Does A Change In Foot Position Have An Effect On The Thickness And Stiffness Of The Plantar Fascia Of The Foot?

Mark Price

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School of Life Sciences and Education
STAFFORDSHIRE UNIVERSITY

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“Science walks forward on two feet, namely theory and experiment.”

Robert Andrews Millikan (Todayinsci, 2021)

To my long-suffering wonderful wife and family for all their support through the years!

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Conflicts of interest

The Dynastat was invented and developed by the Author.

Copyright:

Abstract

The plantar fascia (PF) of the foot is complex in both its structure and function. Ultrasound and Shear wave elastosonography has allowed more detailed non-weight bearing examination of this structure. Previous research has focused on the non-weight bearing assessment of plantar fascia thickness (PFT) and stiffness (PFS) but has not linked these measurements to rearfoot function. The assessment of rearfoot function has engaged many different approaches from functional indices to pain scales.

This study aims to assess if a change in the weight-bearing rearfoot foot position has an effect on the thickness (PFT) and stiffness (PFS) of the plantar fascia of the foot. A unique linear actuator driven 3D printed platform was developed, that was able to reliably move the rearfoot through a range of frontal and sagittal plane angles, whilst weight-bearing. An ultrasound probe capable of shear wave elastography was incorporated into the platform for closed chain assessment (weight-bearing) of the PF and a standardised protocol produced for measurement of the PFT and PFS, whilst weight-bearing. The PFT and PFS was collected for 13 (26 feet) participants (11 male; age 20 - 67 years, *Mean 35.62, SD 15.04*; BMI 22 – 42 kg/m^2, *Mean 30.31, SD 6.22*) from a convenience sample of volunteers from Staffordshire University, subject to exclusion criteria. The data was subject to parametric statistical and, collective and cluster analysis.

The collective analysis shows there was no significant effect on PFT or PFS for changes in the rearfoot frontal or sagittal planes for the group. Individual analysis does show strong polynomial correlation for PFT and PFS for changes in frontal and sagittal plane rearfoot positions for some clusters. The rearfoot sagittal plane cluster demonstrated a negative Poisson ratio in 65.8% of the group, where the PFT and PFS both increased. The frontal plane cluster demonstrated a normal Poisson ratio in 45.8% of the group, where the PFT decreased as the PFS increased.

In conclusion, this study has shown that the closed chain rearfoot can be manipulated through a range of biaxial angles using a novel, accurate and reliable device. The PF can be assessed in the closed chain and the PFT and PFS calculated using a unique validated protocol. The PF does have a specific response to changes in the rearfoot position for individuals which, in some, can show a negative Poisson distribution.

There are several implications for future research and clinical practice.

Keywords: Plantar Fascia, Rearfoot mechanics, Plantar Fascial Thickness, Plantar Fascia Stiffness, Poisson’s ratio, Auxetic.

Table of Contents

List of Tables.

List of Figures.

Glossary

Auxetic - structures or materials that have a negative Poisson's ratio. When stretched, they become thicker perpendicular to the applied force.

Biomechanics - the study of the mechanical laws relating to the movement or structure of living organisms.

Calcaneus – the heel bone of the foot.

Cox-2 - Cyclooxygenase-2, an enzyme that acts to speed up the production of certain chemical messengers, called prostaglandins that play a key role in in promoting inflammation.

Inversion / Eversion - Inversion involves the movement of the sole towards the median plane whilst eversion is movement of the sole away.

Metatarsals - a group of five long bones in the foot, located in front of the tarsal bones.

Metatarsophalangeal Joint (MTPJ) - joints between the metatarsal bones of the foot and the proximal bones (proximal phalanges) of the toes.

Midtarsal Joint (MTJ) - is the articulation between the rearfoot (calcaneus and talus) and the midfoot (navicular and cuboid).

Orthosis - a brace, splint, or other artificial external device serving to support the limbs or spine or to prevent or assist relative movement.

Rearfoot - posterior region of the human foot. The rearfoot area includes the talus and calcaneus bones; the subtalar and talocrural (ankle) joints; and the muscles, tendons, and ligaments in the heel area.

Subtalar Joint (STJ) - articulation between two of the tarsal bones in the foot – the talus and calcaneus.

Chapter 1. Introduction

According to Leonardo Da Vinci, “the human foot is a masterpiece of engineering and a work of art” (Carol Ann Rinzler, 2013). It functions to allow the human species to uniquely stand upright, walk, run and jump. Whilst for the majority of the time, it can freely perform these duties, there can be times when pain and disability can occur. Foot pain, can at times, affect one-fifth of the population and can be more commonly associated with females, age, obesity and secondary to pain elsewhere in the body (Hill, Gill, Menz, & Taylor, 2008). Naturally, foot pain will have a detrimental effect on the health, mobility and quality of life of the affected individual.

The heel is first to strike the ground in normal gait and is likely to be subject to many traumatic, impact, inflammatory or stress (tension) pathologies. There have already been over 20 causes of plantar heel pain identified (Cole, Seto, & Gazewood, 2006) of which the most common pathology, plantar fasciitis, effects one of the foot’s supporting structures, the plantar fascia (PF), at its insertion into the calcaneus. A more accurate term for the condition would be plantar fasciopathy but throughout the literature plantar heel pain is widely referred to as plantar fasciitis. Whilst a term that is misleading and technically inaccurate, plantar fasciitis, can account for about 80% of the causes of plantar heel pain, with a prevalence of around 10% in the population, and is often seen between 40–60 years of age (Neufeld & Cerrato, 2008). This prevalence of 10% in the United States of America can equate to one million patient visits per year to health care professionals and has been estimated as a cost to the United States economy of $192 to $376 million per annum (Riddle & Schappert, 2004). A similar picture is also seen in the UK, where 12.1% of all musculoskeletal foot and ankle consultations in primary care were for heel pain, with 7.5% specifically related to plantar fasciitis (Menz, Jordan, Roddy, & Croft, 2010). The incidence of plantar heel pain within the UK population being given as 9.6% but no economic data is available (Thomas et al., 2019).

Clinical observations of post static dyskinesia (plantar heel pain after rest), increased plantar fascial thickness (PFT) and stiffness (PFS) have been reported in the presentation of this condition (Taş & Bek, 2018). These symptoms can be so severe that 7.9% of the UK population were classed as having disabling plantar heel pain (Thomas et al., 2019).

In the United Kingdom, The National Institute for Clinical Excellence (NICE), identifies that there are a number of treatments for plantar fasciitis but the evidence to support any one of a combination of treatments is limited (Hawke, Burns, Radford, & du Toit, 2008). One of the most widely recommended interventions is orthosis but there is little evidence in the research to support the use of bespoke over prefabricated orthosis in the control of foot function and possibly support PF healing. This may be related to the fact that bespoke orthosis are prescribed from a lack of firm or accurate assessment foundation given the inherent errors in biomechanical assessment (Menz, 1995), which may lead to incorrect "doses" or correction applied to the orthotic prescription. In clinical practice, the static biomechanical assessment of the foot and leg is the standard protocol for orthotic prescription but the key examinations are unreliable (Jarvis, Nester, Jones, Williams, & Bowden, 2012). Furthermore, in foot function assessment of the movement of the navicular (navicular drop and drift) is used as a key indicator of foot position, but this assessment technique has also been shown to be only moderately reliable (Vinicombe, Raspovic, & Menz, 2001). Currently, "there is no consensus on which protocols should be used to assess foot biomechanics in clinical practice" (Jarvis et al., 2012). Therefore, the development of a clinical tool able to accurately and reliably move the foot through a range of angles would increase the diagnostic value of biomechanical assessments and lead to the formation of protocols to aid clinical practice and research.

In the following chapters, the literature will be systematically reviewed to assess the current knowledge on the relationship of the PF thickness and stiffness to the function of the foot. The strategy for a systematic review will also be formulated to develop the proposed research question which will then allow the development of the methodology for the study. The results will be analysed, presented for discussion and draw upon a final conclusion with recommendations for clinical practice.

Chapter 2. Literature Review

2.1 The Plantar Fascia: Anatomy and Function

The plantar fascia is a long tendon like structure that runs across the plantar aspect of the foot from the calcaneum to the forefoot (D. Chen et al., 2014). It is composed of 3 bands that function, in simplicity, to help support the foot, but it also has more complex functions to provide a propulsive function to the foot. Therefore, the plantar fascia can be considered to have many roles in gait from providing stability against deforming forces; to assisting the intrinsic muscles of the foot and preventing excessive interosseus mid-foot forces (Kirby, 2017). The most discussed of these roles being the “windlass” mechanism that occurs to stabilise the foot in propulsion (Aquino & Payne, 1999). This “windlass mechanism” was developed from the original modelling work of Lapidus (1943), who first described the principle of a tie rod connecting two medial and lateral beams of the foot, and further developed by Hicks (1954). According to Hicks (1954), the plantar fascia forms the tie-rod or brace across the “arch” of the foot to support the calcaneus and metatarsals. It is designed to resist the forces acting on the foot by its anatomical position and tensile strength. The windlass element is derived from the wrapping of the PF around the head of the metatarsals, particularly the first, so as to shorten and tighten the PF during the propulsive phase of gait (Hicks, 1954), when the foot is moving forward and the first metatarsal phalangeal joint (1st mtpj) is dorsiflexing. This windlass principle could also be applied to the PF from the motion of the rearfoot.

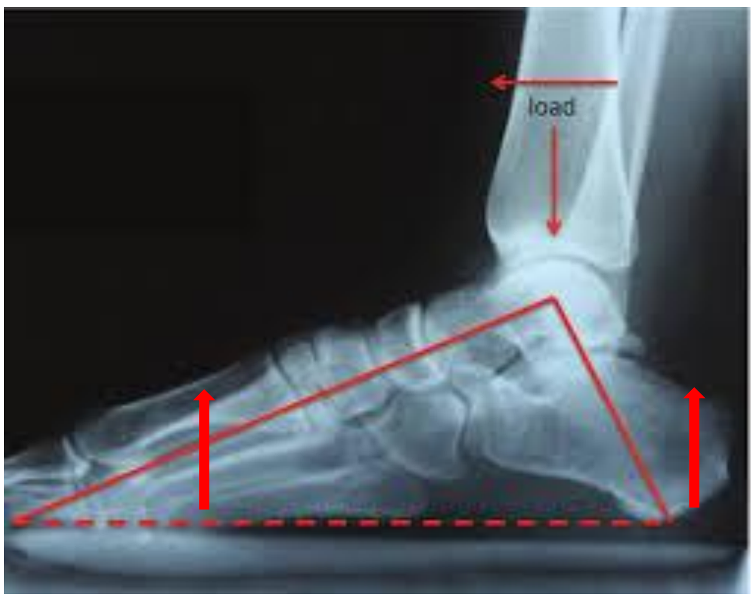


Figure 1: Demonstration of the "Brace and Truss" (D'Amico, 2016).

The triangle shown in figure 1 shows the truss formed by the calcaneus, midtarsal joint, and metatarsals which comprise the beams. The hypotenuse (horizontal line) represents the plantar fascia. The upward arrows depict ground reaction forces, and the downward arrow depicts the body's vertical force. The orientation of the vertical and ground reaction forces would cause a collapse of the truss; however, increased plantar fascia tension in response to these forces maintains the truss's integrity and provides foot support. This tension in the PF is increased by the winding of the PF around the 1st mtpj.

However, the role of other supporting structures such as the short and long plantar ligaments, intrinsic muscles and bone geometry are also important in maintaining foot stability (Huang, Kitaoka, An, & Chao, 1993).

2.2 The Plantar Fascia: Histology

As a result of many possible factors and abnormal forces, the PF thickness can increase and this has been linked to the clinical symptoms of chronic Plantar Fasciitis (Hongying Chen, Ho, Ying, & Fu, 2013; Mahowald, Legge, & Grady, 2011). It has been suggested that the increased thickness of the PF may be due to the reparative process of microtears, fibre degeneration or oedema (Cardinal, Lafortune, & Burns, 1996) and an increase above 4mm is widely considered to be directly related to plantar fasciitis symptoms (Sabir, Demirlenk, Yagci, Karabulut, & Cubukcu, 2005). Furthermore, a PF thickness greater than 4mm is also stated as diagnostic for plantar heel pain in a systematic review and met-analysis but this is based on studies that had poor descriptions of control groups, limited blinding of the assessors, the possibility of over inflated sample sizes and of type 1 errors (McMillan, Landorf, Barrett, Menz, & Bird, 2009). Moreover, further studies have given pathological values of PF thickness of 5mm (McNally & Shetty, 2010) and 6mm (Baur et al., 2021) and a lack of standardised assessment process may account for the variation. All the studies were also performed non- weight bearing and again this may account for variation in the true thickness of the “unloaded” PF.

Therefore, the ability to assess the thickness of the PF can provide clinicians with important clinical information. There are many techniques to assess this measurement, and commonly used are cross-sectional imaging (Magnetic Resonance Imaging – MRI) and B wave ultrasonography (Figure 3 & 3).

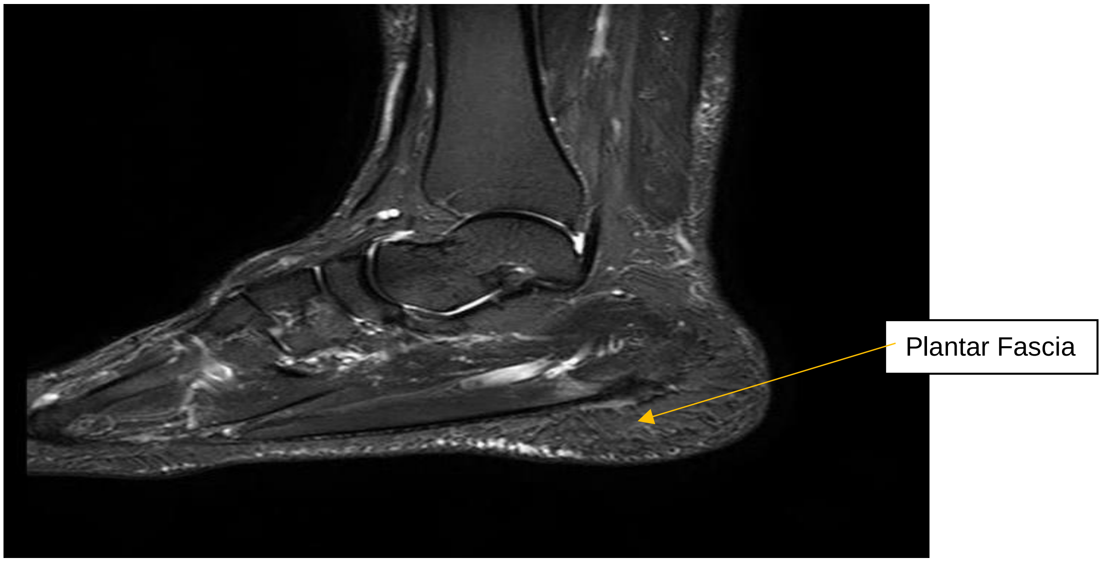


Figure 2: MRI of Plantar Fascial Thickening (Weerakkody, 2020).

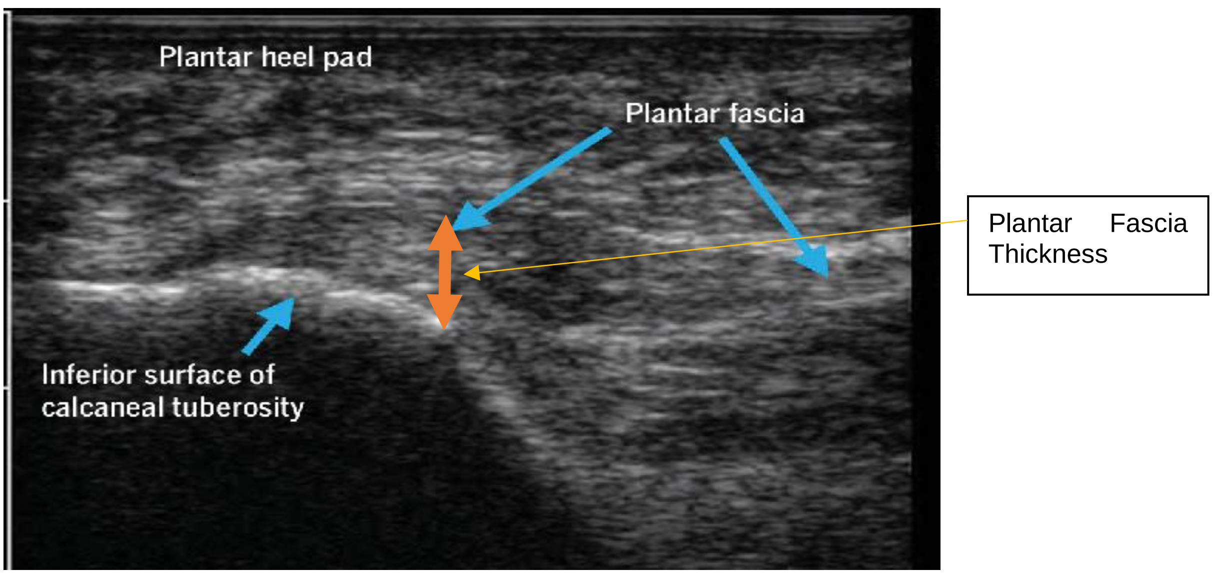


Figure 3: Longitudinal Sonogram of Plantar Fascia at the Calcaneal Origin (McMillan et al., 2013).

According to Stecco et al. (2013), the PF is composed of a variety of cells with different roles but it is mainly composed of type I collagen fibres arranged in a proximal-distal direction with some fibres in transverse and vertical directions. There are also type II collagen fibres near to the calcaneum and type III fibres in the loose connective tissues (Stecco et al., 2013). Collagen is a complex helix structure in which the variability can create different functionality. Type I is more akin to ligament structure and type II is more cartilaginous, whilst Type III is associated to skin and blood vessels (Shoulders & Raines, 2009). The PF has also been shown to vary in thickness along its length from the use of segmental analysis and artificial neural network modelling (Boussouar, Meziane, & Crofts, 2017). This may suggest that the function or morphological structure of the PF may vary along its length.

Whilst it is not specifically mentioned by Stecco et al. (2013), it is assumed that they are referring directly to the medial band of the PF, as the central and lateral bands have been shown to have a different morphology more consistent with a plantar aponeurosis. While the medial band is more consistent with a plantar fascia (Kalicharan, Pillay, Rennie, De Gama, & Kalicharan, 2017).

There are also thin elastic fibres within the PF and the lubricating glycosaminoglycan (hyaluronan) is located amongst the collagen fibres which is probably produced by fibroblastic-like cells (fasciacytes) (Stecco et al., 2018). Nerve endings and the mechanoreceptors, Pacini and Ruffini corpuscles, are also found in the PF and respond to the mechanical deformation of the skin and PF (Fleming & Luo, 2013), and therefore, they would provide a sensory feedback system via the myofascial network to the brain for the locomotory system.

2.3 Plantar Fascial Stiffness (PFS)

This mechanical deformation of the PF during normal or abnormal function will also produce a stretching force (tensile or shear force) which will produce a change in behaviour of the PF. This change is dependent upon a number of factors, such as composition, length and thickness. In traditional physics, the stress (σ) is the force (F) applied per cross sectional area (A) or:

$$\sigma = \frac{F}{A}$$

and strain (Ɛ) is the extension per unit length or deformation due to the applied stress or:

$$\varepsilon = e/\,lo$$

Where *e* is the extension and *lo* is the original length.

The stress and strain are proportional and a graph of stress / strain will produce a constant (Young's modulus) which can be said to represent the "stiffness" of the material (Courtney, 2005). Young's modulus (Figure 4) only refers to the range in which the stress is proportional to the strain and within the plantar fascia is specific to the elastic deformation range.

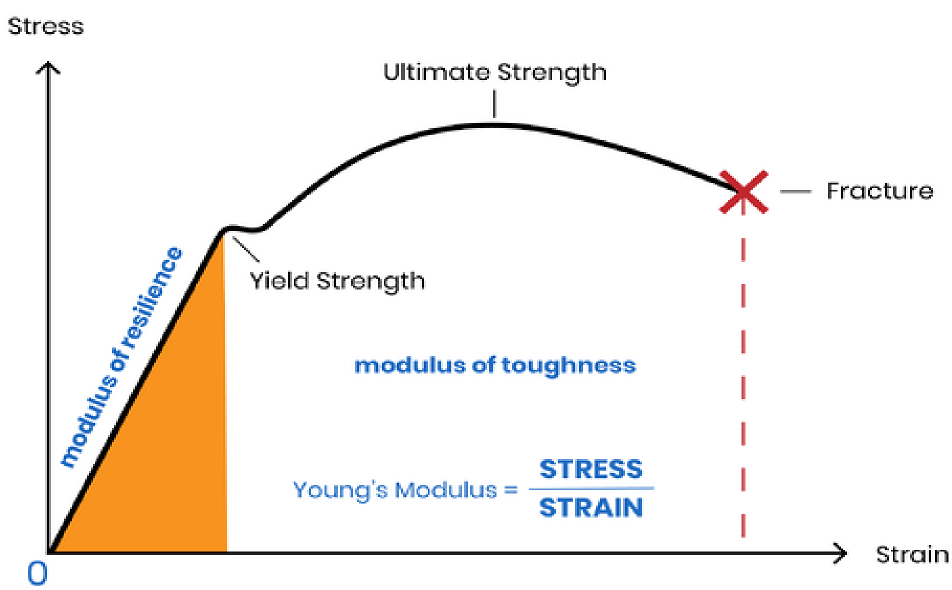


Figure 4: Young's Modulus (Bathie, 2019).

Therefore, given the relationship between the stress and strain, the calculation of Young’s modulus will give the stiffness of the PF, and this can be achieved via the use of ultrasound waves (sonography). There are two recognised mechanisms for measuring the stiffness of the PF using sonography. Strain elastography relies on a force (stress) applied from the “transducer by repetitive manual pressure and the strain (displacement) is calculated by the return velocities of the sound waves over time” (Winn, Lalam, & Cassar-Pullicino, 2016). However, this is a qualitative measurement of the elastic modulus (elastogram) and is variable due to the pressure applied to the tissues by the probe and raises the possibility of errors in technique and measurement.

On the other hand, shear wave elastography (SWE) is an ultrasound based technique (Figure 5) that can evaluate tissue mechanical properties based on remotely induced shear waves. By contrast to strain elastography, SWE can produce a stiffness value by calculating the Young’s modulus from the shear wave velocities which are created by a focused ultrasound pulse and measured using Doppler frequency modulation of simultaneously transmitted probing ultrasound waves. Therefore, the stiffer the tissue the faster the propagated shear waves (Winn et al., 2016).

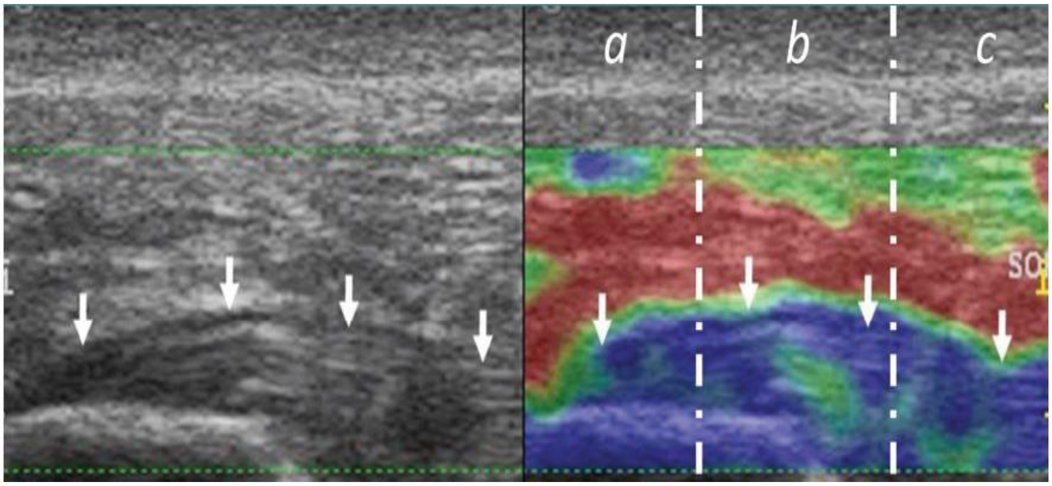


Figure 5: Long Axis image of medial portion of plantar fascia: B-mode US (left) and Shear Waves (right) (Sconfienza et al., 2013).

2.4 Reliability of B Wave Ultrasound and SWE

B wave ultrasound has been used to support the clinical assessment of plantar heel pain as it is non-invasive, cost-effective and easily accessible with good spatial resolution for the superficial structures and evaluation of the tissues with real-time dynamics (Aggarwal, Jirankali, & Garg, 2020). This has resulted in many studies evaluating the non-weightbearing PF which mainly focus on the thickness in normal and pathological conditions. The reliability of the technique for measuring the thickness of the PF has been assessed by comparison to Computerised Tomography

(CT) and Magnetic Resonance Imaging techniques (MRI) and found to show no statistical difference between the techniques (J. Wu, Zhang, Gao, & Luo, 2019). Moreover, in a systematic review of 34 studies, the results indicated that ultrasound can be considered a reliable imaging technique for assessing the thickness of the PF (Mohseni-Bandpei et al., 2014).

Shear wave elastography is a quantitative based technique and has been validated against traditional muscle techniques with strong correlation (Eby et al., 2013). However, this was based on muscle tissue and did identify that the best results are obtained when the probe was perpendicular to the tissues, and this is supported by other researchers (Gennisson et al., 2010). However, this is questioned by Miyamoto, Hirata, Kanehisa, & Yoshitake (2015), who suggest that a probe angle within 20 degrees of perpendicular produced only a 1.3% variance to the perpendicular measures.

Unfortunately, the lack of uniformity between commercial systems makes comparison of outcomes difficult but the results are consistent within the systems (Sigrist, Liau, Kaffas, Chammas, & Willmann, 2017). The combined use of B wave ultrasound and SWE has been found to produce a sensitivity of 100% and a diagnostic accuracy of 90% (Gatz et al., 2020).

Gatz et al. (2020) also found a strong correlation ($r = .6$, $p < .001$) between the Young's moduli and clinical symptoms of plantar fasciitis. In a previous study, the accuracy of combined B wave ultrasound and SWE has shown an accuracy of 95.4% ($p = .016$) and also claimed an "almost perfect" interobserver reproducibility between the most and least experienced clinicians in assessing SWE images (Sconfienza et al., 2013).

In a large randomised clinical trial of 108 cases, the SWE of the PF was compared to control subjects and plantar fasciitis. This demonstrated that the SWE allowed the quantitative assessment of the stiffness of the PF which also decreased in cases with plantar fasciitis (Baur et al., 2021). This confirmation of the quantitative value of SWE is supported by further studies, and suggests that SWE is a validated method of assessing the stiffness of the PF (Gatz et al., 2020; Putz, Hautmann, Banas, & Jung, 2017; Sigrist et al., 2017; H. Zhang et al., 2020).

However, the actual values given in the research for normal PF stiffness, and those found in plantar fasciitis vary considerably, and is probably accounted for by the machines used, sample population and techniques to assess the plantar fascia, such as the location of probe along the length of the PF. Baur et al. (2021), describes the PFS as normal at 152.88 KPa and in plantar fasciitis at 92.54 KPa, whereas Gatz et al. (2020), state

93.3 KPa and 31.9 KPa and Zhang et al. (2020), state “around” 40 KPa and 10 KPa respectively.

2.5 Plantar Fascial Response to Foot Function

There are several studies that identify a link between the PF tension (stiffness) and the foot function either from a change in position of the medial longitudinal arch or first metatarsal phalangeal joint function (Granado, Lohman, Gordon, & Daher, 2018), which also suggests that there is a concomitant reduction in PF thickness as the toes are extended or the PF is put under tension (Windlass activation). Wearing et al. (2007), also suggests a positive correlation of the plantar fascia thickness and the angle of the Medial Longitudinal Arch (MLA), which is taken from the inclination of the calcaneum and the dorsal surface of the 1st metatarsal.

However, in a previous study Wearing et al. (2004), suggests that sagittal plane movement of the medial longitudinal arch is unchanged in Plantar Fasciitis. An alternative measure for the MLA, would have been Meary’s angle which looks at the relationship between the rearfoot and the first ray and reflects the function of the talus (Hastings et al., 2016). Although, the study by Wearing (2004), does have a number of other limitations of low numbers, restricted assessment of the foot function, and may have had different results if Meary's angle had been used instead of the arch angle and 1st mtpj angle (Knipe & Mudgal, 2020). Lee, Hertel, & Lee (2010), also believe that there is an indirect relationship between the frontal plane movement of rearfoot eversion (pronation) together with arch height, and plantar fascia tension. Therefore, the literature suggests that there is a theoretical link that rearfoot function in the sagittal and frontal planes that could influence the variables of both the stiffness (tension) and thickness of the PF.

The thickness of the plantar fascia (PFT) is also known to vary between individuals and it has been shown to be significantly thicker in the patients presenting with Plantar Fasciitis compared to a normal group of healthy subjects (Abul, Ozer, Sakizlioglu, Buyuk, & Kaygusuz, 2015). It is also suggested that the thickness of PF is correlated to the age, gender (Pascual Huerta & Alarcón García, 2007) weight, height and body mass index (Taş, Bek, Ruhi Onur, & Korkusuz, 2017). It is also acknowledged that the PF becomes softer with age and in patients with Plantar Fasciitis (C.-H. Wu, Chang, Mio, Chen, & Wang, 2011). However, this study used a strain elastography technique and the analysis was based on mean colour pixels of the selected histogram, but the quantitative analysis does suggest that the plantar fascia was softer in those over 50 years old. Therefore, it can be concluded that there is a direct relationship between the thickness and stiffness of the PF, although it can be affected by a number of other variables.

The PF can also be subject to many different traumas, and excessive stretching of the PF can result in microtrauma at its insertion or along its length (Cutts, Obi, Pasapula, & Chan, 2012). Some studies have suggested that the condition Plantar Fasciitis is more of a chronic degenerative pathological fasciosis, where there is fibroblastic hypertrophy, disorganized collagen and chaotic vascular hyperplasia with zones of avascularity but with an absence of inflammatory cells (Young, 2019).

However, J. Zhang, Nie, Rocha, Hogan, & Wang (2018), suggests that a direct mechanism exists by which mechanical overloading (in vitro stretching of the PF) at 8% on PF tissue causes inflammation and degeneration, and in addition, to differentiation of the sheath and core stem cells. This intensive loading can induce matrix-degrading enzymes by elevated gene expression (Matrix metalloproteinases-MMP) and enhancing cellular inflammatory responses, through increased COX-2 gene expression and increased inflammatory mediators (IL-6, PGE_2).

This would explain histological findings from surgical biopsy of collagen necrosis, angiofibroblastic hyperplasia and chondroid metaplasia.

Therefore, whilst the histological changes associated with Plantar Fasciitis may be disputed, the research suggests there is a very strong association of clinical observations with pathological and clinical symptoms. The research also suggests that the clinical observations of PF stiffness (PFS) and thickness (PFT) are a direct manifestation of the mechanical overloading of the PF but little evidence to suggest a cause for it, or defining what is considered as normal loading of the PF.

2.6 Foot Function Models

There have been many theoretical concepts of foot function over the centuries, but more recently the models of foot function have been advanced from the original work of Root, Weed, & Orien (1977), who suggested a set of criteria for normalcy of foot function. However, the consensus of normal and abnormal mechanics affecting the tissues of the foot is still debatable (Kirby, 2009). There are a number of models of foot function in the literature (Payne, 2020) with root theory, sagittal plane facilitation theory, subtalar joint (STJ) axis location and rotational equilibrium theory and tissue stress model being the most commonly preferred models in clinical practice (Physiopedia, 2021).

"Rootian theory" proposes that the foot has a number of criteria that refers to a set of norms which the foot should function within, such that the subtalar joint has a neutral position with the mid-tarsal joint fully locked and this should occur at a given point between mid-stance and heel lift during gait. Any deviations from this norm are considered to be an abnormality. Although, a "root" clinical examination is generally conducted in a non-weight bearing position and it is said to not be reflective of the kinematic observations seen in gait (Jarvis, Nester, Bowden, & Jones, 2017). However, it is still the most complete method to classify the foot structure (Kirby, 2006).

Due to the lack of evidence to support "Root's STJ neutral theory", other alternative theories have been proposed. Sagittal plane facilitation theory assumes that the centre of body mass is required to move in a forward direction (sagittal plane) in a smooth and efficient process that uses three pivotal points within the foot (Dannanberg & Payne, 1997):

1. The heel rocker to allow motion from the heel to the forefoot.
2. The forward movement of the tibia over the foot at the ankle of least 10^0.

3. The first metatarsal phalangeal joint (or lesser mtpj's in some cases) as the final rocker with heel lift which encompasses the windlass mechanism of the plantar fascia.

Central to this theory is that any restriction of hallux function will decrease forward progression and cause increased stresses or abnormal load within the tissues of the foot. However, Van Gheluwe, Dananberg, Hagman, & Vanstaen (2006), assessed hallux limitus presentation in gait and found that the navicular drop after heel lift (retrograde pronation) was not present in 80% of the study population and so gave a confusing picture to the theory.

