ANALYSIS OF FOOT PRESSURE PATTERNS AFFECTING ENERGY FLOW OF THE GOLF SWING IN PROFESSIONAL AND AMATEUR PLAYERS

KHEMCHAT CHAEMKLAN

มหาวิทยาลัยเทคโนโลยีสุรนารี

A Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Integrated Science and Innovation
Suranaree University of Technology
Academic Year 2024

การวิเคราะห์รูปแบบแรงกดเท้าที่ส่งผลต่อการไหลของพลังงานของการสวิงกอล์ฟในนักกีฬามืออาชีพและสมัครเล่น

นายเข็มชาติ แช่มกลั่น

มหาวิทยาลัยเทคโนโลยีสุรนารี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาบูรณาการด้านวิทยาศาสตร์และนวัตกรรม
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2567

ANALYSIS OF FOOT PRESSURE PATTERNS AFFECTING ENERGY FLOW OF THE GOLF SWING IN PROFESSIONAL AND AMATEUR PLAYERS

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

Thesis Examining Committee

(Assoc. Prof. Dr. Sirichok Jungthawan)
Chairperson

(Asst. Prof. Dr. Pornthep Rachnavy)
Member (Thesis Advisor)

(Assoc. Prof. Dr. Worawat Meevasana)
Member

(Asst. Prof. Dr. Tanormsak Senakham)
Member

(Asst. Prof. Dr. Rungrudee Srisawat)
Member

(Dr. Wiwat Nuansing)
Member

(Assoc. Prof. Dr. Yupaporn Ruksakulpiwat)
Vice Rector for Academic Affairs
and Quality Assurance

(Prof. Dr. Santi Maensiri)
Dean of Institute of Science

มหาวิทยาลัยเทคโนโลยีสุรนารี

เข็มชาติ แช่มกลั่น : การวิเคราะห์รูปแบบแรงกดเท้าที่ส่งผลต่อการไหลของพลังงานของการสวิงกอล์ฟในนักกีฬามืออาชีพและสมัครเล่น (ANALYSIS OF FOOT PRESSURE PATTERNS AFFECTING ENERGY FLOW OF THE GOLF SWING IN PROFESSIONAL AND AMATEUR PLAYERS) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.พรเทพ ราชนาวี, 95 หน้า

คำสำคัญ: แรงกดฝ่าเท้า, การถ่ายโอนพลังงาน, ประสิทธิภาพวงสวิง, พื้นรองเท้าเซ็นเซอร์

วงสวิงกอล์ฟที่มีประสิทธิภาพขึ้นอยู่กับปัจจัยหลายด้าน รวมถึงการกระจายน้ำหนักและการถ่ายโอนพลังงานของร่างกาย ซึ่งมีผลโดยตรงต่อความเร็วหัวไม้กอล์ฟและความแม่นยำของการตีลูก การศึกษานี้มุ่งเน้นการวิเคราะห์รูปแบบแรงกดที่ฝ่าเท้าและการถ่ายโอนพลังงานในนักกอล์ฟมืออาชีพและสมัครเล่น เพื่อทำความเข้าใจกลไกของการเคลื่อนไหวที่ส่งผลต่อผลลัพธ์ของวงสวิง และนำไปสู่การพัฒนาแนวทางการฝึกซ้อมที่เหมาะสม การวิจัยดำเนินการโดยใช้เซ็นเซอร์วัดแรงกดที่ฝ่าเท้าและการวิเคราะห์ชีวกลศาสตร์กับนักกอล์ฟถนัดขวาจำนวน 30 คน แบ่งเป็นกลุ่มนักกอล์ฟมืออาชีพ 15 คน และสมัครเล่น 15 คน ทำการวิเคราะห์แรงกดที่ฝ่าเท้าในช่วงต่าง ๆ ของวงสวิง รวมถึงเปรียบเทียบผลระหว่างการใช้ไม้กอล์ฟประเภท Driver และ 7-Iron ผลการศึกษาพบว่านักกอล์ฟมืออาชีพสามารถกระจายแรงกดที่ฝ่าเท้าได้สมดุลกว่า ส่งผลให้การถ่ายโอนพลังงานมีประสิทธิภาพมากขึ้น ขณะที่นักกอล์ฟสมัครเล่นมีแนวโน้มที่จะสูญเสียพลังงานเนื่องจากการลงน้ำหนักที่ไม่เหมาะสม นอกจากนี้ การใช้ไม้กอล์ฟที่แตกต่างกันยังมีผลต่อการกระจายน้ำหนัก โดยการใช้ Driver มีแนวโน้มที่จะเพิ่มแรงกดที่ส้นเท้า ในขณะที่ 7-Iron ช่วยให้สามารถควบคุมแรงกดไปที่ฝ่าเท้าด้านหน้าเพื่อเพิ่มความแม่นยำ ผลการศึกษาแสดงให้เห็นว่านักกอล์ฟมืออาชีพสามารถรักษาเสถียรภาพของการเคลื่อนที่และควบคุมจังหวะของวงสวิงได้ดีกว่า ซึ่งส่งผลต่อการถ่ายโอนพลังงานที่มีประสิทธิภาพและช่วยเพิ่มความเร็วหัวไม้กอล์ฟ ข้อมูลที่ได้สามารถนำไปพัฒนาแนวทางการฝึกฝนที่เหมาะสมสำหรับนักกอล์ฟแต่ละระดับ รวมถึงการออกแบบอุปกรณ์กอล์ฟที่ช่วยลดข้อผิดพลาดในวงสวิงและเพิ่มเสถียรภาพในการเล่น อีกทั้งยังเป็นแนวทางในการพัฒนาเทคนิควงสวิง ลดความเสี่ยงจากอาการบาดเจ็บ และออกแบบอุปกรณ์วิเคราะห์วงสวิงที่สามารถตรวจจับแรงกดที่ฝ่าเท้าและการถ่ายโอนพลังงานได้อย่างแม่นยำ

สถานสหวิทยาการและนานาชาติ

ปีการศึกษา 2567

ลายมือชื่อนักศึกษา เข็มชาติ แช่มกลั่น

ลายมือชื่ออาจารย์ที่ปรึกษา________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม________

มหาวิทยาลัยเทคโนโลยีสุรนารี

KHEMCHAT CHAEMKLAN : ANALYSIS OF FOOT PRESSURE PATTERNS AFFECTING ENERGY FLOW OF THE GOLF SWING IN PROFESSIONAL AND AMATEUR PLAYERS. THESIS ADVISOR : ASST. PROF. PORNTHEP RACHNAVY, Ph.D. 95 PP.

Keyword: FOOT PRESSURE PATTERNS, ENERGY FLOW, SWING EFFICIENCY, SMART INSOLE

An effective golf swing depends on several factors, including the distribution of weight and the transfer of energy throughout the body, both of which directly affect clubhead speed and shot accuracy. This study focuses on analyzing foot pressure patterns and energy flow in professional and amateur golfers to understand the biomechanical mechanisms that influence swing outcomes and to develop appropriate training strategies. The research involved 30 right-handed golfers divided into professional (15) and amateur (15) groups and employed foot pressure sensors along with biomechanical analysis. Foot pressure data were collected across various swing phases and compared between swings using a Driver and a 7-Iron. The findings indicate that professional golfers demonstrate a more balanced foot pressure distribution, resulting in more efficient energy transfer, whereas amateur golfers tend to lose energy due to improper weight shifting. Moreover, club type affects weight distribution; using a Driver tends to increase heel pressure, while a 7-Iron facilitates better control of anterior foot pressure, thereby enhancing shot precision. Overall, professionals are able to maintain greater movement stability and control the timing of their swings more effectively, leading to improved energy transfer and increased clubhead speed. These insights can be applied to develop tailored training programs, design golf equipment that minimizes swing errors and injury risk, and innovate swing analysis tools capable of accurately detecting foot pressure and energy transfer.

Department of Interdisciplinary
Science and Internationalization
Academic Year 2024

Student's Signature________________
Advisor's Signature________________
Co-advisor's Signature________________

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisor, Asst. Prof. Dr. Pornthep Rachnavy, for his invaluable guidance, insightful feedback, and unwavering support. His expertise has been instrumental in shaping this research.

I am sincerely grateful to my co-advisor, Assoc. Prof. Dr. Soodkhet Pojprapai, for his constructive suggestions and continuous support, which have significantly contributed to this study.

I extend my appreciation to Suranaree University of Technology and the Department of Interdisciplinary Science and Internationalization, Institute of Science, for providing essential research facilities and resources.

Special thanks to all participants, fellow researchers, and laboratory staff for their assistance and collaboration during this research. I also acknowledge the funding support from Suranaree University of Technology (SUT), Thailand. The authors also received support from external grants and scholarships, including the One Research One Grant (OROG) program, which made this study possible.

Additionally, I would like to extend my sincere appreciation to PTT Public Company Limited and Suratec Co., LTD. for their generous support and contributions to this research project.

My heartfelt gratitude goes to my family and friends for their unwavering support and encouragement. Finally, I appreciate the work of scholars and researchers whose contributions have laid the foundation for this study.

This thesis would not have been possible without the support of many individuals, and I sincerely thank them all.

Khemchat Chaemklan

CONTENTS

มหาวิทยาลัยเทคโนโลยีสุรนารี

CONTENTS (Continued)

มหาวิทยาลัยเทคโนโลยีสุรนารี

LIST OF TABLES

มหาวิทยาลัยเทคโนโลยีสุรนารี

LIST OF FIGURES

มหาวิทยาลัยเทคโนโลยีสุรนารี

LIST OF FIGURES (Continued)

Figure **Page**

มหาวิทยาลัยเทคโนโลยีสุรนารี

LIST OF ABBREVIATIONS

CoP	Center of Pressure
KE	Kinetic Energy
GRF	Ground Reaction Force
OB	Out of Bounds
DOF	Degrees of Freedom
COM	Center of Mass
COG	Center of Gravity
JFP	Joint Force Power
STP	Segment Torque Power
JTP	Joint Torque Power
SP	Segment Power
BSP	Body Segment Parameter
Pro	Professional Golfer
High	High-handicap Amateur Golfer
3D	Three Dimensional
ST	Stand
MB	Middle Backswing
TB	Top of Backswing
IM	Ball Impact
EF	Early Finish
FN	Finish
GT	Great Toe
LT	Lesser Toe
MEDmet	Medial Metatarsal

มหาวิทยาลัยเทคโนโลยีสุรนารี

LIST OF ABBREVIATIONS (Continued)

CENmet	Central Metatarsal
LATmet	Lateral Metatarsal
MEDarc	Medial Arch
LATarc	Lateral Arch
HEEL	Heel
BMI	Body Mass Index
L5S1	Lumbosacral junction

มหาวิทยาลัยเทคโนโลยีสุรนารี

CHAPTER I

INTRODUCTION

1.1 Background

Golf is a globally popular sport enjoyed by people of various professions and ages. It features both amateur and professional competitions, with the player achieving the lowest score (fewest strokes) emerging as the winner. One of the most crucial skills in golf is the swing, a complex bodily movement utilizing the kinetic chain principle to transfer force, enhancing club head momentum and speed while controlling the clubface angle before impact, ensuring accurate ball trajectory towards the target (Bradshaw et al., 2009). Weight transfer during the golf swing is a mechanical concept that golf coaches consider a key indicator in golf swing training (Norman, 1995). The concept of weight transfer was first introduced as a buzzword among players and coaches in a Golf Digest magazine article (Nelson, 1980). This concept has been extensively studied, primarily through variables derived from force platforms, such as vertical force distribution (Chu et al., 2010), center of pressure (Ball and Best, 2011), and torque (Han et al., 2019). Developing a more efficient golf swing is vital for players to succeed in competitions. However, there is a lack of data regarding weight transfer based on pressure measurements between the feet and shoes. This gap in knowledge highlights the need for further research to understand the intricacies of weight transfer and its impact on golf swing performance.

Worsfold et al. (2009) investigated plantar pressure distribution in golfers, focusing on peak pressure rather than pressure fluctuations throughout the swing. Ball and Best (2007) identified two distinct weight transfer patterns ("Front Foot" and "Reverse Pivot") using center of pressure (CoP) analysis. The "Front Foot" pattern involves backward CoP movement during the backswing and forward movement during the downswing, while the "Reverse Pivot" pattern involves backward CoP movement during the backswing and maintaining that position throughout the downswing.

However, Pataky (2015) highlighted. The limitations of relying solely on CoP analysis, emphasizing the importance of considering foot pressure distribution for a comprehensive understanding of force transmission during the golf swing.

A key aspect of golf performance lies in the relationship between biomechanical variables. Chu et al. (2010) analyzed kinematic data and ground reaction forces in 308 golfers, revealing that upper body-pelvis separation (X-Factor), delayed arm and wrist release, forward and lateral body tilting, and weight transfer during the swing significantly correlated with ball speed. Ball and Best (2011) observed a connection between greater CoP displacement and higher club head speed in a sample of 5 players. Their earlier study (2007) found that increased distance and speed of CoP movement during the downswing correlated with higher club head speed in a "forefoot" stance. Pataky (2015) further explored the relationship between foot pressure and club head speed in 32 players with varying handicaps. The study discovered that players with higher club head speeds also generated higher pressure values on the lead foot's lateral side. These findings underscore the importance of biomechanical factors in optimizing golf performance, offering valuable insights for players and coaches seeking to improve their game.

Several studies have investigated the relationship between foot pressure and golf club type. Barrentine et al. (1994) found that ground reaction forces were greater when golfers used a driver compared to other clubs, while vertical torque remained similar (Worsfold et al., 2021). Ball and Best (2011) noted that the pattern of center of pressure (CoP) movement was similar between driver and iron swings. Navarro et al. (2022) observed significant differences in pressure distribution between the left and right feet for both driver and 5-iron swings, but this distribution remained consistent when switching between club types. Additionally, they found differences in foot pressure patterns between professional and amateur golfers, particularly in the medial and lateral areas of the foot throughout the swing.

The study of energy flow is crucial for understanding efficient golf swing mechanics and injury prevention. Takagi (2018) highlighted the importance of coordinated joint movements in transferring energy to the golf club. Proximal joints, like the lumbar and shoulder, play a key role in power generation, and the timing of their movement is essential for optimal energy transfer. Kenny et al. (2008) investigated kinetic energy (KE) transfer in golf swings, finding a strong correlation between peak KE and its timing for both driver and iron shots. This suggests similar trunk and arm velocities for both types of shots. Peak KE consistently increases from proximal to distal body segments during the swing, but the timing of peak KE does not follow this sequence. The arms peak first, followed by the hips, torso, and club, indicating coordinated movement for optimal energy transfer. These findings contribute to understanding KE transfer in golf and can inform swing technique development and equipment design. Nesbit and Serrano (2005) examined the relationship between work and energy in golf swings, revealing that the primary factors influencing club head kinetic energy are the work done by the golfer, club head speed, and club head mass. An efficient swing maximizes energy transfer from the golfer to the club head, and regular practice can help golfers develop a more efficient swing.

