KINEMATICS AND KINETICS ASSESMENT OF LOWER LIMB MOVEMENT IN BHARATANATYAM DANCERS

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FACULTY OF ENGINEERING
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RESEARCH REPORT SUBMITTED TO THE FACULTY OF ENGINEERING UNIVERSITY OF MALAYA, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF BIOMEDICAL ENGINEERING

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KINEMATICS AND KINETICS ASSESMENT OF LOWER LIMB MOVEMENT IN BHARATANATYAM DANCERS

ABSTRACT

Bharatanatyam is one of the eight recognised classical Indian dance genres which is originated from South India. The major difference between Bharatanatyam and other dance form is the wearing of dancing bells at both ankles. Our literature findings support that the bells add stress to the dancer’s feet which overloads the connective tissues of legs and lead to overextension, tendon strain and other connective tissue injuries. The aim of this study is to conduct kinematics and kinetics assessment of lower limb movement in Bharatanatyam dancers. As walking is one of the most common and most important forms of human movement, our study is based on walking gait. Six young adults (three dancers and three non-dancers) recruited to participate on this study. Each subject was instructed to perform five trials of the gait at self-initiated walking speed on six meters of walking platform with bare foot and another five trials with dancing bells attached to both ankles. Results showed that wearing dancing bells seems to impact dancer's ground reaction force by producing high vertical ground reaction peak at maximum loading response (double support phase) and low anterior-posterior force peak at minimum mid-stand phase. Besides that, wearing dancing bells observed to impact our control group kinematics data as we found angular increase/reduction, especially on the frontal plane which involves abduction/adduction especially on ankle and knee. The findings suggest the intense dancing activities and wearing dancing bells have the capacity to change the walking pattern of an individual.

Keywords: Bharatanatyam, Dancing Bells, Walking, Vertical Ground Reaction Force.

PENILAIAN PERGERAKAN KINETIK DAN KINEMATIK BAHAGIAN BAWAH BADAN PENARI BHARATANATYM

ABSTRAK

Bharatanatyam adalah salah satu daripada lapan genre tarian klasik India yang diiktiraf yang berasal dari India Selatan. Perbezaan utama antara Bharatanatyam dan bentuk tarian lain adalah pemakaian loceng tarian di kedua pergelangan kaki. Penemuan kesusasteraan kami menyokong bahawa loceng tarian menambah tekanan pada kaki penari yang dan menyebabkan ketegangan tendon dan kecederaan tisu penghubung yang lain. Tujuan kajian ini adalah untuk mengendalikan penilaian kinematik dan kinetik bahagian bawah badan penari Bharatanatyam. Berjalan adalah salah satu bentuk pergerakan manusia yang sangat penting. Kajian kami berdasarkan pada aktiviti kaki. Enam subjek dewasa (tiga penari Bharatanatyam dan tiga orang bukan penari) dilantik untuk mengambil bahagian dalam kajian ini. Setiap subjek diarahkan berjalan lima kali di atas platform yang berpanjangan enam meter dengan tidak memakai kasut dan lima percubaan seterusnya dengan memakai lonceng tarian pada kedua-dua pergelangan kaki. Keputusan menunjukkan bahawa memakai loceng menari memberi kesan kepada daya tindak balas tanah penari dengan menghasilkan puncak tindak balas tinggi menegak pada tindak balas muatan maksimum (fasa sokongan berganda) dan puncak kekuatan anterior-posterior rendah pada fasa pertengahan minima. Di samping itu, pemakaian loceng tarian diperhatikan untuk memberi kesan kepada data sudut kinematik golongan bukan penari kerana kami mendapati peratusan peningkatan / pengurangan yang sangat tinggi terutamanya pada pergelangan kaki dan lutut. Penemuan ini mencadangkan aktiviti menari yang lasak dan pemakainan loceng tarian mempunyai keupayaan untuk mengubah pola berjalan seorang individu.

Kata kunci: Bharatanatyam, Loceng Tarian, Berjalan, Daya Tindak Balas Tanah

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LIST OF SYMBOLS AND ABBREVIATIONS

IADMS	International Association for Dance Medicine and Science
w DB	Wearing Dancing Bells
w/o DB	Without Wearing Dancing Bells
pB	professional Bharatanatyam
SP	Sagittal Plane
FP	Frontal Plane
TP	Transverse Plane
GRF	Ground Reaction Force
HS	Heel Strike
FF	Flat Foot
MS	Midstance
HO	Heel Off
TO	Toe Off
FP	Force Plate
VGRF	Vertical Ground Reaction Force
BW	Body Weight
COG	Centre of Gravity

CHAPTER 1: INTRODUCTION

Bharatanatyam is one of the eight recognised classical Indian dance genres which is originated from South India. The word Bharatanatyam composed of two syllable which are 'Bharata' and 'Natyam'. The word 'Bharata' is derived from three syllables; Bhava (expression, emotion or state of mind), Raaga (Music) and Tala (Rhythm). The second syllable 'Natyam' derived from 'Rasa' and 'Abinayam'. 'Rasa' is the result of aesthetics flavours from Bhava known for creation of temporary state of mind or feeling. According to Natya Sastra, the Sanskrit text on the Indian performing arts authored sage Bharata Muni (500 BCE), there are nine ‘Rasa’ widely known as ‘Navarasa’. These are temporary changes of a human’s state of mind according to conditions.

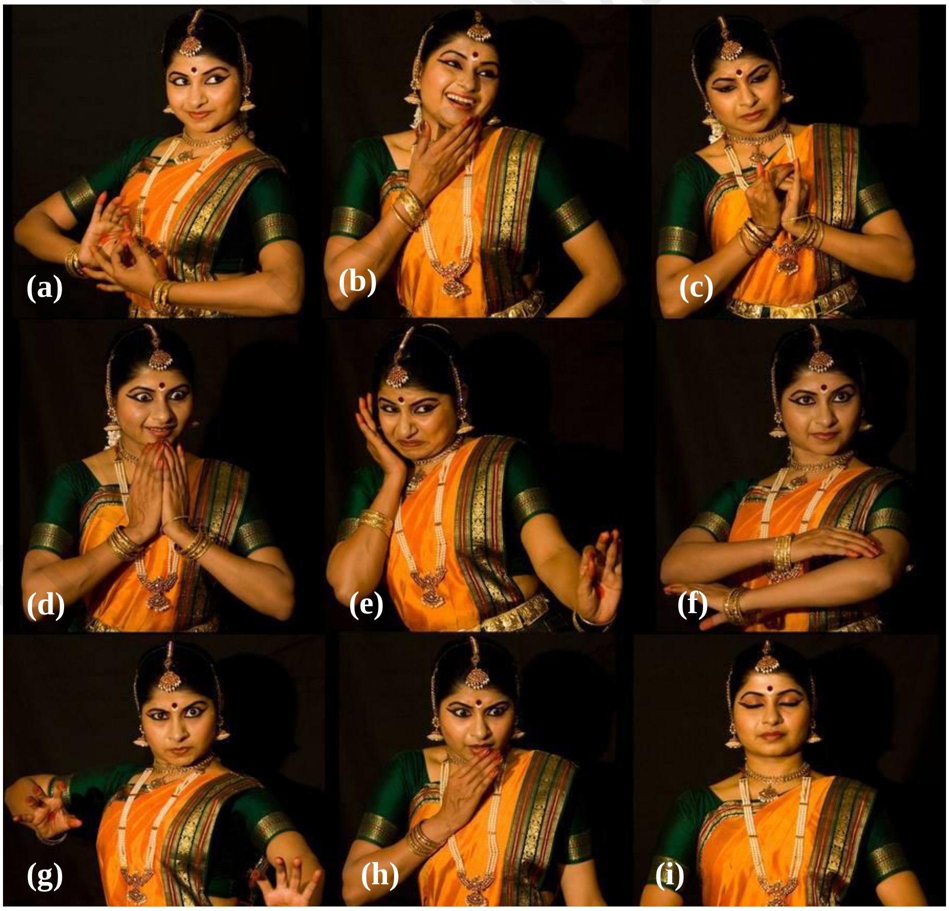


Figure 1.1: The Nine Navarasas of facial expressions reproduced from – Reproduced from Pinterest (Bhat Vasudev, 2017)

The short description of each Navarasas are included in the table below (Bhavanani 2014);

Table 1.1: The short description of each Navarasas

Figure	**Navarasa Name**	**Short Description**
(a)	Shringara	Erotic Love
(b)	Haasya	Humour and Laughter
(c)	Karuna	Compassion
(d)	Adbhuta	Wonder-awe
(e)	Bibhatsa	Disgust
(f)	Veera	Heroism
(g)	Raudra	Anger
(h)	Bhayanak	Fearful Terror
(i)	Shanta	Peacefulness

'Abinayam' on the other hand is the narrative component of this choreatic form, provides dancers with codified series of bodily attitudes and gestures through which they become any character of their narrations (Azzarelli 2014). There are four components of Abhinaya (Rachana);

- Angika: Represents body parts which performs physical actions by moving hand (Hasta), neck (Greeva Bheda), eyes (Dristhi Bheda), head (Shiro Bheda) and lower limbs (Paada Bheda)

- Vacika: Expression through speech, song, intonation to evoke various sentiments in the audience

- Anharya: Use of specific costumes and make-up

• Sattvika: This is the most important of the four representations. The dancer feels the role and the emotion that he is to convey. This emotion is the bhava which has to be expressed in such a way so as to convey the rasa (taste or flavour) to the spectator (Rachana).

Our study is based on the first component, Angika. This abhinaya uses the artistic gestures to rule and regulate the actors bearing, walk and movements of features and limbs (Ghosh 2002).

'Paada Bheda' are one of the most essential elements of Angika which elaborates foot positioning in Bharatanatyam. According to Natya Sastra (Ghosh 2002), there are six basic position of foots available as below;

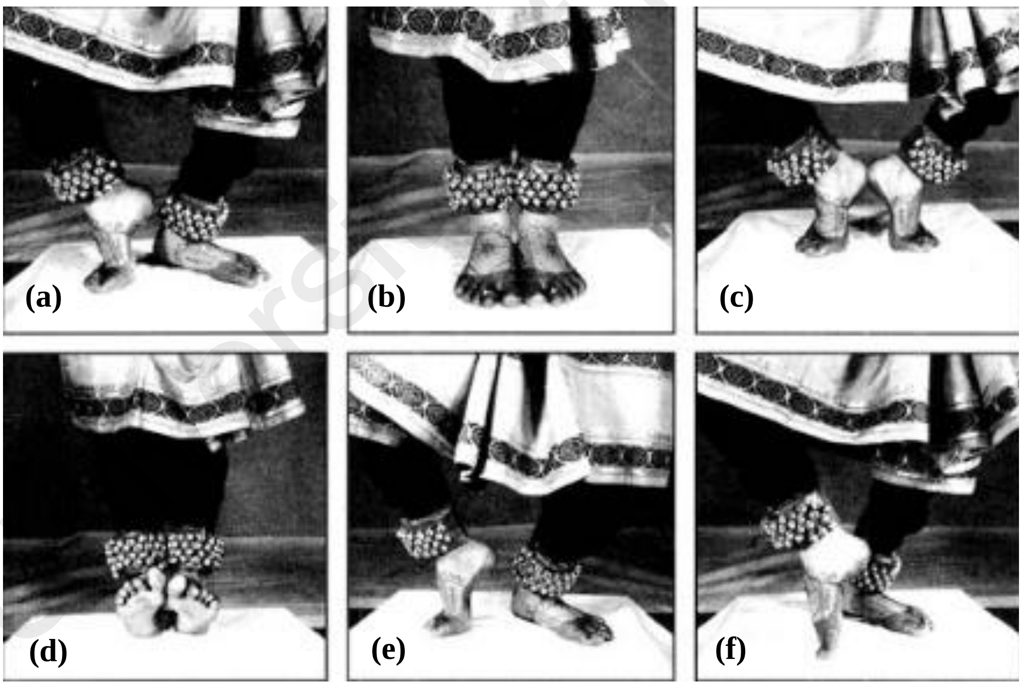


Figure 1.2: The Paada Bheda – Reproduced from Gateway to Koochipoodi (Munukuntla Sambasiva, 1996)

Each Paada Bheda names are included in the table on the next page;

Table 1.2: The Paada Bheda Names – Reproduced from Gateway to Koochipoodi (Munukuntla Sambasiva, 1996)

Figure	Paada Bheda
(a)	Udghatitta Paada
(b)	Sama Paada
(c)	Agratalasanchara Paada
(d)	Anchita Pada
(e)	Kunchitha Paada
(f)	Soochi Paada

Until the early 1930s, the dance form was referred as 'Sadir Nac' or 'Dasi Attam'. The ancient temple dancers known as 'Devadasi' performed the dance form as an offering to the Hindu Gods at the temples of Tanjavur, a district lying to the south of the modern city of Madras (Puri 2004). Besides worships, the art form performed during wedding ceremonies and the King's court. A typical Bharatanatyam recital performed barefoot on flat floor, which lasts for two hours (Puri 2004).

Figure 1.3: A devadasi performing with musicians – Reproduced from The News Minutes (Swarnamalya Ganesh, 2016)

Basis of classical Hinduism revolves around four collections of scripture called as Vedas. They are Rig-Veda, the Yajur-Veda, the Sama-Veda and the Atharva-Veda. According to Bhavanani from her publication on Bharatanatyam and Yoga in 2001, Lord Brahma, the Hindu God of Creations (author of all four Vedas) formed the art form of dance upon the request of Gods from 'Indra Loogam' (Heaven) as a form of entertainment and produced the fifth Veda called Natya Veda. Brahma entered a half-conscious state of mind to recall all four Vedas in order to form Natya Veda. The Lord drew literature from Rig Veda, music from Sama Veda, Abinayam from Yajur Veda and Rasa from Atharva Veda. The lord then passed Natya Veda to his son sage Bharata who descended to his 100 sons to be shared to devotees at earth. Lord Shiva, known as the God of Destroyer took up 'Tandava', the masculine form of movements while Goddess Parvathi his consort took up Lasya, the feminine form. Bharata held first dance with his sons at the Himalayas. Lord Shiva was captivated that he sent his adherent Tandu to Bharata to learn the elements of dance (BHAVANANI and BHAVANANI 2001).

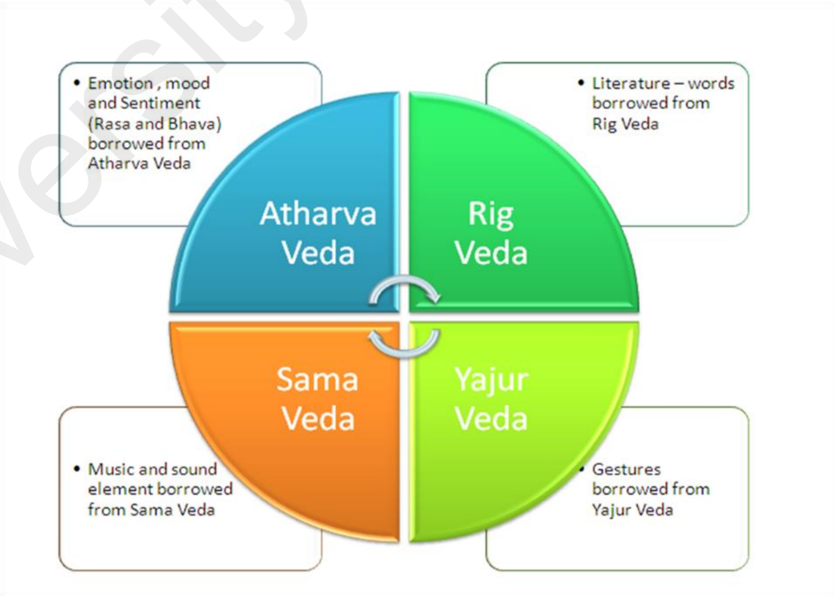


Figure 1.4: Illustration of how four Vedas used to form the fifth Veda; Natya Veda- Reproduced from Blogspot (Vidya Pillai, 2019)

At the functional level, Bharatanatyam has three components;

Table 1.3: Three components of Bharatanatyam

Component	Description
Nritta	Abstract dance movements with rhythm, but without expression of a theme or emotion known as pure dance or Jatis
Nritya	Interpretive dance, using facial expression, hand gestures and body movements to portray emotions and express themes
Natya	The dramatic aspect of stage performance, including spoken dialogue and mime to convey meaning and enact narrative

Bharatanatyam utilizes the strength of a dancer's lower limbs to perform real-time movements from basic postures during $t=0$ till the end of performance. The first basic lower limb posture is Samapadam (leg's together), where a dancer stands still with toes slightly facing sideways. Hands positioned at hip level.

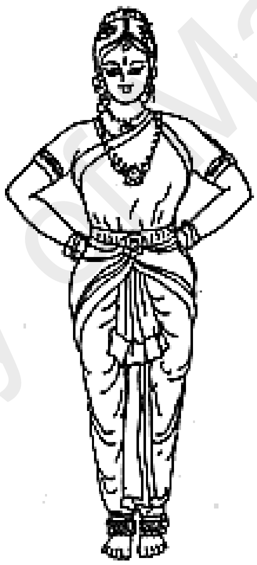


Figure 1.5: Samapadam Position – Reproduced from Nysa Dance Academy, (Saroja Vaidyanathan, 2012)

The second posture, probably the major cause of greater degree of lower extremity turnouts is 'Araimandi' taken from Tamil word 'Arai' which means half and 'Mandi' means sit. In this posture, the dancer squats halfway while his/her heels are joined together along with the toes of both legs pointed to the opposite directions. Here, a diamond shape will be formed in between the legs with a gap of two fingers between the dancer's feet. The dancer's knees are flexed and there is abduction and external rotation at hip joints (Jyothi and Sujaya 2018).

Figure 1.6: Araimandi Position - Reproduced from Nysa Dance Academy, (Saroja Vaidyanathan, 2012)

The third posture is 'Muzhumandi' taken from Tamil language word 'Muzhu' which means full or complete. In this posture, the dancer sits down completely, maintaining the same feet positions as in 'Aramandi'.

Figure 1.7: Muzhumandi Position - Reproduced from Nysa Dance Academy, (Saroja Vaidyanathan, 2012)

Around the dancer's ankles are tied a strand of bells (Ghungaroos), about 50 for each foot, which sound as the bare floor of the stage is slapped with the dancer's bare feet (Puri 2004). The bells contribute to extra load at ankle which provides balance in a dancer’s movements. Chatterjee mentioned that a dancer depends on their dancing bells for balancing in chakkars (spins) during Kathak dance (Chatterjee 2013).

Figure 1.8: Typical Bharatanatyam Dancer’s Ankle Bells – Reproduced from Shutterstock (Santhosh Varghes, 2017)

Similar to Bharatanatyam, classical ballet is another performing art form originated in Renaissance Italy which focusses on lower limb postures at beginner level. The lower limb basic posture is known as ‘Plié’ which means bending in French, referring to the action of bending the knees.

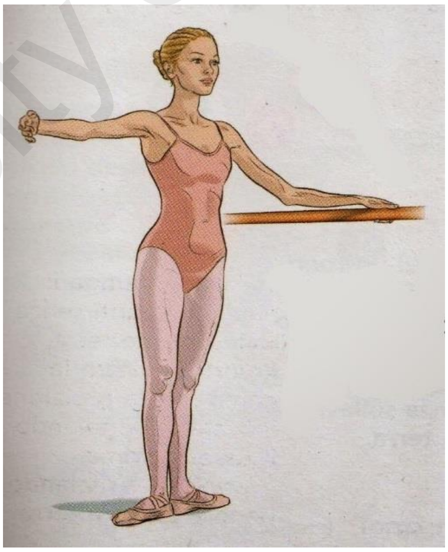


Figure 1.9: Standing Plié – Reproduced from Blogspot (Laura Dodge, 2013)

There are two types of Plié; The Grand Plié and Demi Plié. Grand Plie is similar to ‘Muzhumandi’ in Bharatanatyam, where the dancers fully bend the knees until the thighs are parallel with the floor.

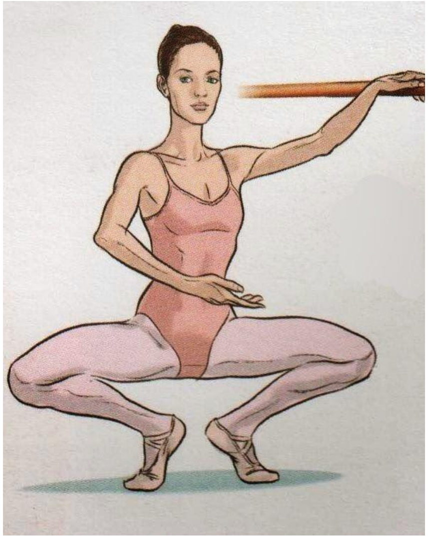


Figure1.10: Grand Plié - Reproduced from Blogspot (Laura Dodge, 2013)

Alike that, Demi Plié is similar to 'Araimandi', where the dancers bend their knees halfway and simultaneously flex their ankle, knees and hips joints without lifting the heels off the ground. Note that Demi- Plié involves movement in which upright torso is lowered with hip, knee flexion and ankle dorsiflexion and return to starting point where the feet remain flat on the floor throughout the movement completion. (Trepman, Gellman et al. 1994). Dance researchers and educators have been concerned about the use of the grand plie and its potential impact on injury incidence for ages now (Barnes, Krasnow et al. 2000).

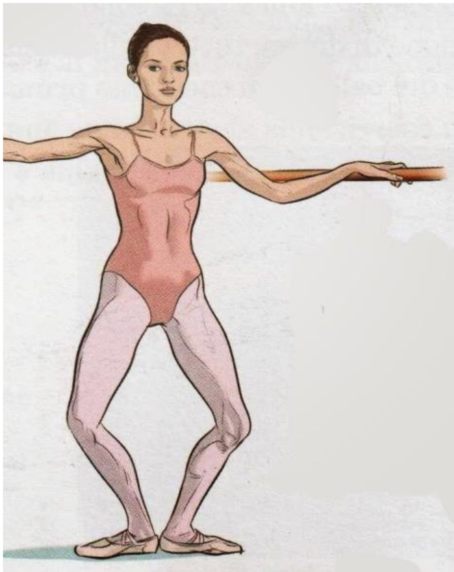


Figure 1.11: Demi Plié - Reproduced from Blogspot (Laura Dodge, 2013)

Dance is a highly demanding activity which requires flexibility, balance, and endurance. Dancers also require balance to maintain position and also while continuously changing (Anbarasi, Rajan et al. 2012). The population of dancers is very unique as they are not just athletes whose work intensity is no less than a football or a tennis player but also, they are artists who constantly strive to perfect the subtle and aesthetic details in performance postures and positions (Anbarasi, Rajan et al. 2012). To execute technical movements, the body takes on positions that place a lot of stress on bones, muscles, tendons, and ligaments. Injuries occur frequently in all dance forms as similar to sports injuries. Chronic injuries were the most common presentation with the lower extremity injuries especially on ankle, knee and hip (Anand Prakash 2017).

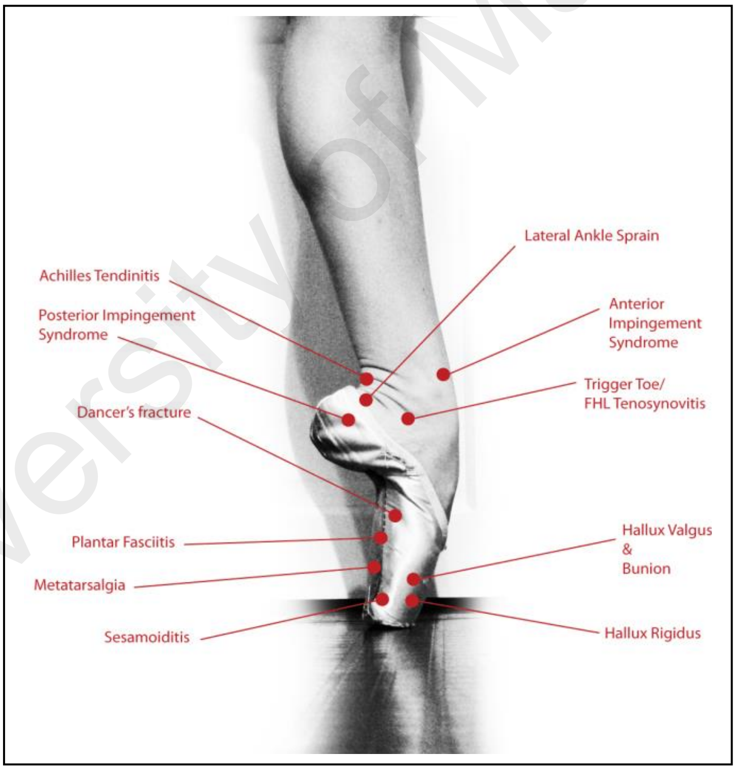


Figure 1.12: Common injuries experienced by ballerinas at ankle – Reproduced from Pinterest (Krisztián Cele, 2016)

One of the earlier study conducted at year 1996 reported that eighty-three of the 148 students (age range, 12 to 28 years) self-declared that prior lower-limb injuries, the most common injury was ankle sprains which consist of 28% of all dancers (Wiesler, Hunter et al. 1996). The study also concluded that age, years of training, body mass index, sex, and ankle range of motion measurement had no predictive value for injury; previous injury and dance discipline both correlated with increased risk of injury (Wiesler, Hunter et al. 1996).

Besides that, another study published at 1999 reported a high incidence of injury was found for three groups of young elite performers consist of gymnasts, ballerina and modern dancers. The study points to the importance of distinguishing between positive and negative stressors in role specific movements in which dancers endure overuse injuries whereas gymnasts tend to suffer slightly more traumatic injuries (Krasnow, Mainwaring et al. 1999). The researcher drew literature dated back in 1983 which was based on a study conducted on ballerinas from Australia. The study discussed about ballet injuries such as strained lumbar muscles, sprained ankle, Achilles tendinitis, clicking hip, jumper's knee, chondromalacia, stress fractures, patellar subluxation, and other knee and tendon problems (Quirk 1983).

Table 1.4: Location of injury for Ballerinas – Reproduced from Modern Dancers and Artistic Gymnasts (Krasnow, Mainwaring et al. 1999)

Body Parts	Ballet	Modern Dance	Gymnasts
Hips	30	10	17
Ankle/Foot	27	26	31
Knee	22	24	5
Lumbar Spine	12	21	18
Cervical, Thoracic Spine	5	8	0
Wrist	0	0	19
Other	4	11	10
Total	100	100	100

Another study on dance injuries was carried out between 2004 and 2007 on students of modern, Mexican folkloric, and Spanish dance at the Escuela Nacional de Danza where a total of 1,168 injuries were registered in 444 students; the injury rate was 4 injuries/student for modern dance and 2 injuries/student for Mexican folkloric and Spanish dance (Echegoyen, Acuña et al. 2010). The rate per training hours was 4 for modern, 1.8 for Mexican folkloric, and 1.5 injuries/1,000 hr of training for Spanish dance (Echegoyen, Acuña et al. 2010). The lower extremity is the most frequent structure injured (70.47%), and overuse injuries comprised 29% of the total. The most frequent injuries were strain, sprain, back pain, and patellofemoral pain (Echegoyen, Acuña et al. 2010).

Various potential risk factors for dancers have been suggested ranging from physical overload to psychological distress, but there is a lack of any conclusive evidence on the risk factor (Scheper, De Vries et al. 2012). In a recent study conducted at 2018 which includes multi genre dancers from the region of Mangalore and Mumbai India, 216 dancers (51: Indian traditional dancers, 51: Western dancers and 164: Recreational dancers) pain levels due to current and past dancing injuries were evaluated (Nair, Kotian et al. 2018). The findings concluded that 42.5% of the dancers were experiencing back pain, followed by 28.3% knee pain and 18.6% ankle pain (Nair, Kotian et al. 2018). These injuries are mainly caused by stress (34%), overwork (24.7%), tiredness (17.2%) and falls during training (13.5%) (Nair, Kotian et al. 2018). Besides that, 43.3 % of dancers claim to perform warm ups before dance while 20% of them claim to perform stretching after dance nevertheless during actual performance, rehearsals or trainings (Nair, Kotian et al. 2018). The study findings strongly indicate that dance injuries predominantly involve the lower limbs and spine are mainly result of cumulative crotrauma (overuse) (Mayers, Bronner et al. 2010). Acute injuries do occur in dance, but overuse injuries are the most common because of the repetitive nature of training and performance. Lack of alignment between the lower-limb structures, such as the hips, knees, and longitudinal arches of the feet, has been described as an important predisposing factor in musculoskeletal injuries among classical ballet dancers (Gontijo, Candotti et al. 2015).

International Association for Dance Medicine and Science (IADMS) has implemented standard measurements associated with dancer's health, including the evaluating and selfreporting injuries. Psychological factors associated with both risk and outcome of dance injury included the following: stress, psychological distress, disordered eating, and coping (Mainwaring and Finney 2017). Factors associated only with risk of injury are sleep, personality, and social support which suggest that psychological variables can affect both the incidence and outcome of dance injury among dancers (Mainwaring and Finney 2017). The core stability and strength enhancement may possibly improve athletic performance and reduce incidence of injury (Jyothi and Sujaya 2018).

From the biomechanical point of view, the human body during walking is a structure consisting of segments interconnected by joints into different types of kinematic chains (Janura, Teplá et al. 2018). Muscle activity of the lower limb during gait differs between the stance phase where the foot is 'fixed' on the ground (closed kinematic chain) and the swing phase where the foot is part of an open kinematic chain (Steindler 1955). Past research confirmed that long-term intensive dance trainings have increased demands on extraordinary range of motion (ROM) in the joints of the lower limbs, and overuse of compensatory strategies could lead to pathological alterations in the musculoskeletal System (Janura, Teplá et al. 2018).

Problem Statement

There is no comprehensive research on Bharatanatyam dancer's biomechanics involving both kinetics and kinematics evaluation in single study done up to the date. Most studies mainly focused on evaluating dancer's injuries; hyper pronation of the foot, knee alignment maintenance with the ipsilateral foot, avoidance of angular misalignments that may cause damage to the pelvis (Gontijo, Candotti et al. 2015), stress level, causes of injury reoccurrence and impact of lacking recovery from past injury etc. It is extremely necessary to access a dancer's basic movement such as walking gait before accessing complex movements available in this dance form. The major difference between Bharatanatyam and other dance form is the wearing of dancing bells at both ankles. Our literature findings support that the bells add stress to the dancer's feet which overloads the connective tissues of legs and lead to overextension, tendon strain and other connective tissue injuries (Andhare, Yeole et al.). Therefore, it is very important to study the impact of wearing dancing bells among Bharatanatyam dancers. Here, we have conducted a pilot study to evaluate the dancers Kinetics and Kinematics of walking gait with (w DB) and without dancing bells (w/o DB) worn at ankle.

Aim

The study aims to compare lower limb walking gait Kinetics and Kinematics data between professional Bharatanatyam dancers (pB) and non-dancers w DB and w/o DB.

Objective

• Conduct lower limb walking gait Kinetics and Kinematics assessment between pB and non-Dancers w DB and w/o DB.

Scope of Research

• Movement chosen for this study: Self-initiated walking w DB and w/o DB.

• Kinetics Evaluation: Maximum and minimum peaks of Ground Reaction Forces from two directions (Vertical Ground Reaction Force and Anterior/Posterior Force).

• Kinematics Evaluation: Maximum and Minimum peaks of three-dimensional angular movements of Hip, Knee and Ankle from two planes (Sagittal and Frontal).

CHAPTER 2: LITERATURE REVIEW

2.1 Kinetics

2.1.1 Definition

Over the years, many Mathematicians and Physicist had defined Kinetics in various term. With respect to movement, Aristotle 384-322 B.C (The father of Kinesiology) supposes a common cause of action for the execution of any movement whatsoever (Chryssafis 1930). A member of the body is always immobile at its origin for it is only the part which if underneath which makes the movement (Chryssafis 1930). For example, when the arms move, the olecranon remains immobile; again, when the whole upper extremity is moved, the shoulder serves as the point of support. In the same manner, the knee is the point of support for the shank, even as the hip serves for the lower limb (Chryssafis 1930). The father of Kinesiology was fascinated by motions of falling bodies and projectiles. His book titled 'De Motu Animalium' has described the ever first movement and locomotion concept, scientific analysis of Gait and geometrical analysis of muscular actions (Borelli 1743). Besides that, he has explained ground reaction forces as "...for just as the pusher pushes, so the pusher is pushed".

Similar theory has been discussed by Sir Isaac Newton (January 1643 – March 1727) in his book ‘Philosophiæ Naturalis Principia Mathematica’ as for attractions made towards body; and the actions of bodies; and the actions of bodies attracting and attracted are always mutual and equal, by the third law of motion (Newton 1802).

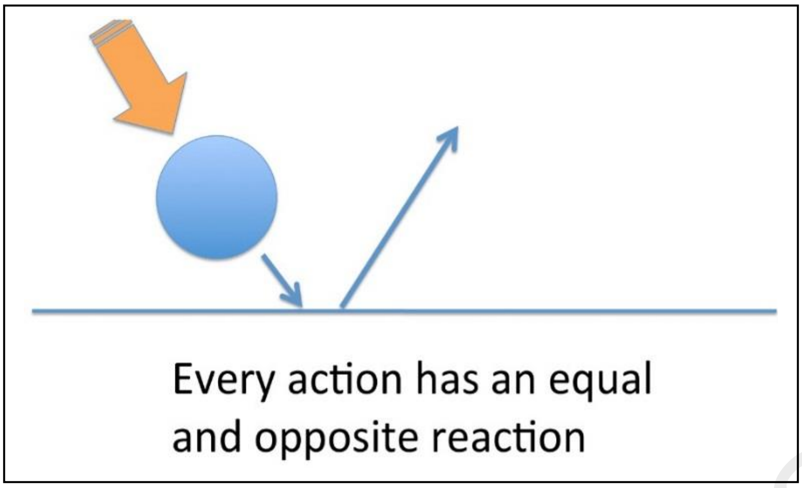


Figure 2.1: Newton's third law illustration – Reproduced from JustScience, 2017

Susan J Hall defined kinetics as a study of forces causing or resulting a motion (Hall 1991). Kinetics is the branch of mechanics dealing with forces and their effects on bodies at rest (statics) and bodies in motion, dynamics (Zatsiorsky and Zaciorskij 2002). Force is a primitive concept of mechanics. We pull on the ends of a string and make it taut; stretch a rubber band to several times its unstretched length; bend a straight rode of steel to circular shape; twist our hands; drag our feet; when we fall down, it hurts; winds topple buildings; a ball thrown upward returns to strike the ground; a magnet moves an iron bar towards itself or pushes it away without touching it (Beatty Jr 2013). These events are influences and examples of force.

2.1.2 Ground Reaction Force

In biomechanics, forces are classified as external (acting between the body and environment; e.g. Gravitational force) and internal which acts between body parts (Zatsiorsky and Zaciorskij 2002). The external forces can be distant forces (e.g., gravitational force) or contact forces.

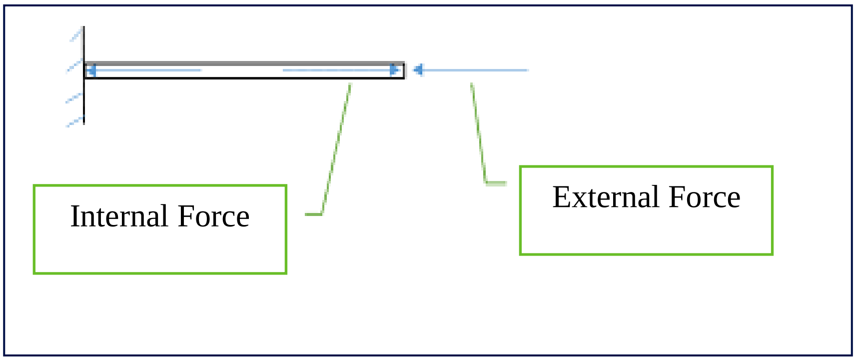


Figure 2.2: Internal Force (force to maintain original structure from within material) and External Force for form deformities on the material acted upon it – Reproduced from Study.com (Paulina M, 2018)

A ground reaction force (GRF) is basically the consequences of Newton's third law where Action is equals to Reaction (Newton 1802). Porter defines GRF as force that acts on a body as a result of the body resting on the ground or hitting the ground (Porter 2013). In other words, GRF are the forces applied to the body by ground as opposed to those applied to the ground, when an individual takes a step. If a person stands on a floor without moving, the person is exerting a force, W (the person's weight) on the floor, while the floor exerts an equal and opposite reaction force on the person (Porter 2013).

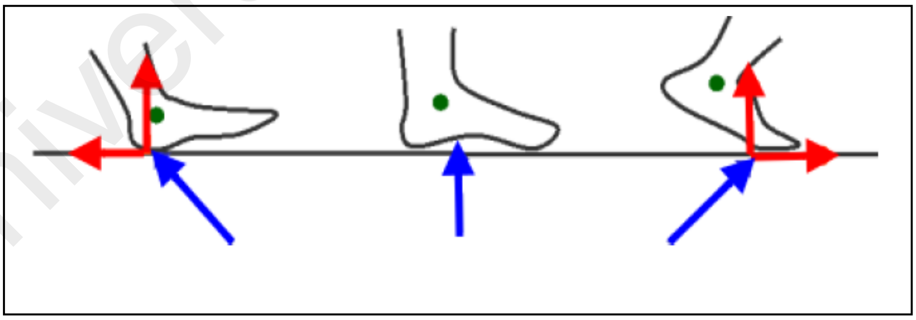


Figure 2.3: Forces acting upon a foot while interacting with the ground during walking gait – Reproduced from BMclinic (Huei Ming Chai, 2007)

These are the forces which keeps a person from falling off while walking, providing balance. (Steindler 1955) stated that walking is 'series of catastrophes narrowly averted' which firstly, the body falls forward, then the legs move under the body to prevent and prevent such an accident from occurring by establishing a new base of support with feet. Walking is accomplished by the alternating action between two lower extremities; In walking, each lower extremity undergoes two phases which consists of eight events: The Swing or recovery phase and Stance or support phase (Luttgens, Hamilton et al. 1997). The stance phase is composed of Heel Strike (HS), Flat Foot (FF), Midstance (MS), Heel Off (HO), and Toe Off (TO) (Luttgens, Hamilton et al. 1997). Besides that, the swing phase is composed of Acceleration, Midswing and Deceleration (Hall 1991).

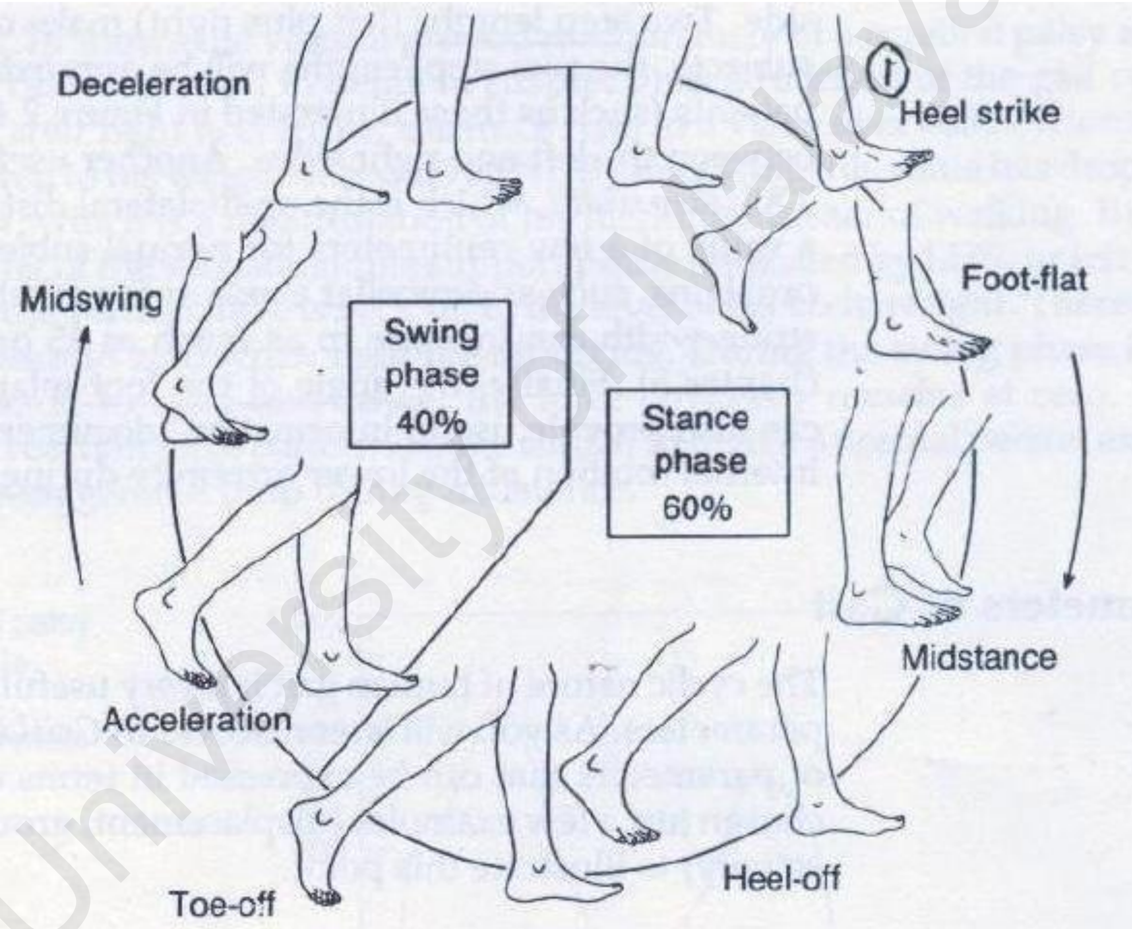


Figure 2.4: Gait events involved in walking – Reproduced from Basic Biomechanics (Hall 1991)

The description of each events available in the table below:

Table 2.1: The description of gait events (drzezo 2019)

Event	Description
Heel Strike (HS)	Initiates the gait cycle and represents the point at which the body's centre of gravity is at its lowest position. Gait cycle starts at first contact made by foot with the ground
Flat Foot (FF)	The foot will be carefully controlled to come down towards the ground and provide a stable base of support for the rest of the body. This time, the plantar surface of the whole foot touches the ground
Midstance (MS)	Occurs when the swinging (contralateral) foot passes the stance foot and the body's centre of gravity is at its highest possible. The body will then roll over the foot with the ankle acting as a "pivot" point and the hip joint will be directly above the ankle joint
Heel Off (HO)	Occurs as the heel loses contact with the ground and push off is initiated via the triceps sure muscles, which plantar flex the ankle
Toe Off (TO)	Terminates the stance phase as the foot leaves the ground. As the foot leaves the ground at the end of the swing phase it is usual for the toe to be the last point of contact and the instant of the toe leaving the ground
Acceleration	Begins as soon as the foot leaves the ground and the subject activates the hip flexor muscles to accelerate the leg forward
Midswing	Occurs when the foot passes directly beneath the body, coincidental with midstance for the other foot
Deceleration	Describes the action of the muscles as they slow the leg and stabilize the foot in preparation for the next heel strike

The body experiences motion in the vertical and mediolateral directions during walking event. As the body moves forward, only one leg will be supporting the mass of the body during the central part of the stance phase. This means that the body is liable to topple because the body mass will be medial to the support point generated by the foot (Blazevich and Blazevich 2017).