The subtalar joint axis location and rotational equilibrium theory identifies that the STJ has multiple axes of movement or rotation that depends on the joint's position, and has a significant mechanical effect on the foot (Kirby, 2001). The interaction of the STJ articular surfaces creates a three-dimensional spatial location of the STJ axis. Whilst this axis is believed to be placed at 16^0 from the sagittal plane and 42^0 from the transverse plane, there have been studies that show significant variance from this proposed "norm". Therefore, a medially deviated axis will present with a significantly pronated foot type which often has a high supination resistance (Payne, 2020).

The Tissue Stress Model is a theory considered to be of more validity in the management of foot conditions and helps to explain the load deformation curve (Figure 4) created in tissues under load (McPoil & Hunt, 1995). In short, it suggests that the increased demand or load on the tissues causes failure and treatment should be aimed at reducing the load upon the affected tissues (McPoil & Hunt, 1995). However, without in vivo finite element analysis to assess tissue stress or load, the model fails to explain the foot function or why the increased load has occurred (Kirby, 2006).

It is, therefore, an overall confusing representation of foot function with many other models and theories in the literature. Whilst many have similar or overlapping principles, there is no evidence that supports a single theory, but it is obvious that the foot does have two opposing roles of pronation and supination and treatment techniques (orthoses) to control these parameters have clinically beneficial results (Landorf, Keenan, & Herbert, 2006; Moraras & Hodge, 1993).

Whilst many papers have been published on the dynamic assessment of the peak pressures of the foot (Orlin & McPoil, 2000), there have been few studies considering the static assessment of the specific role of the rearfoot, or other specific sections of the foot, in foot pathology. The clinical static assessment of the foot also has various models and currently, the most commonly used assessment technique, is the Foot Posture Index (FPI) (Redmond, Crane, & Menz, 2008). This aims to combine a number of subjective assessment criteria based on a “normal” perspective, to create a positional index of the foot, but research by Langley, Cramp, & Morrison (2015), has shown that discrepancies between the chosen foot classification measures exist. Whilst there is no consensus on which protocols should be used to assess foot and lower limb biomechanics in clinical practice, static biomechanical assessment of the foot and leg is still an important tool in inferring the dynamic function (Jarvis et al., 2012). Furthermore, other current techniques for assessment of the calcaneal positions are unreliable due to subjective assessment errors such as skin movement, pen marker thickness and practitioner dexterity (Menz, 1995). In fact, the use of goniometer measurements shows low to moderate reliability by different observers (Menadue, Raymond, Kilbreath, Refshauge, & Adams, 2006) and measurement error can be in the region of two degrees (Haight, Dahm, Smith, & Krause, 2005). Therefore, there is no currently obvious assessment tool that can be utilised to accurately assess the rearfoot function in a closed chain (weight bearing) position, and furthermore, no tool that allows the assessment of the responses of the plantar fascia to a change in function or position of the rearfoot.

Rearfoot angulations can be measured in the weight-bearing and non-weight-bearing positions but it would seem more logical to assess them in the closed chain position as this would represent “the true” loading of the foot and leg, and be more relevant to clinical practice (Searle, Spink, & Chuter, 2018). Furthermore, the rearfoot can be measured biaxially, in the frontal and sagittal planes, with very little movement in the transverse plane. Whilst there is debate in the literature over the principles of axis of motion and models of foot function, the majority of foot orthoses have frontal plane angular posts (root theory) applied to alter foot function (Telfer, Abbot, Rafferty, & Woodburn, 2012). Although, Glaser & Fleming (2016), advocates the use of sagittal plane motion restriction (MASS theory) from a maximum arch control principle. From the review of the literature, it seems these “posts” or “wedges” are based on “educated estimates” as there is no evidence for the accuracy of the chosen clinical value and given the error margin of more than four degrees given by Keenan and Bach (2006), the logic of applying a four-degree medial post is questionable. Therefore, this also questions the validity of results obtain by researchers in the management of Plantar Fasciitis using orthoses as part of the treatment programme, and it also questions the validity of prescribing bespoke orthosis when the margin of error can be substantial. This concept of applying “a wedge” to the foot to control its function has been investigated specifically in relation to the specific effects on the PF. The common application of a medial rearfoot wedge was found to increase the strain within the PF, whilst a lateral forefoot wedge decreased the strain within the PF (Kogler, Veer, Solomonidis, & Paul, 1999). Kogler, Veer, Verhulst, Solomonidis, & Paul (2016) also evaluated the effects of a heel raise on the strain within the PF, and concluded that the elevation of the heel only resulted in a reduction in PF strain when the elevation simulated the arch profile of the shoe. They go on to suggest that the response of the PF may be dependent upon the individual variation in foot structures. However, both studies were undertaken on cadavers and does not consider the intrinsic muscle response but does suggest that the change in foot position can produce a response in the PF.

Moreover, there have been numerous studies that have examined rearfoot kinematics with no conclusive results either way to suggest that foot orthosis have any direct effect on function. A number of studies suggest that rearfoot kinematics have not been changed by orthoses

(Butler, Davis, Laughton, & Hughes, 2003; Nigg, Baltich, Hoerzer, & Enders, 2015; Stackhouse, Davis, & Hamill, 2004) and yet, there are at least an equal number of studies that suggest the opposite (Hennessy, Woodburn, & Steultjens, 2012; Nester, Hutchins, & Bowker, 2001; Stell & Buckley, 1998). This may in part be due to the quality of the studies and the selection of, or classification of “custom foot orthoses”. A true custom foot orthosis should be unique to the pathological findings and the abnormal mechanics of the individual. However, this requires the classification of normality of foot function or position to be defined. Telfer, Abbott, Steultjens, & Woodburn (2013), suggests the concept that the degree or extent of control of foot orthosis is dependent upon the “dose” of control given to the individual and found that there was a significant interaction between the dose-response effect and the rearfoot and knee function. This may suggest that in some studies the custom foot orthosis may be over or under “dosed”, and therefore, be of little value to the individual. A simple analogy to explain this dose concept is that a patient taking a diuretic may see little benefit in the medication if the dose is below a clinically viable dose, but increasing the dose would increase the kidney response, with too higher a dose being clinically dangerous.

Whilst there is debate on a theoretical model of foot function or if an actual functionally normal foot exists, there is a substantial body of peer reviewed evidence from random clinical trials, outcome studies and patient satisfaction studies that all suggest that foot orthoses improve a patient's pain or complaint (Landorf et al., 2006; Moraras & Hodge, 1993). This paradox between clinical effectiveness and method of action of orthosis on foot function serves to highlight the need to understand and assess the function of the foot more fully. Furthermore, given that the majority of foot orthoses are based upon root theory, it suggests that it may, in part, be a viable model.

In summary, the rearfoot has a number of functions during gait but different models of function are debated with no clear universal definition of normal foot function. The plantar fascia is attached to the rearfoot at the medial tuberosity of the calcaneus and any change in function or position of the rearfoot must have an action on the plantar fascia. This can be seen on ultrasound as a change in thickness or stiffness (stress) within the plantar fascia, and clinically as pain and disability. Nevertheless, clinical treatments with orthoses show improvements in patient's symptoms but there is no clear rational for how it is achieved.

Chapter 3. Systematic Review

3.1 Introduction

From the introduction, it can be seen that the PF is a complex structure, and whilst it can be subject to many pathological conditions, one of the most commonly investigated is plantar heel pain (PHP) and is often (miss) referred to as plantar fasciitis. Whilst the majority of the range of PHP conditions can be diagnosed from a clinical assessment (Granado et al., 2018), it is often assessed, or confirmed, as plantar fasciitis using ultrasonography to determine the PF thickness, which has been linked to the clinical presentation (Tsai, Chiu, Wang, Tang, & Wong, 2000).

More recently, with the development of Shear wave elastography, the tension or stiffness of the PF can now be assessed and the relationship between PFT and the elastic young's modulus (stiffness) directly related. L. Zhang et al. (2014), identified that there is a relationship between PFT and the elastic modulus which can also be related to age and plantar fasciitis. They also demonstrated that the PFT was greater and with a lower elastic modulus in the elderly and that this was also seen in the group with plantar fasciitis.

Furthermore, Taş et al. (2017), also demonstrated a direct link of Body Mass Index (BMI) to PFT and PFS, where an increased BMI resulted in an increased PFT and decreased PFS. Although, the use of BMI as a measure has been highlighted to have many pitfalls (Hall & Cole, 2006), there have been other studies which support the relationship between body weight and changes in the PF (Frey & Zamora, 2007; van Leeuwen, Rogers, Winzenberg, & van Middelkoop, 2016).

Assessment of the foot function in Plantar Fasciitis appears to be subject to many different approaches ranging from the Foot Function Index, arch heights, pain scales and the use of a variety of orthosis to modify “function” (Bishop, Thewlis, & Hillier, 2018; Granado et al., 2018). However, from the primary literature search on the relationship between the PF and foot function shows there are a number of studies assessing this relationship. Park et al. (2018), investigated the relationship between PF and foot dysfunction and concludes that abnormal foot position (flat foot) can be related to Plantar Fasciitis and that interventions to control this abnormal function are necessary. Although van Leeuwen et al. (2016), through a systematic review of the risk factors for plantar fasciopathy, identified that there is a lack of evidence for the clinical and mechanical measures of foot function.

Therefore, it can be appreciated that the PF has specific changes in terms of thickness and stiffness and that these may be related to the function of the foot. This allows the research question to be proposed "Does a change in rearfoot position have an effect on the thickness and stiffness of the plantar fascia of the foot?"

This research question can be further summarised in terms of the Patient or Population, Intervention, Comparison and Outcome (PICO) (Schardt, Adams, Owens, Keitz, & Fontelo, 2007):

Population – Sample of non-plantar fasciitis patients.

Intervention – Assessment of PF thickness and stiffness.

Comparison – Modification of the rearfoot angulation in various planes.

Outcome – Measurements of PF thickness and stiffness in different foot positions.

3.2 Search strategy

In order to identify the extent of research into PF thickness, stiffness and foot function measurements, an initial scoping search was undertaken of MEDLINE using Medical Subject Headings (MeSH) 2019 major headings and including subheadings and SmartText searching for “plantar fasciitis”, “Elastic Imaging Techniques” and “Foot” and “Foot Orthosis” using the OR modifier (SpringerLink, 2020). The MeSH 2019 subheadings included a range of key words under the major headings. This produced 2338 results which related to a range of treatments, diagnostics and case studies. The abstracts were briefly scanned to assess the various common terms used in the descriptions. This data gave sufficient information to validate the research proposal and confirm the need for further investigation and the appropriate search terms.

MEDLINE was chosen as it provides an authoritative and extensive coverage of the medical literature and allows the major headings to be identified for searching (Kelly & St Pierre-Hansen, 2008). These can also be exploded to cover all aspects of the subject. The Cumulative Index to Nursing and Allied Health Literature (CINAHL) (EBSCO, 2020) is also an excellent source to assess the qualitative evidence and balances well with MEDLINE (Wright, Golder, & Lewis-Light, 2015).

The CINAHL and MEDLINE databases were searched with the search strategy and terms with no limits applied to English language, dates or age. The scoping search suggested that the number of studies directly related to the research question may be extensive, but it was felt that the combination of the elements (PF thickness or Stiffness AND Rearfoot function) of the research question may produce limited results. MESH and CINAHL headings with Boolean phrase, were used for the search criteria and the screening process undertaken by the author only. The single screening process was undertaken given the UK government restrictions in place from the SARS-2 Covid 19 pandemic. It was felt that the very limited number of papers that met the inclusion criteria justified the targeted single reviewer screening, although it is accepted that it is possible to have missed some papers (Nama et al., 2021).

The headings used allowed for the main terms and common names for Plantar Fascia to be used but also included “OR” statements to include “Heel Spur” or “Tenotomy”. Headings were also used for “Ultrasonography” and included “ultrasound” with sub-headings for Drug interaction, methods and utilisation. A further major heading search term of “foot” was also used with sub-headings for diagnostic imaging, pathology, physiology and physiopathology.

The search terms were then searched with an “AND” statement to obtain the search studies. The studies were then imported into Mendeley and screened for relevance (Mendeley ltd, 2020). After removal of non-relevant studies, there were 97 allotted for further analysis.

A Cochrane database search was also performed for plantar heel syndrome, plantar fasciitis and ultrasound which produced 3 studies (Cochrane Collaboration, 2021) . All of which were not relevant to the research question as they focused on the treatment for plantar fasciitis.

After removal of duplicates, 88 studies were identified and transferred to an excel spreadsheet evidence table to allow data extraction (Appendix 1) (Microsoft Corporation, 2018b) .

From the primary screening, 63 studies were excluded as they failed to meet the inclusion criteria. The primary inclusion criteria were any evidence of:

Plantar fascia thickness assessment

Plantar fascia stiffness assessment

Foot function assessment.

The primary screening assessed the titles and abstracts of the articles identified by the search strategy to identify potentially eligible articles and the need to retrieve full text articles. If it was uncertain from the abstract if an article should be included, the full text article was retrieved and reviewed.

Full text articles were primarily assessed for the research primary inclusion criteria. The initial data extraction was undertaken with data recorded onto an excel spreadsheet and 25 articles were accepted for inclusion for secondary screening, based on the inclusion criteria. The 25 studies were then secondary screened to determine if the study included at least 2 of the primary criteria.

The primary exclusion reasons were identified as:

No assessment of function	= 9
Technique or US only	= 8
Function only	= 1

The 7 articles accepted from secondary screening fulfilled the initial criteria for the research question in that they included an assessment of plantar fascia thickness and / or stiffness and an assessment of foot function. The data extracted from the 7 studies included from the secondary analysis was the study type, assessment of thickness or stiffness, foot function assessment, control group, study number, demographics and summary of outcomes (Table 2).

A critical appraisal skills programme (CASP) Quality checklist tool (Cohort Study) was used to assess the validity of the included studies. The CASP checklist was composed of three sections: Validity of study; What are the results and Will the results help locally (CASP UK, 2018). The CASP tool is the most commonly used assessment tool used for quality appraisal in health-related qualitative evidence evaluation and endorsed by the Cochrane Qualitative and Implementation Methods Group (Long, French, & Brooks, 2020).

3.3 Summary of Systematic Search

All studies (97) were saved to Mendeley and electronically checked for duplicates and 88 accepted following removal of duplicates. All randomised, quasi-experimental and observational studies were considered, but case studies were excluded. The systematic search was performed according to the PRISMA Flowchart shown in figure and the paper further checked against the PRISMA checklist (Moher et al., 2009; Prisma, 2020).

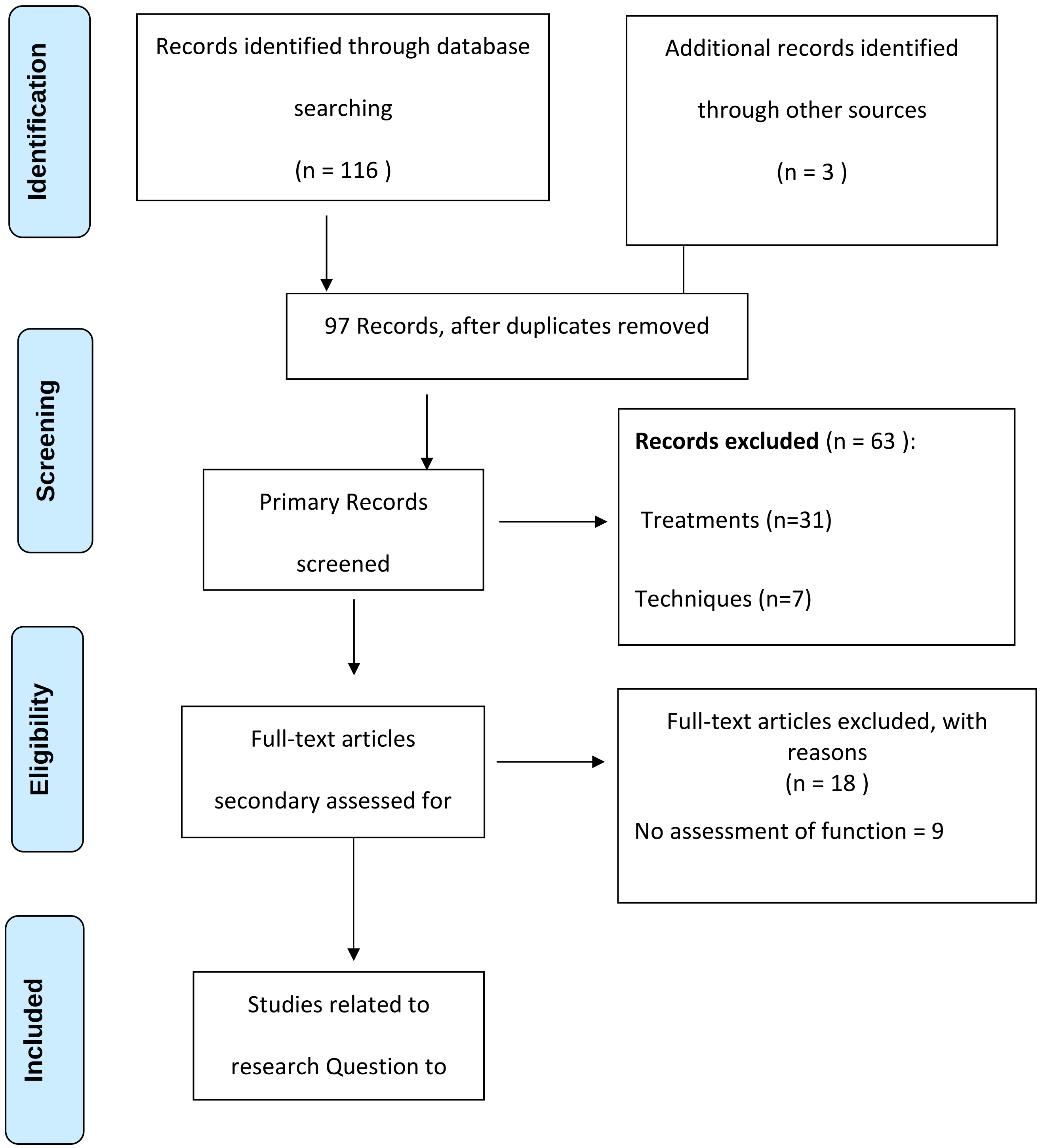


Figure 6: PRISMA Flow Diagram

3.4 Results

A summary of the CASP quality assessment is given in Table 2 and an example CASP review is given in Appendix 2. From the CASP qualitative assessment, six studies did meet most of the requirements of the three qualitative domains, but these studies had weaknesses, and these are discussed further in the discussion section. Only one study met all three inclusion criteria of PF thickness, stiffness and foot function

The systematic search identified seven papers that were suitable for further quality assessment using the CASP assessment tool but only one study met all the inclusion criteria. The other six included assessed the PF thickness and an element of foot function but did not assess the PF stiffness.

Of the seven studies included, there were a total of 289 subjects used in the assessment or treatment groups and 132 in the control groups. Only two of the studies did not use a control group: Taş, & Bek (2018) & Fleischer et al. (2015) and only three studies had matched control numbers: Angin et al. (2014), Fernández-Lao et al. (2016) and Granado et al. (2018).

The seven studies selected all measured the plantar fascial thickness as a comparator to a measure of function, although not all of them recorded the thickness of the PF in the “treatment” group (in millimetres). Only four studies (Table 1) Fleischer et al, (2015), Chen et al, (2013), Fernandez-lao et al, (2016), and Granado et al, (2018) gave the thickness of the PF which when analysed as a group gave a mean PF thickness of 5.4mm with SD 0.43, and a range of minimum of 5mm and maximum of 6.0mm. Of those not recording the PF thickness, Angin et al, (2014), only measured normal PF, Tas et al, (2018) presented only the median value and Bishop et al, (2018), does not give the PF thickness.

Table 1: Plantar Fascia Thickness.

Plantar Fascia Thickness							
	N	Range	Min	Max	Mean	Std. Deviation	Variance
Thickness	4	1.00	5.00	6.00	5.42	.435	.189

Table 2: CASP Quality Assessment Results.

Study	Design	Sampling Method	Intervention	Duration	PF Thickening	PF Stiffness	Foot Function	Participants N		Statistics	Age Range & mean		Male /Female	Outcome	Strength	Weakness
								TT	Control							
Angin, S 2014	Prospective	Matched from University community	Compare muscle & PF in normal & pes planus	NA	YES 3.3mm Norm foot	no	FPI	49	49	T test ($p<0.05$)	18-44 (24.1)	18-44 (23.4)	29 M, 20F	Larger supinator muscle & smaller intrinsic 1st ray, FHL & FDL larger in planus. PF thinner mid foot. NOTE Flex > to sup foot.9-12% deform in gait.	Good probe location.	Uses index to assess function. No cause to flat foot. No assessment of Tib Posterior
Taş, S 2018	Prospective	Strict Inclusion: Female, Sedentary, normal weight & foot function	Balance performance in group of subjects	NA	YES 3.1 (median)	yes	FPI + balance	37	0	Spearman's test ($p<0.5$)	19-35 (22)		37F	Balance worse in thick and stiff PF. Note contrary to theory.	Assessed element of Foot function to PF and stiffness.	FPI is index & in "normal". Not assessed menstrual cycle. Female only. PF varies with age, BMI.

Fleischer, A. E. 2015	Prospective	2 centre with random assignment to 3 groups: custom, prefab or sham orthosis.	2Nd study. Sonographic assessment of PF in 3 groups of support.	12 wks.	YES 5.5 +-1.1	no	Foot supports. FFI & SP36	63	0	Pearson Coefficient & T test	25-75 (49)			Thicker PF (1cm to insertion) > pain. Biconvexity not respond to supports.	PF thickness not related to symptoms or disability. NOTE contrary to others	Height for BMI, time on feet.
Chen, H. 2013	Cross section	Extensive inclusion criteria. From clinic. All Chinese.	Measure PF thick Vascularity and FFI compared to control.	NA	YES 5.0 +-1.3	no	Pain & FFI	38	21 9F, 12 M	T tests & Chi sq. Pearson's P<.05	45.2	45.1	24F 14M	PF > vas and thick on affected side + controls. Thickness vascularity and FFI. >vascularity & thickness associated to dysfunction	>VI=>pain (esp >3/12)	FF index & VAS. Operator error only 1. Only Chinese
Fernández-Lao, C et al. 2016	Observation case control	Good inclusion and exclusion matched sub	Number assessment scale Note Sensors for site of pain	NA	YES 6mm +-1.2	no	SP36 +FAAM	22	22	ANCOVA & Mann-Whitney U & Pearson's	27-73 47.9	27-72 47.2	11m 11f	PF= thicker, <QOL, > sensitivity. No relation to pain.	2nd neck pain > in F. > PF pain < QOL	Pilot study. Quality an of US. Other parameter BMI etc..
Bishop, C.,. 2018	RCT	Local advert, random assign	60 to 3 groups + control.	12 wks.	YES Not given	no	Orthosis custom, sham & Shoes	60	20	Shapiro-Wilks			Cust 13F 7M Sham	Orthosis group less 1st step, <24 hr pain. PF < thick after 4/52	Includes exclusion criteria. Bespoke orthosis plus to Delphi consensus.	Prescription same for all and no measure of angles? Duration of use of shoes, always same one?

Granado, M. J. et al 2018	cohort	Not recorded	1st met moved and thickness measured.	NA	YES 5.2 +-1.1	no	1st mtpj function	20	20	ANOVA	18-65 44.8		13F 7M	PF thicker than control and varied by mtp position. Measure at rest. PF thins with extension.	Suggests stand position for 1st met /toes	Weak inclusion. other causes

3.5 Quality Assessment

The CASP quality assessment results of the six studies that were considered as Cohort studies are given in Table 3. Only Bishop et al. (2018), was considered a randomised clinical trial and required a different CASP assessment. Bishop et al (2018) CASP assessment identified weakness in the design as it fails to describe if the participants were randomised. They also do not give any confidence intervals and the custom orthosis treatment group received orthosis but are not “measured” for a specific pathology and so, it is uncertain how they can be considered “custom”. Although, as stated previously in the introduction, the degree of error in measurements of foot pathology for orthosis prescription is too great to be clinically reliable (Keenan & Bach, 2006).

The cohort studies CASP assessment identified that five of the six studies had some weakness in design or construct. Only Chen et al. (2013), was considered to have a comprehensive CASP assessment meeting all the requirements of assessment. However, overall, the studies were of good quality and only failed the assessment on one or two points.

Table 3: CASP Quality Assessment Summary for Cohort Studies.

Question	Angin	Tas	Fleischer	Chen	Fernandez-lao	Granado
Focused issue	Yes	Yes	Yes	Yes	Yes	Yes
Recruited	Yes	No	Yes	Yes	Yes	Yes
Exposure measure	Yes	Yes	Yes	Yes	Yes	Yes
Outcome Measured	Yes	Yes	Yes	Yes	Yes	Yes
5a Confounding factors	Can't tell	No	No	Yes	Yes	Yes
5b Factors in design	Yes	No	Can't tell	Yes	Yes	No
6a Follow Up complete	Yes	Yes	Yes	Yes	Yes	Yes
6b Follow up long	Yes	Yes	Can't tell	Yes	Yes	Yes
9. Results	Yes	Can't tell	Can't tell	Yes	Yes	Yes
10. Local Population	Yes	No	Yes	Yes	Can't tell	Yes
11. Fit other studies	Yes	Can't tell	Can't tell	Yes	Yes	Yes
12. Practice Implications	Yes	Can't tell	Yes	Yes	Yes	Yes

3.6 Discussion

A meta-analysis can be beneficial to a systematic review, but a meta-analysis is not a formal experimental study and is effectively a non-experimental or descriptive study. It relies on subjective judgments throughout the process and can lead to poor conclusions and can also be heavily dominated by a single study.

The selected studies do not lend themselves to any further meta-analysis, as the results used varied outcomes and the outcome measures are more qualitative than quantitative. This shows the variability in assessing the PF and relating this to the function of the foot.

Foot function can be evaluated with a number of subjective tools. The foot posture index (FPI) (Redmond et al., 2008) is a validated method for quantifying foot posture using a set of normative subjective values for clinicians to assess the foot. It is related to age and pathology but is not influenced by gender or BMI. However, some studies have cast doubt over its reliability as a tool in the older population (Aquino, Avelar, Silva, Ocarino, & Resende, 2018)(M. R. C. Aquino et al., 2018), and the new version of the FPI which uses six criteria rather than eight has been shown to be of limited value (Cornwall, McPoil, Lebec, Vicenzino, & Wilson, 2008). Alternatively, the foot function index (FFI) is a self-reporting tool used to measure the impact of foot pathology on function in terms of pain, disability and activity restriction (Budiman-Mak, Conrad, & Roach, 1991). It uses 23 criteria to assess the foot function and has been shown by Budiman-Mak et al. (1991) to be a useful tool for clinical and research purposes. It has been extensively used across the world with revised and modified versions in different regions (Budiman-Mak, Conrad, Mazza, & Stuck, 2013). However, it is a self-reporting tool, and therefore, subject to user error and no clinician input.

In all the selected studies, there was no consistency in the method used to assess foot function with some using the FPI to quantify the position of the foot as normal or “flat” (pes planus), or SF36 or similar questionnaires to assess the impact of poor function on the quality of life (Lins & Carvalho, 2016). However, Tas et al. (2018), evaluated the PF thickness and stiffness and looked at the foot function in terms of balance during single-leg standing using Biodex Balance Systems, but did this on a limited population of non-active healthy females (Taş & Bek, 2018). Unfortunately, with this restriction to female only subjects they missed the need to assess the menstrual state of the participants, as this can affect the elasticity of the plantar fascia (Petrofsky & Lee, 2015). Tas and Bek (2018), was also the only study that assessed all three criteria of foot function, PF thickness and stiffness.

Angin et al. (2014), also assessed the PF in normal subjects but considered the foot as either normal or pes planus, using the FPI. They found that in the abnormal position of the foot, the supinator muscles and long flexor tendons were larger in cross section than the control group, but the intrinsic muscles were smaller. More interestingly, they also found that the PF was thinner in the pes planus group, but rather than the measure being at the insertion to the calcaneus, they measured it at the mid foot and forefoot, and this may suggest that there is an element of stretching of the PF or certainly poorly comparable results to other studies. However, the use of the FPI as a measure of foot function does not define what happens to the foot in gait and the different compensation measures that could have occurred in the individual, nor does it give any rationale for the pes planus foot.

Chen et al. (2013), also used a FFI (Chinese version) to assess the foot function and also incorporated a visual analogue scale (VAS) for pain. Chen et al. (2013), demonstrated that the PF thickness was related to the degree of foot dysfunction and that the vascularity (degree of inflammation) of the PF was also related to the pain perceived by the subjects. The vascularity was measured using Doppler ultrasonography standardised for high sensitivity using the technique described by H Chen, Ho, Ying, & Fu (2012). This is supported to some extent by Fernandez-Lao et al. (2016), who found that the increased PF thickness was correlated to a poorer quality of life score and increased general sensitivity at key assessment points. However, Fernandez-Lao et al. (2016), did not show any link of PF thickness to pain, but they did not measure the vascular index. Chen et al. (2013), also only used one non-blinded operator to perform the tests and this may be subject to operator bias. Fernandez-lao et al. (2016), does not give any account of the methodology used to obtain the ultrasound results.

Fleischer’s et al. (2015), study was a secondary study from the primary study that looked at the effect of foot supports and orthosis for the treatment of plantar fasciitis, and in this study, found contrary findings to those of Chen et al. (2013), and Fernandez-Lao et al. (2016). Fleischer et al. (2015), found that the PF thickness was not related to symptoms or degree of disability as determined by the FFI. They also found that a PF thickness 1cm distal to the insertion and was linked to a higher self-reported pain level. Furthermore, the Biconvexity of the PF was a factor in unfavourable responses to treatment. Unfortunately, this study had missing data for height and in order to calculate the BMI they used mean values and so, gives concern to the results of the study.

Bishop et al. (2018), in the only randomised clinical trial within the selected studies, also used orthosis and sham foot supports with shoes to assess the effects on the pain levels from plantar fasciitis and PF thickness. They found that the custom orthosis helped improve “first step” pain and reduce PF thickness over a 12-week period. However, the frequency of use or amount of use of the shoes and orthosis over the time of the trail may affect the results but this was not recorded. The use of the term “custom” is also confusing as the prescription variable table shows that all participants had exactly the same prescription for rearfoot control, 1st metatarsal cut out, lateral flare and plate material. Therefore, the orthoses were not patient need specific.

In all the studies, the PF thickness was not assessed using a standardised process with some subjects being prone and others supine. In all studies the subjects were non-weight bearing. However, only one study by Granado et al. (2018), assessed the effect of the toe position on the PF thickness. They found that the PF thickness varied by the position of the toes in that it became thinner as the toes were extended and also increased the strain across the PF. Therefore, this puts into question the findings of the other studies, as they did not account for this variable of toe position. However, Granado’s et al. (2018), inclusion criteria for Plantar Fasciitis was weak and the subjects may have had other causes of heel pain.

Furthermore, ultrasound has been used to assess the PF for pathology since the 1990's, and Wall, Harkness, & Crawford (1993) established the diagnostic value of ultrasound in plantar fasciitis but all studies used a non-weight bearing process, and if Granado et al. (2018), is correct, then all ultrasound assessment results may be subject to error if toe position is not assessed or defined. However, this error maybe consistent if the same process is used for all measurements. In all the studies, the ultrasound assessment of the PF was in a non-weight bearing position, and no other studies could be found in the literature that looked at the PF in a closed change position. Therefore, it would be useful to collect data for the PF in a closed change position and compare this to the non-weight bearing data to assess if the measurement of the PF thickness or stiffness varies according to the loading applied to the foot.

In summary, this systematic review highlights that the ultrasound analysis of the PF has an important role in assessing the PF pathology. However, the use of Sonoelastography to measure the "stiffness" of the PF and measures of foot function have not been assessed in combination. In fact, the measures of foot function have focused on subjective indices by clinicians or self-reported questionnaires which lack objective accurate measurements of the true foot position or function.

3.7 Conclusion

In conclusion, this systematic review would suggest that there is little evidence from the current knowledge to support any definitive conclusion into the relationship between the PF and the position or function of the foot. It also suggests that there is a need for further investigation to assess the thickness and stiffness of the PF and in a range of variable weight-bearing foot positions which can replicate the function of the rearfoot and reactions of the PF whilst on the ground. This would give clinicians and patients valuable information into the role and function of the PF and validate treatment choices.

Chapter 4. Methodology

4.1 Introduction

4.1.1 Aim of the Study

The literature and systematic review have identified that the current information on the relationship between the PF thickness (PFT) and stiffness (PFS) and the rearfoot function is weak with no direct correlation between them. Therefore, it is proposed that an abnormal function of the rearfoot complex will result in the foot having a compensated gait, and function, and tissues being subject to abnormal stress or overloading (McPoil & Hunt, 1995). The PF is intrinsically connected to the rearfoot at the medial tuberosity of the calcaneus and, therefore, should be subject to a change in forces through it according to the position or function of the rearfoot. This review supports the development of the research question "Does a change in foot position have an effect on the thickness and stiffness of the plantar fascia of the foot?". This will form the main aim of the study.

Therefore, to complete this study, there is a need to establish a more accurate, reliable and valid rearfoot assessment tool and a protocol to provide systematic, accurate and repeatable objective data on the rearfoot position and its range of motion through the frontal and sagittal planes. To achieve this a device has been developed (The Dynastat) capable of moving the foot through a range of angles in a weight-bearing position.