Investigating foot pressure patterns in professional and amateur golfers to reveal their correlation with energy flow during the golf swing. This research aims to enhance golf instruction and training methodologies, enabling the development of tailored teaching techniques, drills, and equipment that cater to golfers of all levels. By understanding the intricacies of foot pressure and energy transfer, we can empower players to refine their skills and elevate their overall performance on the course.

1.2 Research objective

1.2.1 To investigate how foot pressure patterns vary during the golf swing when using different club head

1.2.2 To compare foot pressure distribution patterns during the golf swing between professional and amateur golfers.

1.2.3 To analyze the correlation between foot pressure distribution and energy transfer during the golf swing.

1.2.4 To utilize data collected from studying foot pressure and energy flow to develop advanced golf swing analysis tools.

CHAPTER II

LITERATURE REVIEW

In this research, the researcher studied relevant documents and research papers and presented the findings under the following topics:

1. The golf swing movement
2. Biomechanics in Golf Analysis
3. Related Research

2.1 The golf swing movement

Golf is a sport enjoyed worldwide, with a growing number of players each year regardless of gender and age. It can be played for fun, challenge, or competition, and it also promotes good health. Players use golf clubs to hit a golf ball from a starting point into a hole according to the rules. Golf courses feature various obstacles, such as sand traps or water hazards, to add to the challenge of the game.

2.1.1 Golf equipment

A golfer's bag typically contains no more than 14 golf clubs and golf balls. Each club has unique characteristics, including head size, loft angle, and shaft length, to suit various playing situations. The longest clubs are called woods, traditionally made of wood but now commonly made of steel or composite materials. Woods are used for long-distance shots. The driver is the largest and longest wood, designed for tee shots. Fairway woods are smaller and have various loft angles, often referred to by odd numbers like 3-wood, 5-wood, etc. Irons are used for shorter shots, such as approaching the green, while putters have the lowest loft angle and are used for rolling the ball on the green. Modern golf balls have small dimples around them to reduce drag and improve flight stability. Golf shoes have spikes on the sole for better traction on the course.

2.1.2 Golf course

A golf course is an area designed for playing and competing in the sport of golf. The course typically consists of the following elements:

Putting Green is a finely mowed grass surface where the golf ball can roll smoothly. The green contains a hole that is 108 millimeters in diameter and at least 100 millimeters deep. Players use a "putter" (a club with a flat face) to roll the ball into the hole.

Fairway is a well-maintained grassy area where the ball typically lands after being hit from the teeing ground. The fairway is usually around 32 yards wide.

Par on each hole on the course is the number of strokes a skilled golfer is expected to take to complete the hole. A typical golf course has 18 holes and a par of 72 or higher.

Teeing Ground is the starting point for each hole. Players can use plastic or wooden tees to elevate the ball for their first stroke.

Hazards are two types, water hazards and bunkers (sand traps). Hazards make it more difficult for players to hit their shots. If a ball lands in a hazard, the player can usually play it from where it lies without penalty. If the player cannot play the ball from the hazard, they can choose to play from another location but will incur a one-stroke penalty.

Out of Bounds (OB) refers to areas outside the boundaries of the golf course. If a ball lands out of bounds, the player must replay the shot from the original location with a one-stroke penalty.

2.1.3 Golf techniques

Golf is an individual sport with two main swing styles, the Classic swing and the Modern swing.

Classic Swing This swing involves a similar rotation of the shoulder and hip axes during the backswing. It is characterized by digging in the toes and opening the heel of the front foot, allowing for a wider hip angle after a forceful swing. The classic swing maintains an upright posture, which places more stress on the shoulders and can lead to injury. Golfers who can reduce shoulder tension can minimize lateral tilting in their stance. With less bending, there's reduced pressure on the spine, preventing potential lower back injuries (Gluck et al., 2008). Injuries occur frequently and are often a result of incorrect swing technique or overuse (Zouzias et al., 2018).

Modern swing The modern golf swing is characterized by a greater twisting of the shoulder joint compared to the hip joint during the backswing. The front foot remains flat on the ground, unlike the traditional swing, where the heel is lifted. This enhances the control and stability of the club as it's brought back to its starting position. During the downswing and follow-through, the modern swing involves a pronounced tilt of the body, along with a deeper back arch. This twisting motion between the shoulder and hip axes, known as the X-Factor, generates increased clubhead speed and, consequently, greater power on impact. However, this increased rotation can put stress on the lower back and spine, potentially leading to pain and injury. The repeated arching of the back during the swing can exacerbate this issue. Therefore, while the modern swing offers power advantages, it's crucial to be mindful of the potential risks to the back and spine.

2.1.4 Basic golf swing techniques

The Address or Pre-Swing is the setup phase where the golfer positions themselves for the swing. The ball is placed in the center between the feet, with the toes forming a 35-degree angle to the target line. The hands grip the club, the body leans forward about 30 degrees without arching or rounding the back, and the knees are slightly flexed to allow for a full range of motion during the swing. (Broer and Houtz, 1967)

The backswing begins with the arms moving upward and backward, parallel to the target line. It culminates when the arms reach full extension, parallel to the ground." (Cole and Grimshaw, 2016)

The downswing is initiated by the rotation of the hips, leading the motion from the top of the backswing. Skilled golfers transition from the top of the backswing to impact in approximately 0.1 seconds, generating hip rotation power of around 2.5 hp (1864 W). (Carlsoo, 1967)

The follow-through is the final phase of the golf swing, occurring after impact with the ball as the clubhead decelerates. It represents the finishing position of the swing.

2.2 Biomechanics in golf analysis

Golf is a competitive sport that requires physical fitness. It not only demands precision in swinging but also explosive power in the muscles to achieve faster, stronger, and longer swings (Wells et al., 2009). Physical fitness is a crucial component in almost all sports. However, golf is a sport where players need to focus on tactics, skills, techniques, and mental state alongside muscle strength and power (Gordon et al., 2009).

The biomechanical foundation of a golf swing lies in the generation of kinetic energy and its transfer from the golf club to the golf ball at the moment of impact. The forces and torques produced during the backswing determine and control the trajectory of the club, accelerating its movement (Nesbit, 2005). As the velocity of the clubhead increases, more kinetic energy is transferred to the golf ball (Fletcher and Hartwell, 2004; Nesbit, 2005). In addition to strength and power, flexibility is crucial in golf to enable efficient body movement (Baechle and Earle, 2008). This aligns with the concept proposed by (Myers et al., 2008) that the most critical factor in a golfer's ability is the clubhead speed at the point of pelvic-torso separation.

Biomechanics is a scientific field that studies the relationship between force, velocity, acceleration, time, mass, angles of movement, and balance in order to analyze posture, skills, and techniques in golf. This information can be used to correct flaws and improve performance.

2.2.1 Kinematics

Kinematics is the study of the motion of objects or body segments, encompassing both linear and angular motion. It focuses on the characteristics and components of motion that change over time, such as distance, velocity, and acceleration, without considering the causes of the motion.

2.2.2 Kinetics

Kinetics is the study of the motion of objects in relation to the forces acting on them and the resulting moments. It takes into account the forces that cause movement, which can be external forces (such as reaction forces, gravitational force, or friction) or internal forces (such as muscle forces that generate movement or maintain balance and posture).

2.2.3 Kinetic chain

The movement patterns during sports or exercise involve the coordinated contraction of muscles, orchestrated by the nervous system. The kinetic chain mechanism defines the sequential activation of body segments, unique to each individual and based on the transfer of force between muscles and joints. This considers the interconnectedness of body parts and muscles that form joints. Coordinated muscle contractions generate force, combining internal forces and transferring them as angular momentum through lines of action along bones and muscles. This momentum is transmitted sequentially and precisely through interconnected joints in the body, creating a chain-like effect. This coordination controls movement by selecting and combining degrees of freedom (DOF) at joints and muscles, which act as coordinating units.

2.2.4 Inverse dynamics technique

The study of measuring internal forces within the body is limited due to the inability to directly measure individual muscle forces because of the lack of tools and measurement techniques, similar to finding reaction forces at joints. Therefore, the measurement and calculation of muscle forces and joint moments are commonly done using an indirect biomechanical method called the Inverse Dynamics Technique. This technique involves calculating the reaction forces occurring at joints based on Newton's second and third laws and is more popular than direct measurement techniques (Direct Dynamic Technique). The measurement and calculation of forces using this method require data sources consisting of anthropometric measurements, body segment parameters, information about external forces (especially reaction forces), and kinematic data. Biomechanics researchers are interested in developing models using this technique to explain and provide information about the mechanisms of muscle and joint function in the body related to the forces that cause movement. Additionally, they study the mechanical energy generated in each movement activity. The Inverse Dynamic Model has specific agreements for calculating joint reaction forces, as follows:

1. Each body segment has a fixed center of mass (COM) or center of gravity (COG) that remains constant throughout movement and represents the total mass of that body segment.

2. Joints in each segment are considered either hinge joints or ball-and-socket joints.

3. The length of each body segment remains constant throughout movement.

4. Friction between joint surfaces is neglected.

5. Air resistance is neglected.

6. The estimation of body segment parameters from tables is considered highly accurate.

7. The location of the joint center coincides with the location of the skin marker attached to the skin.

The calculation starts from the point where the exact force value is known, which is the area of the foot acted upon by the ground reaction force. This can be measured using a force plate, and then the force acting on the ankle, knee, and hip joints can be calculated in sequence. The formula used for calculating movement in 3 dimensions comes from the equation $F_{total} = ma$ in each axis.

Ankle force:

$$A_x = m_F a_{Fx} - GRF_x$$
$$A_y = m_F a_{Fy} - GRF_y$$
$$A_z = m_F a_{Fz} - GRF_z$$
$$A = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

Knee force:

$$K_x = m_S a_{Sx} - A_x$$
$$K_y = m_S a_{Sy} - A_y$$
$$K_z = m_S a_{Sz} - A_z - m_{Sg}$$
$$K = \sqrt{K_x^2 + K_y^2 + K_z^2}$$

The X-axis represents the medial-lateral (inside-outside) direction.

The Y-axis represents the anterior-posterior (front-back) direction.

The Z-axis represents the vertical (up-down) direction.

Positive values indicate forces directed to the right or upwards.

Negative values indicate forces directed to the left or downwards.

GRF_x GRF_y and GRF_z are the ground reaction forces at the foot in the X, Y, and Z axes, respectively.

A_x A_y and $A_z$are the forces at the ankle joint in the X, Y, and Z axes, respectively.

A is the resultant force at the ankle joint from all 3 axes.

K_x K_y and K_z are the forces at the knee joint in the X, Y, and Z axes, respectively.

K is the resultant force at the knee joint from all 3 axes.

a_{Fx} a_{Fy} and a_{Fz} are the accelerations of the foot in the X, Y, and Z axes, respectively.

a_{Sx} a_{Sy} and a_{Sz} are the accelerations of the shank (lower leg) in the X, Y, and Z axes, respectively.

g is the acceleration due to gravity, which has a value of 9.81 meters per second squared.

M_F and M_S are the masses of the foot and lower leg, respectively. These are calculated by multiplying the body mass with the respective segment proportions, which are constants derived from the Body Segment Parameter (BSP) table. These values are estimated from cadaver dissections, and the data from Dampster is widely accepted.

2.2.5 Energy flow

Energy flow refers to the movement of energy within the body, encompassing energy generation, absorption in joints, and transfer between body segments. This concept is crucial in understanding sports performance and injuries (Martin, 2014). The generation and transfer of mechanical energy in human movement are evaluated using rigid body linkage models and inverse dynamics. Mechanical energy can be transferred through forces and torques between adjacent body segments. Joint torque transmits energy from the proximal to the distal segment when both segments rotate in the same direction, and joint torque acts to accelerate the distal segment. Joint force transfers energy when there is movement at the joint center. In this study of energy flow, the relevant variables are derived from the resultant joint reaction forces and torques using joint power analysis. The variables include Joint Force Power (JFP), Segment Torque Power (STP), Joint Torque Power (JTP), and Segment Power (SP) (Martin et al., 2014).

2.2.5.1 Joint force power (JFP) is the rate of energy transfer by joint forces, resulting from the product of the joint force vector (Fj) and the linear velocity of the joint center (Vj). It can be calculated using the equation:

$$\text{JFP} = (F_j) \bullet (V_j)$$

The rate of energy transfer between body segments via joint forces depends on joint center velocity. When one segment loses mechanical energy, the adjacent segment gains an equal amount. Joint forces with greater linear velocity of the joint center produce higher joint power, leading to faster energy transfer rates.

2.2.5.2 Segment torque power (STP) is the rate of energy transfer by torque at a joint of a body segment. It is calculated from the resultant joint torque (Tj) and the angular velocity of the body segment (θ_S) using the equation:

$$\text{STP} = \left(T_j\right) \bullet (\theta_S)$$

2.2.5.3 Joint torque power (JTP) is the rate of energy absorption or generation by torque at a joint. It is calculated from the hypothetical line of joint torque (Tj) and the angular velocity (α) of the joint. It can be calculated using the equation:

$$\begin{aligned} \text{JTP} &= (\text{Tj}) \bullet (\theta\text{d} - \theta\text{p}) \\ &= (\text{Tj}) \bullet (\alpha) \end{aligned}$$

The characteristics of power in joint torque reveal its ability to create, absorb, and move energy within the body. When body parts rotate in opposite directions, energy is either produced or consumed but doesn't travel between them. Same-direction rotation enables energy transfer due to torque power, which is also known as the rate of energy absorption, generation, or transfer by joint torque.

2.2.5.4 Segment power (SP) is the rate of energy transfer into or out of a body segment. It is the sum of the joint power and segment torque power for each body segment. It can be calculated using the equation:

$$\text{SP} = JFP_d + JFP_p + STP_d + STP_p$$

where d and p refer to the proximal and distal joints of the body segment (Caroline et al., 2014).

2.2.6 Sensor insoles

Sensor insoles are tools used to measure pressure and force distribution under the foot. There are two main types: force platforms and insole systems. Force platforms are biomechanical tools used to measure ground reaction forces during walking, running, or jumping. They are used in motion analysis and gait posture analysis, providing data on the ground reaction force acting on the foot. These platforms offer comprehensive and highly accurate measurements across the entire foot area, capturing data in three axes (X, Y, and Z). However, force platforms are expensive and primarily used in research settings and some hospitals. On the other hand, insole systems are smaller, more affordable, and offer a convenient way to detect foot abnormalities quickly.

2.3 Related research

Navarro et al. (2022) investigated the pressure distribution on the soles of golfers' shoes during swings with driver and 5-iron clubs. The study involved 55 golfers of varying skill levels, each performing five swings per club. Pressure sensors with high spatial resolution (4 sensors/cm^2) captured data at 100 Hz, while a video camera recorded key swing moments. Statistical analysis revealed significant differences in pressure distribution between the left and right feet, regardless of club type. However, the pressure patterns remained consistent across different swings. Notably, professional golfers exhibited distinct pressure distribution patterns compared to medium and high handicap golfers, particularly when transitioning from a 5-iron to a driver. The findings align with the established principle of weight transfer in golf swings, highlighting variations in pressure between the inner and outer areas of the foot.