For instance, during acceleration event, the body supported by the left foot and the centre of the pelvis is offset medially from the left foot. Since the body mass is being moved in three directions (F_x, F_y and F_z), a combination of force actions required in order to accelerate and decelerate the body mass to provide the motion seen during gait (Blazevich and Blazevich 2017).

When an object is accelerated, the relationship can be expressed as;

$$\text{Force} = \text{Mass} \times \text{Acceleration} \qquad \text{Equation (1)}$$

Nowadays, forces measured directly by using a Force Platform (FP) which is mounted in the floor. FP is a mechanical sensing system designed to measure force exerted by the ground on a body known as Ground Reaction Force (GRF). As the foot contacts the floor, the FP able to sense the GRF in directions. FP relies on the use of load cells which contains contain piezoelectric elements, strain gauges, or beam load cells to determine GRF (Lamkin-Kennard and Popovic 2019).

When force is applied to the plate, the sensors distort thereby causing measurable voltage changes that are proportional to the applied force (Lamkin-Kennard and Popovic 2019). Placing the sensors in different orientations enables the direction and magnitude of forces in 3D to be obtained (Lamkin-Kennard and Popovic 2019).

There are three components of GRF;

- Anterior/Posterior also known as horizontal force, F_x
- Vertical Ground Reaction (VGRF), F_y
- Medial/Lateral, F_z

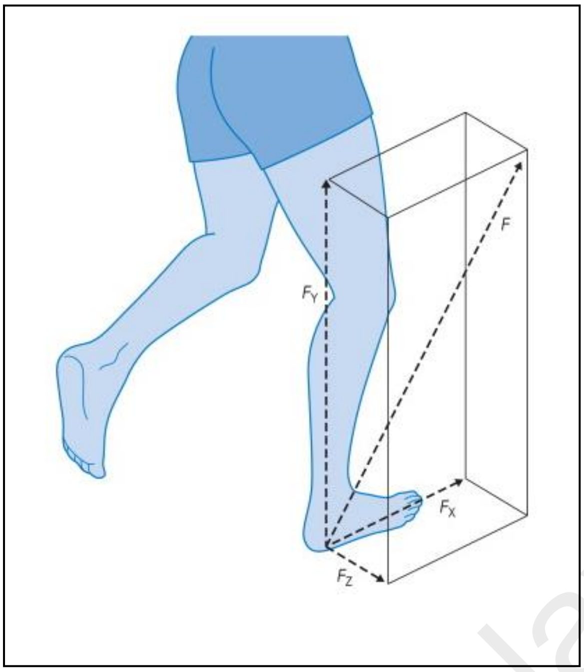
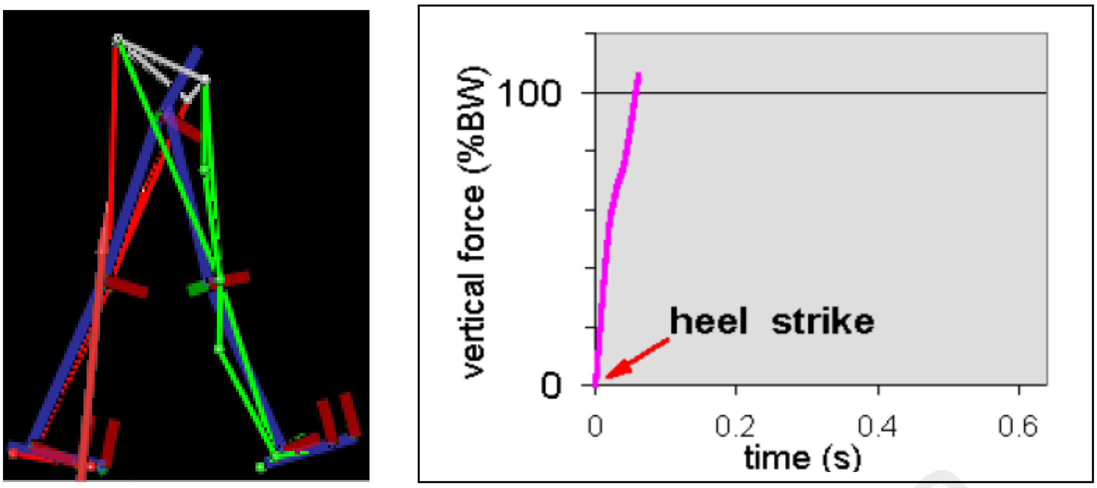


Figure 2.5: Illustration of three forces acting during walking – Reproduced from (Watkins 2009)

2.1.2.1 Vertical Ground Reaction

Taking the VGRF first, there would be 100% body weight for a standing subject who is motionless. It is known that the vertical accelerations can be 20% of gravitational acceleration upwards or downwards. It is expected that the vertical force applied between the foot and floor will be 100%±20% of Body Weight (BW) when motion present.

During stance phase, HS is the beginning of feet contact with the ground. Therefore, the VGRF will be zero. This vertical force will rise very steeply up to almost body weight in a fraction of a second (affhhsna96 2019).



(a) (b)

Figure 2.6: (a) HS event taking place (b) Changes in VGRF graph during HS – Reproduced from Basic Biomechanics (Hall 1991)

At the time point of FF, the body mass is moving downwards and landing on the leg as seen by the motion of the hip centres from the figure below. In order to decelerate this downward motion and at the same time support the body weight, it is necessary to apply a force larger than body weight on the foot (affhhsna96 2019). This instant for the subject reaches 116% BW being applied to the foot (affhhsna96 2019).

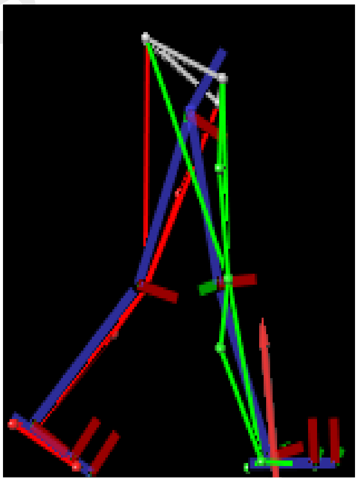
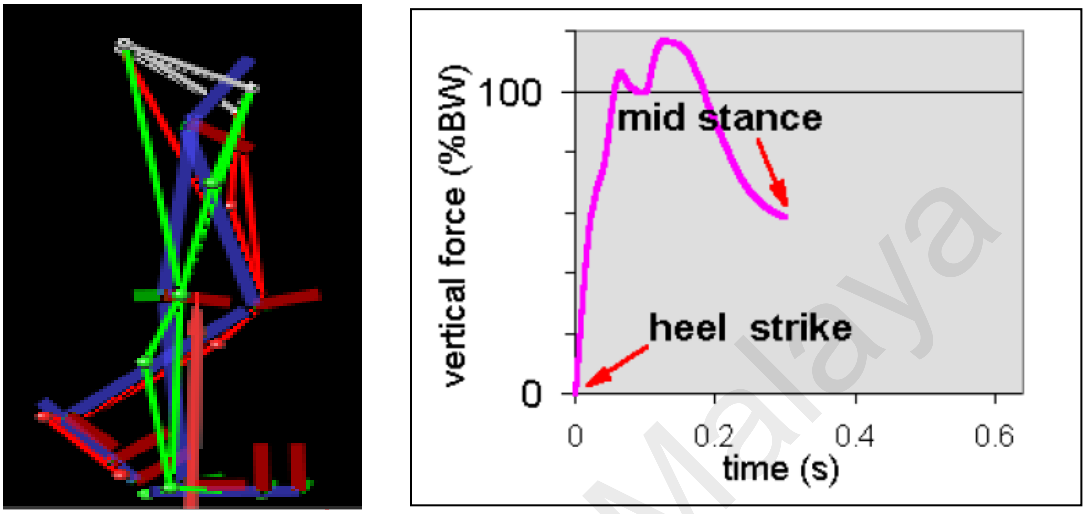


Figure 2.7: FF event taking place

At mid stance the motion of the centre of the body is in an upward arc just like driving a car over a hump-backed bridge (affhhsna96 2019). The upward motion of the body is being decelerated and then allowed to accelerate downwards at the second half of stance (affhhsna96 2019). This acceleration allows a force of less than BW to support the body, but the value of this force is highly variable (affhhsna96 2019). This subject shows 59% BW at mid stance, but it is likely that people with a "springy" style of gait could go as low as 20-30% BW (affhhsna96 2019).



(a) (b)

Figure 2.8: (a) MS event taking place (b) Changes in VGRF graph during MS – Reproduced from Basic Biomechanics (Hall 1991)

At heel raise, the body mass is accelerated forward and upwards ready for the stance phase of the other leg. This means that more than body weight will be required to support the body and as such a force of 117% is experienced by a subject in this event.

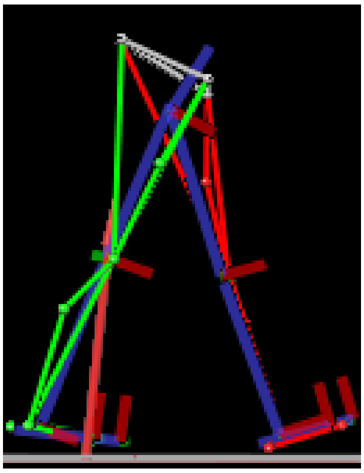
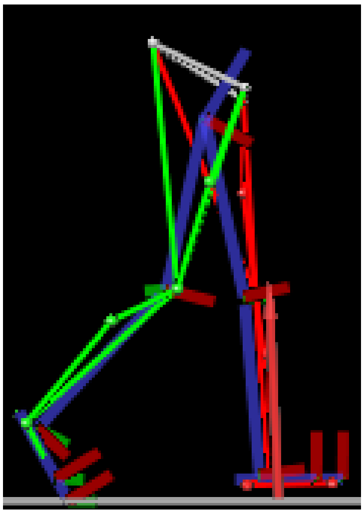
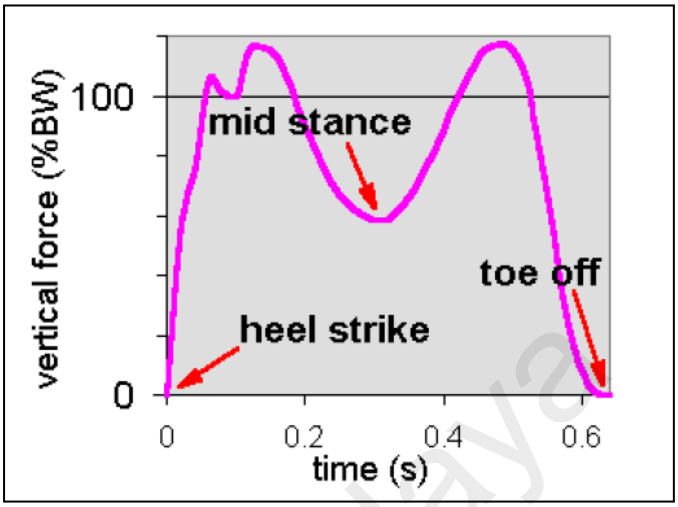


Figure 2.9: HO event taking place

Finally, TO is an instant where contact with the ground is lost and the force will return to zero (affhhsna96 2019).





(a) (b)

Figure 2.10: (a) TO event taking place (b) Changes in VGRF graph during TO – Reproduced from Basic Biomechanics (Hall 1991)

One point of interest is the discontinuity, or spike, on the initial rapid rise of the vertical force from heel strike (affhhsna96 2019). This spike is due to the two-stage landing of the body on the ground (affhhsna96 2019). Although we said that the body lands on the leg during early stance at foot flat, there is an event preceding this where the leg strikes the ground like a hammer being swung from the hip as a pivot point (affhhsna96 2019).

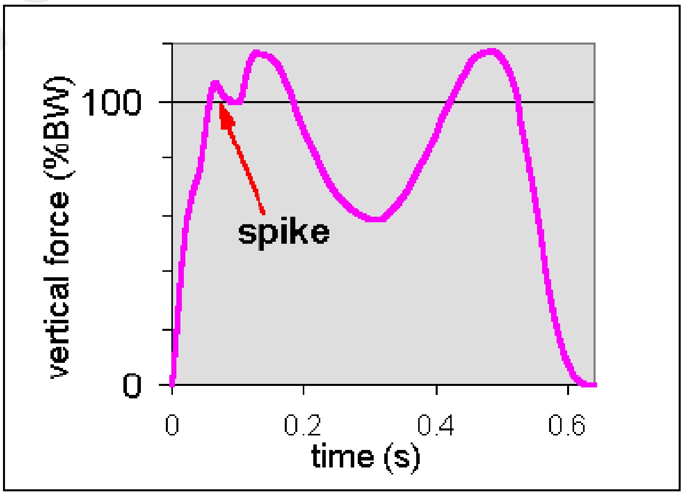


Figure 2.11: Spike appears during HS - Reproduced from Basic Biomechanics (Hall 1991)

The mass and inertial properties of the leg (rather than the whole body) will come to rest more abruptly than the larger mass of the body (affhhsna96 2019). This abrupt velocity change in the mass of the leg represents a "shock" which is no more than a very quick force application due to a change in velocity (affhhsna96 2019).

2.1.2.2 Anterior/Posterior Force

As the body moves forward and up and down, the mass of the body represented by a trolley moving along and undulating up and down surface (affhhsna96 2019). As the body mass moves down the surface it will tend to speed up and as the body mass moves upwards it will tend to slow down (affhhsna96 2019). Again, there will be accelerations forwards and backwards in order to achieve these changes in velocity forward (affhhsna96 2019). Like any mass on the move, these accelerations will require forces on the mass (affhhsna96 2019).

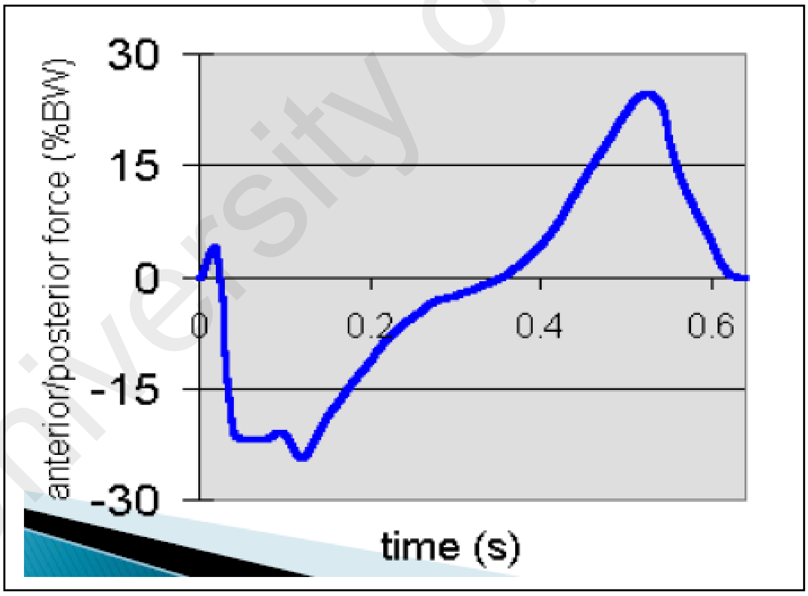


Figure 2.12: Anterior/Posterior Force during one gait cycle - Reproduced from Basic Biomechanics (Hall 1991)

During stance phase, the forces applied to the foot will be backwards as the body lands and then forwards in late stance as the body lifts and moves more rapidly in the forward direction (affhhsna96 2019).

This oscillation from backwards to forwards is important and represents the control of the forward velocity within certain variations (affhhsna96 2019).

It is normal for the velocity of the mass to fluctuate by 15% of the average velocity of forward progression (affhhsna96 2019). During early stance the force applied to the foot will be backwards and can reach 20% body weight at foot flat (affhhsna96 2019). During the propulsion phase after heel raise, the force forward on the foot will reach approximately 20% again (affhhsna96 2019).

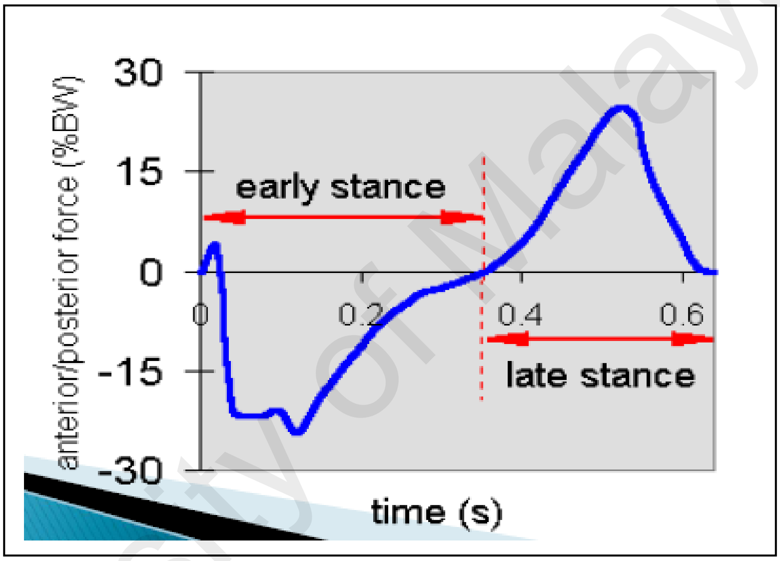


Figure 2.13: Early and late stance occurrence in Anterior/Posterior Force graph during one gait cycle - Reproduced from Basic Biomechanics (Hall 1991)

During mid stance the velocity of forward progression should be not changing and as such there will be no requirement for a horizontal anterior/posterior force (affhhsna96 2019). Therefore, the force will be zero and represents the point of changeover between the deceleration phase and the acceleration phase (affhhsna96 2019). When these data points are combined, we obtain the graph shown opposite and the areas representing the negative and positive parts of this force should be equal in order to maintain a forward velocity of the same value from step to step (affhhsna96 2019).

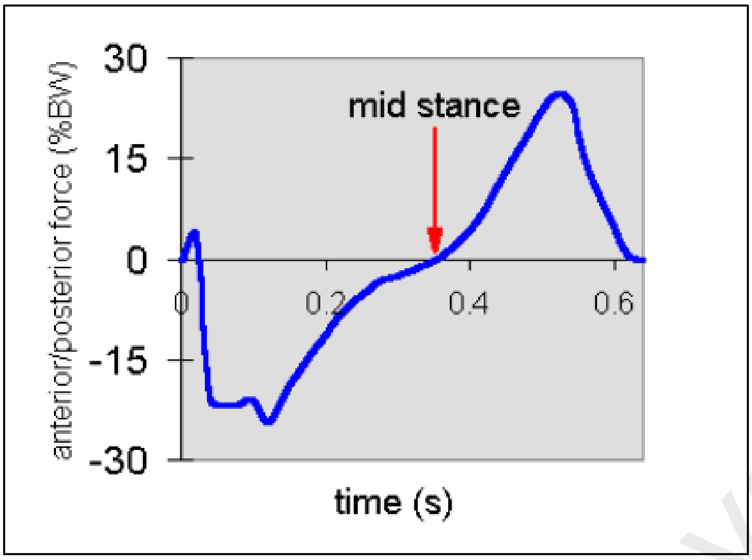


Figure 2.14: Midstance point in Anterior/Posterior Force graph during one gait cycle

- Reproduced from Basic Biomechanics (Hall 1991)

If the negative portion is larger in area than the positive portion, the body will be slowing down and conversely the body will accelerate forward if the positive (affhhsna96 2019).

2.1.2.3 Medial/Lateral

In the human gait the centre of gravity of the body is displaced to the supporting side at every step (Inman and Eberhart 1953) and the foot that steps forward must control the medial-lateral oscillation of the body caused by the thrust of the push-off leg (Ducroquet, Ducroquet et al. 1968). The body balance in the FP is somewhat unstable as shown in the variety of the lateral components of the ground reaction force, but it is very important to control the medial-lateral balance in order to perform a smooth forward movement (Matsusaka 1986).

While walking straight forward, the medial-lateral component is normally very small resulting in little side-to-side movement of the body (Watkins 2009). When a foot is in a swing phase the other foot should be in a single support phase (Midori 2019). On the contrary, when a foot is in a stance phase, it goes through a double support phase (loading response, LR), a single support phase (MS), and another double support phase (Midori 2019).

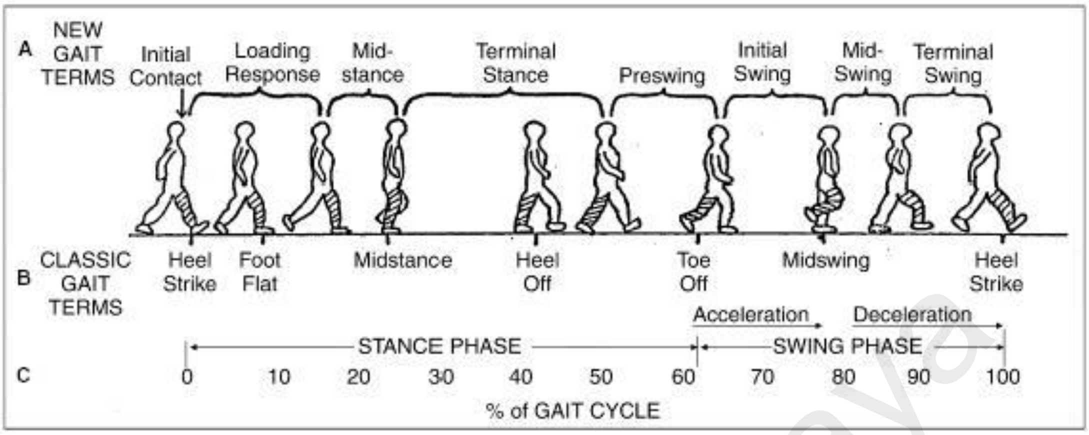


Figure 2.15: Single and Double Support Phase – Reproduced from (Midori 2019)

Here, the medial-lateral component of force acting on the centre of gravity during the gait cycle acts medially during single stance and changes direction during double-support, i.e. from medial on the right foot to medial on the left foot during the period from left heel-strike to right toe-off (Watkins 2009).

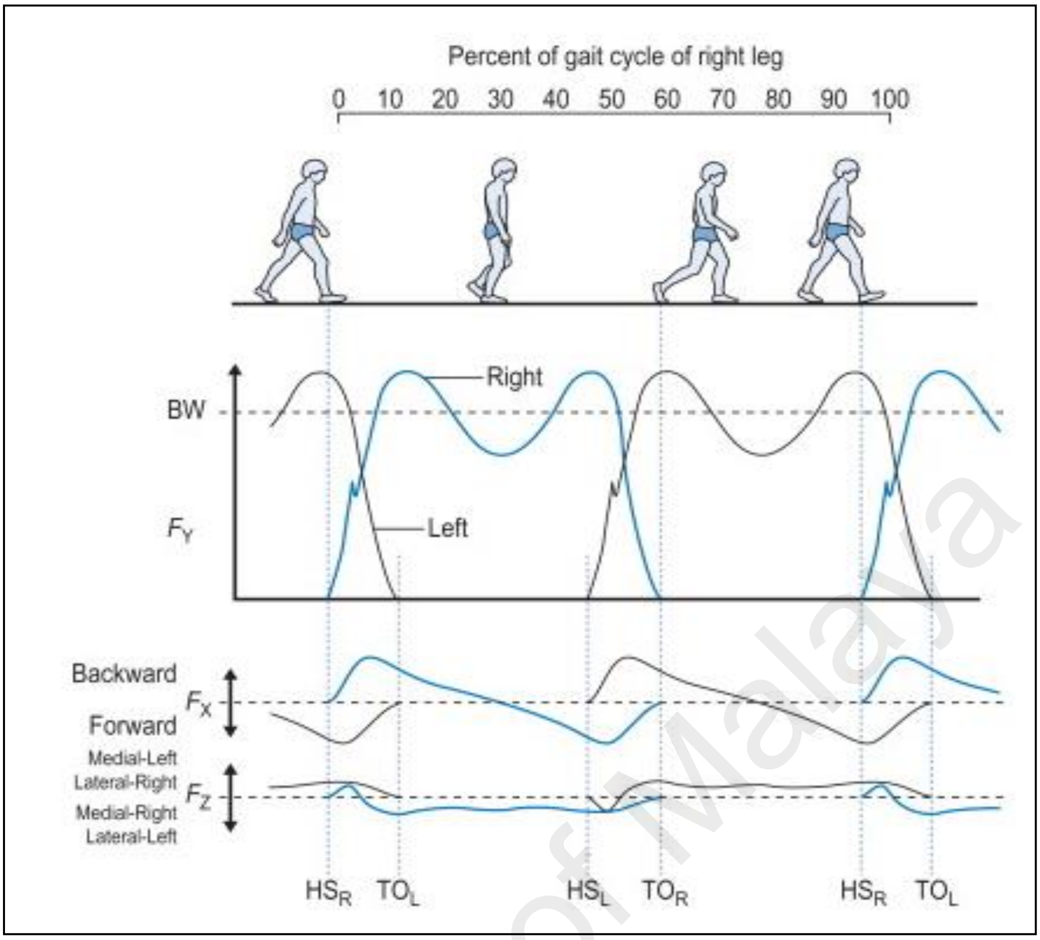


Figure 2.16: Anteroposterior (FX), vertical (FY) and mediolateral (FZ) components of the ground reaction force (F) during the walking gait cycle (Watkins 2009).

2.1.3 Past Studies on Kinetics of movements

(Fujarczuk, Winiarski et al. 2006) assumed that an increase in music tempo influences the frequency in step aerobics which increases the ground reaction forces, leading to altered loads of human movement system. Sixteen healthy professionally qualified female aerobics instructors took part in an experiment which the GRFs were measured on a force plate under different step height and music tempo conditions (Fujarczuk, Winiarski et al. 2006). The GRF characteristics (figure 2.17) begins with the first foot contact of the right foot (with the characteristic shock absorption artefact in the force signal), then the transfer of the body weight to the step bench (Fujarczuk, Winiarski et al. 2006).

It is associated with the upper movement of the body centre of gravity (COG) and the emergence of the first peak force, F_1 (Fujarczuk, Winiarski et al. 2006).

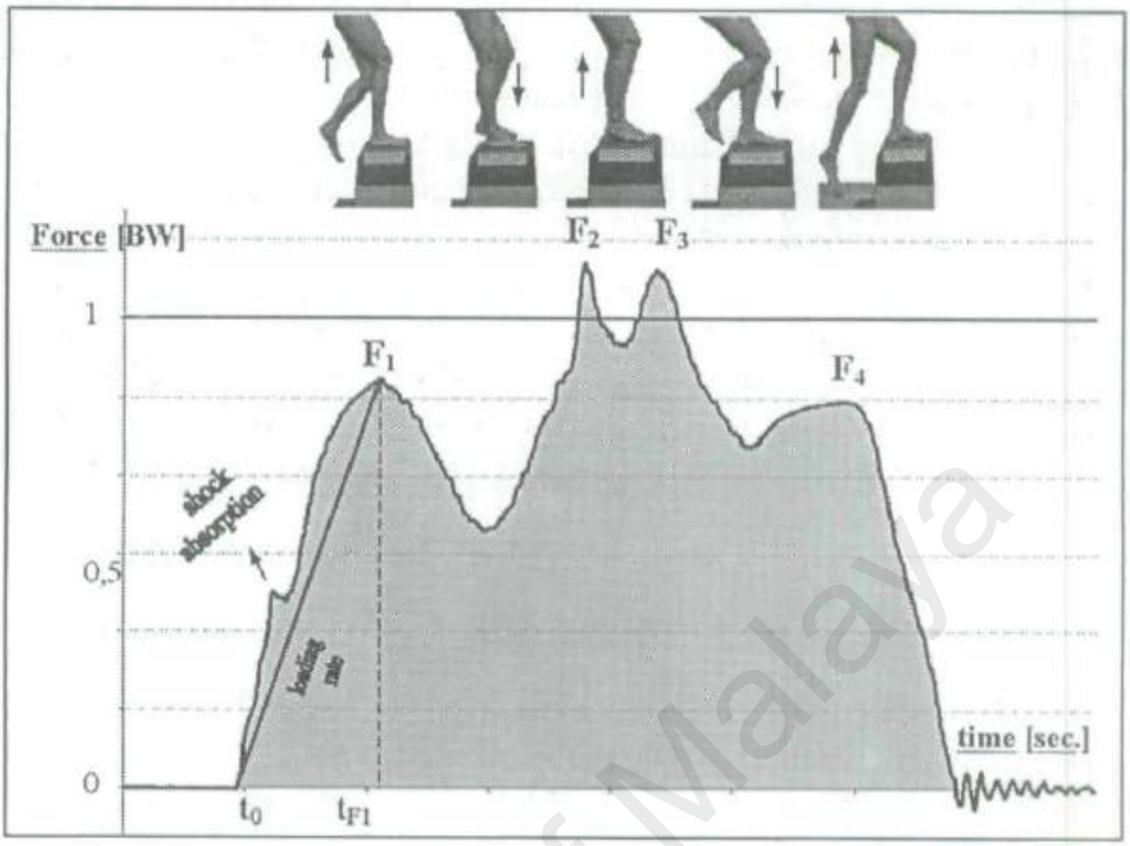


Figure 2.17: A "ghost-shaped" time characteristics of normalized ground reaction force for one cycle of the "basic step. F_1, F_2, F_3 and F_4 are the GRF peaks responsible for the upper horizontal acceleration of the centre of body mass (Fujarczuk, Winiarski et al. 2006).

While the left foot meets the platform body, COG must drop down and then rise again to maintain the straight posture of the subject's body (the 2nd peak force - F_2 occurs) (Fujarczuk, Winiarski et al. 2006). While transferring the weight to the left foot (the right begins stepping down), shortly after the F_2, the third peak force, F_3 occurs (Fujarczuk, Winiarski et al. 2006). The step is terminated with the right foot brought down to the ground (COG lowers for the third time) and while the opposite foot joins the right one it pushes the platform for the fourth and last time, F_4 (Fujarczuk, Winiarski et al. 2006). The step cycle then terminates. Data analysis showed the influence of the step height and music tempo on the maximum values of vertical ground reaction forces, F_1 (Fujarczuk, Winiarski et al. 2006). It was proven that with the increase in the step height the vertical ground reaction force decreases (Fujarczuk, Winiarski et al. 2006). The paper concluded that the maximum ground reaction force and its loading rate in step aerobics are significantly lower than GRF in level walking (Fujarczuk, Winiarski et al. 2006).

Another gender specificity study conducted between fourteen females and fourteen male Aerobic dance instructors to investigate their respective GRF (Rousanoglou and Boudolos 2005). Females demonstrated significantly higher vertical but lower medial lateral GRF compared to male subjects (Rousanoglou and Boudolos 2005). The study concluded with the significant vertical and lateral GRF pattern differences may possibly be associated with the significant anthropometric differences of male and female AD instructor (Rousanoglou and Boudolos 2005).

(Kulig, Fietzer et al. 2011) examined vertical ground reaction force during ‘a saut de chat’ performed by twelve healthy ballerinas. It was hypothesized that vertical ground reaction force during landing would exceed that of take-off, resulting in greater knee extensor moments and greater knee angular stiffness (Kulig, Fietzer et al. 2011).

Figure 2.18: Take-off phases of the saut de chat – Reproduced from (Kulig, Loudon et al. 2011)

The study concluded that a ballerina experience 3.5 times and 4.4 times body weight peak vertical ground reaction force during a saut de chat movement, which was marked as greater than the 1.5 times body weight peak force experienced during walking and the 2.5 times body weight peak force experienced during running (Kulig, Fietzer et al. 2011).

Moreover, S.-W. Yang conducted a study to compare walking kinetics between dancer and non-dancers to understand the causes of ankle sprain. Thirteen students from dancing department and twenty age-matched normal healthy subjects were requested to walk along a 10-meter walkway (Lung, Chern et al. 2008). Measurements of the ground reaction force (GRF) and the centre of pressure (CoP) taken in order to provide useful variables to analyse the walking patterns of dancers, which might help understand the causes of ankle sprain (Lung, Chern et al. 2008). Results showed that the dancers have greater medial shear force of the GRF, and decreased the CoP velocity during the pre-swing phase, delayed peak-CoP velocity occurrence during the mid-stance, and straighter CoP trajectory through the forefoot at push off (Lung, Chern et al. 2008). The intense and demanding dancing activities change the walking pattern of dancers, which may lead to higher chance of getting ankle sprain (Lung, Chern et al. 2008).

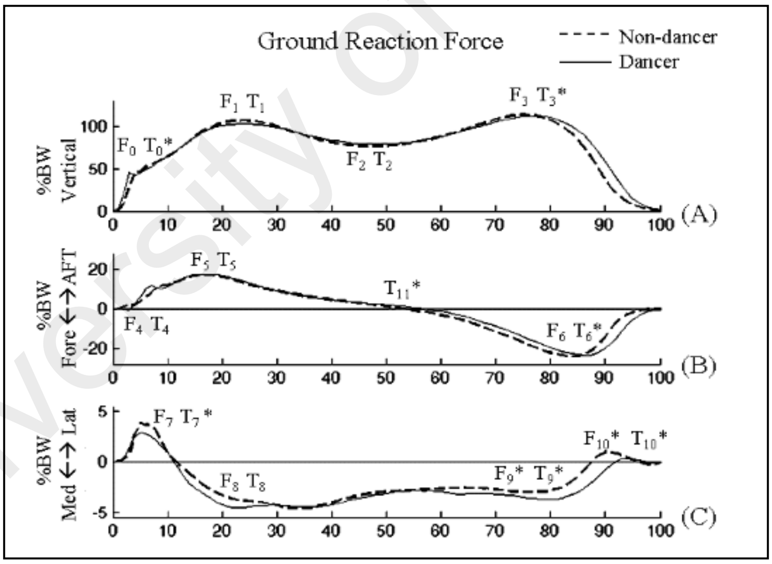


Figure 2.19: GRF comparison between dancer and non-dancer – Reproduced from (Lung, Chern et al. 2008)

Another literature relevant to our study presented by Shruti Jnanesh Shenoy during 37th International Society of Biomechanics in Sport Conference, Oxford, OH, United States on July 2019. Seven experienced Bharatanatyam dancers performed the 'Tatta Adavu' by tapping their feet repeatedly on a force plate at 2 speeds (Shenoy 2019). Peak ground reaction force was found to be 4 to 5 times the body weight (Shenoy 2019). These high forces repeatedly experienced by the lower extremities could contribute to the higher incidence of lower extremity injuries (Shenoy 2019).

Table 2.2 : Mean (SD) Peak GRFV / Body Weight – Reproduced from (Shenoy 2019)

Speed 1		**Speed 3**	
Left	Right	Left	Right
4.55 (1.93)	4.42 (1.48)	5.12 (1.75)	5.08 (1.76)

2.2 Kinematics

2.2.1 Definition

Kinematics is a study of the geometry of motion where a body defined as a part of machine which is constraint to move in a certain manner by virtue of its contact with other machine elements (Beggs 1983). Susan J Hall defined kinematics as a study of the description of motion including consideration of space and time (Hall 1991). According to (Bottema and Roth 1990), kinematics is essentially the study of Euclidean where if D is a displacement, D^{-1} is a displacement; if D_1 and D_2 are displacements, the same hold for D_2D_1; I is a displacement.

Spanish Dominican friar Domingo de Soto (1494–1560) in his commentary on Aristotle's Physics clearly stated that a freely falling body undergoes uniform acceleration 'Motus Uniformiter Difformis': 'For when a heavy object falls through a homogeneous medium from a height, it moves with greater velocity at the end than at the beginning.… And what is more, the [motion] … increases uniformly difformly (Wallace 1968)'. Furthermore, it was accompanied by an explicit indication that because of the uniformly accelerated nature of its motion, the distance travelled by a freely falling body can be calculated using the mean velocity theorem that had been stated and proved in the 14th century by the Oxford Calculators: for in seeking an appropriate global measure of the velocity of a uniformly accelerating object such as a falling heavy body, de Soto notes that 'if the moving object A keeps increasing its velocity from 0 to 8, it covers just as much space as [another object] B moving with a uniform velocity of 4 in the same period of time (Wallace 1968).'

De Soto's writings influenced Galileo Galilei (1564-1642), an Italian physicist known as the 'Father of Modern Science' to study accelerated motion and establish the first equations of kinematics (Garber 2019). Galileo derived the relationship between distance travelled and time as balls rolled down an inclined plane with respect to 'Law of Falling Bodies' using classical Euclidean geometry (Garber 2019). As its velocity is increasing, the distance that it travels in each unit of time increases (Garber 2019). Based on Galileo's 'Discourses on Two New Sciences', he confirmed the law in the following statement: 'The spaces described by a body falling from rest with a uniformly accelerated motion are to each other as the squares of the time-intervals employed in traversing these distances' (Sherman 1974).

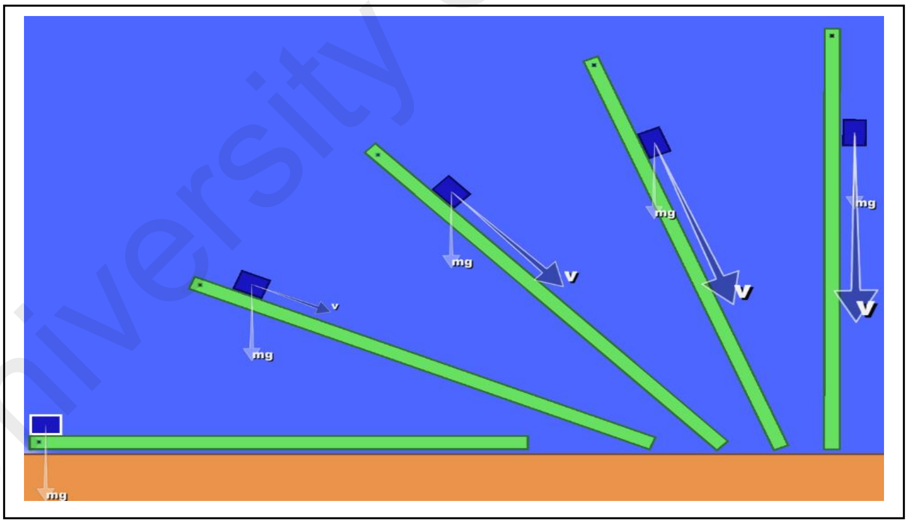


Figure 2.20: Galileo´s inclined planes – Reproduced from (Algodoo, 2019)

Galileo found greater accelerations for steeper incline which the ball attains max acceleration when incline is tipped vertically (Sherman 1974).

2.2.2 Kinematic Abbreviations

Walking is one of the most common and most important forms of human movement (Abdulhassan and Abbas 2013). Many system using digital image processing techniques for kinematic analysis of human walking gait has been developed over the years (O'Malley and de Paor 1993). Subjects installed with passive reflective makers and an automatic routine then uses a set of pattern recognition algorithms to locate accurately and consistently the markers in each image (O'Malley and de Paor 1993). The results may be presented in a variety of ways: stick diagram animation, sagittal displacement graphs, flexion diagrams and gait parameters (O'Malley and de Paor 1993).