4.1.2 Objectives

The study will assess, quantify and validate this proposal by assessing the range of motion at the rearfoot in a closed chain position and, simultaneously measure the changes in thickness and stiffness within the PF. Secondly, it will also be able to uniquely vary the plane of direction of movement allowing the foot to be assessed through its biaxial movements, and again, fully assess the PF changes. The objectives that can be developed for the study are:

Objective 1

Validation of the frontal and sagittal plane measurements of the Dynastat to determine the accuracy of the device through angular measurements of the Dynastat in the Frontal and Sagittal planes by comparison to an accurate angle finder.

Objective 2

To investigate the association between the rearfoot angle in the sagittal and frontal planes and the thickness and stiffness on the Plantar Fascia using Sonoelastography to measure the Plantar Fascia thickness and stiffness under loadbearing conditions.

Objective 3

To Investigate if the PF thickness and stiffness can be quantified based on the rearfoot position, age and Body Mass Index (BMI).

The methodology selected to address the research question “Does a change in foot position have an effect on the thickness and stiffness of the plantar fascia of the foot?” was segmented into key critical steps and based on the objectives in section 4.1.2:

Methodology 1: (Objective 1) Validation of the frontal and sagittal plane measurements of the Dynastat to determine the accuracy of the device through angular measurements of the Dynastat in the Frontal and Sagittal planes by comparison against an accurate angle finder.

Methodology 2: (Objective 2) To investigate the association between the rearfoot angle in the sagittal and frontal planes and the thickness and stiffness on the Plantar Fascia by modification of the Dynastat to accommodate a Sonoelastography probe to enable measurement of Plantar Fascia thickness and stiffness under loadbearing conditions.

Methodology 3: (Objective 3) To Investigate if the PF thickness and stiffness can be quantified based on the rearfoot position, age and BMI.

4.2 Methodology 1 (Objective 1): Preliminary Test of Validity of Dynastat.

The Dynastat rearfoot platform is constructed as a tripod frame of linear actuators on a stable 3D Polylactic Acid (PLA) printed base and with a 3D printed (PLA) upper platform with 3D printed (PLA) posterior and marginal locating supports (Figure 8). The probe holder was also 3D printed from a semi flexible material (polyethylene terephthalate glycol - PETG) to account for minor movement of the ultrasound probe. The actuators are connected using a ball joint mechanism. The movement of the platform is based on the principle of the Stewart Platform model, although only 3 degrees of freedom are required (Stewart, 1965). The mathematical model uses the three Euler angular displacements (yaw, pitch and roll) to define the orientation of the platform with respect to the base (Ohkami, 2003). The pitch and roll angles equating to the sagittal and frontal plane rotations, respectively. The platform cannot achieve yaw, but it would be possible to rotate the pitch and roll axis about the yaw axis so that the frontal and sagittal plane axis could be referenced to the foot orientation rather than the platform.

The rotation and translation of the platform are combined into a transformation matrix based on the following formula:

$$T = O * R * O' * P$$

Where,

T = transformation

O = origin of rotation

O' = inverse of O

P = translation matrix

In order to define the change in movement of the linear actuators, the final unified transformation formula is applied to each point on the upper half of the platform, where coordinate space is given as x, y for the centre of the platform and z is the centre line of the upper platform ball joint:

$$Ex = \text{distance } (U'x - Bx) - Mx$$

Where,

$U'x = Ux * T$

Bx = lower platform positions as vector 4 (x, y, z, 1)

Ux = upper platform positions as vector 4 (x, y, z, 1)

$U'x$ = new positions

Mx = min length of each leg

Ex = extension of each leg

Note that the z axis (yaw) is always zero for the calculations.

The linear actuator movement is controlled from a laptop using software (V0.4.0-alpha) developed by Coded Internet (2021). This uses buffered inputs for rotation and translation. Once all input is complete, the unified matrix is calculated and the extension for each tripod leg determined. Then the extension length (Ex) required is sent to each motor control chip which generates the ramp and moves the connected actuator to the required position.

In order to perform the study, it was first considered necessary to establish that the measurements given for the frontal plane and sagittal plane angles by the Dynastat were reliable and repeatable. The process chosen was to establish that the resultant angle of the platform verified the mathematical formula used in calculating the changes of position of the platform and the accuracy of the actuator movement.

The rearfoot section was placed on a floor in the main biomechanical laboratory and the angle of the base surface was checked with a digital inclinometer angle finder (Wallfire, 2019) with a known accuracy of 0.2 degrees. This angle was 0.1 degrees from level in both directions which was considered within tolerance. The angle finder (Figure 7) was then placed onto the platform and held in place using adhesive putty in both the frontal and sagittal planes and reset to zero.

a) b)

Figure 7 Angle finder in a) Sagittal b) Frontal plane.

The Dynastat rearfoot platform was set at zero degrees in all directions and then randomly and blindly moved by the computer (Dynastat) operator in the frontal plane to four and eight degrees in both inversion (+) and eversion (-) directions. The angle recorded on the angle finder was recorded at each angle. However, the reader of the angle finder was not truly blinded to the actual angle moved by the platform, as it could be seen in which direction it had moved. The controller of the platform was blinded to the results of the angle finder.

The results given in chapter 5 shows that there was no statistical difference between the angle the Dynastat moved and the expected angle and therefore, the methodology could proceed to test the probe location and function.

4.3 Methodology 2 (Objective 2): Preliminary Test of the Ultrasound Probe in Platform.

The Dynastat rearfoot platform was modified to fit a linear array ultrasound probe (4–15 MHz, SL 15-4 Linear transducer, SuperSonic Imagine Ltd) in a closed chain position using Aixplorer® ultrasound machine (Supersonic Imagine, 2017). This was achieved by constructing a 3d printed holder using PETG to the exact measurements of the probe. The probe was moulded into a foam box and a Plaster of Paris replica made for manufacture of the holder off site. The holder will not allow any movement of the probe in the sagittal plane (proximal to distal) or frontal plane (rotation of the probe). This was to allow ultrasound visualisation of the PF and medial tuberosity and the probe was also held slight raised to the platform with standard aqueous sonic coupling gel applied.

The platform also allowed transverse plane rotation of the probe, so it can be moved to accommodate the alternate foot. There is also a support platform for the opposing foot. An appropriate step and support frame were also used to allow safe approach to the platform. This also had the advantage of allowing the probe to be adjusted at a parallel angle to longitudinal axis of the foot so that better B wave visualisation of the PF could be obtained. The foot was placed so that the probe was covered.

The platform was rotated in the transverse plane, so that it allowed for the normal angle and base of gait of the participant and the probe rotated so that it was placed in a line connecting (Figure 8 & 11) the medial tuberosity to the second toe to ensure the correct visualisation of the plantar fascia (J. Wu et al., 2019).

The primary aim for this section was to obtain reliable and repeatable B ultrasound wave images for the calcaneus and plantar fascia which would allow the measurement of the PF and allow good Elastosonography images to be generated.

Figure 8: Closed Chain Placement Of The Foot Above Probe.

Figure 9 shows an example of the B wave ultrasound images with a clear calcaneal line (E) and the plantar long-axis view of the medial plantar fascial band. The normal thickness and compact fibrillar pattern is seen just distal to the origin (white arrowheads). However, at the origin of the calcaneus (C) it is grossly thickened with hypoechoic loss of layered architecture (black arrowheads) with some calcific change (white arrow) at the enthesophyte (E) (Beard & Gousse, 2018).

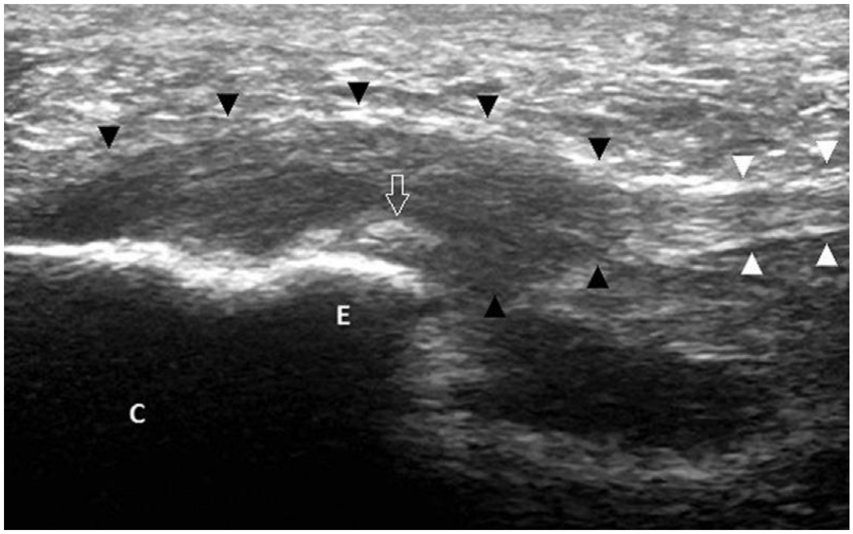


Figure 9: Severe Plantar Fasciosis

The images obtained in this pilot, as shown in Figure 10, show a clear calcaneal line and visible plantar fascia. This also shows the sonoelastographic assessment above the B wave and the results obtained from the shear wave analysis.

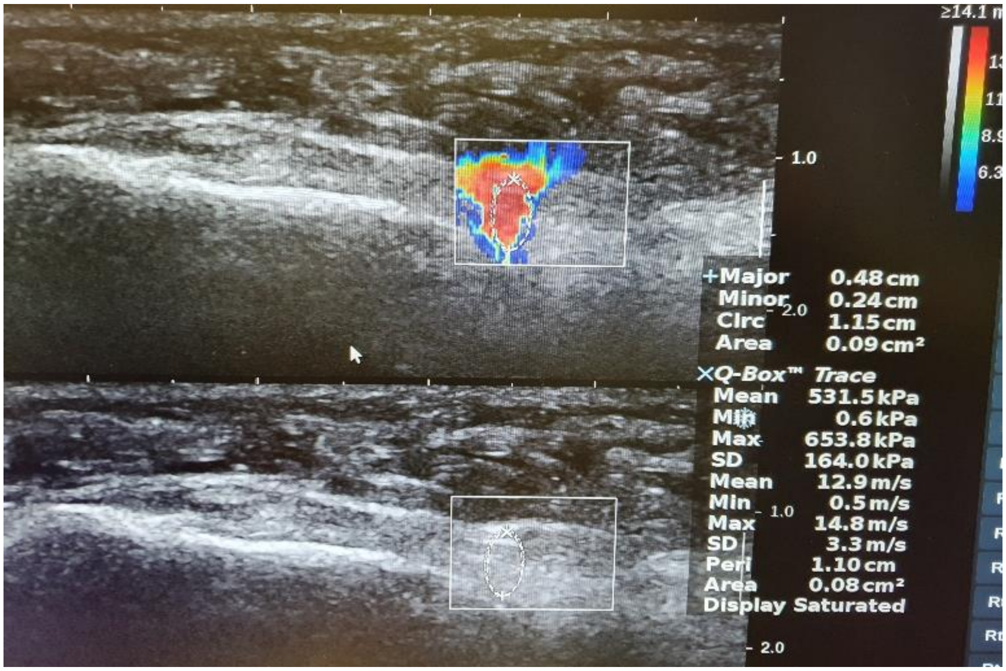


Figure 10: Image Obtain From Closed Chain Assessment Of The Probe.

4.3.1 Location and measurement protocol

The ultrasound assessment of the plantar fascia has been subject to many various levels of studies and in several comprehensive systematic reviews it was concluded that it is an accurate and reliable technique for assessing the thickness of the PF (Mohseni-Bandpei et al., 2014; Radwan et al., 2016). However, in both studies they fail to give a formal protocol for the evaluation of the PF. Indeed, a formal reference point or protocol for measuring the PF is not given in any papers within the systematic reviews with loose reference terms such as “at site of calcaneal insertion” or a point referenced to the “insertion” of the PF. The position of the patient and the foot was also very variable from prone to supine, foot dorsiflexed and plantarflexed and toes in specified positions or not.

Jing Wu (2019), does attempt to guide the placement of the ultrasound probe by indicating the probe should be placed over the medial tuberosity of the calcaneus and in line with the second metatarsal phalangeal joint (Figure 11) and then determine the thickness, at a point close to the insertion point (J. Wu et al., 2019).

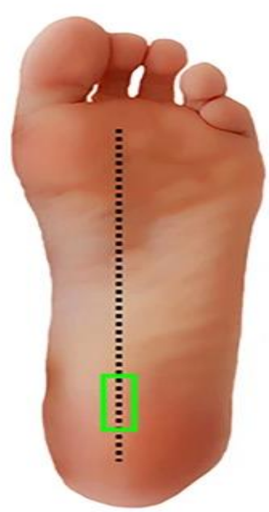


Figure 11: Assessment Line For Probe Placement.

Therefore, the foot was placed on the probe (Figure 88 & 11) so that the apex of the calcaneus could be used as the reference landmark, and this also allowed B wave visualisation of the plantar fascia. The Aixplorer® ultrasound machine was setup according to the assessment protocol (Appendix 3) which allowed good visualisation and assessment.

It was concluded that the thickness of the PF would be made at a point closest to the insertion into the calcaneus as the inferior surface began to move superiorly. This was a position loosely described by Mohseni-Bandpei et al. (2014), Radwan et al. (2016) and J. Wu et al. (2019).

As seen in Figure 9 (Beard & Gousse, 2018), the B wave image shows the calcaneal line and the plantar fascia clearly visible and the same picture is seen in the images obtained in the pilot (Figure 10).

For Sonoelastographic measurement, the foot and ankle measurement was selected with shear wave penetration depth at maximum. The area of interest was identified by allowing the participant to stabilise on the platform with their arms by their side. The sonographic assessment protocol was used to then firstly to develop a region of interest and then the area of interest (Appendix 3).

4.3.1.1 Region of Interest.

The foot was placed on the platform and the probe located in-line with second toe and beneath the heel (Figures 8, 11 & 13,) so that the probe was covered by the heel and sonographic gel medium. The B wave image was observed to ensure the medial tuberosity of the calcaneus is clearly visible with the plantar fascia, and the plate position or foot adjusted until correct visualisation.

Once visualization was achieved the foot was held in place with the side and rear locating clamps.

To achieve the region of interest the margins of the superficial and deep PF were identified and the smallest selection box available placed 20mm from highest point of the medial tuberosity to the proximal margin of the ellipse. This was to achieve a consistent position of measurement and allowed for the anterior edge of the calcaneus not being visible in some angles of the platform. The upper edge of the assessment box was set inline or just above the plantar fascia with the depth of box set to encompass the depth of the PFT. This should give a shear wave reading just off the anterior edge to the calcaneus.

4.3.1.2 Area of Interest

The Shear wave display that demonstrated the most comprehensive coverage of the selection box was chosen by freezing the frame and selecting the most extensive coverage. Then using the B wave scan, the ellipse facility in which the height was set from the inferior and superior margins of the plantar fascia (thickness) and linearly at 15mm in length. This should encompass good shear wave readings. After enlarging the image to a maximum, a Q-box trace was then manually performed, using the pen tool, and by tracing over the ellipse created on the B wave. This produced an area of interest for comparable analysis.

The results from this initial testing showed that consistent data could be obtained using the protocol but there was some minor slippage of the foot on the platform which may cause some variable results. A means of stabilising the foot through the range of movements needed to be found but it should not impede the measurements or distort the plantar fascia fat pad. Lateral pressure to the fat pad may push more tissue beneath the foot and influence the PF measurement or create a moment for movement about the rearfoot.

A 3-way guard was built that can be clamped into position to hold the foot from slipping in the frontal and sagittal planes (Figure 8) and this was not present on the first testing trial.

The initial test used a fixed probe that could not be moved in the sagittal plane, and it was felt that this may produce different results as the closed chain pressure would have a direct effect on the sonoelastographic measurements. Therefore, a flexible probe holder was developed using 3D printed springs from Thermoplastic Polyurethane (TPU) fixed at each end with captive threaded bolts, so that the results from both protocols could be assessed. This allowed the probe to incline in the sagittal plane depending on the weight placed upon it and would allow the BMI not to influence the reactive force from a fixed probe.

Figure 13 shows the displacement of the superior surface of the probe holder upon which the probe rests and allows the probe to maintain contact with the plantar surface of the heel and tilt to accommodate the plantar surface shape.

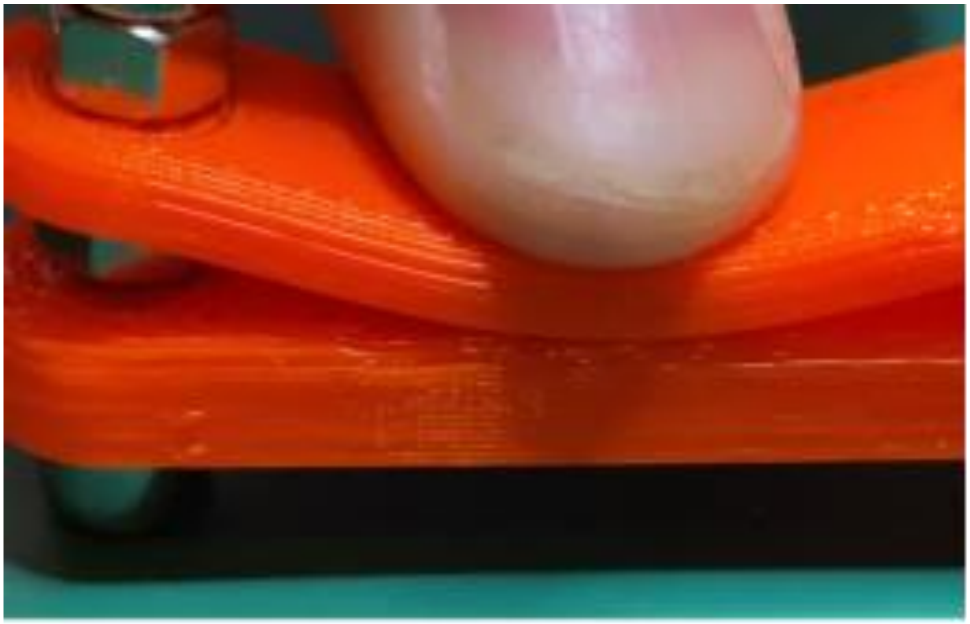


Figure 12: Demonstration Of Flexible Probe Holder.

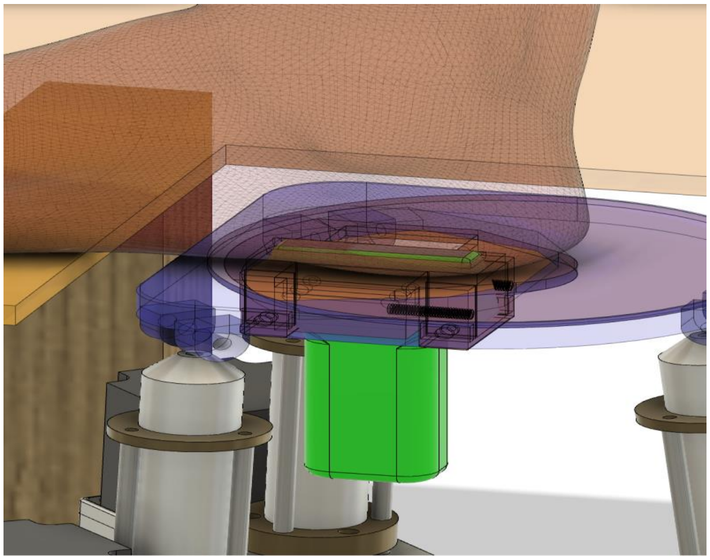


Figure 13: Holder And Probe Insitu.

The results obtained in Chapter 5 from the initial test suggested that a pilot study would be favourable with a fixed or flexible probe holder. It was felt that the results demonstrated that a flexible probe holder had a greater range and consistency of measurements and would be used for the main study.

4.3.2 Data Reliability & Repeatability

The Aixplorer ultrasound machine (Supersonic Imagine, 2017) has been previously validated using phantoms. Phantoms are a variety of structures made from materials (oil in gelatine dispersions) that mimic soft tissues with a known consistency. The SWE measurements are compared to the known reference values and show significant agreement (Bercoff, 2008; Madsen et al., 2006). The Supersonic shear imagining technique has been further validated in vivo in a number of tissues (Deffieux, Montaldo, Tanter, & Fink, 2009). The reliability of this data in the PF has been discussed in section 2.4.

The internal validity of the collected data was assessed for reliability and repeatability. The principal objectives of this section were designed to assess the integration of the probe within the platform, the protocol design and the consistency of the B wave and SWE values. It was considered that the following analyses would be required:

1. Assessment of repeated measurement of the Plantar Fascial stiffness and thickness at the zero position.
2. Same frame analysis of mean stiffness and traceability of the selection area.
3. One clip different frame analysis.
4. Fixed or Flexible Probe.

4.3.2.1 Repeated Measures

The data from the pilot study which contained repeated measures at a rearfoot angle of zero degrees (relaxed calcaneal stance position) was compared to the study data obtained for the same participant for the same foot and angle. This compared 3 sets of data obtained for the plantar fascial stiffness and thickness from two separate events.

4.3.2.2 Same Frame Analysis of Mean Stiffness and Traceability

Clip 61 was randomly selected from participant four and the measurements repeated five times for the same frame. Once a measurement was completed “the erase all” function was used to remove all previous information. This also tested the ability of the assessor to trace the Q-box analysis.

4.3.2.3 One Clip Different Frame Analysis

To determine if there was variability in the data collection depending on the selection of the frame chosen, a single clip was selected for assessment from participant 4 clip 60 at an 8^0 sagittal plane rearfoot position and was assessed for 5 consecutive frames (35-39).

4.3.2.4 Fixed or Flexible Probe

As described in section 4.3.1.2 Area of interest, the position of the probe relative to the foot will obviously determine the quality of the images and the usability of the image for data analysis. The data was collected from the pilot study and the same participant 2 using a fixed probe and a flexible probe holder at various rearfoot frontal plane angles from -8^0 to $+8^0$ and analysed for the plantar fascial stiffness and thickness.

4.4 Methodology 3: (Objective 3) To Investigate if the PF thickness and stiffness can be quantified based on the rearfoot position, age and BMI.

The initial pilot study was undertaken on the same participant from the testing of the probe in the platform (a 65-year-old male participant with a body weight of 108 kg). The same protocols for placement and assessment were followed and undertaken with the fixed probe and flexible probe holder.

The results given in chapter 5 show that the protocol and probe location produced results that could be used for the main formal study.

4.5 Design

A quantitative quasi experimental design was selected as the independent variable will be manipulated and the dependent variables measured (BMJ, 2020). However, the participants were a convenience sample rather than a true random selection. This may weaken the data given that there may be a sampling bias.

4.6 Sample

Participants will be volunteer students or colleagues. A minimal sample size of 12 participants or 24 feet was calculated with G power and estimated using a linear multiple regression with a 1 tailed test, medium effect size of 0.3, alpha 0.05, power 0.8 and 2 predictors (Faul, Erdfelder, Lang, & Buchner, 2007). There is little information to base the effect size on prior to the study and so the effect size of 0.3 for correlation has been used (Durlak, 2009).

It is proposed to include 13 particiapants (26 feet). The age, height, weight and BMI of the participant will also be recorded.

The inclusion criteria will be that participants are able to step up onto the platform and stand on the assessment platform to perform repeated tests and not have any exclusion criteria.

Exclusion criteria:

History of systemic disease including fibromyalgia, pain syndrome, diabetes.

Inflammatory arthropathy

Heel pain (as a result of tumours, infections, neuroma or OA)

Trauma to the foot

Impairment of mobility to perform tests.

Disabling pain or cognitive disorders

History of treatment for foot deformity or function.

4.7 Data Collection

All potential participants will receive an information leaflet (Appendix 4) and if they choose to proceed will sign a consent form (Appendix 5). A risk assessment has been conducted (Appendix 6) to establish the safety of the process, equipment and environment. This was submitted as part of the ethics submission.

Participants will be asked to step up and stand on a supporting platform and place a foot on the Dynastat rearfoot platform. They will be supported by a nearby frame to assist the stepping process. The rearfoot platform can be controlled by computer software and moved electronically via linear actuators (Coded Internet, 2021). The platform has been 3D printed from PLA and modified to allow placement of an ultrasound probe within a holder below.

The angles in the frontal and sagittal planes can be modified and recorded digitally by the software. The plantar fascia thickness and stiffness will also be recorded at the varying platform angles using the software provided with the Aixplorer ultrasound machine (Supersonic Imagine, 2017) and the agreed assessment protocol. The data for the angle of the rearfoot and the respective plantar fascial thickness and stiffness will be recorded on an Excel table by the researcher (Microsoft Corporation, 2018a).

Each measurement will be taken three times and a mean value calculated to reduce the risk of error and influence of any outliers that may be obtained (Guo, Logan, Glueck, & Muller, 2013). It has been shown that reliability increases when using the mean of three measurements compared with one (Bartlett & Frost, 2008). In the plantar fascia measurements, it has been shown that limits of agreement based on intratester reliability shows that changes in PF thickness that are larger than 0.6 mm can be considered actual changes in thickness and not a result of measurement error (Skovdal Rathleff, Moelgaard, & Lykkegaard Olesen, 2011).

The measurements of PFT and PFS will be recorded at frontal plane angles of 0, 2, 4, 8 and -2, -4, and -8 degrees and sagittal plane angles of 0, 2, 4, and 8 degrees (inclination) for both feet and entered onto an Excel spreadsheet (Appendix 7) (Microsoft Corporation, 2018a).

4.8 Statistical Analysis

The data will be input from the spreadsheet into SPSS 27 (IBM Corp., 2020) and then be subject to appropriate statistical analysis using a linear multiple regression: fixed model, single regression coefficient, ANOVA, t tests and cluster analysis where appropriate. Further statistical tests may be required once the data is collected and analysed.

4.9 Ethics

It is now more apparent that ethical considerations are an essential part of any research study. This is partly due to greater awareness of human rights and legal protection of data. Therefore, informed consent is an ethical and legal requirement for research that involves human participants (Nijhawan et al., 2013).

Following guidelines issued by Staffordshire University Research Ethics Committee a proportionate review application form was submitted for approval with appropriate supporting documentation (Staffordshire University Ethics Committee, 2019). Approval was granted in October 2020 (Appendix 8).

Chapter 5. Results

The research question “Does a change in foot position have an effect on the thickness and stiffness of the plantar fascia of the foot” has been considered as 3 key objectives. The results are presented by each objective.

5.1 Objective 1

Validation of the frontal and sagittal plane measurements of the Dynastat to determine the accuracy of the device through angular measurements of the Dynastat in the Frontal and Sagittal planes by comparison to an accurate angle finder.

5.1.1 Preliminary Test of Validity of Dynastat Results.

The test for reliability of measurement of the Dynastat are given in Table 1 and were subject to statistical analysis for Intraclass Correlation Coefficient (ICC) and these are given in Table 6a and b.

Table 4: Dynastat Reliability Results.

Dynastat Moved (Frontal Plane)	Dynastat Moved (Sagittal Plane)	Measured 1	Measured 2	Measured 3
8.0		7.8	7.8	7.9
4.0		4.1	4.0	4.0
0		0.1	0.1	0
-4.0		-4.0	-4.0	-4.0
-8.0		-7.7	-7.7	-7.8
	0	0.1	0.1	0
	4	4.1	4.0	4.1
	8	8	7.8	7.9

The descriptive statistics given in Table 5 show that there is a low kurtosis and that there is a lack of outliers in the data.

Table 5: Descriptive Statistics.

Descriptive Statistics									
	N	**Range**	**Min**	**Max**	**Mean**	**S.D.**	**Variance**	**Kurtosis**	
								Statistic	Std. Error
Moved Angle	5	16.00	-8.00	8.00	.00	6.32	40.00	-1.20	2.00
Measure 1	5	15.50	-7.70	7.80	.06	6.18	38.23	-1.37	2.00
Measure 2	5	15.50	-7.70	7.80	.04	6.17	38.03	-1.32	2.00
Measure 3	5	15.70	-7.80	7.90	.02	6.23	38.81	-1.27	2.00

The ICC was calculated using SPSS (IBM Corp., 2020) for the frontal plane (Table 6a) shows complete reliability between the repeated Dynastat measurements and the data collected by the angle finder. The average measure was 1.00 with a 95% confidence of .999 to 1.00 ($F(4,12) = 19585.8$, $p = 0.00$). Therefore, there was no difference between the moved angle and the measured angle.

Table 6a: Intraclass Correlation Coefficient (Frontal).

Intraclass Correlation Coefficient							
	Intraclass Correlation [b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	1.00[a]	.999	1.00	19585.8	4	12	.00
Average Measures	1.00[c]	1.00	1.00	19585.8	4	12	.00
Two-way mixed effects model where people effects are random and measures effects are fixed.							
a. The estimator is the same, whether the interaction effect is present or not.							
b. Type A intraclass correlation coefficients using an absolute agreement definition.							
c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.							

The ICC was also calculated for the sagittal plane (Table 6b) and shows complete reliability between the repeated Dynastat measurements, and the data collected by the angle finder. The average measure was 1.00 with a 95% confidence of .999 to 1.00 ($F(2,6) = 11751.32$, $p = 0.00$). Therefore, there was no difference between the moved angle and the measured angle.

Table 6b: Intraclass Correlation Coefficient (Sagittal)

Intraclass Correlation Coefficient							
	Intraclass Correlation [b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	1.00[a]	.999	1.00	11751.32	2	6	.00
Average Measures	1.00[c]	1.00	1.00	11751.32	2	6	.00
Two-way mixed effects model where people effects are random and measures effects are fixed.							
a. The estimator is the same, whether the interaction effect is present or not.							
b. Type A intraclass correlation coefficients using an absolute agreement definition.							
c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.							

5.2 Objective 2

To investigate the association between the rearfoot angle in the sagittal and frontal planes and the thickness and stiffness on the Plantar Fascia using Sonoelastography to measure the Plantar Fascia thickness and stiffness under loadbearing conditions.

5.2.1 Preliminary Test of the Ultrasound Probe in Platform.

To test the protocol for probe function in the platform, a basic assessment was undertaken by taking angular measurements of the foot at six degrees inverted (+) and everted (-) in the frontal plane and six degrees inclined in the sagittal plane and an angle of zero degrees on the platform on one participant. The participant (2) was a 65 year old male with a weight of 108 kg (Table 7).

Using the agreed protocol, the results obtained were:

Table 7: Results of Preliminary Test.

	B Wave		Q Box Trace				
Angle	**Thickness cm**	**Area of ellipse cm2**	**Mean kPa**	**Min kPa**	**Max kPa**	**SD**	**SW Speed Mean m/s**
0	0.44	0.87	354.5	0.1	520.8	181.1	10.1
+ 6 Frontal	0.45	0.88	419.6	0.1	619.7	169.7	11.2
- 6 Frontal	0.42	0.85	183.7	7.9	491.5	126.8	7.3
6 sagittal	0.43	0.51	505.9	1.2	800	245.6	12.3

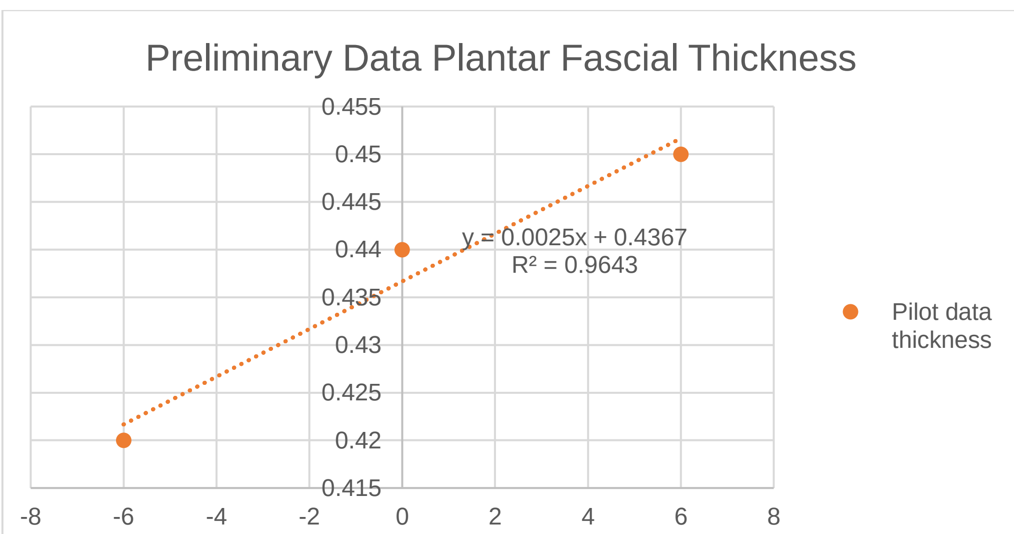


Figure 14 Plantar Fascial Thickness with Changes in the Frontal Plane.