Worsfold et al. (2009) investigated the relationship between golf shoe outsole design and human kinematics during the golf swing. Using pressure-measuring insoles and force platforms, they analyzed both in-shoe pressure and ground reaction forces while participants wore three different outsole types (metal spikes, alternative spikes, and flat soles). The study found that while the forefoot generated more force and torque than the rearfoot, this was not significantly affected by outsole type. However, metal spike outsoles were associated with increased rearfoot torque compared to flat soles. Additionally, in-shoe pressure distribution varied considerably depending on outsole design. These results highlight the importance of outsole design in influencing both golfer performance and comfort. By understanding the impact of different outsole features on ground reaction forces and pressure distribution, researchers and manufacturers can develop shoes that optimize traction, stability, and overall performance. The study's use of two simultaneous measurement methods allowed for a comprehensive assessment of the interaction between the foot, shoe, and ground. This integrated approach could inform future research and design efforts aimed at creating golf shoes that cater to the specific needs of individual golfers and playing conditions.

Ball and Best (2012) investigated the relationship between weight transfer and club head speed in professional and amateur golfers. Their study involved analyzing the center of pressure (CP) position and speed, along with club head speed at impact, for 50 driver swings by each golfer. The research revealed that weight transfer plays a crucial role in club head speed for all golfers. However, the specific relationship between CP and club head speed varied for each individual, highlighting the influence of individual styles and factors. Professional golfers exhibited faster forward weight transfer during the downswing and a wider overall range of weight transfer, which correlated with higher club head speeds. Conversely, amateur golfers tended to have a wider range of weight transfer, particularly shifting more weight backward, and a faster rate of weight transfer during the top of the backswing and mid-follow-through. This distinct pattern also related to higher club head speed in amateurs. These findings underscore the significance of weight transfer in the golf swing and emphasize the need for personalized analysis to comprehend the unique factors influencing each golfer's performance.

Pataky (2015) investigated the relationship between foot pressure distribution and clubhead speed in 32 amateur golfers. Using a Pedar-X insole system to measure plantar pressure (PP) and a Doppler radar system to track clubhead speed during driver swings, the study found a significant positive correlation ($p < 0.05$) between maximum PP on the lateral forefoot of the target foot (closest to the target) and clubhead speed. This suggests that weight distribution towards the outside of the front foot is crucial for generating clubhead speed in amateur golfers. The research also employed statistical parametric mapping (SPM) to analyze pressure distribution across the entire foot, providing a deeper understanding of the relationship between pressure and clubhead speed.

Ball and Best (2007) studied weight transfer during the golf swing using cluster analysis to classify different weight transfer styles. Weight transfer in the golf swing refers to the movement of weight between the feet during the swing. In general, Weight starts with an even distribution. It then moves to the back foot during the backswing and to the front foot during the downswing. Researchers have found that there are two main patterns of weight transfer: the "Front Foot" and the "Reverse" Front Foot groups. Will continuously move weight towards the front foot until it hits the ball. While the Reverse group has a characteristic of moving the weight back to the back foot before the point of impact. Both of these weight transfer styles are found in golfers of all skill levels. This indicates that none of the patterns were a technical error. These findings highlight the importance of consideration. Different swing patterns in statistical analysis This is to avoid misinterpretation of the research results. and to understand the various mechanisms of the swing correctly.

Han et al. (2019) studied how a golfer's interaction with the ground affects their clubhead speed. By measuring ground reaction forces and moments using motion capture and force plates, they found a strong link between maximum clubhead speed and two specific interaction moments: the ground reaction force moment about the front/back axis and the rotation moment about the vertical axis. The lead foot mainly produced the ground reaction force moment, while the trail foot played a bigger role in the rotation moment. The moment of maximum angular force happened when the leading arm was parallel to the ground, emphasizing the importance of shifting weight to the lead foot around this point to maximize both moments and ultimately achieve optimal clubhead speed.

Chu et al. (2010) investigated the relationship between biomechanical variables and driving performance in golf. Analyzing swing kinematics and ground reaction force data from 308 golfers, their study identified key factors significantly related to ball velocity. These factors included X-Factor (angle separation between the upper torso and pelvis), delayed release of the arms and wrists, trunk tilting (forward and lateral), and weight-shifting during the swing. The study's findings validated several established golf coaching principles for increasing ball speed and may provide valuable guidance for skill and strength training in golfers.

Takagi (2018) investigated the effect of joint movement on force and torque applied to a golf club during a swing, aiming to understand how energy is transferred from the golfer to the club. The study involved 16 skilled golfers, whose movements were captured using 3D motion capture technology. The power of wrist joint force and torque power of the golf club segment were analyzed in relation to the velocity of the pelvis's center of gravity and the angular velocity of the pelvis, waist, shoulder, and wrist joints. The study revealed that the angular velocity of the pelvis plays a crucial role in generating power at the wrist joint. Moreover, the force associated with the pelvis and the angular velocity of joints near the body's center reach their maximum simultaneously. These findings suggest that synchronizing peak power might be a key strategy for golfers to maximize energy transfer and achieve a more powerful swing.

Kenny et al. (2008) investigated the proximal-to-distal transfer of kinetic energy in the human body during a golf swing. Utilizing a computer model driven by 3D kinematic data from an elite male golfer, and employing combined inverse and forward dynamics analyses, the study examined kinetic energy changes in rigid body segments including the torso, hips, arms, and club head. Results confirmed a sequential increase in peak kinetic energy magnitude from proximal to distal segments for both driver and 7-iron swings, supporting the principle of summation of speed. However, the timing of peak kinetic energy did not follow this sequential pattern. Instead, the arms peaked first, followed by the hips, torso, and finally the club, suggesting a specific coordination sequence rather than simultaneous peak energy transfer.

Nesbit and Serrano (2005) investigated the mechanics of the golf swing by analyzing the work and power involved. They used two computer models to track how energy is generated, transferred, and transformed within both the golfer's body and the golf club throughout the swing. Their research specifically focused on the downswing, measuring the internal work done by the body and the energy changes within the club. By studying four amateur golfers, they found that this energy-based approach revealed new insights into swing mechanics, such as identifying which body segments contribute most to power generation, pinpointing the forces that accelerate the club, and demonstrating the importance of both force and range of motion for clubhead speed.

มหาวิทยาลัยเทคโนโลยีสุรนารี

CHAPTER III

MATERIALS AND METHODS

This experimental research aimed to investigate the differences in foot pressure patterns and energy flow during the golf swing between professional and amateur golfers. The research involved the following steps:

1. Population and samplings
2. Data Collection Design
3. Data collection
4. Data Analysis

3.1 Population and samplings

3.1.1 Population

The population for this research was selected using purposive sampling. It consisted of right-handed golfers aged between 18-35 years, divided into two groups:

Group 1: Professional golfers (Pro)

Group 2: High handicap amateur golfers (handicap >15) (High)

3.1.2 Sample

Thirty golfers were divided into two groups based on their performance level: professional players and amateur players with a handicap higher than 15. These classes were named Pro and High, with 15 participants in each group.

Sample size determination using G*Power software. Following Cohen's (1988) recommendations, the effect size was set as large, medium, and small with values of 0.2, 0.5, and 0.8, respectively.

Given:

Effect size f = 0.8

β/α ratio = 1

Total sample size = 30

Group 1 size = 15

Group 2 size = 15

The resulting Power (1- β err prob) = 0.8607720

3.1.3 Sampling

Fifteen professional golfers and fifteen amateur golfers with handicaps exceeding 15 were categorized into two groups designated as "Pro" and "High" respectively.

3.1.3.1 Inclusion Criteria:

1. Professional golfers: Individuals who primarily play golf for income and have passed the qualification exam to become professional golfers.
2. Amateur golfers: Individuals who play golf for personal enjoyment and challenge.
3. Right-handed dominance in golf practice and competition.
4. Consistent practice of more than 3 times per week.
5. No history of severe injuries or surgeries in the core muscles, spine, wrists, elbows, shoulders, torso, knees, or ankles that would hinder participation in the research, within 6 months prior to joining the study.
6. Willingness to participate in the research.
7. All research participants can withdraw from the study immediately if they experience any potential risks to their health.

3.1.3.2 Exclusion Criteria:

1. Participants experience unforeseen events that prevent them from continuing in the research, such as injuries from accidents, illness, etc.
2. Participants no longer wish to participate in the study.

3.2 Instrumentation

1. One computer with 3D motion capture and analysis software.
2. Six Qualisys Camera Oqus (Oqus 7+ series, Qualisys AB, Sweden).
3. Visual 3D Motion Analysis software (C-Motion, Germantown, MD).
4. Two Kistler force platforms (Model 9286BA, Kistler Group, Switzerland).
5. One calibration set (wand and L frame) for defining reference coordinates in the research area (Qualisys AB, Sweden).
6. Retro-reflective markers (15 mm diameter) with flat bases (B&L Engineering, Tustin, CA, USA).
7. SuraSole Pro 8 sensor insoles (Surasole Pro 8, Suratec Co., Ltd., Nakhon Ratchasima, Thailand).
8. Documentation forms for recording experimental results

3.3 Construction and efficiency of the instrument

This research study analyzed the differences in pressure distribution on the sole of the foot and energy flow during a golf swing. The swing was recorded using video, and the recorded video was then transferred to a computer for playback and frame-by-frame analysis. The video was paused at specific points in the swing to capture still images for further data analysis.

3.3.1 Steps in designing data collection methods:

1. Study documents, principles, concepts, theories, documents, textbooks, articles, related research. and suggestions from experts and experienced people.

2. Determine methods for studying and analyzing differences in pressure distribution on the soles. and energy flow during the golf swing of golfers in the two sample groups.

3.3.2 Testing of research tools includes:

1. Testing reliability using the proposed data collection method. Thesis advisors will consider suitability and provide data collection methods to experts. Two people in the area of sports biomechanics performed the inspection. After that, the

revised data collection method was presented to the thesis advisor to apply the validated data collection method to the sample group.

2. Conduct a pilot study using data collection methods that have been passed. Check and then try to find the variable value of the distribution of pressure on the sole. and energy flow during the virtual golf swing studied in a sample group.

3.4 Data collection

3.4.1 Protection of research participants' rights

In this research, the researcher has protected the rights of the participants by obtaining permission from the Ethics Committee of Suranaree University of Technology (EC-67-152). The researcher has prepared informed consent forms for data collection, explaining the research objectives, and ensuring the confidentiality of the participants. The researcher will not disclose any individual information and will only analyze and present the data in aggregate form.

3.4.2 Equipment setup

1. Six sets of computer equipment with motion analysis software, recording devices, and 3D motion capture cameras. These are to be arranged to cover an analysis area of 6 x 6 x 8 meters. Marker position data and motion capture footage will be processed using Qualisys motion analysis software. Data synchronization will be implemented to ensure simultaneous data recording across all sources. The motion capture cameras will be connected to computers equipped with Visual 3D Motion Analysis software and configured to record at a frequency of 200 frames per second.

2. The cameras are positioned at a 45-degree angle in front of and behind the athlete. The image recording frequency is 200 Hz, and continuous recording is used with automatic light adjustment. The cameras are set up to cover the sample area and the golf swing cycle, along with the force plate, which records data at a frequency of 1,500 Hz. Both devices record data simultaneously (Synchronization).

3. Calibrate the accuracy of the motion analysis cameras by recording a 1-meter reference rod for 3 seconds. The calibration kit consists of a 300mm carbon fiber rod and an L-frame. After calibration, do not move or disturb the cameras from their original positions. Align the camera's coordinate system with the real-world

distances (Camera Calibration) using dynamic calibration. Set a reference point (0, 0, 0) to represent the X, Y, and Z positions of objects within the study area (Global Reference System). The X-axis points from left to right, the Y-axis points from back to front, and the Z-axis points from bottom to top. Then, record the motion by flashing a light towards all 6 motion analysis cameras simultaneously. The calibration process will be conducted on the day of equipment setup and before each participant's serving test, prior to data recording.

3.4.3 Basic data collection

1. On the day of basic data collection and golf swing testing, participants will receive documents explaining the details of the data collection process and instructions for proper practice. They will then be asked to sign a consent form to participate in the research.

2. Participants in the research will complete a basic information form. Additional notes recorded by the researcher include age, playing experience, and competition experience. After that, body measurements including weight and height will be taken.

3. After collecting the basic information, participants will wear 1.5-centimeter retro-reflective markers to identify the coordinates of various body joints based on physiological principles, using a standard skin marker set. Participants will wear shorts, skin-tight clothing, and sneakers without colored or reflective materials. The skin at the marker placement sites will be cleaned using an alcohol-moistened cotton swab before attaching the markers to the designated positions. The entire marker attachment process will take approximately 45 minutes.

4. Subjects performed a warm-up to familiarize themselves with the markers attached to their bodies and golf clubs. By being given time to become familiar with Test environment and as many locators as needed (Caroline et al., 2012).

5. Body Segment Model Parameter in this study, there were 15 body segments, consisting of 14 body segments, namely the head, torso, upper arms, distal arms, hands, upper legs, lower legs, and both feet. side and 1 part of the golf club. Attaching 42 fluorescent markers according to the body part and position on the golf club.

Table 3.1 All 42 location points.