In Kinematics, it is important to understand how the body moves and how muscles work together to generate movement (Thompson 2017). There are three axes involved in producing angular movement. They are (Documentation 2016);

• Transverse Plane (TP) are those axes which pass from one side of the body to the other

• Sagittal Plane (SP) pass from the back of the body to the front

• Frontal Plane (FP) pass in a direction from the centre of the body through the top of the head

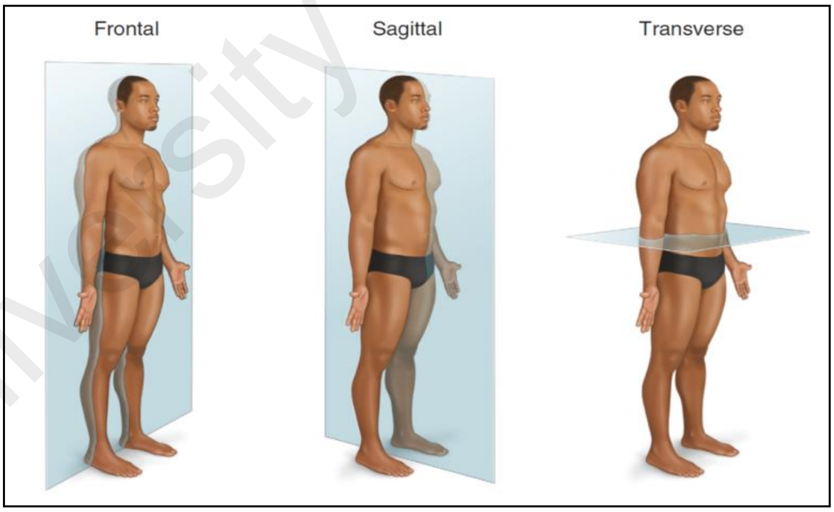


Figure 2.21: SP, FP and TP axes – Reproduced from (Payne 2019)

From the graphical representation of one a normal subject’s hip angle while walking on SP, there is a single peak of flexion (Flx) and extension (Ext) in each cycle (Abdulhassan and Abbas 2013).

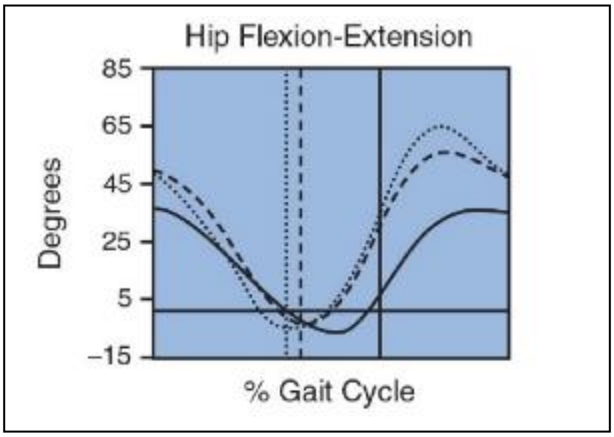


Figure 2.22: Single peak of hip Flx and Ext occur during one gait cycle at SP – Reproduced from (Chegg, 2017)

The hip extends during the stance phase, and then starts to flex at about heel strike for the other leg, continuing flexion through the swing phase (Abdulhassan and Abbas 2013). The range of hip flexion/extension increases with stride length; the increase is mainly in flexion, since the hip will not extend more than about 30 degrees (Abdulhassan and Abbas 2013). At the hip, there are only two movements in the step cycle, and both are active; that is, the hip flexors (Ilipsoas) produce flexion, and the extensors produce extension (Whittle 2014).

The hip joint is created between the femur (thigh bone) and the acetabulum of the pelvis (socket of the hipbone) (Thompson 2017). Here, a ball and socket joint collaborate to perform actions.

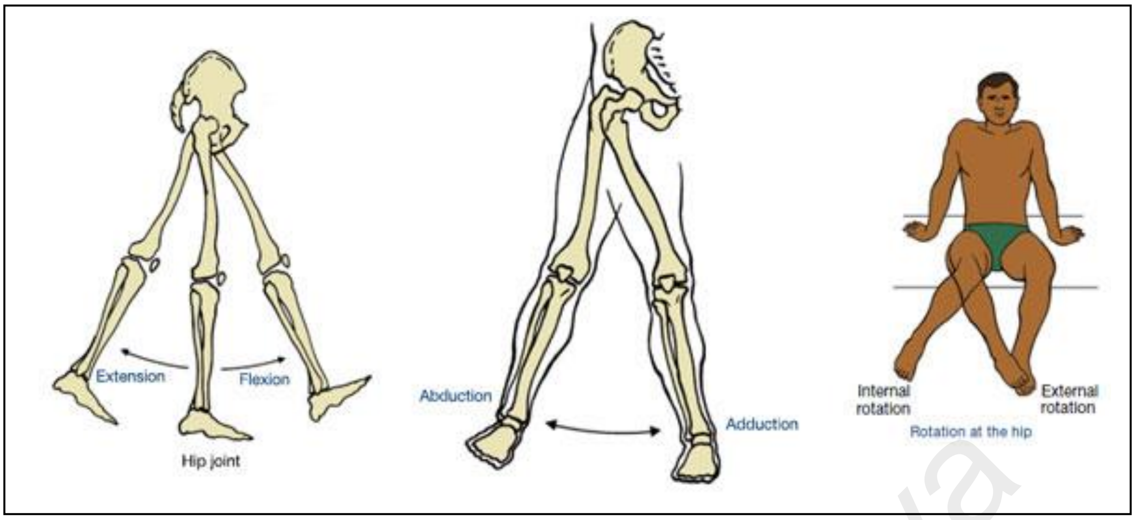


Figure 2.23: Hip Kinematics – Reproduced from (Thompson 2017)

Hip Kinematics	Movement Description
Hip Flexion	Thigh lifted upward in front of the body
Hip Extension	From anatomical position, thigh lifted towards back
Hip Abduction	Leg lifted out to the side, or from a squatting position, knees fall out to the side
Hip Adduction	From a position of hip abduction, thigh lowered to the anatomical position
Internal Rotation (Irot) of the Hip	Leg rotated in toward the midline of the body
External Rotation (ERot) of the Hip	Leg rotated out away from the midline of the bod

Table 2.3 : The description of Hip Kinematics – Reproduced from (Thompson 2017)

From the graphical representation of one a normal subject's knee angle while walking on SP, two peaks of flexion present; a small one in the stance phase, where the knee yields to flatten the path of the COG and a second, larger peak which allows the foot to clear the ground (Abdulhassan and Abbas 2013).

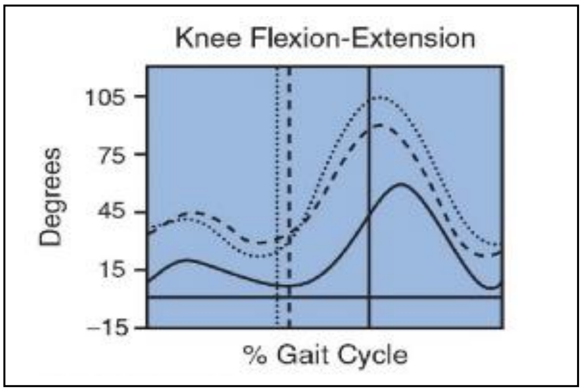


Figure 2.24: Two peaks of knee's flexion occur during one gait cycle at SP–

Reproduced from (Chegg, 2017)

The flexion in stance phase increases with walking speed (Whittle 2014). The flexion in the swing phase is followed by an extension which ends just before heel contact (Abdulhassan and Abbas 2013). The knee angle is not zero at extended legs, at heel-up phase of gait, as the knee angle models also the anatomical angle between the femur and the tibia in FP.

The knee joint consists of the end of femur bone connecting with the top of the tibia and fibula (Thompson 2017). Below is the knee kinematics observed at SP.

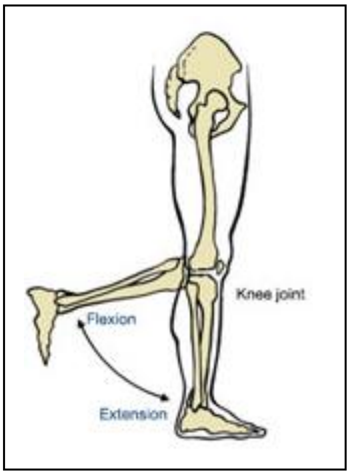


Figure 2.25: Knee Kinematics– Reproduced from (Thompson 2017)

Table 2.4 : The description of Knee Kinematics – Reproduced from (Thompson 2017)

Knee Kinematics	Movement Description
Knee flexion	Bending of knee
Knee Extension	Straightening of knee

Besides that, the ankle contributes to balance during walking too by modulating the CoP and GRF through an ankle moment (Vlutters, van Asseldonk et al. 2019). The ankle joint consists of the distal ends of the tibia and fibula and the talus (Thompson 2017). The main actions of the ankle are plantarflexion (PF) and dorsiflexion (DF) which happens on SP. The subtalar joint (articulation between the talus and calcaneus) allows inversion (Inv) and eversion (Eve) of the foot, a kinematics movements which occur on the FP (Thompson 2017).

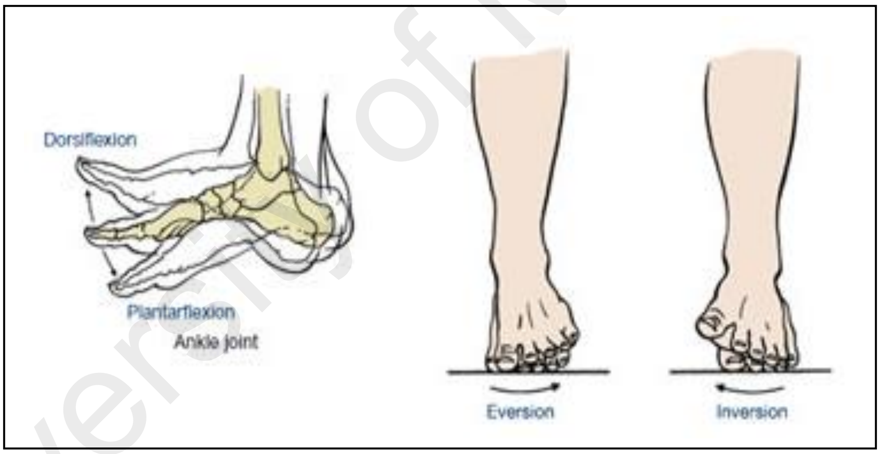


Figure 2.26: Ankle Kinematics on SP and FP– Reproduced from (Thompson 2017)

Table 2.5 : The description of Ankle Kinematics – Reproduced from (Thompson 2017)

Ankle Kinematics	Movement Description
Ankle plantarflexion	Pointing toes with the foot off the ground, or when standing, lifting heels off the floor
Ankle dorsiflexion	Lifting toes up off the floor toward the shin
Ankle inversion	Pull the foot toward the midline (ankle rolled out)
Ankle eversion	Pull the foot away from the midline (ankle rolled in)

Despite bearing high compressive and shear forces during gait, the ankle's bony and ligamentous structure enables it to function with a high degree of stability and compared with other joints such as the hip or knee, it appears far less susceptible to degenerative processes such as osteoarthritis, unless associated with prior trauma (Brockett and Chapman 2016). The ankle range of motion (ROM) has been shown to vary significantly between individuals due to geographical and cultural differences based on their activities of daily living, in addition to the method used for assessing ROM (Grimston, Nigg et al. 1993). Several studies have indicated an overall ROM in the SP of between 65 and 75°, moving from 10 to 20° of dorsiflexion through to 40–55° of plantarflexion (Brockett and Chapman 2016).

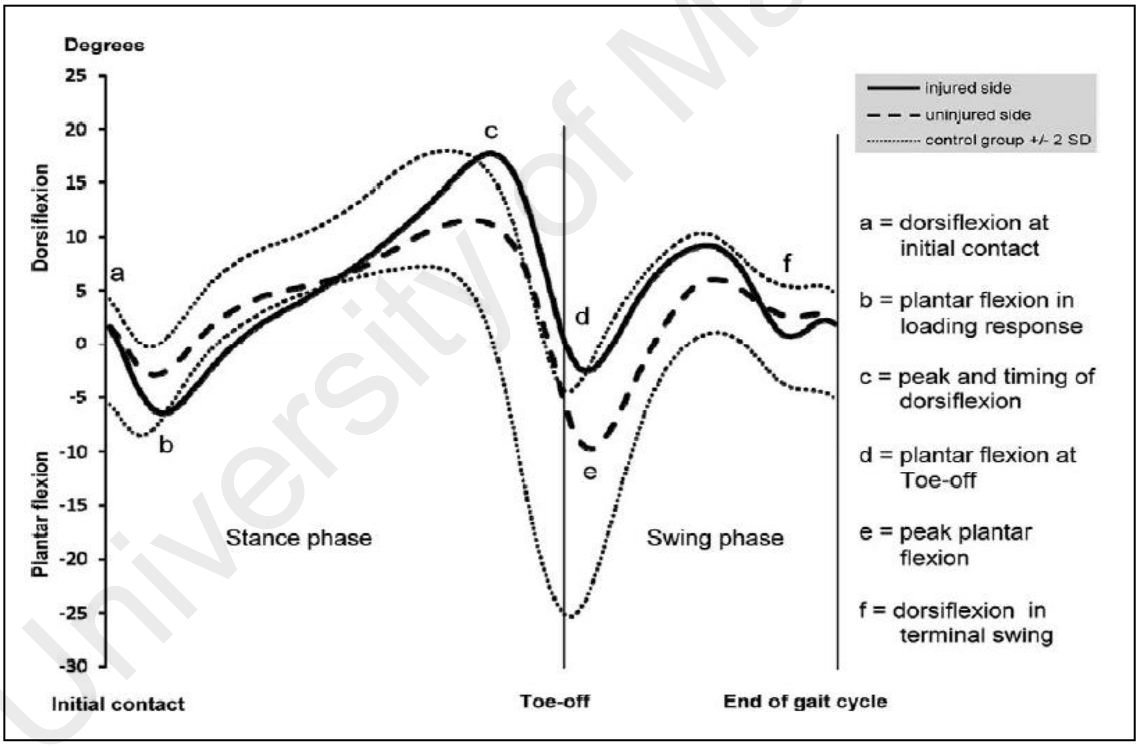


Figure 2.27: Ankle kinematics in the SP. Ankle movement (y-axis) during the gait cycle (x-axis) on the injured and uninjured side of 1 representative patient. (a) Dorsiflexion at initial contact; (b) plantar flexion in LR; (c) peak and timing of dorsiflexion; (d) plantar flexion; (e) dorsiflexion in terminal swing – Reproduced from (Tengman and Riad 2013).

The total range of motion in the FP is approximately 35° (23° inversion − 12° eversion) (Brockett and Chapman 2016). However, in everyday activities, the ROM required in the SP is much reduced, with a maximum of 30° for walking, and 37° and 56° for ascending and descending stairs, respectively (Brockett and Chapman 2016).

2.2.3 Past Studies on Kinematics of Movements

The ankle joint complex bears a force of approximately five times body weight during stance in normal walking, and up to thirteen times body weight during activities such as running (Burdett 1982). Age and gender are both influential factors that may change ankle ROM. A study compared gender differences within different age groups, between 20 and 80 year of age (Nigg, Fisher et al. 1994). This demonstrated that younger females (20–39 years old) have a higher ankle ROM compared to males (Nigg, Fisher et al. 1994). However, with increasing age, older females demonstrated 8° less dorsiflexion and 8° greater plantar flexion compared to male patients in the oldest age group (70–79 years old) (Nigg, Fisher et al. 1994). Additionally, there was a reduction in ROM for both genders in the oldest age groups (Nigg, Fisher et al. 1994).

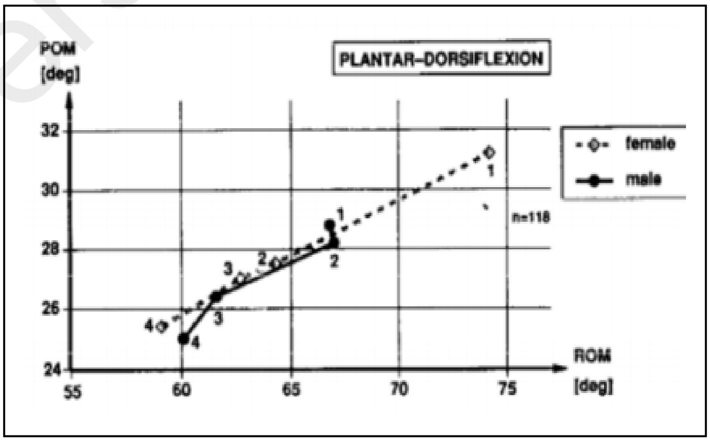
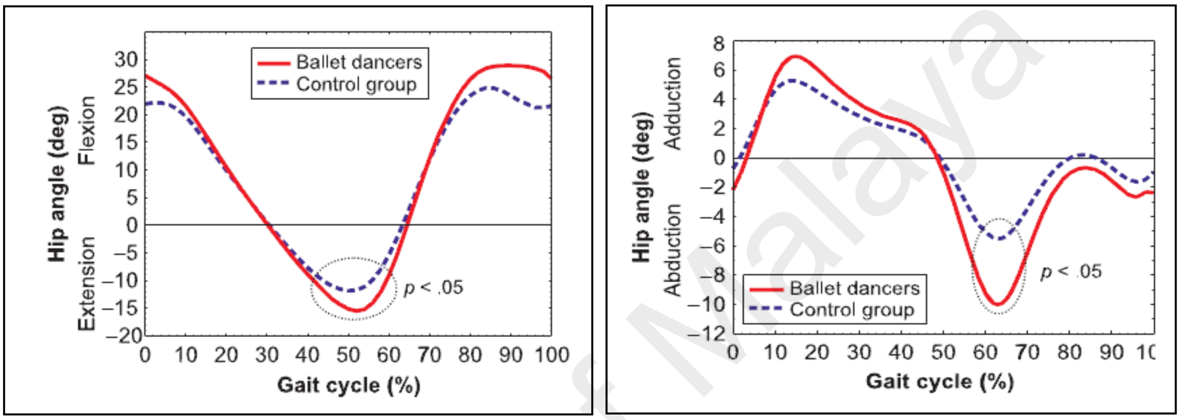


Figure 2.28: Comparison of Relationship between Path of Motion (POM) and (ROM) between females and males during ankle Plantar-Dorsiflexion during one walking gait– Reproduced from (Nigg, Fisher et al. 1994).

A ballet dance routine places extreme functional demands on the musculoskeletal system and affects the motor behaviour of the dancers (Teplá, Procházková et al. 2014). An extreme ballet position places high stress on many segments of the dancer's body and can significantly influence the mobility of the lower limb joints (Teplá, Procházková et al. 2014). The aim of this study was to observe the differences in the gait pattern between ballet dancers and non-dancers (control group) (Teplá, Procházková et al. 2014).



(a) (b)

Figure 2.29 : Hip movement in the SP (a) and FP (b) during walking gait–Reproduced from (Teplá, Procházková et al. 2014)

From the findings reported above, the dancers result in greater hip extension (–15.30 ± 3.31° vs. –12.95 ± 6.04°; p = .008) and hip abduction (–9.18 ± 5.89° vs.–6.08 ± 2.52°; p < .001) peaks.

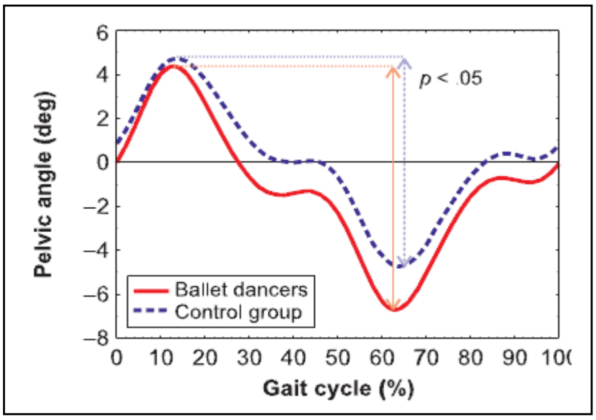


Figure 2.30 : Pelvic movement in the FP during walking gait – Reproduced from (Teplá, Procházková et al. 2014)

Besides that, increase in pelvic tilt (3.33 ± 1.26° vs. 3.01 ± 1.46°; p = .020), pelvic obliquity (12.46 ± 3.05° vs. 10.34 ± 3.49°; p < .001) and pelvic rotation (14.29 ± 3.77° vs. 13.26 ± 4.91°; p = .029) were observed too among dancer compared to control (Teplá, Procházková et al. 2014).

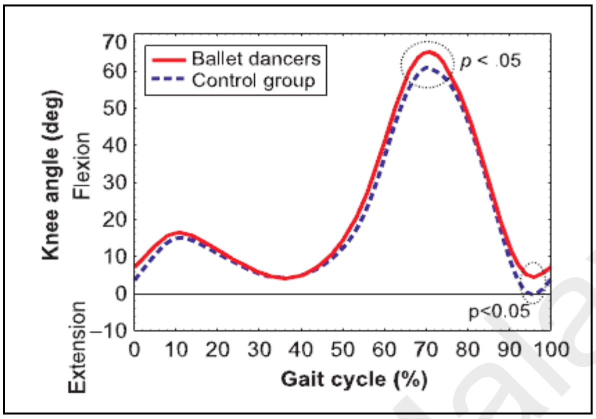


Figure 2.31 : Knee movement in the SP during walking gait – Reproduced from (Teplá, Procházková et al. 2014)

Additionally, the dancers demonstrated greater knee flexion (65.67 ± 4.65° vs. 62.45 ± 5.24°; p = .002) and knee extension (3.80 ± 4.02° vs. –1.54 ± 5.65°; p < .001) peaks during the swing phase when compared to the controls (Teplá, Procházková et al. 2014).

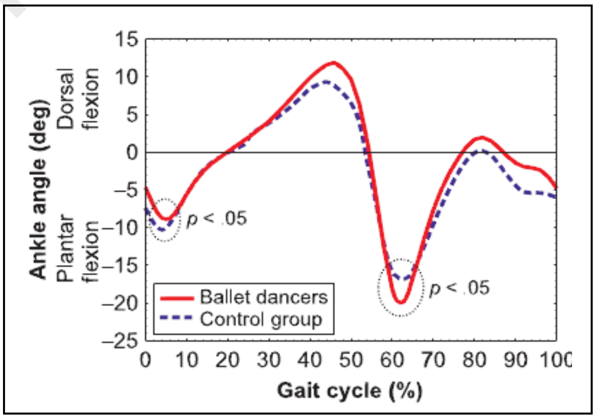


Figure 2.32 : Ankle movement in the SP during walking – Reproduced from (Teplá, Procházková et al. 2014)

Moreover, the dancers demonstrated decreased in maximal ankle plantar flexion during the LR (–8.84 ± 3.74° vs. –10.50 ± 3.99°) and increased maximal ankle plantar flexion in terminal stance (–20.30 ± 4.93° vs. –17.00 ± 3.99°; p = .025) (Teplá, Procházková et al. 2014). The study confirmed that long-term intensive ballet training affects the kinematic pattern of particular joints during gait performance (Teplá, Procházková et al. 2014). The findings suggest overloading in the lumbosacral region and dysfunction or weakness of several muscles in ballet dancers (Teplá, Procházková et al. 2014).

An extension of this study was presented in December 2018 aimed to assess the kinematics of the lower limbs and pelvis during normal walking in professional ballet dancers and to investigate relationships between movements of segments of the lower limbs and pelvis (Janura, Teplá et al. 2018). Thirty one professional ballet dancers and twenty eight controls completed five walking trials at their preferred speed (Janura, Teplá et al. 2018).

The female ballet dancers had in comparison with the controls significantly knee flexion in the swing phase and hip abduction in the pre-swing phase (Janura, Teplá et al. 2018). Compared to the control group, the male ballet dancers had significantly larger dorsiflexion in the final stance and the total pelvic tilt range of motion (Janura, Teplá et al. 2018). The number of significant correlations between kinematic parameters was higher in the female ballet dancers (Janura, Teplá et al. 2018).

The study concluded that specific movement techniques and compensatory strategies used in ballet dance can alter relationships between movements of segments of the lower limbs during normal walking (Janura, Teplá et al. 2018). The relationships between movements in the joints of the lower limbs and pelvis are stronger in women (Janura, Teplá et al. 2018).

	Women		Men	
	Dancers	Controls	Dancers	Controls
Ankle				
SP plantarflexion peak 1	-6.9 ± 2.50	-7.9 ± 3.06	-6.7 ± 1.9	-6.0 ± 2.29
SP dorsiflexion peak	13.7 ± 2.23	14.0 ± 2.65	**13.9 ± 2.55***	10.6 ± 2.59
SP plantarflexion peak 2	-21.7 ± 5.37	-21.8 ± 3.7	-19.2 ± 4.91	-17.3 ± 2.54
SP ROM	35.4 ± 4.68	35.8 ± 4.71	33.1 ± 5.92	27.9 ± 3.54
TP external rotation peak	-24.2 ± 6.02	-21.9 ± 4.14	-17.1 ± 3.92	-12.8 ± 6.24
TP internal rotation peak	7.0 ± 6.74	8.4 ± 4.84	5.9 ± 4.53	10.0 ± 7.68
TP ROM	31.2 ± 7.40	30.3 ± 6.29	23.0 ± 3.92	22.8 ± 6.64
Knee				
SP flexion peak 1	15.9 ± 5.08	18.7 ± 3.27	**14.0 ± 5.9***	21.3 ± 4.88
SP extension peak	1.3 ± 2.02	1.7 ± 2.00	2.2 ± 1.69	1.9 ± 1.42
SP flexion peak 2	**63.7 ± 3.52***	61.3 ± 3.16	63.7 ± 3.8	63.7 ± 9.35
SP ROM	62.4 ± 3.72	59.6 ± 4.74	61.5 ± 4.63	61.8 ± 8.93
FP abduction peak	4.2 ± 4.24	3.6 ± 4.87	14.4 ± 7.72	8.9 ± 6.97
FP adduction peak	-8.8 ± 5.52	-11.5 ± 7.38	-3.6 ± 4.24	-4.9 ± 3.56
FP ROM	13 ± 3.60	15.1 ± 5.08	18 ± 5.93	13.7 ± 4.17
TP external rotation peak	-12.4 ± 7.28	-12.2 ± 5.26	-11.6 ± 7.11	-11.1 ± 5.95
TP internal rotation peak	10.0 ± 7.87	6.6 ± 8.2.00	11.7 ± 8.04	10.7 ± 8.65
TP ROM	**22.4 ± 7.8***	18.8 ± 5.75	23.3 ± 5.88	21.8 ± 7.07
Hip				
SP flexion peak	30.6 ± 3.78	29.3 ± 3.30	28.4 ± 3.41	28.0 ± 1.74
SP extension peak	-17.1 ± 3.67	-16.0 ± 2.65	-16.2 ± 2.58	-16.2 ± 3.64
SP ROM	47.7 ± 3.86	45.3 ± 4.23	44.6 ± 2.6	44.2 ± 3.82
FP abduction peak	**-7.7 ± 2.01***	-6.1 ± 1.85	-6.7 ± 1.84	-6.2 ± 1.72
FP adduction peak	9.6 ± 3.19	9.1 ± 2.24	7.5 ± 1.82	6.3 ± 3.02
FP ROM	17.3 ± 3.5	15.2 ± 2.26	14.2 ± 2.49	12.5 ± 3.24
TP external rotation peak	-0.9 ± 4.98	-2.6 ± 4.16	-1.2 ± 5.19	-2.8 ± 3.67
TP internal rotation peak	5.0 ± 5.11	6.3 ± 3.97	6.1 ± 4.49	6.0 ± 3.70
TP ROM	5.9 ± 4.87	8.9 ± 2.72	7.3 ± 4.55	8.8 ± 3.47
Pelvis				
Tilt anterior peak	1.0 ± 4.98	2.6 ± 4.16	1.2 ± 5.19	2.8 ± 3.67
Tilt posterior peak	5.0 ± 5.11	6.3 ± 3.97	6.1 ± 4.49	6.0 ± 3.70
SP ROM	4.0 ± 4.59	3.7 ± 0.75	**4.9 ± 1.15***	3.2 ± 0.82
Obliquity down peak	-6.4 ± 2.62	-5.4 ± 1.58	-4.5 ± 2.05	-5.0 ± 2.5
Obliquity up peak	5.8 ± 4.1	4.8 ± 0.75	3.8 ± 0.92	3.7 ± 1.24
FP ROM	12.2 ± 3.64	10.2 ± 1.92	8.3 ± 2.60	8.7 ± 3.20
External rotation peak	-5.8 ± 1.94	-6.6 ± 2.44	-5.7 ± 1.61	-6.9 ± 2.22
Internal rotation peak	6.2 ± 3.85	6.3 ± 2.63	5.8 ± 2.34	6.9 ± 1.89
TP ROM	12 ± 5.45	12.9 ± 5.01	11.5 ± 3.83	13.8 ± 3.95

Figure 2.33: Peak angular values and ROMs in the ballet dancers and the control group; All values are in degrees and presented as mean ± standard deviation. * indicates statistically significant difference with the control group – Reproduced from (Janura, Teplá et al. 2018).

2.3 Summary of Literature Review from Related References

Table 2.6: 30 Related References Comparison Table

No	Title	Authors	Methodology	Pro	Con	Remarks
1	Ground reaction forces and heart rate profile of aerobic dance instructors during a low and high impact exercise programme	(Rousanoglou and Boudolos 2005)	(1) Fourteen females and 14 males' instructors performed a 35 min AD (Aerobic dance) exercise programme (warm up--low impact (LI) interval--in high impact (HI) interval--cool down)	This study was designed to investigate 2 parameters which are GRF and heart rate (HR)	No Kinematic study	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Four Ground Reaction Forces (GRF) measurements were taken during pre-determined intervals	14 females and 14 males' instructors recruited for this study; there is balance is subject numbers and gender	Long data collection: 35 mins	
			(3) Heart rate (HR) was recorded throughout the whole experimental procedure and was synchronised to GRF measurements	Preliminary studies measure HR only. There is clear path set towards the result of this research	ECG reading affected by sweat	
2	Ground reaction forces in step aerobics	(Fujarczuk, Winiarski et al. 2006)	(1) Sixteen healthy female students recruited with signed consents provided	Female gender focused study	Low frequency force plate; 250 Hz	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Each subject asked to perform 11 basic steps on the force plate	Good choices of basic steps		
			(3) The movement was repeated 10 times by the subjects. On the 11th trial the subject was instructed to remain on the platform for additional 5 seconds for her weight measurement	Predefined baseline for GRF as subject asked to stand on force plate for 5 seconds; this ensures accurate data collected and avoid errors		
				COG studies included		
				Good result presentation; Graphs, Bar charts and tables		
3	Rehabilitation of a Female Dancer with Patellofemoral Pain Syndrome: Applying Concepts of Regional Interdependence in Practice	(Welsh, Hanney et al. 2010)	(1) A 17-year-old female dancer with patellofemoral pain syndrome recruited	Detailed patient assessment	No Kinematic and kinematics study	Full published articles with complete assessments and rehabilitation plan
			(2) Subject's bio info (height, weight, mass, waist-hip ratio and mass index), trauma history and dancing history recorded	Health and trauma history recorded	No statistical analysis, based on observation only	
			(3) Perform test and measures: Standing postural assessment, Measure subject's active range of motion (AROM), pain level test, muscle length & strength and Lower Extremity Functional Scale	Propose simple exercises, which can be done by all age groups to enhance muscle endurance and reactivate neuro muscular	Only one subject studied	

			(4) Plan rehabilitation program	Patient's improvement can be monitored gradually due to the frequency of the visits	Other factors not considered; gender, race etc	
			(5) Record patient's progress over 5 visits			
4	Ground reaction forces and knee mechanics in the weight acceptance phase of a dance leap take-off and landing	(Kulig, Fietzer et al. 2011).	(1) Twelve dancers (six males, six females with no history of low back pain or lower extremity pathology recruited	Examined the vertical ground reaction force and knee mechanics during a saut de chat (specific dance movement) performed by healthy dancers	Limited Kinetics analysis	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Subjects fitted with reflective markers	Hypothesis set before experiment: Vertical ground reaction force during landing would exceed that of take-off, resulting in greater knee extensor moments and greater knee angular stiffness		
			(3) Each subject required to perform a standing static trial, followed by movements	Proper lab: Three-dimensional lower extremity kinematic data were collected using an eight-camera motion analysis system at a sampling rate of 250 Hz	Dominant and non-dominant leg not considered	
			(4) Three-dimensional lower extremity kinematic data were collected using an eight-camera motion analysis system at a sampling rate of 250 Hz	Both Kinetics and Kinematics studies included		
			(5) Data were filtered using a fourth-order, zero-lag Butterworth 12-Hz low-pass filter	Modern analysis: All statistical procedures were conducted using SPSS software version 16.0		
5	Lower extremity kinetics in tap dance	(Mayers, Bronner et al. 2010)	(1) Six professional tap dance performers recruited for this study with written consent	A one-way repeated measures ANOVA was used to assess differences in the vertical GRFs	Lab calibration not included	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Four commonly performed tap dance sequences were selected for study: flaps, cramp rolls, pullbacks, and one self-selected sequence considered by the subject to be technically demanding	Post hoc comparisons using Bonferroni corrections were conducted		
			(3) Subjects practiced each sequence prior to data collection to synchronize their movements	Subjects consist of Six professional tap dance performers	Kinematics data not studied	
			(4) These movements were repeated 4 to 8 times on the force plate within each sequence, and a tape recording of a metronome with voice instruction overlay provided the tempo	A power analysis (power 0.80) using pilot data to calculate one and two-tailed test sample size determined that six subjects were sufficient for the study		

			(5) Means for each kinetic variable (peak vertical, anterior-posterior, and medial- lateral GRFs, and hip, knee, and ankle joint net forces and moments) were calculated for each subject to minimize intra-subject variability. Descriptive statistics were calculated for each sequence	Descriptive statistics were calculated for each sequence	Too much gap in participant age	
6	Analysis of Lower Extremity Muscle Flexibility among Indian Classical Bharathnatyam Dancers	(Anbarasi, Rajan et al. 2012)	(1) 401 female dancers (177 – Normal, 224 – Injured) and 17 male dancers (13 – Injured, 4 – Normal) recruited with signed consents	Good inclusion and exclusion Criteria applied in subject selection	Number of female and male subjects not balanced	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Flexibility variables (joint angle) were measured using a 3m plastic goniometer of 360° movements	Big number of subjects consist of professional dancers studied		
			(3) *Hamstring study*: The subjects were positioned in supine lying such that the lower extremity to be measured was in 90° of hip flexion and full knee extension. Assistance taken to maintain the hip in 90° of flexion and subjects were asked to do knee extension actively without verbal encouragement	Background info captured; Each dancer was given a questionnaire to know their age, years of experience and duration of dancing per week also those who had pain were asked to describe its quality, nature duration and associated disability.	No Kinetics and Kinematics analysis	
			(4) *Tendoachilles study*: Ankle dorsiflexion was measured in full knee extension as well as in 90° knee flexion in high sitting		Observational Study conducted for muscle tightness and flat foot. Concrete results can be achieved with statistical methods	
			(5) *Hip Internal and External Rotation (IR & ER):* Passive range of motion in internal and external rotation for hip was measured in supine, with both knees flexed and extended over the end of treatment plan	Both observational method and statistical analysis applied		
			(6) *Iliotibial Band Tightness (ITB):* Measured in side lying, where hip is stabilized and the knee joined is extended, abducted and allowed to fall in internal rotation	Modern analysis: All statistical procedures were conducted using SPSS software version 12.0		
			(7) Elly's Method: To find the quadriceps muscle tightness			
			(8) Measure Flatfoot: Subject stand in single leg and observe the medial arch position. If the foot musculature is weak then the medial arch collapses	The whole lower limb muscles studied		
7	Ground Reaction Forces and Loading	(Puddle and Maulder 2010)	(1) Ten male New Zealand based traceurs were recruited for this study	Landing strategy based on Bressel et al., 2005; Dufek et al., 1990	Lack of literature surrounding the	Full published articles complete

	Rates Associated with Parkour and Traditional Drop Landing Techniques		(2) Participants perform three types of drop landings (5 trials) from a platform from different heights	Five trials taken based on recommendations from Bates et al (1992) that state that five trials are required to achieve adequate statistical power when recording data from 10 participants.	Parkour pursuit and thus no normative data in which to base specific technique instruction upon	with data and report. Therefore, easy to follow the procedure
			(3) Dominant leg, or leading leg as it will be referred to in this study, was determined by having participants perform several drop landing trials without any instruction. Leading leg refers to the moving leg, whereas the non-dominant leg refers to the leg used for support	Pre-experiment; During the testing session participants completed a thorough warm up [involving five minutes of non-weight bearing activity (cycling) followed by self-directed dynamic stretching. A familiarization period of three attempts at each drop landing was employed following the warm-up.		
			(4) Data collected using BioWare software integrated with the force plate	Pre-determined hypothesis; Both Parkour techniques would result in lower vertical ground reaction forces and loading rates, with slower times to maximal vertical force than the traditional technique, based on the dissipation of forces involved in both respective movement patterns		
8	Correlation of Degree of Toe Out and Anterior Knee Pain in Bharatanatyam Dancers	Anand Heggannavar, Sanjana KS, Santosh Metgud	(1) 50 subjects with mix of males and females aged between 18 to 30 years recruited for this study with signed consent	Big number of subjects consist of professional dancers studied	Legacy way to determine angle and rotation; Draw on paper	Full published articles complete with data and report. Unfortunately, old methodology used. Subjects are beginners in dancing
			(2) Subjects asked to answer Kujala scoring questionnaire (Kujala et al, 1993); It documents response to activities especially associated with anterior knee pain syndrome. Scoring was done for 100. Lesser the scoring greater is the pain or disability	Kujala scoring questionnaire (Kujala et al, 1993) used to measure knee pain	No Kinetics study	
			(3) Visual Analogue Scale: VAS is a horizontal line, 100 mm in length, anchored by word descriptors at each end. The subject marks on the line the point that they feel represents their perception of their current state. The VAS score is determined by measuring in millimetres from the left-hand end of the line to the point that the patient marks	Correlation between various parameters studied: BMI, VAS, Kujala, and Toe out score Spearman's rank	Number of female and male subjects not balanced	

			(4) Degree of Toe: Out Functional turn out: The toe-out angle is defined as the degree of external rotation of the foot with respect to the direction of progression; measured by asking the subject to stand on a white paper and assume the position which they assume in their dance class	Excellent data representation; Combination of Line and Dot graph	Subjects are not professional dancers, only beginners	
			(5) A tracing was made around their feet. The angle bisecting the longitudinal arches of the foot was measured using a universal goniometer. This was functional turnout angle. Hip external rotation was measured by asking the subject to sit in high sitting position. Then the subject's passive hip external rotation was measured using universal goniometer	Kolmogorov smirnov test used for statistical analysis	Result of study still may not be as accurate as VICON systems	
			(1) Sixteen female Irish dancers between 14 and 25 years of age were recruited from the 3 highest competitive levels	Hypothesis set before experiment: 8 moves would produce different GRFs	Dancers were cued to produce a good trial	
			(2) Each performed a warm-up, reviewed 8 common Irish dance moves, and then performed each move 3 times upon a force plate	Peak forces normalized by each dancer's body weight were significantly different across moves		
9	Ground Reaction Forces for Irish Dance Landings in Hard and Soft Shoes	(Klopp 2017)	(3) Four moves each were performed in soft and hard shoes	Data collected after the training for a major competition was complete and before the training for the next major competition began		Full published articles complete with data and report. Therefore, easy to follow the procedure
			(4) GRFs were measured using a 3-dimensional force plate	This study examined 16 female nonprofessional Irish dancers that have reached the top 3 competitive levels, Open Prizewinner, Preliminary Championships, and Open Championships.	No Kinematics study	
			(5) Peak force, rise rate, and vertical impulse were calculated	Dancers practiced each sequence prior to data collection to synchronize movements to the metronome and ensure landing on the force plate.		
10	Ground Reaction Forces during Tatta Adavu of Bharatanatyam	(Shenoy 2019)	(1) Seven experienced dancers recruited for the study. Inclusion Criteria: be at least 18 years of age, have at least 5 years of experience, and practice the dance at least 2 times a week. Exclusion criteria: Any injury in the past 6 months or surgeries in the past year and if they practiced any other dance form to avoid adulteration	This was a first of a kind study looking into the biomechanics of the Bharatanatyam dance form	No GRF graph included in results	Full published article. Incomplete data and results. Researchers without Indian dance background might have trouble identifying the movements
			(2) Subjects conducted a 10-minute warm up before the session			