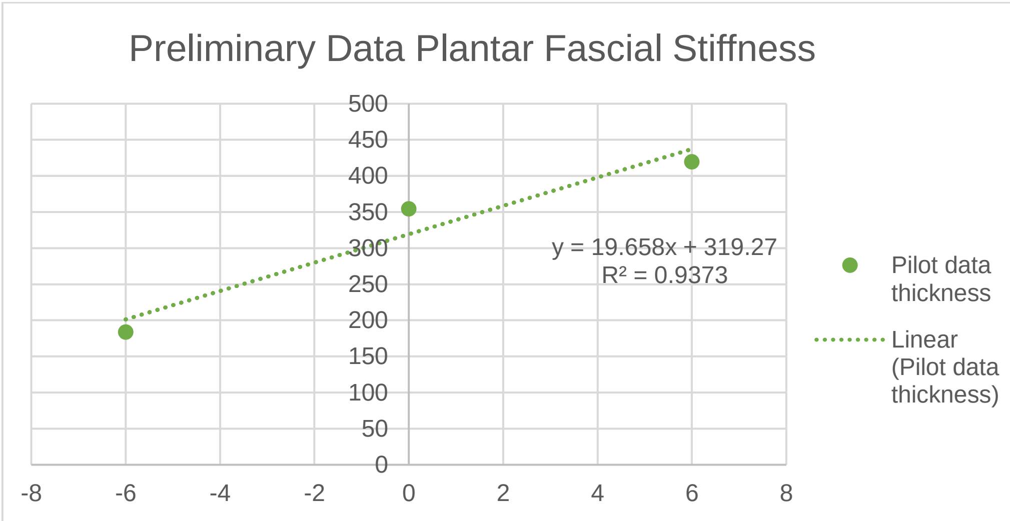


Figure 15: Plantar Fascial Stiffness with Changes in the Frontal Plane.

Figures 14 and 15 would suggest that there is a relationship between the angle of the Rearfoot and Plantar Fascial Thickness (PFT) and Plantar Fascial Stiffness (PFS), where there is a strong corelation between the rearfoot frontal plane angle and the PFT ($n=3$, $r^2 = .96$) and PFS ($N=3$, $r^2 = .93$).

5.2.2 Data Reliability and Repeatability

A further pilot study was undertaken to establish the validity of undertaking the study by assessing the function of the Dynastat, the probe positioning and ability to take appropriate repeated measurements. Two sets of data were collected for a flexible and fixed probe at zero, four and eight degrees in eversion (negative), inversion (positive) and sagittal plane inclination angle (Table 13).

The data was subject to analysis to assess if it produced valid and repeatable results:

1. Assessment of repeated measurements of the Plantar Fascial stiffness and thickness at the Relaxed Calcaneal Stance Position (RCSP is zero degree position) (5.2.2.1)
2. Same frame analysis of mean stiffness and traceability of the selection area (5.2.2.2).
3. One clip different frame analysis (5.2.2.3).
4. Fixed or Flexible Probe (5.2.2.4).
5. Comparison of measurements from pilot data and study data through range of angles (5.2.2.5)

5.2.2.1 Assessment of Repeated Measures

The measures undertaken at zero degrees or relaxed calcaneal stance position (RCSP) for mean stiffness of the plantar fascia and mean speed of ultrasound waves were further analysed to assess the coefficient of variation (CoV) using the formula:

$$Cov = \frac{\text{Standard deviation (SD)}}{\text{Mean}}$$

Table 8: Repeated Measures Pilot Data.

Measure	Thickness (cm)	Mean stiffness (KPa)	SD	Mean speed (m/s)	SD
1	0.35	192.7	133.4	7.3	3.3
2	0.33	352.4	194.7	10.1	3.8
3	0.36	148	179	5.6	4.2
Mean scores	**0.34**	**231.03**	**169.03**	**7.67**	**3.77**
Standard Deviation	0.02	107.46	31.84	2.27	0.45
Coefficient of Variation	0.04	0.47	0.19	0.30	0.12

The results (Table 8) show that there was large variation in the results for mean stiffness and mean speed of sound waves for the plantar fascia at zero degrees in the pilot data. The PFT had a low coefficient of variation.

Table 9: Repeated Measures From Study (Same Participant).

Measure	Thickness (cm)	Mean stiffness (KPa)	SD	Mean speed (m/s)	SD
1	0.26	236.80	173.00	6.30	3.60
2	0.29	447.10	184.60	8.90	3.70
3	0.29	435.20	203.10	8.10	4.20
Mean scores	**0.28**	**373.03**	**186.90**	**7.77**	**3.83**
Standard Deviation	0.02	118.13	15.18	1.33	0.32
Coefficient of Variation	0.06	0.32	0.08	0.17	0.08

The measures were repeated on the same participant for the same foot (left) at zero degrees (Table 9). This shows that whilst there was still a large variation in the individual scores, the coefficient of variation was similar at both sessions for mean stiffness. There was a low CoV across the data with an improved CoV for the PFS.

An intraclass correlation coefficient for the plantar fascia stiffness and speed of sound waves for the pilot data and study data for the same participant and the same angle (zero) showed that there was little agreement between the two sets of data (Table 10). The average measure was .26 KPa with a 95% confidence of -.30 to .96 ($F(2,2) = 2.10$, $p = .32$).

Table 10: Intraclass Correlation Coefficient For Stiffness Of Plantar Fascia And Speed Of Sound Waves For Pilot And Study Data.

Intraclass Correlation Coefficient							
		95% Confidence Interval		F Test with True Value 0			
	Intraclass Correlation [b]	Lower Bound	Upper Bound	Value	df1	df2	Sig
Stiffness: Single Measures	.22[a]	-.30	.95	2.10	2	2	.32
Average Measures	.37[c]	-.85	.98	2.10	2	2	.32
Speed: Single Measures	.47[a]	-2.39	.98	2.20	2	2	.31
Average Measures	.64[c]	3.44	.99	2.20	2	2	.31

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

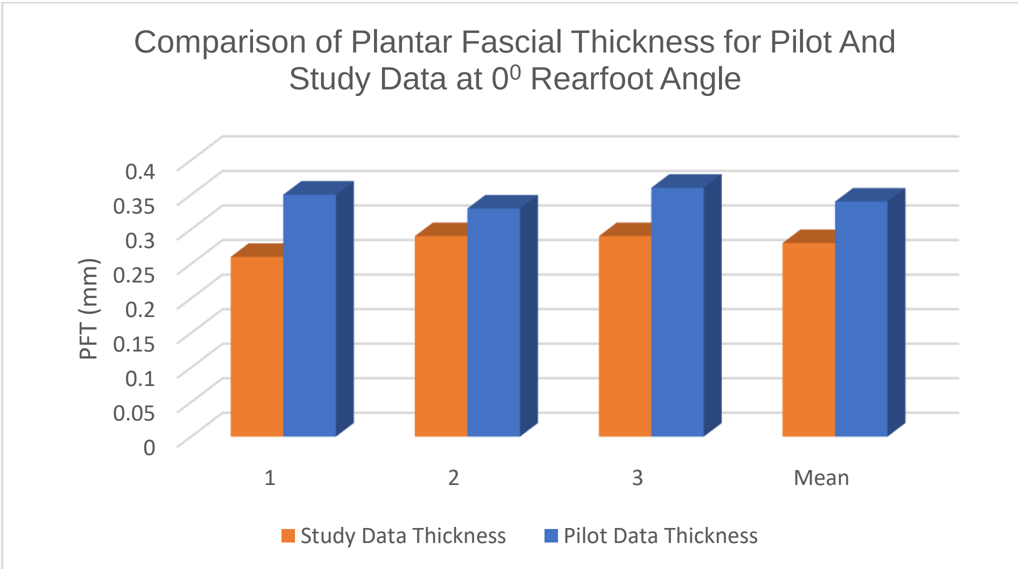


Figure 16: Graph Showing Same Participant At Same Angle For Pilot And Study Data Plantar Fascial Thickness.

There was variation of the pilot and study data plantar fascial thickness on repeated measures of the same participant at the same rearfoot position in the frontal plane.

5.2.2.2 Same Frame Analysis of Mean Stiffness and Traceability

The random frame selected was analyzed for repeatability of the assessment technique of the researcher. This would assess the area of selection and traceability of the q-box. The results obtained are given in table 11.

Table 11: Same Frame analysis of mean Stiffness and Traceability.

Test	B wave				Stiffness (KPa)				Speed (m/s)					
	Major	Minor	circumference	Area	Mean	Min	Max	SD	Mean	Min	Max	SD	Peri	Area
1	0.37	0.15	0.85	0.04	488.2	22	547.6	60	12.7	2.7	13.5	1.2	0.88	0.05
2	0.37	0.15	0.85	0.04	487.5	22	547.6	59.3	12.7	2.7	13.5	1.2	0.9	0.05
3	0.37	0.15	0.85	0.04	488.1	22	547.6	60.8	12.7	2.7	13.5	1.2	0.88	0.05
4	0.37	0.15	0.85	0.04	487.4	22	547.6	60.1	12.7	2.7	13.5	1.2	0.9	0.05
5	0.37	0.15	0.85	0.04	486.8	22	547.6	59.6	12.7	2.7	13.5	1.2	0.9	0.05
Mean	0.37	0.15	0.85	0.04	487.6	22	547.6	59.96	12.7	2.7	13.5	1.2	0.89	0.05
SD	0	0.00	0.00	0.00	0.57	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.01	0.00
CoV	0	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00

To assess the reliability, the coefficient of variation was calculated for the stiffness of the plantar fascia. The mean for the stiffness was 487.6 with SD 0.57 which gives a Coefficient of Variation of .0. Therefore, the repeated measures of the same frame were consistent.

5.2.2.3 One Clip Different Frame Analysis

The single clip taken for assessment was from participant 4 clip 60 for 8^0 sagittal plane rearfoot position and was assessed for 5 consecutive frames. The results are given in table 12.

Table 12: One clip Different Frame Analysis.

Frame	B wave					Stiffness (KPa)			Speed (m/s)					
	Major	Minor	circumference	Area	Mean	Min	Max	SD	Mean	Min	Max	SD	Perimeter	Area
35	0.33	0.15	0.78	0.04	492	491.5	500.1	1.3	12.8	12.8	12.9	0	0.79	0.04
36	0.34	0.15	0.81	0.04	493	491.5	521.3	5.2	12.8	12.8	13.2	0.1	0.81	0.04
37	0.34	0.15	0.8	0.04	493	491.5	521.3	5.1	12.8	12.8	13.2	0.1	0.9	0.04
38	0.33	0.15	0.78	0.04	489.9	383.4	493.2	13.3	12.8	11.3	12.8	0.2	0.79	0.04
39	0.33	0.15	0.79	0.04	481.6	152.8	491.6	45.7	12.6	7.1	12.8	0.7	0.81	0.04
Mean	0.33	0.15	0.79	0.04	489.9	402.1	505.5	14.1	12.8	11.4	13.0	0.22	0.82	0.04
SD	0.01	0.00	0.01	0.00	4.81	147.04	14.77	18.19	0.09	2.47	0.20	0.28	0.05	0.00
CoV	0.02	0.00	0.02	0.00	0.01	0.37	0.03	1.29	0.01	0.22	0.02	1.26	0.06	0.00

The coefficient of variation was calculated for the plantar fascial thickness, stiffness and speed to assess the variability of the five frames (table 12).

The results show that the assessment of the five frames from the one clip were consistent with a low CoV of for PFT (.02) and PFS (.01).

5.2.2.4 Fixed or Flexible Probe

The ultrasound probe was placed in either the fixed holder or the flexible holder and a range of measurements in the frontal plane were taken according to the protocol . The results ae given in table 13.

***The repeated zero angles were taken 3 times and the mean value calculated (shaded row).**

Table 13: Fixed and Flexible Probe Results.

	RF	PF Thick	B wave			Elastography									
	Frontal Angle	Major	Minor	Circumference	Area	Mean Stiffness	Min	Max	SD	Mean speed	Min	Max	SD	Perimeter (circ)	Area
Repeated*	0	0.35	0.17	0.85	0.05	192.7	0.40	491.50	133.40	7.30	0.40	12.80	3.30	1.57	0.07
	0	0.33	0.15	0.78	0.04	352.4	5.50	666.90	194.70	10.10	1.40	14.90	3.80	0.81	0.04
	0	0.36	0.18	0.87	0.05	148.0	0.10	498.50	179.00	5.60	0.20	12.90	4.20	0.92	0.05
	0	0.35	0.17	0.83	0.05	231.03	2.00	552.30	169.03	7.67	0.67	13.53	3.77	1.10	0.05
Flexible	-4	0.37	0.18	0.89	0.05	426.5	22.9	575.70	111.10	11.80	2.80	13.90	2.00	0.09	0.05
	-8	0.40	0.20	0.96	0.06	642.9	3.70	800.00	180.80	14.40	1.10	16.30	2.80	0.96	0.06
	4	0.43	0.21	10.30	0.07	364.4	0.60	491.50	187.60	10.20	0.40	12.80	4.20	1.05	0.07
	8	0.46	0.23	1.10	0.08	495.4	1.10	776.00	242.50	12.00	0.60	16.10	4.60	1.14	0.08
Fixed Probe	0	0.38	0.19	0.92	0.06	315.7	0.10	491.50	168.30	9.50	0.20	12.80	3.90	0.97	0.06
	-4	0.49	0.25	1.19	0.09	358.5	1.00	655.20	211.50	10.00	0.60	14.80	4.40	1.20	0.09
	-8	0.48	0.24	1.15	0.09	531.5	0.60	653.80	164.00	12.90	0.50	14.80	3.30	1.10	0.08
	4	0.41	0.21	1.00	0.07	458.4	0.90	784.40	248.40	11.40	0.50	16.20	4.70	0.97	0.06
	8	0.40	0.20	0.97	0.06	496.5	0.80	792.60	186.80	12.30	0.50	16.30	3.60	1.00	0.06

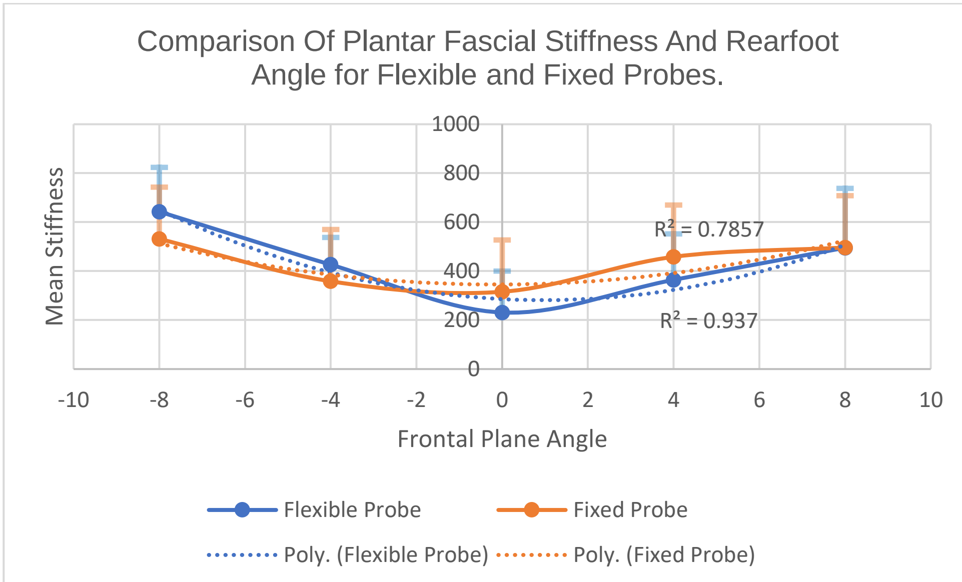


Figure 17: Graph Showing Elastographic Results Plantar Fascial Stiffness For Positions Of The Rearfoot With Flexible And Fixed Probe.

The results in Table 13 and Figure 17 show that both flexible and fixed probe produced similar curves, but the flexible probe holder had a greater range. The polynomial relationship shows strong polynomial (order 2) correlation (*fixed* $r^2 = .79$, *flexible* $r^2 = .94$) for PFS.

Levene's test for Equality of Variance showed there was homogeneity of variance ($F(8) = .94$, $p = .36$). Therefore, an independent samples t-test was performed to assess if the data obtained from the two types of probe holders was statistically significant. There was no significant difference for the type of probe holder used *t(8) = -.183, p = .859*, despite the fixed holder (*M = 432.12, SD = 91.77*) having a higher mean stiffness than the flexible holder (*M = 415.44, SD = 181.92*).

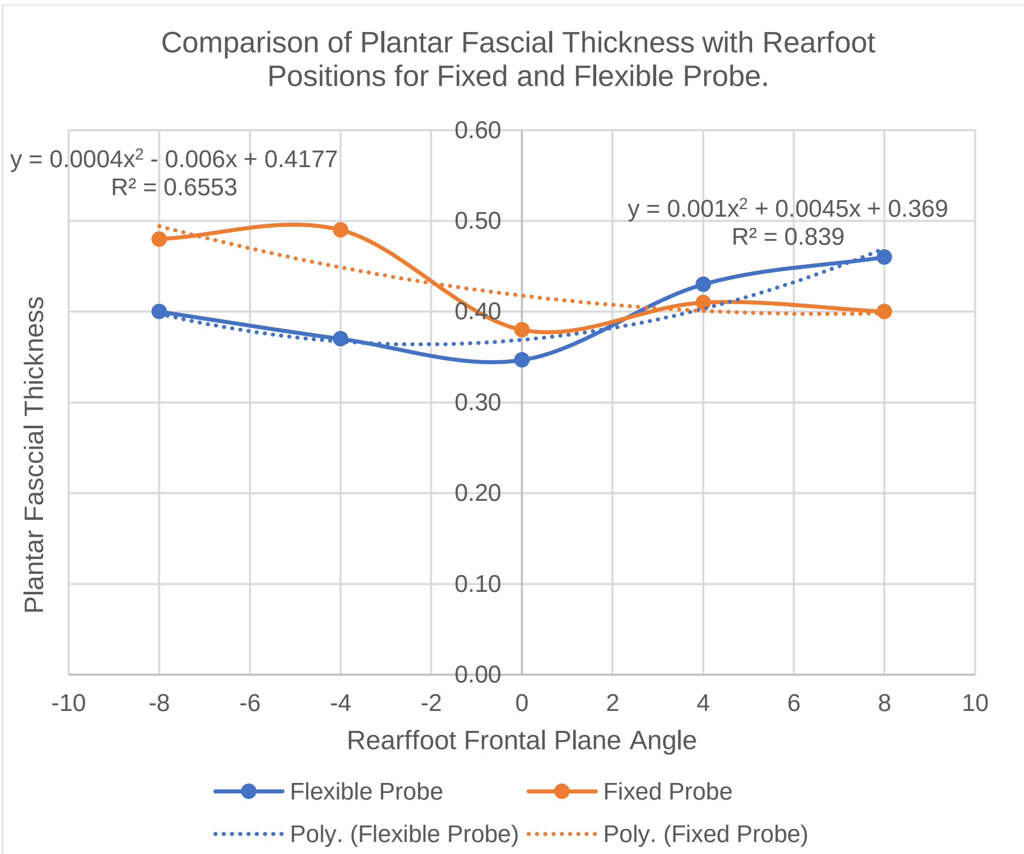


Figure 18: Graph Showing Sonographic Results For Plantar Fascial Thickness For Positions Of The Rearfoot With Flexible And Fixed Probe.

The results from Table 13 and Figure 18 also shows that plantar fascial thickness demonstrates a relationship to the angle of the rearfoot, but the range was a much smaller variance than the shear wave elastography for mean stiffness of the plantar fascia. The flexible probe ($r^2 = .84$) showed stronger polynomial correlation than the fixed probe ($r^2 = .65$). The PFS also showed that the flexible probe had a stronger polynomial (order 2) correlation ($r^2 = .94$) than the fixed probe holder ($r^2 = .78$). There was no significant difference for the type of probe holder used $t(8) = -.97, p = .36$, despite the fixed holder ($M = .43, SD = .05$) having a higher mean thickness than the flexible holder ($M = .40, SD = .04$).

5.2.2.5 Assessment of measurements from pilot data and study data through range of angles.

The same participant used for the pilot study was also used in the main study. The pilot data was compared to the study data through the frontal and sagittal planes for the plantar fascial thickness and stiffness.

The study data was collected on a different day and the mean of 3 readings was taken.

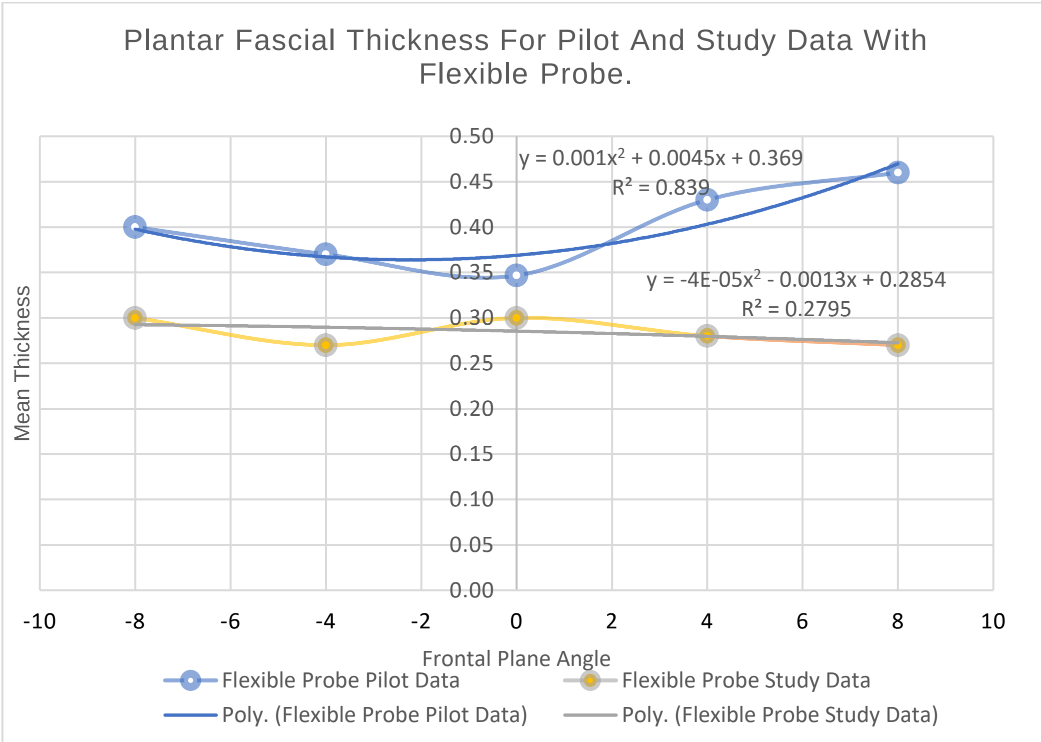


Figure 19: Graph Showing Plantar Fascial Thickness For Pilot And Study Data With Flexible Probe.

Figure 19 shows that the data from the pilot study and the study for PFT has a similar pattern but stronger correlation for mean thickness between the pilot data ($r^2 = .84$) and the study data ($r^2 = .28$).

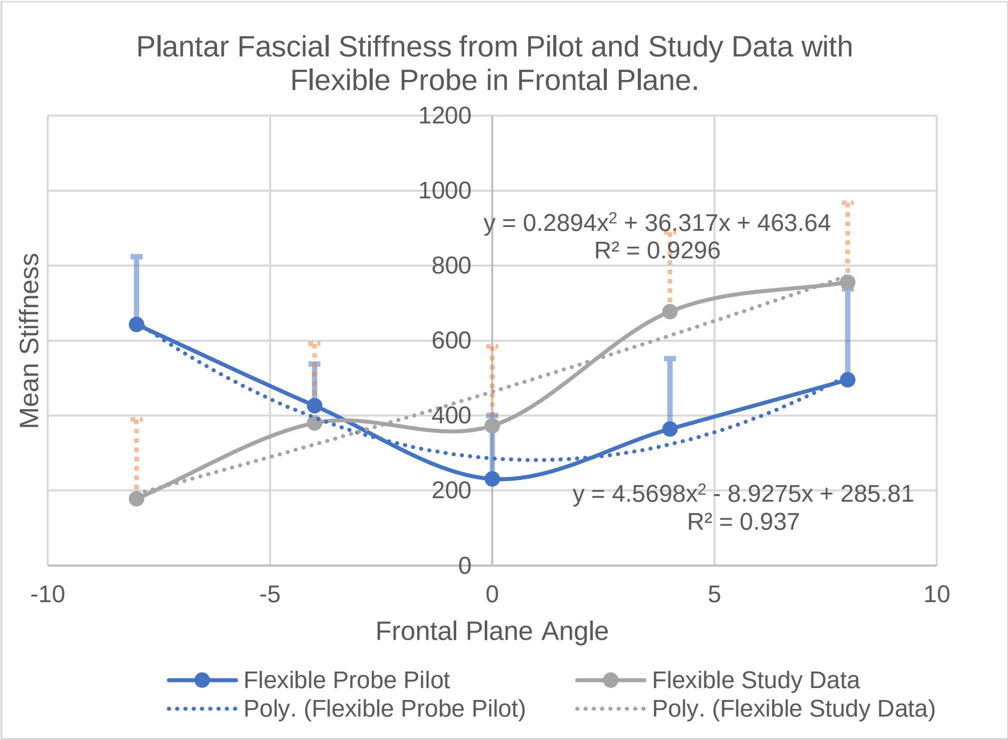


Figure 20: Graph Showing Plantar Fascial Stiffness From Pilot And Study Data With Flexible Probe In Frontal Plane.

Figure 20 shows that the data from the pilot study and the study for PFS has a similar pattern and similar strong correlation for mean stiffness between the pilot data (r^2 = *.94*) and the study data (r^2 = *.93*).

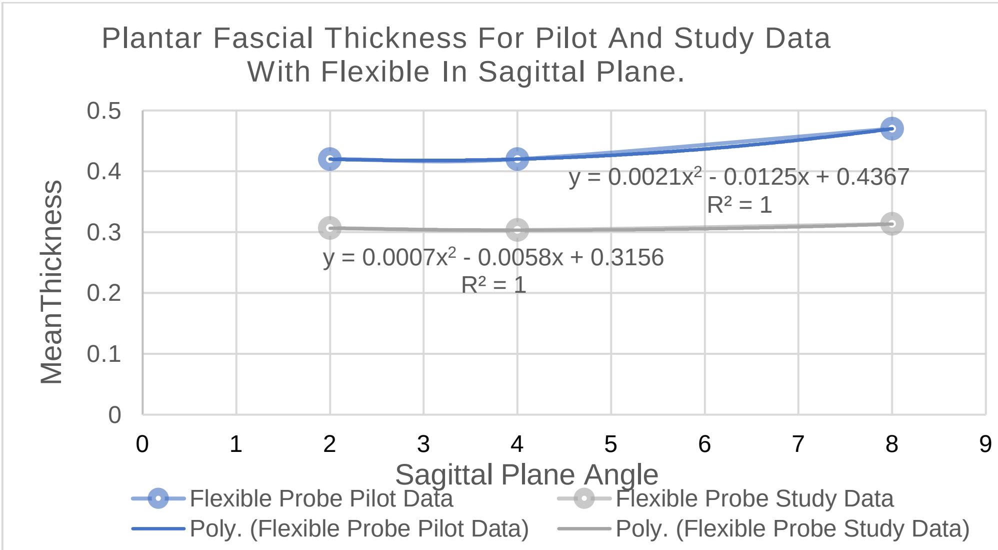


Figure 21: Graph Showing Plantar Fascial Thickness Results Of Rearfoot Positions With Flexible Probe From Pilot And Study Data.

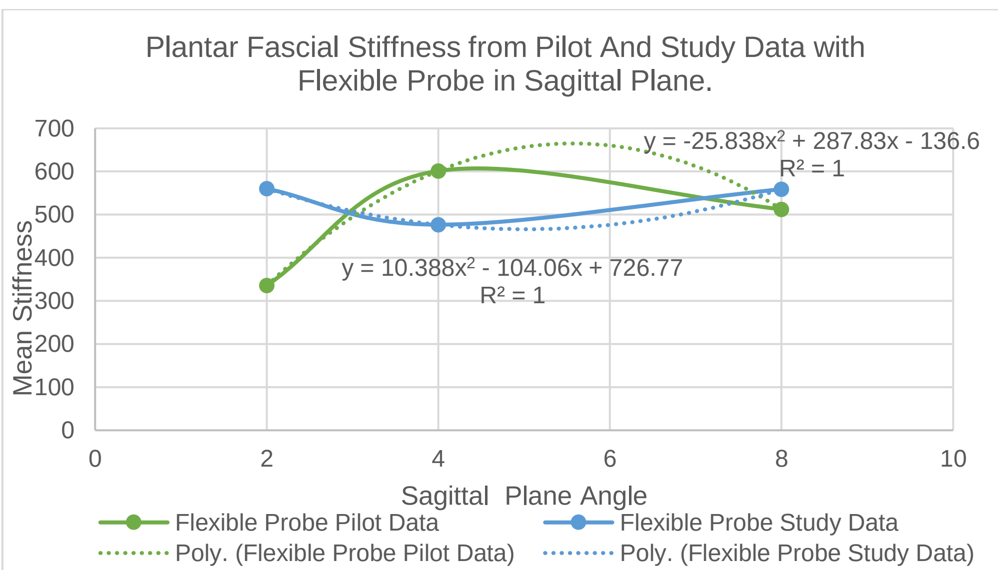


Figure 22: Graph Showing Plantar Fascial Stiffness From Pilot And Study Data With Flexible Probe In Sagittal Plane.

Figure 21 shows little change in the thickness of the plantar fascial in the sagittal plane angle for this participant. The pilot and study show a mild inverse relationship to each other.

Figure 22 shows that there is uniform (curvilinear) change in the PFS at different angles in the sagittal plane. The pilot and study data was also different, but both had strong polynomial (order 2) correlation to the angle change ($r^2 = 1$).

5.3 Objective 3

To investigate if the PF thickness and stiffness can be quantified based on the rearfoot position, age and Body Mass Index (BMI).

The results to these objectives are presented below.

5.3.1 To Investigate if the PF thickness and stiffness can be quantified based on the rearfoot position, age and BMI.

5.3.1.1 Test for Normality

The data for age, height, weight, thickness, stiffness, both overall group and RCSP scores, were tested for normality and all showed a normal distribution using the Kolmogorov-Smirnow and Shapiro-Wilk tests (Table 14). Therefore, parametric tests were considered appropriate for interval data.

Table 14 Test For Normality.

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Age	.21	13	.13	.89	13	.10
Left PFT OGS	.17	13	.20*	.96	13	.70
Left PFS OGS	.14	13	.20*	.96	13	.79
Left RCSP PFT	.14	13	.20*	.93	13	.32
Left RCSP PFS	.13	13	.20*	.95	13	.54
Right PFT OGS	.15	13	.20*	.92	13	.29
Right PFS OGS	.12	13	.20*	.93	13	.34
Right RCSP PFT	.24	13	.05	.90	13	.15
Right RCSP PFS	.16	13	.20*	.88	13	.07
Height	.19	13	.19	.90	13	.14
Weight	.14	13	.20*	.96	13	.77
BMI	.18	13	.20*	.92	13	.25

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

5.3.1.2 The Sample

The sample group (Table 15) comprised of 11 male and 2 female participants with an age range of 20 - 67 years (*Mean 35.62, SD 15.04*). The BMI was calculated for each participant with a range of 22 – 42 kg/m^2 (*Mean 30.31, SD 6.22*).

Table 15: Participant Demographics.

Participant	Age (yrs)	Height (m)	Weight (kg)	BMI
1	51	1.81	119	36.32
2	67	1.83	106	31.65
3	25	1.6	60.1	23.48
4	57	1.74	96	31.71
5	23	1.74	128	42.28
6	20	1.83	72.4	21.62
7	45	1.74	82	27.08
8	22	1.84	93	27.47
9	39	1.84	94.1	27.79
10	24	1.67	71	25.46
11	35	1.73	88.2	29.47
12 (Female)	33	1.71	83.2	28.45
13 (Female)	26	1.73	123	41.10
Range	20 - 67	1.6 – 1.84	60.1 - 128	21.62 - 42.28
Mean	35.92	1.75	93.54	30.30
SD	15.04	.07	20.83	6.29

Table 16 shows the range of plantar fascial thickness of the left foot was .22 to .52mm (*Mean .35, SD .07*) and the right foot was .2 to .51 (*Mean .36, SD .06*) and stiffness of the left foot was 24.5 to 800 KPa (*Mean 508.92, SD 108.76*) and the right foot was 67.1 to 800 KPa (*Mean 489.89, SD 99.17*) for the sample group across all rearfoot angles in the frontal and sagittal planes.

The “overall group score” (OGS) was calculated from the average of all measurements taken for each participant at all angles of the rearfoot motion (except at zero degrees) and the Relaxed Calcaneal Stance Position (RCSP) was taken from the three tests performed with the rearfoot angle set at zero degrees in the frontal and sagittal planes.

Table 16: OGS and RCSP for PFT And PFS.