Number	Marker	Location on the body
1	HeadFront	Forehead
2	HeadL, HeadR	Just above the ear center
3	LShoulderTop, RShoulderTop	On the outside of the elbow (bony prominence)
4	LElbowOut, RElbowOut	On the outside of the elbow (bony prominence)
5	LElbowIn, RElbowIn	On the inside of the elbow (bony prominence)
6	LWristIn, RWristIn	On the inside of the wrist (bony prominence on the thumb side)
7	LWristOut, RWristOut	On the outside of the wrist (bony prominence on the pinky side)
8	Chest	Upper part of the sternum
9	WaistLFront, WaistRFront	On the front of the pelvis (bony prominence)
10	LThighFrontLow, RThighFrontLow	Above the kneecap
11	LKneeOut, RKneeOut	On the outside of the knee (bony prominence)
12	LKneeIn, RKneeIn	On the inside of the knee (bony prominence)
13	LShinFrontHigh, RShinFrontHigh	Front of the shin
14	LAnkleOut, RAnkleOut	On the outside of the ankle
15	LForefoot5, RForefoot5	On the base of the fifth toe
16	LForefoot2, RForefoot2	On the base of the second toe
17	SpineThoracic2	On the 2nd prominence below the biggest prominence on the top of the spine
18	LArm, RArm	On the back of the upper arm
19	LHand2, RHand2	On the back of the hand at the base of the index finger
20	SpineThoracic12	A few cm below the midpoint of the lower tip of the shoulder blades
21	WaistBack	On the midpoint between the two prominences on the back of the pelvis
22	WaistL, WaistR	On the sides of the pelvis (bony prominence)
23	LHeelBack, RHeelBack	Back of the heel

มหาวิทยาลัยเทคโนโลยีสุรนารี

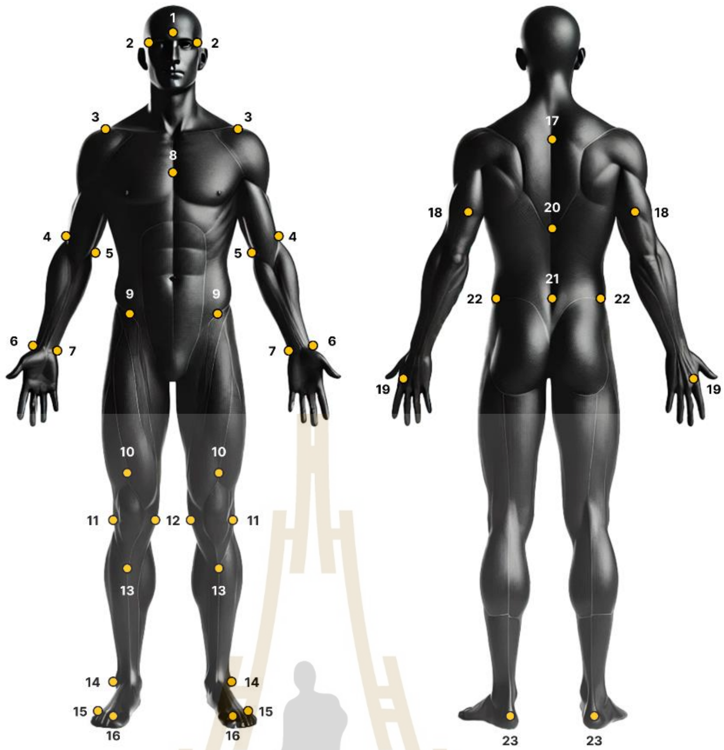

Figure 3.1 Color Atlas of Skeletal Landmark Definitions: Guidelines for Reproducible Manual and Virtual Palpations. (Jan and Van, 2007)

3.4.4 Golf swing test

The researcher explained the details and procedures for collecting data to the participants. The researcher and research assistant will attach reflective markers for marking points on various positions on the participants' bodies, totaling 42 positions (as shown in Table 3.1). Then, the researcher and research assistant will take the plates. The sensor insoles were for participants to wear inside their own shoes. Once the equipment was installed, the participants had to warm up for about 10 minutes to get used to the equipment attached to their bodies. Then it will be time to collect test data. The participants performed golf swings and movements similar to a real competition situation with each swing. To achieve the best total of 5 swings with each different golf club head. There is a 1 minute rest period after each swing and movement. When the participants completed the test, they were asked to stretch their muscles for at least 10 minutes after the test to relax the muscles after being used.

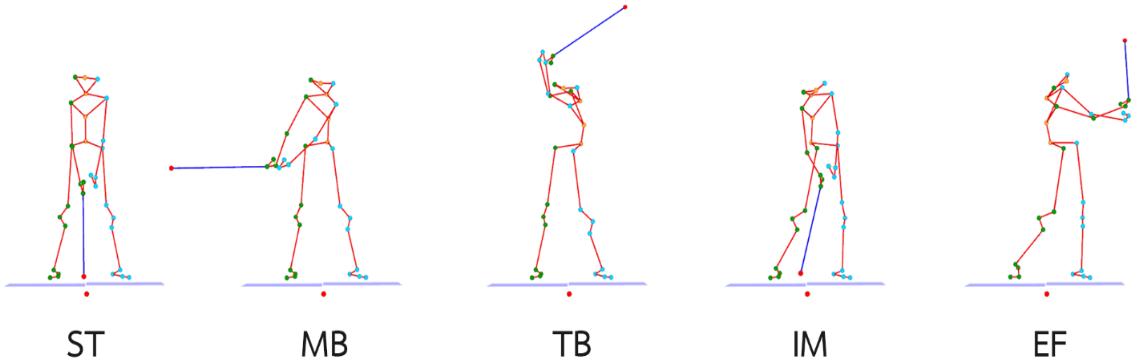

Figure 3.2 Key moments of the swing: Stand (ST), The golfer stands in position and ready to start the swing; Middle Backswing (MB), The club is moved backward and upward until the shaft is parallel to the ground; Top of backswing (TB), The club reaches its highest point in the backswing and starts to move downward; Ball Impact (IM), The clubface strikes the ball; Early finish (EF), The golfer continues the swing, with the shaft moving past the vertical axis.

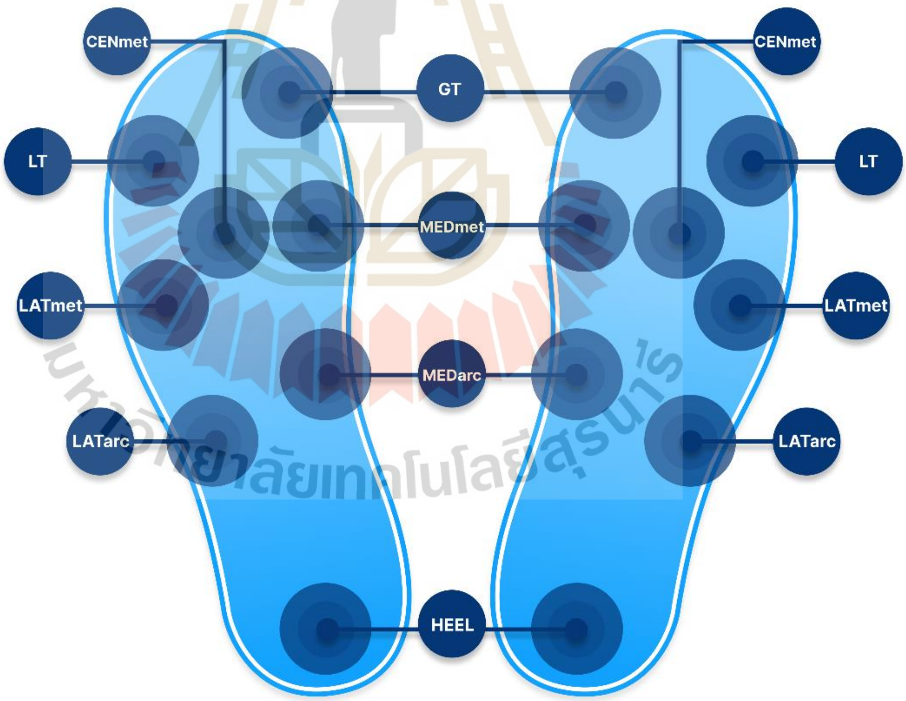

Figure 3.3 Eight Foot plantar areas defined for the statistical analysis: great toe (GT), lesser toe (LT), medial metatarsal (MEDmet), central metatarsal (CENmet), lateral metatarsal (LATmet), medial arc (MEDarc), lateral arc (LATarc), heel (HEEL).

3.4.5 Data analysis

1. The recorded images were analyzed for kinematic and kinetic data using a motion analysis program (Visual 3D Motion Analysis). The analysis was divided into five phases: Stand (ST), Middle Backswing (MB), Top of Backswing (TB), Ball Impact (IM), and Early Finish (EF). The image data were then imported into a computer to convert the recorded frames into marker positions over time (digitization), followed by processing to calculate linear velocity, angular velocity, and joint/body segment motion. In particular, for the kinetic data, Visual 3D's "Normalize using default normalization" option was employed, which automatically normalizes variables such as joint moments and joint powers by dividing them by the subject's body mass. This allows for meaningful comparison of biomechanical parameters across individuals with different body sizes.

2. Kinematic data analysis includes the analysis of force, resultant joint force, and joint torque, with calculations following the Cardan sequence (Z-X-Y) in flexion-extension, abduction-adduction, and internal-external rotation of body segments.

3. Analyze kinetic data to determine energy flow from the kinetic chain, including joint force power, segment torque power, joint torque power, and segment power during the golf swing between the two groups of subjects. Signal processing to manage noise will involve filtering with a Butterworth low-pass filter with a cutoff frequency of 6 Hertz.

4. Plantar pressure analysis was performed using data collected from smart insole sensors. Each foot had eight sensor positions, and the pressure values were initially recorded in kilopascals (kPa). These values were then converted into a percentage of total foot loading per foot. Specifically, the total pressure across all eight sensors on a given foot was normalized to 100%, and the pressure at each individual sensor location was expressed as a percentage of this total.

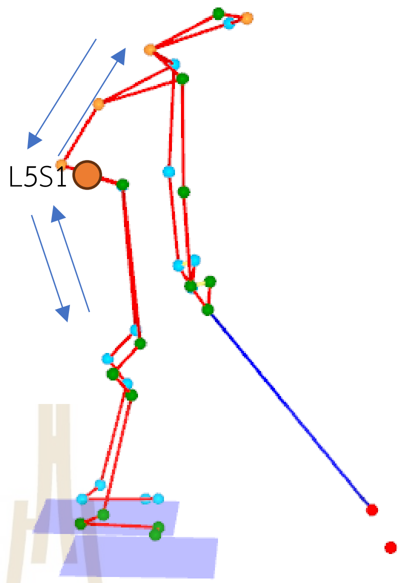

Figure 3.4 Illustrates the energy flow at the lumbosacral junction (L5S1), the connection point between the 5th lumbar vertebra (L5) and the 1st sacral vertebra (S1).

3.5 Statistics used to analyze data

This study aims to investigate foot pressure patterns and energy flow in the golf swing. The research process involves data collection and analysis using both kinematic and kinetic calculations. Statistical analysis was performed using SPSS 26.0 software (IBM Corporation, Somers, NY, USA).

1. Preliminary data analysis to understand the characteristics of the sample group and the distribution of variables used in the research by calculating basic statistics, including mean and standard deviation.

2. Comparison of foot pressure differences between different golf clubs within a group of professional golfers using Paired T-Test analysis.

2.1 Quantitative data measured on a ratio scale, from a single population.

2.2 Repeated measures taken twice: before and after.

2.3 Data distribution is normal, and data collection is randomized.

3. Compare the difference in foot pressure between the two sample groups using a T-Test analysis.

3.1 The data is measured on a ratio scale.

3.2 The data distribution is normal (Normal distribution).

3.3 The data is randomly sampled (Randomized data) from two independent populations.

3.4 The population variance is unknown, and the sample size is small.

4. Determine the relationship between foot pressure and energy flow values using Pearson Correlation Coefficient analysis.

4.1 Data must be quantitative.

4.2 The relationship must be linear.

4.3 Data should be normally distributed.

มหาวิทยาลัยเทคโนโลยีสุรนารี

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.

มหาวิทยาลัยเทคโนโลยีสุรนารี

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/m^2. 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/m^2. 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.

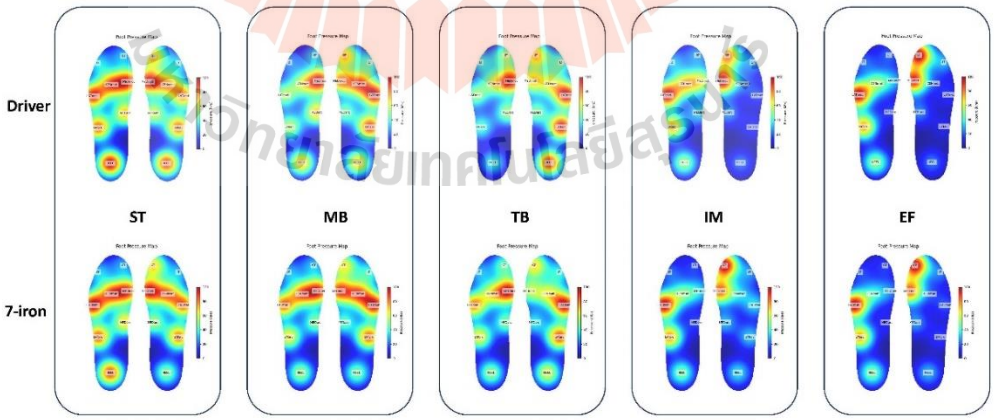

Figure 4.1 Average maximum plantar pressure distribution across different foot areas between the driver and 7-iron golf clubs in professional player at the key moments of the swing

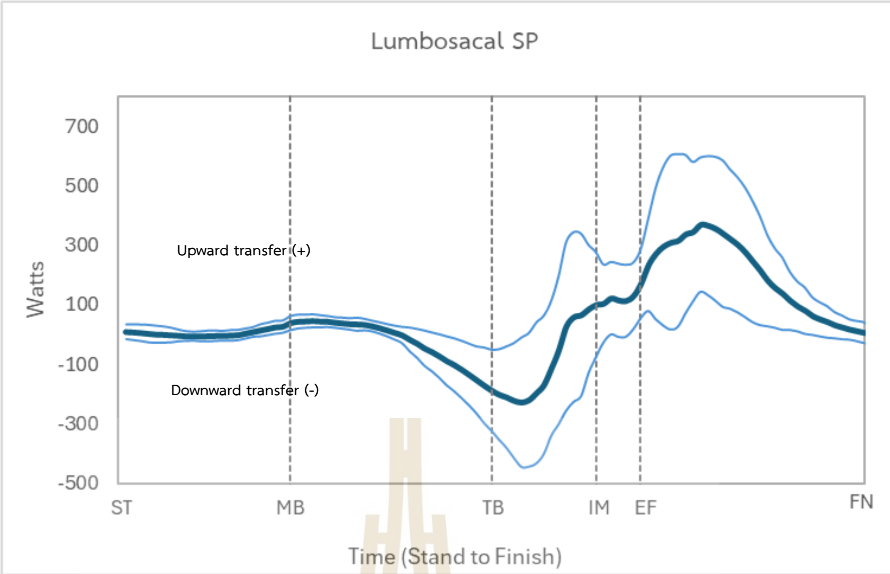

Figure 4.2 Mean normalized segment power (SP) in professional players using a driver, indicating the rates of energy transfer in the lumbosacral (L5S1).

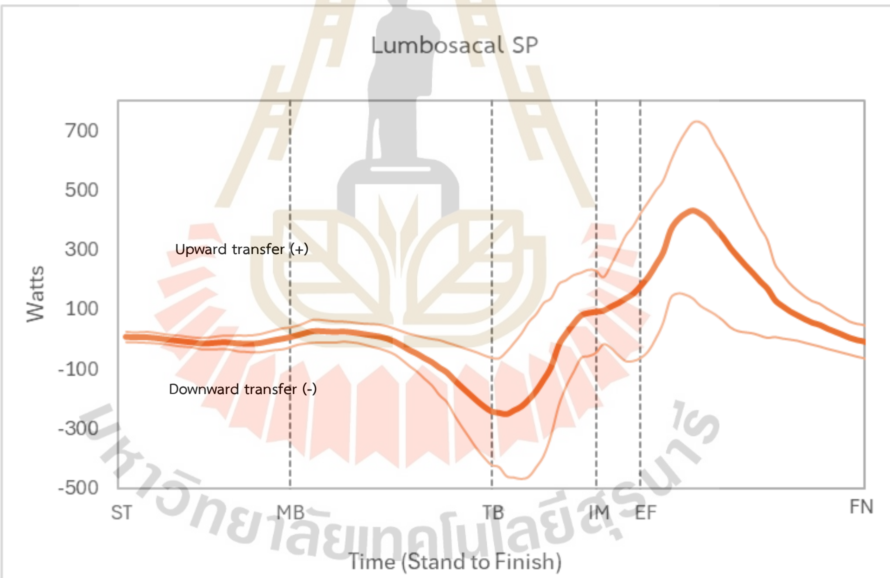

Figure 4.3 Mean normalized segment power (SP) in professional players using a 7-Iron, indicating the rates of energy transfer in the lumbosacral (L5S1).

