CHAPTER IV
RESULTS AND DISCUSSIONS

This study examines the differences in plantar pressure distribution and its variations during the golf swing between professional and amateur golfers. The findings are presented in tables and visual representations, structured into three main sections.

1. Demographic Characteristics and Basic Variables

The study presents demographic and basic variables of participants, including age, weight, height, and body mass index (BMI). These variables contextualize differences in foot pressure patterns during golf swings. Descriptive statistics summarize these characteristics, highlighting average values and standard deviations for each golfer group.

2. Plantar Pressure Changes during the Golf Swing

This section analyzes plantar pressure variations at key swing phases: Stand (ST), Middle Backswing (MB), Top of Backswing (TB), Ball Impact (IM), and Early Finish (EF). Pressure data from eight foot regions (Great Toe, Lesser Toe, Medial Metatarsal, Central Metatarsal, Lateral Metatarsal, Medial Arch, Lateral Arch, and Heel) illustrates differences in weight distribution and center of pressure (CoP) between skill levels, providing insights into swing mechanics.

3. Correlation between Plantar Pressure and Energy Transfer

The final section explores correlations between plantar pressure distribution and energy transfer within the kinetic chain, emphasizing segment power transmission at the lumbosacral joint (L5S1), which is essential for generating torque and angular momentum during the golf swing.

4.1 Demographic characteristics and basic variables

Table 4.1 Statistical description of individual characteristics.

Variables	PRO M ± SD	HIGHT M ± SD	P
Age (years)	24.27 ± 4.47	25.47 ± 3.20	0.424
Weight (kg)	75.00 ± 20.00	70.00 ± 10.06	0.394
Height (cm)	169.87 ± 5.41	168.73 ± 4.86	0.551
BMI (kg/m^2)	25.83 ± 5.96	24.56 ± 3.24	0.474

M: Mean; SD: Standard Deviation; BMI: Body Mass Index.

The statistical summary of the basic characteristics of the two sample groups, namely professional golfers (PRO) and high-handicap golfers (High Handicap), is presented in Table 4.1. Each group consisted of 15 participants, comprising 8 males and 7 females. The professional golfer group had an average age of 24.27 ± 4.47 years, an average body weight of 75.00 ± 20.00 kg, an average height of 169.87 ± 5.41 cm, and an average body mass index (BMI) of 25.83 ± 5.96 kg/m². The high-handicap golfer group had an average age of 25.47 ± 3.20 years, an average body weight of 70.00 ± 10.06 kg, an average height of 168.73 ± 4.86 cm, and an average BMI of 24.56 ± 3.24 kg/m². Statistical analysis using independent samples t-tests revealed no significant differences between the two groups in terms of age, weight, height, or BMI ($p > 0.05$ for all variables).

4.2 Plantar pressure and changes during the golf swing

Table 4.2 Differences in normal pressure in the left foot between the driver and 7-iron golf clubs in professional player at the key moments of the swing.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P
GT	0	0.982	0	0.975	2	0.056	2 (*)	0.014	1	0.486
LT	0	0.418	-1	0.123	2 (*)	0.001	1	0.089	1	0.221
MEDmet	0	0.873	2	0.204	2	0.461	5	0.087	1	0.735
CENmet	-1	0.359	-4 (*)	0.000	0	0.794	2	0.194	3	0.149
LATmet	-2	0.096	-5 (*)	0.004	-3	0.208	-5 (*)	0.045	-3	0.220
MEDarc	0	0.869	5 (*)	0.006	2	0.424	2	0.164	0	0.627
LATarc	-1	0.446	-2	0.164	-3	0.235	-6 (*)	0.044	-2	0.462
HEEL	2	0.156	4 (*)	0.002	-2	0.180	-2	0.278	-1	0.605

ST: Stand; MB: Middle Backswing; TB: Top of Backswing; IM: Ball Impact; EF: Early Finish; GT: Great Toe; LT: Lesser Toe; MEDmet: Medial Metatarsal; CENmet: Central Metatarsal; LATmet: Lateral Metatarsal; MEDarc: Medial Arch; LATarc: Lateral Arch; HEEL: Heel; * significant differences at $p < 0.05$.

The analysis of Table 4.2 reveals that during the Stand (ST) phase, there was no statistically significant difference ($p > 0.05$) in normal pressure between the driver and the 7-iron across all foot regions. During the Middle Backswing (MB) phase, significant differences ($p < 0.05$) were observed in the Central Metatarsal (CENmet), Lateral Metatarsal (LATmet), Medial Arch (MEDarc), and Heel (HEEL). Specifically, pressure at CENmet and LATmet was lower when using the driver, whereas pressure at MEDarc and HEEL was higher when using the driver. At the Top of Backswing (TB) phase, a statistically significant difference ($p < 0.05$) was found in the Lesser Toe (LT) region, where pressure was higher when using the 7-iron compared to the driver. During the Ball Impact (IM) phase, significant differences ($p < 0.05$) were detected in the Great Toe (GT), Lateral Metatarsal (LATmet), and Lateral Arch (LATarc). The GT region exhibited higher pressure when using the 7-iron, while pressure in the LATmet and LATarc regions was lower when using the 7-iron compared to the driver. In the Early Finish (EF) phase, no statistically significant differences ($p > 0.05$) were observed in normal pressure between the driver and the 7-iron across all foot regions.

Table 4.3 Differences in normal pressure in the right foot between the driver and 7-iron golf clubs in professional player at the key moments of the swing.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P
GT	-1	0.329	-1	0.554	-2	0.204	-1	0.604	-2	0.548
LT	0	0.902	-1	0.290	0	0.638	1	0.514	2	0.160
MEDmet	-1	0.327	-3	0.081	1	0.463	9 (*)	0.012	5	0.241
CENmet	-2 (*)	0.010	0	0.805	-1	0.610	-2	0.286	0	0.947
LATmet	-2 (*)	0.013	-1	0.587	-2	0.404	-3 (*)	0.041	0	0.781
MEDarc	0	0.718	0	0.992	1	0.348	1	0.542	1	0.690
LATarc	-1	0.409	1	0.647	0	0.877	-4 (*)	0.018	-2 (*)	0.047
HEEL	7 (*)	0.014	5 (*)	0.014	2	0.441	-1	0.634	-3	0.370

ST: Stand; MB: Middle Backswing; TB: Top of Backswing; IM: Ball Impact; EF: Early Finish; GT: Great Toe; LT: Lesser Toe; MEDmet: Medial Metatarsal; CENmet: Central Metatarsal;

LATmet: Lateral Metatarsal; MEDarc: Medial Arch; LATarc: Lateral Arch; HEEL: Heel; * significant differences at $p < 0.05$.

The analysis of Table 4.3 reveals that during the Stand (ST) phase, there were statistically significant differences ($p < 0.05$) in normal pressure in the right foot between using the driver and the 7-iron at the Central Metatarsal (CENmet), Lateral Metatarsal (LATmet), and Heel (HEEL) regions. Specifically, pressure at CENmet and LATmet was lower when using the driver, while pressure at HEEL was higher when using the driver. During the Middle Backswing (MB) phase, a significant difference ($p < 0.05$) was observed in the Heel (HEEL) region, where pressure was higher when using the driver compared to the 7-iron. At the Top of Backswing (TB) phase, there were no statistically significant differences ($p > 0.05$) in normal pressure in the right foot between the driver and the 7-iron across all foot regions. During the Ball Impact (IM) phase, significant differences ($p < 0.05$) were detected in the Medial Metatarsal (MEDmet), Lateral Metatarsal (LATmet), and Lateral Arch (LATarc) regions. The MEDmet region exhibited higher pressure when using the 7-iron, whereas pressure at LATmet and LATarc was lower when using the 7-iron compared to the driver. In the Early Finish (EF) phase, a statistically significant difference ($p < 0.05$) was found in the Lateral Arch (LATarc) region, where pressure was lower when using the 7-iron compared to the driver.

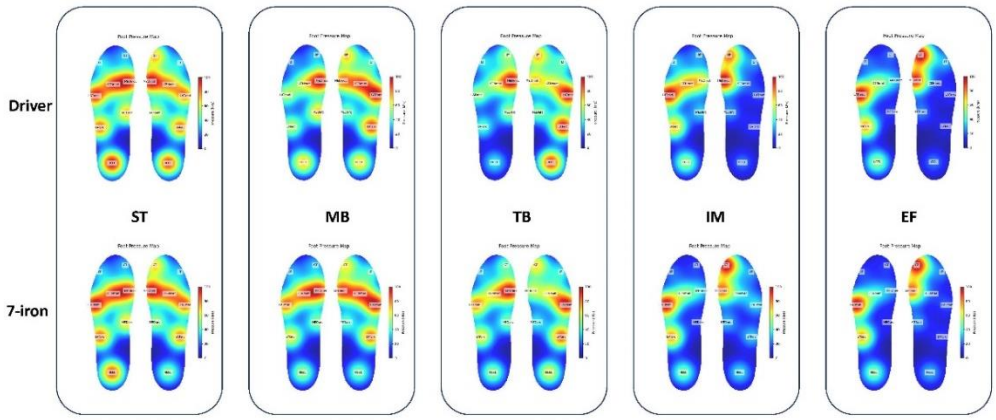

Figure 4.1 Average maximum plantar pressure distribution across different foot areas between the driver and 7-iron golf clubs in professional player at the key moments of the swing

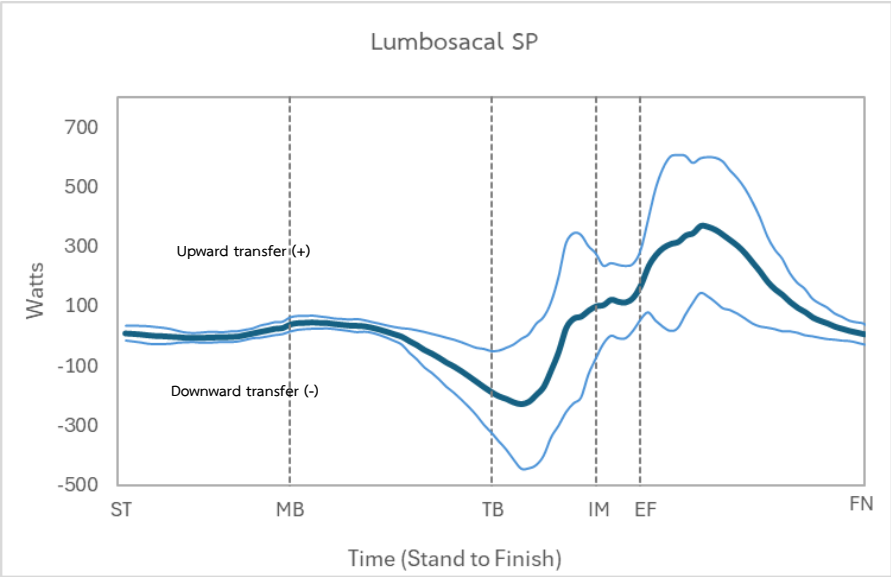

Figure 4.2 Mean normalized segment power (SP) in professional players using a driver, indicating the rates of energy transfer in the lumbosacral (L5S1).

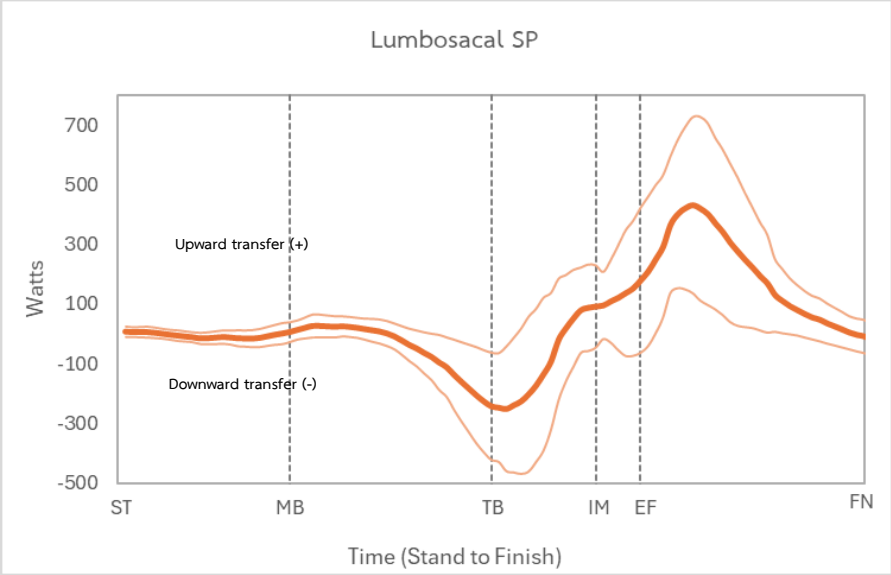

Figure 4.3 Mean normalized segment power (SP) in professional players using a 7-Iron, indicating the rates of energy transfer in the lumbosacral (L5S1).