			(3) The dancers attained the ardhamandala posture (half sit) and performed the tatta adavu step at two speeds – 49 beats per minute and 200 beats per minute.	Result compared with other published dance forms and movements	No Data analysis during flexion and extension of the leg	
			(4) The dancers performed the step with only one foot on the force plate at a time. And repeated the movement with the other foot on the force plate			
			(5) The data was analysed using R and presented as descriptive statistics			
11	Biomechanics and Proprioceptive Differences during Drop Landings between Dancers and Non-Dancers	(Volkerding 2013)	(1) Eight collegiate dance majors (min 8 years training) with ballet as a specialty recruited as subjects. Likewise, seven non-dancers recruited as well for comparison. All subjects signed consents	Balanced number between dancers and non-dancers	Per session data collection takes up to 30 mins, subjects might be exhausted and physically drained	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Participant filled out a questionnaire, which contained both medical history and physical activity	Precise kinematics study: Markers on dominant side		
			(3) Reflective markers placed on the predetermined landmarks and joints along the right side of the body for each subject (sagittal plane, dominant side)	Natural data collected: Random height and eyes condition selection. Besides, jump based on self-initiated time frame		
			(4) With barefoot, subjects instructed to step from the platform and land with both feet on the force plate simultaneously	Both medical history and physical activity of subjects documented		
			(5) kinematic recordings were conducted on subject's dominant side	Good literature review on kinematics and kinetics of landings between genders		
			(6) The subjects then performed drop landings from three different heights (0.2m, 0.5 m, 0.8 m), landing onto the force plate with the right side of the body facing the camera for data collection.	Both Kinetics and Kinematics studies included	Due to the height of the box with multiple trials, subjects might experience fatigue	
			(7) Total four Successful trials taken (2 for eyes open, and 2 for closed eyes			
			(8) All jumps are self-initiated	Statistical analysis of the data was conducted to determine the significance of the results with an alpha value of 0.05. A repeated measure 3 (heights) x 2 (groups) x 2 (vision conditions) MANOVA was performed in SPSS 16.0		
			(9) Conditions set: 0.2 m vision, 0.2 m no vision, 0.5 m vision, 0.5 m no vision, 0.8m vision, and 0.8m no vision			
			(10) subject was randomly assigned to the order of 0.2m, 0.5m, 0.8m, the subject would drop from each height with eyes open and eyes closed two times (alternating between vision and non-vision depending			

			on what they were randomly assigned to) before proceeding to the next height.			
12	Analysis of foot load during ballet dancers' gait	(Prochazkova, Tepla et al. 2014)	(1) Thirteen professional dancers (5 men, 8 women) and 13 nondancers (5 men, 8 women) recruited with signed consent	Professional dancers recruited for this study	Only foot analysis	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) The participants were instructed to walk across the platform at a self-selected pace barefoot	The control group; non-dancers consist of members from maximum competitive level in sport activities and also no operations of lower extremities		
			(3) Foot pressure analysis during gait was collected using a 2 m pressure plate	The software allows foot to be automatically divided into 10 areas	There is no Kinetics and Kinematics studies	
			(4) Three gait cycles were necessary for the data analysis	Specific foot analysis: % of pressure peak, % contact, and % pressure impulse		
			(5) The gathered data were analysed by the Footscan gait software			
13	Comparison of gait kinematics between professional ballet dancers and non-dancers	(Janura, Teplá et al. 2018)	(1) Thirty-one professional ballet dancers (17 women and 14 men) recruited for this study. The control group comprised 28 participants: 18 women and 10 men	Subjects have average ballet dance experience of 19 years (range 9–28). All dancers practiced 5 or 6 days a week, on average 7.3 hours a day (range 6–10)	No balance between genders in the control group	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) All the participants underwent anthropometrical measurements where their body mass, body height, functional length of the lower limbs, and ankle and knee widths were obtained	Methodology explained clearly, step by step		
			(3) sixteen reflective markers were attached on the lower limbs and the pelvis according to the Vicon Plug-in Gait model	Equipment and software information mentioned in detail		
			(4) Each participant underwent several trials for familiarization and five trials recorded for analysis	Excellent statistical analysis: Statistica 10.0 was used for all statistical analyses. Shapiro-Wilk test was performed to assess normality of data distribution.	Limited data representation: Only table	
			(5) Walking trials were conducted on a 9-meter-long walkway, which had in its centre embedded two force plates	t-test: detect differences between the ballet dancers and the control group for variables that conformed to the normal distribution		

			(6) Subjects walked barefoot at their self-selected preferred speed on the walkway	Associations between variables were determined with Spearman rank correlation coefficients		
			(7) Recorded kinematic data were filtered in Vicon Nexus 1.6 (Woltring filter with a cut off frequency of 10 Hz)	Detailed discussion; flexibility and muscular strength studied		
			(8) Kinetic data were divided into the stance and swing phases			
14	Dancers entrain more effectively than non-dancers to another actor's movements	(Washburn, DeMarco et al. 2014)	(1) Seventy undergraduate students ranged in age from 18 to 35 years recruited for this study. Thirty-five participants (16 female, 19 male) did not have formal dancer training, while the other thirty-five participants (31 female, 4 male) were dancers who had at least 5 years of formal dance training	Professional dancers recruited for this study	Dancers' background info is not taken into consideration; health, trauma history and training frequency	Full published articles complete with data and report. Therefore, easy to follow the procedure
				Another way to collect kinematics data: Microsoft Kinect for Windows sensor used to collect Kinetics data		
			(2) Each participant was asked to stand in the centre of the room diagonally behind the confederate (1 m behind and 2 m to right), and facing the same direction as the confederate	Each dance sequence lasted 60 seconds, experiment time frame doesn't cause subjects to be exhausted		
			(3) Microsoft Kinect for Windows sensor was placed on the floor, ~2 m in front of the confederate and 0.67 m to the right of the confederate's starting position. Movement data were collected by the Kinect at a sampling rate of 10 Hz	The last 50 s of each trial were used for analysis to eliminate transients that occurred at the beginning of each trial	Other parameters ignored: shoe type, room lighting etc	
				Statistical analysis performed using MATLAB (Cross-correlation coefficient, xcorr(h) etc)		
			(4) Three distinct sequences of dance-like movements were choreographed for use in this study	Multiple signal analysis for comparison: Cross-correlation, Cross-wavelet spectral analysis and Cross-recurrence quantification analysis		
15	Gait Kinematics After Taping in Participants With Chronic Ankle Instability	(Chinn, Dicharry et al. 2014)	(1) A total of 15 individuals (8 men, 7 women) with self-reported chronic ankle instability recruited for this study with signed consent. All subjects had a history of at least 1 ankle sprain	Subjects are consist of students and surrounding community	Costly lab setup	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) For data collection, participants walked and then jogged on the treadmill at speeds of 1.34 m/s and 2.68 m/s	All participants were involved in moderate or vigorous physical activity at least 3 times per week as determined by the Godin Leisure Time Exercise Questionnaire		
			(3) Synchronized ground reaction force data were collected by a multi-axis strain gauge force plate embedded under a custom-built treadmill		Requires assistance from clinician to be on standby	

			(4) Gait kinematics were computed from captured reflective marker locations sampled at 250 Hz using a 12-camera analysis system	Conditions assigned randomly to subjects		
			(5) Synchronized ground reaction force data were collected by a multi-axis strain gauge force plate embedded under a custom-built treadmill	Good results and data representation		
			(6) Vertical ground reaction forces were sampled at 1000 Hz with a threshold of 60 N to determine initial contact and toe-off during walking and running	Subjects Exclusion criteria were a history of ankle fracture, vestibular or neurologic disorders, or any lower extremity or lumbosacral injuries within the previous 3 months that could adversely affect neuromuscular function		
			(7) Three-dimensional joint kinematics were collected using a Vicon Plug-in Gait model			
16	Kinematic analysis of the gait in professional ballet dancers	(Teplá, Procházková et al. 2014)	(1) Thirteen professional ballet dancers (5 males, 8 females) and twelve non-ballet dancer subjects (control group) recruited for this study	None of the participants had any history of serious musculoskeletal pathology or injury or surgery in the lower limbs	No Kinetics study	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Each subject performed five trials of the gait at self-selected walking speed	Non-parametric test (Mann-Whitney U test, $p < .05$) was applied for comparing the dancers and the controls		
			(3) Kinematic data was obtained using the Vicon MX optoelectronic system	Professional ballet dancers recruited for this study	No balance between genders among	
			(4) The kinematic data was processed in the Vicon Nexus and Vicon Polygon programmes and statistically evaluated in Statistica	Calibration done prior to experiment		
17	Comparison of lower limb stiffness between male and female dancers and athletes during drop jump landings	(Ward, Fong Yan et al. 2019)	(1) Forty dancers (20 M and 20 F) and 40 team sport athletes (20 M and 20 F) were recruited as subjects	Subjects consist of Six professional dancers and athletes	Due to technical issues, data from one male dancer were incomplete for the purpose of calculating joint stiffness	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Subjects performed three single-leg drop landings from a 30-cm platform onto a force plate	All participants had no history of surgery to the lower extremities, no current lower extremity injuries, and no lower extremity injuries within the previous year	Studies only focused on dominant leg	

			(3) Subjects were required to cross their arms over their chest and begin each trial in single- limb stance on the dominant leg	Net joint moments were calculated for each joint by standard inverse dynamic techniques using specialized computer software (Visual 3D; C-Motion Inc, Rockville, MD, USA)	Each subject wore their own personal athletic shoes	
			(4) Subjects then dropped off the platform and landed on the force plate using the same leg	A spring-mass model was used to calculate vertical leg stiffness (Kleg) and joint stiffness (Kjoint) of the hip, knee, and ankle	Dancers were older than athletes, but males and females were of similar age across both training groups	
			(5) Kinematics data collected at 250 Hz using eight Eagle cameras			
			(6) Ground reaction forces (GRFs) were recorded at 2500 Hz with a multi-component force plate	Clear methodology; Movement image included		
18	Electromyographic analysis of ankle muscles in young adults with Down syndrome before and after the implementation of a physical activity programme based on dance	(Massó-Ortigosa, Gutiérrez-Vilahú et al. 2018)	(1) Subjects consist of Twelve young adults with Down Syndrome (DS) and 12 young adults without DS aged around 17-22 recruited with both theirs's and parent's consent	The inclusion criteria: For the DS group were a level of ID (Intellectual Disabilities) between 30% and 59%, which implies an Intellectual Quotient percentile (IQ) of 33-70%	Baseline setup doesn't require both closed and open eyes	Full published articles. Methodology is not clear as placings of EMG sensors not defined; dominant/non-dominate side, no images on experimental procedure
			(2) Medical history and anthropometric assessment	The exclusion criteria: For the DS group were; mobility problems, standing difficulty, vestibular or neuromuscular disease, and any additional psychiatric diagnoses requiring drug therapy	No long-term follow-up since most students in the study transitioned from the education centre to a workplace	
			(3) Setting baseline: Subjects stand static while keeping their eyes fixed on a Y-shaped mark located in front of them at approximately eye-level. Procedure repeated with closed eyes	Standards, measures, and recommendations of the International Society for Progress in Cineantropometría were used for anthropometric assessment		
			(4) Electromyographic (EMG) assessment; Sensors attached at the lateral and medial gastrocnemius, anterior tibialis, and soleus. For each recorded time interval, two variables were computed for each muscle: the area under the curve for the processed EMG signal and the mean amplitude	For the descriptive data, differences between groups were analysed by Mann Whitney U test	Study on based on one side of lower extremity; dominant side	
			(5) Subjects in both groups followed an 18-week PA programme (two 90 min sessions per week) based on classical, modern, and creative dance	Intra-group differences in pre- and post-training values were analysed by Wilcoxon test	Study did not separate the groups by gender	
			(6) After completion of each PA session, repeat (3)	An ANOVA was used to assess differences in pre- and post-exercise changes between groups.		

19	The Differences in Gait Pattern Between Dancers and non-Dancers	(Lung, Chern et al. 2008)	(1) Thirty-three subjects were recruited for the purposes of this study where 13 of them are female students of dancing department. The control group consist of 20 individuals who were young female and non-dancers	The exclusion criteria for all of the subjects were history of injury to the lower leg, ankle, and foot within 6 months of study commencement, as well as foot structural problems as examined by radiography	Single gender-based study	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Subjects were instructed to walk along the 10-meter walkway at a self-selected walking speed to eliminate the influence of ambulation velocity on the kinetic variables measured by the force plate incorporated with pressure plate	A set of baseline data, including age, body weight and height, and active ankle joint range of motion, were measured before gait analysis. Maximum dorsi-plantar flexion, and inversion-eversion were measured with a fixture in unweight bearing. Tibial torsion was assessed by measuring the thigh-foot angle when the subjects relaxed and knelt on chair, with his knee and ankle each at 90 degrees	A pressure plate incorporated flush with the top of an force plate	
			(3) During the trials, subjects were asked to look at a target placed about 160 ~ 170cm above floor level on the wall at the end of the track	Gait variables defined clearly with equations	Final Result: GRF graph is not clear	
			(4) A successful trial was defined as one in which the foot of the subject landed completely on the pressure plate	Statistical analysis performed: Kolmogorov-Smirnov test		
			(5) Each subject walked through the walkway ten times	Visual fixation performed to prevent the subjects from adjusting their walking style while aiming at the pressure plate		
			(6) The averaged data from five successful steps for each foot was used in the analysis			
20	A comparison between professional dancers and non-dancers	Ana M. Azevedo, Ra´ ul Oliveira, Jo˜ao R. Vaz, Nelson Cortes	(1) 15 professional dancers and 15 non-dancers recruited for this study	A complete 3 trials processed	The multisegmented foot model not considered for this research	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Marker trajectories and synchronized ground reaction forces collected using motion capture and a force plate, during multidirectional single leg jump-landings	Exclusion criteria: Trials were excluded if participants lost balance, hopped, stepped off or shifted the dominant foot on the force plate; if they touched the force plate with the non-dominant foot; or if they removed their hands from the hips		
			(3) Sagittal and frontal hindfoot-tibia, forefoot-hindfoot, and hallux-forefoot kinematics of the multi-segmented foot model were computed at initial contact, peak vertical ground reaction force and peak knee flexion	Data were analysed using SPSS and mixed model analysis of variance (ANOVA) was performed to assess differences for all dependent variables	No comprehensive foot kinematic data of the foot-ankle function	

			(4) Repeated measures ANOVAs were conducted (p<0.05)	If significant differences were attained, pairwise comparisons with a Bonferroni adjustment were conducted	Muscular contribution for shock absorption not considered	
21	Comparison of Gait of Young Men and Elderly Men	(Blanke and Hageman 1989)	(1) 24 healthy males recruited, 12 between 20 and 32 years of age and 12 between 60 and 74 years of age. Young men were recruited to match the elderly men based on right-leg length	All subjects were found to be free of disabling physical conditions or minor ailments that could affect or influence locomotion based on a medical review and an objective examination by a licensed physical therapist	Long experiment: 45 mins (subjects can be stressed especially the older ones)	Full published articles complete with data and report. Pilot study established back in 1989 to capture kinematics data using video recording and markers placed at joints
			(2) Each subject participated in three filmed trials of free-speed ambulation down a 14-m walkway	An average of three independent measurements was used to determine values for leg length and for skinfold thickness, which were used to determine the percentage of body fat	Markers location at joints not defined and unclear	
			(3) The processed film was analysed for eight gait characteristics			
			(4) Differences in characteristics between the two groups were examined using a correlated t test (p < .01)	Leg lengths were measured to ensure that each subject was without a leg-length discrepancy (±1.9 cm) as defined by Subotnick		
22	A Comparison of Gait Characteristics in Young and Old Subjects	(Ostrosky, VanSwearingen et al. 1994)	(1) Sixty subjects in good health were recruited. Thirty subjects (15 male, 15 female) were between 20 and 40 years of age, and 30 subjects (15 male, 15 female) were between 60 and 80 years of age	The health status of each subject was determined by a screening evaluation performed by a licensed physical therapist	Long experiment: 45 mins (subjects can be stressed especially the older ones)	Full published articles complete with data and report. Early study established back in 1994 to capture kinematics data using integrated computer video system is tailored for motion analysis and consists of an NEC TI-23A CCD video camera with a 12.5-mm television lens on a tripod approximately 81 cm above the floor, a high-intensity light mounted parallel to
			(2) Subjects were videotaped walking down a 6-m walkway with reflective markers at six locations along their right side	All subjects participating were without appreciable leg-length discrepancy (≤ 0.5 cm), demonstrated freedom of movement in all planes of trunk motion, and complained of no functional limitations in trunk movements	Requires high intensity light to activate the markers	
			(3) The videotape was analysed for nine gait characteristics using a two-dimensional video motion analysis system	Subjects undergo standard muscle test	Manual distance travelled measured: The investigator drew a	

			(4) Differences in gait characteristics between the two groups were examined using a multivariate analysis of variance, followed by univariate F tests	Markers placing defined: iliac crest, greater trochanter, middle of the knee joint, approximate centre of mass of the lower leg and foot, heel, and fifth metatarsophalangeal joint	line joining the hip and knee centroids on the computer monitor, and the actual distance (in centimetres) between the hip and knee markers measured on the subject was equated with the number of pixels (the computer unit of distance) between these two points	the video camera, a Panasonic Model TR-124MA video monitor, Panasonic Model AG- 6300 VHS player a VP-110 video processor and an IBM AT computed with display terminal and mouse
23	Principal Components Analysis of Comtemporary Dance Kinematics	(Hollands, Wing et al. 2004)	(1) Two contemporary dancers recruited for this study (1 female and 1 male)	Whole body setup: 32 markers	Small sample size; only 2 subjects	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) A 15s movement phrase of contemporary dance choreographed			
			(3) The first dancer was instructed to create a movement phrase by defining 3 self-selected reference points in space around the body and then weave a series of movements in and around these points in such a way that both hands passed repeatedly through the reference points	Whole body kinematics studied; 32 markers	Complex data processing	
			(4) Once the first dancer was content with the movement phrase he had created, he was asked to reproduce it 6 times without further change	Application of Principal Components Analysis (PCA); An algorithm extracts a small number of components that sufficiently describe the total variation in the original variables. PCA can be used for complex data		
			(5) The first dancer transfers the knowledge to the second dancer the phrase and, once she was confident, she had memorised the sequence, she reproduced it 6 times			

24	Dancers with Achilles Tendinopathy Demonstrate Altered Lower Extremity Takeoff Kinematicsrates	(Kulig, Loudon et al. 2011)	(1) Sixteen female dancers with and without a history of AT (Achilles tendinopathy) recruited for this study	Well defined inclusion criteria: (1) history of pain located completely within the Achilles tendon, confirmed by tenderness to palpation, (2) history of pain with Achilles tendon loading tasks (jumping, leaping, running, etc) for a duration of greater than 3 months, and (3) currently training and performing without self-reported activity limitations related to Achilles tendon pain or other causes	Single gender-based study	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Each subject performed a minimum of 3 trials of a saut de chat. They were instructed to, “Perform your best, performance-level saut de chat	Well defined exclusion criteria: Participants were excluded if they had any of the following: (1) history of lower extremity surgery or trauma, (2) ankle or knee effusion, or (3) ankle or knee joint instability	Data collected retrospectively and, therefore, were unable to show kinematic differences that might have occurred prior to the onset of AT	
			(3) Kinematic data were collected using an 8-camera, 3-dimensional motion analysis system	Statistical analyses were performed using SPSS statistical software	The statistical analyses were presented for each variable and were not corrected for multiple comparisons; therefore, the possibility of a type II error cannot be excluded	
				Differences in peak joint angles between groups for each phase, for each joint motion, in the sagittal, frontal, and transverse planes were evaluated using independent samples t tests	Due to the limited amount of movement in the transverse and frontal planes, there was a possibility of greater relative measurement error	
25	A Comparison of Basic Rhythm Movement Kinematics Between Expert and Non-	(Sato, Nunome et al. 2013)	(1) Ten expert (experts) and twelve non-expert (non-experts) hip hop dancers recruited in this study	Expert subjects evaluated by experienced judges	Result: Unable to confirm the relationship between motion characteristics	Full published articles complete with data and report. Methodology unclear; marker
			(2) Five experienced judges with an average judging history of 10.2±3.7 years evaluated the performance of all dancers	Judges were also blinded to the evaluations of other judges		

	Expert Hip Hop Dancers		(3) In the basic rhythm movement, dancers were required to bounce their body up and down repeatedly by flexing and extending neck, trunk and lower extremities		and judge’s evaluation on hip hop dance	placing not defined, lack in visual aids
			(4) There are two different techniques of basic rhythm movement; namely the DOWN and UP techniques; In the DOWN technique, dancers move the body downward synchronizing with the downbeat while in the UP technique, dancers get into the rhythm by upward body movement synchronizing with the down beat	Several kinematic parameters were calculated including neck, trunk, hip, knee joint angles and the displacement of the body centre of mass (COM)	Assumptions: Vertical amplitude in rhythm movement was not an important factor distinguishing between expert and the non-expert performers	
			(5) Subjects perform the basic rhythm movement to the pulse of the metronome operating at 100 beats per minute (bpm)	Statistical differences of the average values between the groups were examined using unpaired t-tests		
			(6) Ten cycles of bouncing kinematics data produced from movements by the DOWN technique were recorded for each subject			
26	Kinematic Evaluation of the Classical Ballet Step “Plié”	(Gontijo, Candotti et al. 2015)	(1) 20 Ballerinas recruited for this study with signed consent	The exclusion criteria were any musculoskeletal or sub-acute injury within the prior 12 months that interfered with lower extremity function and moving the right foot sole on the ground during execution of the movements being tested	Only right side studied	Full published articles complete with data and report. Clear methodology; markers placing and movement information
			(2) The assessment protocol consisted of performing the plié	For scanning and 3D kinematic reconstruction of filming of the dancers executing a plié, a special software was used (Dvideow, UNICAMP, Campinas, Brazil)		
			(3) Two demipliés followed by two grand pliés in first position followed immediately by the same movements in second position maintaining the arms abducted on the shoulder line	The protocol for placement of the reflective markers19 was conducted by a team of four trained and experienced evaluators	Limited resources: no of cameras	
			(4) Kinematics data captured with four video cameras along with a 3D calibrator	All cameras have been recalibrated; The test environment was arranged so that, throughout the entire execution of the plié, each reflective point was captured by at least two cameras		

			(5) For analysis of metrics and angular variations of anatomical landmarks, a mathematical software was used	Raw data filtered with Butterworth filter, lowpass, fourth-order, with an average cut-off frequency of 2.1 Hz		
27	Assessment of muscle strength in female Bharatanatyam dancers	(Jyothi and Sujaya 2018)	(1) 32 dancers and 33 nondancers recruited as subject for this study	Inclusion criteria: Normal healthy sedentary female subjects who are in the same age group and BMI matched	The study involved a small group of dancers and nondancers. So, it difficult to generalise the results of this study to whole dancers' population as it involves both male and female dancers	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Subject's Height, weight and BMI were measured	Exclusion criteria: Subjects with history of injury in past 1 year, pregnancy, practicing dance forms other than Bharatanatyam or sports activities		
			(3) Lower limbs muscle strength was assessed by 6 metre hop test and wall sit test	The modified push – ups test used to assess muscular strength and endurance	One gender studied; Female	
			(4) Upper limbs muscle strength was tested by modified push ups test	The modified push – ups test assessed muscular strength and endurance		
				Single-legged hop tests are performance-based measures used to assess the combination of muscle strength, neuromuscular control		
28	Multi-segment spine kinematics: Relationship with dance training and low back pain	(Swain, Whyte et al. 2019)	(1) 60 female subjects (21 dancers and 39 non dancers) recruited for this study	Good number of subjects	One gender studied; Female	Full published articles complete with data and report. Therefore, easy to follow the procedure
			(2) Standing posture assessment, as well as ROM and movement asymmetry for side bend and trunk rotation tasks tested	To obtain a more complete description of the LBP experience, participants with LBP indicated their current, typical, and worst pain intensity on a visual analogue pain scale and completed the Tampa Scale for Kinesiophobia (TSK) and Pain Catastrophizing Scale (PCS)		
			(3) A nine-camera motion analysis system sampling at 100 Hz used to record kinematics data		No of dancers and non-dancers not balanced	
			(4) A two-way ANOVA was performed for each of the outcome variables to detect any differences between dancers and non-dancers, or individuals with and without lower back pain	Exclusion criteria for all groups included known spinal deformities, pregnancy, or the presence of injury in any body region other than the lower back resulting in a modified training load or compromised spinal kinematics at the time of testing		

29	Comparison of Lower Extremity Muscle Flexibility in Amateur and Trained Bharatanatyam Dancers and Nondancers	(Monica Sharma, Nuhmani et al. 2018)	(1) 105 healthy female volunteers, with 70 female Bharatanatyam dancers (35 trained, 35 amateurs) and 35 controls recruited for this study	Good literature review on dancer's lower limb muscle conditions and similar protocol used in ballet dancers	Too many assumptions to support results	Full published articles complete with data and report. Clear methodology; markers placing and movement information
			(2) Participants were assessed for range of motion (ROM) in hip flexion, hip extension, hip abduction and adduction, hip external rotation, hip internal rotation, knee flexion, knee extension, ankle dorsiflexion (DF), and ankle plantar flexion (PF) by using a standardized goniometer	The control group consist of non-dancers who were not involved in any sports or training activities	A prospective follow up study with larger sample can establish pattern of flexibility imbalances in Bharatanatyam dancers	
			(3) To assess for significant difference between groups, one-way ANOVA was applied, and multiple comparisons were made using Bonferroni correction	All subjects asked to complete injury questionnaire which includes demographics, training information and history of injury	History of injury rate was not considered	
30	Kinematics of Hip, Knee and Ankle During Cross- Slope Walking	(Damavandi 2015)	(1) Ten healthy adult male students were selected through available sampling method and walked along an inclinable walkway in both level (0°) and cross-slope (10°) configurations	SP, TP and FP angle graph included	To fully evaluate the cross-slope walking, the kinematic alterations of hip, knee, and ankle during the swing phase should be studied	Full published articles complete with data and report. Clear graph and data representation
			(2) The 3D angles of hip, knee, and ankle along with their time of occurrence (the time reaching to the maximum values for each specific joint angle) were analysed using repeated measures multivariate analysis of variance (MANOVA) by SPSS 17	Data presented for each event occur during walking for one gait cycle		
				Data analysis was done using SPSS software	Single gender-based study	
			(3) P<0.05 was considered significant	Difference between two groups analysed with one-way ANOVA and multiple comparison done using Bonferroni correction		

CHAPTER 3: METHODOLOGY

3.1 Participants

Three pB employed at Dhadeewalla Production, Malaysia recruited as subjects for this study: two women (mean ± SD: age =29.5±0.5 years, body height =161.5±3.5 cm, body mass=56.25±8.75 kg) and one man (age=26 years, body height=174.5 cm, body mass=68.5 kg). They had average Bharatanatyam dance experience of 14 years (range 11-20). All PB subjects are Malaysians attended Scholl on full time basis in the past. Two of them began their dancing training at tender age of five while one started during her teenage years. Our pB subjects past and current injuries due to traumas (accidents, falls etc) recorded. At the time of our assessment, our PB subjects have trainings and stage performing experiences ranging from 11-20 years with 1-2 hours weekly recoded dancing activity.

The control group consists of three subjects: two women (age 24 ± 1.0 years, body height 154.25 ± 1.25 cm, body mass 52.5 ± 2 kg) and 1 man (age 28 years, body height 150 cm, body mass 58 kg). These subjects were not involved in any elite-level sports or extreme physical activities. Therefore, they were free of any structural or functional impairment that could affect their gait.

The study population included 6 subjects in total (12 involved feet)—3 dancers and 3 non-dancers (control group). Both feet of the same subject are considered as independent foot (Menz 2004). S1-S3 consist of pB subjects while S4-S6 are the control group.

Table 3.1: Subject's Information

Subject	Age	Gender	Mass (kg)	Height (cm)	Years of Practice	Leg length (cm)		Knee Width (cm)		Ankle Width (cm)		Practise Frequency	Stretching	Past Trauma History
						R	**L**	**R**	**L**	**R**	**L**			
S1	26	Male	68.5	174.5	20	95.5	92.5	10.4	10.5	7.5	7.2	3 times weekly, 2 hrs per session	Before and After Training	Accident in 2011
S2	29	Female	47.5	158.0	11	88.0	88.5	5.5	5.7	5.5	5.9	3 recorded activity monthly, 30 mins each session	Before and After Training	Accident in 2013 with pelvic and kidney shut down
S3	30	Female	65.0	165.0	11	92.5	92.0	9.8	9.7	6.5	6.4	1-3 times weekly, ranging from 1-2 hours per session	Before Training	Motorcycle accident in 2007 and 2016
S4	23	Female	50.5	153.0	na	82.0	83.0	6.5	6.0	5.6	5.2	-	-	-
S5	25	Female	54.5	155.5	na	81.7	81.0	9.1	8.9	5.5	5.5	-	-	-
S6	28	Male	58.0	150.0	na	87.0	85.0	10.0	10.3	6.7	6.9	-	-	-

3.2 Anthropometrical measurements

Subjects undergo anthropometrical measurements where their body mass, body height, both leg lengths, ankle and knee widths were measured and recorded. Subjects asked to stand with legs apart. Here, their leg's length was measured between the ASIS (most prominent aspect of the iliac crest anteriorly) marker and the medial malleolus, via the knee joint.

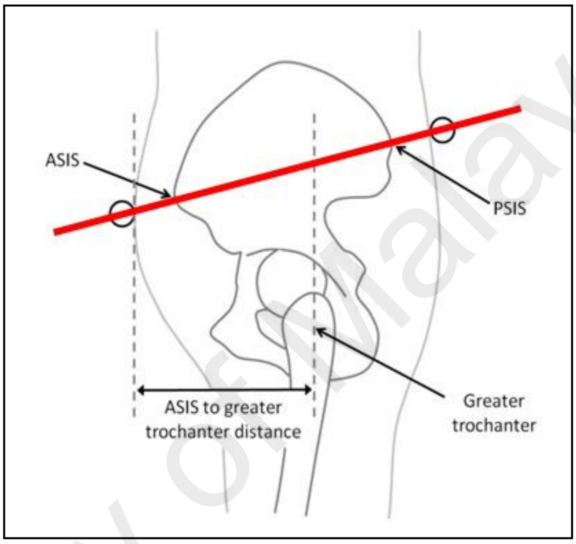


Figure 3.1: ASIS area – Reproduced from (van Sint Jan 2007)

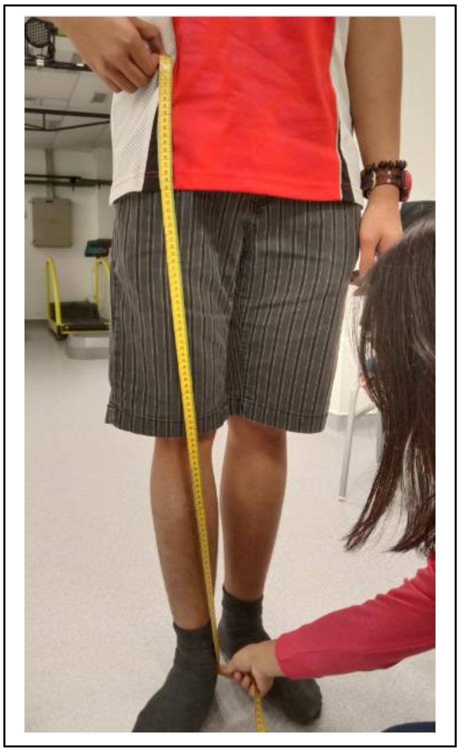


Figure 3.2: One of subject's leg length being measured with tape measure

The equipment used for subject's measurements are listed in the table below:

Measurement Taken	Equipment Used
Body Mass and Height	Beam Scale
Leg length	Tape measure
Knee and Ankle Width	Anthropometer

Table 3.2: The equipment used for subject's measurements

Figure 3.3: Anthropometer available at Performance of Body and Analysis of Movement' laboratory under the Faculty of Biomedical Engineering, University of Malaya

3.3 Marker Installation

Sixteen reflective 14mm sized markers attached securely on subject's lower limb based on Vicon plug-in Gait lower body modelling developed by Helen Hayes, Vicon Clinical Manager, Newington, and Cleveland Clinic.

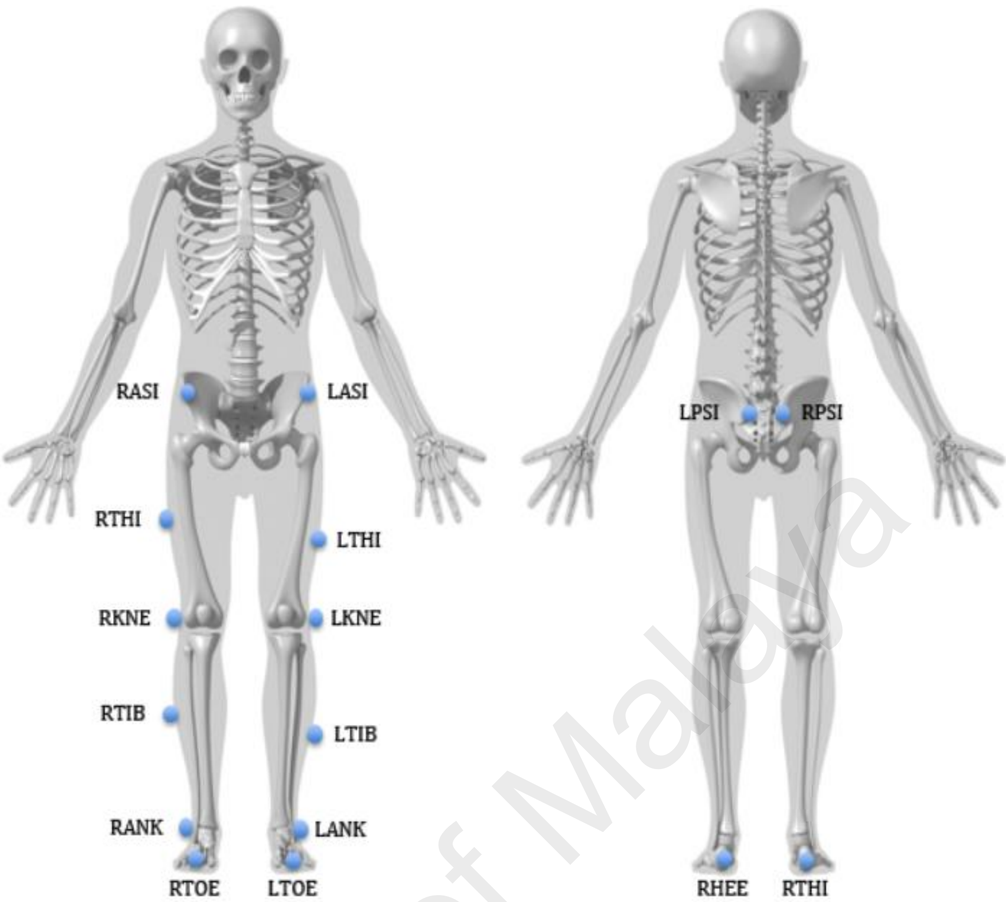


Figure 3.4: The Vicon Plug-In Gait marker set – Reproduced from (Merriaux, Dupuis et al. 2017)

Figure 3.5: Reflective 14mm sized markers available at Performance of Body and Analysis of Movement' laboratory under the Faculty of Biomedical Engineering, University of Malaya

All subjects are advised to wear plain coloured tights, the kind of garment which shapes the lower limb. The reflective markers were secured using masking tape and double-sided tape. Subjects advised to remove all reflective materials attached to their body such as watches and jewellery as well.

Figure 3.6: Markers attached to our subjects with dancing bells worn at ankles

The THI and TIB markers anterior-posterior position is critical for identifying the orientation of the knee and ankle flexion axis. At least three markers required to obtain six degrees of freedom (to construct one body segment). Therefore, the best practice is to place four markers on the pelvis (LASI/RASI/LPSI/RPSI), so that even if one of the four markers is occluded during motion capture, the required three markers will still be visible to the camera.

The Dancing Bell specifications are in the table below:

Table 3.3: The specifications of dancing bells used in this study

Weight	242 grams
Length	9.8 inch
Width	3.4 inch
Belt Material Type	Leather
Bell Material Type	Copper
No of bells	50
Bells arrangments	Five lines, ten in each rows

3.4 Data Acquisition

University of Malaya is equiped with the ‘Performance of Body and Analysis of Movement’ laboratory under the Faculty of Biomedical Engineering. The flooring of the labrotory had its center embedded with two piezoelectric force plates marked as 1 and 2 (Kistler 9281CA, Kistler Instrumente AG, Winterthur, Switzerland) operating at sampling frequency of 1000 Hz.

Figure 3.7: Performance of Body and Analysis of Movement’ laboratory under the Faculty of Biomedical Engineering, University of Malaya

Our study was conducted on optoelectronic motion system Vicon MX (Vicon Motion Systems, Oxford Metrics Group, London, United Kingdom) using five infrared cameras (T40-S, sampling frequency 250 Hz, resolution 2336 × 1728 pixels).

Figure 3.8: Infrared VICON camera availabe Performance of Body and Analysis of Movement' laboratory under the Faculty of Biomedical Engineering, University of Malaya

Both forceplate and cameras intergarted with Vicon Nexus 1.8.5 software for data acquisition and processing.

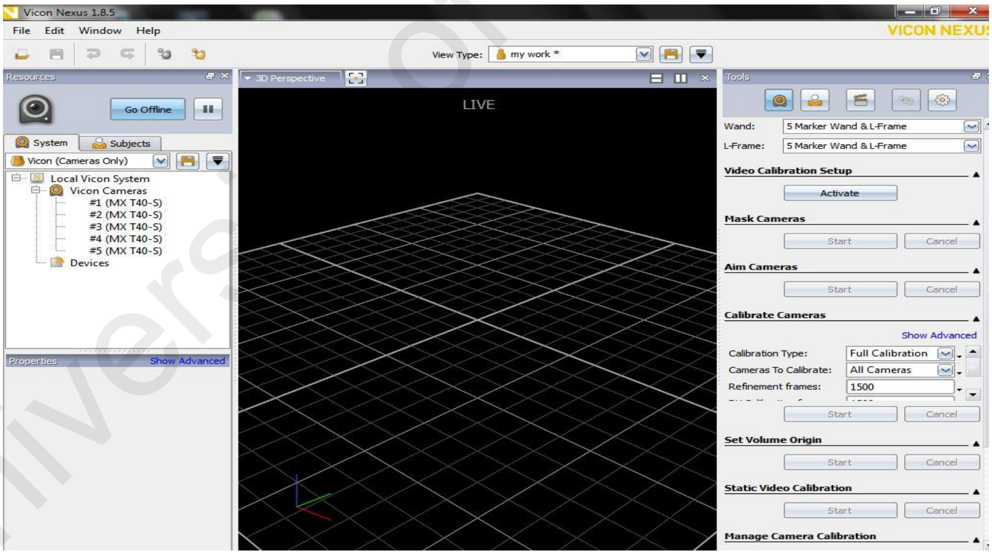


Figure 3.9: The Vicon Nexus 1.8.5 software

3.5 Equipment Calibration

All five cameras calibrated by swinging the 'calibration tool' with reflective markers in clockwise and counter clockwise direction. Red light emitted by the cameras as indication of 'require calibration' and green light to indicate the camera has been calibrated succesfully. Error rate maintaned to be below 0.3. Next, the calibration tool is placed on the force plate to calibrate the three direction axis; x, y and z to (0,0,0).

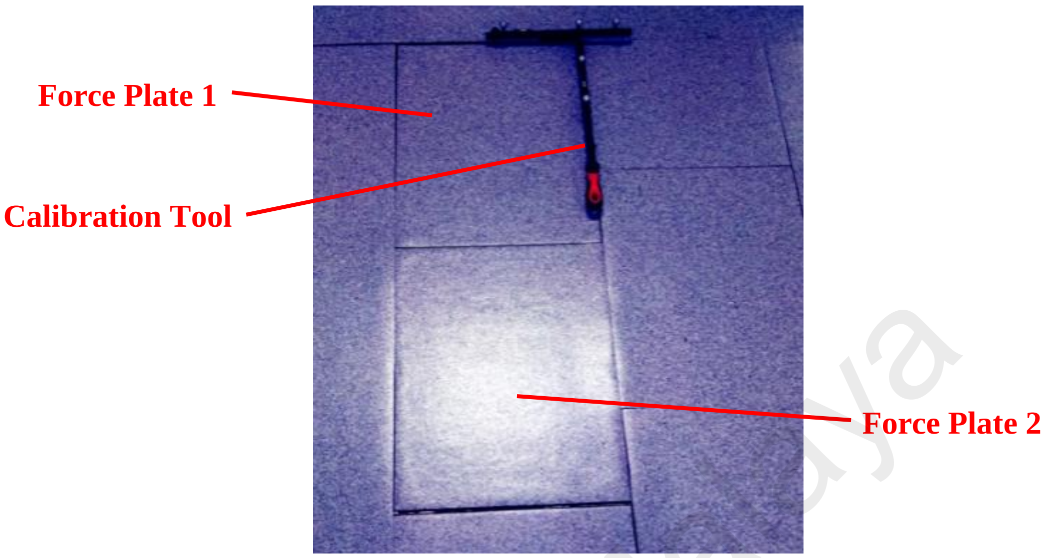
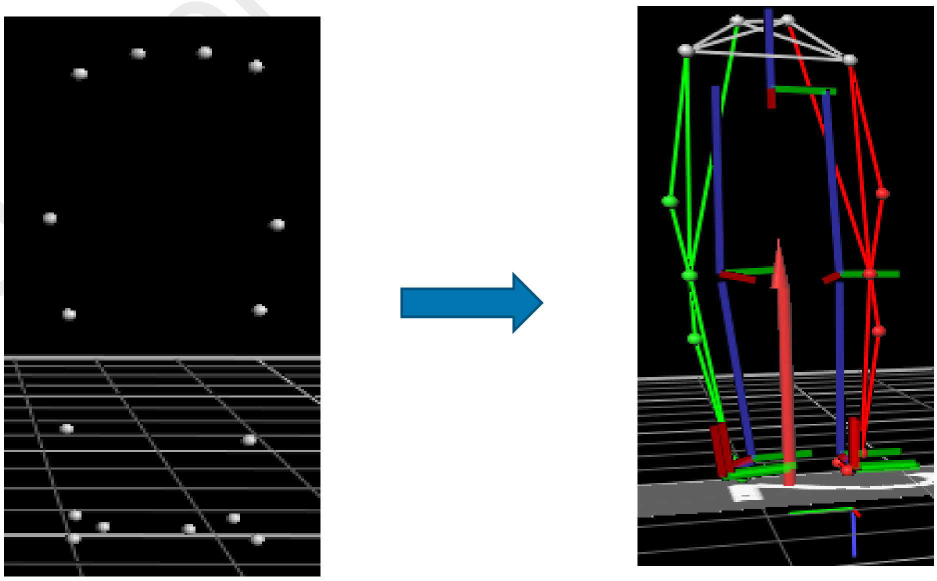


Figure 3.10: The calibration tool places on (0,0,0) axis on the force plate

3.6 Subject Static Calibration

We have requested our subjects to stand still with bare foot and arms crossed around chest for their lower limb marker calibration (refer to Figure below). The red arrow indicates forces present on the force plate. If unrelated forces detected, subject is requested to walk out of the Vicon System and re-enter.