มหาวิทยาลัยเทคโนโลยีสุรนารี

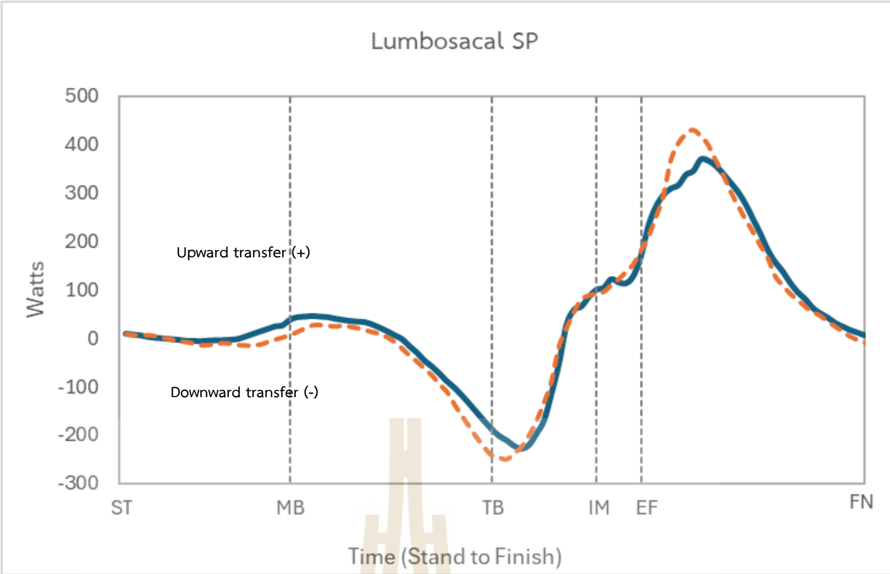

Figure 4.4 Mean normalized segment power (SP) in professional players using a driver (solid line) and 7-iron (dashed line), indicating the rates of energy transfer in the lumbosacral (L5S1).

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.

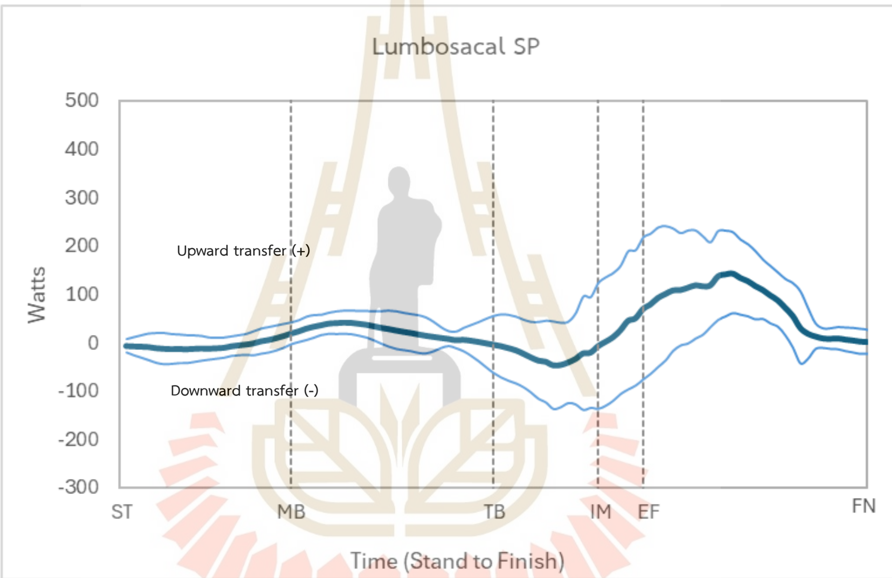

Figure 4.5 Mean normalized segment power (SP) in high handicap players using a driver, indicating the rates of energy transfer in the lumbosacral (L5S1).

มหาวิทยาลัยเทคโนโลยีสุรนารี

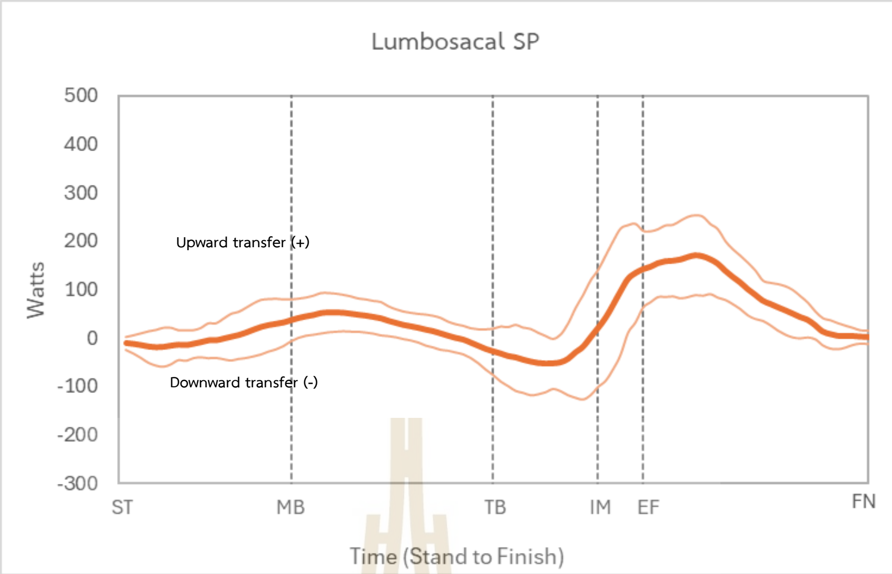

Figure 4.6 Mean normalized segment power (SP) in high handicap players using a 7-iron, indicating the rates of energy transfer in the lumbosacral (L5S1).

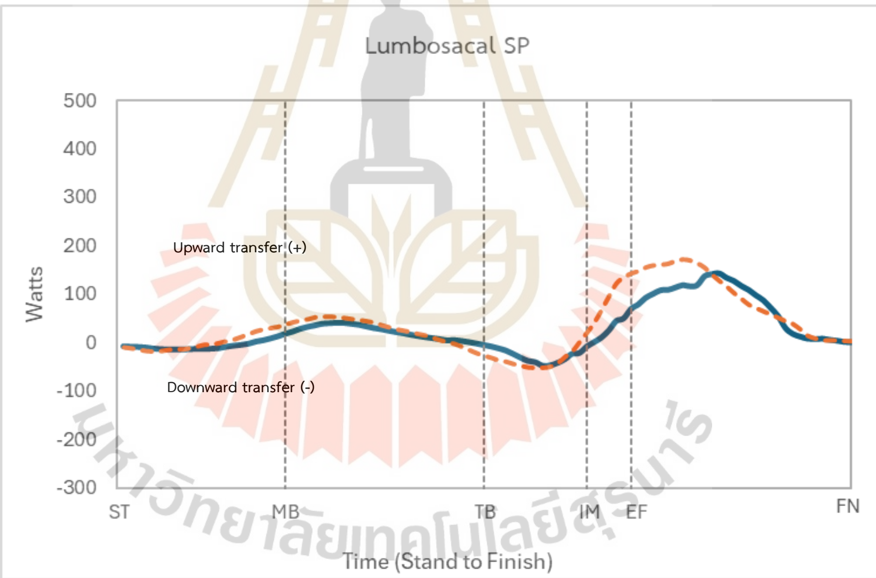

Figure 4.7 Mean normalized segment power (SP) in high handicap players using a driver (solid line) and 7-iron (dashed line), indicating the rates of energy transfer in the lumbosacral (L5S1).

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.

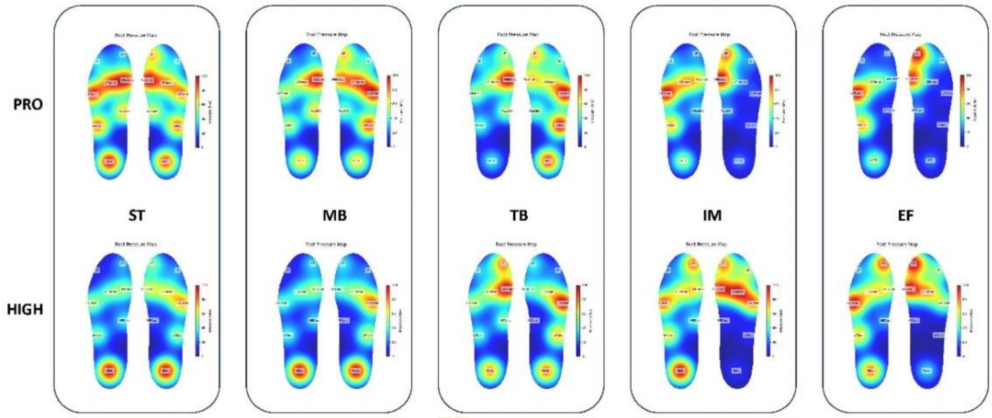

Figure 4.8 Average maximum plantar pressure distribution across different foot areas between professional and high handicap players using a driver at the key moments of the swing.

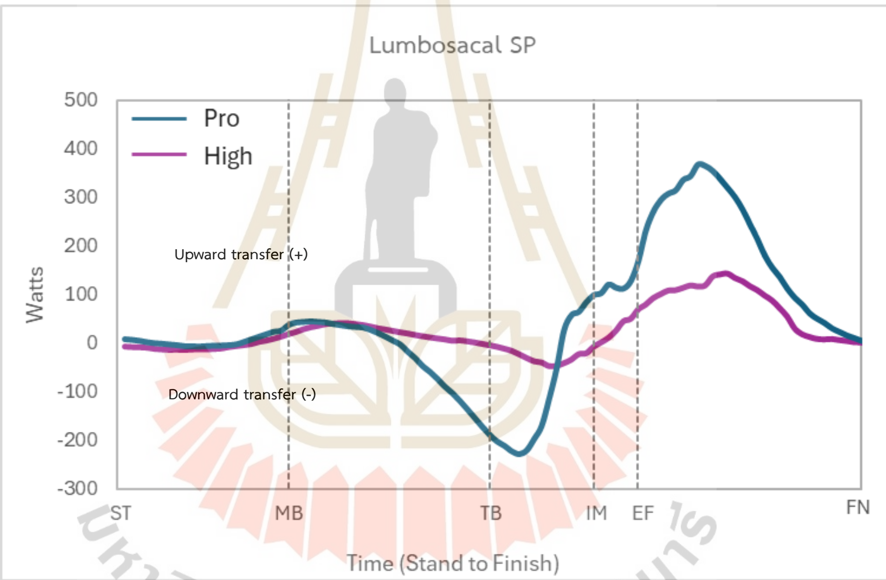

Figure 4.9 Mean normalized segment power between professional and high handicap players using a driver, indicating the rates of energy transfer in the lumbosacral (L5S1).

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

มหาวิทยาลัยเทคโนโลยีสุรนารี

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.

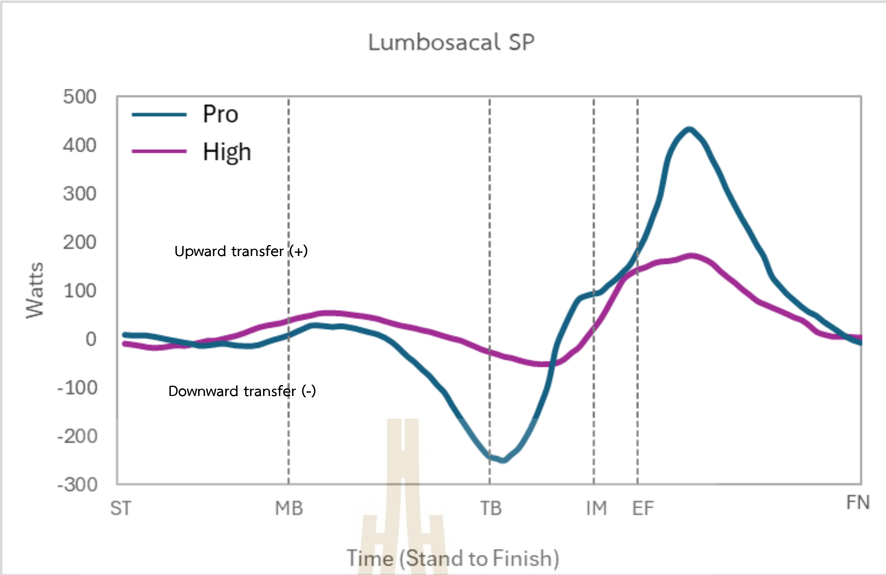

Figure 4.11 Mean normalized segment power between professional and high handicap players using a 7-iron, indicating the rates of energy transfer in the lumbosacral (L5S1).

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).

มหาวิทยาลัยเทคโนโลยีสุรนารี

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.

มหาวิทยาลัยเทคโนโลยีสุรนารี

CHAPTER V

CONCLUSIONS

This study focuses on analyzing foot pressure patterns that affect energy flow during the golf swing between professional and amateur golfers, as well as the impact of different types of golf clubs. The findings indicate that professional golfers exhibit a more balanced foot pressure distribution, leading to more efficient energy transfer, while amateur golfers tend to lose energy due to improper weight shifting. The use of different golf clubs also influences weight distribution; using a Driver tends to increase heel pressure, supporting greater energy buildup for powerful swings, whereas a 7-Iron allows for better anterior foot pressure control, enhancing shot accuracy.

The study also found that professional golfers apply higher pressure in the Medial Metatarsal and Lateral Arch areas, which facilitates a smoother energy transfer to the upper body, optimizing power generation. In contrast, amateur golfers tend to exert excessive pressure on the toes and heels, leading to energy loss. Additionally, during different swing phases, professional golfers are more adept at maintaining weight balance, particularly during the backswing and ball impact phases, which contributes to improved energy transfer efficiency and reduced energy dissipation.

Based on these findings, the results can be applied to developing training programs aimed at improving foot pressure distribution and weight shifting efficiency. Moreover, insights from this study could be used in designing golf shoes that enhance foot stability and prevent excessive pressure in critical areas. The development of smart insoles with real-time pressure sensors could also help golfers adjust their swing mechanics more effectively. Additionally, utilizing Motion Capture technology for swing analysis can assist golfers in refining their techniques with greater precision.

Furthermore, the differences in foot pressure patterns between professional and amateur golfers identified in this study provide useful guidelines for defining optimal foot pressure distribution during the golf swing. These insights can be used to develop golf swing analysis applications that compare a user's foot pressure with ideal patterns from professional golfers. This allows the app to provide real-time feedback to help users correct incorrect weight transfer and improve energy transfer during the swing.

In terms of sensor design, the observed relationship between foot pressure and energy flow during each swing phase suggests that smart insole sensors should be strategically positioned. Key areas such as the heel during stance and the forefoot during impact and follow-through are critical for detecting weight shifts. This study also provides guidance on the appropriate number and placement of sensors to effectively capture energy flow, supporting the development of more accurate and personalized swing analysis systems.