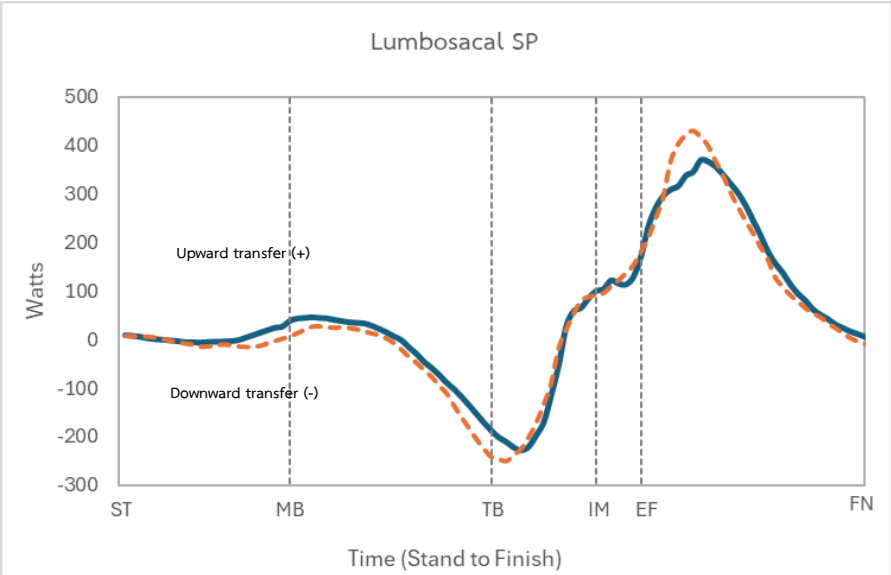

Figure 4.4 Mean normalized segment power (SP) in professional players using a driver (solid line) and 7-iron (dashed line), indicating the rates of energy transfer in the lumbosacral (L5S1).

The analysis of Figure 4.4 indicates that during the Stand (ST) phase, golfers have not yet initiated their swing movement, resulting in a low level of energy transfer. The energy accumulated during this phase remains relatively stable, with no significant difference between the driver and the 7-iron, suggesting that weight distribution strategies are similar at this stage. In the Middle Backswing (MB) phase, the energy values for both the driver and the 7-iron are slightly positive, indicating the flow of energy into the upper body. Professional golfers utilize energy at this stage to control torso movement and begin the energy storage process. The driver exhibits slightly higher energy values than the 7-iron, reflecting the greater energy demand required to manage the larger swing arc of the driver. As the swing progresses to the Top of Backswing (TB) phase, energy values drop to their lowest negative levels, signifying the transfer of weight to the lower body in preparation for the transition from the backswing to the downswing. The driver reaches a similar minimum negative energy level as the 7-iron, though the shift occurs more gradually, reflecting the greater force and weight transfer required to control the larger and longer club. This phase highlights the increased effort needed to maintain balance in the swing when using a driver. During the Impact (IM) phase, energy values surge into positive levels, representing the rapid transfer of energy back into the upper body to generate maximum clubhead

speed for impact. However, the comparison between the two clubs reveals a similar energy flow pattern at this stage, indicating that the mechanics of energy transfer during impact are consistent between the driver and the 7-iron. Finally, in the Early Finish (EF) phase, energy flow continues to rise, reaching its peak during the EF - FN transition, which represents the post-impact force transmission process. Professional golfers maintain positive energy levels, but the energy values for both the driver and 7-iron gradually decline toward equilibrium. At this stage, the two energy curves become increasingly similar, indicating a natural completion of the swing and a smooth transition into the finishing phase.

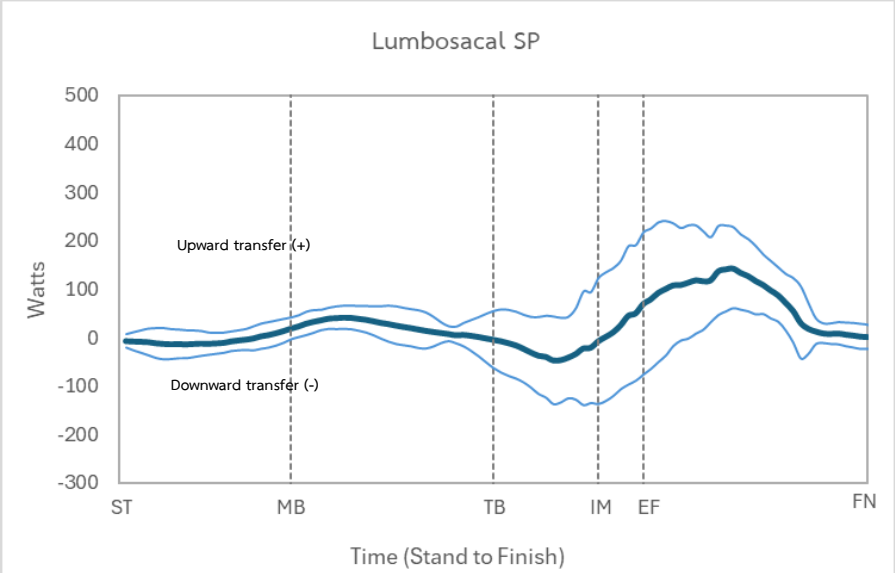

Figure 4.5 Mean normalized segment power (SP) in high handicap players using a driver, indicating the rates of energy transfer in the lumbosacral (L5S1).

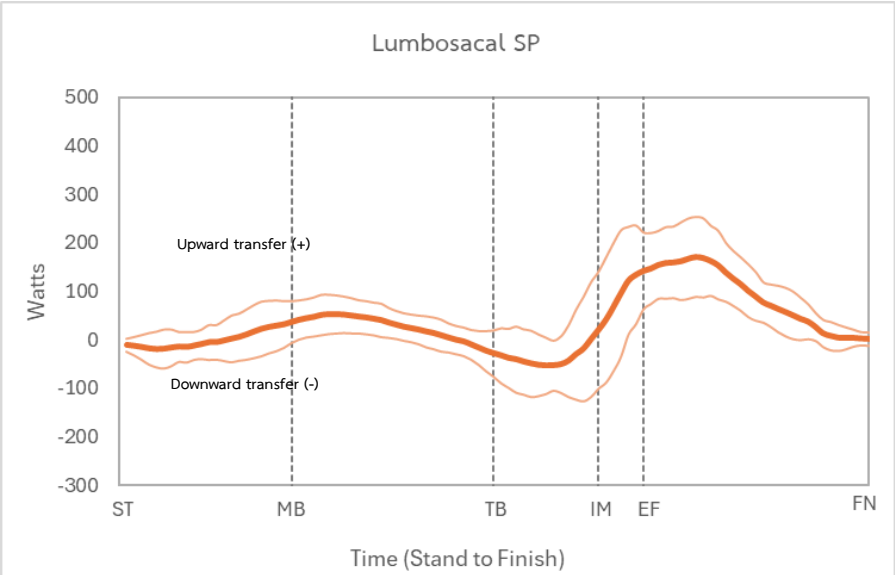

Figure 4.6 Mean normalized segment power (SP) in high handicap players using a 7-iron, indicating the rates of energy transfer in the lumbosacral (L5S1).

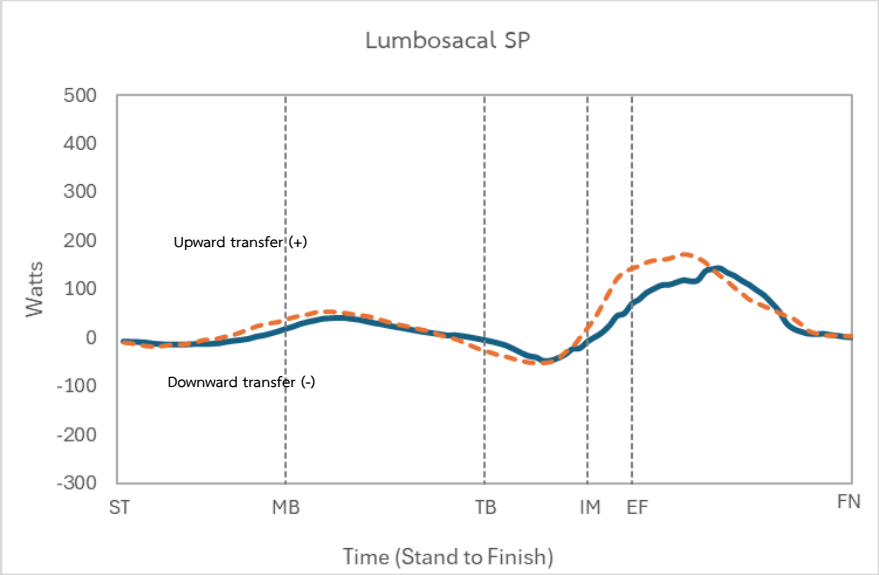

Figure 4.7 Mean normalized segment power (SP) in high handicap players using a driver (solid line) and 7-iron (dashed line), indicating the rates of energy transfer in the lumbosacral (L5S1).

The analysis of Figure 4.7 indicates that during the Stand (ST) phase, amateur golfers have not yet initiated their swing movement, resulting in a low level of energy transfer. The energy accumulated during this phase remains relatively stable, with no significant difference between the driver and the 7-iron, suggesting that weight distribution strategies are similar at this stage. In the Middle Backswing (MB) phase, the

energy values for both the driver and the 7-iron are slightly positive, which may be due to differences in energy transfer control among high-handicap golfers. As the swing progresses to the Top of Backswing (TB) phase, energy levels slightly decrease before transitioning into the downswing. High-handicap golfers using the 7-iron are able to maintain energy levels better than those using the driver, indicating differences in energy control between the two clubs. During the Impact (IM) phase, energy values increase only slightly, suggesting that only a small amount of energy is transferred back into the upper body. However, the comparison between the driver and the 7-iron shows a similar pattern of energy flow in this phase. Finally, in the Early Finish (EF) phase, energy flow continues to increase, reaching its peak during the EF - FN transition, which represents the post-impact force transmission process. However, the energy levels of both the driver and the 7-iron gradually decline toward equilibrium, with both curves becoming more similar as the swing concludes.

Table 4.4 Differences in normal pressure in the left foot between professional and high handicap players using a driver at the key moments of the swing.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P
GT	-3 (*)	0.010	-3	0.091	-5 (*)	0.040	-10 (*)	0.001	-12 (*)	0.001
LT	3 (*)	0.001	3 (*)	0.016	2	0.315	3 (*)	0.007	1	0.310
MEDmet	2	0.322	7 (*)	0.013	4 (*)	0.042	4	0.282	-3	0.248
CENmet	2	0.429	0	0.846	1	0.571	4	0.076	3	0.242
LATmet	1	0.704	0	0.882	1	0.750	6 (*)	0.017	8 (*)	0.002
MEDarc	2	0.393	5	0.055	3	0.343	-1	0.623	-2	0.406
LATarc	1	0.626	0	0.935	1	0.660	3	0.313	7 (*)	0.013
HEEL	-8	0.085	-12 (*)	0.035	-7 (*)	0.035	-8 (*)	0.012	-2	0.375

ST: Stand; MB: Middle Backswing; TB: Top of Backswing; IM: Ball Impact; EF: Early Finish; GT: Great Toe; LT: Lesser Toe; MEDmet: Medial Metatarsal; CENmet: Central Metatarsal; LATmet: Lateral Metatarsal; MEDarc: Medial Arch; LATarc: Lateral Arch; HEEL: Heel; * significant differences at $p < 0.05$.

The analysis of Table 4.4 indicates that during the Stand (ST) phase, there were statistically significant differences ($p < 0.05$) in normal pressure in the left foot between professional golfers and high-handicap golfers when using the driver. Significant differences were found in the Great Toe (GT) and Lesser Toe (LT) regions, where

pressure at GT was lower in professional golfers, whereas pressure at LT was higher compared to the high-handicap group. During the Middle Backswing (MB) phase, significant differences ($p < 0.05$) were observed in the Lesser Toe (LT), Medial Metatarsal (MEDmet), and Heel (HEEL) regions. Pressure at LT and MEDmet was higher in professional golfers, while pressure at HEEL was lower compared to high-handicap golfers. At the Top of Backswing (TB) phase, significant differences ($p < 0.05$) were detected in the Great Toe (GT), Medial Metatarsal (MEDmet), and Heel (HEEL) regions. Pressure at GT and HEEL was lower in professional golfers, whereas pressure at MEDmet was higher compared to the high-handicap group. During the Ball Impact (IM) phase, significant differences ($p < 0.05$) were found in the Great Toe (GT), Lesser Toe (LT), Lateral Metatarsal (LATmet), and Heel (HEEL) regions. Pressure at GT and HEEL was lower in professional golfers, while pressure at LT and LATmet was higher compared to high-handicap golfers. In the Early Finish (EF) phase, statistically significant differences ($p < 0.05$) were observed in the Great Toe (GT), Lateral Metatarsal (LATmet), and Lateral Arch (LATarc) regions. Pressure at GT was lower in professional golfers, whereas pressure at LATmet and LATarc was higher compared to the high-handicap group.