Participant	Left Foot (Overall Group Score & RCSP)						Right Foot (Overall Group Score & RCSP)					
	Thickness (mm)			Stiffness (kPa)			Thickness (mm)			Stiffness (kPa)		
	Range Overall	Mean Overall (SD)	RCSP	Range Overall	Mean Overall (SD)	RCSP	Range Overall	Mean Overall (SD)	RCSP	Range Overall	Mean Overall (SD)	RCSP
1	0.35-0.49	0.41 (.04)	0.30	61.9-729.1	424.75 (159.09)	254.37	0.31-0.46	0.39 (.03)	0.37	70.1-583.3	377.18 (124.64)	319.67
2	0.25-0.33	0.29 (.02)	0.28	236.8-798.6	502.08 (187.03)	373.03	0.2-0.34	0.28 (.03)	0.27	197.5-776.7	616.66 (165.50)	635.77
3	0.22-0.33	0.26 (.03)	0.32	47.8-637.6	398.08 (129.17)	274.10	0.2-0.27	0.24 (0.2)	0.27	254.4-790.6	482.25 (131.35)	511.83
4	0.33-0.44	0.38 (.03)	0.37	205.7-702.6	455.06 (112.05)	546.30	0.32-0.38	0.35 (.02)	0.36	290.7-639.8	464.79 (81.15)	446.47
5	0.18-0.27	0.22 (.03)	0.20	24.5-800	589.72 (195.55)	764.73	0.28-0.46	0.39 (.05)	0.37	391.8-775.3	606.78 (116.50)	634.77
6	0.39-0.52	0.45 (.04)	0.41	364-760.2	533.58 (94)	530.47	0.34-0.42	0.37 (.02)	0.39	338.4-717.5	531.28 (102.48)	644.00
7	0.25-0.33	0.29 (.03)	0.30	108.8-465.8	356.05 (97.91)	360.07	0.27-0.43	0.33 (.04)	0.30	221.5-648	416.43 (88.45)	319.13
8	0.36-0.51	0.43 (.04)	0.41	383.4-694.4	486.19 (50.45)	615.67	0.25-0.34	0.29 (.02)	0.32	61.7-554.2	383.24 (93.70)	431.70
9	0.32-0.38	0.34 (.02)	0.33	505.9-800	687.04 (87.86)	687.00	0.35-0.46	0.41 (.03)	0.38	345.6-800	660.22 (117.46)	597.90
10	0.32-0.4	0.36 (.02)	0.38	415.4-657.1	483.76 (54.34)	445.80	0.39-0.49	0.43 (.03)	0.41	354.1-667.5	508.86 (74.75)	544.47
11	0.35-0.44	0.39 (.02)	0.42	414.6-787.7	696.46 (85.53)	718.90	0.3-0.41	0.36 (.04)	0.42	175.6-746.5	445.37 (165.04)	539.90
12	0.31-0.4	0.36 (.02)	0.36	263.8-719.1	507.70 (114.42)	415.27	0.37-0.51	0.43 (.03)	0.39	210.7-657.8	378.69 (99.84)	315.93
13	0.35–0.41	0.38 (.02)	0.39	364.1–766.9	586.06 (114.33)	668.57	0.39–0.44	0.41 (.02)	0.42	171 - 800	501.28 (180.93)	586.87
Group	0.22-0.52	0.35 (.07)	0.34 (.06)	24.5-800	508.92 (108.76)	511.87 (171.56)	0.2-0.51	0.36 (.06)	0.36 (.05)	67.1-800	489.89 (99.17)	502.19 (124.08)

5.3.2 Comparison of Thickness & Stiffness for Overall Group Score (OGS) and RCSP.

Using the data from Table 16, the OGS and the RCSP score were analysed for any difference between the PFT and PFS with the feet in the RCSP (zero degrees) and the OGS using a T-test (paired samples, 2 tailed) in the frontal plane.

For the 13 participants:

Overall Group left PF thickness score (*M = .35, SD = .07*) was compared to the left RCSP thickness (*M = .34, SD = .06); t(12) = .62, p = .55*).

Overall Group left PF stiffness score (*M = 515.19, SD = 101.32*) was compared to the left RCSP stiffness (*M = 511.87, SD = 171.56); t(12) = .11, p = .91*).

Overall Group right PF thickness score (*M = .36, SD = .06*) was compared to the right RCSP thickness (*M = .35, SD = .05); t(12) = ..82, p = .43*).

Overall Group right PF stiffness score (*M = 490.23, SD = 93.75*) was compared to the right RCSP stiffness (*M = 502.19, SD = 124.08); t(12) = -.64, p = .53*).

These results indicate that there was no significant difference between the plantar fascia thickness and stiffness for the Overall Group Scores and the RCSP scores for both the left and right feet.

Table 17: Descriptive Statistics.

	Mean	N	Std. Deviation	Std. Error Mean
Left PFT OGS	.35	13	.068	.019
Left PFT RCSP	.34	13	.063	.018
Left PFS OGS	515.19	13	101.32	28.10
Left PFS RCSP	511.87	13	171.56	47.58
Right PFT OGS	.36	13	.060	.017
Right PFT RCSP	.35	13	.05	.014
Right PFS OGS	490.23	13	93.74	26.00
Right PFS RCSP	502.18	13	124.08	34.41

Table 18: Paired Samples t-Test.

Paired Samples Test								
	Paired Differences					t	df	Sig. (2-tailed)
	Mean	SD	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Left PFT OGS & Left PFT RCSP	.01	.04	.011	-.017	.03	.62	12	.54
Left PFS OGS & Left PFS RCSP	3.33	105.68	29.32	-60.54	67.19	.11	12	.91
Right PFT OGS & Right PFT RCSP	.01	.024	.01	-.01	.02	.82	12	.43
Right PFS OGS & Right PFS RCSP	-11.95	66.88	18.55	-52.37	28.47	-.64	12	.53

5.3.3 Relationship between Age, Height, Weight, BMI and PFT and PFS

It has been established that the data was normally distributed from section 5.3.1.1. and parametric tests were appropriate. The data from Table 16 was analysed using a Pearson correlation to assess the relationship of Age and BMI to the PFT and PFS for the OGS and RCSP.

Table 19: Correlation for Age and PFT and PFS.

Correlations						
		Age	OGS PFT	OGS PFS	RCSP PFT	RCSP PFS
Age	Pearson Correlation	1.00	-.15	-.09	-.33	-.30
	Sig. (2-tailed)		.45	.68	.10	.13
	N	26.00	26.00	26.00	26.00	26.00

There was no correlation with age and both feet for PFT (*OGS r (26)* = *-.15, p = .45; RCSP r (26) = -.33, p = .10*) or PFS *(OGS r (26) = -..9, p = .68; RCSP r (26) = -.30, p = .13*).

Table 20: Correlation for BMI and PFT and PFS.

Correlations							
		BMI	OGS PFT	OGS PFS	RCSP PFT	RCSP PFS
BMI	Pearson Correlation	1.00	.01	.19	-.14	.24
	Sig. (2-tailed)		.95	.36	.49	.24
	N	26.00	26.00	26.00	26.00	26.00

There was no correlation with BMI with both feet for PFT (*OGS r (26) = -.01, p = .95; RCSP r (26) = -.14, p = .49*) or PFS (*OGS r (26) = .19, p = .36; RCSP r (26) = .24, p = .24*).

5.3.4 Automatic Linear Regression Modelling

The PFS at the RCSP for both the left and right foot was subjected to automatic linear regression modelling to assess if the covariates of age, height, weight, BMI or PFT were predictors of the PFS.

Table 21: Right Foot RCSP PFS Predictors.

Source*	Sum of Squares	Df	Mean Square	F	Significance	Importance
Corrected Model	25042.19	5	5008.44	.22	.94	
Age	9822.05	1	9822.08	.43	.53	.37
Height	5543.99	1	5543.99	.24	.64	.21
BMI	4281.96	1	4281.96	.19	.69	.16
Weight	3934.08	1	3934.08	.17	.69	.15
PFT	2740.42	1	2740.42	.12	.74	.1
Residual	159713.49	7	22816.21			
Corrected Total	184755.69	12				

*Note the variables were transform by the modelling. Standard Modelling was used and included all predictors.

The Table 21 shows that age was the most important predictor of PFS with height, BMI, weight and PFT being less important. All predictors were not significant.

Table 22: Left Foot RCSP PFS Predictors.

Source*	Sum of Squares	Df	Mean Square	F	Significance	Importance
Corrected Model	215517.33	5	43103.47	2.19	.19	
Height	56782.37	1	56782.37	2.89	.13	.32
BMI	52351.96	1	52351.96	2.66	.15	.3
Weight	46071.53	1	46071.53	2.34	.17	.26
Age	19204.76	1	19204.76	.98	.36	.11
PFT	1812.05	1	1812.05	.09	.77	.01
Residual	137670.92	7	19667.27			
Corrected Total	353188.25	12				

*Note the variables were transform by the modelling. Standard Modelling was used and included all predictors.

The Table 22 shows that height was the most important predictor of PFS with BMI, weight, age and PFT being less important. All predictors were not significant.

5.3.5 Comparison of RCSP and Maximum Frontal and Sagittal Plane Positions.

5.3.5.1 Left Foot PFT in Frontal Plane

Table 23: Left Frontal Plane PFT.

Descriptive Statistics			
	Mean	Std. Deviation	N
Left PFT RCSP	.34	.06	13
Left PFT_-8^0	.34	.06	13
Left PFT +8^0	.35	.07	13

Table 24: Left PFT Frontal Plane ANOVA.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.77	1.60[b]	2.00	11.00	.25	.22
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

The mean PFT for the left foot at zero and +8 and -8 degrees were analysed using a one-way repeated measures ANOVA. There was a no significant effect for left foot PFT with motion of the frontal plane at -8^0 eversion, 0^0 or $+8^0$ inversion, Wilks' Lambda = *.77, F (2, 11) =1.60, p = .25*.

5.3.5.2 Left Foot PFT Sagittal Plane

Table 25: Sagittal Plane T Test Results, Both Feet PFT & PFS.

Paired Samples Test								
	Paired Differences					t	df	Sig. (2-tailed)
	Mean	SD	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Left PFT RCSP & Left PFT sag +8^0	-.01	.06	.016	-.04	.03	-.43	12	.67
Right PFT RCSP & Right PFT sag +8^0	-.01	.04	.011	-.03	.015	-.83	12	.42
Left PFS RCSP & Left PFS sag +8^0	-45.83	142.40	39.49	-131.88	40.22	-1.16	12	.27
Right PFS RCSP & Right PFS sag +8^0	-30.81	145.77	40.43	-118.89	57.28	-.76	12	.46

Table 26: Descriptive Statistics Sagittal Plane.

Descriptive Statistics					
	N	Min	Max	Mean	Std. Deviation
Left RCSP PFT	26	.20	.42	.35	.056
Right RCSP PFT	13	.24	.43	.36	.06
Left PFT 8 deg	13	.23	.46	.35	.07
Right PFT 8 deg	13	.23	.48	.36	.07

The mean PFT (Table 25 & 26) for the left foot at zero (RCSP) and +8 degrees in the sagittal plane were analysed using a paired samples t-test. There was no significant effect for increased sagittal plane angle on PFT where $t(12) = -.43, p = .67$.

5.3.5.3 Right Foot PFT in Frontal Plane

The mean PFT for the right foot at zero and +8 and -8 degrees were analysed using a one-way repeated measures ANOVA (Table 27 & 28). There was a no significant effect for right foot PFT with motion of the frontal plane at -8^0 eversion, 0^0 or $+8^0$ inversion, Wilks' Lambda = $.97$, $F(2, 11) = 1.60, p = .86$.

Table 27: Right Frontal Plane PFT.

Descriptive Statistics			
	Mean	Std. Deviation	N
Right PFT RCSP	.35	.05	13
Right PFT -8^0	.36	.06	13
Right PFT $+8^0$	.36	.06	13

Table 28: Right PFT Frontal ANOVA.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.97	.16[b]	2.00	11.00	.86	.03
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

5.3.5.4 Right Foot PFT Sagittal Plane

The mean PFT (Table 26) for the right foot at zero (RCSP) and +8 degrees in the sagittal plane were analysed using a paired samples t-test. There was no significant effect for increased sagittal plane angle on PFT where $t(12) = -.83, p = .42$.

5.3.5.5 Left Foot Stiffness Frontal Plane

The mean PFS for the left foot at zero and +8 and -8 degrees were analysed using a one-way repeated measures ANOVA (Table 29 & 30). There was a no significant effect for left foot PFS with motion of the frontal plane at -8^0 eversion, 0^0 or $+8^0$ inversion, Wilks' Lambda = $.98, F (2, 11) = .09, p = .92$.

Table 29: Left PFS Frontal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
Left PFS RCSP	511.87	171.56	13
Left PFS -8^0	502.96	160.58	13
Left PFS $+8^0$	495.23	137.38	13

Table 30: Left Frontal Plane PFS.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.98	.09[b]	2.00	11.00	.92	.02
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

5.3.5.6 Left Foot Stiffness Sagittal Plane

The mean PFS (Table 26) for the left foot at zero (RCSP) and +8 degrees in the sagittal plane were analysed using a paired samples t-test. There was no significant effect for increased sagittal plane angle on PFT where $t(12) = -1.16, p = .27$.

5.3.5.7 Right Foot Stiffness Frontal Plane

The mean PFS for the right foot at zero and +8 and -8 degrees were analysed using a one-way repeated measures ANOVA (Table 31 & 32). There was a no significant effect for right foot PFS with motion of the frontal plane at -8^0 eversion, 0^0 or $+8^0$ inversion, Wilks' Lambda = *.89, F (2, 11) = .66, p = .53*.

Table 31: Right Sagittal Plane PFS.

Descriptive Statistics			
	Mean	Std. Deviation	N
Right PFS RCSP	502.19	124.08	13
Right PFS -8^0	482.87	122.62	13
Right PFS $+8^0$	531.98	155.80	13

Table 32: Right Sagittal Plane PFS ANOVA.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.89	.66[b]	2.00	11.00	.53	.11

a. Design: Intercept
Within Subjects Design: factor1

b. Exact statistic

5.3.5.8 Right Foot Stiffness Sagittal Plane

The mean PFS (Table 26) for the right foot at zero (RCSP) and +8 degrees in the sagittal plane were analysed using a paired samples t-test. There was no significant effect for increased sagittal plane angle on PFT where $t(12) = -.76$, $p = .46$.

5.3.6 Generalized Linear Modelling

A further assessment of PFT and PFS was performed using generalised Linear Modelling (GLM) to assess the effects of the covariates of age, height, weight, BMI and PFT with PFS as the dependent variable. All PFT and PFS values for each angle for each participant were included. The GLM allows other types of distribution to be assessed for between subjects where the coefficient is determined by the maximum likelihood (Wobbrock, 2019).

5.3.6.1 Combined Left and Right

The Omnibus test was significant (X^2 *(7, N=260) = 27.45, p = .00*), and demonstrated that the model outperforms the null model.

Table 33: GLM - Tests of Model Effects, Both Feet.

Tests of Model Effects			
	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	.03	1	.85
Plate Angle Sagittal	2.51	1	.11
Plate Angle Frontal	.39	1	.53
Age	3.38	1	.07
Height	6.08	1	.01
Weight	3.81	1	.05
BMI	4.34	1	.04
PFT	.32	1	.57
Dependent Variable: PFS Model: (Intercept), Plate Angle Sagittal, Plate Angle Frontal, Age, Height, Weight, BMI, PFT.			

Table 33 shows that Height (X^2 *(1, N=260) = 6.08, p = .01*), BMI (X^2 *(1, N=260) = 4.34, p = .04*) and Weight (X^2 *(1, N=260) = 3.81, p = .05*) had a significant effect on PFS, but Age (X^2 *(1, N=260) = 3.38, p = .07*) and the angle of the rearfoot (*Frontal plane angle* X^2 *(1, N=260) = .39, p = .53 &*

Sagittal plane angle X^2 (1, N=260) = 2.51, p = .11) or PFT (*X^2 (1, N=260) = .32, p = .57*) did not have a significant effect.

Table 34: GLM - Parameter Estimates, Both Feet.

Parameter Estimates							
			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-.49	2.66	-5.71	4.72	.03	1	.85
Plate Angle Sagittal	.01	.01	-.00	.02	2.51	1	.11
Plate Angle Frontal	.00	.00	-.00	.01	.39	1	.53
Age	-.00	.00	-.00	.00	3.38	1	.07
Height	3.82	1.55	.78	6.85	6.08	1	.01
Weight	-.03	.02	-.06	.00	3.81	1	.05
BMI	.10	.05	.01	.20	4.34	1	.04
PFT	-.15	.26	-.67	.37	.32	1	.57
(Scale)	.06[a]	.00	.05	.07			
Dependent Variable: PFS Model: (Intercept), Plate Angle Sagittal, Plate Angle Frontal, Age, Height, Weight, BMI, PFT.							
a. Maximum likelihood estimate.							

The data from Table 34 shows that Height had a more marked effect on the PFS given that the coefficient (*B = 6.23*) is greater than the other covariates and was significant (*p = .01*). The predictors BMI (*B = .10*) also had a significant positive effect ($p = .04$) on the PFS, whilst Weight ($B = -.03$) also had a significant negative effect ($p = .05$) on the PFS.

5.3.6.2 Left Foot

Using the GLM with SPSS, the scale response was set to gamma distribution with Log as the link function (IBM Corp., 2021). This gives transformation of the dependent variable that allows estimation of the model.

The Omnibus test was significant (X^2 *(7, N=130) = 27.85, p = .00*), and demonstrated that the model outperforms the null model.

Table 35: GLM – Tests of Model Effects, Left Foot.

Tests of Model Effects			
	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	1.57	1	.21
Plate Angle Sagittal	.98	1	.32
Plate Angle Frontal	.02	1	.88
Age	4.87	1	.03
Height	8.00	1	.01
Weight	5.75	1	.02
BMI	6.49	1	.01
PFT	.01	1	.98
Dependent Variable: PFS Model: (Intercept), Plate Angle Sagittal, Plate Angle Frontal, Age, Height, Weight, BMI, PFT			

Table 35 shows that Height (*X^2 (1, N=130) = 8, p = .01*), BMI (*X^2 (1, N=130) = 6.49, p = .01*), Weight (*X^2 (1, N=130) = 5.75, p = .02*) and Age (*X^2 (1, N=130) = 4.87, p = .03*) had a significant effect on PFS but the angle of the rearfoot (*Frontal plane angle X^2 (1, N=130) = .02, p = .88 & Sagittal plane angle X^2 (1, N=130) = .98, p = .32*) or PFT (*X^2 (1, N=130) = .01, p = .98*) didn't have a significant effect on PFS.

Table 36: GLM – Parameter Estimates, Left Foot.

Parameter Estimates							
			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-4.74	3.78	-12.15	2.66	1.57	1	.21
Plate Angle Sagittal	.01	.01	-.01	.02	.98	1	.32
Plate Angle Frontal	-.00	.00	-.01	.01	.02	1	.88
Age	-.00	.00	-.01	.00	4.87	1	.03
Height	6.23	2.20	1.9	10.56	8.00	1	.01
Weight	-.06	.02	-.10	-.01	5.75	1	.02
BMI	.18	.07	.04	.31	6.49	1	.01
PFT	-.03	.39	-.79	.72	.01	1	.93
(Scale)	.06[a]	.01	.05	.08			
Dependent Variable: PFS Model: (Intercept), Plate Angle Sagittal, Plate Angle Frontal, Age, Height, Weight, BMI, PFT.							
a. Maximum likelihood estimate.							

The data from Table 36 shows that Height had a more marked significant effect (*p = .01*) on the PFS given that the coefficient (*B = 6.23*) is greater than the other covariates. The predictors BMI (*B = .18*) also had a significant positive effect (*p = .01*) on the PFS, whilst Weight (*B = -.06, p = .02*) and Age (*B = -.00, p = .03*) also had a significant negative effect on the PFS.

5.3.6.3 Right Foot

The GLM with the same parameters as the left foot was performed for the right foot.

The Omnibus test was significant (X^2 *(7, N=130) = 7.21, p = .41*), and demonstrated that the model does not outperform the null model.

Table 37: GLM – Tests of Model Effects, Right Foot.

Tests of Model Effects			
	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	1.31	1	.25
Plate Angle Sagittal	1.66	1	.20
Plate Angle Frontal	1.31	1	.25
Age	.10	1	.75
Height	.27	1	.60
Weight	.06	1	.80
BMI	.09	1	.76
PFT	.00	1	.95
Dependent Variable: PFS Model: (Intercept), Plate Angle Sagittal, Plate Angle Frontal, Age, Height, Weight, BMI, PFT.			

The data from Table 37 shows that the covariates Frontal plane angle (X^2 *(1, N=130) = 1.31, p = .25*), Sagittal plane angle (X^2 *(1, N=130) = .98, p = .32*), Height (X^2 *(1, N=130) = .27, p = .60*), Age (X^2 *(1, N=130) = .10, p = .75*), BMI (X^2 *(1, N=130) = .09, p = .76)*, Weight (X^2 *(1, N=130) = .06, p = .80*) and PFT (X^2 *(1, N=130) = .00, p = .95*) did not have any significant effect on the PFS of the right foot.

Table 38: GLM – Parameter Estimates, Right Foot.

Parameter Estimates							
			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	4.18	3.65	-2.97	11.34	1.31	1	.25
Plate Angle Sagittal	.01	.01	-.01	.03	1.66	1	.20
Plate Angle Frontal	.01	.01	-.00	.02	1.30	1	.25
Age	-.00	.00	-.00	.00	.10	1	.75
Height	1.10	2.12	-3.06	5.30	.27	1	.60
weight	-.01	.02	-.05	.04	.06	1	.80
BMI	.02	.07	-.11	.16	.09	1	.76
PFT	-.02	.40	-.81	.76	.00	1	.95
(Scale)	.06[a]	.01	.05	.07			
Dependent Variable: PFS Model: (Intercept), Plate Angle Sagittal, Plate Angle Frontal, Age, Height, Weight, BMI, PFT.							
a. Maximum likelihood estimate.							

The data from Table 38 shows that Height had a more marked effect on the PFS given that the coefficient (*B = 1.10*) is greater than the other covariates, but it was not a significant effect (*p = .60*).

5.4 Individual Participant Relationship of Plantar Fascial Thickness and Stiffness

Individual analysis of individual participants results can be found in Appendix 9. An example of the data presented is given below.

5.4.1 Participant 1

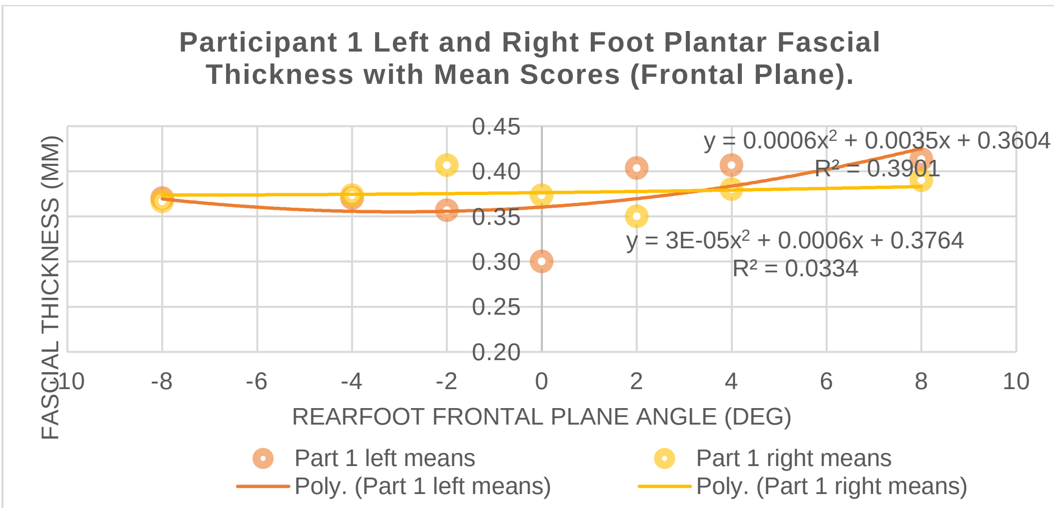


Figure 23: Graph Showing PFT And Frontal Plane – Participant 1.

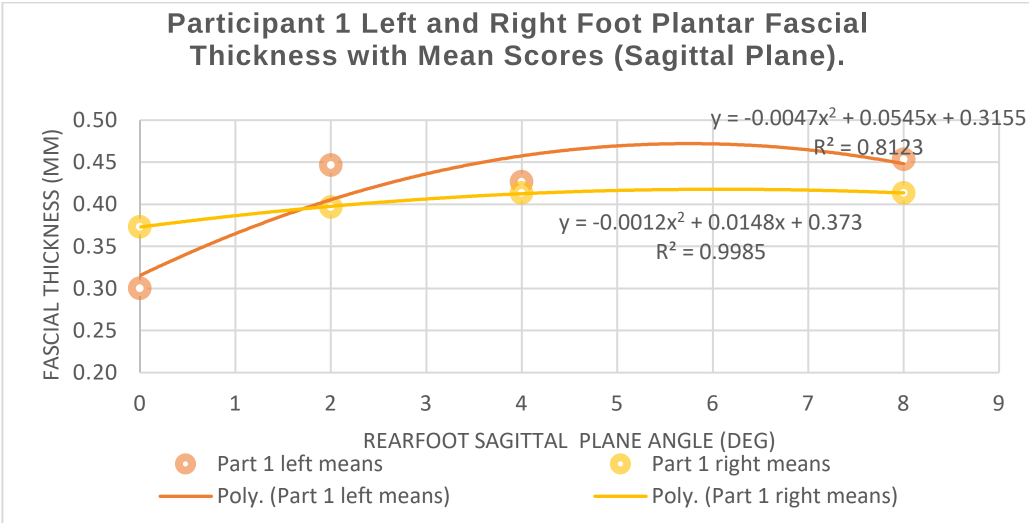


Figure 24: Graph Showing PFT And Sagittal Plane – Participant 1.

Participant 1 shows poor polynomial (order 2) correlation for plantar fascial thickness (PFT) with a change in the rearfoot frontal plane angle in both feet (*Left* r^2 = *.39, Right* r^2 = *.03*) but good polynomial (order 2) correlation in the sagittal plane (*Left* r^2 = *.81, Right* r^2 = *.99*).

The PFT increases as the foot moves into inversion (+8) and eversion (-8) in the frontal plane and as the sagittal plane angle increased.

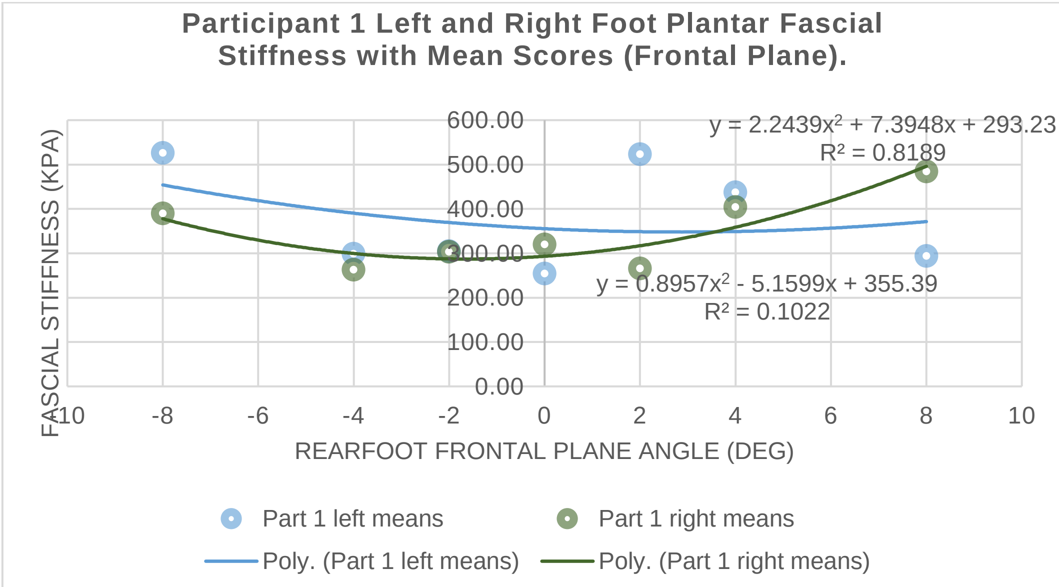


Figure 25: Graph Showing PFS And Frontal Plane – Participant 1.

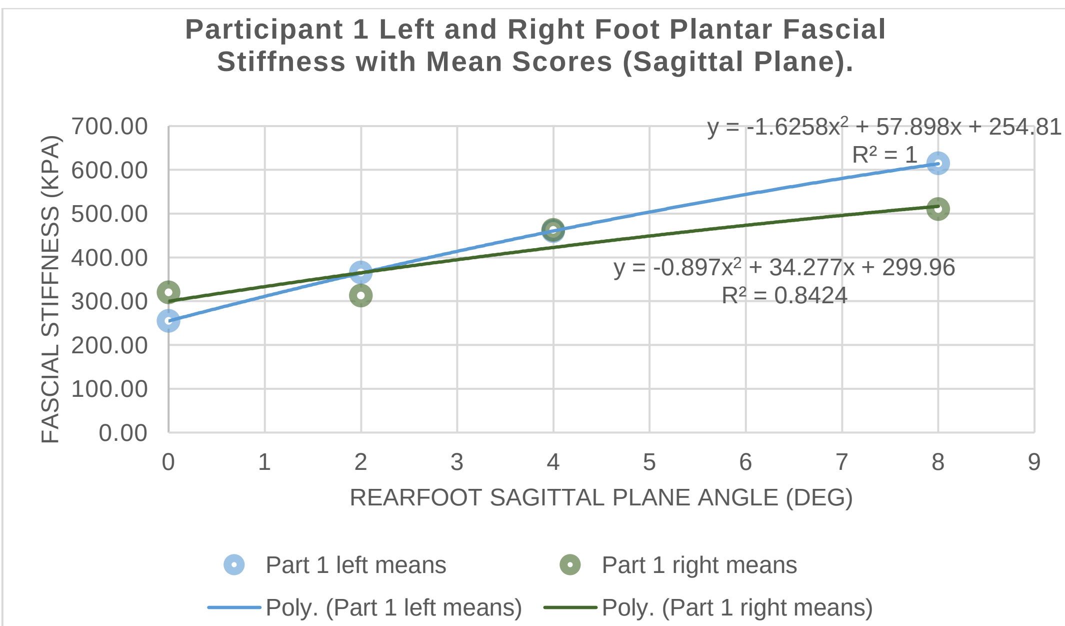


Figure 26: Graph Showing PFS And Sagittal Plane – Participant 1.

The Plantar Fascial Stiffness (PFS) shows a strong polynomial (order 2) correlation in the right foot (*Left* $r^2 = .10$, *Right* $r^2 = .82$). for the frontal plane angle and very strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left* $r^2 = 1.0$, *Right* $r^2 = .84$). The PFS also increased as the frontal plane angle moved into inversion and eversion. The PFS also increased as the sagittal plane angle increased.

In summary, when the individual reactions of the sample group are considered, there are very strong correlations for PFT and PFS to the changes in the rearfoot position, more so in the sagittal plane. Some demonstrate an increased PFT with increased PFS whilst others demonstrate the opposite.

5.5 Analysis Of PFT and PFS At All Angles

Using SPSS general linear model, a repeated measures ANOVA was performed to establish if there was a significant difference for the PFT or PFS and the rearfoot motion in the frontal and sagittal planes.

5.5.1 RIGHT PFT And Frontal Plane All Angles.

Table 39: Right PFT in Frontal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
PFT RCSP R	.36	.05	13
PFT neg 2 R	.36	.07	13
PFT neg 4 R	.35	.06	13
PFT neg 8 R	.36	.06	13
PFT 2 R	.35	.06	13
PFT 4 R	.36	.07	13
PFT 8 R	.36	.06	13

Table 40: Right PFT ANOVA Frontal Plane.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.15	6.50[b]	6.00	7.00	.01	.85
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

There was a significant difference for the right foot PFT and the frontal plane angle suggesting a relationship between the PFT and the rearfoot angle (Wilks' Lambda = *.15, F (6, 7) = 6.50, p = .01)*.

5.5.2 LEFT PFT And Frontal Plane All Angles

Table 41: Left PFT in Frontal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
PFT RCSP L	.34	.06	13
PFT neg 2 L	.35	.07	13
PFT neg 4 L	.34	.07	13
PFT neg 8 L	.34	.06	13
PFT 2 L	.35	.07	13
PFT 4 L	.35	.06	13
PFT 8 L	.35	.07	13

Table 42: Left PFT ANOVA Frontal Plane.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.5	1.17[b]	6.00	7.00	.41	.50
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

There was no significant difference for the left foot PFT and the frontal plane angle suggesting no relationship between the PFT and the rearfoot angle (Wilks' Lambda = *.5, F (6, 7) = 1.17, p = .41)*.

5.5.3 Right PFS And Frontal Plane All Angles

Table 43: Right PFS in Frontal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
PFS RCSP R	502.18	124.082	13
PFS neg 2 R	472.53	109.70	13
PFS neg 4 R	458.13	100.44	13
PFS neg 8 R	482.87	122.62	13
PFS 2 R	482.84	133.98	13
PFS 4 R	476.51	133.62	13
PFS 8 R	531.98	155.80	13

Table 44: Right PFS ANOVA Frontal Plane.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.60	.78[b]	6.00	7.00	.61	.40
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

There was no significant difference for the right foot PFS and the frontal plane angle suggesting no relationship between the PFS and the rearfoot angle (Wilks' Lambda = *.60, F (6, 7) = .78, p = .61)*.

5.5.4 Left PFS And Frontal Plane All Angles

Table 45: Left PFS in Frontal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
PFS RCSP L	511.87	171.56	13
PFS neg 2 L	520.52	164.42	13
PFS neg 4 L	533.99	172.49	13
PFS neg 8 L	502.96	160.58	13
PFS 2 L	509.91	123.77	13
PFS 4 L	515.00	122.65	13
PFS 8 L	495.23	137.38	13

Table 46: Left PFS ANOVA Frontal Plane.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.49	1.22[b]	6.00	7.00	.40	.51
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

There was no significant difference for the left foot PFS and the frontal plane angle suggesting no relationship between the PFS and the rearfoot angle (Wilks' Lambda = *.49, F (6, 7) = 1.22, p = .40)*.