However, this study was conducted with a sample group of 30 right-handed golfers, which may limit the generalizability of the findings to left-handed players. Further longitudinal studies are recommended to assess the long-term effects of training interventions on swing mechanics. Additionally, other influencing factors, such as playing surface conditions, footwear design, and fatigue, should be investigated to provide a more comprehensive understanding of foot pressure dynamics in golf.

The findings highlight that professional golfers have superior control over foot pressure, leading to more efficient weight shifting and improved swing performance. In contrast, amateur golfers often show inefficiencies that reduce energy transfer and impact power. These insights can inform the development of personalized training, optimized equipment, and advanced swing analysis tools that measure foot pressure and energy flow accurately. Such applications can help golfers of all levels enhance performance, prevent injuries, and achieve a more efficient and powerful swing.

REFERENCES

REFERENCES

Ball, K., and Best, R. (2012). Centre of pressure patterns in the golf swing: Individual-based analysis. *Sports Biomechanics, 11*(2), 175–189.

Ball, K., and Best, R. (2007). Different center of pressure patterns within the golf stroke I: Cluster analysis. *Journal of Sports Sciences, 25*(7), 757–770.

Ball, K., and Best, R. (2011). Golf styles and center of pressure patterns when using different golf clubs. *Journal of Sports Sciences, 29*(6), 587–590.

Barrentine, S. W., Fleisig, G. S., Johnson, H., and Woolley, T. W. (1994). Ground reaction forces and torques of professional and amateur golfers. In A.J. Cochran, and M.R. Farrally, (Eds.), Science and golf II. *Proceedings of the World Scientific Congress of Golf (pp. 33–39)*. E and FN Spon.

Baechle, T. R., and Earle, R. W. (Eds.). (2008). Essentials of strength training and conditioning (3rd ed.). *Human Kinetics*.

Belotti, A., Bisazza, N., Calcari, A., Perrone, P., and Biscarini, A. (2024). The Ground-X-Factor: Training the Proprioceptive and Propulsive Function of the Foot for Improved Technique and Enhanced Performance of the Golf Swing. In *Preprints*: Preprints.

Bradshaw, E. J., Keogh, J. W. L., Hume, P. A., Maulder, P. S., Nortje, J., and Marnewick, M. (2009). The effect of biological movement variability on the performance of the golf swing in high- and low-handicapped players. *Research Quarterly for Exercise and Sport, 80*(2), 185-196.

Broer, M. R., and Houtz, S. J. (1967). *Patterns of muscular activity in selected sports skills : an electromyographic study.*

Carlsöö, S. (1967). A kinetic analysis of the golf swing. *The Journal of Sports Medicine and Physical Fitness, 7*(2), 76-82

Chu, Y., Sell, T. C., and Lephart, S. M. (2010). The relationship between biomechanical variables and driving performance during the golf swing. *Journal of Sports Sciences, 28*(11), 1251–1259.

Cole, M. H., and Grimshaw, P. N. (2016). The biomechanics of the modern golf swing: Implications for lower back injuries. *Sports Medicine, 46*(3), 339–351.

Dong, R., and Ikuno, S. (2023). Biomechanical analysis of golf swing motion using Hilbert–Huang transform. *Sensors*, *23*(15).

Fletcher, I. M., and Hartwell, M. (2004). Effect of an 8-week combined weights and plyometrics training program on golf drive performance. *The Journal of Strength & Conditioning Research, 18*(1), 59-62.

Gluck, G. S., Bendo, J. A., and Spivak, J. M. (2008). The lumbar spine and low back pain in golf: A literature review of swing biomechanics and injury prevention. *The Spine Journal, 8*(5), 778-788.

Gordon, B. S., Moir, G. L., Davis, S. E., Witmer, C. A., and Cummings, D. M. (2009). An investigation into the relationship of flexibility, power, and strength to club head speed in male golfers. *The Journal of Strength & Conditioning Research, 23*(5), 1606-1610.

Han, K. H., Como, C., Kim, J., Lee, S., Kim, J., Kim, D. K., and Kwon, Y. (2019). Effects of the golfer-ground interaction on clubhead speed in skilled male golfers. *Sports Biomechanics, 18*(1), 115–134.

Hiley, M. J., Bajwa, Z., Liang, Y., and Blenkinsop, G. M. (2021). The effect of uphill and downhill slopes on centre of pressure movement, alignment and shot outcome in mid-handicap golfers. *Sports Biomechanics, 20*(7), 781-797.

Jones, K. M., Wallace, E. S., and Otto, S. R. (2024). The relationship between skill and ground reaction force variability in amateur golfers. *Sports Biomechanics, 23*(10), 1625-1639.

Kenny, I. C., McCloy, A. J., Wallace, E. S., and Otto, S. R. (2008). Segmental sequencing of kinetic energy in a computer-simulated golf swing. *Sports Engineering, 11*(1), 37–45.

MacKenzie, S., McCourt, M., and Champoux, L. (2020). How amateur golfers deliver energy to the driver. *International Journal of Golf Science, 8*(1).

Martin, C. (2014). Tennis serve biomechanics in relation to ball velocity and upper limb joint injuries. *Journal of Medicine and Science in Tennis, 19*(2), 110-112.

Martin, C., Bideau, B., Bideau, N., Nicolas, G., Delamarche, P., and Kulpa, R. (2014). Energy flow analysis during the tennis serve: Comparison between injured and noninjured tennis players. *The American Journal of Sports Medicine, 42*(11), 2751-2760.

Myers, J., Lephart, S., Tsai, Y. S., Sell, T., Smoliga, J., and Jolly, J. (2008). The role of upper torso and pelvis rotation in driving performance during the golf swing. *Journal of Sports Sciences, 26*(2), 181-188.

Navarro, E., Mancebo, J. M., Farazi, S., del Olmo, M., and Luengo, D. (2022). Foot insole pressure distribution during the golf swing in professionals and amateur players. *Applied Sciences, 12*(1), 358.

Nelson, L. (1980). A better weight shift made the difference. *Golf Digest*, 37-38.

Nesbit, S. M. (2005). A three-dimensional kinematic and kinetic study of the golf swing. *Journal of Sports Science & Medicine, 4*(4), 499.

Nesbit, S. M., and Serrano, M. (2005). Work and power analysis of the golf swing. *Journal of Sports Science and Medicine, 4*(4), 520-533.

Norman, G. (1995). Advanced golf. *Heinemann.*

Outram, T., and Wheat, J. (2021). Test-retest reliability of segment kinetic energy measures in the golf swing. *Sports Biomechanics, 20*(3), 344-359.

Pataky, T. C. (2015). Correlation between maximum in-shoe plantar pressures and clubhead speed in amateur golfers. *Journal of Sports Sciences, 33*(2), 192–197.

Sheehan, W. B., Bower Rg Fau - Watsford, M. L., and Watsford, M. L. Physical Determinants of Golf Swing Performance: A Review. (1533-4287 (Electronic)).

Takagi, T. (2018). Joint motions affecting the energy transfer to the club during the golf swing. *Proceedings of the 36th Conference of the International Society of Biomechanics in Sports, 36*(1), 972-975.

You, X., Xu, Y., Liang, M., Baker, J. S., and Gu, Y. (2023). The Relationship between Ground Reaction Forces, Foot Positions and Type of Clubs Used in Golf: A Systematic Review and Meta-Analysis. *Applied Sciences, 13*(12).

มหาวิทยาลัยเทคโนโลยีสุรนารี

Wells, G. D., Elmi, M., and Thomas, S. (2009). Physiological correlates of golf performance. *The Journal of Strength & Conditioning Research, 23*(3), 741-750.

Worsfold, P., Smith, N. A., and Dyson, R. J. (2009). Kinetic assessment of golf shoe outer sole design features. *Journal of Sports Science & Medicine, 8*(4), 607–615.

Worsfold, P., Smith, N. A., and Dyson, R. J. (2008). Low handicap golfers generate more torque at the shoe-natural grass interface when using a driver. *Journal of Sports Science & Medicine, 7*(3), 408–414.

Zouzias, I. C., Hendra, J., Stodelle, J., and Limpisvasti, O. (2018). Golf injuries: Epidemiology, pathophysiology, and treatment. *JAAOS-Journal of the American Academy of Orthopaedic Surgeons, 26*(4), 116-123.

มหาวิทยาลัยเทคโนโลยีสุรนารี

APPENDICES

มหาวิทยาลัยเทคโนโลยีสุรนารี

APPENDIX A

NORMAL FOOT PRESSURE DURING THE GOLF SWING

Table 1 Normal pressure on the left foot during key moments of the golf swing when using a driver in professional players.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD
GT	5.17	1.56	6.54	1.35	12.03	3.08	6.41	2.05	5.69	2.98
LT	6.05	2.05	5.41	2.06	8.19	3.16	7.08	1.90	5.80	1.52
MEDmet	14.23	6.94	19.98	6.86	23.67	5.87	14.37	10.30	7.30	6.57
CENmet	12.42	3.90	10.88	1.83	11.01	3.42	15.13	5.07	13.67	5.91
LATmet	15.18	3.16	11.63	1.51	11.99	3.97	22.35	5.64	28.14	3.41
MEDarc	12.21	4.13	15.26	4.48	13.24	5.22	6.83	5.47	3.80	4.25
LATarc	14.33	5.30	12.11	5.66	9.61	3.50	15.81	7.06	21.19	6.38
HEEL	20.41	13.18	18.20	10.36	10.26	4.69	12.02	5.49	14.40	5.91

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.

Table 2 Normal pressure on the right foot during key moments of the golf swing when using a driver in professional players.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD
GT	12.05	4.43	11.70	4.30	12.14	4.77	27.29	10.81	32.20	7.74
LT	5.66	1.68	6.81	1.31	7.25	1.74	7.91	4.80	8.08	5.84
MEDmet	15.92	4.56	12.65	3.10	11.70	6.61	31.02	11.22	30.35	10.57
CENmet	11.25	3.80	13.49	3.36	9.49	3.80	4.55	3.40	2.26	3.25
LATmet	12.70	3.46	16.14	2.50	16.90	4.42	5.10	3.48	4.63	3.20
MEDarc	10.34	3.47	7.73	3.49	7.78	4.95	9.17	3.52	9.19	3.69
LATarc	14.16	5.16	15.77	2.94	16.35	4.26	5.02	3.87	2.91	3.28
HEEL	17.93	12.91	15.71	12.10	18.38	13.56	9.95	9.59	10.37	8.59

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.

Table 3 Normal pressure on the left foot during key moments of the golf swing when using a 7-iron in professional players.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD
GT	5.16	2.21	6.55	1.50	9.72	4.10	4.73	1.94	5.14	3.12
LT	5.71	1.68	6.16	1.67	6.26	1.93	5.79	1.77	5.04	1.54
MEDmet	14.13	6.77	17.48	4.45	21.43	9.86	9.08	8.32	6.55	6.26
CENmet	13.19	2.72	14.68	3.41	11.36	3.78	12.74	5.79	10.64	6.07
LATmet	16.93	3.15	16.53	5.93	15.26	8.39	27.77	6.07	30.74	5.35
MEDarc	12.06	4.28	10.61	4.76	11.37	6.00	4.48	5.60	3.36	3.70
LATarc	14.84	4.78	13.87	4.18	12.69	9.36	21.46	8.13	23.20	7.43
HEEL	17.98	10.10	14.11	10.63	11.90	5.55	13.97	5.39	15.32	6.36

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.

Table 4 Normal pressure on the right foot during key moments of the golf swing when using a 7-iron in professional players.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD
GT	12.87	2.67	12.66	7.73	13.89	6.20	28.60	10.89	33.79	8.25
LT	5.61	1.22	7.38	2.20	7.59	2.29	7.08	3.19	6.53	4.76
MEDmet	17.35	2.74	15.69	8.39	10.65	3.37	21.57	10.57	25.42	11.14
CENmet	13.49	2.78	13.90	4.94	10.38	5.83	6.07	5.04	2.35	3.74
LATmet	14.65	3.13	17.01	4.91	18.53	5.07	8.11	5.29	4.98	3.45
MEDarc	10.09	1.99	7.74	2.55	6.85	4.22	8.55	2.32	8.66	3.22
LATarc	14.93	4.40	15.12	6.42	16.14	5.01	8.64	5.83	4.96	4.09
HEEL	11.01	7.28	10.50	6.81	15.98	10.62	11.38	8.87	13.31	11.18

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.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Table 5 Normal pressure on the left foot during key moments of the golf swing when using a driver in high handicap players.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD
GT	7.77	3.17	9.79	6.85	17.05	8.22	16.32	8.93	17.55	11.42
LT	2.57	3.06	2.44	3.86	5.98	7.72	3.95	3.60	4.94	2.86
MEDmet	12.13	4.07	13.39	6.67	19.23	5.57	10.86	6.84	10.09	6.36
CENmet	10.79	6.86	10.46	7.92	9.82	7.26	10.83	7.51	10.96	6.47
LATmet	14.42	6.96	11.89	6.71	11.36	6.44	16.65	6.57	19.68	8.67
MEDarc	10.40	6.89	10.20	8.55	10.65	8.98	7.85	5.78	5.39	5.92
LATarc	13.48	4.16	11.86	10.24	8.81	5.97	13.12	7.31	14.52	7.29
HEEL	28.45	11.40	29.96	17.49	17.11	11.01	20.43	10.86	16.87	8.82

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.

Table 6 Normal pressure on the right foot during key moments of the golf swing when using a driver in high handicap players.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD
GT	11.21	6.92	9.20	6.67	9.36	5.42	19.39	18.57	25.20	22.84
LT	5.54	2.64	5.07	2.37	4.75	3.14	12.85	8.88	11.66	9.68
MEDmet	13.12	5.41	9.38	3.57	9.07	4.81	20.18	8.27	22.92	11.34
CENmet	12.34	6.08	12.02	8.05	12.00	6.96	20.16	11.59	15.89	11.98
LATmet	17.28	6.03	20.24	7.71	23.60	8.01	18.29	11.24	12.36	10.07
MEDarc	4.07	5.47	3.38	4.90	2.26	3.67	2.91	9.15	2.52	9.76
LATarc	12.23	3.96	14.95	4.90	18.29	9.80	2.93	4.29	0.77	2.03
HEEL	24.22	9.73	25.76	13.06	20.67	11.59	3.30	4.62	8.69	25.73

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.

Table 7 Normal pressure on the left foot during key moments of the golf swing when using a 7-iron in high handicap players.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD
GT	8.65	5.12	8.18	7.12	13.63	12.30	10.28	8.94	12.53	7.61
LT	3.95	3.58	3.13	5.22	3.25	3.78	2.72	3.86	4.10	2.77
MEDmet	12.02	3.83	11.52	6.55	16.74	11.90	8.77	6.51	7.19	4.77
CENmet	10.63	9.21	11.00	9.66	9.09	9.18	10.52	10.87	9.22	9.01
LATmet	14.40	5.97	10.45	6.40	9.30	6.63	14.24	11.56	15.60	10.54
MEDarc	10.30	8.07	9.77	9.00	9.62	9.46	7.05	7.68	5.36	6.22
LATarc	13.26	5.57	11.17	12.88	7.65	6.71	12.33	9.30	14.73	11.11
HEEL	26.79	13.32	28.11	18.25	17.40	14.31	20.75	17.94	17.94	10.98

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.