Table 4.5 Differences in normal pressure in the right foot between professional and high handicap players using a driver at the key moments of the swing.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P
GT	1	0.696	2	0.234	3	0.147	8	0.166	7	0.276
LT	0	0.890	2 (*)	0.019	3 (*)	0.013	-5	0.072	-4	0.230
MEDmet	3	0.137	3 (*)	0.012	3	0.225	11 (*)	0.005	7	0.074
CENmet	-1	0.562	1	0.519	-3	0.232	-16 (*)	0.000	-14 (*)	0.001
LATmet	-5 (*)	0.016	-4	0.067	-7 (*)	0.008	-13 (*)	0.000	-8 (*)	0.012
MEDarc	6 (*)	0.001	4 (*)	0.009	6 (*)	0.002	6 (*)	0.020	7 (*)	0.020
LATarc	2	0.259	1	0.582	-2	0.487	2	0.171	2 (*)	0.042
HEEL	-6	0.143	-10 (*)	0.037	-2	0.624	7 (*)	0.025	2	0.812

ST: Stand; MB: Middle Backswing; TB: Top of Backswing; IM: Ball Impact; EF: Early Finish; GT: Great Toe; LT: Lesser Toe; MEDmet: Medial Metatarsal; CENmet: Central Metatarsal; LATmet: Lateral Metatarsal; MEDarc: Medial Arch; LATarc: Lateral Arch; HEEL: Heel; * significant differences at $p < 0.05$.

The analysis of Table 4.5 indicates that during the Stand (ST) phase, there were statistically significant differences ($p < 0.05$) in normal pressure in the right foot between professional golfers and high-handicap golfers when using the driver. Significant differences were observed in the Lateral Metatarsal (LATmet) and Medial Arch (MEDarc) regions, where pressure at LATmet was lower in professional golfers, whereas pressure at MEDarc was higher compared to the high-handicap group. During the Middle Backswing (MB) phase, significant differences ($p < 0.05$) were found in the Lesser Toe (LT), Medial Metatarsal (MEDmet), Medial Arch (MEDarc), and Heel (HEEL) regions. Pressure at LT, MEDmet, and MEDarc was higher in professional golfers, while pressure at HEEL was lower compared to high-handicap golfers. At the Top of Backswing (TB) phase, statistically significant differences ($p < 0.05$) were detected in the Lesser Toe (LT), Lateral Metatarsal (LATmet), and Medial Arch (MEDarc) regions. Pressure at LT and MEDarc was higher in professional golfers, whereas pressure at LATmet was lower compared to the high-handicap group. During the Ball Impact (IM) phase, significant differences ($p < 0.05$) were observed in the Medial Metatarsal (MEDmet), Central Metatarsal (CENmet), Lateral Metatarsal (LATmet), Medial Arch (MEDarc), and Heel (HEEL) regions. Pressure at MEDmet, MEDarc, and HEEL was higher in professional golfers, while pressure at CENmet and LATmet was lower compared to high-handicap golfers. In the Early Finish (EF) phase, statistically significant differences ($p < 0.05$) were found in the Central Metatarsal (CENmet), Lateral Metatarsal (LATmet), Medial Arch (MEDarc), and Lateral Arch (LATarc) regions. Pressure at CENmet and LATmet was lower in professional golfers, whereas pressure at MEDarc and LATarc was higher compared to the high-handicap group.

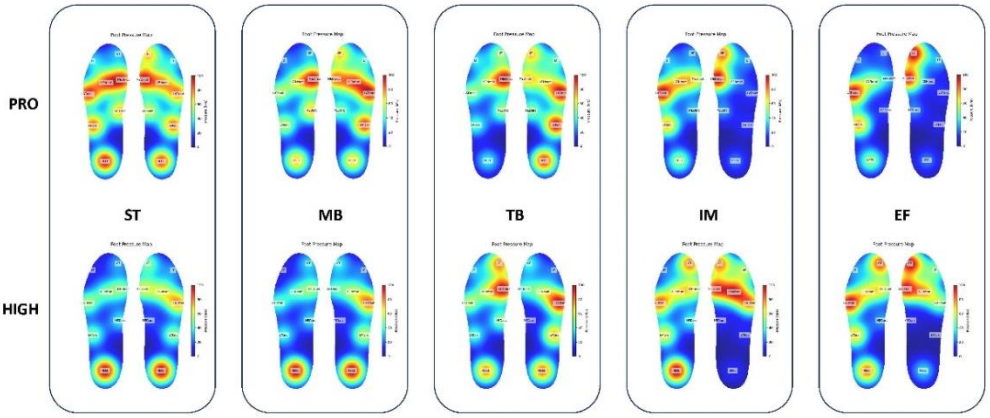

Figure 4.8 Average maximum plantar pressure distribution across different foot areas between professional and high handicap players using a driver at the key moments of the swing.

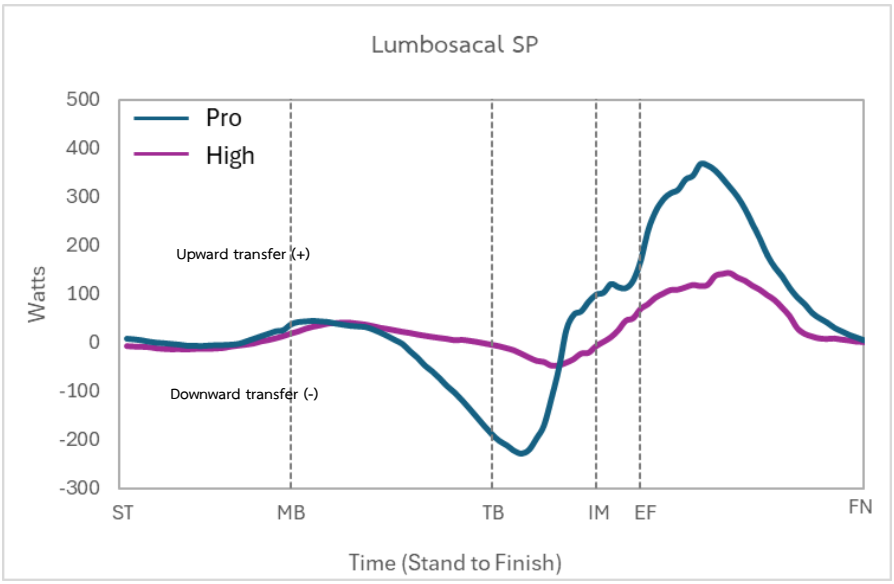

Figure 4.9 Mean normalized segment power between professional and high handicap players using a driver, indicating the rates of energy transfer in the lumbosacral (L5S1).

The analysis of Figure 4.9 reveals that during the Stand (ST) phase, energy levels remain low, with no significant difference between professional and amateur golfers. This indicates that both groups have not yet begun generating energy during the swing preparation phase. In the Middle Backswing (MB) phase, energy begins to accumulate progressively, with professional golfers storing more energy than amateur golfers. This difference may be attributed to more efficient pressure distribution and torso rotation, which enhances energy retention and transfer. As the swing progresses to the Top of Backswing (TB) phase, professional golfers exhibit significantly higher energy levels than

amateur golfers, indicating that they can store more energy in preparation for the downswing. In contrast, amateur golfers may experience energy loss due to suboptimal weight distribution techniques. During the Impact (IM) phase, where energy surges into the upper body, professional golfers achieve a more effective energy transfer to the golf club, resulting in a greater impact force on the ball. Conversely, amateur golfers may experience energy leakage, leading to a lower amount of energy being transferred to the club. Finally, in the Early Finish (EF) phase, energy flow continues to increase, reaching its peak during the EF - FN transition, which represents the post-impact force transmission process. Energy levels then decline to their lowest point as the swing concludes. Professional golfers maintain better body balance and control over residual force, whereas amateur golfers may exhibit greater fluctuations in energy values due to less refined postural control.

Table 4.6 Differences in normal pressure in the left foot between professional and high handicap players using a 7-iron at the key moments of the swing.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P
GT	-3 (*)	0.026	-2	0.399	-4	0.260	-6 (*)	0.033	-7 (*)	0.003
LT	2	0.102	3 (*)	0.047	3 (*)	0.012	3 (*)	0.011	1	0.258
MEDmet	2	0.305	6 (*)	0.007	5	0.250	0	0.912	-1	0.758
CENmet	3	0.317	4	0.182	2	0.386	2	0.491	1	0.618
LATmet	3	0.162	6 (*)	0.012	6 (*)	0.040	14 (*)	0.001	15 (*)	0.000
MEDarc	2	0.463	1	0.753	2	0.550	-3	0.303	-2	0.296
LATarc	2	0.409	3	0.446	5	0.101	9 (*)	0.008	8 (*)	0.020
HEEL	-9	0.051	-14 (*)	0.017	-6	0.182	-7	0.180	-3	0.433

ST: Stand; MB: Middle Backswing; TB: Top of Backswing; IM: Ball Impact; EF: Early Finish; GT: Great Toe; LT: Lesser Toe; MEDmet: Medial Metatarsal; CENmet: Central Metatarsal; LATmet: Lateral Metatarsal; MEDarc: Medial Arch; LATarc: Lateral Arch; HEEL: Heel; * significant differences at $p < 0.05$.

The analysis of Table 4.6 indicates that during the Stand (ST) phase, there was a statistically significant difference ($p < 0.05$) in normal pressure in the left foot between professional golfers and high-handicap golfers when using the 7-iron. A significant difference was observed in the Great Toe (GT) region, where pressure at GT was lower in professional golfers compared to the high-handicap group. During the Middle Backswing (MB) phase, significant differences ($p < 0.05$) were found in the Lesser

Toe (LT), Medial Metatarsal (MEDmet), Lateral Metatarsal (LATmet), and Heel (HEEL) regions. Pressure at LT, MEDmet, and LATmet was higher in professional golfers, whereas pressure at HEEL was lower compared to high-handicap golfers. At the Top of Backswing (TB) phase, statistically significant differences ($p < 0.05$) were detected in the Lesser Toe (LT) and Lateral Metatarsal (LATmet) regions, where pressure at LT and LATmet was higher in professional golfers compared to the high-handicap group. During the Ball Impact (IM) phase, significant differences ($p < 0.05$) were observed in the Great Toe (GT), Lesser Toe (LT), Lateral Metatarsal (LATmet), and Lateral Arch (LATarc) regions. Pressure at GT was lower in professional golfers, while pressure at LT, LATmet, and LATarc was higher compared to the high-handicap group. In the Early Finish (EF) phase, statistically significant differences ($p < 0.05$) were found in the Great Toe (GT), Lateral Metatarsal (LATmet), and Lateral Arch (LATarc) regions. Pressure at GT was lower in professional golfers, whereas pressure at LATmet and LATarc was higher compared to the high-handicap group.

Table 4.7 Differences in normal pressure in the right foot between professional and high handicap players using a 7-iron at the key moments of the swing.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P	MEAN (%)	P
GT	3	0.162	5	0.083	6 (*)	0.007	11	0.072	10	0.134
LT	2	0.075	3 (*)	0.001	3 (*)	0.005	0	0.904	-5	0.065
MEDmet	4 (*)	0.027	7 (*)	0.008	4 (*)	0.004	6	0.139	7	0.141
CENmet	1	0.631	3	0.187	2	0.479	-9 (*)	0.007	-10 (*)	0.006
LATmet	-2	0.382	0	0.993	0	0.938	-10 (*)	0.015	-6	0.053
MEDarc	6 (*)	0.001	5 (*)	0.013	5 (*)	0.004	7 (*)	0.000	9 (*)	0.000
LATarc	2	0.185	0	0.990	0	0.912	2	0.434	4 (*)	0.010
HEEL	-15 (*)	0.008	-17 (*)	0.002	-7	0.166	7 (*)	0.024	6	0.445

ST: Stand; MB: Middle Backswing; TB: Top of Backswing; IM: Ball Impact; EF: Early Finish; GT: Great Toe; LT: Lesser Toe; MEDmet: Medial Metatarsal; CENmet: Central Metatarsal; LATmet: Lateral Metatarsal; MEDarc: Medial Arch; LATarc: Lateral Arch; HEEL: Heel; * significant differences at $p < 0.05$.

The analysis of Table 4.7 indicates that during the Stand (ST) phase, there were statistically significant differences ($p < 0.05$) in normal pressure in the right foot between professional golfers and high-handicap golfers when using the 7-iron. Significant differences were observed in the Medial Metatarsal (MEDmet), Medial Arch

(MEDarc), and Heel (HEEL) regions. Pressure at MEDmet and MEDarc was higher in professional golfers, whereas pressure at HEEL was lower compared to the high-handicap group. During the Middle Backswing (MB) phase, significant differences ($p < 0.05$) were found in the Lesser Toe (LT), Medial Metatarsal (MEDmet), Medial Arch (MEDarc), and Heel (HEEL) regions. Pressure at LT, MEDmet, and MEDarc was higher in professional golfers, while pressure at HEEL was lower compared to high-handicap golfers. At the Top of Backswing (TB) phase, statistically significant differences ($p < 0.05$) were detected in the Great Toe (GT), Lesser Toe (LT), Medial Metatarsal (MEDmet), and Medial Arch (MEDarc) regions. Pressure at GT, LT, MEDmet, and MEDarc was higher in professional golfers compared to the high-handicap group. During the Ball Impact (IM) phase, significant differences ($p < 0.05$) were observed in the Central Metatarsal (CENmet), Lateral Metatarsal (LATmet), Medial Arch (MEDarc), and Heel (HEEL) regions. Pressure at CENmet and LATmet was lower in professional golfers, whereas pressure at MEDarc and HEEL was higher compared to the high-handicap group. In the Early Finish (EF) phase, statistically significant differences ($p < 0.05$) were found in the Central Metatarsal (CENmet), Medial Arch (MEDarc), and Lateral Arch (LATarc) regions. Pressure at CENmet was lower in professional golfers, while pressure at MEDarc and LATarc was higher compared to the high-handicap group.