5.5.5 Right PFT And Sagittal Plane All Angles

Table 47: Right PFT in Sagittal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
PFT sag 0 R	.36	.05	13
PFT sag 2 R	.37	.05	13
PFT sag 4 R	.36	.06	13
PFT sag 8 R	.36	.07	13

Table 48: Right PFT ANOVA Sagittal Plane.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.94	.23[b]	3.00	10.00	.87	.06
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

There was no significant difference for the right foot PFT and the sagittal plane angle suggesting no relationship between the PFT and the rearfoot angle (Wilks' Lambda = *.94, F (3, 10)* = *.23, p* = *.87)*.

5.5.6 Left PFT And Sagittal Plane All Angles

Table 49: Left PFT in Sagittal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
PFT sag 0 L	.34	.06	13
PFT sag 2 L	.36	.09	13
PFT sag 4 L	.35	.08	13
PFT sag 8 L	.35	.07	13

Table 50: Left PFT ANOVA Sagittal Plane.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.89	.40[b]	3.00	10.00	.75	.11
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

There was no significant difference for the left foot PFT and the sagittal plane angle suggesting no relationship between the PFT and the rearfoot angle (Wilks' Lambda = *.89, F (3, 10) = .40, p = .75)*.

5.5.7 Right PFS And Sagittal Plane All Angles

Table 51: Right PFS in Sagittal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
PFS sag 0 R	502.18	124.08	13
PFS sag 2 R	477.70	121.81	13
PFS sag 4 R	496.56	121.14	13
PFS sag 8 R	532.99	111.82	13

Table 52: Right PFS ANOVA Sagittal Plane.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.83	.68[b]	3.00	10.00	.58	.17
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

There was no significant difference for the right foot PFS and the sagittal plane angle suggesting no relationship between the PFS and the rearfoot angle (Wilks' Lambda = *.83, F (3, 10) = .68, p = .58)*.

5.5.8 LEFT PFS And Sagittal Plane All Angles

Table 53: Left PFS in Sagittal Plane.

Descriptive Statistics			
	Mean	Std. Deviation	N
PFS sag 0 L	511.87	171.56	13
PFS sag 2 L	515.14	120.06	13
PFS sag 4 L	492.53	82.14	13
PFS sag 8 L	557.70	108.27	13

Table 54: Left PFS ANOVA Sagittal Plane.

Multivariate Tests[a]						
Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Wilks' Lambda	.69	1.49[b]	3.00	10.00	.28	.31
a. Design: Intercept Within Subjects Design: factor1						
b. Exact statistic						

There was no significant difference for the left foot PFS and the sagittal plane angle suggesting no relationship between the PFS and the rearfoot angle (Wilks' Lambda = *.69, F (3, 10) = 1.90, p = .28)*.

5.6 Manual Group Analysis and Trends

5.6.1 Left PFT And Frontal Plane Angles

The PFT for all 13 participants were plotted against the rearfoot frontal plane angle and the combined line of best fit was applied. There was no polynomial (order 2) correlation for the combined scores (*r^2 = .004)*.

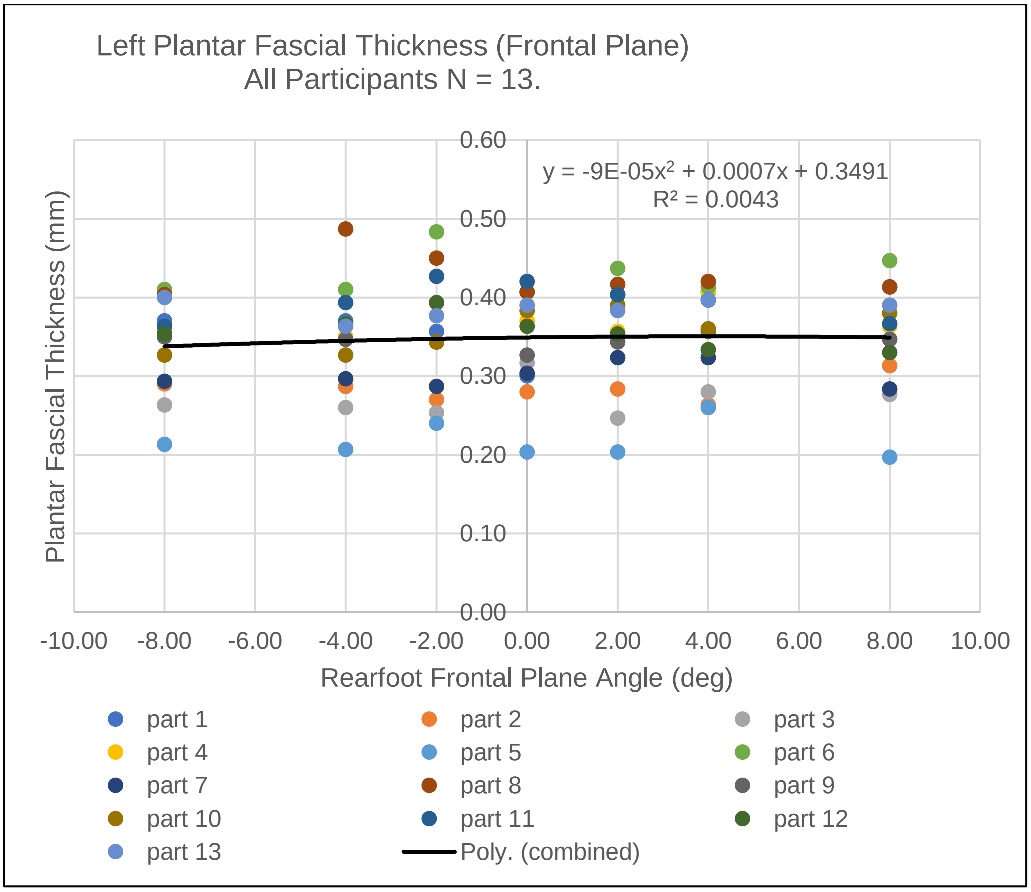


Figure 27: Left PFT in Frontal Plane For All Participants.

The total group analysis showed no polynomial (order 2) correlation (*r2 = .004*) for left foot PFT with the frontal plane angle. When a manual cluster analysis was performed, it showed that 6 (1, 2, 3, 4, 5, 13) of the 13 (46.1%) had a PFT increase as the angle increased into eversion or inversion. Two participants (15.4%) had a flat relationship and 5 (38.5%) an inverse relationship where the thickness decreased as the frontal plane angle increased.

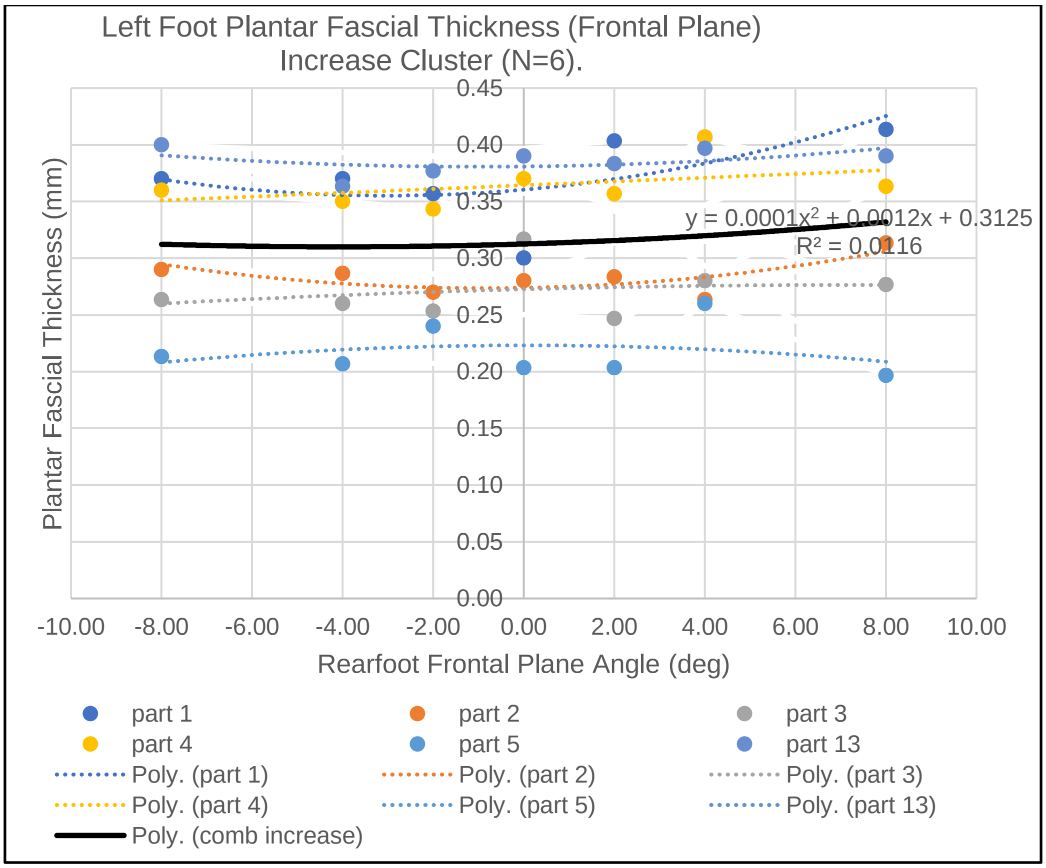


Figure 28: Left PFT in Frontal Plane Increase Cluster.

There was no polynomial (order 2) correlation for the increase cluster PFT for left foot in the frontal plane PFT (*r^2 = 0.1*). Only 2 participants (1,2) had an increased PFS matching the 6 participants in this cluster. This increase cluster also had 4 matching participants (1,2,4,5) where the PFT increased as the sagittal plane angle increased. The Left PFT in the frontal plane also showed 5 matching participants (1,2,4,5,13) for increased PFS in the sagittal plane.

5.6.2 Left PFT And Sagittal Plane Angles

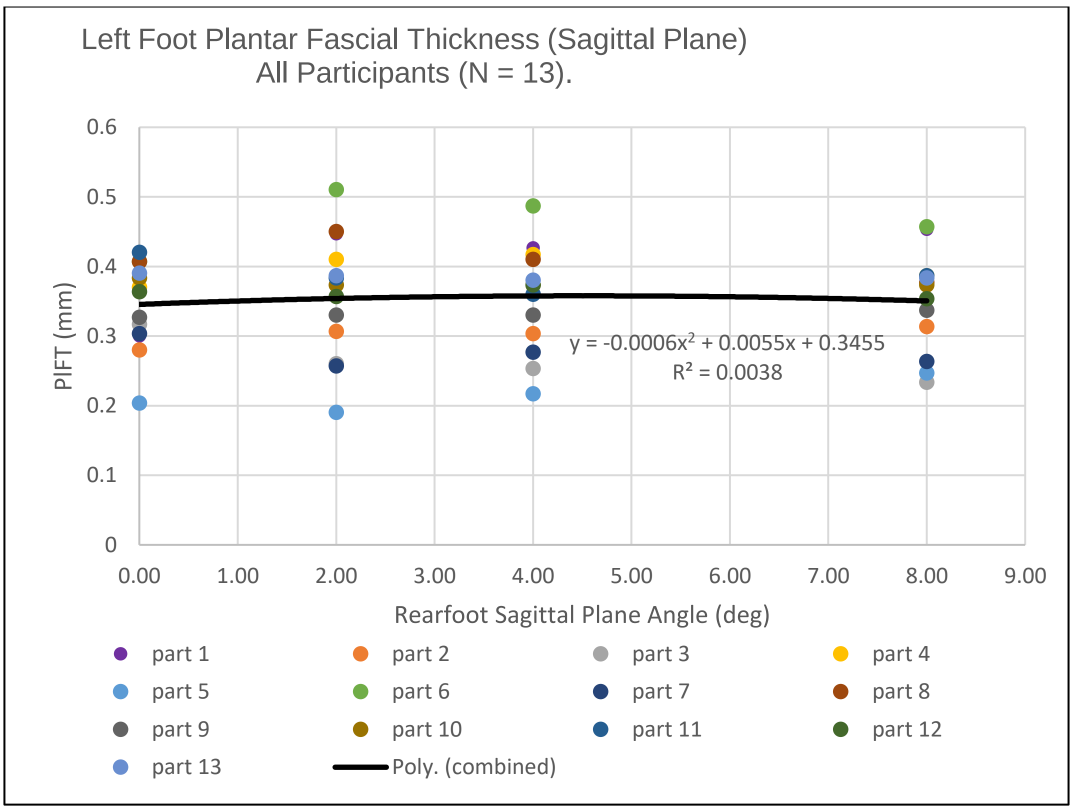


Figure 29: Left PFT in Sagittal Plane For All Participants.

The total group analysis showed no polynomial (order 2) correlation (r^2 = *.004*) for left foot PFT with the sagittal plane angle. When a cluster analysis was performed it showed that 5 (1,2,4,5,6) of the 13 (38.5%) had a PFT increase as the angle increased but then flattened off. Three participants (23%) had a flat relationship and 5 (38.5%) an inverse relationship (3,7,8,11,13) where the thickness decreased as the frontal plane angle increased.

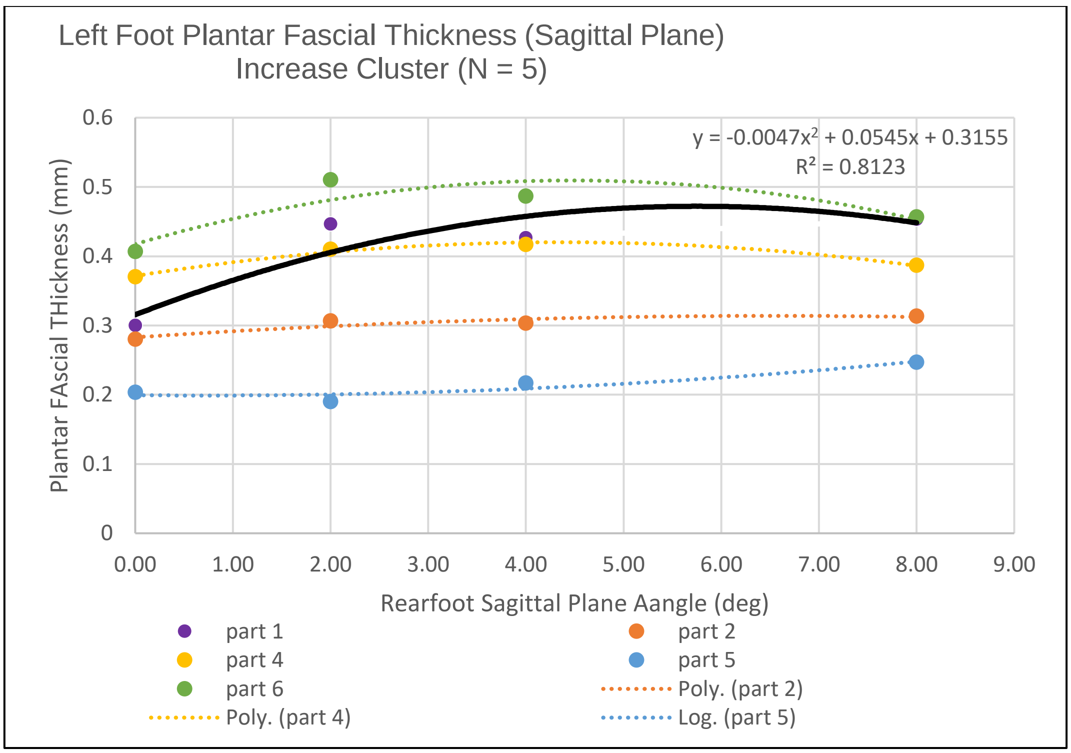


Figure 30: Left PFT in Sagittal Plane Increase Cluster.

In the increase cluster (1,2,4,5,6) the PFT showed a strong polynomial (order 2) correlation (r^2 = *.81*) to the rearfoot sagittal plane angle with polynomial relationship and flattening off of the increase at about 5^0 inclined. Within this cluster the PFS also increase as the PFT in all but one of them (1,2,4,5).

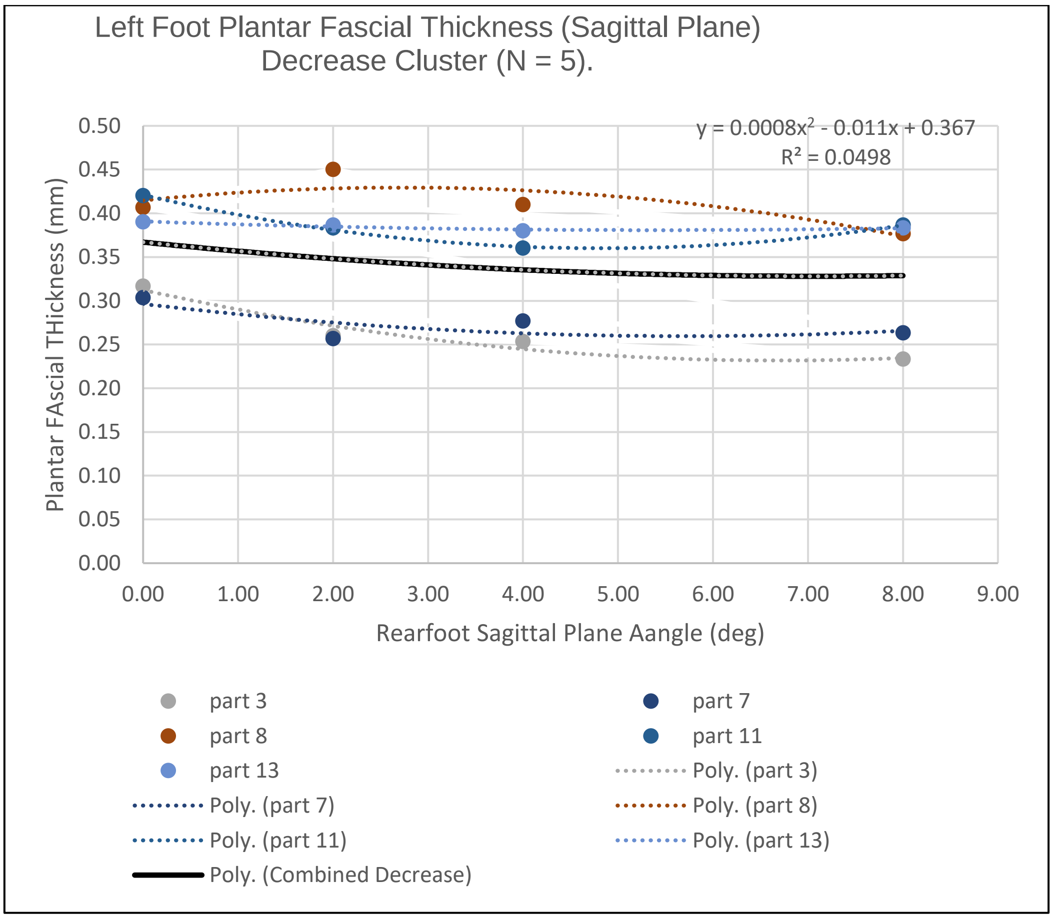


Figure 31: Left PFT in Sagittal Plane Decrease Cluster.

In the decrease cluster group (3,7,8,11,13) where the general trend was to decrease the PFT as the sagittal angle increased, there was no polynomial (order 2) correlation (r^2 = .05). Only two of this group (3,11) had a decrease in the PFS with the decrease in the PFT and increasing sagittal plane angle.

5.6.3 Left Foot PFS And Frontal Plane Angles

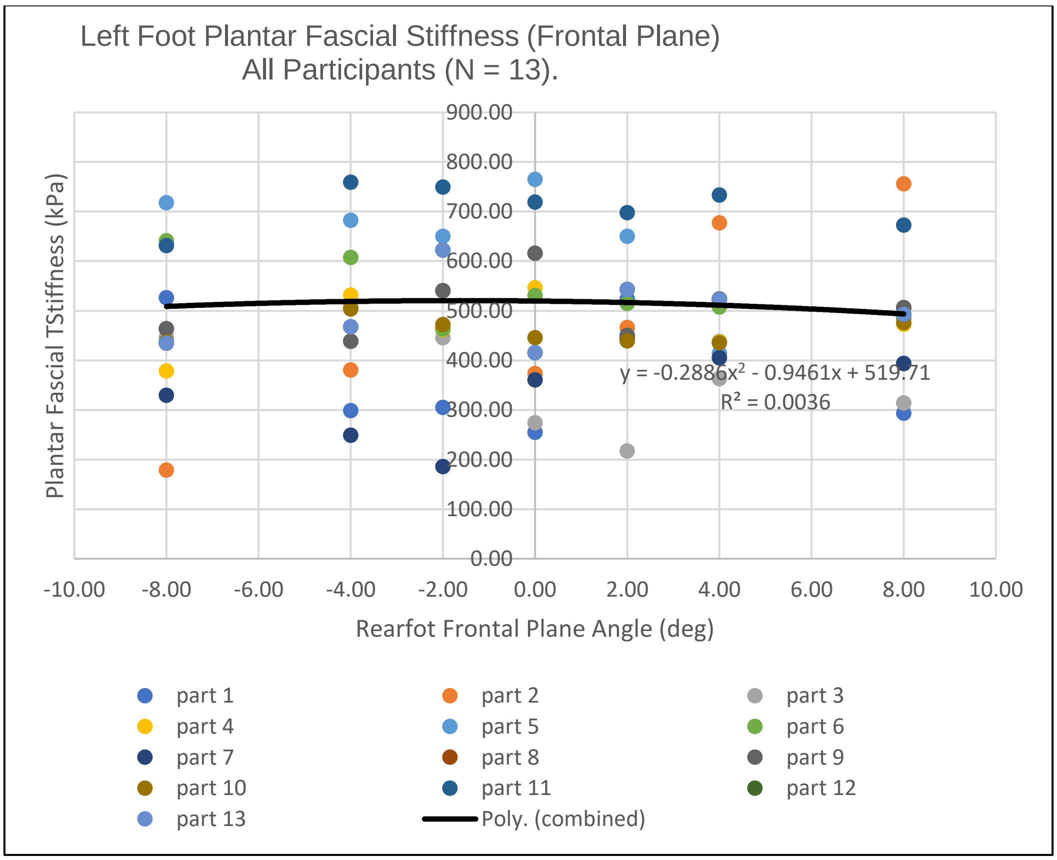


Figure 32: Left PFS in Frontal Plane For All Participants.

The total group analysis showed no polynomial (order 2) correlation (r^2 = *.004*) for left foot PFS with the frontal plane angle. When a manual cluster analysis was performed it showed that 3 (1,2,7) of the 13 (23%) had a PFS increase as the angle increased into eversion or inversion. Four participants (31%) had a flat relationship (8,9,10,12) and 6 (46%) an inverse relationship (3,4,5,6,11,13) where the stiffness decreased as the frontal plane angle increased.

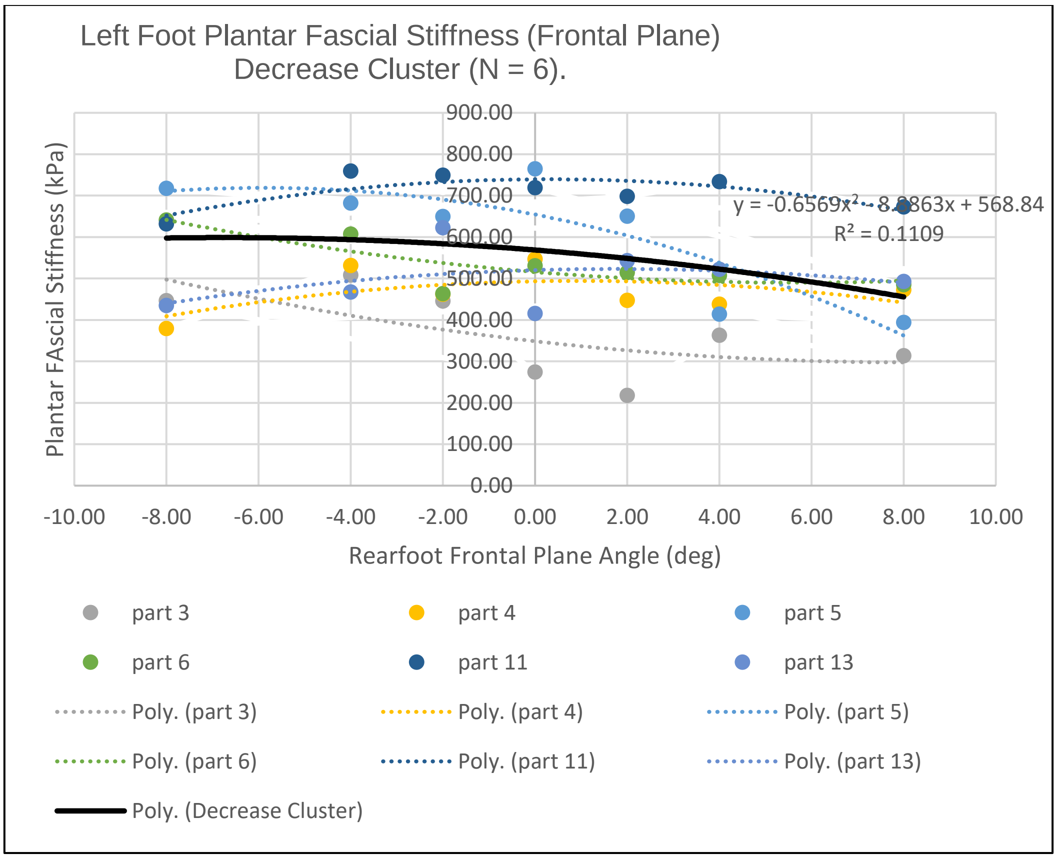


Figure 33: Left PFT in Frontal Plane Decrease Cluster.

The decrease cluster group had a moderate correlation (r^2 = *.44*) with a decrease in the PFS as the foot moved into an increased frontal plane angle (inversion). Four of this group (3,4,5,13) also had an increased PFT as the foot moved into inversion.

5.6.4 Left Foot PFS And Sagittal Plane

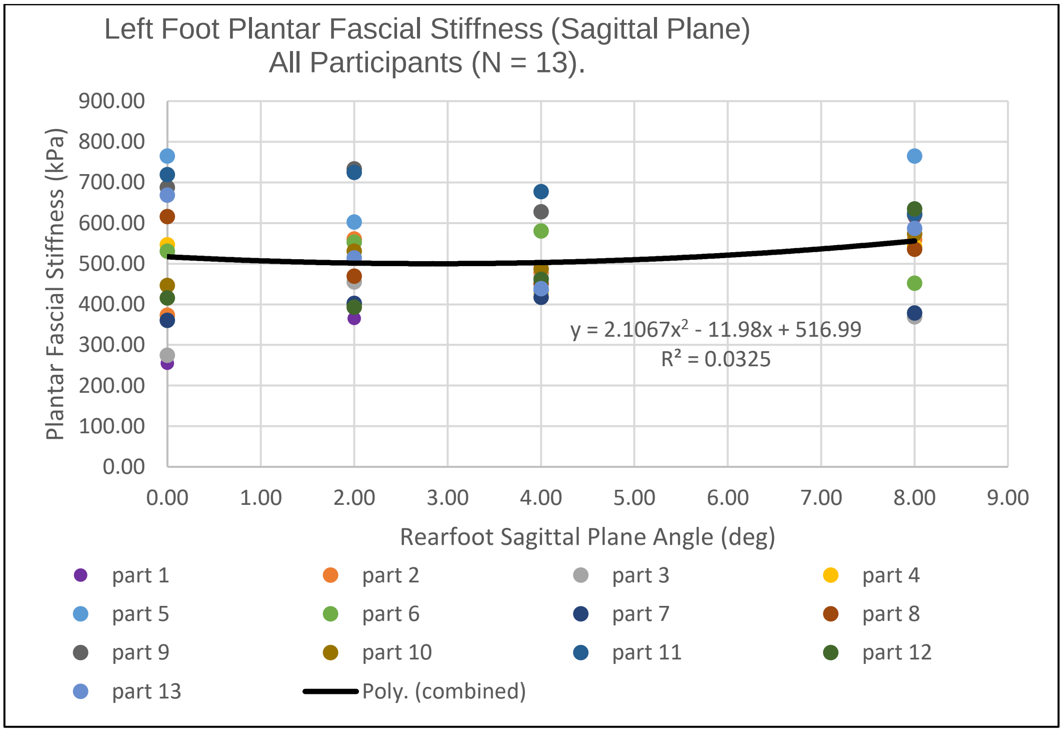


Figure 34: Left PFS in Sagittal Plane For All Participants.

The total group analysis showed no polynomial (order 2) correlation (r^2 = *.03*) for left foot PFS with the sagittal plane angle. When a manual cluster analysis was performed it showed that 9 (1,2,4,5,7,8,10,12,13) of the 13 (69%) had a PFS increase as the sagittal plane angle increased. Four participants (3,6,9,11) had an inverse relationship (31%) where the stiffness decreased as the sagittal plane angle increased.

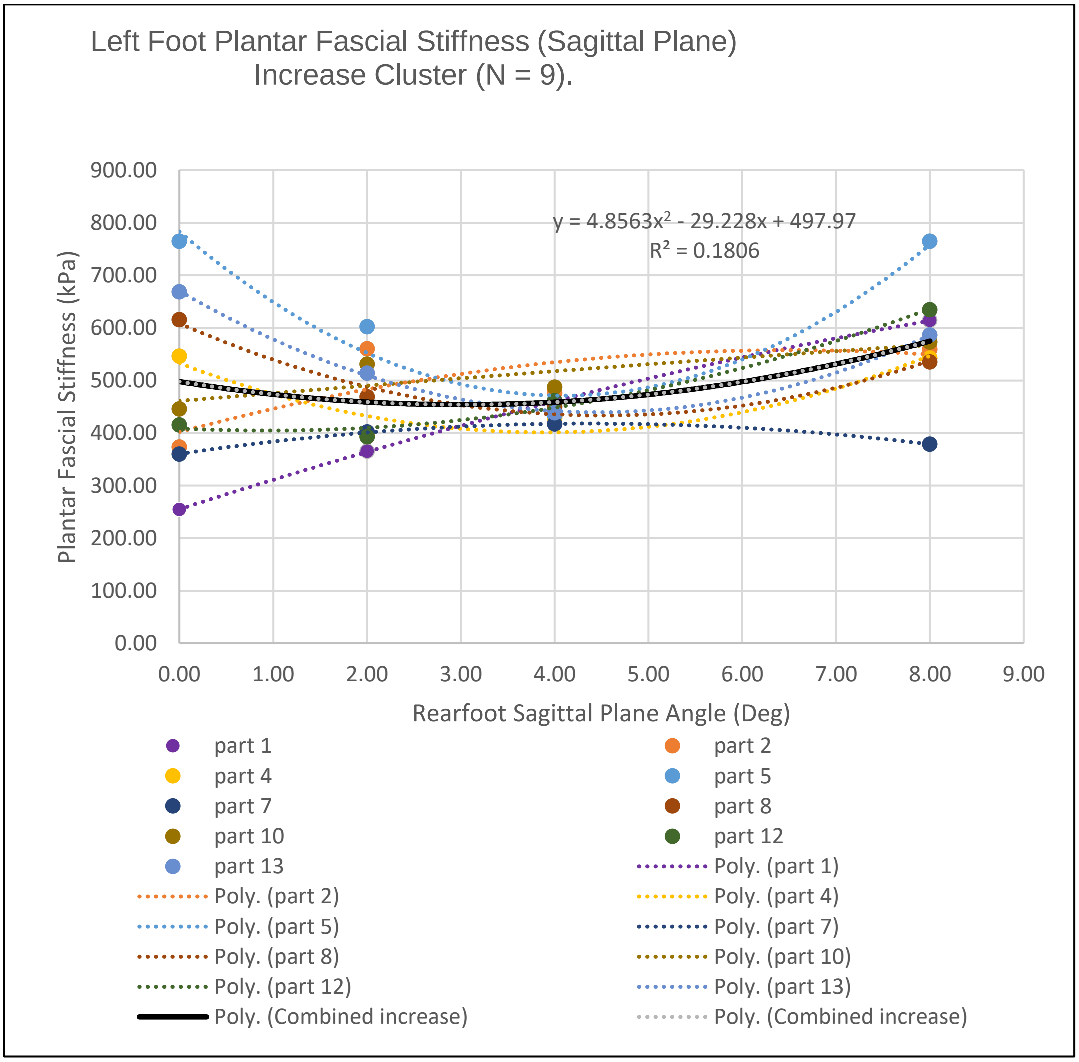


Figure 35: Left PFT in Sagittal Plane Increase Cluster.

The increase cluster showed moderate polynomial (order 2) correlation (r^2 = *.18*). Four of the group (1,2,4,5) also showed an increase in PFT as the sagittal plane increased whilst 3 of the group (7,8,13) showed a decrease in PFT as the sagittal plane increased. All six of the left PFT frontal plane group (1,2,3,4,5,13) also showed a complete match to the PFS sagittal plane increase cluster group.