(a) (b)

Figure 3.11: Subject's Static Calibration on Force Plates and Vicon Cameras; (a) Before pipeline calibration (b) After pipeline calibration

For a successful static calibration, all sixteen reflectives markers should be captured for five seconds. Green pipeline indictates right side of the lower limb while the red pipeline indicated the left side of the lower limb. Next, these markers labelled as per their respective position based on The Vicon Plug-In Gait marker set labelling.

Table 3.4: Marker labelling based on The Vicon Plug-In Gait marker set

Marker Short Form	Representation
LASI	Left Anterior Superior Iliac
RASI	Right Anterior Superior Iliac
LPSI	Left Posterior Superior Iliac
RPSI	Right Posterior Superior Iliac
LTHI & RTHI	Left Thigh & Right Thigh
LKNE & RKNE	Left Knee & Right Knee
LTIB & RTIB	Left Tibia & Right Tibia
LANK & RANK	Left Ankle and Right Ankle
LHEE & RHEE	Left Heel and Right Heel
LTOE & RTOE	Left Toe and Right Toe

3.7 Data Collection

All subject's anthropometrical measurements recorded at Vicon Nexus 1.8.5 software under subject's information.

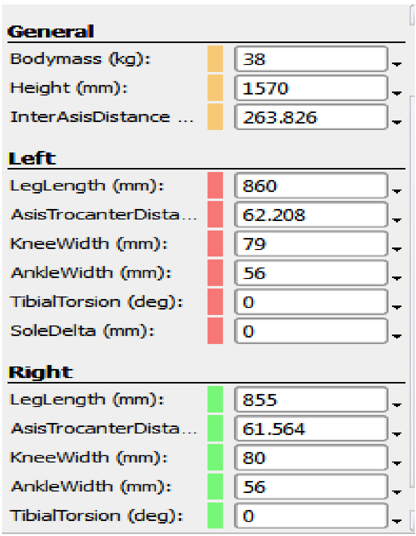


Figure 3.12: Aanthropometrical Measurements template available in the Vicon Nexus 1.8.5 software

Subsequently, each subjects was instructed to perform five trials of the gait at self-initiated walking speed on six meters of walking platform with bare feet and another five trials with dancing bells attached to both ankles.

One successful trial selected based on following inclusion criteria:

• Subject’s each foot fully landed on one force plat at a time

• Four markers on the pelvis (LASI/RASI/LPSI/RPSI) visible throughout the trial

• No noise recorded on the trajectories

Trial Exclusion criteria are;

• Subject’s foot does not land on force plate, or partially land

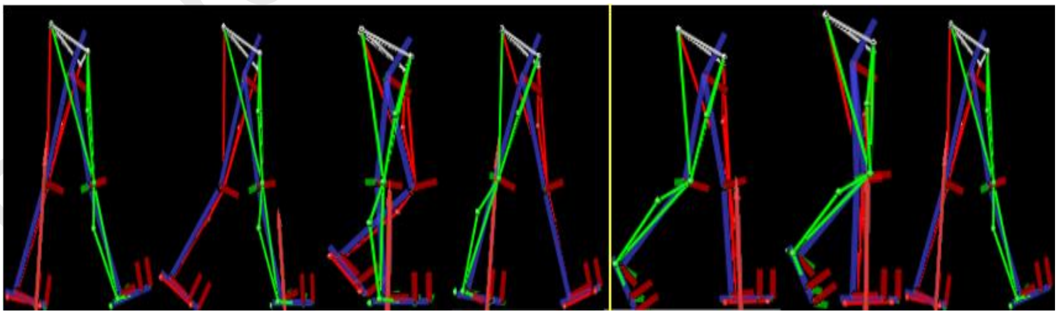
• Markers fall

• Too many missing markers (not captured by Vicon cameras)

• Minor accidents; Subject’s experienced fall or slip

The second gait cycle of each successful trials extracted for further processing. Each gait cycle inclusive of following phase;

Stance Phase 60 % **Swing Phase 40 %**



HS FF MS HR TO Mid Swing HS

Figure 3.13: One Walking GaitCycle

3.8 Data Processing

The Vicon Nexus 1.8.5 software provides inbuilt data processing options for reserachers. The components used for this research captured below:

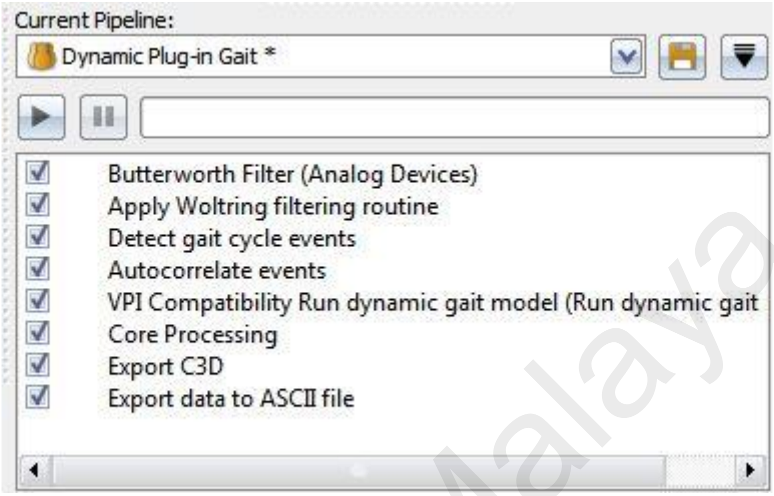


Figure 3.14: Data Processing options availabe in Vicon Nexus 1.8.5 software

Raw analog signal from the force plates filtered using the fourth order with zero lag low pass digital Butterworth filter with cut off frequency of 300 Hz. Than, the raw kinematic data filtered using Woltring Filtering Routine which is based on a fifth order spline interpolating function available in the software. 'Detect Gait Cycle' operation marks gait cycle events such as footstrikes and toe off to the time bar throughout the trial using vertical GRF measured by the force plate connected to the Vicon system.

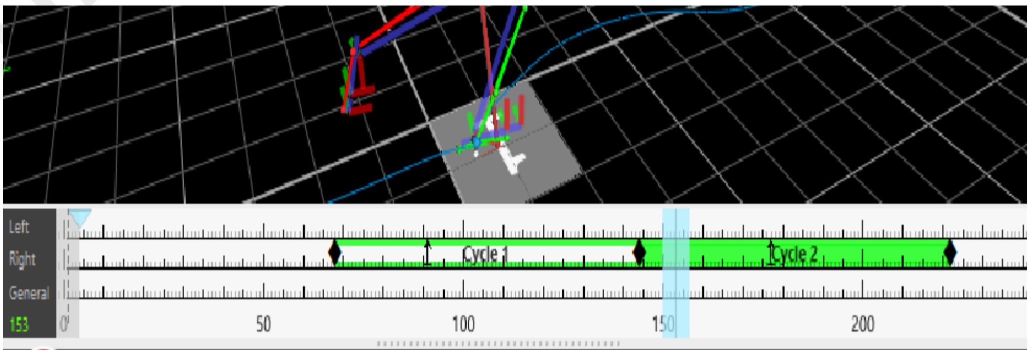


Figure 3.15: Gait Cycle events marked at time bar. Black Diomond indicated Heel Strike

Furthermore, Autocorrelate Events operation performed to detect the pattern of the tracked marker at the set events and define these events for the rest of the trials. In case there are missing markers, the 'Gap Filling' function is used to refill the void using a third order spline interpolation algorithm. Here, the recommended refill options will be available as below:

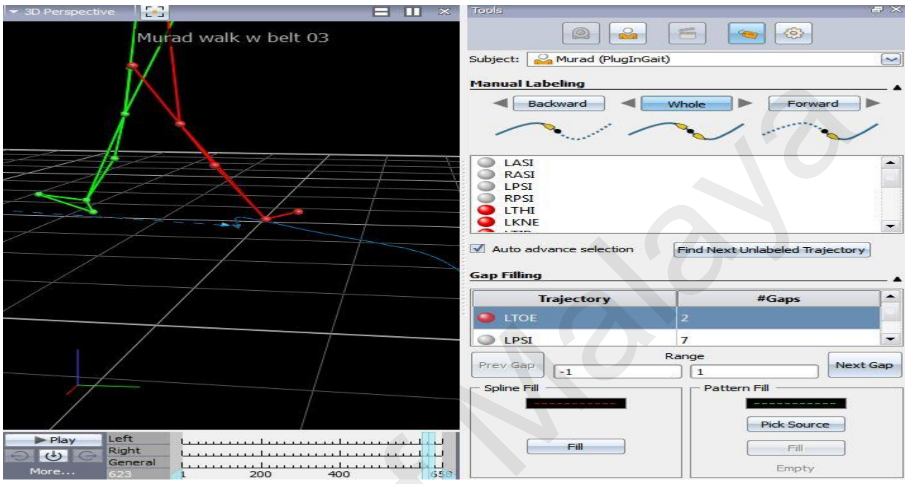


Figure 3.16: Gap Filling operation in Vicon Nexus 1.8.5 software

The current state of data will be exported to a .c3d file which can be opened to be further processed in other Vicon softwares such as Vicon Polygon to visualize the bones structure. The final processed data coverted into ASCII format to produce .csv files, which can be visualized in Microsoft Excel for statistical analysis.

3.9 Data Analysis

The mean and standard deviation (SD) were calculated for both kinetics and kinematics data. The best one trial out of five trials used for statistical analysis. The Kinetics data consist of GRFs produced from stance phase (Lung, Chern et al. 2008). These data are normalized to subject's body weight. This ensures stable convergence of weight towards data comparison between dancers and control. Subject's body mass is converted into Force by multiplying their mass with gravitational acceleration constant 9.8066 ms^{-2} (Katopodes 2019). All computations and analysis done in Microsoft Excel 2016.

Table 3.5 : Subject's body mass conversion from kilograms (kg) to Newton (N)

Subjects	Mass (kg)	Force (N)
S1	68.5	671.75
S2	47.5	465.81
S3	65.0	637.43
S4	50.5	495.23
S5	54.5	534.46
S6	58.0	568.78

Subject's GRFs data divided with their respective Force information, to generate the normalised data. Review the example below:

<u>Normalizing Subject 1's VGRF data</u>

293.55
297.13
302.35
306.57
312.69
317.15
321.50
325.78
329.61
333.87
337.59

(a)

Divide 671.75

0.43
0.44
0.45
0.46
0.47
0.47
0.48
0.48
0.49
0.49
0.50

(b)

Figure 3.17: (a) Actual data (b) Normalised data

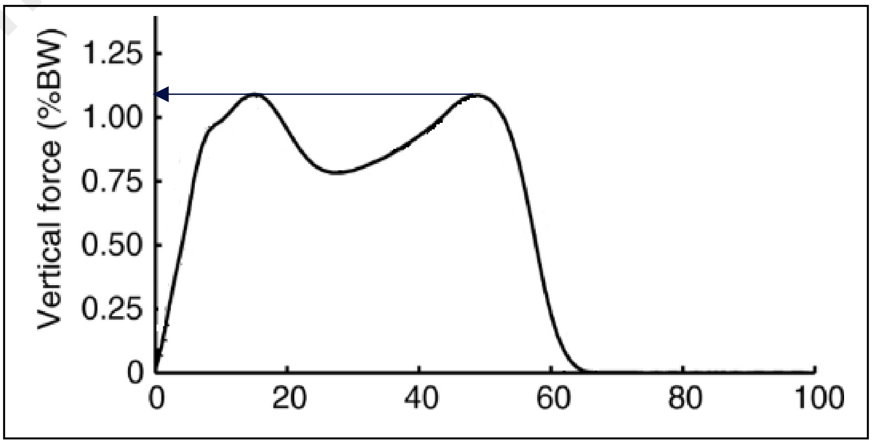


Figure 3.18: Example of VGRF (normalized to BW) during walking with stride rates (max=+20%) – Reproduced from (Brian R, 2007)

CHAPTER 4: RESULT AND DISCUSSION

Table 4.1: Ground Reaction Forces of all six subjects collected from one best trial

Subjects	VGRF						ANT-POS				MED-LAT							
	Max LR		Min MS		Max TS		Min MS		Max TS		Max LR		Min MS		Min TS		Max Pre TO	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
S1 GRF w/o DB	0.988	1.049	0.851	0.893	1.045	1.089	-0.088	-0.074	0.084	0.101	0.021	na	-0.023	na	-0.029	na	0.015	na
S2 GRF w/o DB	1.128	1.164	0.816	0.812	1.227	1.162	-0.098	-0.061	0.102	0.126	0.004	na	-0.017	na	-0.013	na	0.007	na
S3 GRF w/o DB	0.986	0.954	0.856	0.867	0.945	1.037	-0.041	-0.065	0.070	0.092	na	na	na	na	na	na	na	na
S4 GRF w/o DB	0.966	1.047	0.912	0.881	1.032	1.073	-0.082	-0.080	0.104	0.122	0.005	na	-0.023	na	-0.016	na	0.012	na
S5 GRF w/o DB	0.983	0.994	0.782	0.852	1.082	1.145	-0.074	-0.064	0.108	0.111	0.006	na	-0.019	na	-0.013	na	0.020	na
S6 GRF w/o DB	1.157	1.014	0.859	0.816	1.132	1.129	-0.089	-0.115	0.109	0.110	0.011	na	-0.040	na	-0.040	na	0.011	na
S1 GRF w DB	1.097	1.072	0.845	0.812	1.130	1.168	-0.095	-0.068	0.084	0.110	0.036	na	-0.017	na	-0.019	na	0.008	na
S2 GRF w DB	1.235	1.114	0.670	0.809	1.199	1.168	-0.132	-0.094	0.107	0.121	0.005	na	-0.025	na	-0.021	na	0.008	na
S3 GRF w DB	0.952	1.039	0.884	0.928	1.025	1.007	-0.109	-0.081	0.043	0.077	na	na	na	na	na	na	na	na
S4 GRF w DB	1.057	1.166	0.868	0.867	1.062	1.123	-0.083	-0.093	0.112	0.124	0.018	na	-0.021	na	-0.018	na	0.010	na
S5 GRF w DB	1.038	1.036	0.799	0.785	1.141	1.151	-0.078	-0.080	0.121	0.114	0.006	na	-0.022	na	-0.017	na	0.014	na
S6 GRF w DB	1.006	1.105	0.823	0.880	1.091	1.178	-0.103	-0.077	0.072	0.100	na	na	na	na	na	na	na	na

*Remark: na indicates not available due to subjective graph obtained. Please refer Figure 4.1-4.12.

The table above produced based on (Lung, Chern et al. 2008).

Past Trauma History

We noticed a common fact while recording past trauma history information of our subjects. All dancers have experienced accidents on road before while our control experienced none of such incidents. S1 encountered a car accident back in 2011 which impacted his right lower limb, causing difficulties in balancing and stress while standing for a long duration. Besides that, S1 reports to experience pain during ‘Araimandi’ and ‘Muzhumandi’ posture too. S2 on the other hand experienced a car accident in 2013 which caused her kidney to shut down. Furthermore, S3 experienced two major motorcycle accident in 2007 and 2016. S2 and S3 did not report any negative outcomes of the accidents which stops them from performing any daily activities or dance. The high frequency of accidents reported among our pBs strongly supports our literature review which states dancers rank high in injuries due to factors such as stress (34%), overwork (24.7%), tiredness (17.2%) and falls during training (13.5%) (Prochazkova, Tepla et al. 2014).

Percentage of Difference: w/o DB and w DB

The normalised ground reaction forces allow us to study our subjects results without bias. We have computed percentage of difference between pB and control GRF data as below:

Table 4.2: Percentage of difference between pB and control GRF

Subjects	VGRF						ANT-POS			
	Max LR		Min MS		Max TS		Min MS		Max TS	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
S1 w DB vs w/o DB	11%	2%	-1%	-9%	8%	7%	8%	-8%	0%	9%
S2 w DB vs w/o DB	9%	-4%	-18%	0%	-2%	1%	35%	54%	5%	-4%
S3 w DB vs w/o DB	-3%	9%	3%	7%	8%	-3%	166%	25%	-39%	-16%
S4 w DB vs w/o DB	9%	11%	-5%	-2%	3%	5%	1%	16%	8%	2%
S5 w DB vs w/o DB	6%	4%	2%	-8%	5%	1%	5%	25%	12%	3%
S6 w DB vs w/o DB	-13%	9%	-4%	8%	-4%	4%	16%	-33%	-34%	-9%

Remarks: - (negative symbol) indicates there is reduction of GRF after wearing DB
Red indicates two events where highest reduction of GRF recorded after wearing DB
Green indicates two events which results highest of GRF recorded after wearing DB

With reference to Table 4.2, pB w DB found to exert abnormal spikes on GRF ranging from (54%-166%). S2 have 18% of decrease on right foot VGRF during minimum MS while S6 have 13% decrease on right foot VGRF during maximum LR. This event contradicting with our literature as adding load to ankle should increase the resultant forces as there is increase in mass (BW+DB mass). S1 and S4 recorded 11% of increment on right and left foot VGRF (F_y) respectively during maximum LR. Our literature mentions that in the event of LR, feet goes through a double support phase where both feet in contact with the ground. Therefore, wearing DB results S1 (pB) and S4 (control) to exert more VGRF compared to the rest of the subjects. Besides there, we observe there are abnormal spikes occur and these data recorded in the table below:

Table 4.3: Maximum (max) and average (avg) percentage difference between pB after wearing DB

Subject	Max Difference (+)	Max Difference (-)	Avg Difference
Dancer	166%	-39%	15.8%
Control	25%	-34%	8.9%

S3 recorded 166% of increment on right foot GRF during minimum MS and 39% decrease on right foot GRF during maximum TS at ANT-POS (F_x direction). S2 recorded 52% and 35% of increment on both right and foot GRF during minimum MS. Data spikes observed to be abnormal here compared to others.

<u>Mean and Standard Deviation (mean±std)</u>

Table 4.4: Mean and standard deviation (std) GRF of pB and Control

Subjects	**VGRF**			**ANT-POS**	
	Max LR	**Min MS**	**Max TS**	**Min MS**	**Max TS**
pB w/o DB	1.045±0.085	0.849±0.031	1.084±0.100	-0.071±0.020	0.096±0.019
Control w/o DB	1.027±0.070	0.850±0.046	1.099±0.044	-0.084±0.017	0.111±0.006
pB w DB	1.085±0.093	0.825±0.088	1.116±0.081	-0.097±0.022	0.090±0.029
Control w DB	1.068±0.058	0.837±0.040	1.124±0.042	-0.086±0.010	0.107±0.019

Remarks: Green indicates pB found to produce higher peak than control
Red indicates pB found to produce lower peak than control

From table 4.4, for both walking w DB and w/o DB event, we found that pB exert higher VGRF at LR. Besides that, pB w DB also found to have lower ANT-POS force peak at MS. Furthermore, both pB DB and control DB produce lower force during MS and produce higher force during TS. For the remaining events, control found to exert higher forces. These observations are very similar to findings reported by (C.-W. Lung, 2008), where he compared walking gait of Ballerinas and Control (non-dancers).

Table 4.5: Comparison of VGRF and ANT-POS forces between Ballerinas and non-Dancers – Reproduced from C.-W. Lung, 2008

Subjects	**VGRF**			**ANT-POS**	
	Max LR	**Min MS**	**Max TS**	**Min MS**	**Max TS**
Ballerinas	1.073±0.0975	0.7499±0.0837	1.1471±0.0579	-0.0289± 0.0282	0.2104± 0.0632
Control	1.0945±0.0960	0.7451±0.0634	1.1219±0.0909	-0.0238± 0.0301	0.1883± 0.0316

Remarks: Green indicates Ballerinas found to produce higher peak than control
Red indicates Ballerinas found to produce lower peak than control

C.-W. Lung found that Ballerinas produce higher VGRF at MS and higher ANT-POS force at TS. Moreover, Ballerinas also found to have lower peak at MS. For the remaining events, control found to exert higher/lower peak forces.

Comparison with past studies (C.-W. Lung, 2008)

Table 4.6: Comparison of VGRF and ANT-POS forces between Ballerinas and pB.

Subjects	**VGRF**			**ANT-POS**	
	Max LR	**Min MS**	**Max TS**	**Min MS**	**Max TS**
pB w/o DB	1.045±0.085	0.849±0.031	1.084±0.100	-0.0710±0.020	0.096±0.019
Ballerinas	1.073±0.0975	0.7499±0.0837	1.1471±0.0579	-0.0289± 0.0282	0.2104± 0.0632

Remarks: Green indicates pB found to produce higher peak than control

From the table above, pB w/o DB found produce higher VGRF during MS compared to Ballerinas. For the remaining events, Ballerinas found to exert higher/lower peak forces. Based on Table 4.1 and Figure 4.1-43.12, our recorded Medial/Lateral forces have unique and subjective pattern compared to literature (Figure 2.19). Therefore, for analysis, we have only considered VGRF and Anterior/Posterior forces only.

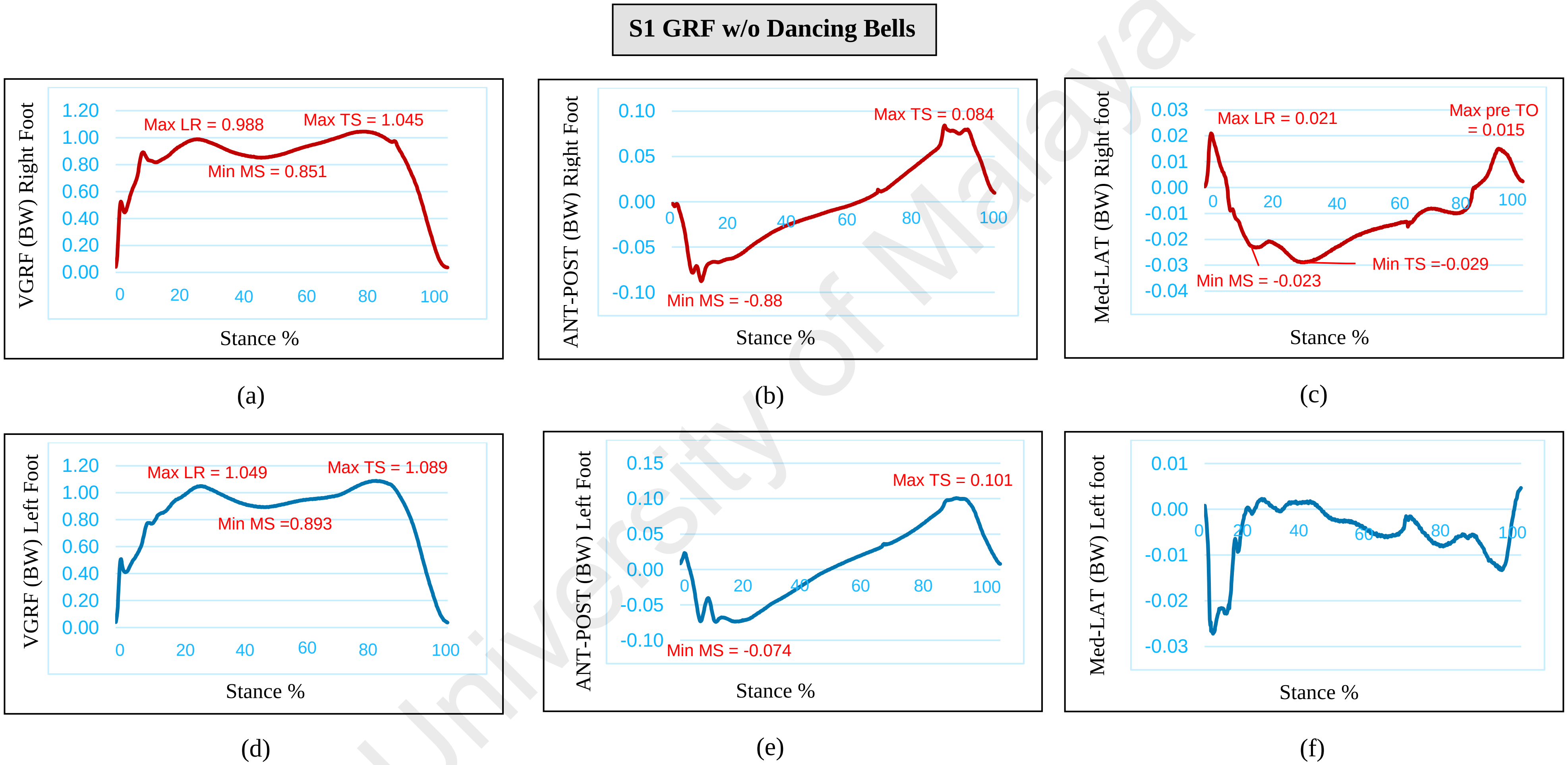


Figure 4.1: Ground Reaction force of S1 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walked without wearing dancing bells

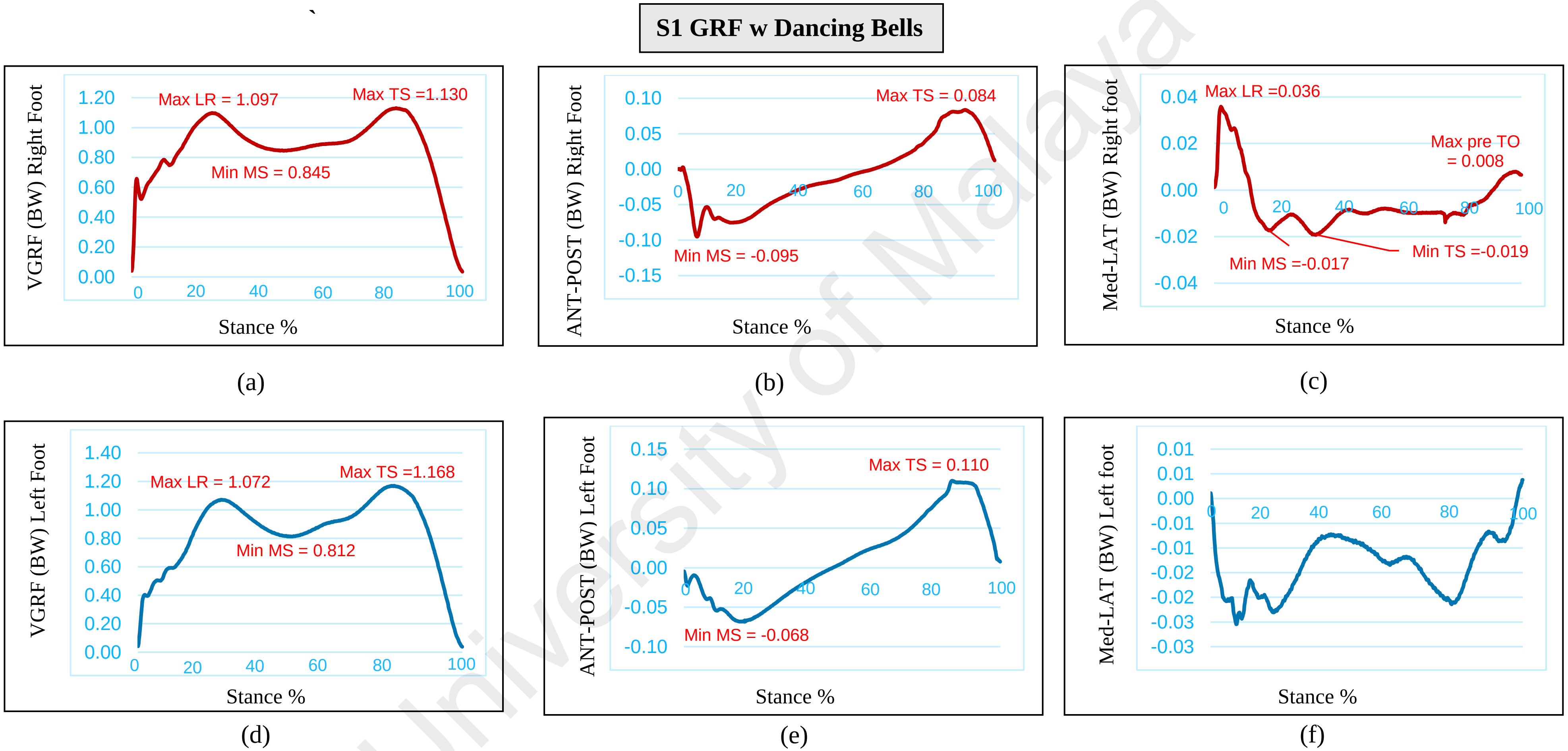


Figure 4.2: Ground Reaction force of S1 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking wearing dancing bells

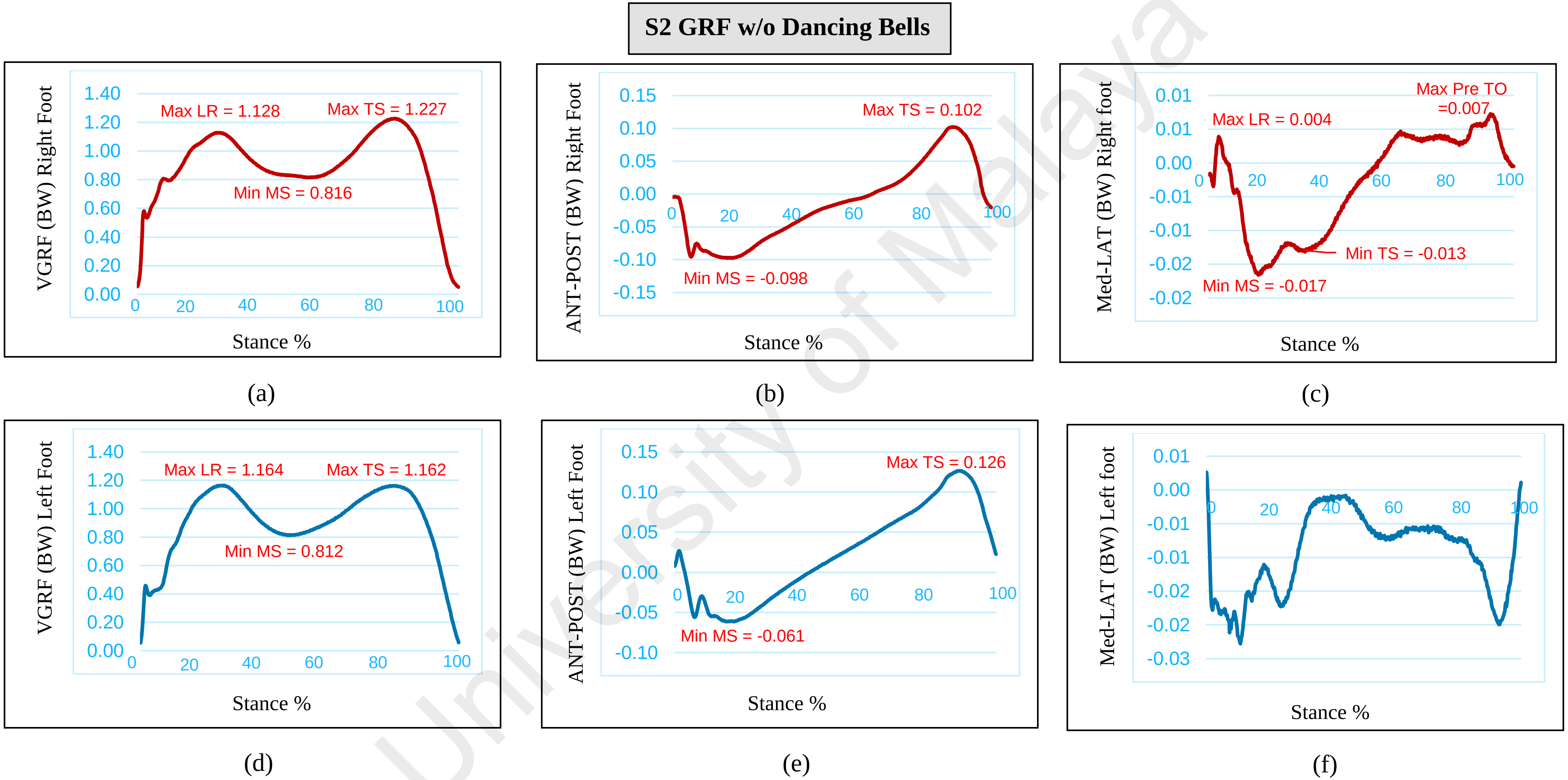


Figure 4.3: Ground Reaction force of S2 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking without wearing dancing bells

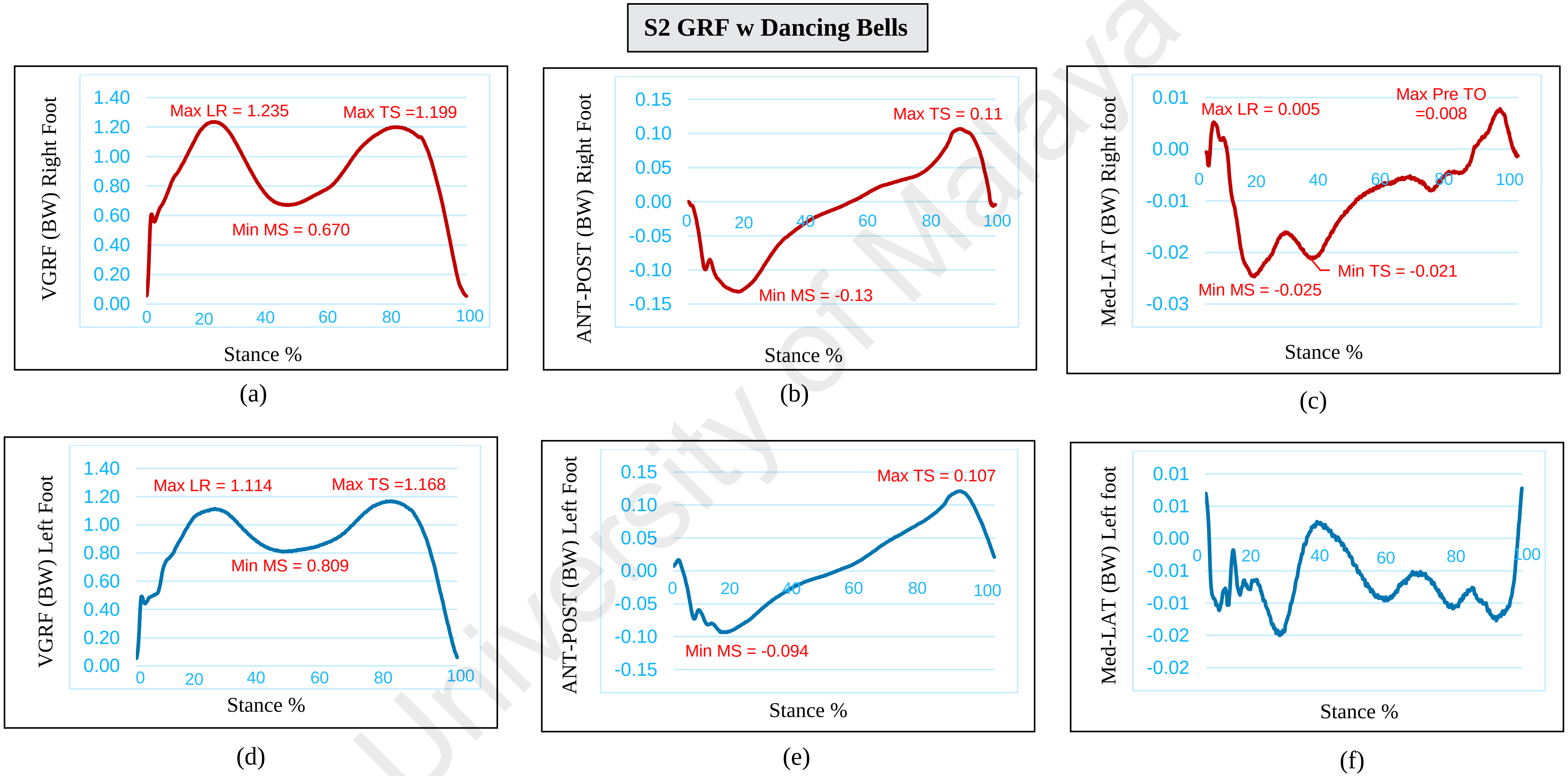


Figure 4.4: Ground Reaction force of S2 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking wearing dancing bells

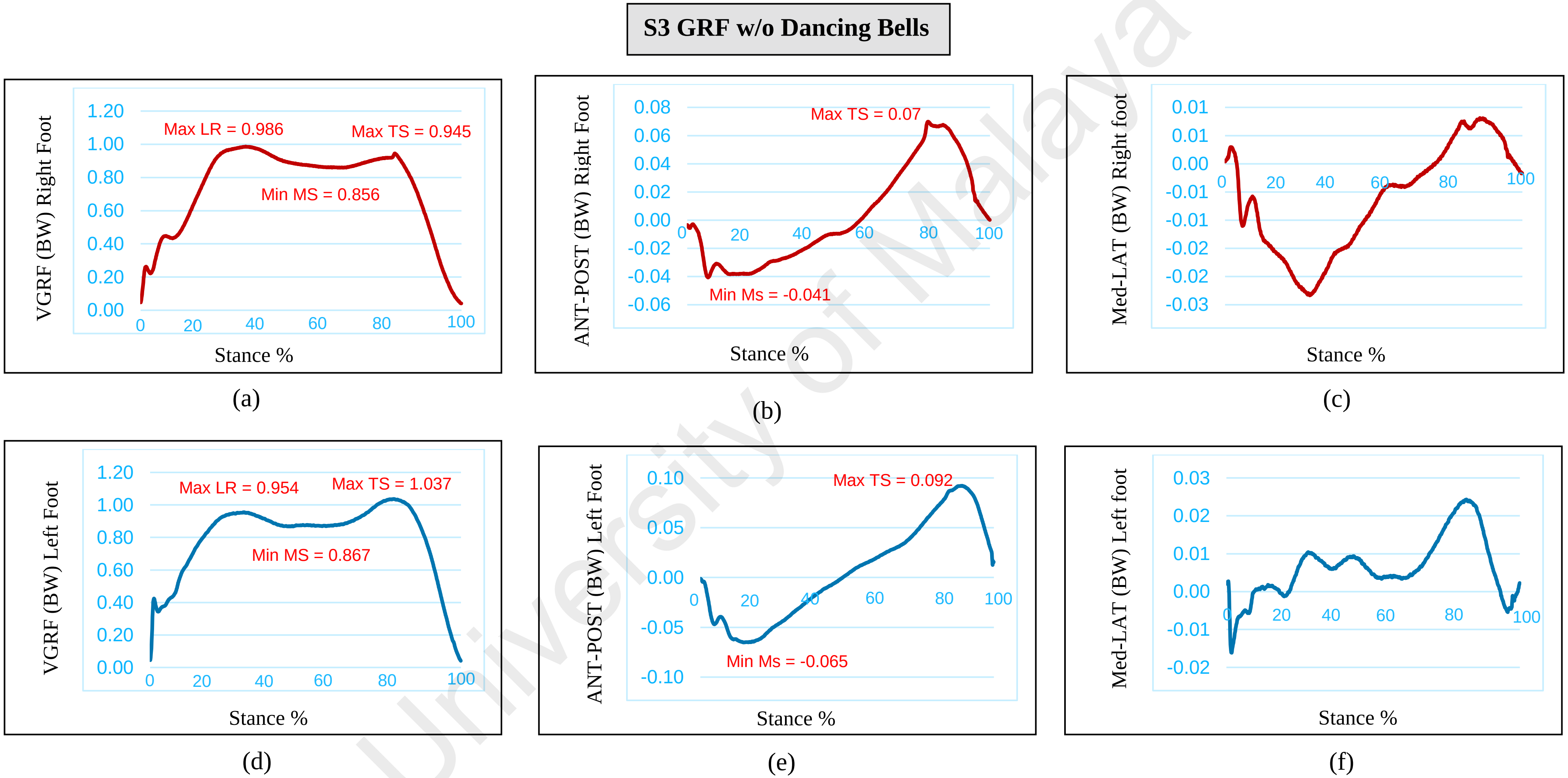


Figure 4.5: Ground Reaction force of S3 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking without wearing dancing bells