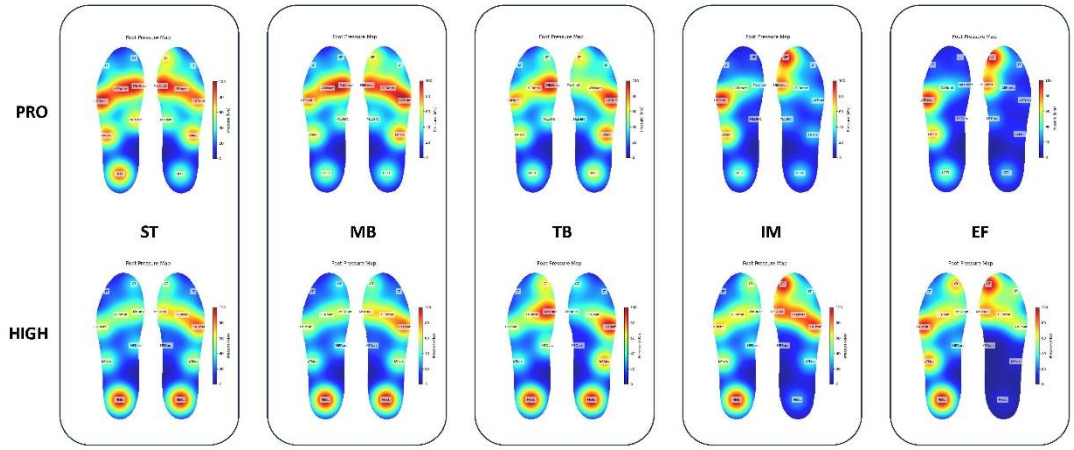

Figure 4.10 Average maximum plantar pressure distribution across different foot areas between professional and high handicap players using a 7-iron at the key moments of the swing.

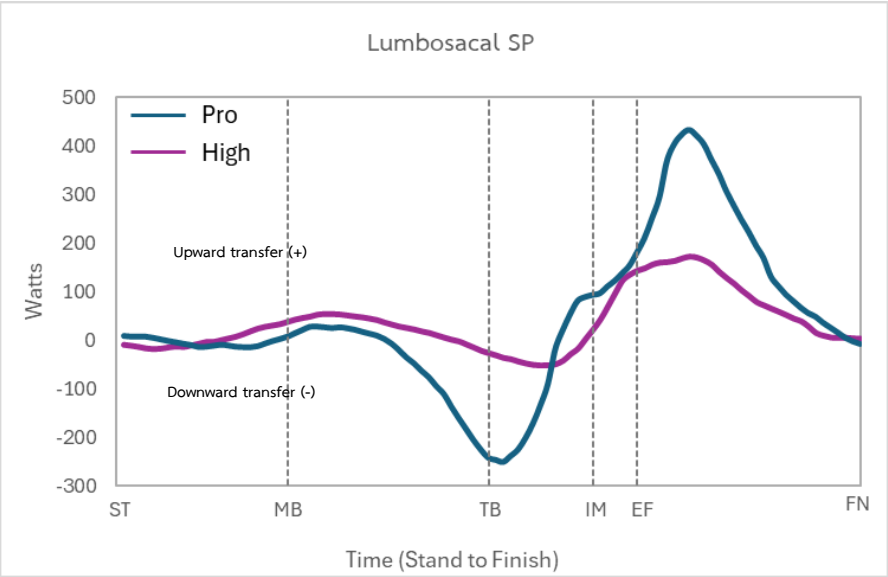

Figure 4.11 Mean normalized segment power between professional and high handicap players using a 7-iron, indicating the rates of energy transfer in the lumbosacral (L5S1).

The analysis of Figure 4.11 shows that during the Stand (ST) phase, energy levels remain low, with no noticeable difference between professional and amateur golfers. In the Middle Backswing (MB) phase, energy begins to accumulate progressively, with amateur golfers transferring more energy to the upper body than professional golfers. As the swing progresses to the Top of Backswing (TB) phase, professional golfers exhibit significantly higher energy levels than amateur golfers, indicating that they can store more energy in preparation for the downswing. In contrast, amateur golfers may experience some energy loss due to suboptimal weight distribution techniques. During the Impact (IM) phase, where energy surges rapidly into the upper body, professional golfers achieve an efficient energy transfer to the golf club, generating a greater impact force on the ball. Conversely, amateur golfers may experience energy leakage, leading to less energy being transferred to the club. Finally, in the Early Finish (EF) phase, energy flow continues to increase, reaching its peak during the EF - FN transition, which represents the post-impact force transmission process. Energy levels then decline to their lowest point as the swing concludes. Professional golfers maintain better body balance and control over residual forces, while amateur golfers may experience greater fluctuations in energy values due to less refined postural control.

4.3 Correlation between plantar pressure and energy transfer

Table 4.8 Correlation between segment power and plantar pressure of the left foot in the professional group using a driver at the key moments of the swing.

	ST		MB		TB		IM		EF	
AREAS	PEARSON CORRELATION	P	PEARSON CORRELATION	P	PEARSON CORRELATION	P	PEARSON CORRELATION	P	PEARSON CORRELATION	P
GT	-0.524*	0.045	0.299	0.280	-0.933*	0.000	-0.664*	0.007	0.101	0.720
LT	-0.709*	0.003	-0.133	0.636	-0.613*	0.015	-0.487	0.066	0.227	0.416
MEDmet	-0.618*	0.014	0.549*	0.034	-0.494	0.061	0.237	0.394	0.366	0.179
CENmet	-0.409	0.130	0.450	0.092	-0.646*	0.009	0.175	0.532	0.383	0.159
LATmet	0.071	0.803	0.449	0.093	-0.660*	0.007	0.237	0.395	-0.132	0.639
MEDarc	0.610*	0.016	0.502	0.057	-0.780*	0.001	-0.046	0.870	-0.172	0.540
LATarc	0.690*	0.004	0.135	0.630	-0.840*	0.000	0.076	0.787	-0.285	0.303
HEEL	0.660*	0.007	-0.466	0.080	0.005	0.986	-0.108	0.700	-0.325	0.237

ST: Stand; MB: Middle Backswing; TB: Top of Backswing; IM: Ball Impact; EF: Early Finish; GT: Great Toe; LT: Lesser Toe; MEDmet: Medial Metatarsal; CENmet: Central Metatarsal; LATmet: Lateral Metatarsal; MEDarc: Medial Arch; LATarc: Lateral Arch; HEEL: Heel; * significant correlations at $p < 0.05$.

The analysis of Table 4.8, which presents the correlation between normal pressure in the left foot and segmental body energy in professional golfers using a driver, reveals several key findings. During the Stand (ST) phase, pressure at the Great Toe (GT), Lesser Toe (LT), and Medial Metatarsal (MEDmet) exhibited a negative correlation with body energy, indicating that an increase in pressure in these regions corresponds to a decrease in body energy utilization. Conversely, pressure at the Medial Arch (MEDarc), Lateral Arch (LATarc), and Heel (HEEL) showed a positive correlation with body energy, meaning that higher pressure in these areas is associated with an increase in body energy. In the Middle Backswing (MB) phase, pressure at the Medial Metatarsal (MEDmet) had a positive correlation with body energy, suggesting that greater pressure in this region contributes to increased energy transfer within the body during the middle phase of the backswing. During the Top of Backswing (TB) phase, a negative correlation was observed between pressure at the Great Toe (GT), Lesser Toe (LT), Central Metatarsal (CENmet), Lateral Metatarsal (LATmet), Medial Arch (MEDarc), and Lateral Arch (LATarc) and body energy. This indicates that higher pressure in these areas tends to reduce body energy during the peak of the backswing. At the Ball Impact (IM) phase, a negative correlation was found between pressure at the Great

Toe (GT) and body energy, suggesting that an increase in pressure at this location is associated with a reduction in body energy at the moment of impact. In the Early Finish (EF) phase, no statistically significant correlations were observed ($p > 0.05$), indicating that pressure distribution in the left foot during this phase does not significantly influence body energy transfer.

Table 4.9 Correlation between segment power and plantar pressure of the right foot in the professional group using a driver at the key moments of the swing.

	ST		MB		TB		IM		EF	
AREAS	PEARSON CORRELATION	P	PEARSON CORRELATION	P	PEARSON CORRELATION	P	PEARSON CORRELATION	P	PEARSON CORRELATION	P
GT	-0.185	0.510	0.375	0.168	-0.859*	0.000	0.402	0.138	0.143	0.611
LT	-0.698*	0.004	0.311	0.259	-0.786*	0.001	0.339	0.216	-0.212	0.447
MEDmet	-0.392	0.149	0.420	0.119	-0.383	0.159	0.598*	0.019	0.566*	0.028
CENmet	-0.626*	0.013	0.471	0.076	-0.045	0.875	0.265	0.341	0.389	0.152
LATmet	-0.188	0.502	0.636*	0.011	-0.488	0.065	0.377	0.166	0.350	0.200
MEDarc	0.754*	0.001	0.268	0.335	-0.734*	0.002	0.377	0.165	0.350	0.201
LATarc	0.766*	0.001	0.566*	0.028	-0.709*	0.003	0.090	0.748	-0.262	0.345
HEEL	0.492	0.062	-0.393	0.147	0.380	0.163	-0.329	0.231	-0.245	0.379

ST: Stand; MB: Middle Backswing; TB: Top of Backswing; IM: Ball Impact; EF: Early Finish; GT: Great Toe; LT: Lesser Toe; MEDmet: Medial Metatarsal; CENmet: Central Metatarsal; LATmet: Lateral Metatarsal; MEDarc: Medial Arch; LATarc: Lateral Arch; HEEL: Heel; * significant correlations at $p < 0.05$.

The analysis of Table 4.9, which presents the correlation between normal pressure in the right foot and segmental body energy in professional golfers using a driver, reveals several key findings. During the Stand (ST) phase, pressure at the Lesser Toe (LT) and Central Metatarsal (CENmet) exhibited a negative correlation with body energy, indicating that an increase in pressure in these regions corresponds to a decrease in body energy utilization. In contrast, pressure at the Medial Arch (MEDarc) and Lateral Arch (LATarc) showed a positive correlation with body energy, suggesting that higher pressure in these areas is associated with an increase in body energy. In the Middle Backswing (MB) phase, a positive correlation was observed between pressure at the Lateral Metatarsal (LATmet) and Lateral Arch (LATarc) and body energy, meaning that greater pressure in these regions may contribute to increased body energy during the middle phase of the backswing. During the Top of Backswing (TB) phase, a negative correlation was found between pressure at the Great Toe (GT), Lesser Toe (LT), Medial

Arch (MEDarc), and Lateral Arch (LATarc) and body energy, suggesting that higher pressure in these areas is associated with a reduction in body energy at the peak of the backswing. At the Ball Impact (IM) phase, pressure at the Medial Metatarsal (MEDmet) showed a positive correlation with body energy, indicating that an increase in pressure in this region may contribute to higher body energy during ball impact. In the Early Finish (EF) phase, pressure at the Medial Metatarsal (MEDmet) was positively correlated with body energy, suggesting that greater pressure in this region may contribute to an increase in body energy during the early stage of the follow-through.

4.4 Stand (ST)

4.4.1 Differences in plantar pressure when using the driver and 7-iron in professional golfers at the stand (ST)

The stand Phase (ST) is a crucial period in which golfers adjust their body position to prepare for the initiation of the swing. The distribution of plantar pressure during this phase influences postural stability and the subsequent kinematic sequence in the backswing and downswing (Ball and Best, 2012). Previous studies have indicated that foot positioning and weight distribution directly affect the generation of torque in the trunk, which is a key factor in producing a powerful and accurate swing (Nesbit and Serrano, 2005; You et al., 2023). Recent research has demonstrated variations in plantar pressure between the left and right foot during the ST phase, which correlate with the type of club used and the golfer's skill level (MacKenzie et al., 2020; Sheehan et al., 2022)

An analysis of professional golfers' plantar pressure data revealed no significant differences in the left foot's pressure between different club types, indicating that golfers maintain balance regardless of the club used (You et al., 2023). However, the right foot exhibits significant variations in pressure when using a driver compared to a 7-iron. Specifically, when using a driver, the pressure on the right heel was 7% higher ($p=0.014$) than when using a 7-iron (Pataky, 2015). This finding aligns with the trend that using a driver requires greater weight transfer towards the heel to generate more energy during the backswing (Han et al., 2019). Conversely, when using a 7-iron, pressure on the central metatarsal (CENmet) and lateral metatarsal (LATmet)

regions was approximately 2% higher (p=0.010 and p=0.013, respectively) than when using a driver. This shift in pressure towards the forefoot reflects a strategy for enhancing precision and control over the club's direction (MacKenzie et al., 2020; You et al., 2023).