5.6.5 Right Foot PFT And Frontal Plane Angles

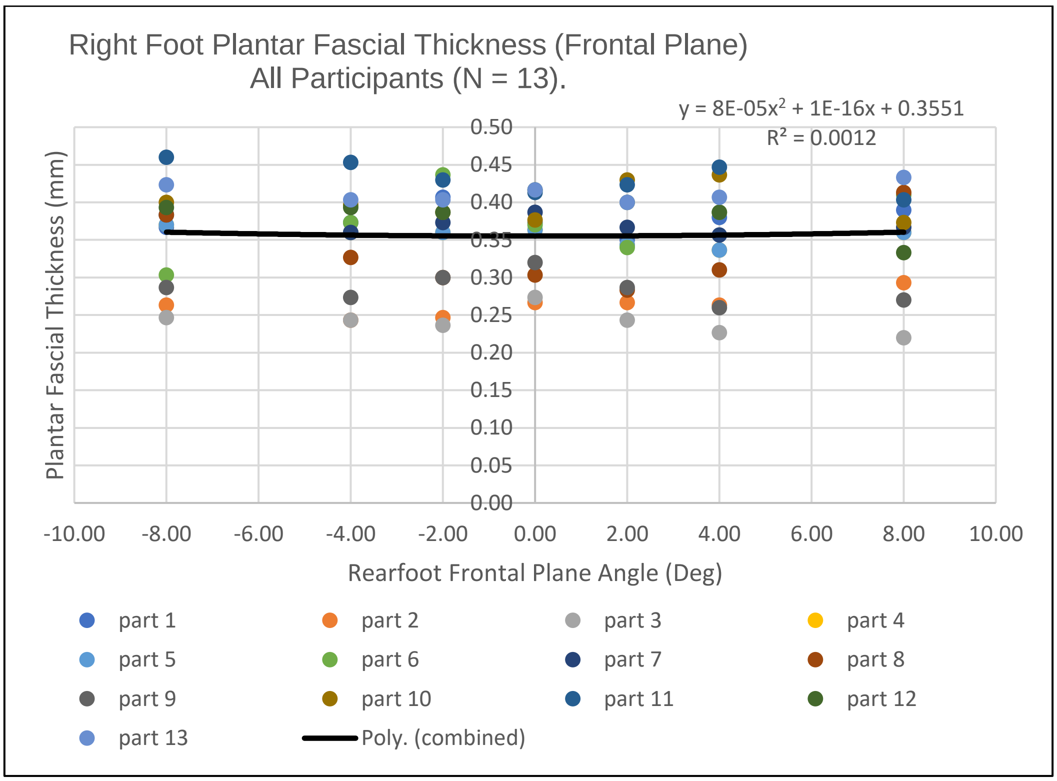


Figure 36: Right Foot PFT in Frontal Plane For All Participants.

The total group analysis showed no polynomial (order 2) correlation (r^2 = *.001*) for right foot PFT with the frontal plane angle. When a manual cluster analysis was performed it showed that 5 (2,7,10,12,13) of the 13 (38.5%) had a PFT increase as the angle increased into eversion or inversion. Five participants (38.5%) had a flat relationship (1,4,5,6,9) and 3 (3,8,11) an inverse relationship (23%) where the thickness decreased as the frontal plane angle changed.

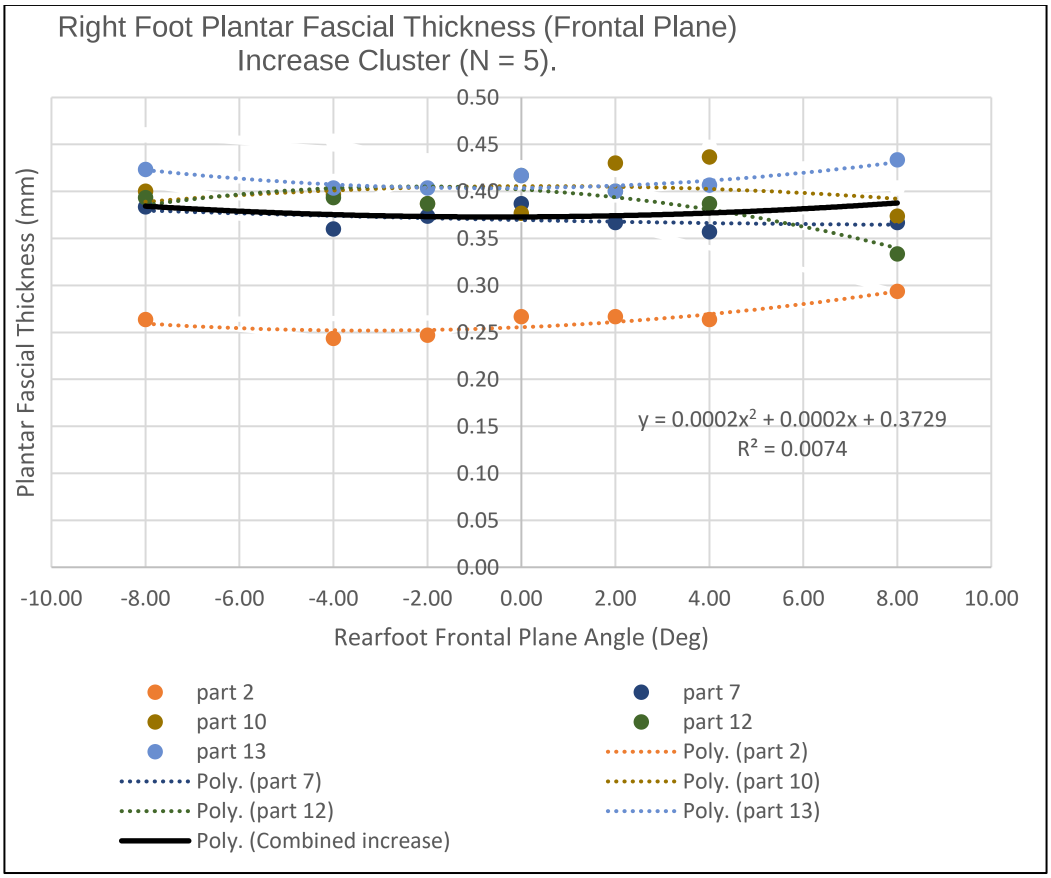


Figure 37:Right Foot PFT in Frontal Plane For Increase Cluster.

The increase cluster showed no polynomial (order 2) correlation (r^2 = *.007*) for right PFT and frontal plane angles. There was little relationship of the PFT frontal plane to the PFS or Sagittal plane.

5.6.6 Right Foot PFT And Sagittal Plane Angles

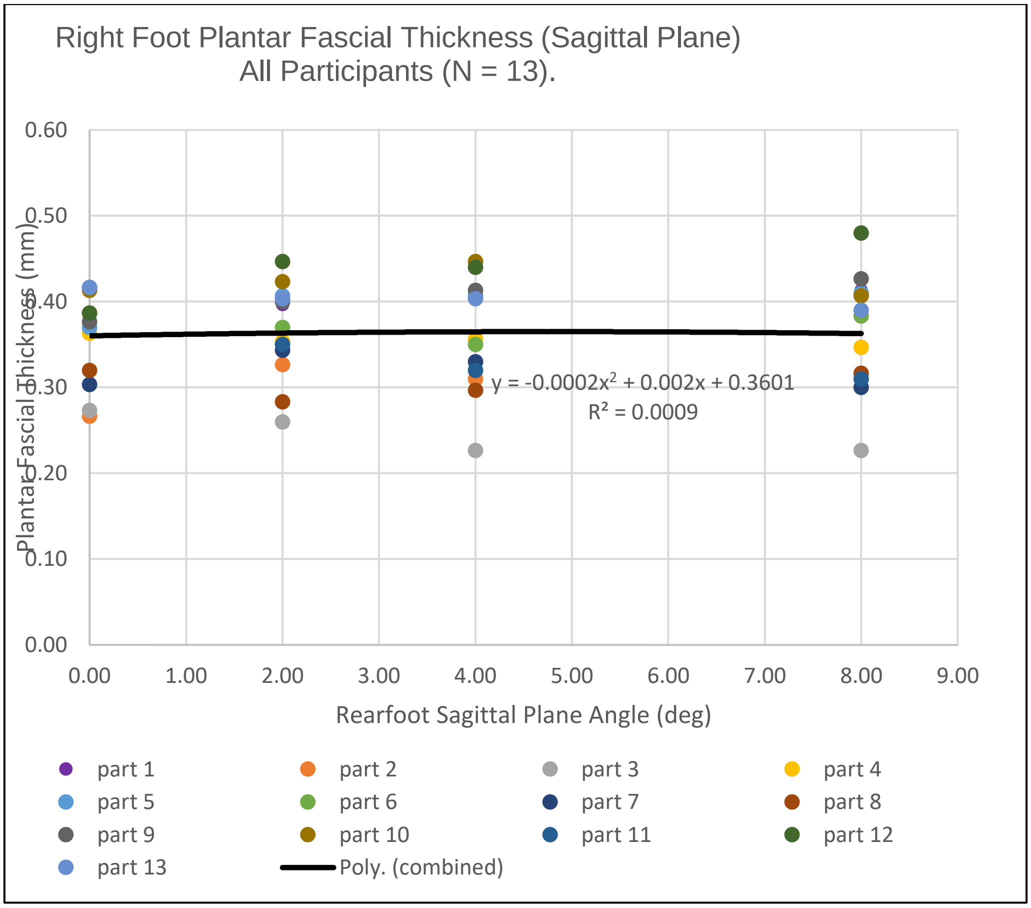


Figure 38: Right Foot PFT in Sagittal Plane For All Participants.

The total group analysis showed no polynomial (order 2) (r^2 = *.009*) for right foot PFT with the sagittal plane angle. When a manual cluster analysis was performed it showed that 8 (1,2,4,5,6,8,9,12) of the 13 (61.5%) had a PFT increase as the sagittal angle increased. One participant (10) had a flat relationship (7.7%) and 4 (3,7,11,13) had an inverse relationship (30.8%) where the thickness decreased as the sagittal plane angle increased.

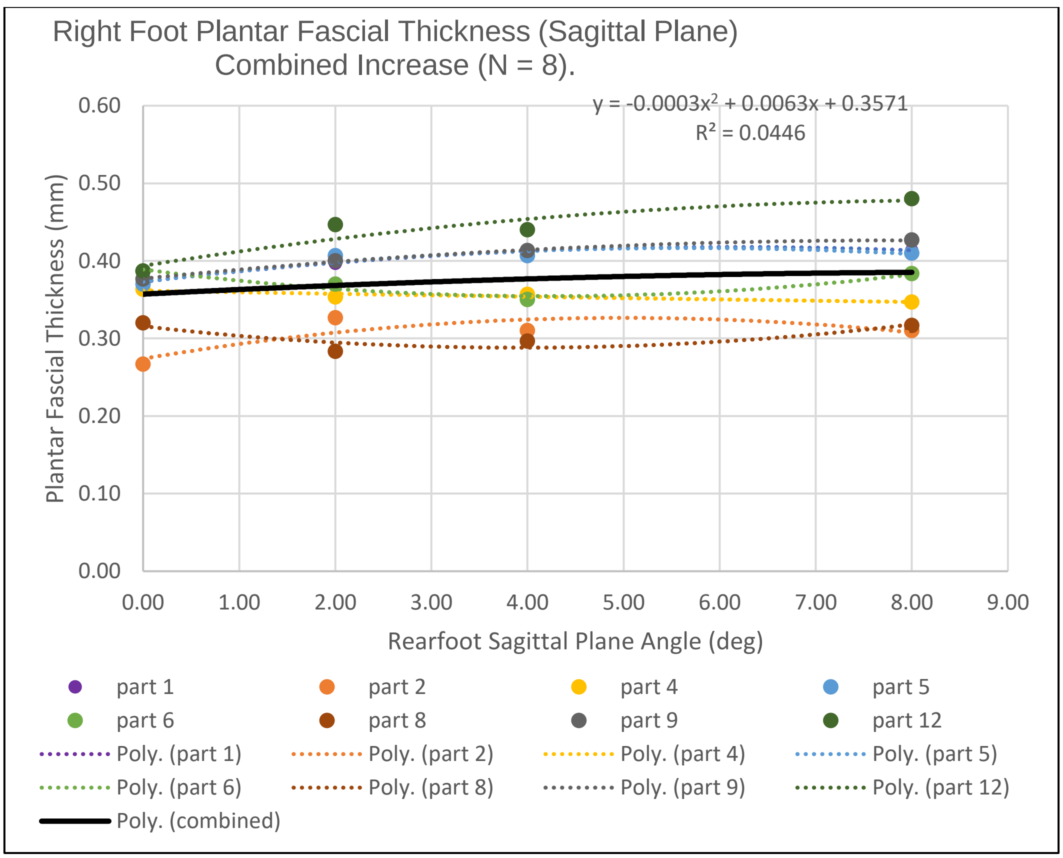


Figure 39: Right Foot PFT in Frontal Plane For Increase Cluster.

The increase cluster (8) showed no correlation (r^2 = *.04*) for PFT and an increase in the sagittal plane angle.

5.6.7 Right Foot PFS And Frontal Plane Angles

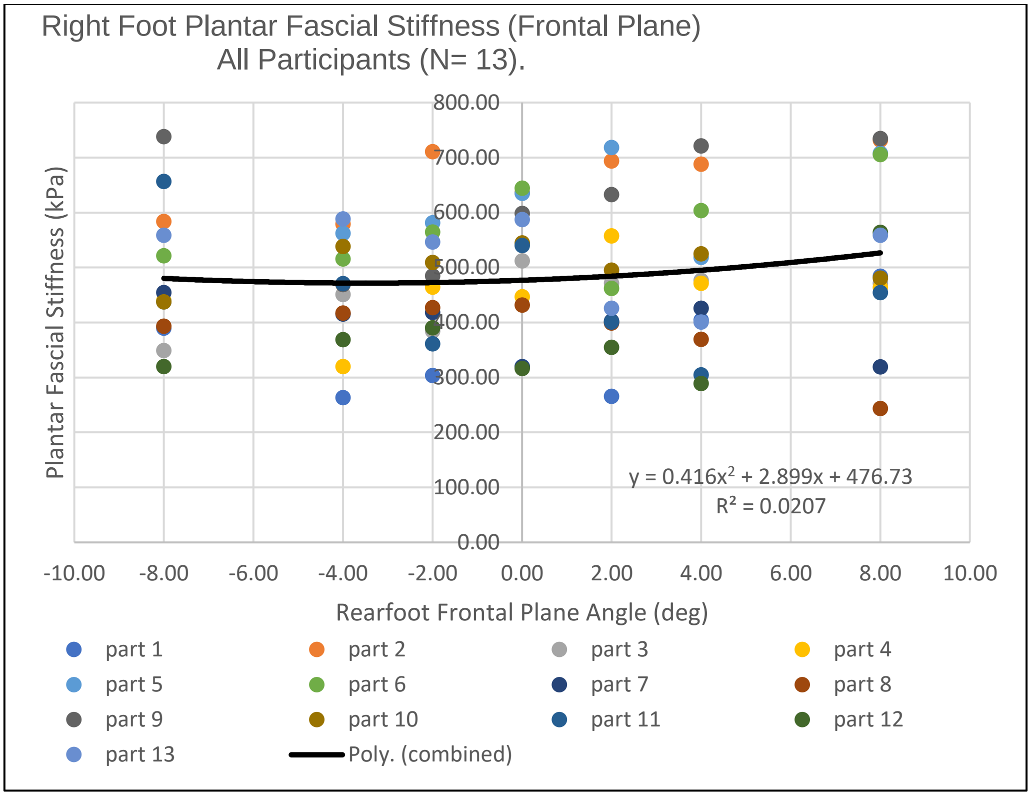


Figure 40: Right Foot PFS in Frontal Plane All Participants.

The total group analysis showed no polynomial (order 2) correlation (r^2 = *.02*) for right foot PFS with the frontal plane angle. When a manual cluster analysis was performed it showed that 10 (1,2,3,4,5,6,9,12,13) of the 13

(77%) had a PFS as the frontal plane angle changed. Three participants (7,8,10) had an inverse relationship (23%) where the stiffness decreased as the frontal plane angle changed.

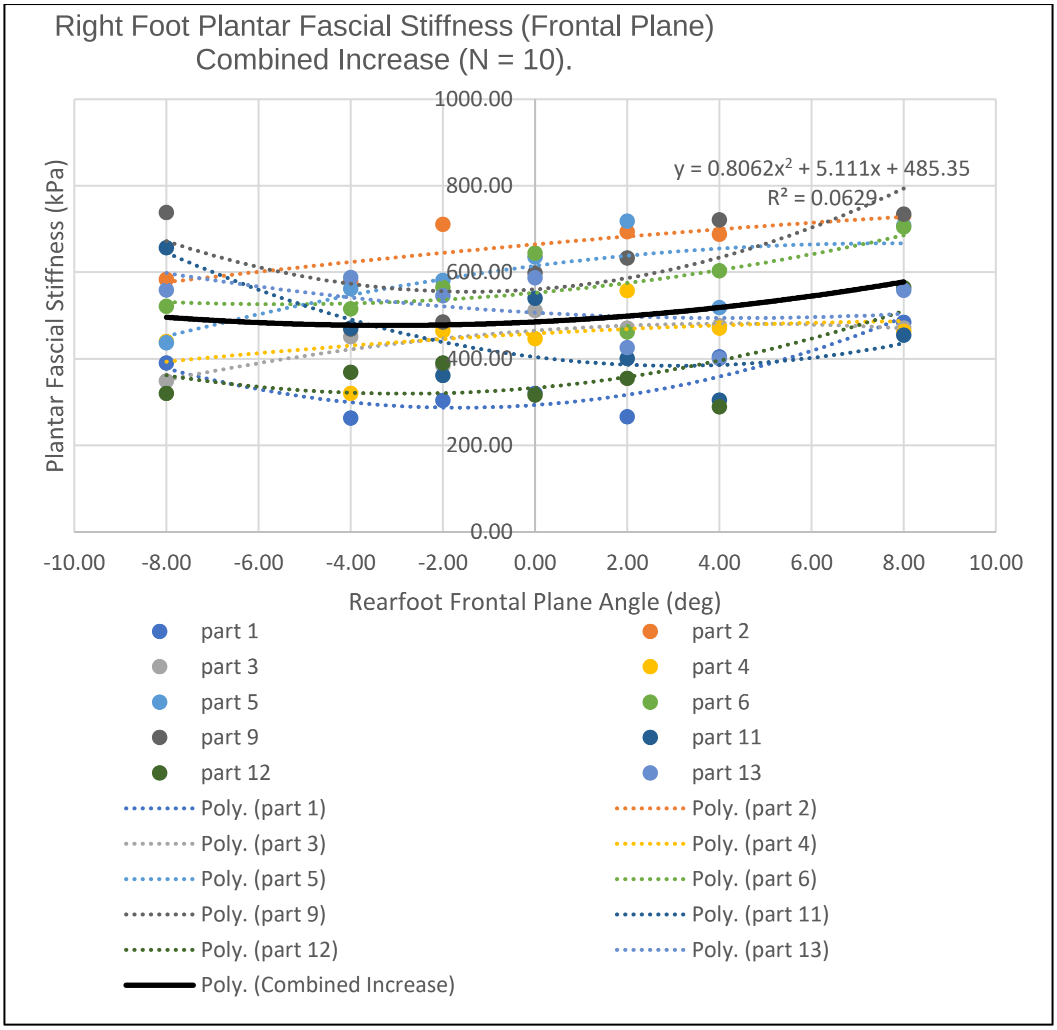


Figure 41: Right Foot PFS in Frontal Plane For Increase Cluster.

The increase cluster (10) showed no polynomial (order 2) correlation *(r^2 = .06)* for PFS and the frontal plane angle. Of the increase cluster 7 (1,2,4,5,6,9,12) of the 13 (54%) also had increased PFT in the sagittal plane and 7 (1,3,4,6,9,11,12) also an increased stiffness in the sagittal plane.

5.6.8 Right Foot PFS And Sagittal Plane Angle

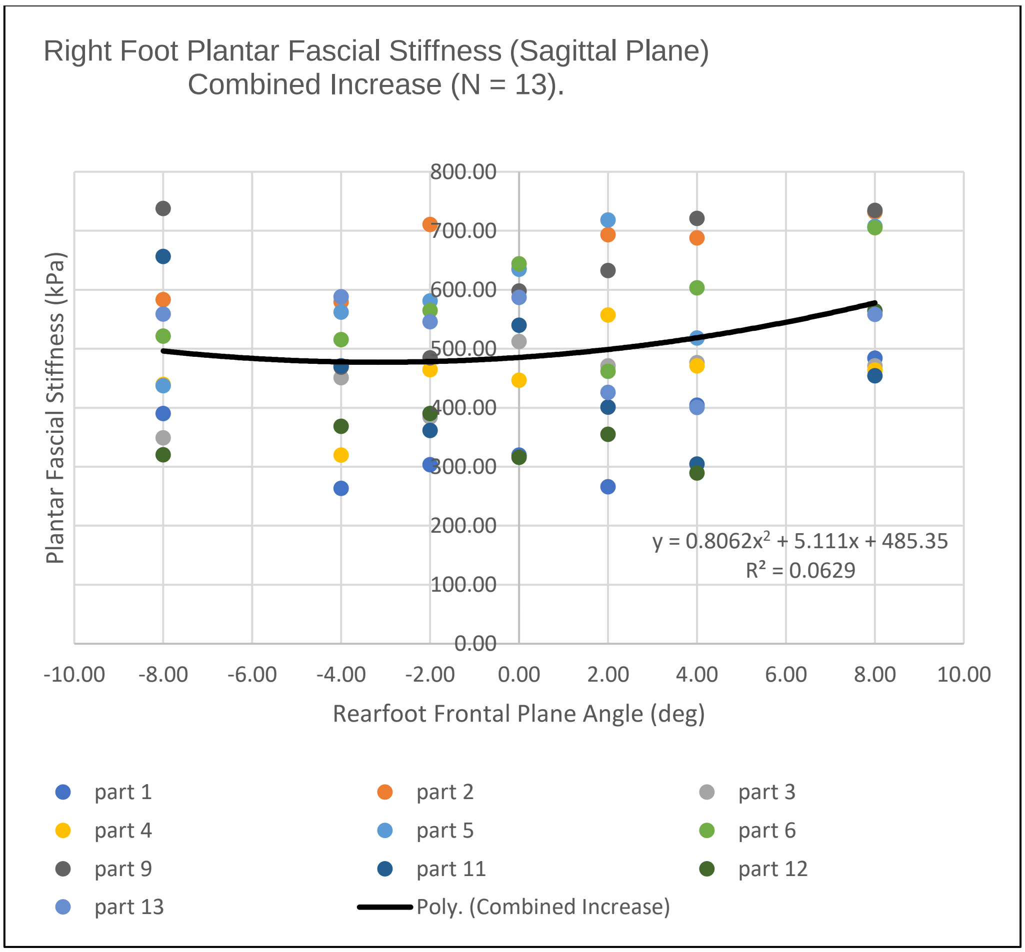


Figure 42: Right Foot PFS in Sagittal Plane All Participants.

The total group analysis showed no polynomial (order 2) correlation *(r^2 = .06)* for right foot PFS with in the sagittal plane. When a manual cluster analysis was performed it showed that 10 (1,3,4,6,7,8,9,10,11,12) of the 13 (77%) had an increased PFS as the sagittal plane angle increased. Three participants (,2,5,13) had an inverse relationship (23%) where the stiffness decreased as the sagittal plane increased.

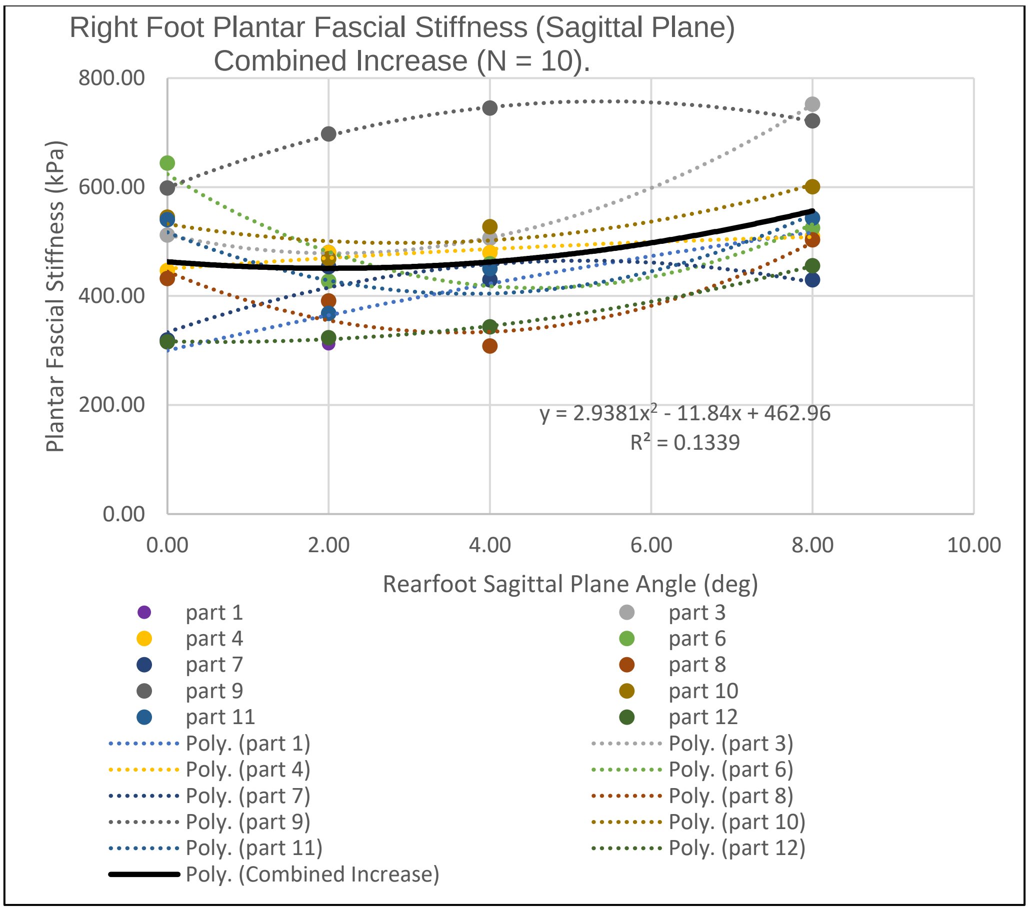


Figure 43: Right Foot PFS in Frontal Plane Increase Cluster.

The increase cluster (10) showed weak polynomial (order 2) correlation ($r^2 = .13$) for PFS and the sagittal plane angle. The increase cluster also showed that 6 (1,4,6,8,9,12) had an increased PFT in the sagittal plane but only 3 (7,10,12) had and increased PFT in the frontal.

5.7 Summary Of Manual Group Analysis and Trends

The trends for both feet in the frontal plane can be summarised in Table 55 which shows the relationship of the PFT and PFS to each other. The individuals with a flat or minimal change are not shown.

Table 55: Summary of Frontal Plane Trends.

Frontal Plane	> PFT	< PFT	> PFS	< PFS	>PFT & > PFS	>PFT & < PFS	< PFT & > PFS	< PFT & < PFS
Left	1,2,3,4, 5,13	7,8,10, 11,12	1,2,7	3,4,5, 6,11,13	1,2	3,4, 5,13	7	11
Right	2,7,10, 12,13	3,8,11	1,2,3,4, 5,6, 9,11, 12,13	7,8,10	2,12, 13	7,10	3,11	8
Total (N = 26)	11 (42%)	8 (31%)	13 (50%)	9 (35%)	5 (19%)	6 (23%)	3 (11%)	2 (8%)

This shows that there was more increased PFT and PFS with the frontal plane angle changes. The overall assessment shows that there is equal increased (19%) and decreased (23%) PFS with increased PFT.

The trends for both feet in the sagittal plane can be summarised in Table 56 which shows the relationship of the PFT and PFS to each other. The individuals with a flat or minimal change are not shown.

Table 56: Summary of Sagittal Plane Trends.

Sagittal Plane	> PFT	< PFT	> PFS	< PFS	>PFT & > PFS	>PFT & < PFS	< PFT & > PFS	< PFT & < PFS
Left	1,2,4, 5,6	3,7,8, 11,13	1,2,4, 5,7,8, 10,12,13	3,6, 9,11	1,2,4,5	6	7,8,13	3,11
Right	1,2,4, 5,6, 8,9,12	3,7, 11,13	1,3,4, 6,7,8, 9,10, 11,12	2,5,13	1,4,6, 8,9,12	2,4	3,7,11	13
Total (N = 26)	13 (50%)	9 (35%)	19 (73%)	7 (27%)	10 (38%)	3 (11%)	6 (23%)	3 (11%)

This shows that the strong trend towards increasing PFT and PFS as the sagittal plane increases. The increased PFT also shows an increased PFS for a large percentage of the group (38%), and with moderate decrease in PFT with increased PFS (23%).

5.8 Cluster Analysis

5.8.1 All Variable Analysis

To support the manual group analysis of the trends a Two-Step cluster analysis was performed for all variables of participant, BMI, weight, height, age, PFT, PFS, sagittal plane angle and frontal plane angle. The noise handling was set to 25% which removes outliers that do not fit the cluster features tree.

The initial analysis for all variables produced a 4 tree cluster with fair to good measures (*0.4*) of cohesion and separation (Figure 44).

Model Summary

Algorithm	TwoStep
Inputs	9
Clusters	4

Cluster Quality

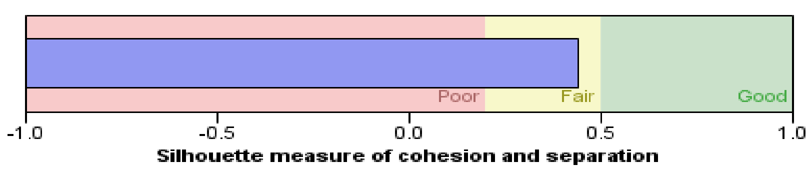
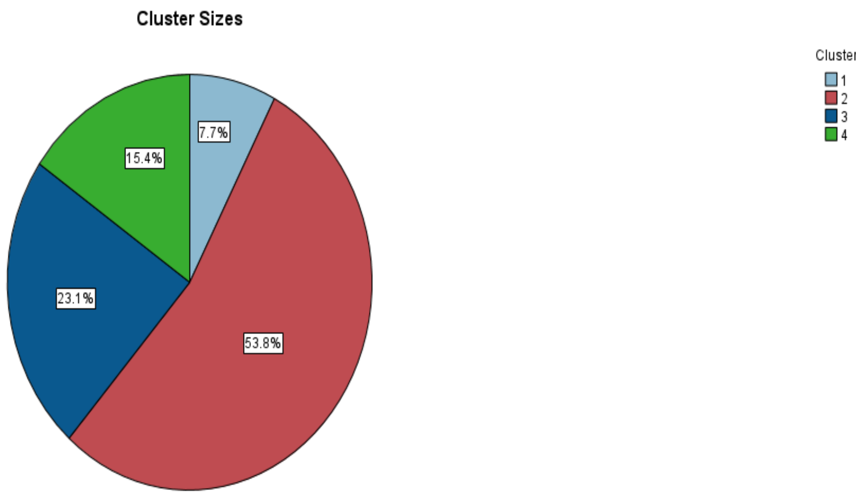


Figure 44: Initial Cluster Analysis (All variables).

The cluster sizes was dominated by cluster 2 (53.8%) with cluster 3 (23.1%), cluster 4 (15.4%) and cluster 1 (7.7%) having a lesser impact.



Size of Smallest Cluster	20 (7.7%)
Size of Largest Cluster	140 (53.8%)
Ratio of Sizes: Largest Cluster to Smallest Cluster	7.00

Figure 45: Breakdown Of Clusters (All Variables).

The main predictor of the cluster grouping was BMI (1.00) with weight (.85), age (.63), participant (.46), height (.23), PFT (.12) and PFS (.04) have a diminishing level of importance (Figure 46).

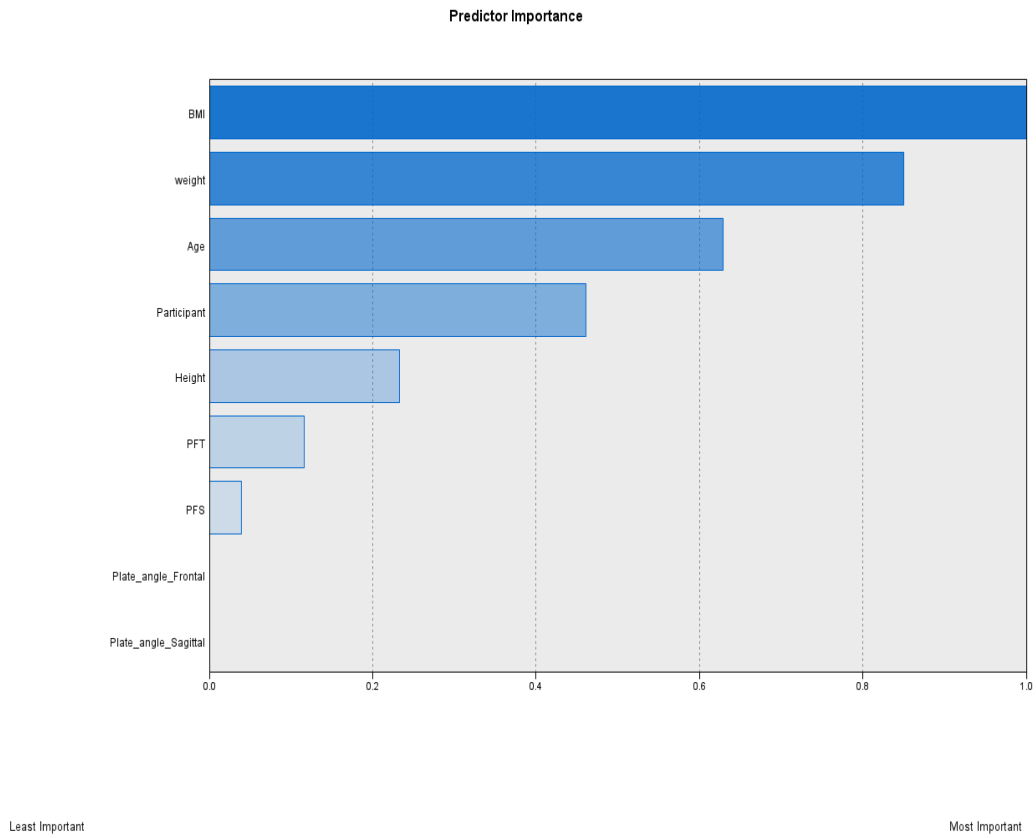


Figure 46: Predictor Importance (All Variables).