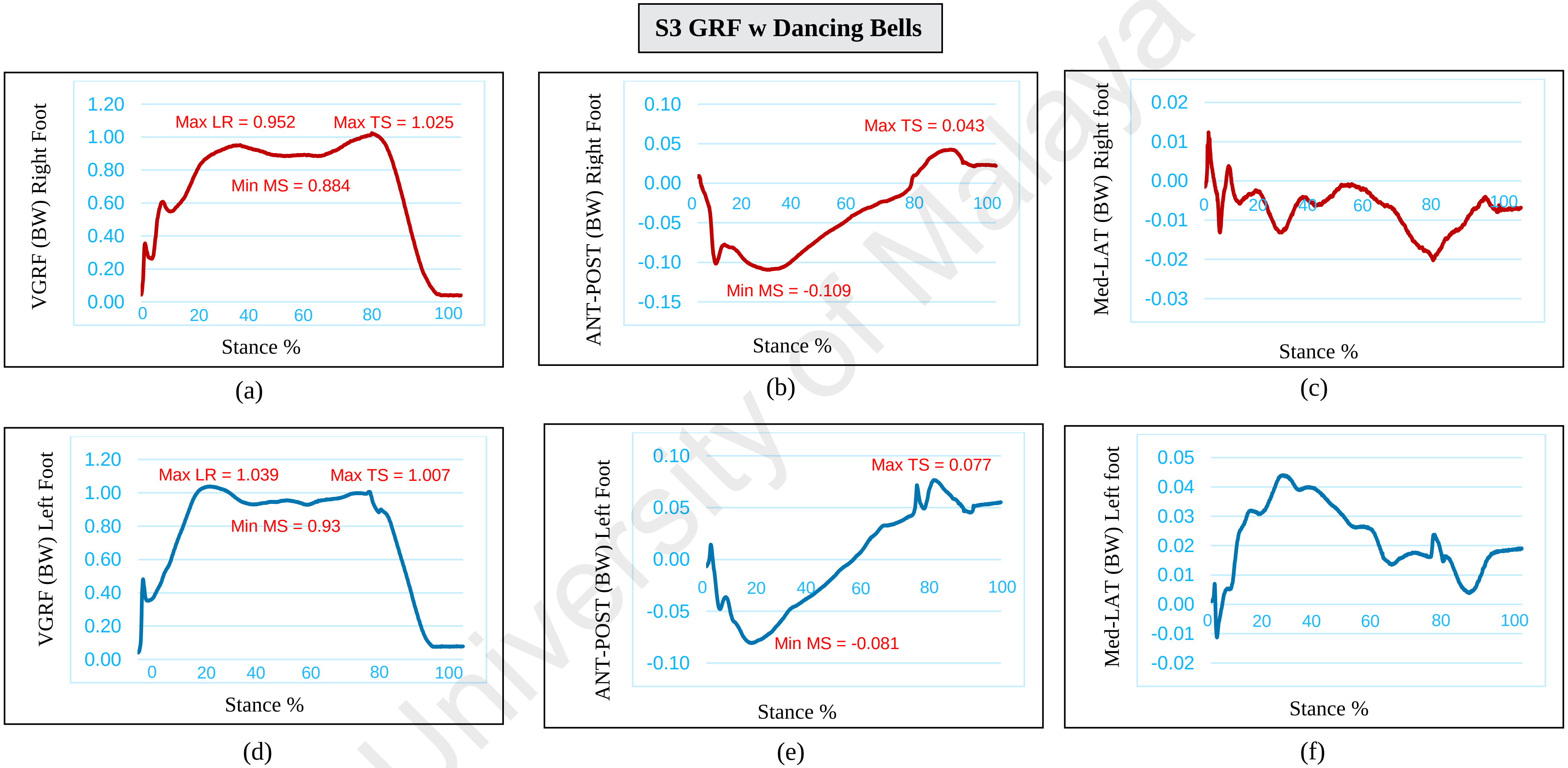


Figure 4.6: Ground Reaction force of S3 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking wearing dancing bells

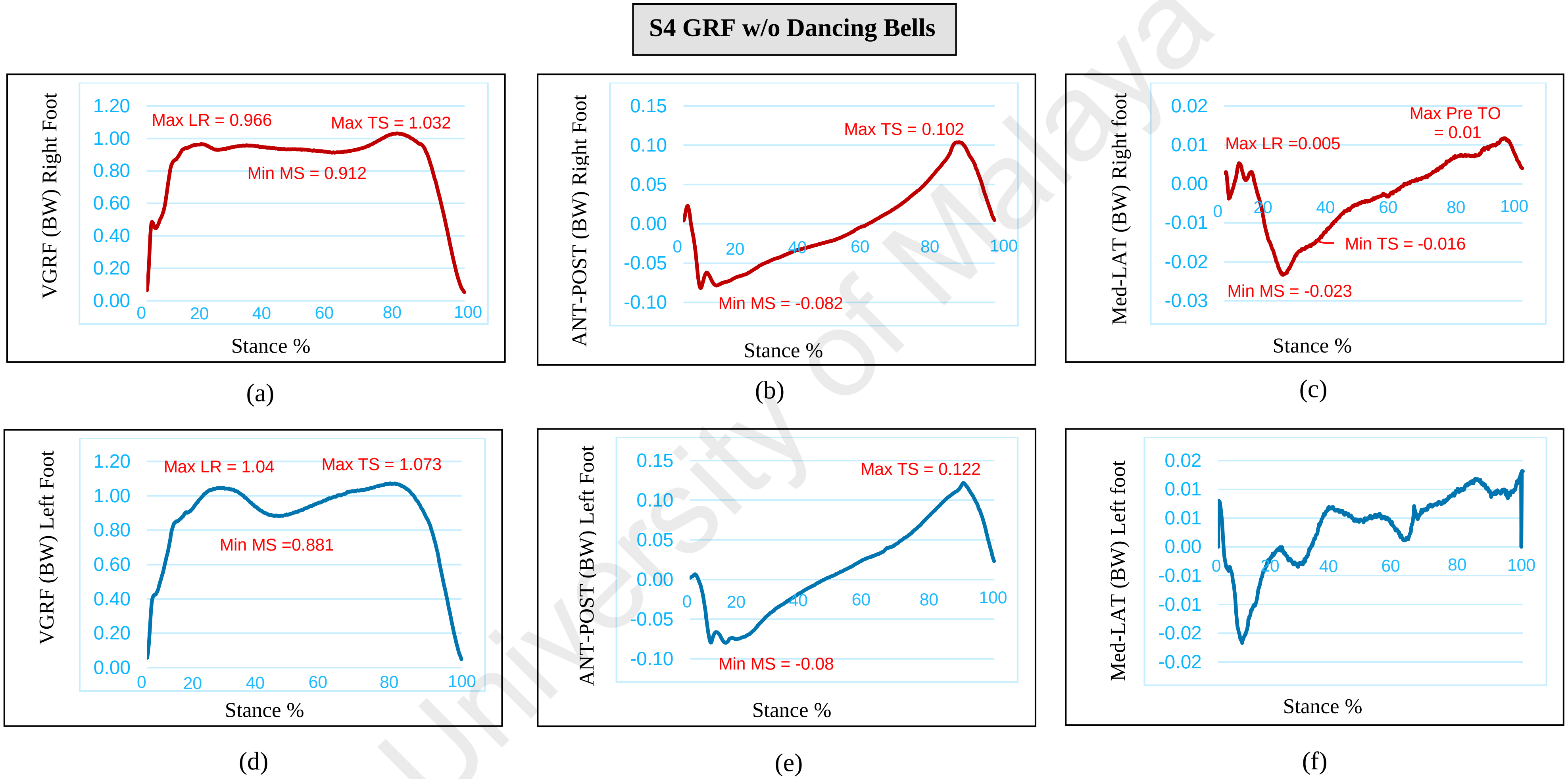


Figure 4.7: Ground Reaction force of S4 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking without wearing dancing bells

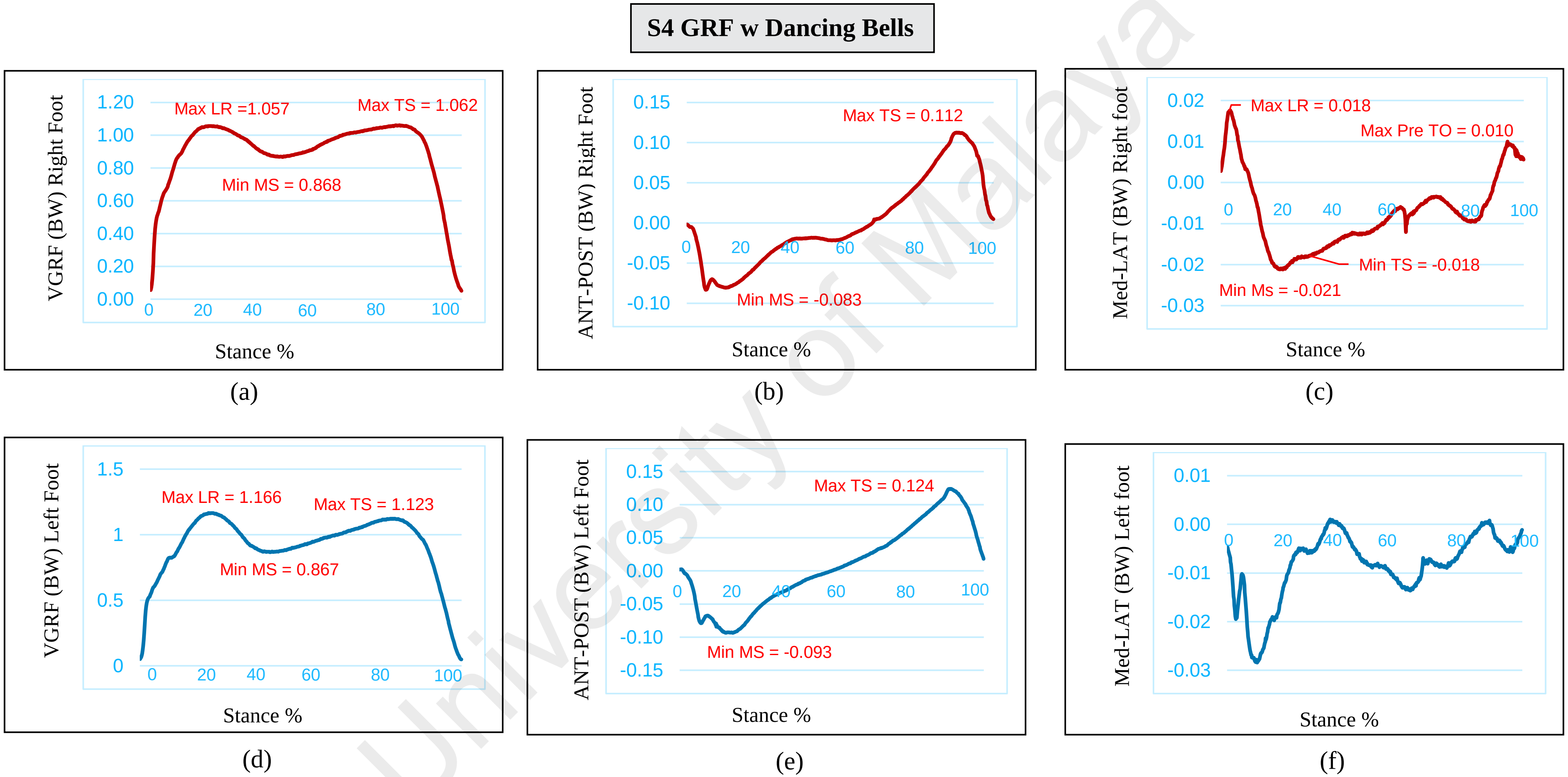


Figure 4.8: Ground Reaction force of S4 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking wearing dancing bells

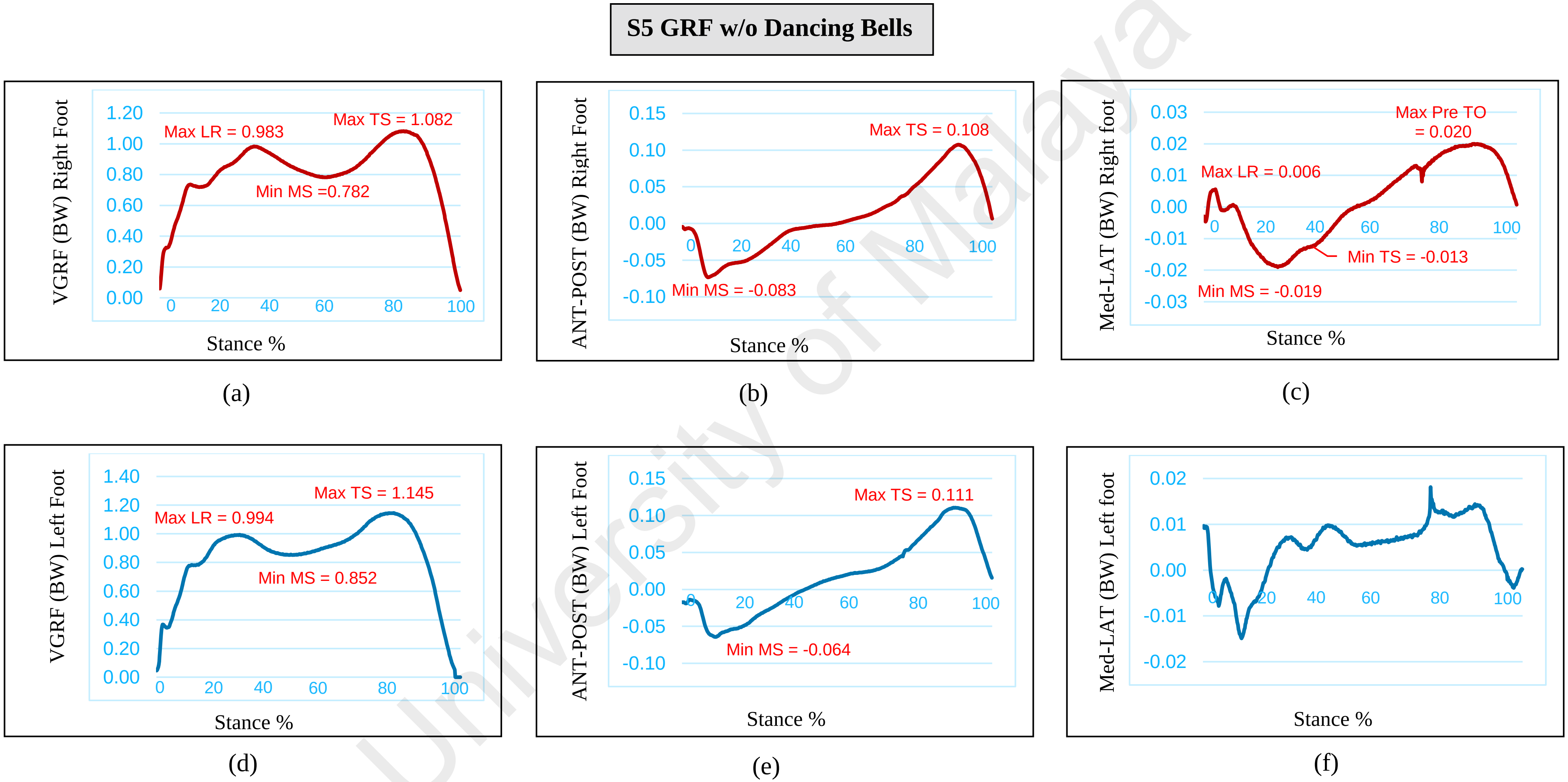


Figure 4.9: Ground Reaction force of S5 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking without wearing dancing bells

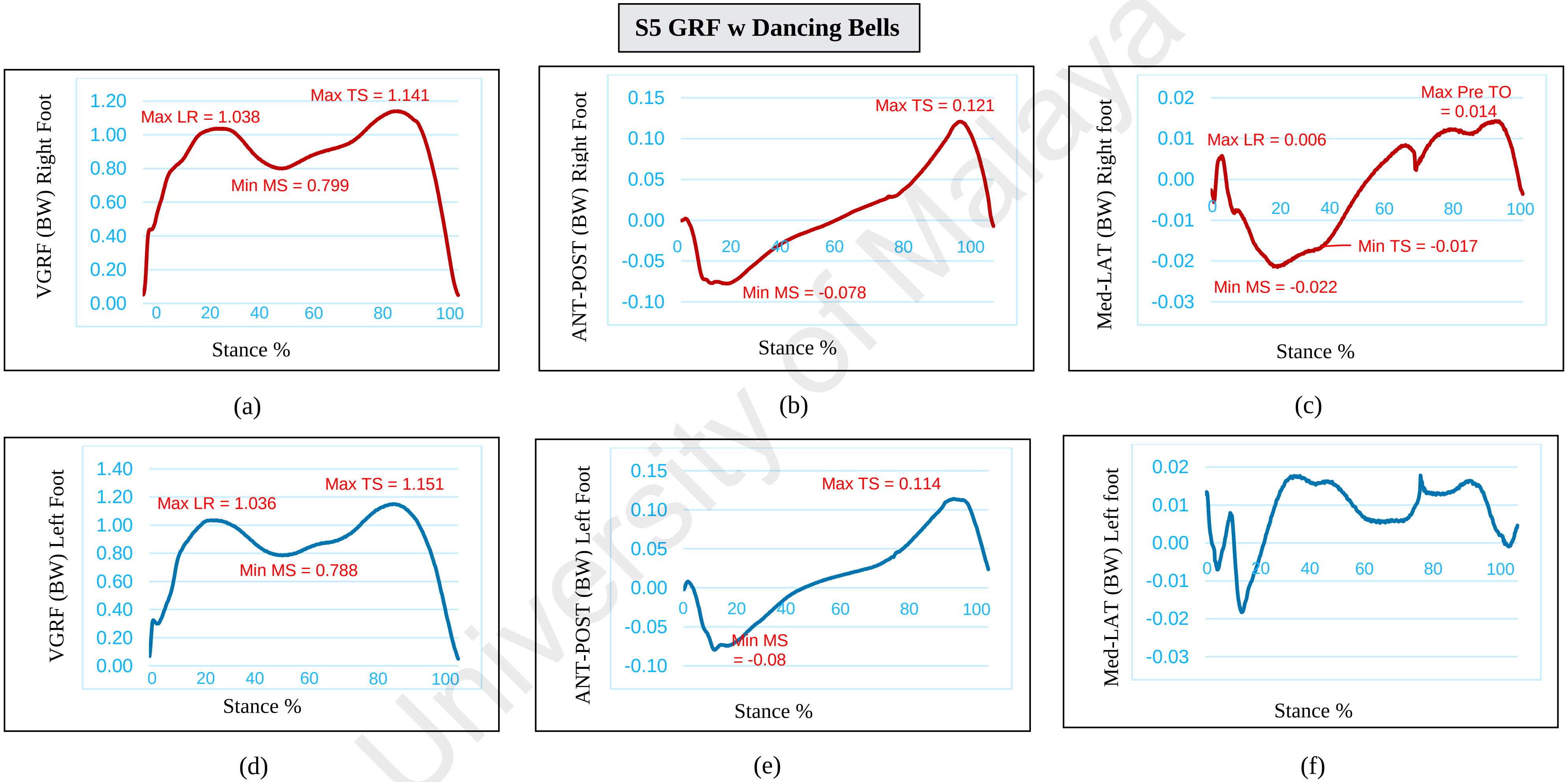


Figure 4.10: Ground Reaction force of S5 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking wearing dancing bells

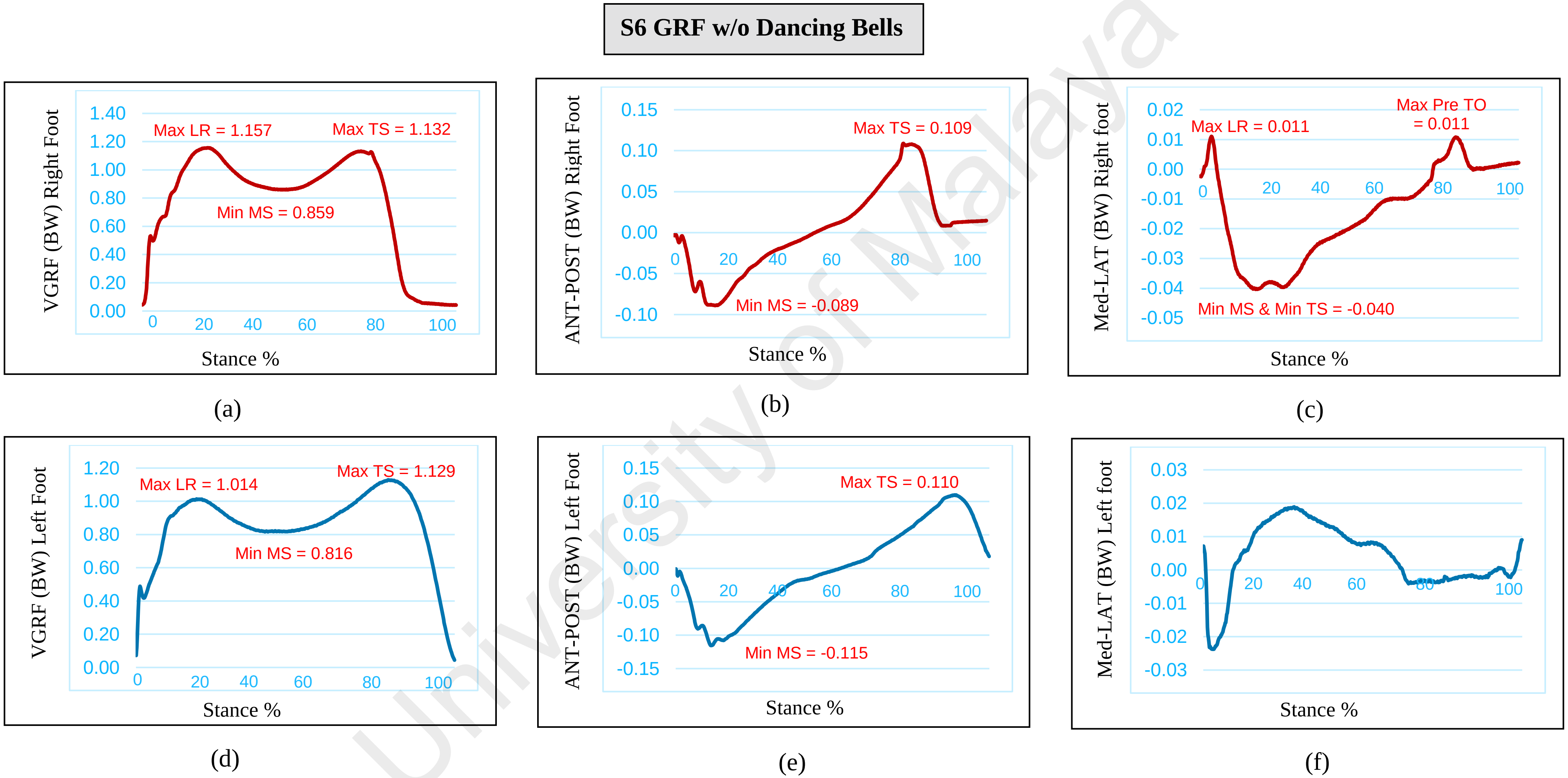


Figure 4.11: Ground Reaction force of S6 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking without wearing dancing bells

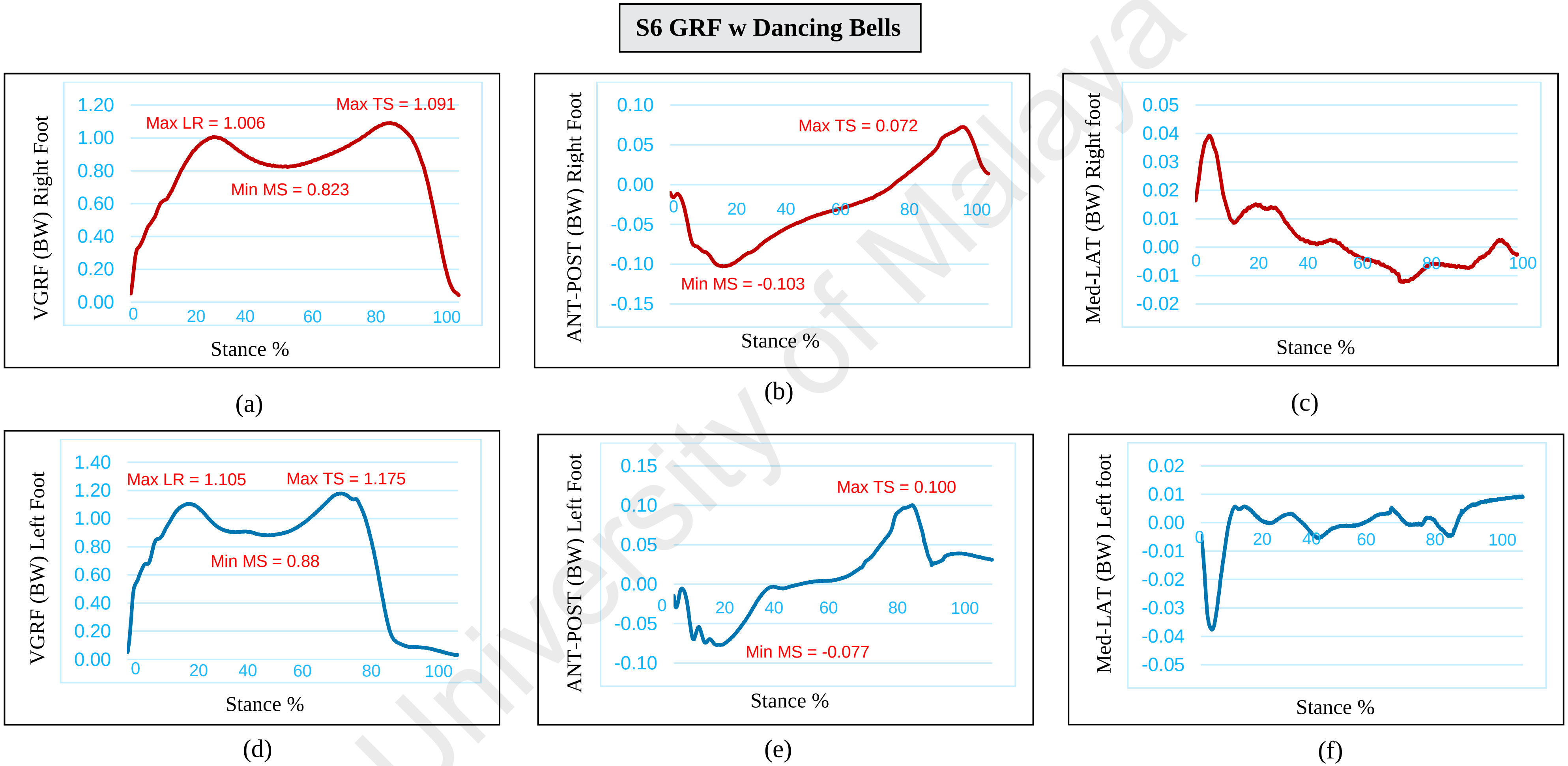


Figure 4.12: Ground Reaction force of S6 (a) VGRF of right foot, (d) VGRF of left foot, (b) Anterior/Posterior (ANT-POST) Force of right foot, (e) Anterior/Posterior (ANT-POST) of left foot, (c) Medial Lateral (MED-LAT) Force of right foot and (f) Medial Lateral (MED-LAT) Force of left foot taken during stance phase while subject walking wearing dancing bells

Table 4.7: Three-Dimensional angular kinematics for the hip, knee, and ankle for all six subjects from one best trial

Plane		S1 w/o DB		S2 w/o DB		S3 w/o DB		S4 w/o DB		S5 w/o DB		S6 w/o DB		S1 w DB		S2 w DB		S3 w DB		S4 w DB		S5 w DB		S6 w DB	
		Right	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Hip	**Sagital**																								
	Ext (-)	-19.787	-20.014	-16.289	-11.822	-11.664	-2.937	3.492	1.283	7.809	9.194	-13.235	-9.363	-21.020	-21.185	-16.259	-18.993	-5.245	0.089	-1.894	6.199	7.296	11.283	-13.229	na
	Flx (+)	15.836	19.820	30.149	28.451	33.122	35.936	39.382	51.937	47.193	49.549	27.181	36.701	19.853	20.720	30.617	30.959	38.814	41.803	38.313	40.918	47.290	49.807	30.062	na
	Frontal																								
	Abd (-)	-9.07	-11.437	-11.368	-6.425	-6.822	-6.633	-11.094	-8.086	-7.902	-9.390	-6.068	-11.962	-8.027	-12.649	-9.883	-9.606	-10.249	-6.633	-13.675	-4.741	-8.678	-8.474	-6.204	na
	Add (+)	5.411	-0.231	8.687	7.720	5.357	7.224	3.732	10.411	4.267	2.400	7.813	-4.105	3.961	-0.170	8.885	7.443	3.465	7.552	4.384	14.091	4.683	5.157	4.572	na
	Transverse																								
	ERot (-)	-18.817	-21.161	-0.626	-31.523	-11.664	-6.633	-13.685	10.748	16.971	17.343	1.906	-23.144	-45.066	-22.913	-2.652	-30.262	14.792	26.048	-22.874	5.571	16.182	17.489	6.097	na
	Irot (+)	37.759	-10.105	14.166	-14.388	25.246	7.683	0.699	25.281	26.063	26.578	38.663	-7.204	-7.873	-10.009	9.456	-19.105	22.514	36.835	0.680	18.097	26.322	27.909	61.233	na
Knee	**Sagital**																								
	Ext (-)	-26.102	-6.426	2.340	4.098	-1.786	0.019	-5.272	-3.815	-13.807	-4.493	-8.592	-6.425	-7.113	-0.006	-2.367	4.010	2.863	-0.556	-4.696	2.610	-11.631	-3.061	na	-14.873
	Flx (+)	49.645	57.113	67.890	63.234	47.362	49.745	54.161	64.704	46.911	60.873	59.156	65.496	48.906	60.211	66.930	66.252	55.460	56.119	56.082	67.333	47.588	58.632	na	55.370
	Frontal																								
	Abd (-)	-11.593	-3.952	-5.291	-15.105	0.020	3.619	-3.637	0.150	-1.909	1.580	-2.280	0.541	-8.871	-8.656	-5.537	-19.798	3.137	4.141	-7.314	-5.998	-1.631	1.507	na	-1.989
	Add (+)	4.729	7.729	5.892	4.634	20.228	12.616	9.073	19.085	21.413	27.621	24.828	7.729	3.732	6.276	5.626	4.591	22.166	30.023	6.194	10.426	22.594	27.121	na	11.642
	Transverse																								
	ERot (-)	-34.924	-1.931	-33.381	-16.679	-15.178	-12.035	-65.319	-47.466	-64.532	-5.384	-53.180	-32.470	-19.553	4.672	-25.033	-12.442	-14.273	-19.000	-58.652	-48.644	-58.608	-6.315	na	-12.839
	Irot (+)	1.846	19.838	20.863	21.097	13.282	18.877	-31.585	1.204	-48.022	15.191	3.102	0.297	5.976	21.073	16.053	17.348	14.090	17.330	-28.775	-11.907	-44.142	14.619	na	12.488
Ankle	**Sagital**																								
	PF (-)	-20.693	-14.195	-15.391	-10.727	-7.067	-4.212	-40.961	-32.856	-32.392	-25.673	-16.195	-15.124	-17.353	-9.984	-7.649	-21.344	-10.925	-4.737	-50.388	-28.568	-27.690	-14.422	na	-12.302
	DF(+)	8.299	12.956	21.781	15.529	15.209	20.269	17.461	10.273	12.843	13.064	8.889	15.821	13.469	18.163	23.609	15.463	17.035	23.248	32.379	17.339	15.971	19.536	na	14.292
	Frontal																								
	Eve (-)	-3.601	-0.105	-9.282	-5.925	1.347	2.151	-12.630	-2.882	-7.505	2.654	-9.210	-6.988	-4.500	0.114	-7.511	-7.140	1.766	3.923	-19.470	-7.059	-6.800	2.787	na	-3.526
	Inv (+)	2.702	4.059	1.368	2.614	4.847	6.303	-5.065	2.316	-3.654	5.170	2.903	-0.614	-0.858	3.853	28.808	2.367	5.378	8.490	-3.922	-0.807	-2.839	5.025	na	0.881
	Transverse																								
	ERot (-)	-22.255	-23.790	-8.834	-17.182	-32.759	-38.362	25.184	-17.223	16.938	-33.319	-19.801	-0.508	3.409	-22.705	-14.750	-15.987	-36.849	-47.285	20.352	0.196	12.706	-32.563	na	-8.081
	Irot (+)	22.821	0.814	34.589	25.535	-10.950	-16.792	48.256	11.959	34.108	-18.354	42.844	29.158	28.322	-0.560	28.808	30.506	-14.126	-27.770	59.421	32.212	31.350	-19.242	na	14.076

***Remarks: na indicates not available as kinematic data not captured by Vicon system. Please refer to Figure 4.13-4.36.

The table above produced based on (Teplá, Procházková et al. 2014).

Mean and Standard Deviation (mean±STD)

Table 4.8: Mean and standard deviation (std) GRF of Three-Dimensional angular kinematics between pB and Control

Plane		pB w/o DB	Control w/o DB	pB w DB	Control w DB
Hip	**Sagittal**				
	Ext (-)	-13.752±6.436	-0.137±9.188	-13.769±9.009	1.931±9.733
	Flx (+)	27.219±7.813	41.991±9.351	30.461±9.012	41.278±7.804
	Frontal				
	Abd (-)	-8.626±2.353	-9.084±2.187	-9.508±2.051	-8.354±3.395
	Add (+)	5.695±3.184	4.086±4.980	5.189±3.392	6.577±4.210
	Transverse				
	ERot (-)	-15.071±11.075	1.690±16.815	-10.009±27.477	4.493±16.265
	Irot (+)	10.060±20.123	18.347±17.621	5.303±21.501	26.848±22.052
Knee	**Sagittal**				
	Ext (-)	-4.643±11.124	-7.067±3.704	-0.528±3.978	-6.330±6.971
	Flx (+)	55.832±8.353	58.550±7.023	58.980±6.923	57.001±7.098
	Frontal				
	Abd (-)	-5.384±7.005	-0.926±1.987	-5.931±8.857	-3.085±3.563
	Add (+)	9.305±6.118	18.291±8.206	12.069±11.178	57.001±8.840
	Transverse				
	ERot (-)	-19.021±12.808	-44.725±22.774	-14.272±10.279	-37.012±25.479
	Irot (+)	15.967±7.488	-9.969±24.287	15.312±5.111	-11.543±25.601
Ankle	**Sagittal**				
	PF (-)	-12.048±5.975	-27.200±10.174	-11.999±6.211	-26.674±15.196
	DF(+)	15.674±4.908	13.059±3.231	18.498±4.134	19.903±7.234
	Frontal				
	Eve (-)	-2.569±4.496	-6.094±5.330	-2.225±4.826	-6.814±8.112
	Inv (+)	3.649±1.779	0.176±3.993	8.006±10.653	-0.332±3.520
	Transverse				
	ERot (-)	-23.864±10.606	-4.788±22.727	-22.361±17.854	-1.478±20.557
	Irot (+)	9.336±21.207	24.662±24.529	7.530±25.272	23.563±28.912

*Remarks: Yellow Highlight indicates dataset with large STD
Red indicates pB found to produce lower peak than control
Green indicates high increase in angular displacement w DB

From the table above, high standard deviation observed on Transverse plane angles. This indicates that the data points are spread out over a large range of values. The transverse plane measurements are usually less used and generally show the lowest reliability (Rosso, Gastaldi et al. 2017).

At Sagittal plane, during walk w/o BD event, pB found to have lower angular peak at Hip Ext and knee abduction while Control found to have higher angular peak at Hip Flx and Knee Flx. Besides that, pB w DB produce lower peak during hip Ext while control w DB produce higher peak during hip Flx. Here, pB w DB found to have 11.91% of increase of hip Flx angle. Besides that, pB w DB recorded 88.62% of reduction of peak Knee Ext angle while Control WB only recorded 10.43 % of the same. Moreover, Control w DB found to have 52.4% of angular increase at Ankle DF while pB w DB recorded 18% of the same.

At frontal plane, during walk w/o BD event, Control have lower angular peak at Hip Abduction and higher angular peak at knee adduction while pB found to have higher peak Hip Adduction angle and lower peak Knee Abduction angle. Besides that, pB w DB produce angular reduction during hip Abd ~10.23% compared to pB w/o DB while Control W DB recorded 60.96% of angular increase at Hip Add. Furthermore, lower peak knee Abd angle occur in both pB w DB and control w DB with reduction of 10.16% and 233.15% respectively. Here, more controlled movement observed after wearing bells. In additional to that, higher peak knee Add angle occur in both pB w DB and control w DB with increment of 30.78 % and 211.63% respectively. Moreover, an increase of 119.40% at peak of Ankle Inv observed in pB w DB while control w DB observed to have 288.64% of reduction at peak of Ankle Inv.

From kinematics analysis point of view, wearing dancing bells impacts our control group greatly as we can observe high percentage of angular increase/reduction, especially on the frontal plane which involves Abd/Add especially on ankle and knee.