Energy transfer analysis during the ST phase indicates that the energy transfer at the lumbosacral joint (L5S1) remains low and relatively stable, suggesting that at the beginning of the swing, golfers have not yet engaged significant lower-body force (Nesbit and Serrano, 2005). The energy distribution graph for both the driver and the 7-iron follows a similar trend during this phase, showing that professional golfers can effectively maintain energy balance regardless of the club used. However, the differences in plantar pressure distribution between the two clubs highlight distinct set-up strategies: golfers tend to exert greater pressure on the right heel when using a driver, whereas they distribute more weight to the forefoot and midfoot regions when using a 7-iron to enhance swing precision (Dong and Ikuno, 2023).

Plantar pressure distribution during the ST phase directly influences energy transfer efficiency and swing stability. Professional golfers tend to adjust their foot pressure according to the club type: increasing heel pressure when using a driver to facilitate greater acceleration and power, while shifting weight towards the forefoot when using a 7-iron to enhance club control accuracy (Sheehan et al., 2022). A study by Quinn et al. (2022) found that golfers who optimally adjust their foot pressure during the ST phase can generate torque more effectively and minimize swing errors.

The ST phase is a critical component in establishing body stability and determining the subsequent swing mechanics. Professional golfers tend to shift more weight onto their heels when using a driver to generate higher torque and increase swing power. In contrast, when using a 7-iron, they distribute weight more towards the forefoot and midfoot for improved accuracy. Amateur golfers may need to refine their set-up techniques according to club type, particularly in controlling foot pressure to optimize energy transfer during the backswing and downswing (Quinn et al., 2022; Worsfold et al., 2009).

4.4.2 Differences in plantar pressure between professional and amateur golfers at the stand (ST)

The stand phase (ST) is a crucial moment when golfers align their body and prepare for the initiation of the swing. The distribution of plantar pressure during this phase plays a significant role in maintaining balance and facilitating weight transfer into the backswing and downswing (Ball and Best, 2012). Differences in plantar pressure between professional and amateur golfers can directly impact body stability and swing efficiency, particularly during the address position (MacKenzie et al., 2020; Sheehan et al., 2022). An analysis of plantar pressure data reveals significant differences between professional and amateur golfers during the ST phase, with distinct pressure distribution patterns depending on the type of golf club used (You et al., 2023).

When using a Driver, professional golfers tend to reduce pressure on the left great toe (GT) by 3% ($p = 0.010$), potentially reflecting a weight distribution strategy that minimizes forward lean by alleviating pressure on the forefoot. At the same time, they exhibit a 3% increase ($p = 0.001$) in pressure on the lesser toe (LT), which may result from shifting weight laterally to balance left foot pressure. This pattern aligns with the tendency of professional golfers to maintain early swing stability by evenly distributing pressure to synchronize with torso movement. On the right foot, lateral metatarsal (LATmet) pressure is reduced by 5% ($p = 0.016$) compared to amateur golfers, indicating a strategy to offload pressure from the outer right foot and minimize unnecessary lateral movement. Conversely, pressure on the medial arch (MEDarc) increases by 6% ($p = 0.001$), suggesting an enhanced ability to stabilize the torso and hips by shifting weight to areas that contribute to torque generation during the backswing. These differences likely stem from the more refined weight-shifting techniques employed by professional golfers, which optimize swing efficiency while reducing unnecessary plantar loading.

When using a 7-Iron, professional golfers maintain the same trend of reducing pressure on the left great toe (GT) by 3% ($p = 0.026$), with no significant changes in other left foot zones. This suggests a consistent weight distribution strategy that supports balance control without relying on the great toe for stability. In contrast, the right foot of professional golfers exhibits a distinct pressure adaptation, with a 4%

increase ($p = 0.027$) in medial metatarsal (MEDmet) pressure and a 6% increase ($p = 0.001$) in medial arch (MEDarc) pressure, while heel (HEEL) pressure decreases by 15% ($p = 0.008$). The reduction in heel pressure may be a deliberate strategy to shift weight toward the forefoot, enhancing control over swing direction. These differences highlight the ability of professional golfers to fine-tune plantar pressure adjustments, ensuring optimal balance and precise club movement control.

The distribution of plantar pressure during the ST phase directly influences energy transfer through the kinetic chain, a critical mechanism affecting body movement throughout the swing. Data from Figure 4.9 and Figure 4.11 indicate that energy transfer at the lumbosacral joint (L5S1) during the ST phase remains low and relatively stable, with no significant differences between the use of a Driver and a 7-Iron or between professional and amateur golfers. Although energy levels in this region remain low, the contrasting energy control strategies between the two golfer groups suggest variations in balance maintenance and preparation for subsequent swing phases. Professional golfers exhibit more stable energy distribution, maintaining consistent energy values with higher stability. This suggests their ability to sustain a steady posture and minimize unnecessary movements during the ST phase, which facilitates smoother and more efficient energy transitions into the backswing. Conversely, amateur golfers tend to show slightly more energy fluctuation, likely due to compensatory balance adjustments or unstable positioning during address. These energy fluctuations may reflect uneven plantar pressure distribution, causing minor shifts in the body's center of mass and potentially affecting swing performance in later phases. The ability of professional golfers to maintain stable L5S1 energy levels may result from better plantar pressure control, particularly increased medial arch pressure, which optimally engages hip and torso mechanics. Additionally, reduced heel pressure may minimize resistance and enhance energy transition from the lower body to the torso, supporting a more efficient backswing (MacKenzie et al., 2020; Dong and Ikuno, 2023).

Professional golfers demonstrate superior plantar pressure adjustments, reducing unnecessary loading and enhancing directional control of the swing more effectively than amateur golfers. Moreover, the energy flow generated by plantar

pressure influences hip rotation and body movement control, both of which are essential for swing performance. Amateur golfers can apply these insights in training to improve stability and correct plantar pressure distribution errors, ultimately refining their technique in alignment with optimal body mechanics (Quinn et al., 2022; Worsfold et al., 2009).

4.4.3 Relationship between plantar pressure and energy flow in professional golfers at the stand (ST)

Analyzing the relationship between plantar pressure and energy flow during stand phase (ST) is a crucial component in understanding the mechanics of movement and energy transfer at the initial stage of the golf swing. This phase is when the body establishes structural alignment and foot positioning to prepare for subsequent movement into the backswing. Data from Table 4.8 and Table 4.9, which present Pearson correlation coefficients, indicate varying relationships between plantar pressure and energy flow depending on the foot region. Professional golfers demonstrate greater control over plantar pressure at different foot zones, leading to more efficient energy flow, reflecting a complex mechanism of balance control and optimized energy transfer for the swing.

For the left foot, a significant negative correlation was observed between pressure on the great toe (GT), lesser toe (LT), and medial metatarsal (MEDmet) with energy flow (GT: $r = -0.524$, $p<0.05$; LT: $r = -0.709$, $p<0.01$; MEDmet: $r = -0.618$, $p<0.05$). This suggests that increased pressure in these areas corresponds with reduced energy flow toward the torso. This trend indicates that professional golfers tend to avoid excessive loading on the forefoot during the set-up phase, instead distributing weight towards the midfoot and heel to maintain balance and support energy transfer into the hips and torso (Ball and Best, 2012). Conversely, significant positive correlations were found between pressure at the medial arch (MEDarc) and lateral arch (LATarc) with energy flow (MEDarc: $r = 0.754$, $p<0.01$; LATarc: $r = 0.766$, $p<0.01$), implying that increased pressure in these regions is associated with more stable energy flow. Professional golfers utilize pressure from the arches to enhance body stability and facilitate a more efficient energy transfer into the backswing (Dong and Ikuno, 2023).

For the right foot, a similar trend was observed. A significant negative correlation was found between pressure on the lesser toe (LT) ($r = -0.698$, $p<0.01$) and central metatarsal (CENmet) ($r = -0.626$, $p<0.05$) with energy flow. This suggests that increased pressure in these areas may be linked to reduced energy transfer at the beginning of the swing. This data reflects the tendency of professional golfers to avoid excessive forefoot pressure on the right foot during the set-up phase to prevent balance disruptions and minimize interference with energy transfer to the torso (Sheehan et al., 2022). Meanwhile, significant positive correlations were found between pressure at the lateral metatarsal (LATmet) and lateral arch (LATarc) with energy flow (LATmet: $r = 0.636$, $p = 0.011$; LATarc: $r = 0.566$, $p = 0.028$). This suggests that increasing pressure in these areas contributes to enhanced body stability and improved energy transfer efficiency. Professional golfers leverage pressure on the arches and lateral metatarsal regions to maintain balance and optimize energy transition from the lower body to the torso (Pataky, 2015; Chu, Sell, and Lephart, 2010).

The findings indicate that the relationship between plantar pressure and energy flow is a key factor in determining a golfer's weight distribution strategy. Professional golfers tend to reduce pressure on the forefoot and instead distribute it toward the arches and heels, which helps create a more stable and efficient energy flow. In contrast, amateur golfers may be more prone to applying pressure in ways that disrupt balance and reduce energy transfer efficiency toward the torso. Therefore, refining plantar pressure distribution is a crucial factor in improving energy transfer and optimizing overall swing mechanics (MacKenzie et al., 2020; You et al., 2023).

4.5 Middle backswing (MB)

4.5.1 Differences in plantar pressure when using the driver and 7-iron in professional golfers at the middle backswing (MB)

The Middle Backswing (MB) is a critical phase where golfers begin shifting their weight onto the right foot (for right-handed golfers) and generating rotational torque to prepare for the Top of Backswing (TB). Differences in plantar pressure between the left and right foot at this stage play a significant role in maintaining balance and preparing for power generation in the downswing. Analyzing plantar

pressure patterns during this phase provides insights into efficient weight distribution strategies, which can contribute to refining swing techniques (You et al., 2023; Dong and Ikuno, 2023). Studies on plantar pressure during the MB phase indicate that professional golfers tend to increase pressure on the arches and metatarsals, enhancing rotational torque while maintaining stability. The pressure distribution between the left and right foot also varies depending on the type of golf club used (Belotti et al., 2024).

When using a Driver, pressure on the medial metatarsal (MEDmet) of the left foot tends to increase by 2% compared to using a 7-Iron, while pressure on the lateral metatarsal (LATmet) and central metatarsal (CENmet) decreases by 5% and 4%, respectively ($p < 0.05$). This indicates that when using a Driver, golfers tend to shift weight toward the medial arch to reduce body sway and enhance stability for efficient torque generation (Ball and Best, 2012; Pataky, 2015). Conversely, when using a 7-Iron, pressure is more evenly distributed across the midfoot and lateral metatarsals, reflecting an attempt to maintain body stability and improve swing accuracy. Golfers who effectively distribute pressure toward the midfoot and lateral zones exhibit better club control, a characteristic commonly seen in high-performance golfers (Sheehan et al., 2022; Jones et al., 2024).

For the right foot, significant differences in pressure between the Driver and 7-Iron are observed, particularly in the heel (HEEL) and arch regions (MEDarc, LATarc). When using a Driver, heel pressure increases by 5% ($p < 0.05$) compared to a 7-Iron, indicating a tendency to shift more weight onto the right heel to support rotational torque and enhance backswing stability (Sheehan et al., 2022). Conversely, when using a 7-Iron, golfers distribute more pressure toward the midfoot and forefoot, leading to greater stability in the MB phase. These findings align with research by Nesbit and Serrano (2005) and Hiley et al. (2021), which suggest that heel and arch pressure play a crucial role in maintaining balance during the backswing.

Data from Figure 4.4, which illustrates energy transfer at the Lumbosacral (L5S1) joint, indicates a slight increase in energy levels during the MB phase. However, overall energy remains low, as golfers are still in the torque generation phase, without fully accelerating the club. Energy values between the Driver and 7-Iron are

comparable in this phase, although the Driver may show briefly higher energy values due to its longer shaft and greater force requirements (Han et al., 2019).

Studies by Burden et al. (2013) and Outram and Wheat (2021) emphasize that the MB phase marks the beginning of energy accumulation through body rotation and torque generation. Golfers who can effectively manage energy transfer in this phase can store energy efficiently and transfer it seamlessly into the club during the downswing. Plantar pressure in the MB phase plays a vital role in maintaining body balance and energy generation for club acceleration in the downswing. Professional golfers tend to distribute pressure evenly, with a tendency to increase pressure on the right heel and left arch, promoting a stable rotational movement and efficient energy storage. In contrast, amateur golfers often apply more pressure to the forefoot and midfoot, which may compromise balance and reduce torque efficiency necessary for the swing (Kenny et al., 2008; Jones et al., 2024).