Table 8 Normal pressure on the right foot during key moments of the golf swing when using a 7-iron in high handicap players.

	ST		MB		TB		IM		EF	
AREAS	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD	MEAN (%)	SD
GT	10.09	6.88	7.41	8.27	7.46	5.96	17.62	19.68	23.59	23.73
LT	3.96	3.16	4.00	2.70	4.48	3.27	7.33	7.25	11.96	9.70
MEDmet	13.46	5.83	8.89	3.87	6.39	4.13	15.68	10.62	18.88	12.44
CENmet	12.45	7.70	10.57	8.16	8.69	7.04	15.48	11.10	12.26	11.62
LATmet	16.72	8.36	16.99	7.66	18.31	9.32	17.97	13.26	11.07	10.80
MEDarc	3.99	5.68	3.23	5.87	2.14	3.93	1.26	3.79	0.00	0.00
LATarc	12.98	3.43	15.14	5.29	16.42	8.46	6.71	7.38	1.19	3.29
HEEL	26.36	18.44	27.11	16.60	22.78	15.18	4.63	6.42	7.71	25.69

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.

มหาวิทยาลัยเทคโนโลยีสุรนารี

APPENDIX B

PUBLICATION

Chaemklan, K., Rachnavy, P., Pojprapai, S., & Agrawal, D. K. (2025). Dynamic plantar pressure patterns and their role in optimizing energy transfer during the golf swing. *Annals of Applied Sport Science*. Advance online publication. doi:10.61186/aassjournal.149

มหาวิทยาลัยเทคโนโลยีสุรนารี

10.61186/aassjournal.1496 Video summary on YouTube Infographic summary on LinkedIn

Ann Appl Sport Sci 13(2): e1496, 2025.
e-ISSN: 2322-4479; p-ISSN: 2476-4981

ORIGINAL ARTICLE

Dynamic Plantar Pressure Patterns and Their Role in Optimizing Energy Transfer During the Golf Swing

[1]Khemchat Chaemklan, [2]Pornthep Rachnavy*, [3]Soodkhet Pojprapai, [4]Dipak Kumar Agrawal

[1]Department of Interdisciplinary Science and Internationalization, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima, Thailand.
[2]School of Sports Science, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima, Thailand.
[3]School of Ceramic Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand.
[4]School of Telecommunication Engineering, Faculty of Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand.
***. Corresponding Author: Pornthep Rachnavy; E-mail:** rachnavy@sut.ac.th

Submitted December 14, 2024; Accepted February 17, 2025.

CrossMark

KEYWORDS
Golf Biomechanics,
Foot Pressure Patterns,
Ground Reaction Force,
Smart Insole,
Energy Flow.

ABSTRACT
Background. Transferring energy from the lower extremities to the torso is a crucial mechanism enabling an effective golf swing. However, the optimal plantar pressure distribution that facilitates this energy flow has not been thoroughly investigated. **Objectives.** This study explored the relationship and predictive potential between peak in-shoe plantar pressures at specific locations and the mechanical energy flow to the torso region during the golf swing. **Methods.** Thirty amateur golfers, each with a handicap between 0 and 15, participated in this study. This range represents golfers with moderate skill levels, including highly skilled amateurs (closer to 0) and intermediate players (closer to 15). Plantar pressure distribution was recorded with instrumented insoles, and torso energy flow was measured using a 3D motion analysis system and force plate. Stepwise regression analysis identified pressure locations contributing to energy transfer ($p<0.05$). **Results.** Peak plantar pressures at the right medial metatarsal ($\beta=1.75$, $t=4.31$, $p=0.001$) and left lateral arch ($\beta=1.35$, $t=2.22$, $p=0.048$) were positively linked to trunk energy transfer, while left great toe pressure ($\beta=-20.06$, $t=-4.51$, $p=0.001$) showed a significant negative correlation. The regression model had an R^2 of 0.80. **Conclusion.** The findings suggest optimal plantar pressure supports efficient energy transfer, while pressure in unfavorable locations may hinder swing efficiency.

INTRODUCTION

The golf swing represents one of the most sophisticated and demanding biomechanical movements within the sporting domain (1). An effective golf swing necessitates synchronizing various body parts to produce and transmit kinetic energy to the clubhead, ultimately influencing clubhead speed and ball flight distance. Proper weight transfer, specifically shifting body mass during the swing, is a crucial factor in this process (2). Recent research has highlighted the influence of various factors on golf swing performance, including the role of ground reaction force (3), the interplay of linear and angular momentum (4), and the significance of physical conditioning (5).

Previous research has demonstrated the importance of weight transfer patterns and center of pressure (COP) location concerning clubhead speed (6, 7). Skilled golfers generally exhibit greater COP displacement, characterized by increased weight shift towards the front foot and reduced loading on the rear foot prior to impact (7). Ball and Best (8) identified two distinct swing patterns: "Front Foot," where weight is transferred to the front foot through impact, and "Reverse," where weight shifts back toward the rear foot near impact. These patterns have been further explored in studies examining the impact of different swing styles and club types on COP trajectories (5).

However, these studies primarily focus on overall COP movement, which may not fully capture nuanced variations in pressure distribution across specific areas of the foot. Plantar pressure distribution has been suggested as a valuable measure to provide more detailed insights into localized pressure patterns during the swing, potentially influencing energy generation and transfer. Pataky (9) found a positive correlation between clubhead speed and pressure on the lateral side of the leading foot, suggesting that weight transfer location, not just the amount of transfer, may be a critical factor. Similarly, Worsfold et al. (10) supported that plantar pressure distribution can influence clubhead speed. The role of plantar pressure distribution in golf swing biomechanics has been further investigated in a recent study (11), which utilized the Hilbert-Huang transform to analyze golf swing motion and identify movements associated with different ball trajectories.

Despite some research examining plantar pressure distribution, most studies have emphasized static measurements and lack in-depth analysis of dynamic mechanical energy flow within the body. Recent studies have highlighted the importance of examining segment kinetic energy to explore sequential movements and ground reaction forces in enhancing swing technique and performance (12, 13). For instance, Outram and Wheat (12) investigated the reliability of segment kinetic energy measures in the golf swing. Belotti et al. (13) explored the impact of foot proprioception training on ground reaction forces and swing performance. These studies underscore the need for a more comprehensive understanding of how plantar pressure dynamics contribute to energy transfer and overall swing efficiency. Understanding how foot loading patterns influence energy flow through different body segments, particularly the trunk, which serves as a conduit for energy transfer from the lower to the upper body, remains a key area requiring further investigation. This study addresses this gap by investigating the correlation between dynamic plantar pressure distribution and energy transfer in the golf swing, utilizing a comprehensive approach that incorporates kinetic and kinematic analyses.

This study investigates the correlation between plantar pressure distribution and mechanical energy flow in the trunk during the golf swing. By analyzing data at a localized level within the foot, this research seeks to understand the role of specific plantar pressure patterns in facilitating energy transfer from the lower body to the trunk, focusing on a cohort of 30 golfers with handicaps ranging from 0 to 15. Unlike previous studies that primarily focused on the overall center of pressure movement, this study provides a more nuanced understanding of swing mechanics by examining localized plantar pressure patterns and their dynamic relationship with energy transfer. The findings will contribute to a deeper understanding of swing mechanics and energy transfer in golfers of varying skill levels.

MATERIALS AND METHODS

Participants. A priori power analysis using G*Power software was conducted to determine the appropriate sample size for this multiple linear regression study. The analysis aimed for a power of 0.80 with an alpha error probability of 0.05, using an effect size (R square) of 0.60 based on similar previous research (9). This analysis indicated a minimum required sample size of 23 participants.

This study (EC-67-152) received ethical approval from the Suranaree University of Technology, and all participants gave informed consent before participating. Participants wore their appropriate athletic attire and used their clubs for our measurements. Thirty golfers with handicaps ranging from 0 to 15 participated in the study, comprising 15 male and 15 female golfers. Hand dominance was determined by asking each participant which hand they used for golfing. This study had specific inclusion and exclusion criteria. Participants were considered for inclusion in this study if they had a handicap ranging from 0 to 15, had no history of lower extremity or spine musculoskeletal injuries in the past 6 months, and were right-hand dominant. Participants were excluded from this study if they had a history of lower extremity or spine musculoskeletal injuries in the past 6 months or were left-hand dominant. The individual characteristics of the participants are summarized in Table 1, which outlines the descriptive statistics for key participant characteristics, comprising the demographic attributes of age, weight, height, and body mass index (BMI).

Table 1. Statistical Description of Individual characteristics.

Variables	M ± SD
Age (years)	24.20 ± 4.74
Weight (kg)	75.80 ± 20.00
Height (cm)	170.60 ± 5.41
BMI (kg/m^2)	25.83 ± 5.96

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

Data Collection. All participants wore appropriate sports attire and used their familiar driver golf clubs during the plantar pressure and energy transfer measurements. The analysis focused on the period surrounding ball impact. Participants were equipped with 42 reflective markers placed on anatomical landmarks of the body and the club. The markers were placed according to the Qualisys Sports Marker Set (14). Body and club movement during the golf swing was captured using six motion capture cameras (Oqus 7+ series, Qualisys AB, Sweden) at a sampling rate of 200 Hz. Ground reaction forces were measured for each foot using two force platforms (Kistler 9286BA, Kistler Group, Switzerland) at 1500 Hz. Plantar pressure distribution was recorded using insole sensors (Surasole Pro 8, Suratec Co., Ltd., Nakhon Ratchasima, Thailand). The insoles contained eight resistive sensors embedded within each insole, strategically positioned to capture pressure variations across the foot. Data collected during the trials was segmented into eight-foot areas, as shown in Figure 1. These sensors interfaced with a microcontroller via a voltage divider circuit, with the output connected to a 10-bit analog-to-digital converter. The circuit was calibrated for each sensor to operate within a full-scale force range (0-20 kg) and had a response time of less than 10 microseconds, sampled at 20 Hz.

The researchers utilized Visual3D software (C-Motion, Germantown, MD) to compute joint forces and moments, employing a comprehensive full-body model comprising 14 segments and 26 degrees of freedom. Segmental power analysis for the trunk segment was employed to quantify the energy flow (15). Joint force power (JFP), segment torque power (STP), and segment power (SP) were calculated as follows:

$$JFP = (F_j) \cdot (V_j)$$

$$STP = (T_j) \cdot (\omega_s)$$

$$SP = JFP_d + JFP_p + STP_d + STP_p$$

Where F_j is the joint reaction force, V_j is linear joint velocity, T_j is the joint moment, and ω_s is segment angular velocity. To assess energy transfer, the rate of energy flow out of or into a body segment (SP) is the combination of joint force power (JFP) and segment torque power (STP), with d and p referring to the distal and proximal joints of the segment, respectively (16-19).

Following equipment setup, participants completed a 10-minute warm-up to acclimate to the equipment. All measurements were performed by the same researcher throughout the study to ensure consistency in data collection. This individual was responsible for fitting participants with instrumented insoles, calibrating the motion capture system, and supervising data collection. Each participant's golf swing was assessed using standardized biomechanical protocols to ensure accuracy and reliability in measurement. During data collection, participants performed five golf swings, replicating competitive conditions for each swing. A one-minute rest period was provided between swings. Upon completion of testing, participants engaged in a 10-minute cool-down involving stretching exercises.

Statistical Analysis. Data from the five recorded swings of each participant were analyzed using stepwise multiple linear regression to identify significant predictors of total energy flow at the lumbosacral joint (L5S1). This method sequentially adds independent variables to the regression equation based on their correlation with the dependent variable. The significance of each variable in the equation is continuously evaluated, and non-significant variables are removed. Before analysis, the assumptions of linear regression were assessed, including data independence, normality of residuals, linearity of the relationship, and homoscedasticity. All statistical analyses were performed using SPSS 26.0 software (IBM Corporation, Somers, NY, USA).

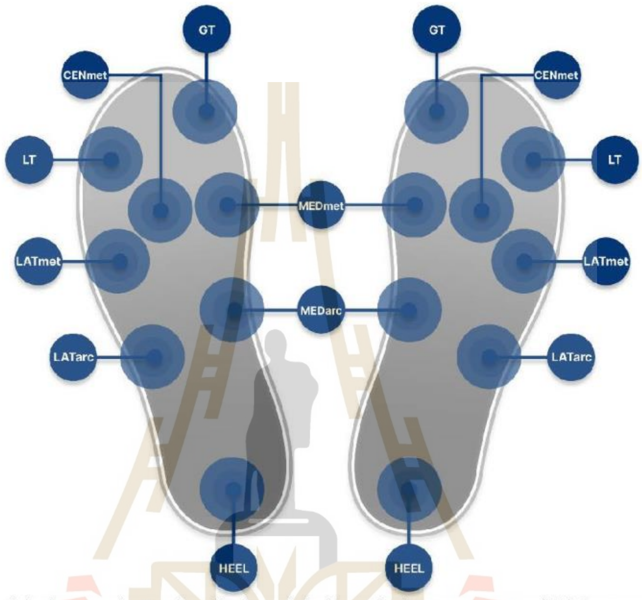

Figure 1. The eight plantar regions analyzed in the statistical investigation were: great toe (GT), lesser toe (LT), medial metatarsal (MEDmet), central metatarsal (CENmet), lateral metatarsal (LATmet), medial arc (MEDarc), lateral arc (LATarc), heel (HEEL).

RESULTS

Examination of the peak in-shoe plantar pressure patterns observed during the impact phase of the golf swing demonstrated distinct distributions across the eight defined sensor regions on each foot. Locations significantly correlated with energy flow are highlighted by a star symbol to indicate their predictive influence, as shown in Figure 1. The analysis revealed peak plantar pressures at the right foot's medial metatarsal (85.19 ± 49.52 kPa) and the lateral arch of the left foot (50.07 ± 32.93 kPa). Notably, the left great toe region exhibited significantly lower pressure than the other areas (Table 2).

Energy transfer at the lumbosacral joint (L5S1) reaches its peak during the downswing to impact transition, as illustrated in Figure 2. This peak signifies the effective transfer of energy from the lower body to the trunk, facilitated by optimal plantar pressure distribution between both feet. Conversely, imbalances or improper plantar pressure distribution can negatively impact energy transfer. As shown in Figure 3, pressure patterns that deviate from efficient movement mechanics may diminish the energy transferred to the trunk, hindering the generation of a smooth and powerful swing.

Table 2. Mean and standard deviation of plantar pressure for eight areas on each foot during ball impact.

Areas	Left foot (kPa)	Right foot (kPa)
	M ± SD	M ± SD
Great Toe (GT)	17.56 ± 4.35	70.57 ± 32.21
Lesser toe (LT)	19.36 ± 2.73	21.08 ± 13.38
Medial Metatarsal (MEDmet)	36.49 ± 22.67	85.19 ± 49.52
Central metatarsal (CENmet)	41.89 ± 11.58	12.59 ± 9.65
Lateral Metatarsal (LATmet)	65.61 ± 22.74	13.96 ± 8.94
Medial Arc (MEDarc)	22.64 ± 23.03	22.89 ± 12.21
Lateral Arc (LATarc)	50.07 ± 32.93	13.16 ± 9.18
Heel (HEEL)	36.09 ± 21.84	19.44 ± 10.55

M: Mean; SD: Standard Deviation.

