interaction effect	Sphericity Assumed	223.060	2	111.530	2.807	0.067	0.072	5.614	0.662
	Huynh-Feldt	223.060	1.757	126.923	2.807	0.075	0.072	4.933	0.628

Paired Samples t-test

	Mean	Std. Deviation	Std. Error Mean	98.5% Confidence Interval of the Difference				
				Lower	Upper	t	df	Sig. (2-tailed)
driver mid-follow – 3iron mid-follow	-4.965	8.299	1.346	-8.400	-1.530	-3.688	37	0.001
driver mid-follow – 7iron mid-follow	-7.557	11.169	1.812	-12.179	-2.934	-4.171	37	0.000
3iron mid-follow – 7iron mid-follow	-2.592	7.511	1.218	-5.700	0.517	-2.127	37	0.040