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 $\mathbf{F_{total}} = \mathbf{ma}$ 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.

$\mathrm{GRF_x}$ $\mathrm{GRF_y}$ and $\mathrm{GRF_z}$ are the ground reaction forces at the foot in the X, Y, and Z axes, respectively.

$\mathrm{A_x}$ $\mathrm{A_y}$ and $\mathrm{A_z}$ 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.

$\mathrm{K_x}$ $\mathrm{K_y}$ and $\mathrm{K_z}$ 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.

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

$\mathrm{a_{Sx}}$ $\mathrm{a_{Sy}}$ and $\mathrm{a_{Sz}}$ 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.

$\mathrm{M_F}$ and $\mathrm{M_S}$ 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:

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

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:

$$\mathrm{STP} = (T_j) \bullet (\theta_S)$$

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:

$$\mathrm{JTP} = (\mathrm{Tj}) \bullet (\theta\mathrm{d} - \theta\mathrm{p})$$
$$= (\mathrm{Tj}) \bullet (\alpha)$$

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:

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

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.