During the Middle Backswing (MB), professional and amateur golfers exhibit distinct plantar pressure patterns. Professional golfers tend to increase pressure on the left arch and right heel, aiding in torque generation and body stability, while amateur golfers often shift pressure toward the forefoot and midfoot, potentially leading to balance loss and less efficient energy transfer. Proper foot pressure management can enhance swing efficiency and reduce errors resulting from imbalanced weight distribution (Belotti et al., 2024).

4.5.2 Differences in plantar pressure between professional and amateur golfers at the middle backswing (MB)

During the Middle Backswing (MB), golfers must precisely control weight transfer and plantar pressure to maintain body balance and generate rotational torque, which enhances power and swing accuracy. Research by Ball and Best (2007) highlights that proper weight transfer during the backswing directly influences torso torque generation and overall stability. Additionally, Horan et al. (2010) found that golfers who effectively manage plantar pressure during the backswing tend to reduce transition errors leading to the Top of Backswing (TB).

When using a Driver, professional golfers tend to shift weight more toward the midfoot and arch of the right foot, which helps maintain balance and generate

efficient torque for torso rotation. In contrast, amateur golfers often place excessive weight on the toes or heels, potentially leading to loss of control and reduced swing stability (Han et al., 2019). Table 4.4 reveals that in the left foot, professional golfers exhibit significantly higher pressure on the medial metatarsal (MEDmet) (+7, p=0.013). This aligns with findings by Nesbit and Serrano (2005), which suggest that increased medial metatarsal pressure plays a crucial role in maintaining balance and controlling torso rotation. Meanwhile, heel pressure decreases (-12, p=0.035), indicating a balance adjustment that facilitates smooth torso rotation by reducing excess load on the heel (McNitt-Gray et al., 2014). According to Table 4.5, for the right foot, professional golfers display higher pressure on the medial metatarsal (MEDmet) (+3, p=0.012) and medial arch (MEDarc) (+4, p=0.009). This pattern enhances body stability and prevents excessive leaning during torso rotation (Hume et al., 2005). In contrast, heel pressure decreases (-10, p=0.037), suggesting that professional golfers tend to minimize heel loading to maintain fluid body movement (Kwon et al., 2013).

When using a 7-Iron, a club that emphasizes precision over power, professional golfers maintain a similar weight distribution strategy as with the Driver, but with more balance between both feet. Table 4.6 shows that in the left foot, pressure on the medial metatarsal (MEDmet) (+6, p=0.007) and lateral metatarsal (LATmet) (+6, p=0.012) is higher, supporting swing stability (Lindsay and Horton, 2006). Table 4.7 reveals that in the right foot, professional golfers exhibit higher medial metatarsal (MEDmet) (+7, p=0.008) and medial arch (MEDarc) (+5, p=0.013) pressure, contributing to swing control and movement continuity (Horan et al., 2010). Heel pressure decreases significantly (-17, p=0.002), demonstrating efficient weight transfer and improved body balance (McNitt-Gray et al., 2014).

The MB phase marks the beginning of energy accumulation through weight transfer from the lead foot to the trail foot. Professional golfers control plantar pressure more effectively, ensuring smooth and efficient energy transfer. In contrast, amateur golfers experience rapid and inconsistent changes in plantar pressure, which may disrupt energy transfer to the core and hips at the end of the backswing (Dong and Ikuno, 2023). Figure 4.9 illustrates that when using a Driver, professional golfers efficiently accumulate energy during MB before significantly increasing energy output

in the Top Backswing (TB) and Downswing. Conversely, high-handicap amateur golfers exhibit lower energy values and less energy fluctuation in the MB phase, indicating limitations in energy transfer efficiency. The Driver requires greater torso-generated power, making the energy difference between professional and amateur golfers more pronounced (Belotti et al., 2024). On the other hand, Figure 4.11, which presents data from the 7-Iron, reveals that during MB, high-handicap amateur golfers surprisingly show higher energy levels than professionals. This may result from excessive but inefficient energy use. Professional golfers expend less energy during MB but can accumulate it more efficiently for TB and Downswing. The energy gap between professional and amateur golfers narrows when using a 7-Iron, as a shorter club requires less torso-generated power (Jones et al., 2024).

Professional golfers demonstrate systematic energy accumulation and transfer, leading to efficient energy utilization, while amateur golfers may overuse energy in MB but lack proper energy management, reducing Downswing efficiency. The Driver emphasizes performance differences between the two groups more than the 7-Iron. Amateur golfers can enhance their performance by improving weight transfer control and swing timing for optimized energy use (You et al., 2023).

Plantar pressure distribution during MB has a direct impact on body stability and rotational torque efficiency. Professional golfers maintain better balance by utilizing arch and heel pressure as primary support points, enabling efficient torque generation and smooth energy transfer into the club. In contrast, amateur golfers who place excessive pressure on the toes or forefoot may struggle with weight transfer, leading to energy loss and reduced swing accuracy. By refining weight transfer techniques, amateur golfers can enhance balance, minimize instability, and improve swing mechanics (Belotti et al., 2024).

An analysis of plantar pressure between professional and amateur golfers during MB indicates that professional golfers strategically shift weight toward the heel and arch, improving body stability and reducing excessive forefoot pressure. In contrast, amateur golfers often place weight on the forefoot, which may cause balance loss and inefficient energy transfer. By focusing on controlled arch and heel pressure, amateur golfers can improve energy flow, maintain balance, and enhance swing precision.

Practicing optimal plantar pressure management can lead to smoother energy transitions and greater swing efficiency (Belotti et al., 2024).

4.5.3 Relationship between plantar pressure and energy flow in professional golfers at the middle backswing (MB)

The Middle Backswing (MB) is the phase where golfers initiate torso rotation and shift weight from the lead foot to the trail foot, preparing for the Top of Backswing (TB) and the subsequent energy transfer into the downswing. Plantar pressure during this phase plays a crucial role in maintaining balance and creating optimal conditions for efficient energy utilization. Analyzing data from Table 4.8 and Table 4.9, which present the correlation between plantar pressure and body energy in professional golfers using a Driver, provides deeper insight into this mechanism (Quinn et al., 2022; Worsfold et al., 2009).

Table 4.8 reveals a significant positive correlation between medial metatarsal (MEDmet) pressure and body energy ($r = 0.549$, $p = 0.034$), indicating that increased pressure in this region tends to be associated with higher body energy during MB. However, other areas of the left foot, such as the heel (HEEL), exhibit a negative correlation with body energy ($r = -0.466$, $p = 0.080$). Although not statistically significant, this trend suggests a weight shift from the left to the right foot in preparation for the swing transition. Additional analysis shows that energy levels in the MB phase remain relatively low, with no significant differences between professional and amateur golfers, indicating that both groups are still in the process of energy buildup, and more pronounced differences in energy transfer may emerge in later phases, such as Top of Backswing (TB) or Impact (IM).

Table 4.9 indicates that lateral metatarsal (LATmet) and lateral arch (LATarc) pressure show significant positive correlations with body energy (LATmet: $r = 0.636$, $p = 0.011$; LATarc: $r = 0.566$, $p = 0.028$). This suggests that increasing pressure in these regions plays a crucial role in enhancing stability and supporting energy transfer during MB. In contrast, heel pressure (HEEL) exhibits a negative correlation with body energy ($r = -0.393$, $p = 0.147$), indicating that professional golfers may not rely heavily on heel pressure during this phase to avoid balance loss and facilitate more efficient torso rotation. Comparing previous research findings, professional golfers tend to

increase pressure on the arch and lateral metatarsal rather than relying solely on heel pressure, enabling better body movement control and effective energy transfer into the backswing (Pataky, 2015; Chu et al., 2010).

Although the correlation values found in the MB phase are not as high as those observed in the Top of Backswing (TB) or Impact (IM) phases, the findings suggest that pressure on the lateral metatarsal and arch regions exhibits strong correlations with body energy. This indicates that golfers should focus on weight distribution toward the arch and lateral metatarsal instead of relying excessively on the heel. Amateur golfers should train to shift weight onto the arch and lateral foot regions, helping them maintain balance and increase body stability during MB. Enhancing pressure on the lateral arch may improve energy transfer efficiency into the backswing, whereas over-reliance on heel pressure may lead to energy loss and reduced control over body movement. Developing appropriate weight transfer techniques for different clubs is another critical factor. Using a Driver requires greater right foot pressure, whereas a 7-Iron may demand increased left foot pressure for directional control. Additionally, core strength training is essential, as core muscles play a crucial role in maintaining body balance and enabling efficient plantar pressure utilization.

The Middle Backswing (MB) is a stabilization phase where golfers prepare for energy transfer into the backswing. While the correlation between plantar pressure and body energy is not yet at its peak, data from Table 4.8 and Table 4.9 suggest that increased lateral metatarsal and arch pressure is associated with higher body energy levels, which may enhance energy transfer into later swing phases. Amateur golfers can integrate these findings into training programs to develop optimal weight transfer techniques, which can improve energy generation efficiency and reduce errors caused by improper plantar pressure distribution (Quinn et al., 2022; Worsfold et al., 2009).

4.6 Top of backswing (TB)

4.6.1 Differences in plantar pressure when using the driver and 7-iron in professional golfers at the top of backswing (TB)

The Top of Backswing (TB) represents the peak of the golfer's rotational movement, where maintaining balance and preparing for the downswing is crucial. At

this phase, the body regulates energy direction and weight transfer to maximize swing efficiency. Understanding the differences in plantar pressure between the Driver and the 7-Iron during TB is essential, as it significantly influences clubhead speed and shot accuracy, allowing golfers to refine their weight and energy transfer strategies for optimal performance (Ball and Best, 2012; Chu et al., 2010).

Table 4.2 indicates that pressure on the left lesser toe (LT) increases significantly (+2%, $p = 0.001$) when using a Driver compared to a 7-Iron, suggesting that greater toe pressure is required for balance maintenance during TB. This difference in weight distribution reflects the distinct energy requirements between the two clubs, supporting the findings of Nesbit and Serrano (2005), who reported that longer clubs necessitate a forward weight shift to generate higher rotational force. Table 4.3 shows that right foot pressure does not differ significantly between Driver and 7-Iron usage, suggesting that the right foot primarily serves a stabilizing function rather than contributing directly to energy generation at TB. The ability to effectively transfer weight onto the right foot is a key characteristic of technically proficient golfers, aligning with Smith et al. (2017), who found that proper right foot weight transfer enhances hip torque and improves downswing efficiency.

Figure 4.4 illustrates energy transfer variations between Driver and 7-Iron usage at TB. Professional golfers using a Driver exhibit less negative energy values in the Lumbosacral (L5S1) region, meaning energy remains more concentrated in the upper body rather than being transferred downward. This stored energy likely contributes to a more forceful downswing. Conversely, when using a 7-Iron, significantly more energy is transferred to the lower body and ground, resulting in greater stability and precision during the swing (MacKenzie et al., 2020; You et al., 2023). Plantar pressure at TB plays a pivotal role in balance and energy transfer for club acceleration in the downswing. Professional golfers demonstrate a well-balanced distribution of plantar pressure, with a tendency to increase pressure on the left lesser toe (LT), promoting stable rotation and effective energy transfer toward the upper body. In contrast, amateur golfers often shift weight toward the forefoot and midfoot, potentially compromising balance and reducing rotational force generation.

At the Top of Backswing (TB), professional and amateur golfers exhibit distinct plantar pressure patterns. Professional golfers tend to increase pressure on the left lesser toe, enhancing torque generation and body stability, while amateurs distribute more pressure across the forefoot and midfoot, which may lead to balance loss and inefficient energy transfer. Optimizing plantar pressure control can improve swing efficiency and reduce errors caused by improper weight distribution (Belotti et al., 2024).

4.6.2 Differences in Plantar Pressure Between Professional and Amateur Golfers at the top of backswing (TB)

The Top of Backswing (TB) represents the highest point of the backswing, where the golfer's body prepares for the energy transfer into the downswing. Plantar pressure distribution during this phase plays a crucial role in maintaining stability and generating clubhead speed. Professional golfers tend to exhibit more efficient weight transfer patterns compared to amateurs, allowing them to store and transfer energy more effectively into the downswing, ultimately resulting in greater clubhead speed and shot accuracy (Ball and Best, 2012; Nesbit and Serrano, 2005; Belotti et al., 2024).

When using a Driver, professional golfers tend to distribute more weight toward the midfoot and inner foot arch, reducing pressure on the toes and heels. The difference in weight distribution between the left and right foot suggests a strategic approach by professionals to enhance stability and optimize weight shift into the downswing, minimizing balance loss and maximizing hip torque for efficient energy transfer (You et al., 2023). For the left foot, professional golfers exhibit lower pressure on the left great toe (GT) (-5%, p=0.040) and left heel (HEEL) (-7%, p=0.035) compared to amateurs. This indicates that professionals tend to reduce pressure on the toe and heel to maintain body balance, ensuring an optimal position for accelerating the club during the downswing. In contrast, amateur golfers place greater pressure on the toes and heels, which may lead to balance loss and reduced rotational efficiency (Dong and Ikuno, 2023). For the right foot, professional golfers show higher pressure on the medial metatarsal (MEDmet) (+4%, p=0.028) and medial arch (MEDarc) (+6%, p=0.001) compared to amateurs. This suggests that professionals tend to load more pressure onto the midfoot and arch to generate torque for weight transfer into the downswing,

while amateurs often overload the heel, which may compromise stability and reduce club acceleration efficiency (Pataky, 2015).