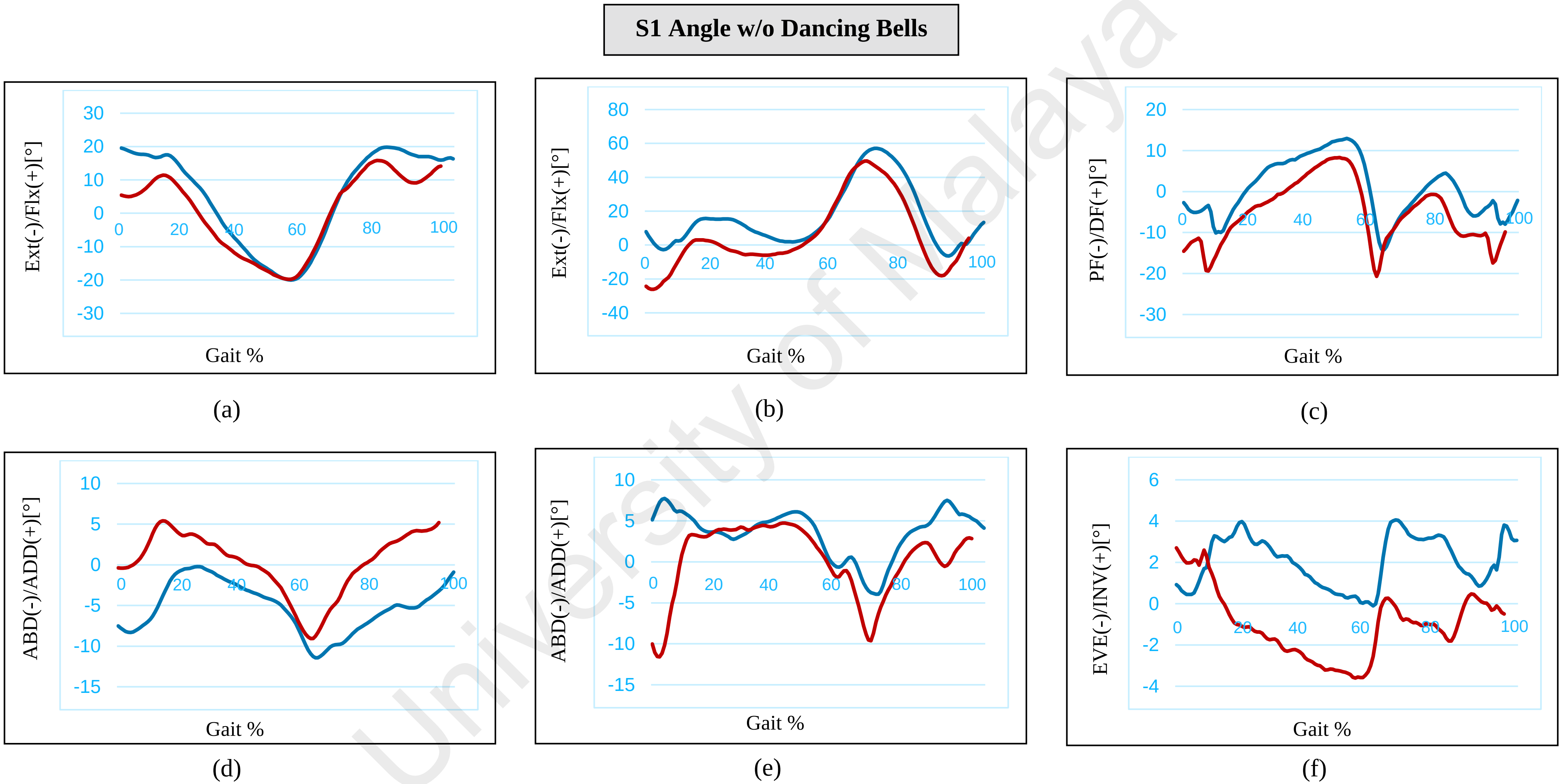


Figure 4.13: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 1 without wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion

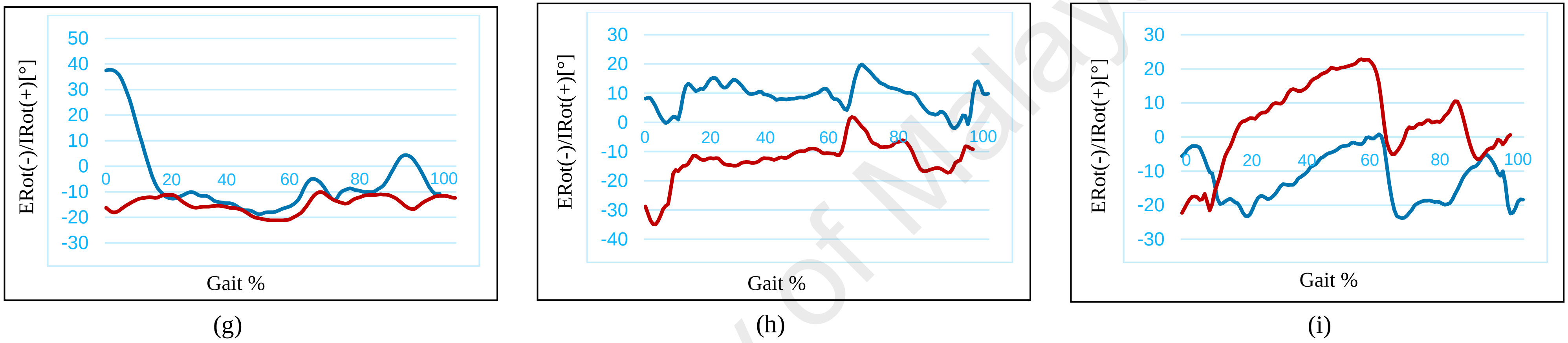


Figure 4.14: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 1 without wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

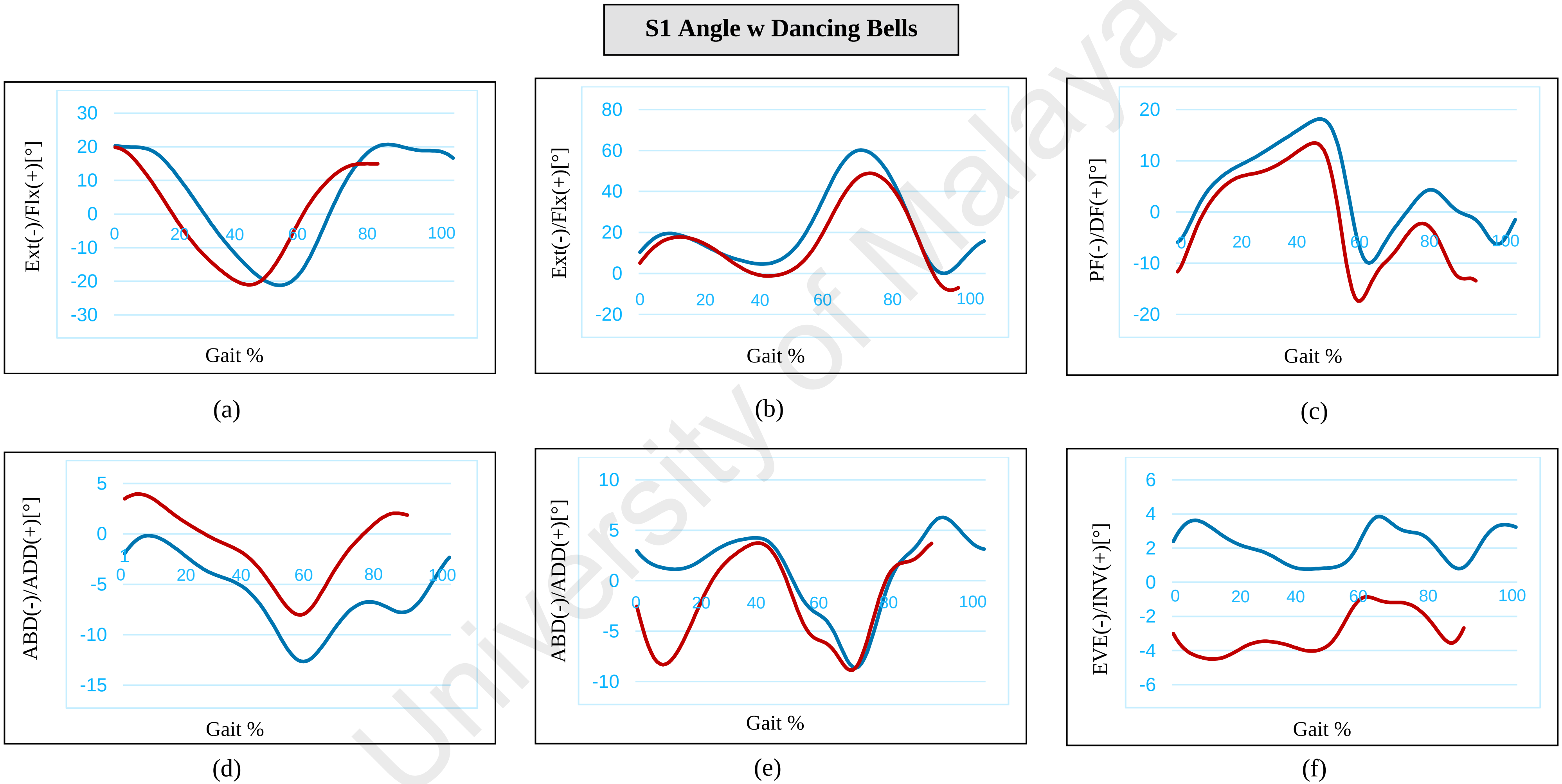
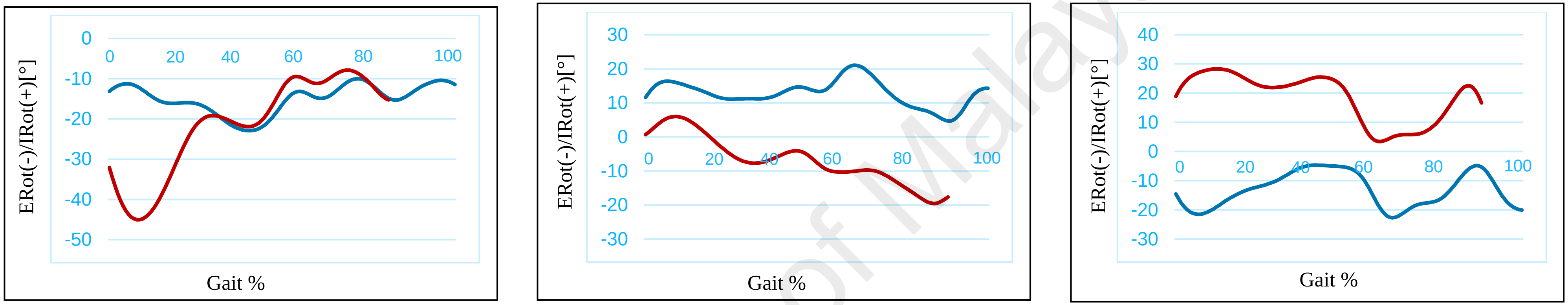


Figure 4.15: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 1 wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g) (h) (i)

Figure 4.16: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 1 wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

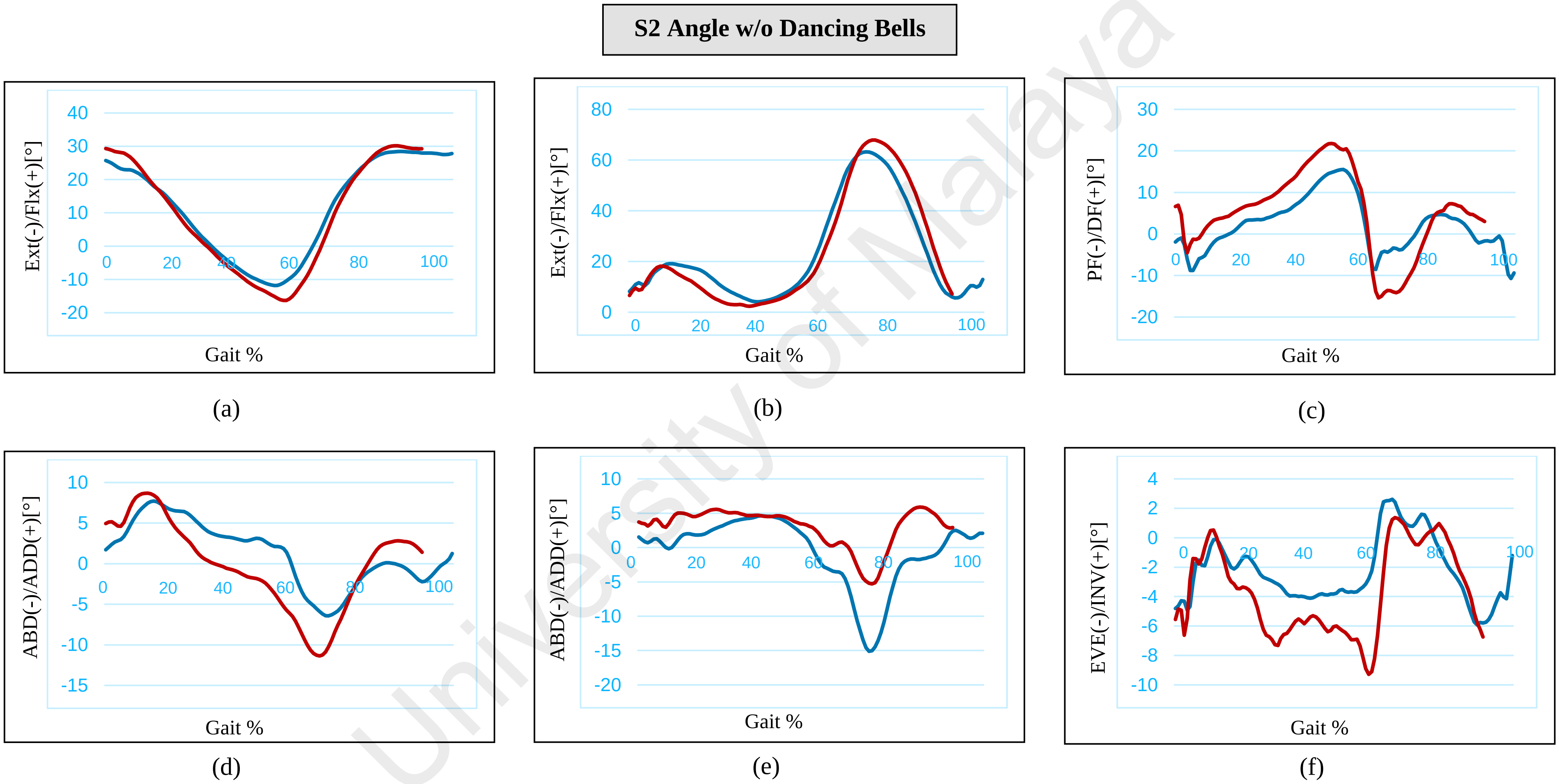
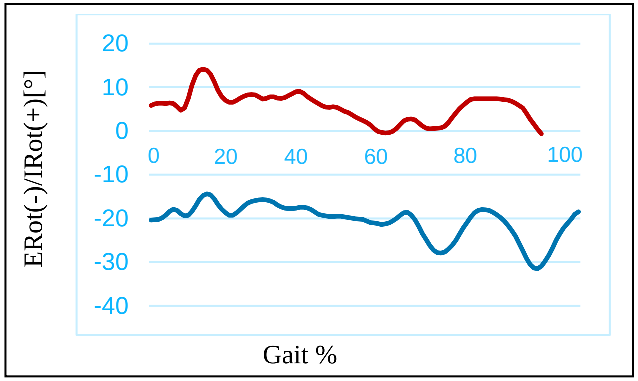
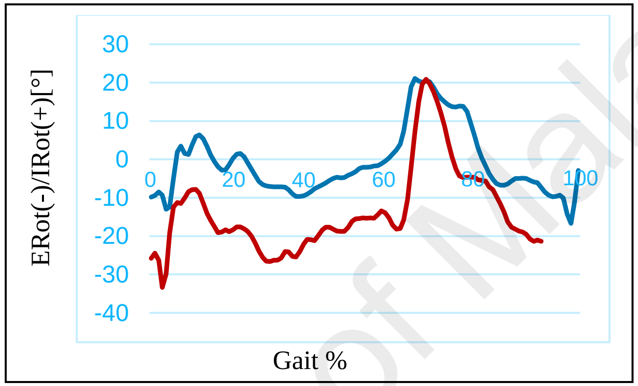


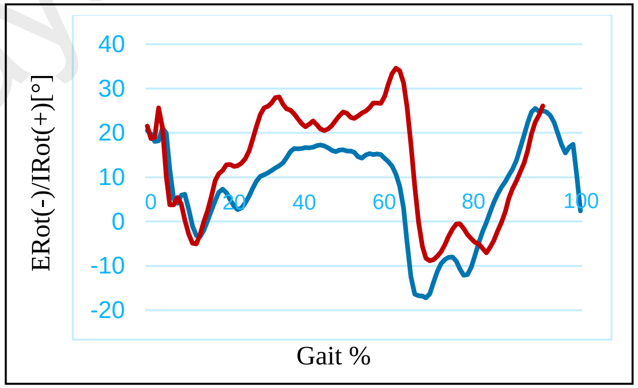
Figure 4.17: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 2 without wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g)



(h)



(i)

Figure 4.18: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 2 without wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

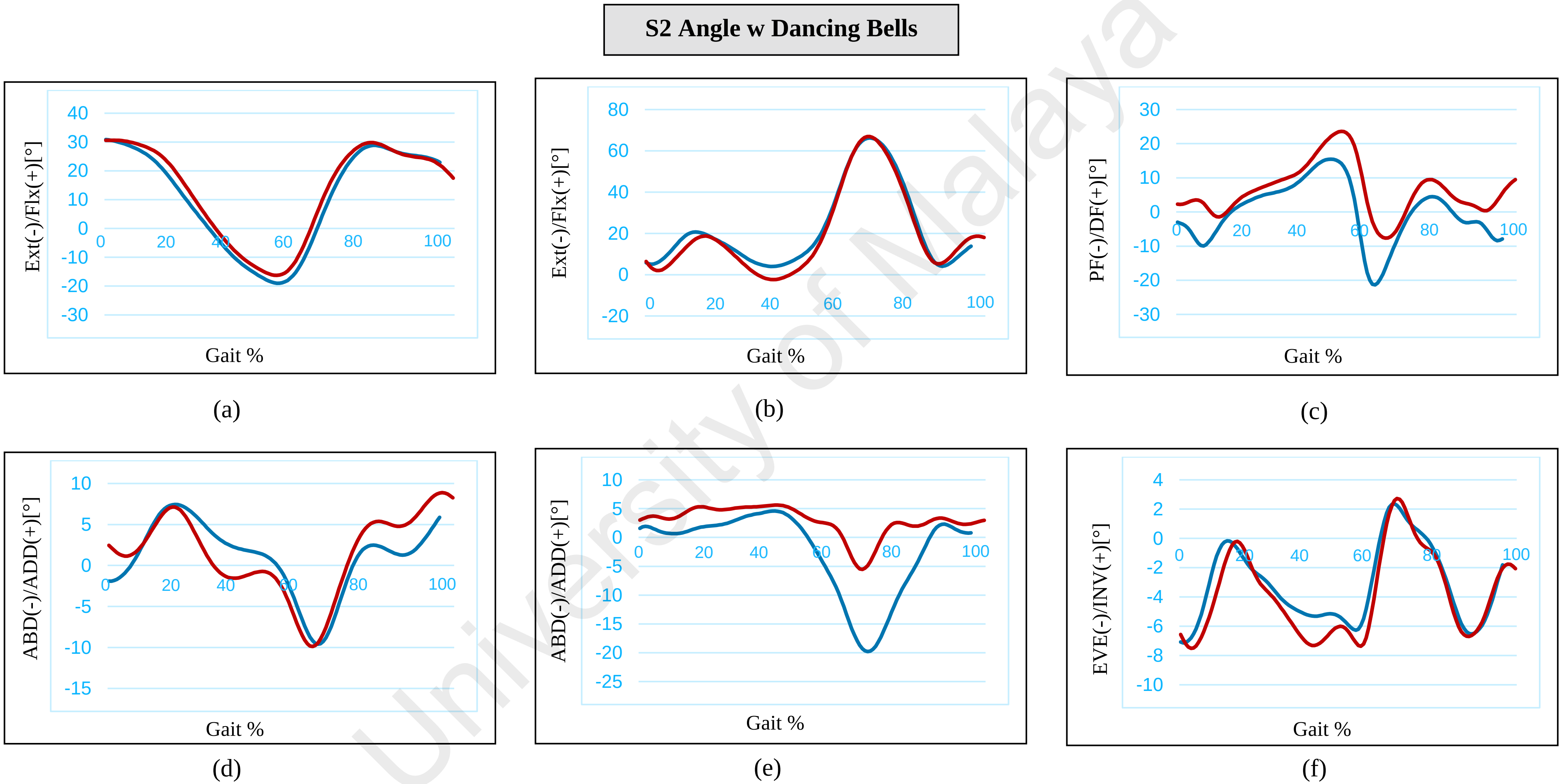
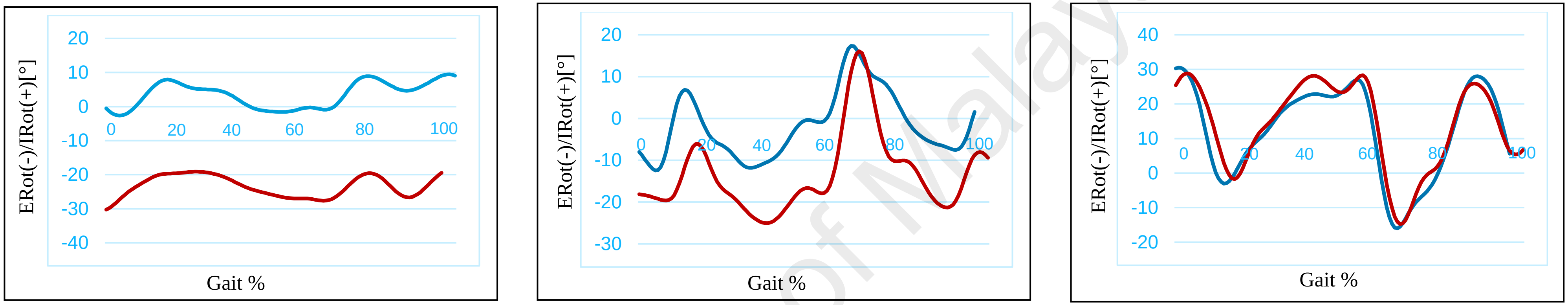


Figure 4.19: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 2 wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g) (h) (i)

Figure 4.20: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 2 wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

S3 Angle w/o Dancing Bells

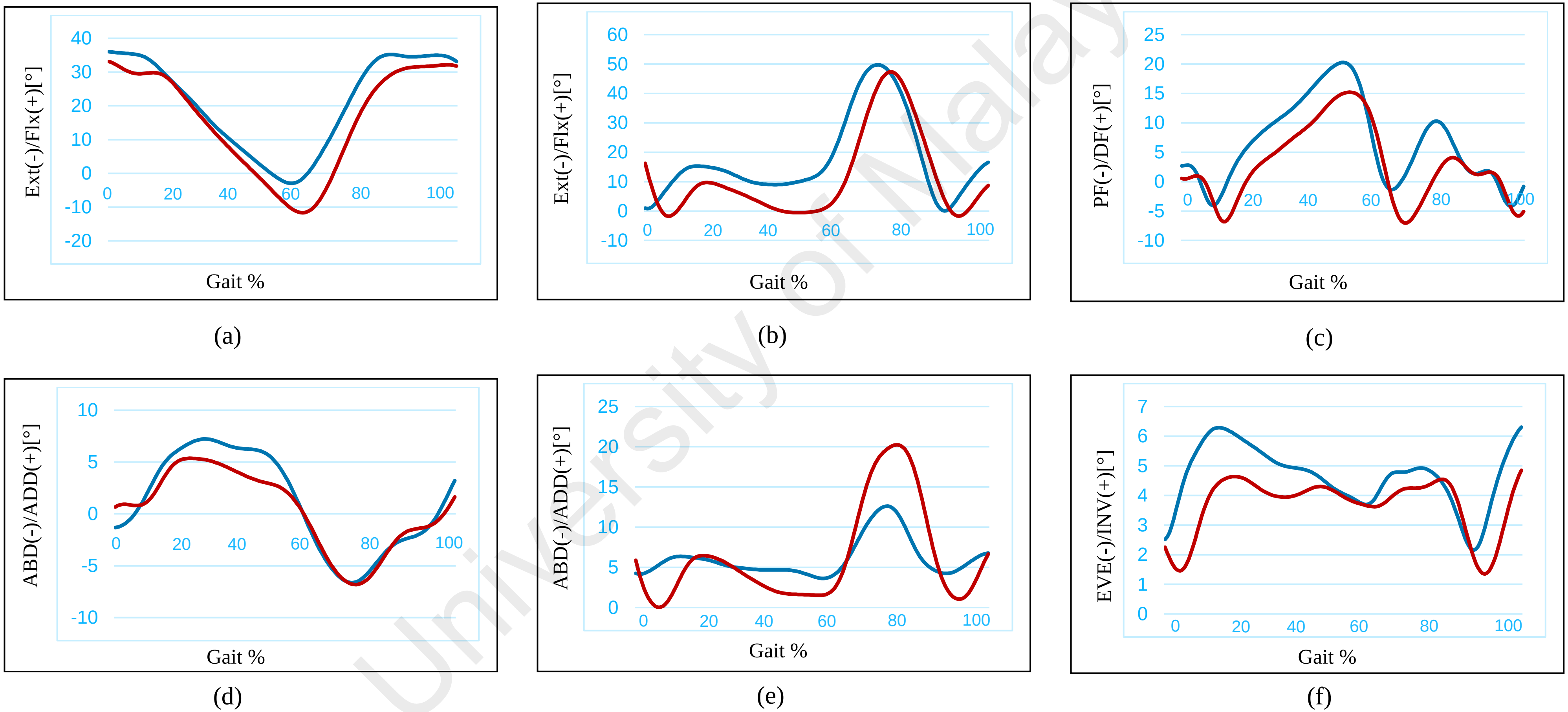
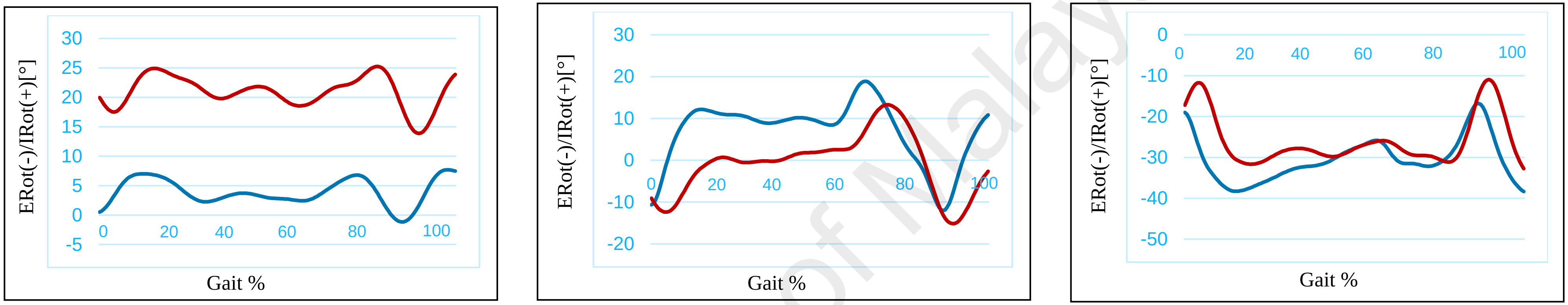


Figure 4.21: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 3 without wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g) (h) (i)

Figure 4.22: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 3 without wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

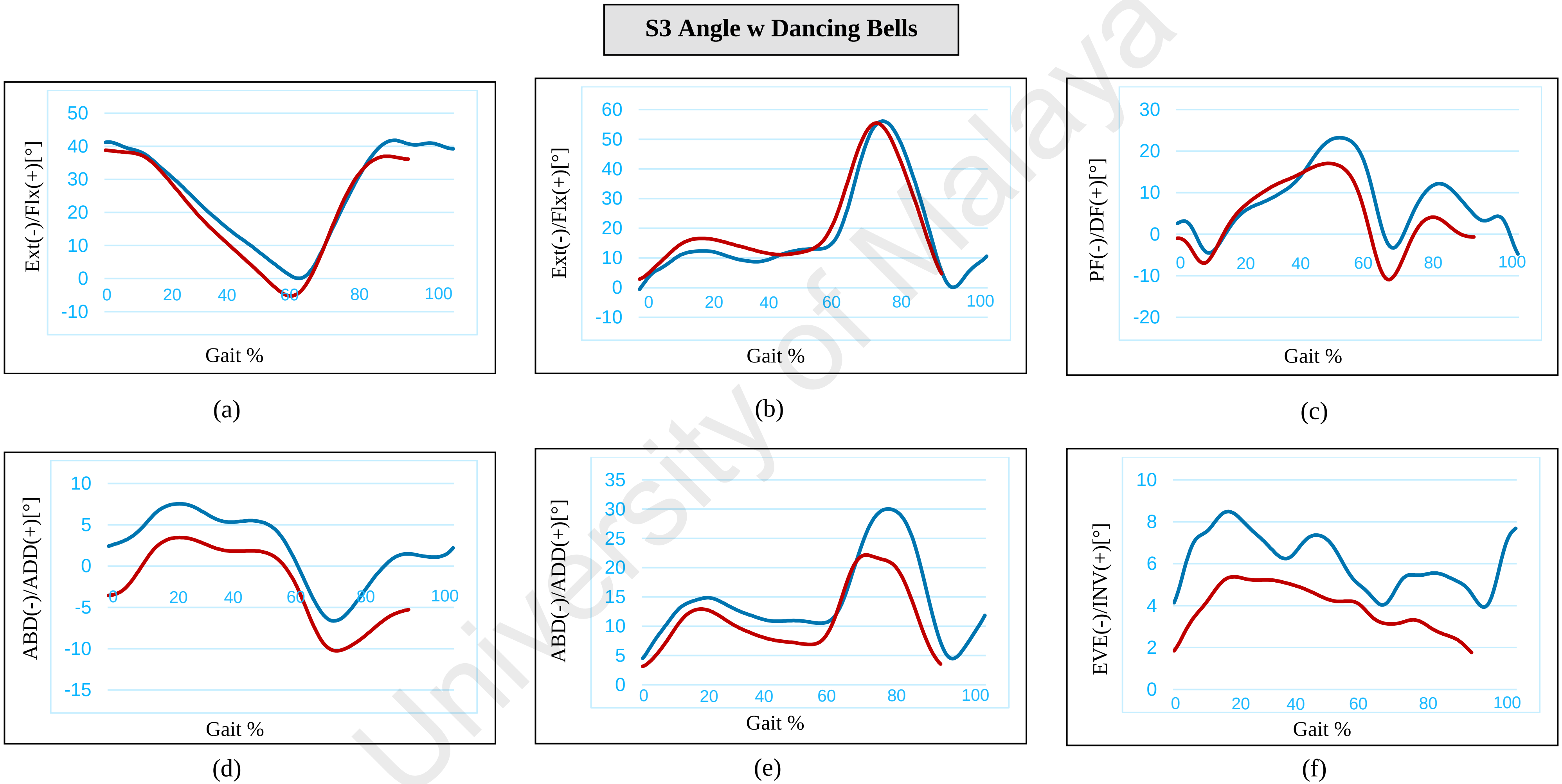
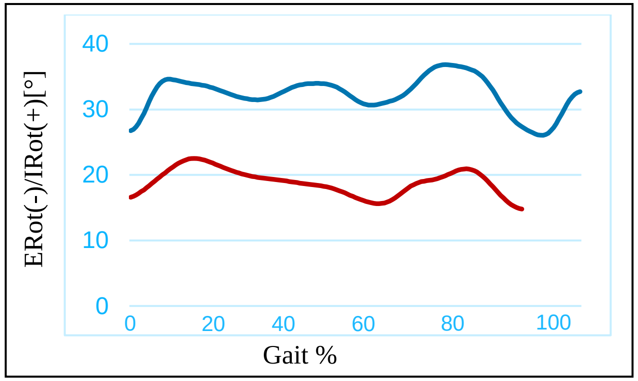
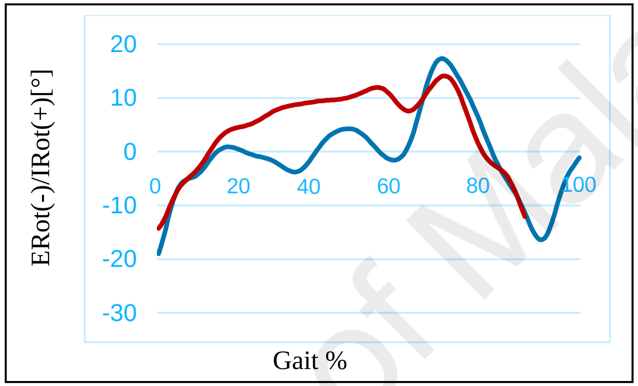


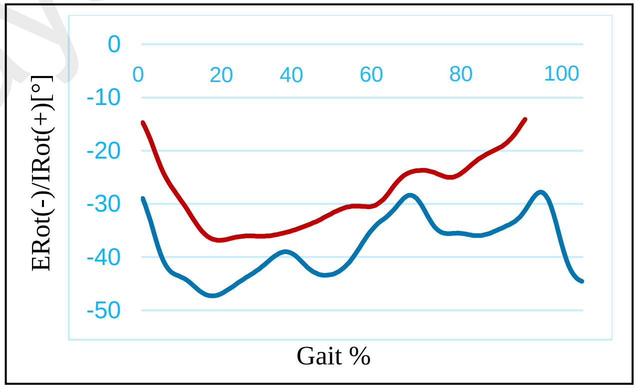
Figure 4.23: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 3 wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g)



(h)



(i)

Figure 4.24: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 3 wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

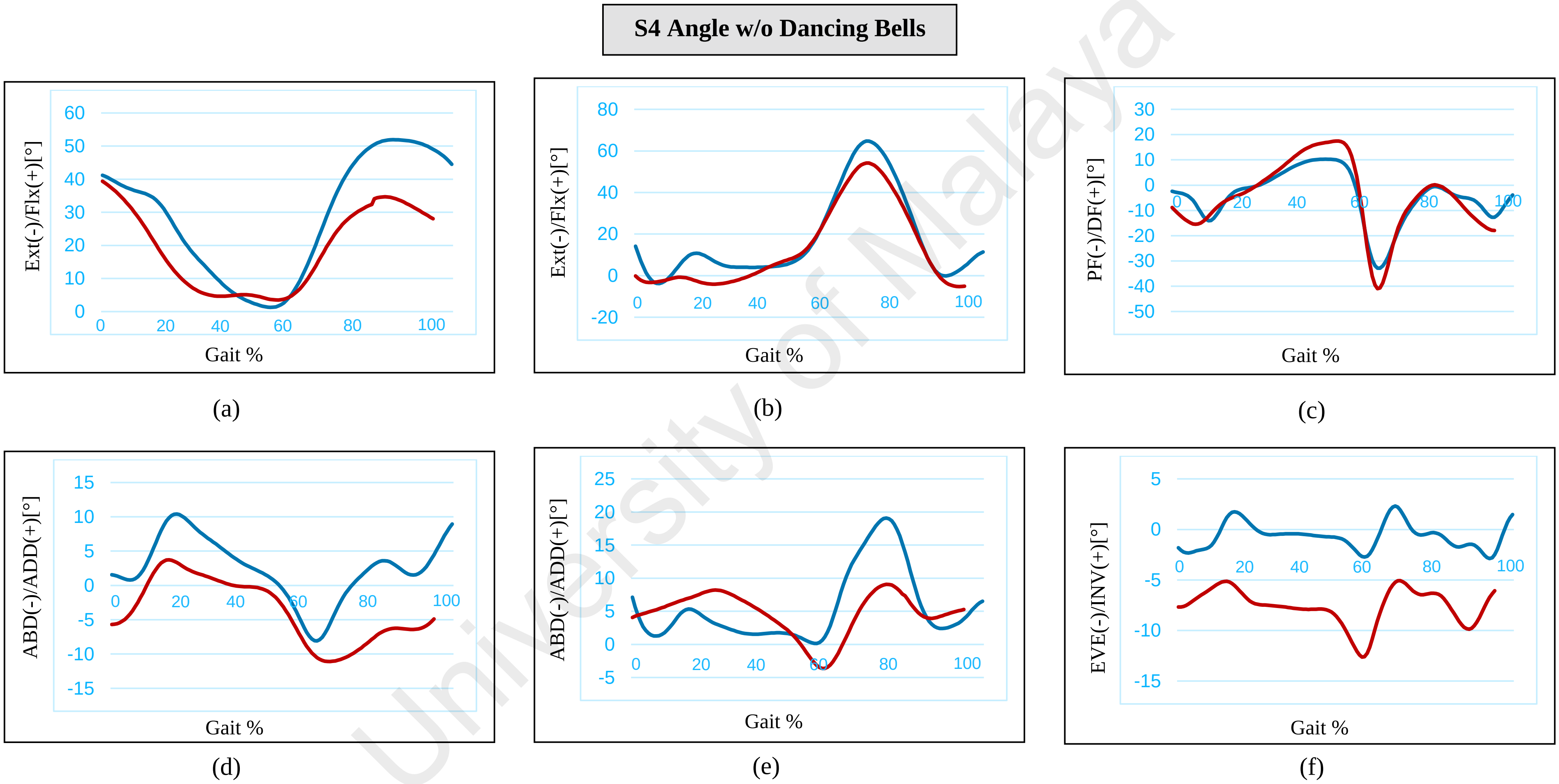


Figure 4.25: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 4 without wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion

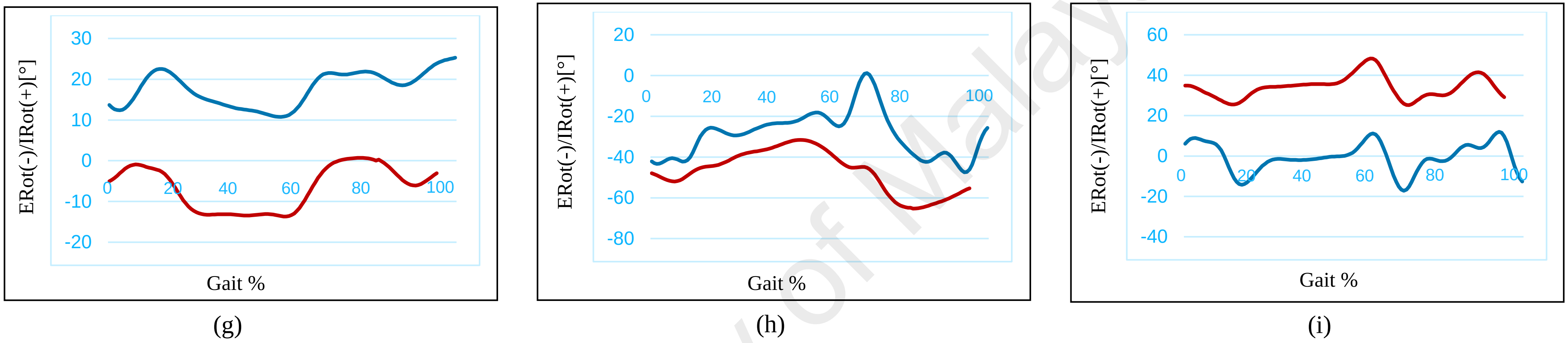


Figure 4.26: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 4 without wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

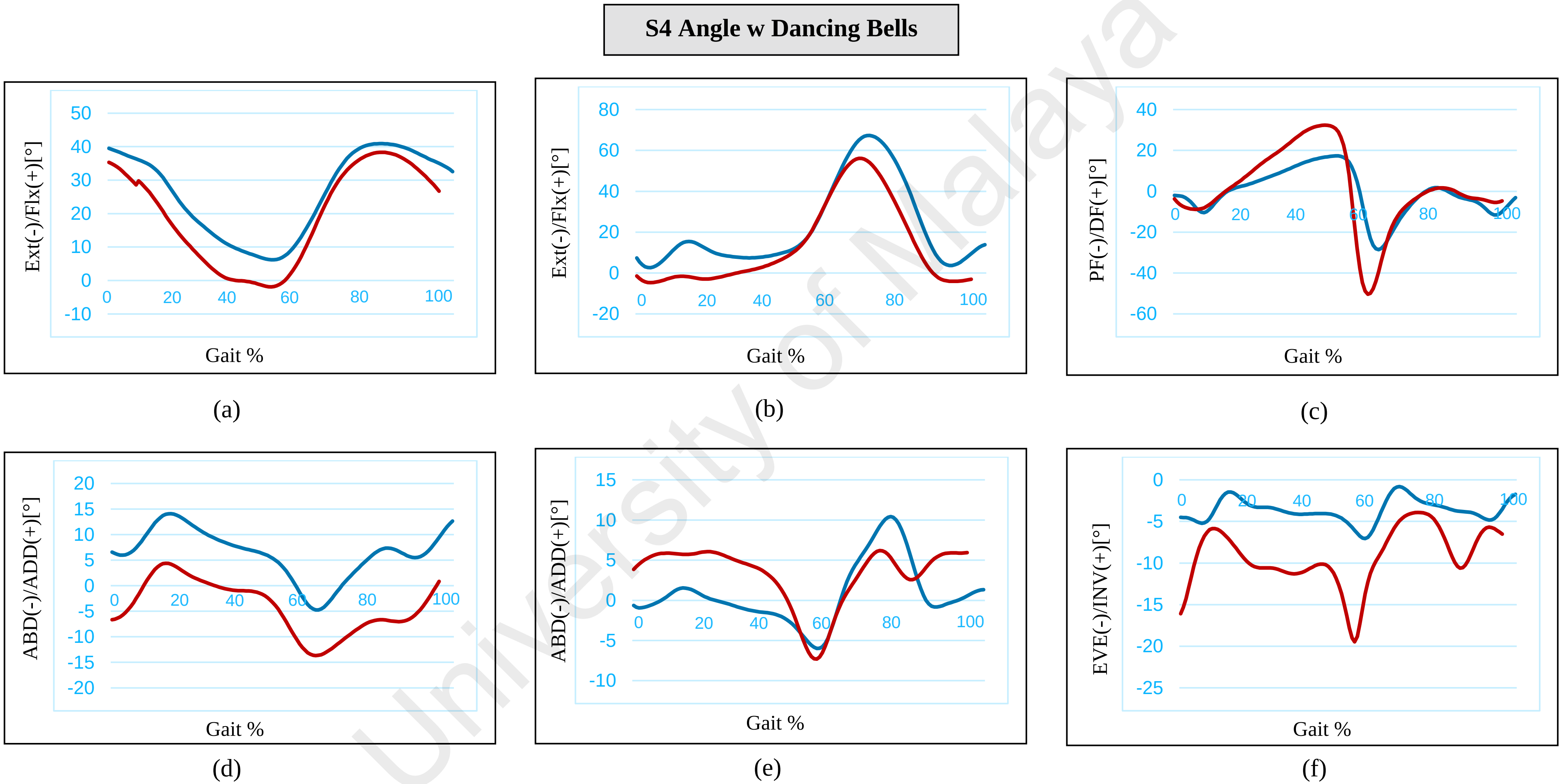
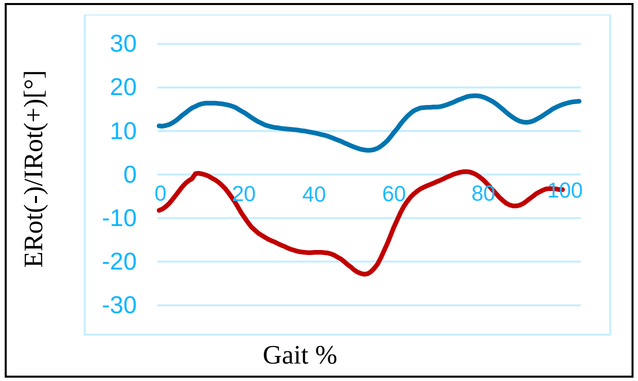
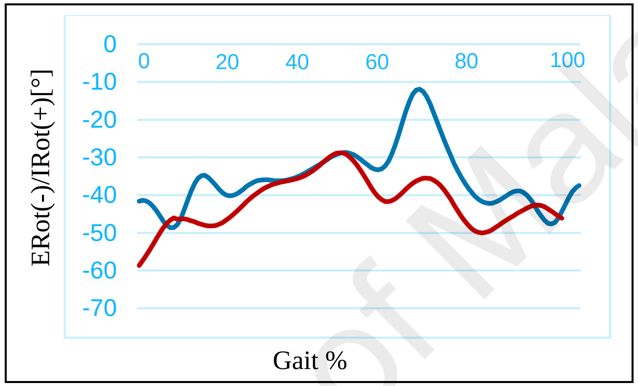