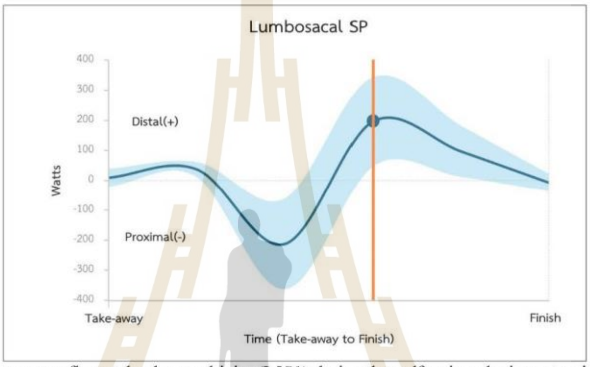

Figure 2. Average energy flow at lumbosacral joint (L5S1) during the golf swing, the impact point indicated by an orange vertical line to highlight this critical moment.

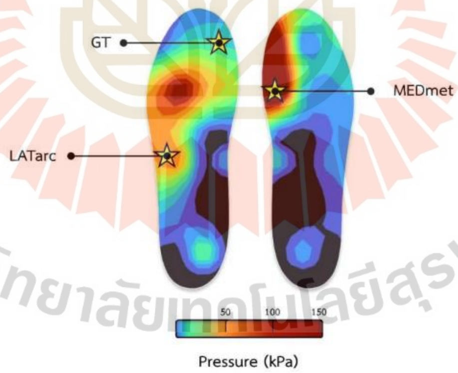

Figure 3. Average maximum plantar pressure distribution across different foot areas during the golf swing at ball impact.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Analysis of the relationship between plantar pressure and mechanical energy transfer at the lumbosacral joint (L5S1) using stepwise multiple linear regression revealed that pressure in the medial metatarsal of the right foot (β = 1.75, t = 4.31, p = 0.001) and the lateral arch of the left foot (β = 1.35, t = 2.22, p = 0.048) was positively associated with energy transfer, while pressure in the left great toe region (β = -20.06, t = -4.51, p = 0.001) was negatively associated. The model had a coefficient of determination (R^2 = 0.799), indicating that these variables accounted for 79.9% of the variance in energy transfer (Table 3).

Table 3. Relationship and predictive ability of the segmental power (SP) at the lumbosacral joint (L5S1) during ball impact.

Variable		Beta Coefficient	t-value	p-value
Constant		331.68	3.41	0.006†
Left foot	GT	-20.06	-4.51	0.001†
Left foot	LATarc	1.35	2.22	0.048*
Right foot	MEDmet	1.75	4.31	0.001†
R^2			0.80	

R^2: Coefficient of Determination; *: Significant at $p<0.05$; †: Significant at $p<0.01$.

DISCUSSION

This study examined the relationship between the peak plantar pressures measured within the shoes and mechanical energy flow in the trunk during the golf swing in 30 golfers with handicaps ranging from 0 to 15. The findings highlight the significant role of plantar pressure distribution in supporting energy transfer, aligning with biomechanical principles that suggest optimal pressure distribution enhances efficient movement (1, 20).

The study's results revealed that appropriate plantar pressure distribution plays a crucial role in supporting energy transfer from the lower body to the trunk, especially during key stages of the golf swing, such as the impact event. This process aligns with the concept of kinetic linking, which underscores the sequential energy transfer through body segments (21). These findings are consistent with previous studies by Ball and Best (2, 6, 8), which demonstrated that proper movement of the center of pressure (COP) enhances torque and driving forces necessary for generating clubhead speed. Additionally, recent research (22) has explored the influence of uphill and downhill slopes on COP movement and shot outcomes, further emphasizing the importance of COP control in dynamic swing conditions.

Conversely, imbalanced pressure distribution, such as excessive pressure in certain regions, may reduce energy transfer efficiency. This inefficiency can result from mechanical compensations, such as diminished torque at the hip or lumbosacral joints (1, 9). This study also supports the findings of Bradshaw et al. (23), who noted that golfers with abnormal plantar pressure patterns often experience difficulties in controlling movement consistency and maintaining swing efficiency. Furthermore, a recent study (24) investigated the relationship between skill and ground reaction force variability in amateur golfers, highlighting the impact of inconsistent plantar pressure patterns on overall swing variability.

This research underscores the importance of plantar pressure distribution in energy transfer during the golf swing. Proper pressure distribution enhances movement efficiency and significantly reduces the risk of injury, particularly in the lower back, a common issue among golfers (25, 26). This finding provides a reassuring insight into the potential for injury prevention in the sport. Recent research has also explored the role of various factors in golf-related injuries, including swing biomechanics and physical conditioning (5, 25).

Moreover, these findings can inform the development of golf-specific footwear and assistive devices that optimize plantar pressure distribution. As sports scientists, golf coaches, and footwear designers, your role in applying these findings to design insoles that enhance pressure distribution or implement training routines focusing on proper weight transfer is crucial. This application could significantly improve swing efficiency and mitigate injury risks for golfers.

This study investigated the relationship between plantar pressure and energy transfer in golfers with handicaps of 0-15 (15 male, 15 female) using the Modern swing. While this study design allows for a focused analysis, it also presents certain limitations. Our findings' generalizability may be limited as the sample does not encompass golfers with higher handicaps, different swing styles, or diverse physical characteristics. Future research could include a broader array of golfers to enhance the universality and comparability of the findings. Additionally, this study did not explicitly examine the influence of individual differences in foot morphology, which can affect plantar pressure patterns and energy transfer. Further research is needed to explore how variations in foot morphology impact these variables.

CONCLUSION

This investigation contributes to a more profound comprehension of the underlying mechanisms governing energy transfer during the golf swing by emphasizing the pivotal role of plantar pressure distribution in enabling balanced and efficient movement patterns. The findings offer valuable applications for research, sports equipment development, and training strategies to improve performance and reduce injury risks for golfers across all skill levels. Specifically, these findings can inform the design of future longitudinal studies investigating the long-term effects of plantar pressure training on swing performance and injury prevention. Furthermore, the results can guide the development of targeted interventions, such as personalized footwear or orthotics, to optimize plantar pressure distribution and enhance energy transfer during the golf swing.

APPLICABLE REMARKS

- Integrating plantar pressure assessment and energy transfer evaluation can provide insights into how pressure distribution influences the energy transfer through the kinetic chain during the golf swing.
- Golf footwear design should incorporate findings on optimal plantar pressure zones to enhance stability and efficiency while mitigating injury risks.
- Training programs should focus on balancing plantar pressure during key swing phases to improve kinetic chain efficiency and swing consistency.

ACKNOWLEDGMENTS

The authors would likely like to thank all participants for their voluntary efforts in this research.

AUTHORS' CONTRIBUTIONS

Study concept and design: Khemchat Chaemklan, Pornthep Rachnavy. Acquisition of data: Khemchat Chaemklan. Analysis and interpretation of data: Khemchat Chaemklan. Drafting of the manuscript: Khemchat Chaemklan, Dipak Kumar Agrawal. Critical manuscript revision for important intellectual content: Khemchat Chaemklan, Pornthep Rachnavy, Dipak Kumar Agrawal. Statistical analysis: Khemchat Chaemklan. Administrative, technical, and material support: Pornthep Rachnavy, Soodkhet Pojprapai. Study supervision: Khemchat Chaemklan, Pornthep Rachnavy, Soodkhet Pojprapai.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

FINANCIAL DISCLOSURE

The authors have no financial interests related to the materials in the manuscript.

FUNDING/SUPPORT

This research was made possible by funding from Suranaree University of Technology (SUT), Thailand. The authors also received support from external grants and scholarships, including the One Research One Grant (OROG) program.

ETHICAL CONSIDERATION

This study was approved by the Human Research Ethics Committee of the Suranaree University of Technology (Project code: EC-67-152). Informed consent was obtained from all participants involved in this study.

ROLE OF THE SPONSOR

The funding organizations are public institutions and have no role in the study design, data collection, data analysis, interpretation of results, manuscript preparation, or decision to submit the article for publication.

ARTIFICIAL INTELLIGENCE (AI) USE

Artificial intelligence tools were not utilized in this manuscript's conceptualization, data analysis, or writing, except for general-purpose language models used for proofreading or editing assistance, where applicable.

REFERENCES

1. Nesbit S, Serrano M. Work and Power Analysis of the Golf Swing. Journal of sports science & medicine. 2005; 4:520-33.
2. Ball K, Best R. Centre of pressure patterns in the golf swing: individual-based analysis. Sports Biomech. 2012; 11(2):175-89. [doi:10.1080/14763141.2012.673007] [PMid:22900399]
3. You X, Xu Y, Liang M, Baker JS, Gu Y. The Relationship between Ground Reaction Forces, Foot Positions and Type of Clubs Used in Golf: A Systematic Review and Meta-Analysis. Applied Sciences. 2023; 13(12). [doi:10.3390/app13127209]
4. MacKenzie S, McCourt M, Champoux L. How amateur golfers deliver energy to the driver. International Journal of Golf Science. 2020; 8(1).
5. Sheehan WB, Bower RG, Watsford ML. Physical determinants of golf swing performance: A review. J Strength Cond Res. 2022; 36(1):289-97. [doi:10.1519/JSC.0000000000003411] [PMid:31868818]
6. Smith AC, Roberts JR, Kong PW, Forrester SE. Comparison of centre of gravity and centre of pressure patterns in the golf swing. European Journal of Sport Science. 2017; 17:168–78. [doi:10.1080/17461391.2016.1240238] [PMid:27737623]
7. Chu Y, Sell T, Lephart S. The relationship between biomechanical variables and driving performance during the golf swing. Journal of sports sciences. 2010; 28:1251-9. [doi:10.1080/02640414.2010.507249] [PMid:20845215]
8. Ball K, Best R. Different centre of pressure patterns within the golf stroke I: Cluster analysis. Journal of sports sciences. 2007; 25:757-70. [doi:10.1080/02640410600874971]
9. Pataky TC. Correlation between maximum in-shoe plantar pressures and clubhead speed in amateur golfers. Journal of Sports Sciences. 2015;33(2):192-7. [doi:10.1080/02640414.2014.932917] [PMid:25010946]
10. Worsfold P, Smith NA, Dyson RJ. Kinetic assessment of golf shoe outer sole design features. J Sports Sci Med. 2009;8(4):607-15.
11. Dong R, Ikuno S. Biomechanical Analysis of Golf Swing Motion Using Hilbert–Huang Transform. Sensors. 2023; 23(15). [doi:10.3390/s23156698] [PMid:37571482]
12. Outram T, Wheat J. Test-retest reliability of segment kinetic energy measures in the golf swing. Sports Biomechanics. 2021; 20(3):344-59. [doi:10.1080/14763141.2018.1553244] [PMid:30707089]
13. Belotti A, Bisazza N, Calcari A, Perrone P, Biscarini A. The Ground-X-Factor: Training the Proprioceptive and Propulsive Function of the Foot for Improved Technique and Enhanced Performance of the Golf Swing. 2024. [doi:10.20944/preprints202411.2224.v1]
14. Van Sint Jan S. Color Atlas of Skeletal Landmark Definitions: Guidelines for Reproducible Manual and Virtual Palpations: Churchill Livingstone/Elsevier. 2007.
15. Sado N, Yoshioka S, Fukashiro S. Mechanical power flow from trunk and lower limb joint power to external horizontal power in the track and field block start. European Journal of Sport Science. 2022;1–18. [doi:10.1080/17461391.2022.2109067] [PMid:35913105]
16. Lertwonghattakul T, Sriramatr S, Rachnavy P. Analysis of Kinetic Chain Mechanism Affecting Energy Flow in Kick Topspin Tennis Serve in Elite and Amateur Tennis Players. Ann-Appl-Sport-Sci. 2023;11(2):0-. [doi:10.52547/aassjournal.1133]
17. Suzuki Y, Kobayashi Y, Takizawa M. Effects of Joint Moments on Horizontal and Vertical Velocities of Body Mass Center during Jumping in Different Directions. International Journal of Sport and Health Science. 2018; 16:41-9. [doi:10.5432/ijshs.201628]
18. A. WD. Biomechanics and Motor control of Human Movement. 4th ed. Hoboken, N.J: John Wiley & Sons; 2009.
19. Arata K, Yoshioka S, Fukashiro S. Contribution of Hip Joint Kinetics to Rotate the Pelvis during Baseball Pitching. International Journal of Sport and Health Science. 2020;18. [doi:10.5432/ijshs.201920]

20.Putnam CA. Sequential motions of body segments in striking and throwing skills: Descriptions and explanations. Journal of Biomechanics. 1993; 26:125-35. [doi:10.1016/0021-9290(93)90084-R] [PMid:8505347]

21.Kenny IC, McCloy AJ, Wallace ES, Otto SR. Segmental sequencing of kinetic energy in a computer-simulated golf swing. Sports Engineering. 2008;11(1):37-45. [doi:10.1007/s12283-008-0005-0]

22.Hiley MJ, Bajwa Z, Liang Y, Blenkinsop GM. The effect of uphill and downhill slopes on centre of pressure movement, alignment and shot outcome in mid-handicap golfers. Sports Biomechanics. 2021;20(7):781-97. [doi:10.1080/14763141.2019.1601250] [PMid:31070109]

23.Bradshaw E, Keogh J, Hume P, Maulder P, Nortje J, Marnewick M. The Effect of Biological Movement Variability on the Performance of the Golf Swing in High- and Low-Handicapped Players. Research quarterly for exercise and sport. 2009;80:185-96. [doi:10.1080/02701367.2009.10599552] [PMid:19650383]

24.Jones KM, Wallace ES, Otto SR. The relationship between skill and ground reaction force variability in amateur golfers. Sports Biomechanics. 2024;23(10):1625-39. [doi:10.1080/14763141.2021.1965649] [PMid:34455916]

25.Quinn SL, Olivier B, McKinon W. Lower Quadrant Swing Biomechanics Identifies Golfers With Increased Risk of Low Back Pain: A Prospective Longitudinal Cohort Study. Journal of Sport Rehabilitation. 2022;31:1–11. [doi:10.1123/jsr.2021-0191] [PMid:35894899]

26.Edwards N, Dickin C, Wang H. Low back pain and golf: A review of biomechanical risk factors. Sports medicine and health science. 2020 Mar 1;2(1):10-8. [doi:10.1016/j.smhs.2020.03.002] [PMid:35783335]

มหาวิทยาลัยเทคโนโลยีสุรนารี

CURRICULUM VITAE

Name: Khemchat Chaemklan

Date of Birth: 30 October 1998

Place of Birth: Nakhonsawan, Thailand

Education:

2022-present

M.Sc. in Department of Interdisciplinary Science and Internationalization (Currently Studying), Institute of Science, Suranaree University of Technology

2017-2021

B.Sc. in Sports Science, Institute of Science, Suranaree University of Technology

มหาวิทยาลัยเทคโนโลยีสุรนารี