When using a 7-Iron, professionals tend to distribute more weight toward the lateral metatarsal and arch rather than relying on toes or heels. This weight distribution helps maintain body stability and precise club control, improving swing rhythm and consistency (Quinn et al., 2022). For the left foot, professional golfers exhibit higher pressure on the left lesser toe (LT) (+3%, p=0.012) and lateral metatarsal (LATmet) (+6%, p=0.040) compared to amateurs, which enhances stability and precise swing control. In contrast, amateurs tend to place excessive weight on the toes, potentially leading to imbalance and reduced rotational control (Takagi, 2018). For the right foot, professionals continue to focus pressure on the medial metatarsal and arch to maintain balance and control club movement in the downswing. Amateur golfers, however, tend to shift weight toward the toes and heels, increasing instability and reducing club acceleration efficiency (Belotti et al., 2024).

The Top of Backswing (TB) phase is where golfers begin transferring stored energy into the downswing. Professional golfers demonstrate superior foot pressure control, resulting in smooth and efficient energy flow. In contrast, amateurs often experience rapid and inconsistent pressure changes, which may hinder effective energy transfer to the hips and torso (Dong and Ikuno, 2023). Figure 4.9 (Driver) data shows that professional golfers using a Driver can store and transfer energy more effectively during TB, leading to higher efficiency in downswing power generation. In contrast, amateurs exhibit lower energy storage efficiency, possibly due to inadequate energy transfer to the legs or energy leakage, resulting in a less effective downswing (Takagi, 2018). Figure 4.11 (7-Iron) data indicates that professional golfers continue to transfer more energy to the legs compared to amateurs. However, the performance gap between professionals and amateurs is less significant with a 7-Iron, as the shorter club requires less rotational force, making energy transfer patterns more similar between both groups.

Plantar pressure distribution at the Top of Backswing phase (TB) directly impacts body stability and rotational torque efficiency. Professional golfers maintain better balance by utilizing midfoot and arch pressure as primary support points,

enabling efficient torque generation and optimal energy transfer into the club. In contrast, amateur golfers who place excessive pressure on the toes or heels may struggle with weight transfer, leading to energy loss and reduced swing accuracy (Belotti et al., 2024). An analysis of plantar pressure between professional and amateur golfers during TB indicates that professionals tend to shift weight toward the midfoot and arch, improving stability and reducing excessive toe pressure. In contrast, amateur golfers often place weight on the forefoot, which may compromise balance and reduce energy transfer efficiency. By focusing on midfoot and arch pressure control, amateur golfers can improve energy flow, maintain balance, and enhance swing precision. Practicing proper plantar pressure management can optimize energy transfer and improve overall swing performance (Belotti et al., 2024).

4.6.3 Relationship between plantar pressure and energy flow in professional golfers at the top of backswing (TB)

The Top of Backswing (TB) represents the peak of energy storage in the golfer's body before it is transferred into the downswing to increase clubhead speed and impact force with the ball (Nesbit and Serrano, 2005). Plantar pressure distribution during this phase plays a crucial role in body balance and energy transfer efficiency. Professional golfers tend to optimize weight distribution to enhance stability and minimize energy loss, whereas amateur golfers may struggle with plantar pressure control, reducing energy transfer efficiency (Belotti et al., 2024).

Analysis of Tables 9 and 10 reveals a negative correlation between toe and arch pressure and energy flow, indicating that increased pressure in these regions may reduce energy transfer to the torso (You et al., 2023). Professional golfers tend to adjust weight distribution to reduce excessive pressure in these areas, ensuring a more stable energy transfer process (Sheehan et al., 2022). For the left foot, there is a significant negative correlation between pressure on the great toe, lesser toe, central metatarsal, lateral metatarsal, medial arch, and lateral arch and energy transfer ($p < 0.05$). The strongest negative correlations were found at the great toe ($r = -0.933$, $p = 0.000$) and lateral arch ($r = -0.840$, $p = 0.000$), suggesting that increased pressure in these areas significantly reduces energy transfer to the torso (Ball and Best, 2012). Professional golfers tend to reduce pressure on the toes and arch while shifting weight

toward the midfoot and heel, which improves stability and enhances energy transfer efficiency (Hume et al., 2005). However, heel pressure ($r = 0.005$, $p = 0.986$) shows no significant correlation with energy flow, indicating that heel pressure is not a primary factor in energy transfer control (McNitt-Gray et al., 2022). For the right foot, there is also a significant negative correlation between pressure on the great toe, lesser toe, medial arch, and lateral arch and energy transfer ($p < 0.05$). The strongest negative correlations were at the great toe ($r = -0.859$, $p = 0.000$) and lesser toe ($r = -0.786$, $p = 0.001$), suggesting that applying excessive pressure in these regions reduces energy transfer efficiency to the torso, decreasing swing effectiveness (Lindsay and Horton, 2006). This trend indicates that professional golfers avoid excessive pressure on the toes and arches during TB to prevent balance loss and improve energy transfer efficiency to the torso and club (Sheehan et al., 2022). However, pressure on the medial metatarsal, central metatarsal, lateral metatarsal, and heel shows no significant correlation ($p > 0.05$), indicating that pressure control in these areas does not directly influence energy transfer during TB (Belotti et al., 2024).

The findings demonstrate that plantar pressure significantly influences energy transfer efficiency at TB. Professional golfers tend to reduce pressure on the toes and arches, shifting weight toward the midfoot and heel, which ensures a smoother and more efficient energy transfer process. In contrast, amateur golfers often apply excessive pressure to unstable areas, reducing energy flow to the torso and diminishing swing power (Han et al., 2023).

4.7 Ball Impact

4.7.1 Differences in plantar pressure when using the driver and 7-iron in professional golfers at ball impact (IM)

Analyzing plantar pressure at Ball Impact (IM) is crucial for understanding how energy is transferred from the body to the club and ultimately to the golf ball. The IM phase is characterized by maximum ground reaction forces and is a key moment that affects clubhead speed, ball direction, and shot distance (Ball and Best, 2011). Controlling plantar pressure during this phase directly impacts shot accuracy and power. Professional golfers demonstrate precise pressure adjustments, optimizing

energy transfer efficiency, while amateur golfers may struggle with pressure control, potentially reducing swing effectiveness (Belotti et al., 2024).

Table 4.2 shows a significant difference in left foot pressure between using a Driver and a 7-Iron. Great toe (GT) pressure increases significantly ($p = 0.014$) when using a Driver, aligning with findings from Ball and Best (2012) that suggest increased great toe pressure correlates with higher clubhead speed. Conversely, lateral metatarsal (LATmet) and lateral arch (LATarc) pressure decrease significantly ($p = 0.045$ and $p = 0.044$, respectively), indicating that golfers tend to shift weight toward the inner foot instead of relying on the outer edge, possibly reducing foot rotation and improving swing stability (Chu et al., 2010).

Table 4.3 highlights that medial metatarsal (MEDmet) pressure increases significantly ($p = 0.012$) with a Driver, while lateral metatarsal (LATmet) and lateral arch (LATarc) pressure decrease significantly ($p = 0.041$ and $p = 0.018$, respectively). This suggests that using a Driver requires greater torque and more efficient energy transfer from the right foot to the left foot before impact (Pataky, 2015). Additionally, Chu et al. (2010) reported that increased medial foot pressure enhances hip rotation energy, a critical factor in maximizing clubhead speed.

Figure 4.4 illustrates that energy transfer during IM is slightly higher when using a Driver compared to a 7-Iron. Energy distribution in the Lumbosacral (L5S1) region suggests that Drivers require more energy to generate higher impact forces, allowing the ball to travel greater distances (McNitt-Gray et al., 2022). Energy transmitted from the torso to L5S1 plays a critical role in torque generation and energy transfer through the legs to the ground. Golfers with well-structured body mechanics can utilize this stored energy efficiently (You et al., 2023). Dynamic analysis reveals that forces at IM directly influence hip torque and torso rotation, correlating with energy transmission efficiency to the golf club. Professional golfers with better plantar pressure control exhibit higher energy transfer rates and reduced energy loss during weight transitions. Efficient energy transfer from the torso to the legs enhances impact precision and swing power (You et al., 2023).

Using a Driver and a 7-Iron results in significant differences in plantar pressure and energy transfer. Drivers require increased great toe pressure to generate

higher impact forces, while reduced lateral foot pressure on the right foot minimizes resistance. In contrast, 7-Irons exhibit greater medial foot pressure, emphasizing shot accuracy over raw power. Golfers can use these insights to optimize energy transfer strategies based on club selection, improving swing efficiency and reducing injury risks (Han et al., 2023).

4.7.2 Differences in Plantar Pressure Between Professional and Amateur Golfers at ball impact (IM)

The Ball Impact (IM) phase is a critical moment when force from the body is transferred to the golf club and subsequently to the ball. Differences in foot pressure patterns during IM between professional and amateur golfers reflect energy transfer efficiency and swing control ability. Professional golfers tend to exhibit optimal pressure distribution, allowing them to transfer energy more effectively, increasing clubhead speed and shot accuracy. In contrast, amateur golfers may have limitations in weight transfer, leading to less efficient energy transmission at impact (Nesbit and Serrano, 2005; Takagi, 2018).

Table 4.4 indicates that professional golfers using a Driver exhibit significantly lower pressure (-10%, $p = 0.001$) on the left great toe (GT) compared to amateurs. This suggests that professionals reduce toe pressure and shift weight toward the medial forefoot, enhancing torque efficiency and clubface control. In contrast, amateur golfers tend to apply excessive pressure on the great toe, which may cause balance loss at impact. Meanwhile, pressure on the left lesser toe (LT) is higher in professionals (+3%, $p = 0.007$), indicating that they use the lateral forefoot for stability and rotational control. Additionally, heel pressure (HEEL) in professionals is 8% lower ($p = 0.012$) compared to amateurs, suggesting that professionals efficiently shift weight from the heel toward the midfoot and forefoot, optimizing force generation for club acceleration. Table 4.5 reveals that medial metatarsal (MEDmet) pressure on the right foot is 11% higher ($p = 0.005$) in professionals compared to amateurs, indicating a more effective transition of weight from the trail foot to the lead foot, which enhances hip torque and accelerates the clubhead. Conversely, central metatarsal (CENmet) and lateral metatarsal (LATmet) pressures are significantly lower (-16% and -13%, respectively, $p < 0.001$) in professionals, demonstrating their ability to minimize

unnecessary pressure and focus force on areas crucial for energy transfer to the golf ball (Pataky, 2015). Furthermore, medial arch (MEDarc) pressure is 6% higher in professionals ($p = 0.020$), suggesting greater weight stability during IM.

Tables 7 and 8 show that significant plantar pressure differences persist between professional and amateur golfers when using a 7-Iron. Left lateral metatarsal (LATmet) pressure in professionals is 14% higher ($p = 0.001$), indicating better stability and posture control during impact. Meanwhile, left heel pressure (HEEL) in professionals is 7% lower ($p = 0.180$), suggesting that amateurs struggle with complete weight transfer, which may reduce impact efficiency. On the right foot, central metatarsal (CENmet) and lateral metatarsal (LATmet) pressures in professionals are significantly lower (-9%, $p = 0.007$; -10%, $p = 0.015$, respectively), showing that professionals focus energy transfer on key areas rather than distributing pressure inefficiently.

Figure 4.9 indicates that segment power at IM is significantly higher in professionals than in amateurs when using a Driver, meaning that amateurs lose more energy into the ground rather than transferring it to the club. This energy loss is likely due to inefficient plantar pressure distribution or suboptimal weight transfer techniques, which reduce impact force and limit shot distance (Burden et al., 2013). Figure 4.11 (7-Iron) further demonstrates that professionals also transfer energy more efficiently than amateurs, though the difference is less pronounced compared to the Driver. This suggests that professionals utilize superior energy transfer mechanisms, leading to higher clubhead speed and impact efficiency, while amateurs may waste energy through unnecessary movements or flawed techniques (Quinn et al., 2022).

Proper plantar pressure distribution directly influences impact efficiency. Professional golfers efficiently transfer weight from the right foot to the left foot, optimizing pressure distribution for maximum clubhead speed. In contrast, amateur golfers are more likely to misdirect weight transfer, leading to energy loss into the legs rather than the club. Amateurs may need to refine their weight transfer mechanics to improve swing efficiency and impact force (Takagi, 2018).

The findings indicate that professional golfers distribute plantar pressure and transfer energy more effectively than amateurs, both with a Driver and a 7-Iron.

Optimal pressure distribution enables maximum clubhead speed and impact force. Amateur golfers may need to improve weight transfer mechanics to reduce energy loss in the legs and direct more energy to the club, which can be achieved through training focused on foot pressure control and proper biomechanical movement.