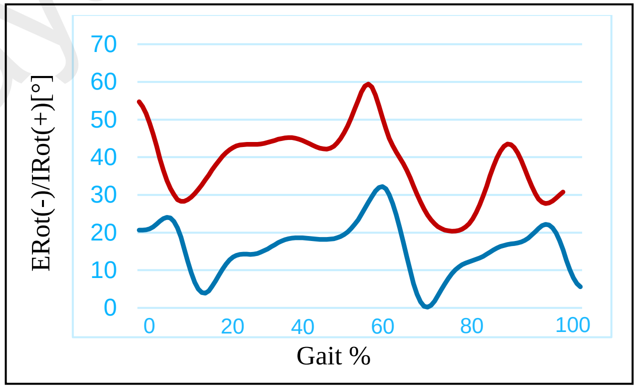
Figure 4.27: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 4 wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g)



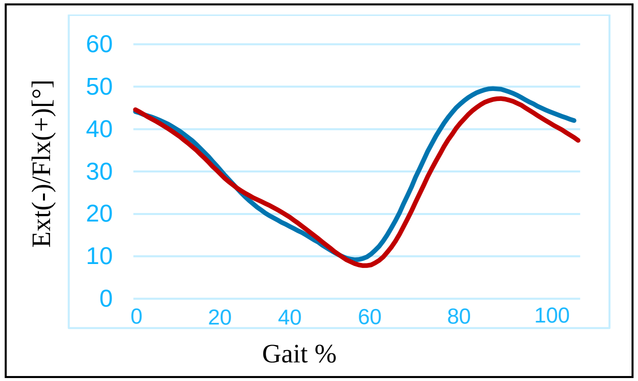
(h)



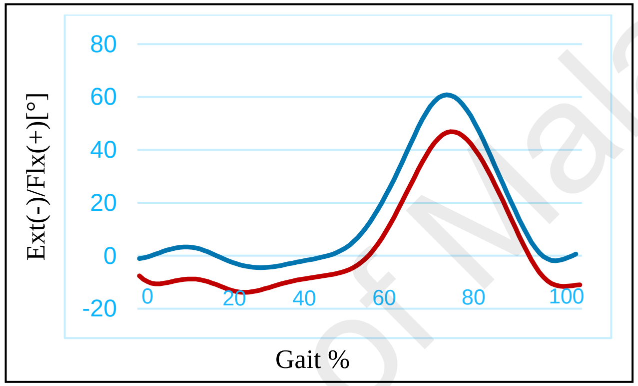
(i)

Figure 4.28: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 4 wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

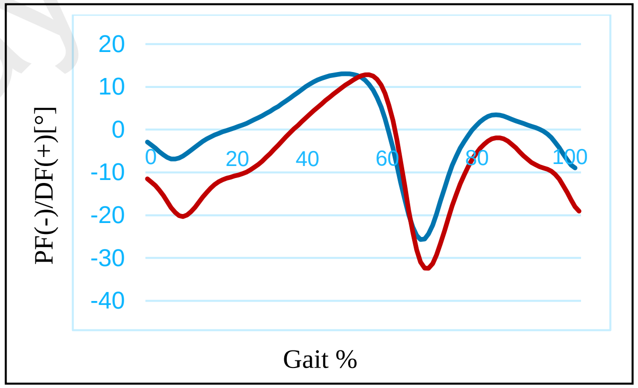
S5 Angle w/o Dancing Bells



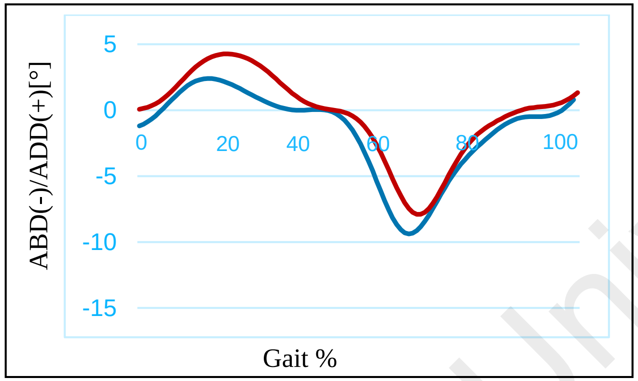
(a)



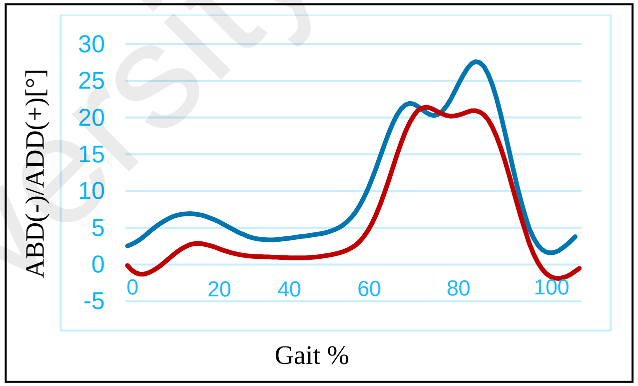
(b)



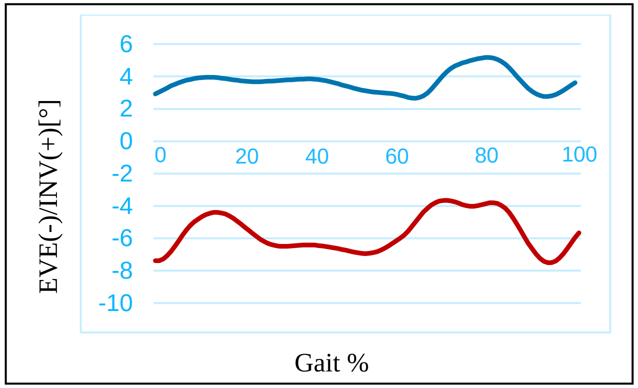
(c)



(d)

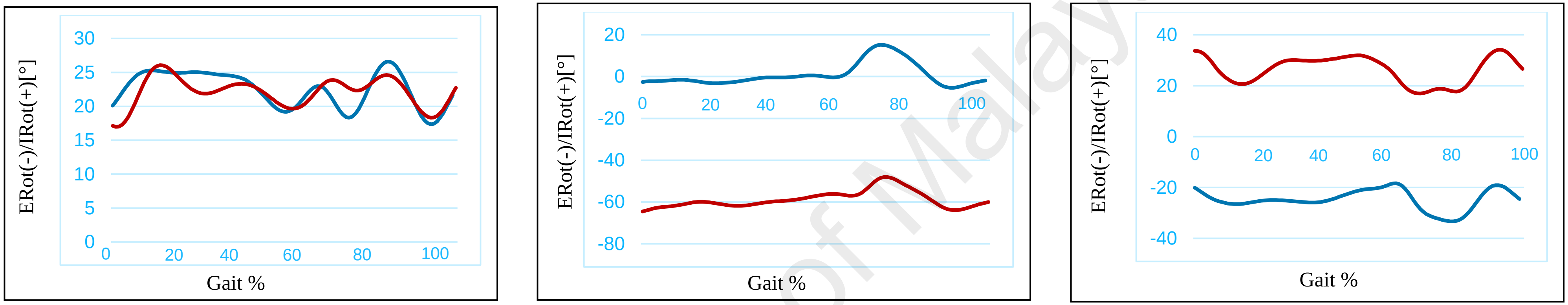


(e)



(f)

Figure 4.29: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 5 without wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g) (h) (i)

Figure 4.30: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 5 without wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

S5 Angle Dancing Bells

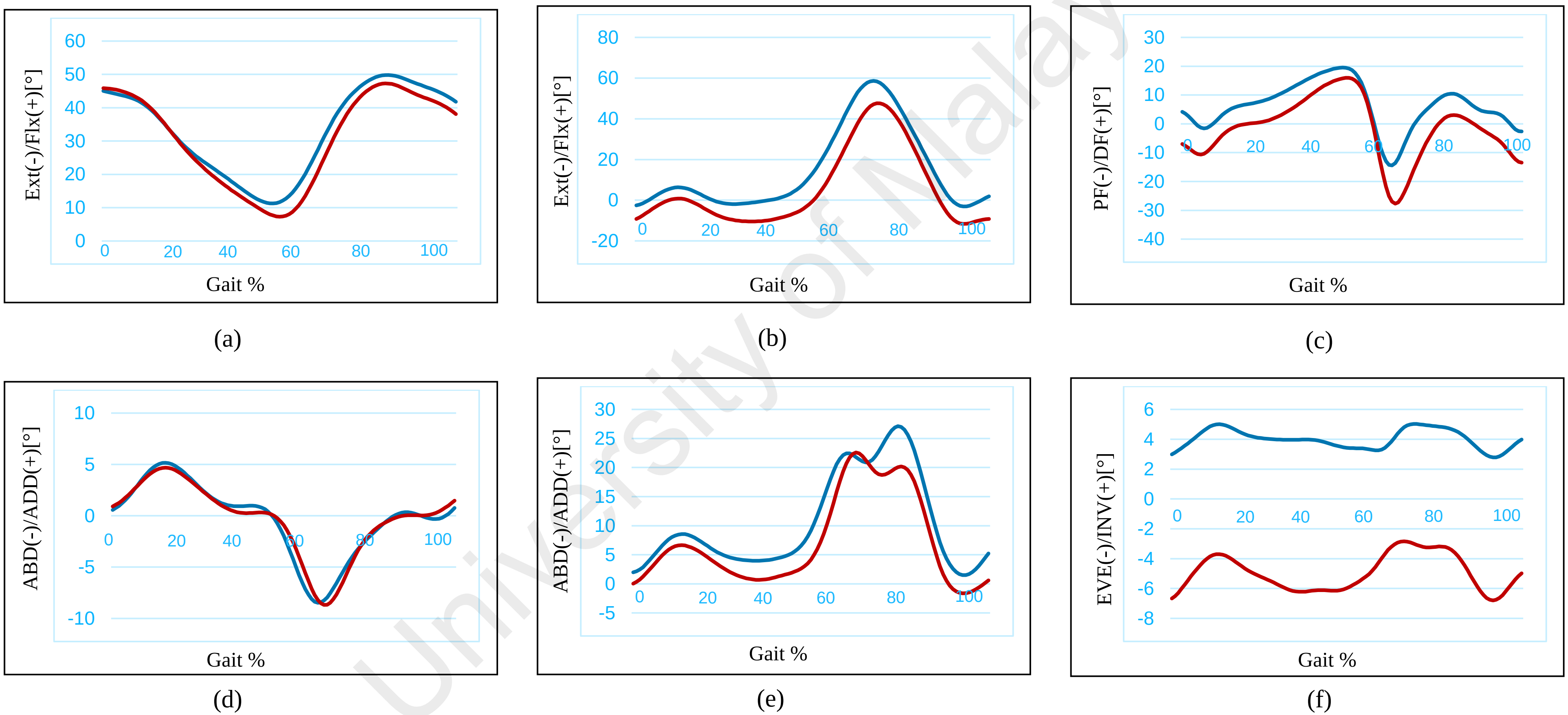
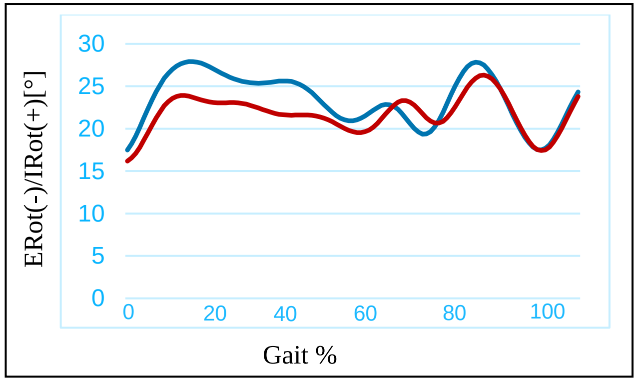
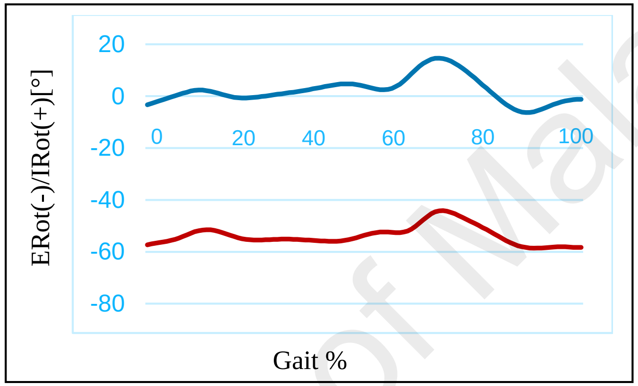


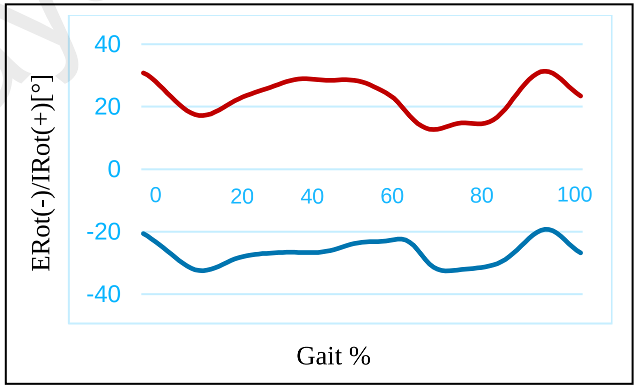
Figure 4.31: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 5 wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g)



(h)



(i)

Figure 4.32: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 5 wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

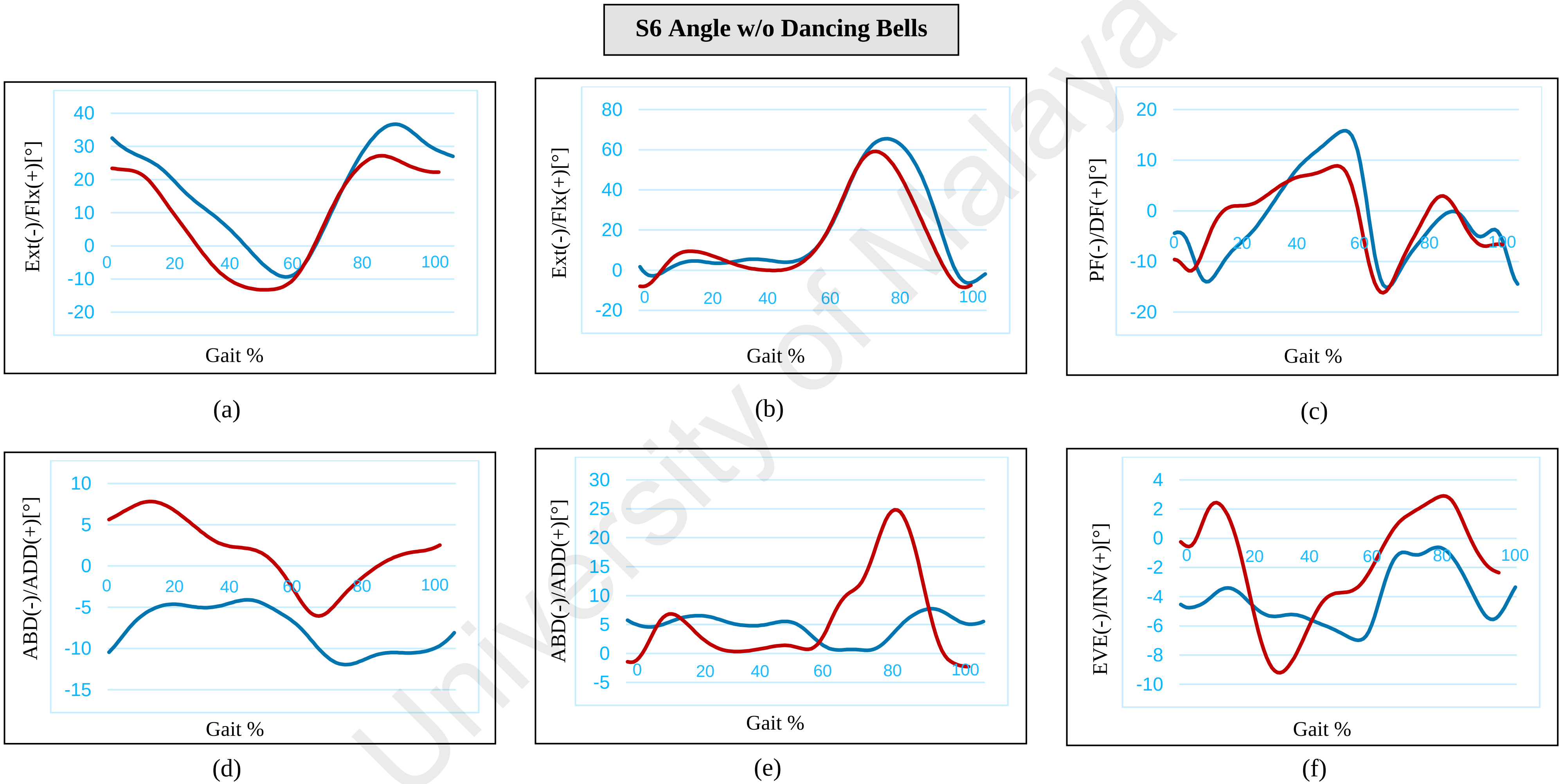
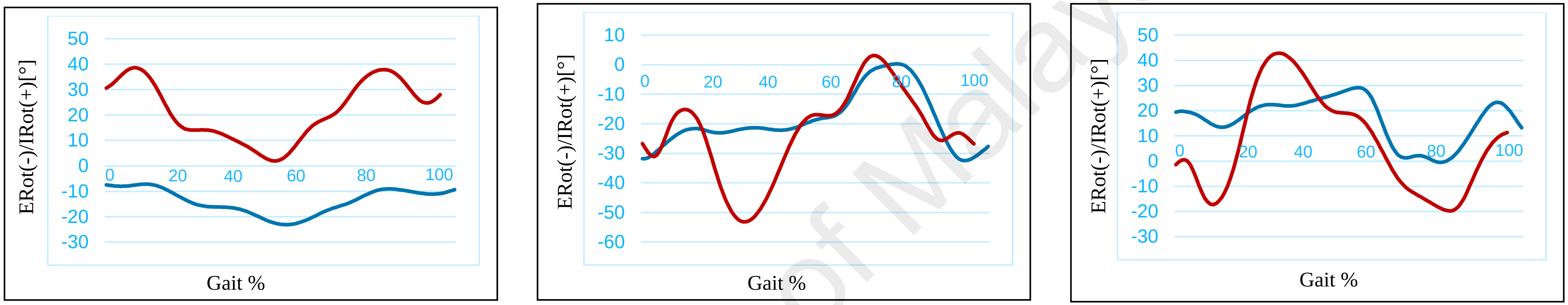


Figure 4.33: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 6 without wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g) (h) (i)

Figure 4.34: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 6 without wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

S6 Angle w Dancing Bells

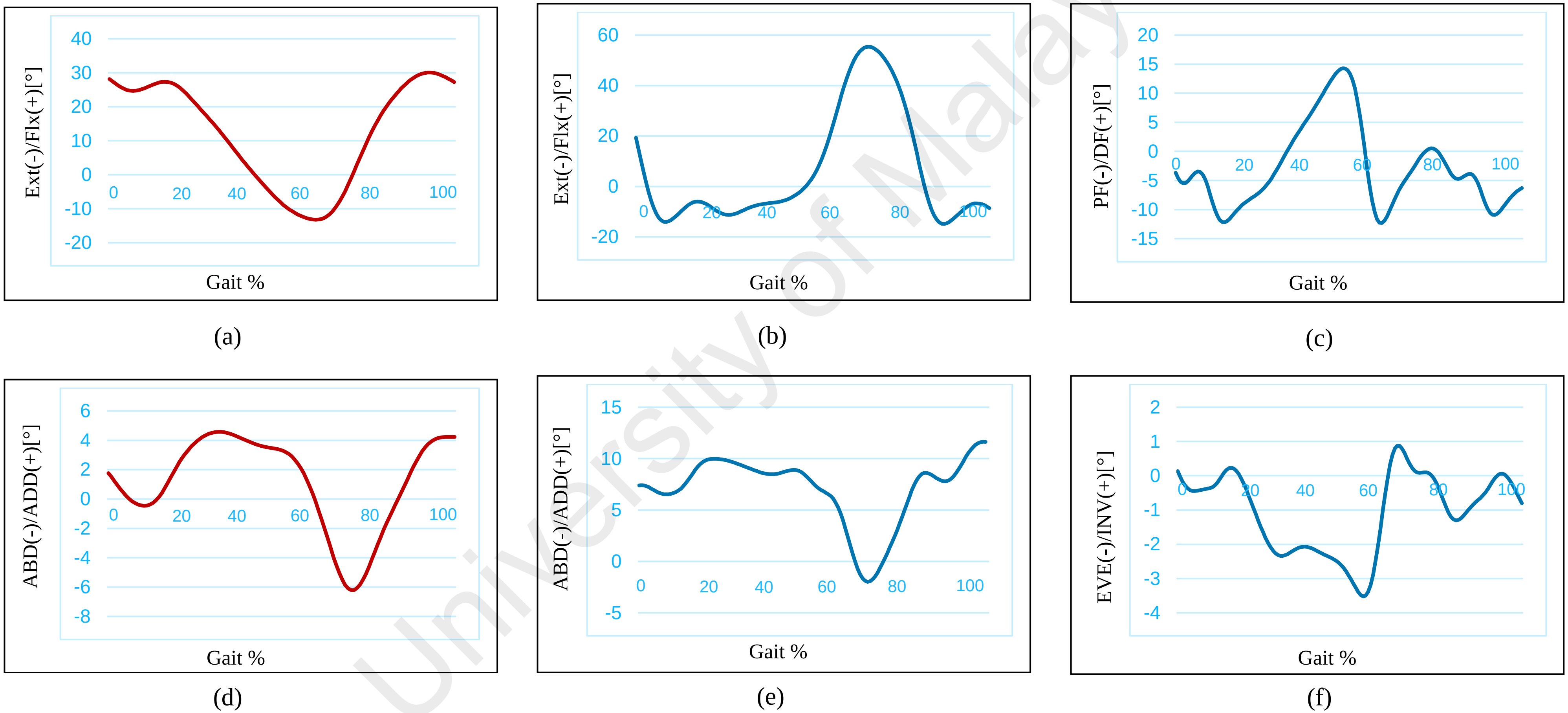
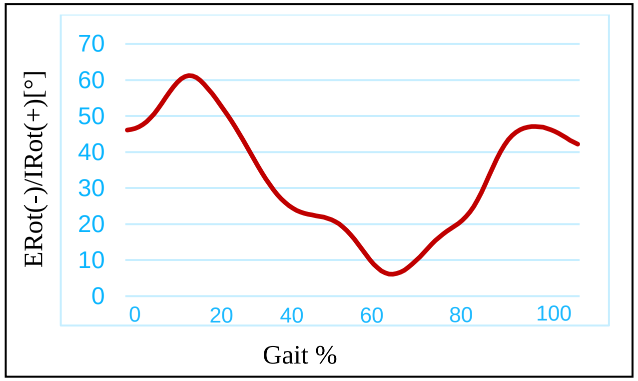
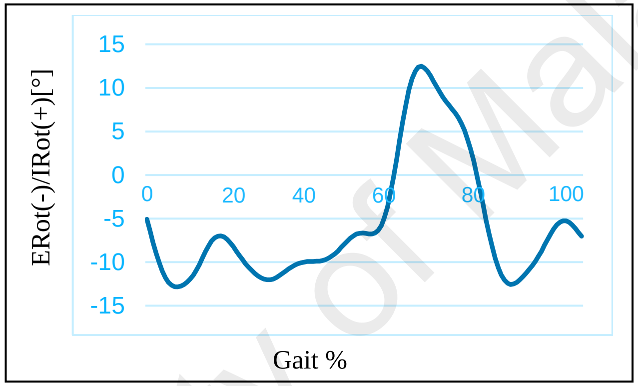


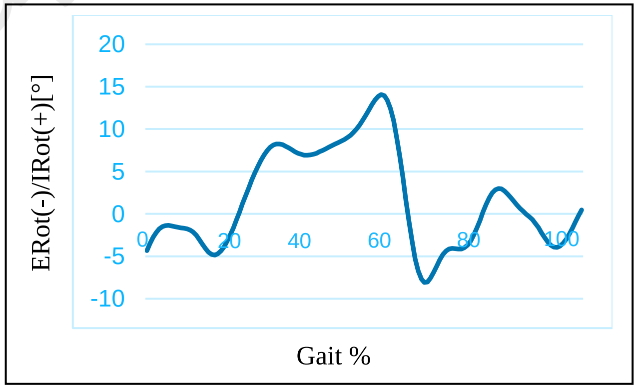
Figure 4.36: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 6 wearing dancing bells at **Sagittal plane** (a) Hip flexion /extension, (b) Knee flexion/extension, (c) Ankle plantar/dorsal flexion; **Frontal Plane** (d) Hip adduction/abduction, (e) Knee adduction/abduction, (f) Ankle Eversion/Inversion



(g)



(h)



(i)

Figure 4.36: Left (Blue Line) Leg and Right (Red) Leg Three-Dimensional angular kinematics for the hip, knee, and angle during walking gait of Subject 6 wearing dancing bells at **Transverse Plane** (g) Hip External rotation/Internal rotation, (h) Knee External rotation/Internal rotation, (i) Ankle External rotation/Internal rotation

CHAPTER 5: DISCUSSION

Both right and left foot are treated as independent contributor of this study (Menz 2004). Therefore, information captured from both feet are unique and require further study to explore their gait pattern. We are unable to 'break the code' behind medial/lateral forces and Transverse Plane Angle information gathered from pB and control due to it's subjective pattern and uniqueness.

Besides that, our study did not have any concrete inclusion and exclusion criteria during subject selection. Most published literatures give importance to both these criteria to reduce error and provide data (justification) of subject appropriateness. Researchers across the globe has applied well defined exclusion criteria in their dance related studies which the participants were excluded if they had any of the following: (1) history of lower extremity surgery or trauma, (2) ankle or knee effusion, or (3) ankle or knee joint instability, (4) pregnancy, (5) practicing dance forms other than Bharatanatyam or sports activities etc.

Moreover, if this study keen to be extended in the future, we should consider evaluating subject's leg dominant. Leg dominance questionnaire such as 'Waterloo Footedness Questionnaire-Revised' able to evaluate subject's dominance leg which can assist researchers to justify their findings further (van Melick, Meddeler et al. 2017).

It is extremely important to calibrate and service (once reaching the usage limit) the equipment used to capture data (VICON cameras and Kistler Force Plate). Over a long period of time, due to high usage, the gauge strains can be exhausted and start producing inaccurate results. Markers requires calibration and testing as well as some of them depend on external reflective paper material wrapping. Corrupted markers impact Vicon camera from capturing kinematic information and leads to missing markers in the raw angular data. Marker replotting may not be accurate and bias from one researcher to another based on experience.

While conducting experiment, it is very crucial to perform the all steps correctly in order to produce accurate results. Some researcher suggest subject to look at a target placed about 160 ~ 170cm above floor level on the wall at the end of the walking platform to encourage them to walk casually (Lung, Chern et al. 2008). Besides that, after two first trials over, consider processing the first two data to check for any errors (missing marker, noise on FP etc).

One major limitation of the current work is number of participants. We only recruited 3 pB and 3 controls (involves 12 foots in total). Researchers across the globe who has published their findings have good number of subjects involved. For example, Anbarasi has performed analysis of lower extremity muscle Flexibility among 401 Indian Classical Bharathnatyam Dancers (Anbarasi, Rajan et al. 2012).

CHAPTER 6: CONCLUSION

Our literature states dancer's community ranks high on accidents. We observed the same pattern among our pB too. From Kinetics data analysis, pB w DB found to exert abnormal spikes on GRF ranging from (54%-166%). DB seems to impact pB's GRF more compared to Control especially producing high VGRF peak at max LR (double support phase) and low ANT-POS force peak at min MS. Wearing dancing bells impacts our control group kinematics data as we can observe high percentage of angular increase/reduction, especially on the frontal plane which involves Abd/Add especially on ankle and knee. Overall, we observe difference in kinetics and kinematics information obtained from pB and Control when they walk barefoot and wearing dancing bells at both ankles.

The findings suggest the intense dancing activities and wearing dancing bells have the capacity to change the walking pattern of an individual. This study should be extended by recruiting more pB and Controls to validate the current findings. Experimental procedures should be observed closely to avoid occurrence of digital noise and missing markers.

References

Abdulhassan, Z. M. and S. J. Abbas (2013). "Kinematic analysis of human climbing up and down stairs at different inclinations." Engineering and Technology Journal **31**(8 Part (A) Engineering): 1556-1566.

affhhsna96 (2019). "Course Hero." from https://www.coursehero.com/file/p4mfums50.

Anand Prakash, A. (2017). "Medical attention seeking dance injuries: systematic review of case reports." The Physician and sportsmedicine **45**(1): 64-74.

Anbarasi, V., et al. (2012). "Analysis of lower extremity muscle flexibility among Indian classical Bharathnatyam dancers." pain: 225-230.

Andhare, N., et al. "Effect of Intrinsic Muscle Training on Balance in Bharatanatyam Dancers: Randomized Control Trial."

Azzarelli, S. (2014). Dancing Across Gender Boundaries Queer Experiences in Bharatanatyam Abhinaya, NTNU.

Barnes, M. A., et al. (2000). "Knee rotation in classical dancers during the grand plié." Medical Problems of Performing Artists **15**(4): 140-147.

Beatty Jr, M. F. (2013). Principles of Engineering Mechanics: Kinematics—The Geometry of Motion, Springer Science & Business Media.

Beggs, J. S. (1983). Kinematics, CRC Press.

Bhavanani, A. (2014). "Classical and folk dances in Indian culture." Yoganjali Natyalayam, &.

BHAVANANI, Y. D. A. B. and Y. S. D. BHAVANANI (2001). "Bharatanatyam and Yoga." Pondicherry-13, South.

Blanke, D. J. and P. A. Hageman (1989). "Comparison of gait of young men and elderly men." Physical Therapy **69**(2): 144-148.

Blazevich, A. and A. J. Blazevich (2017). Sports biomechanics: the basics: optimising human performance, Bloomsbury Publishing.

Borelli, G. A. (1743). De motu animalium, Apud Petrum Gosse.

Bottema, O. and B. Roth (1990). Theoretical kinematics, Courier Corporation.

Brockett, C. L. and G. J. Chapman (2016). "Biomechanics of the ankle." Orthopaedics and trauma **30**(3): 232-238.

Burdett, R. (1982). "Forces predicted at the ankle during running." Medicine and science in sports and exercise **14**(4): 308-316.

Chatterjee, A. (2013). "The therapeutic value of Indian classical, folk, and innovative dance forms." Rupkatha Journal on Interdisciplinary Studies in Humanities **5**(1): 75-83.

Chinn, L., et al. (2014). "Gait kinematics after taping in participants with chronic ankle instability." Journal of athletic training **49**(3): 322-330.

Chryssafis, J. (1930). "Aristotle on kinesiology." The Journal of Health and Physical Education **1**(7): 14-56.

Damavandi, M. (2015). "Kinematics of hip, knee and ankle during cross-slope walking." **5** فیزیک درمانی-نشریه تخصصی فیزیوتراپی(2): 89-96.

Documentation, N. (2016). "Plug-in Gait kinematic variables."

drzezo (2019). "Gait Evaluation and Management." Musculoskeletal key. from https://musculoskeletalkey.com/gait-evaluation-and-management/.

Ducroquet, R., et al. (1968). Walking and limping: a study of normal and pathological walking, Lippincott.

Echegoyen, S., et al. (2010). "Injuries in students of three different dance techniques." Medical Problems of Performing Artists **25**(2): 72.

Fujarczuk, K., et al. (2006). "Ground reaction forces in step aerobics." Acta of Bioengineering & Biomechanics **8**(2).

Garber, G. (2019). "Kinematics Equations and constant acceleration."

Ghosh, M. (2002). "Natyashastra (ascribed to Bharata Muni)." Varanasi: Chowkhamba Sanskrit Series Office.

Gontijo, K. N. S., et al. (2015). "Kinematic evaluation of the classical ballet step “plié”." Journal of Dance Medicine & Science **19**(2): 70-76.

Grimston, S. K., et al. (1993). "Differences in ankle joint complex range of motion as a function of age." Foot & ankle **14**(4): 215-222.

Hall, S. J. (1991). Basic biomechanics, Mosby Incorporated.

Hollands, K., et al. (2004). Principal components analysis of contemporary dance kinematics. Proceedings of the 3rd IEEE EMBSS UK & RI Postgraduate Conference in Biomedical Engineering & Medical Physics, University of Southampton, Citeseer.

Inman, V. T. and H. D. Eberhart (1953). "The major determinants in normal and pathological gait." JBJS **35**(3): 543-558.

Janura, M., et al. (2018). "Comparison of gait kinematics between professional ballet dancers and non-dancers." Neuroendocrinology Letters **39**(5).

Janura, M., et al. (2018). "Comparison of gait kinematics between professional ballet dancers and non-dancers." Neuroendocrinology Letters **39**(5): 385-390.

Jyothi, S. and B. Sujaya (2018). "Assessment of muscle strength in female Bharatanatyam dancers."

Katopodes, N. D. (2019). "Chapter 10 - Characteristic Analysis." Free-Surface Flow: 518-595.

Klopp, S. E. (2017). "Ground Reaction Forces for Irish Dance Landings in Hard and Soft Shoes."

Krasnow, D., et al. (1999). "Injury, stress, and perfectionism in young dancers and gymnasts." Journal of Dance Medicine & Science **3**(2): 51-58.

Kulig, K., et al. (2011). "Ground reaction forces and knee mechanics in the weight acceptance phase of a dance leap take-off and landing." Journal of sports sciences **29**(2): 125-131.

Kulig, K., et al. (2011). "Dancers with Achilles tendinopathy demonstrate altered lower extremity takeoff kinematics." journal of orthopaedic & sports physical therapy **41**(8): 606-613.

Lamkin-Kennard, K. A. and M. B. Popovic (2019). "Sensors: Natural and Synthetic Sensors."

Lung, C.-W., et al. (2008). "The differences in gait pattern between dancers and non-dancers." Journal of Mechanics **24**(4): 451-457.

Luttgens, K., et al. (1997). Kinesiology: scientific basis of human motion, Brown & Benchmark Madison, WI.

Mainwaring, L. M. and C. Finney (2017). "Psychological risk factors and outcomes of dance injury: A systematic review." Journal of Dance Medicine & Science **21**(3): 87-96.

Massó-Ortigosa, N., et al. (2018). "Electromyographic analysis of ankle muscles in young adults with Down syndrome before and after the implementation of a physical activity programme based on dance." Apunts. Medicina de l'Esport **53**(198): 63-73.

Matsusaka, N. (1986). "Control of the medial-lateral balance in walking." Acta Orthopaedica Scandinavica **57**(6): 555-559.

Mayers, L., et al. (2010). "Lower extremity kinetics in tap dance." Journal of Dance Medicine & Science **14**(1): 3-10.

Menz, H. B. (2004). "Two feet, or one person? Problems associated with statistical analysis of paired data in foot and ankle medicine." The foot **14**: 2-5.

Merriaux, P., et al. (2017). "A study of vicon system positioning performance." Sensors **17**(7): 1591.

Midori (2019). "Walking in Graphs."

Monica Sharma, M., et al. (2018). "Comparison of Lower Extremity Muscle Flexibility in Amateur and Trained Bharatanatyam Dancers and Nondancers." Med Probl Perform Art **33**(1): 20-25.

Nair, S. P., et al. (2018). "Survey of musculoskeletal disorders among Indian dancers in Mumbai and Mangalore." Journal of Dance Medicine & Science **22**(2): 67-74.

Newton, I. (1802). Mathematical principles of natural philosophy, A. Strahan.

Nigg, B., et al. (1994). "Gait characteristics as a function of age and gender." Gait & posture **2**(4): 213-220.

O'Malley, M. and D. L. A. de Paor (1993). "Kinematic analysis of human walking gait using digital image processing." Medical and Biological Engineering and Computing **31**(4): 392-398.

Ostrosky, K. M., et al. (1994). "A comparison of gait characteristics in young and old subjects." Physical Therapy **74**(7): 637-644.

Payne, A. (2019). "SAGITTAL, FRONTAL & TRANSVERSE PLANES EXPLAINED (WITH EXERCISES)."

Porter, S. (2013). Tidy's Physiotherapy E-Book, Elsevier Health Sciences.

Prochazkova, M., et al. (2014). "Analysis of foot load during ballet dancers' gait." Acta of bioengineering and biomechanics **16**(2).

Puddle, D. and P. Maulder (2010). "Ground reaction forces and loading rates associated with Parkour and traditional drop landing techniques."

Puri, R. (2004). "Bharatanatyam performed: a typical recital." Visual Anthropology **17**(1): 45-68.

Quirk, R. (1983). "Ballet injuries: the Australian experience." Clinics in sports medicine **2**(3): 507-514.

Rachana, M. "THEATRES IN INDIA: AN OVERVIEW."

Rosso, V., et al. (2017). Gait measurements in the transverse plane using a wearable system: An experimental study of test-retest reliability. 2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), IEEE.

Rousanoglou, E. and K. Boudolos (2005). "Ground reaction forces and heart rate profile of aerobic dance instructors during a low and high impact exercise programme." Journal of sports medicine and physical fitness **45**(2): 162.

Sato, N., et al. (2013). A comparison of basic rhythm movement kinematics between expert and non-expert hip hop dancers. ISBS-Conference Proceedings Archive.

Scheper, M. C., et al. (2012). "Generalized joint hypermobility in professional dancers: a sign of talent or vulnerability?" Rheumatology **52**(4): 651-658.

Shenoy, S. (2019). "GROUND REACTION FORCES DURING TATTA ADAVU OF BHARATANATYAM." ISBS Proceedings Archive **37**(1): 177.

Sherman, P. D. (1974). "Galileo and the inclined plane controversy." The Physics Teacher **12**(6): 343-348.

Steindler, A. (1955). Kinesiology of the human body under normal and pathological conditions, Thomas Springfield.

Swain, C. T., et al. (2019). "Multi-segment spine kinematics: Relationship with dance training and low back pain." Gait & posture **68**: 274-279.

Tengman, T. and J. Riad (2013). "Three-dimensional gait analysis following Achilles tendon rupture with nonsurgical treatment reveals long-term deficiencies in muscle strength and function." Orthopaedic journal of sports medicine **1**(4): 2325967113504734.

Teplá, L., et al. (2014). "Kinematic analysis of the gait in professional ballet dancers." Acta Gymnica **44**(2): 85-91.

Thompson, N. (2017). "Muscles That Move the Leg."

Trepman, E., et al. (1994). "Electromyographic analysis of standing posture and demi-pile in ballet and modern dancers." Medicine and science in sports and exercise **26**: 771-771.

van Melick, N., et al. (2017). "How to determine leg dominance: The agreement between self-reported and observed performance in healthy adults." PloS one **12**(12).

van Sint Jan, S. (2007). Color Atlas of Skeletal Landmark Definitions E-Book: Guidelines for Reproducible Manual and Virtual Palpations, Elsevier Health Sciences.

Vlutters, M., et al. (2019). "Ankle muscle responses during perturbed walking with blocked ankle joints." Journal of neurophysiology **121**(5): 1711-1717.

Volkerding, K. E. (2013). "Biomechanical and Proprioceptive Differences during Drop Landings between Dancers and Non-dancers." International Journal of Exercise Science **6**(4): 4.

Wallace, W. A. (1968). "The enigma of Domingo de Soto: Uniformiter difformis and falling bodies in late medieval physics." Isis **59**(4): 384-401.

Ward, R. E., et al. (2019). "Comparison of lower limb stiffness between male and female dancers and athletes during drop jump landings." Scandinavian journal of medicine & science in sports **29**(1): 71-81.

Washburn, A., et al. (2014). "Dancers entrain more effectively than non-dancers to another actor's movements." Frontiers in human neuroscience **8**: 800.

Watkins, J. (2009). Pocket Podiatry: Functional Anatomy, Elsevier Health Sciences.

Welsh, C., et al. (2010). "Rehabilitation of a female dancer with patellofemoral pain syndrome: applying concepts of regional interdependence in practice." North American journal of sports physical therapy: NAJSPT **5**(2): 85.

Whittle, M. W. (2014). Gait analysis: an introduction, Butterworth-Heinemann.

Wiesler, E. R., et al. (1996). "Ankle flexibility and injury patterns in dancers." The American journal of sports medicine **24**(6): 754-757.

Zatsiorsky, V. M. and V. M. Zaciorskij (2002). Kinetics of human motion, Human Kinetics.