4.7.3 Relationship between plantar pressure and energy flow in professional golfers at Ball Impact (IM)

The Ball Impact (IM) phase is the moment when energy from the body is directly transferred to the golf club, significantly influencing clubhead speed and impact force. Golfers who efficiently transfer energy can increase ball distance and improve shot accuracy (Nesbit and Serrano, 2005). Plantar pressure distribution during IM plays a vital role in swing efficiency and serves as an indicator of energy transfer quality from the body to the club (Chu et al., 2010).

Table 4.8 shows that pressure on the left great toe (GT) has a significant negative correlation with segment power ($r = -0.664$, $p = 0.007$). This suggests that reducing great toe pressure increases energy transfer to the golf club. Minimizing great toe pressure may help enhance torso rotation and reduce resistance from the left leg, leading to a more efficient club acceleration (Pataky, 2015). However, pressure on the left lesser toe (LT), medial metatarsal (MEDmet), central metatarsal (CENmet), lateral metatarsal (LATmet), medial arch (MEDarc), lateral arch (LATarc), and left heel (HEEL) does not show a significant correlation with energy transfer ($p > 0.05$). This suggests that pressure distribution in these areas does not directly impact energy generation.

Table 4.9 reveals that pressure on the right medial metatarsal (MEDmet) has a significant positive correlation with segment power ($r = 0.598$, $p = 0.019$), meaning that increasing pressure in this area enhances energy transfer to the golf club. Increased medial foot pressure may play a crucial role in hip torque generation and ground reaction force (GRF) production, which contribute to greater clubhead speed at impact (Burden et al., 2013). However, pressure on the right great toe (GT), lesser toe (LT), central metatarsal (CENmet), lateral metatarsal (LATmet), medial arch (MEDarc), and lateral arch (LATarc) does not show a significant correlation with energy transfer ($p > 0.05$). Interestingly, heel pressure on the right foot (HEEL) has a negative correlation with segment power ($r = -0.329$, $p = 0.231$). Although not statistically significant, this

suggests that excessive weight on the right heel may reduce energy transfer efficiency to the club. Han et al. (2019) found that excessive heel pressure can hinder hip rotation, leading to energy loss before impact.

These results indicate that plantar pressure distribution directly affects energy transfer efficiency during IM. Golfers who can effectively control plantar pressure by reducing left great toe pressure and increasing right medial metatarsal pressure can optimize energy transfer to the club, enhancing impact efficiency. However, amateur golfers may struggle with proper pressure distribution, leading to energy loss into the legs or ground instead of transferring it to the club. Professional golfers leverage plantar pressure mechanics more effectively, ensuring better energy transfer. Amateur golfers who lack precise pressure control may need to develop swing techniques that enhance energy flow into the club, which can be achieved through training focused on foot pressure control and proper body positioning during IM.

4.8 Early Finish (EF)

4.8.1 Differences in plantar pressure distribution when using the driver and 7-iron in professional golfers at the early finish (EF)

The Early Finish (EF) phase occurs when the golf club moves past impact and enters the follow-through stage, where the body must reestablish balance after transferring energy to the golf ball. During this phase, golfers must maintain proper plantar pressure to control body posture and sustain swing stability. Foot pressure distribution in EF plays a crucial role in minimizing rotational impact forces and facilitating efficient weight transfer from the back foot to the front foot. Professional golfers typically exhibit more balanced pressure distribution compared to amateurs, allowing them to execute a smoother follow-through.

Table 4.2 shows that left foot pressure during EF does not significantly differ between the Driver and 7-Iron ($p > 0.05$). Professional golfers effectively manage left foot pressure, distributing it evenly across the heel (HEEL), medial arch (MEDarc), and central metatarsal (CENmet). Although statistical values do not indicate major differences, data trends suggest that when using a Driver, golfers tend to apply more pressure on the lateral foot to support torso rotation in the follow-through phase (Ball

and Best, 2012). When using a 7-Iron, golfers tend to shift more weight to the heel, which enhances stability and directional control in the follow-through. Pataky (2015) found that left heel pressure plays a key role in preventing balance loss during the finish.

Table 4.3 indicates a significant reduction in right foot lateral arch (LATarc) pressure by -2% ($p = 0.047$) when using a Driver compared to a 7-Iron, suggesting that Driver swings require faster weight transfer and a different balance strategy. Other pressure locations do not show significant differences ($p > 0.05$). In general, during EF, golfers shift weight from the right foot to the left foot, reducing right foot pressure significantly, particularly at the heel and medial arch. However, forefoot and midfoot pressure remain relatively high, helping to absorb body inertia.

When using a Driver, professional golfers effectively balance plantar pressure, ensuring smooth torso movement in the follow-through (Sheehan et al., 2022). When using a 7-Iron, right foot pressure remains higher, indicating that golfers rely more on the right foot for weight support compared to the Driver swing. This may be due to the 7-Iron's focus on precision rather than power, meaning that the body does not need to accelerate weight transfer to the left foot as aggressively as with the Driver (Nesbit and Serrano, 2005).

Figure 4.4 illustrates that energy levels in EF peak rapidly, as the body continues releasing energy from the torso into the club. While energy values for the Driver and 7-Iron remain similar, the Driver shows slightly higher energy output due to its longer shaft and greater control demands (Burden et al., 2013). Increased energy levels in EF result from inertia generated after energy transfer to the ball. Professional golfers regulate this energy efficiently by adjusting plantar pressure, ensuring a stable follow-through posture. Plantar pressure in EF is essential for body balance and energy stabilization. Professional golfers smoothly transition weight from the right foot to the left foot, particularly when using a Driver, which enables a complete follow-through and minimizes injury risks. Amateur golfers, however, tend to retain excessive right foot pressure, reducing their ability to shift weight effectively, which can lead to imbalance and an inconsistent follow-through (Kenny et al., 2008).

During Early Finish (EF), golfers must shift weight from the right foot to the left foot to maintain stability and counteract body inertia from the swing. Professional golfers execute this transition more efficiently than amateurs, exhibiting greater left foot pressure, particularly in the lateral and midfoot regions. Amateurs tend to retain excessive right foot pressure, which can cause balance loss. Energy levels in EF increase sharply, with the Driver requiring more energy than the 7-Iron due to greater control demands. Effective plantar pressure management in EF is crucial for executing a complete follow-through, reducing impact forces that could cause injury, and ensuring a smooth and continuous swing.

4.8.2 Differences in Plantar Pressure Between Professional and Amateur Golfers at the early finish (EF)

The Early Finish (EF) phase marks the final stage of energy transfer from the body to the golf club, influencing movement continuity, body balance, and shot direction control. Professional golfers typically demonstrate more efficient weight transfer patterns, allowing them to control foot pressure distribution more effectively than amateur golfers (Nesbit and Serrano, 2005). This study aims to analyze foot pressure differences between professionals and amateurs to compare their balance control strategies during this phase.

When using a Driver, professional golfers exhibit significantly lower left great toe (GT) pressure (-12%, $p = 0.001$) than amateur golfers, suggesting that professionals shift more weight to the right foot to maintain balance after impact. Reducing great toe pressure enhances fluid body movement, enabling a smoother follow-through rotation. Additionally, professionals show higher lateral metatarsal (LATmet) and lateral arch (LATarc) pressure (+8%, $p = 0.002$ and +7%, $p = 0.013$, respectively), indicating their ability to utilize foot structures for balance support and weight transition, which is essential for a stable follow-through (Ball and Best, 2011). For the right foot, professionals display lower central metatarsal (CENmet) and lateral metatarsal (LATmet) pressure (-14%, $p = 0.001$ and -8%, $p = 0.012$, respectively), suggesting a more efficient weight transfer from the right foot to the left foot and upper body. This enables smoother momentum control, whereas amateurs tend to retain more weight on the back foot, which can result in energy loss that should have been

transferred to the golf club. However, professionals exhibit higher medial arch (MEDarc) and lateral arch (LATarc) pressure (+7%, p = 0.020 and +2%, p = 0.042, respectively), suggesting their reliance on foot arch structures to stabilize the body at the end of the swing (Cools et al., 2015).

When using a 7-Iron, professional golfers demonstrate significantly lower left great toe (GT) pressure (-7%, p = 0.003) than amateurs, reflecting a more effective weight transfer to the right foot for balance control. Conversely, professionals exhibit higher lateral metatarsal (LATmet) and lateral arch (LATarc) pressure (+15%, p = 0.000 and +8%, p = 0.020, respectively), improving swing stability and follow-through consistency. Regarding the right foot, professionals show lower CENmet and LATmet pressure (-10%, p = 0.006 and -6%, p = 0.053, respectively) than amateurs, indicating a more efficient weight transition forward for energy generation. Meanwhile, professionals exhibit higher MEDarc and LATarc pressure (+9%, p = 0.000 and +4%, p = 0.010, respectively), aiding in balance and torque control during the Early Finish phase.

Figures 7 and 8 support these findings, showing that when using a Driver, professionals exhibit significantly higher segment power than amateurs, demonstrating their ability to retain and transfer more energy into the golf club. Amateurs tend to lose more energy due to improper plantar pressure distribution or balance loss. In contrast, when using a 7-Iron, the energy difference between professionals and amateurs is smaller, likely because the 7-Iron requires more control than raw power, allowing amateurs to retain more energy compared to the Driver (Takagi, 2018).

These findings suggest that professional golfers exhibit superior foot pressure control and weight transfer mechanics, leading to better balance and more efficient energy generation during the Early Finish phase. Professionals successfully transfer weight from the right foot to the left foot, while amateurs tend to retain excessive back-foot pressure, leading to energy loss before swing completion. Improving follow-through techniques and training plantar pressure distribution may help amateur golfers optimize their swing efficiency and reduce energy loss (Nesbit and Serrano, 2005; Ball and Best, 2011).

4.8.3 Relationship Between Plantar Pressure and Energy Transfer at the Early Finish (EF)

The Early Finish (EF) phase occurs after ball impact and marks the transition into the follow-through, where the body continues to move to dissipate residual inertia from the swing. Controlling foot pressure and energy transfer during this phase plays a crucial role in maintaining body balance and ensuring an effective follow-through. Studying the relationship between plantar pressure and energy transfer during EF helps to understand the biomechanical differences between professional and amateur golfers, particularly in post-swing movement control.

Analysis of left foot pressure and energy transfer in Table 4.8 reveals no statistically significant correlation ($p > 0.05$) between left foot pressure and energy transfer values during EF. Pearson correlation coefficients for different regions of the left foot, including central metatarsal (CENmet, $r = 0.383$, $p = 0.159$) and medial metatarsal (MEDmet, $r = 0.366$, $p = 0.179$), show a positive trend but lack statistical significance. This suggests that as plantar pressure increases, energy transfer in EF tends to rise, though not conclusively enough to determine the precise role of left foot pressure in energy transmission. Meanwhile, left heel pressure (HEEL, $r = -0.325$, $p = 0.237$) exhibits a negative correlation, implying that as golfers shift more weight onto the left foot, heel pressure tends to decrease. This shift occurs because the body moves forward to balance the inertia generated by the follow-through (Nesbit and Serrano, 2005).

Analysis of right foot pressure and energy transfer in Table 4.9 shows that medial metatarsal (MEDmet) pressure on the right foot has a statistically significant positive correlation with segment power ($r = 0.566$, $p = 0.028$, $p < 0.05$). This finding indicates that increasing medial metatarsal pressure enhances energy transfer to the upper body and golf club. Research by MacKenzie et al. (2020) highlights the importance of medial foot pressure in generating torque and facilitating energy transmission to the upper torso during the follow-through. Although central metatarsal (CENmet, $r = 0.389$, $p = 0.152$) and lateral metatarsal (LATmet, $r = 0.350$, $p = 0.200$) pressure show positive trends with energy transfer, they do not reach statistical significance. Right heel pressure (HEEL, $r = -0.245$, $p = 0.379$) exhibits a negative

correlation with segment power, although not statistically significant. This suggests that reducing right heel pressure during EF may contribute to more efficient energy transfer. Golfers who decrease heel pressure and shift weight toward the forefoot may be better able to maintain balance during the follow-through (Sheehan et al., 2022).

The impact on swing technique highlights that the relationship between plantar pressure and energy transfer in EF demonstrates the crucial role of right medial metatarsal (MEDmet) pressure in effective energy transmission. Professional golfers distribute plantar pressure more efficiently, allowing them to transfer energy more effectively to the upper torso and golf club. In contrast, amateur golfers tend to retain excessive pressure on the right foot in inefficient locations, leading to energy loss and compromised balance in the follow-through. Golfers who can reduce right heel pressure while increasing pressure on the medial and central forefoot are more likely to control energy transfer effectively, ensuring a smoother follow-through. Training to optimize plantar pressure distribution during EF is a key factor in improving swing performance and maintaining stability (Kenny et al., 2008).

During Early Finish (EF), increased pressure at the right medial metatarsal (MEDmet) positively correlates with efficient energy transfer to the upper body and club. Conversely, decreased right heel (HEEL) pressure correlates with improved energy flow. This indicates that effective foot pressure management enhances swing stability and energy transfer efficiency.