5.8.2 PFT, PFS, Rearfoot Frontal Plane Angle and Sagittal Plane Angle Cluster Analysis

5.8.2.1 Frontal Plane

A further Two-Step Cluster analysis was performed to establish the relationship of the PFT, PFS and the frontal plane angle of the rearfoot for both feet. This produced 3 clusters: Cluster 1 (30%), Cluster 2 (45.8%) and Cluster 3 (24.2%) with a cluster quality of fair (*0.4*) (Figure 47).

The most important predictor was PFS (1.0) and PFT (0.59) with the Frontal plane angle (0.05).

Clusters

Input (Predictor) Importance

1.0 0.8 0.6 0.4 0.2 0.0

Cluster	2	1	3
Label			
Description			
Size	45.8% (119)	30.0% (78)	24.2% (63)
Inputs	PFS 477.32	PFS 400.16	PFS 680.72
	PFT 0.40	PFT 0.29	PFT 0.34
	Plate_angle_Frontal 0.82	Plate_angle_Frontal -1.31	Plate_angle_Frontal 0.06

Figure 47: Cluster Breakdown for Frontal Plane, PFS and PFT.

The cluster breakdown analysis (Figures 48, 49, 50) showed that cluster 1 negative frontal plane angles (*mean = -1.31*) gave decreased values for PFS (*Mean = 400.16*) and PFT (*Mean = .29*).

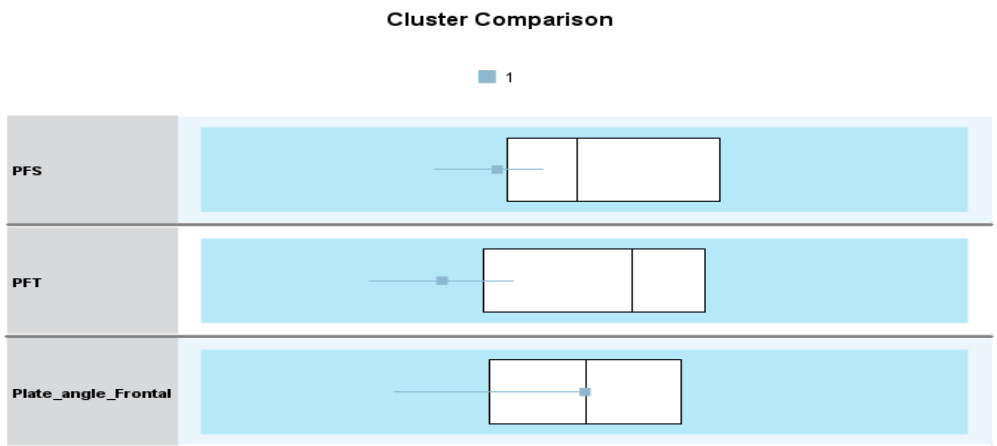


Figure 48: Cluster 1. Frontal Plane Grouping.

Cluster 2 showed positive values for frontal plane angle (*Mean = .82*) with increased PFS (*Mean = 477.32*) but little change in the PFT (*Mean = .4*).

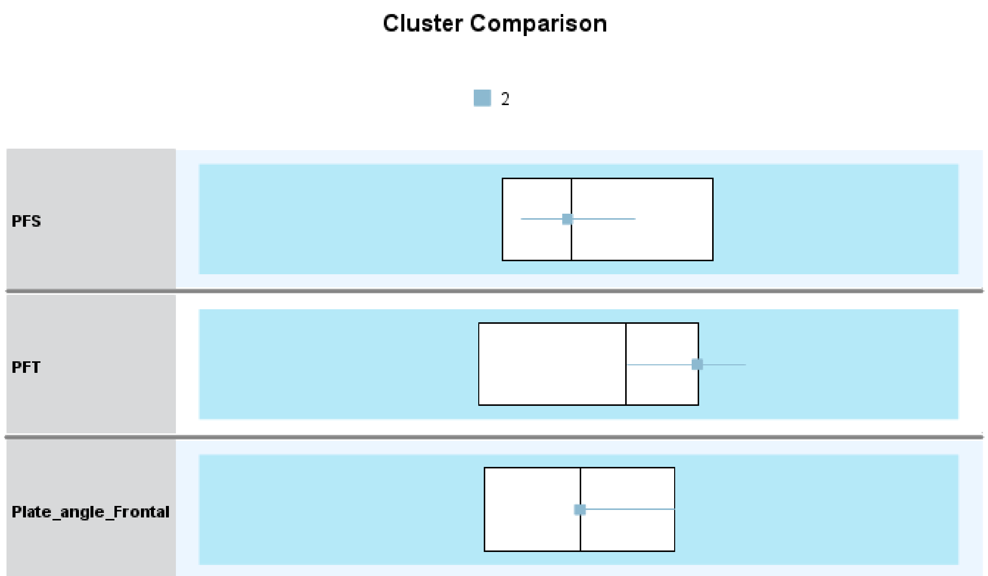


Figure 49: Cluster 2. Frontal Plane.

Cluster 3 showed a neutral frontal plane angle (*Mean* = *.06*) with large increase in PFS (*Mean* = *680.72*) and reduced PFT (*Mean* = *.34*).

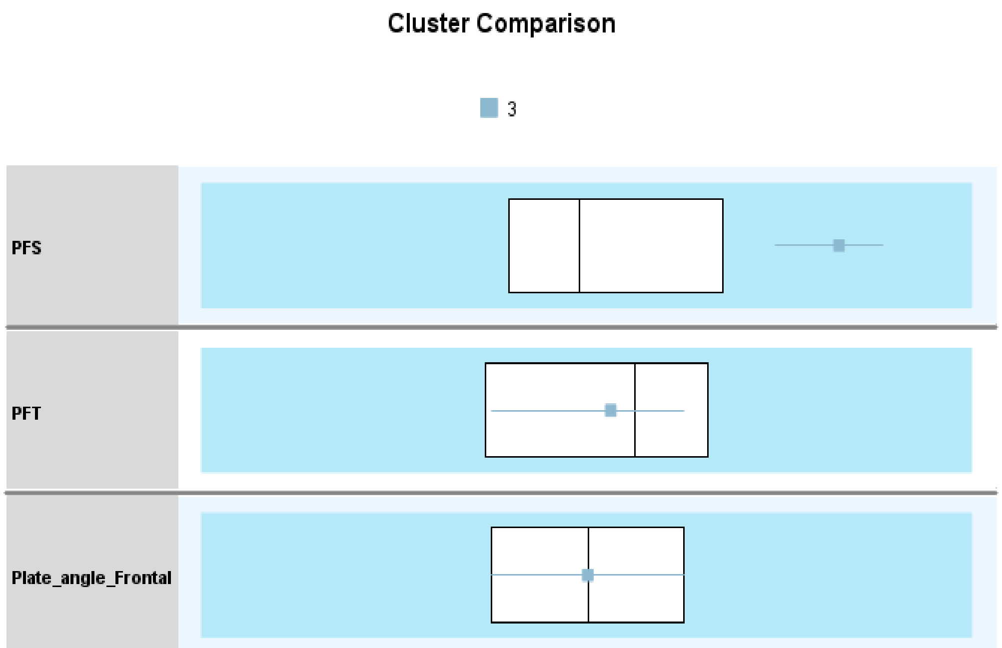


Figure 50: Cluster 3. Frontal Plane.

5.8.2.2 Sagittal Plane

A further Two-Step Cluster analysis was performed to establish the relationship of the PFT, PFS and the sagittal plane angle of the rearfoot for both feet using the automatic facility of SPSS (IBM Corp., 2020). This produced 5 clusters: Cluster 1 (11.5%), Cluster 2 (24.2%), Cluster 3

(36.9%), Cluster 4 (17.3%) and Cluster 5 (10%) with a cluster quality of fair (*0.4*) (Figure 51).

Clusters

Input (Predictor) Importance

1.0 0.8 0.6 0.4 0.2 0.0

Cluster	3	2	4	1	5
Label					
Description					
Size	36.9% (96)	24.2% (63)	17.3% (45)	11.5% (30)	10.0% (26)
Inputs	Plate_angle_Sagittal 0.81	Plate_angle_Sagittal 0.79	Plate_angle_Sagittal 0.53	Plate_angle_Sagittal 0.13	Plate_angle_Sagittal 8.00
	PFS 480.21	PFS 487.85	PFS 685.36	PFS 301.47	PFS 545.35
	PFT 0.40	PFT 0.27	PFT 0.38	PFT 0.35	PFT 0.36

Figure 51: Cluster Breakdown for Sagittal Plane, PFS and PFT.

The most important predictor was sagittal plane angle (1.0) and PFS (0.73) with the PFT (0.61).

The Cluster analysis shows that in cluster 1 a sagittal plane angle of zero degrees (*Mean* = *.13*) has a reduced PFS (*Mean* = *301.47*) and PFT (*Mean* = *.35*).

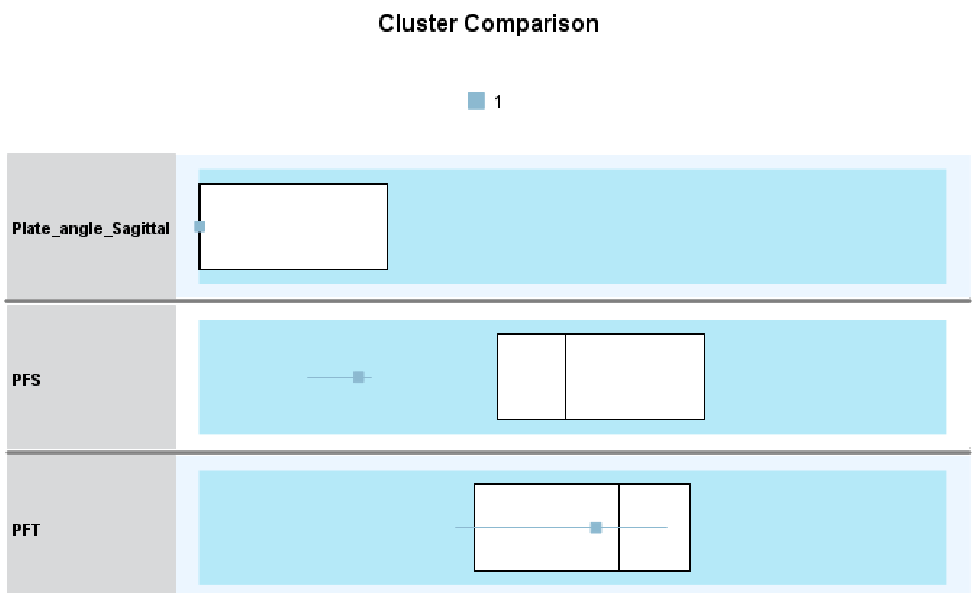


Figure 52: Cluster 1. Sagittal Plane.

Cluster 2 shows that the sagittal plane is almost at zero with a reduced PFS (*Mean = 487.85*) and a greater reduced PFT (*Mean = .27*).

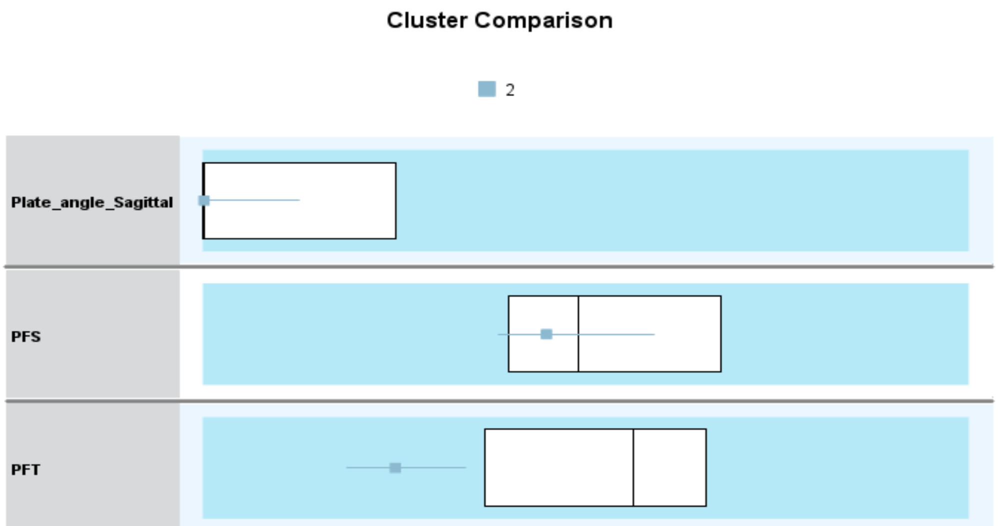


Figure 53: Cluster 2. Sagittal Plane.

Cluster 3 also shows a low sagittal plane angle (*Mean* = *.81*) with PFS only slightly reduced (*Mean* = *480.21*) but much greater PFT (*Mean* = *.40*).

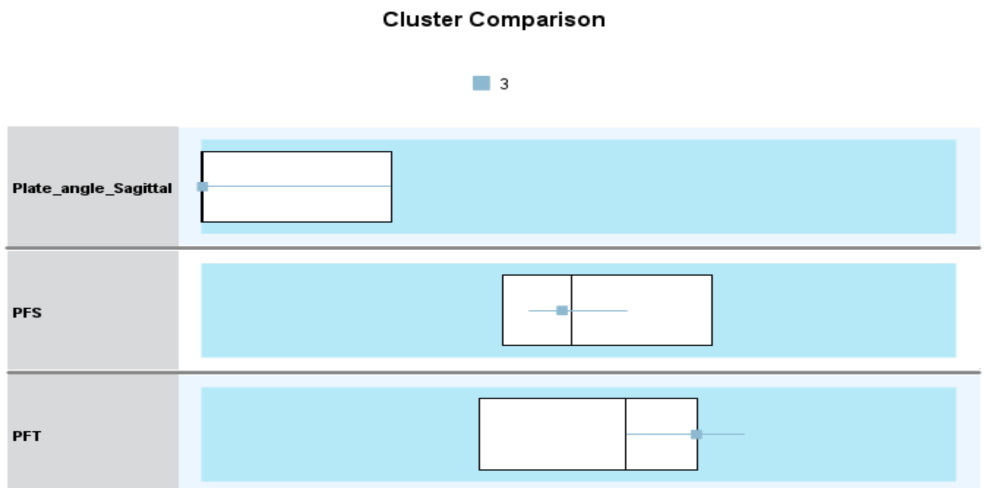


Figure 54: Cluster 3. Sagittal Plane.

Cluster 4 also has a low sagittal plane angle (*Mean* = *.53*) but demonstrates a greater PFS (*Mean* = *685.36*) and PFT (*Mean* = *.38*).

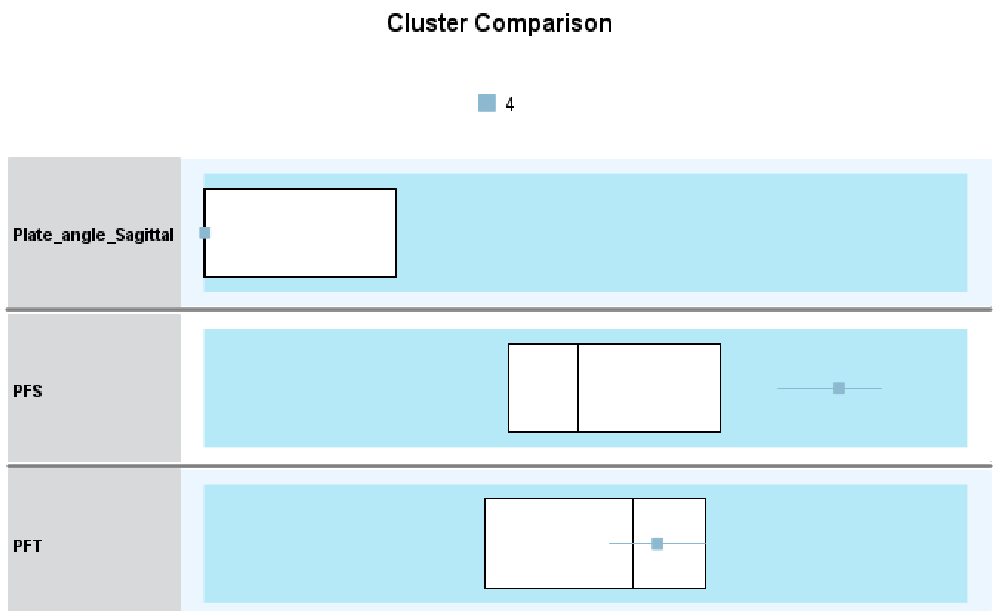


Figure 55: Cluster 4. Sagittal Plane

Cluster 5 demonstrated maximum sagittal plane angle (*Mean = 8.0*) with increased PFS (*Mean = 545.35*) and PFT (*Mean = .36*).

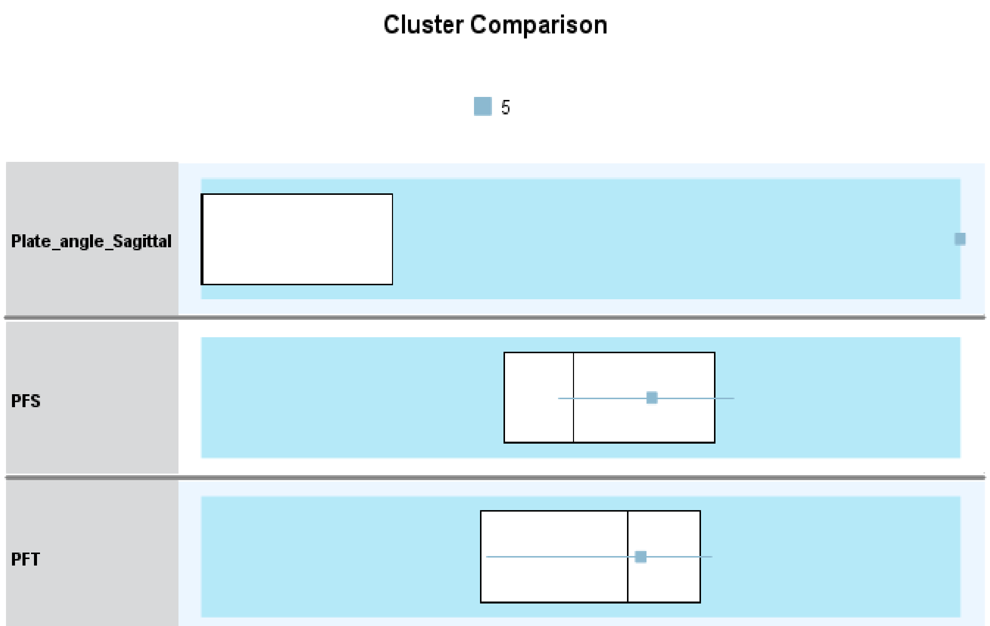


Figure 56: Cluster 5. Sagittal Plane.

When the Two-Step analysis was restricted to 3 clusters it also produced the same results as the automatically generated 5 cluster groups. However, this cluster analysis showed Cluster 1 (34.2%), Cluster 2 (55.8%) and Cluster 3 (10%) with a cluster quality of fair to good (*0.5*).

These clusters also had a similar pattern to the 5 cluster analysis with cluster 1 having low sagittal plane angle (*Mean* = *.61*) and reduced PFT (*Mean* = *.29*) and PFS (*Mean* = *443.18*).

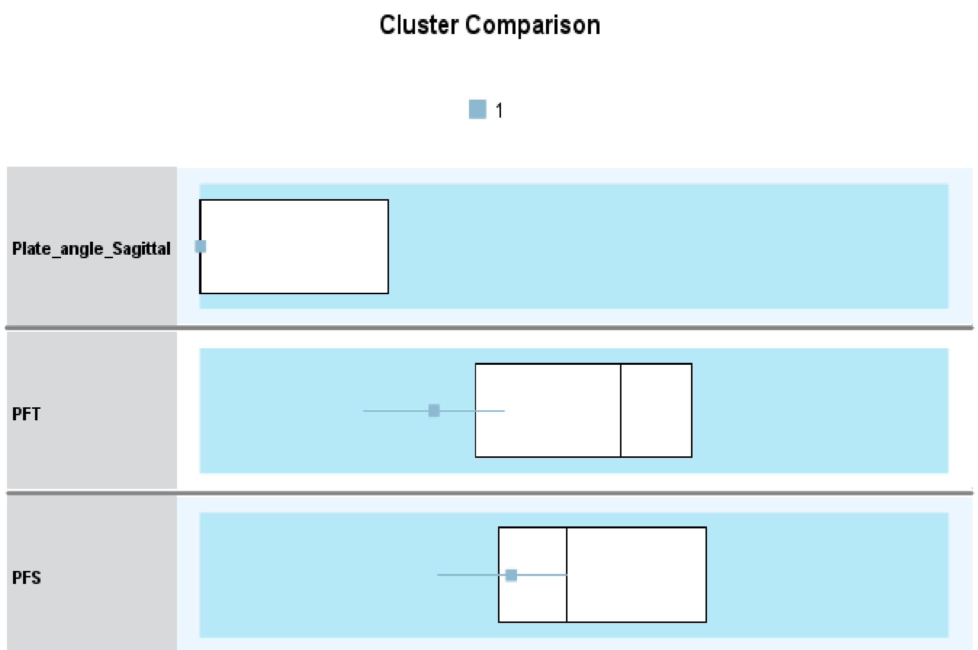


Figure 57: Cluster 1. Sagittal Plane - 3 cluster analysis.

Cluster 2 also shows a low sagittal plane angle (*Mean* = *.70*) with increased PFT (*Mean* = *.39*) and PFS (*Mean* = *532.94*).

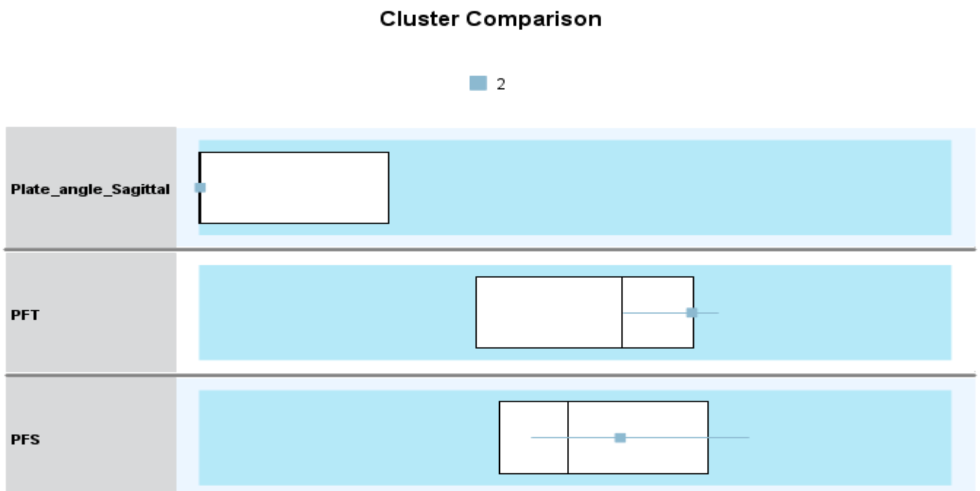


Figure 58: Cluster 2. Sagittal Plane - 3 cluster analysis.

Cluster 3 also shows a similar pattern with the Increased Sagittal plane angle (*Mean = 8.00*) with increased PFT (*Mean = .36*) and PFS (*Mean = 545.35)*.

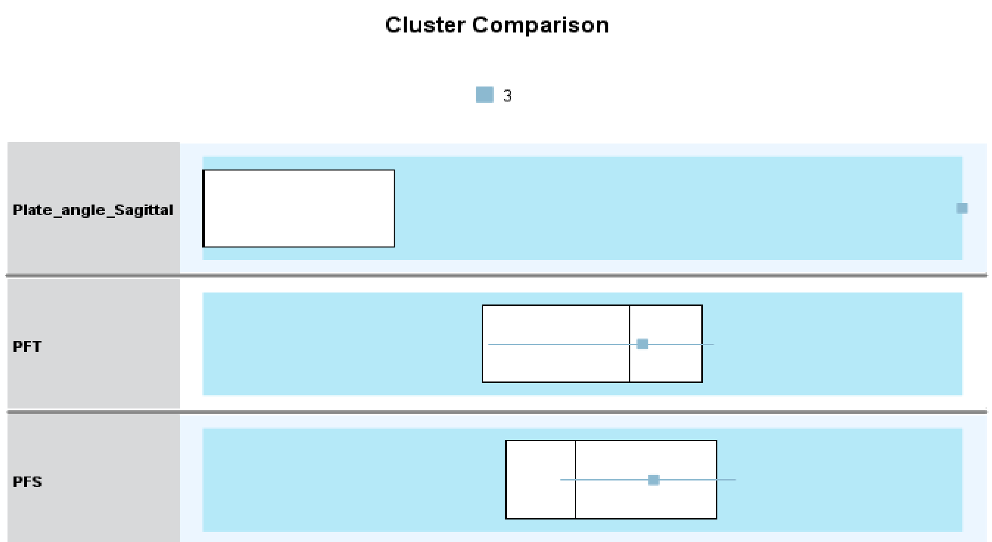


Figure 59: Cluster 3. Sagittal Plane - 3 cluster analysis.

Therefore, this 3 cluster analysis shows that 65.8% of the sagittal plane group have an increased PFT and PFS with only 10% demonstrating this with an increased sagittal plane angle.

5.9 Summary of Results

5.9.1 Objective 1

The angle moved by the platform matched the angle found on the angle finder in the frontal and sagittal planes.

5.9.2 Objective 2

1. The pilot data suggested a relationship between rearfoot angle and PFT and PFS.

2. The PFT and PFS data showed variable data on repeated measures.

3. Variable data from pilot to study data.

4. The protocol showed repeatable and reliable data using the suggested technique.

5. The flexible probe showed strong correlation for a change in rearfoot angle and PFT and PFS and was slightly better correlation than the fixed probe.

5.9.3 Objective 3

1. The data for analysis was normally distributed.

2. The range of PFT was .2 to .5 with a mean .34 (.07) in the left and .0 to .51 mean .36 (.06) for the right.

3. The range of PFS was Left 24.5 to 800 KPa, mean 508.92 (SD 108.76) and Right 67.1 to 800 KPa, mean 489.89 (SD99.17).

4. Parametric analysis of the data showed no significant relationships for PFT, PFS and rearfoot angles.

5. Individual analysis shows that some participants show strong correlations for PFT, PFS and rearfoot angles.

6. Two-Step Cluster analysis shows that BMI and age were the main predictors of PFT and PFS. It also shows that the PFT and PFS both increased in some participants with a low sagittal plane angle.

Chapter 6. Discussion

6.1 Introduction to Discussion

This study’s main aim was to assess if a change in the rearfoot position had an effect on the thickness and stiffness of the plantar fascia of the foot. From the literature, the PF has been shown to have a unique structure and function which can be influenced by the position or function of the foot (Granado et al., 2018; Lee et al., 2010; Wearing et al., 2007, 2004; J. Zhang et al., 2018). However, the function of the foot is complicated, and previous studies have only assessed the foot indices or provided poor standardised control, in investigating the PF responses. Furthermore, all of the responses of the PF being assessed by variable ultrasound protocols with non-weight bearing static assessments. In order to answer the main developed research question, a number of other objectives needed to be achieved. For clarity, the objectives are discussed singularly with the strengths and weakness of the objective explored in each section before a final combined discussion is given.

6.2 The Sample

The sample selected for the main study was from volunteers within Staffordshire University, but the accessibility to a sample population was limited due to the SARS-2 Covid 19 pandemic, which had restricted the access of staff and students to the University. However, the sample of 13 participants (26 feet) did meet the requirements of the power analysis which required 12 participants or 24 feet. The Shapiro-Wilk test for normality was undertaken with SPSS 27 (IBM Corp., 2020) and showed all variables were normally distributed.

6.2.1 Strengths And Weakness Of Sample

The sample was an enforced opportunistic sample because of the UK government restrictions for Universities in place at the time of the study. However, whilst the sample was not a random selection and lacks external validity, it was normally distributed and met the power requirements for the study. Unfortunately, the effect size was not known prior to the study as no previous study could be found that had compared the movement of the rearfoot and the effects on the weight-bearing plantar fascia, and therefore, had to be estimated. This could be argued was a weakness to the study but was based on effect size recommendations (Durlak, 2009). Therefore, the opportunistic sample selection cannot be generalised to the population, but it is a convenient and cost effective method that was enforced upon the study design. However, the sample was subject to exclusion criteria and given the normal distribution for age, height, weight, BMI and power of the study, it was felt that the sample met the study requirements.

6.3 Objective 1

The first objective was to establish if a rearfoot platform (Dynastat) could be built that would be able to withstand the body weight (load) and accurately move the rearfoot through a range of angles in the frontal and sagittal planes. The results of objective one showed that the Dynastat was able to move the rearfoot through the range of required motion, and that there was no significant difference between the recorded angle in the frontal and sagittal planes on the Dynastat software, and the angle recorded by the angle finder. This was confirmed by an intraclass correlation coefficient of 1.00 with a 95% confidence.

The ability of the Dynastat to measure the frontal and sagittal plane angles accurately and reliably, in a closed chain position, will allow the assessment of the rearfoot through a biaxial axis, with three-degrees of freedom. This is a unique feature not found on any known clinical foot assessment devices. This allows the production of a new unparalleled vector description for the rearfoot position given that it can produce a sagittal plane and frontal plane co-ordinate for rearfoot positioning. This could lead to the further development of 3D printed orthosis from foot scans, and the unique combining of the sagittal and frontal plane angulations. Thus, combining, or in part unifying, the theoretical elements of MASS Theory, Sagittal Plane Facilitation Theory and Subtalar Joint Neutral Theory (Glaser & Fleming, 2016; K. Kirby, 2006; Root, Orien, & Weed, 1977).

Since the early work of Root et al (1977), in which they developed the theory of normalcy, and described a subtalar joint (STJ) axis in a three dimensional orientation with a suggested STJ neutral position, a number of people have agreed that the axis passes through the medial head of the talus from the plantar lateral side of the calcaneus (Jones, 1945). A number of techniques have been developed to try to assess, or quantify, the position of the STJ axis which could have substantial clinical benefits in allowing better control of the rearfoot motion. The STJ movement and axis of rotation are complex with extensive debate in the literature. The anatomy of the STJ presents with a large posterior convex calcaneal facet with the concave talar facet, and anteriorly the talus rests on the anterior and middle facts of the calcaneus and the navicular (Krähenbühl, Horn-Lang, Hintermann, & Knupp, 2017). This anatomical manifestation results in a complex motion around a variable axis. This was supported by Cho, Kwak, and Kim (2014) who also attributes the variations in STJ axis to the variations in the shape of the bones forming the joint. This was further demonstrated in a cadaver study which showed half the sample had a very different type of motion at the STJ to the other half of the sample (Stiehl, 1991). However, the STJ axis was still given at an average of "42^{o} in the sagittal plane and 23^{o} medial deviation in the axial plane" (Krähenbühl et al., 2017). Although, more current research has suggested that the STJ axis is not singular but a number of discrete axis of rotation (Kirby, 2001). Therefore, the ability to locate the "STJ axis" will help clinicians develop treatment programmes around this axial position to improve the rearfoot function in pathological conditions. To expand this, the ability to locate the STJ axis means that a more measured assessment of the torque effect of the ground reaction forces about the axis can be achieved. This would necessitate the use of both the rearfoot and forefoot platforms and the pressure plate system found on the full Dynastat system. Additionally, this would allow the loading of the 4th metatarsal to be evaluated at the maximum ranges of pronation and supination of the foot, and then quantification of the loading related to sub-talar and mid-tarsal joint positions. Thus, by the application of the principle of the tissue stress model will allow the construction of a more directed, and hopefully, effective orthotic therapy (McPoil & Hunt, 1995) .

Currently, the most familiar method of STJ axis localisation is a palpation technique extrapolated from the location and rotational equilibrium theory proposed by Kirby (2001), and is claimed as a reliable and valid clinical tool. Moreover, greater experience in performing the palpation technique has a positive influence on the accuracy of the STJ axis determination. In the context of evidence-based practice, this technique could be a standard tool in the examination of patients with lower-limb-related pathologic disorders as it allows the clinician to consider the placement of appropriate posts in relation to the axis of motion (De Schepper et al., 2012; Van Alsenoy, D'Aoû t, Vereecke, De Schepper, & Santos, 2014; Van Alsenoy, De Schepper, Santos, Vereecke, & D'Août, 2014).

However, whilst the clinical palpation technique may be reliable, the interpretation has been considered weak (De Schepper et al., 2012).

Therefore, a combination of this axial palpation technique, or similar techniques, with the ability to utilise the Dynastat to manipulate the foot within a biaxial axis could provide improve localisation of the true or functional STJ axis, as suggested above. Spooner and Kirby (2006) have developed a device that has attempted to track the spatial location of the STJ axis during closed chain movements. However, in their study they report the use of incremental frontal plane wedges under the rearfoot to reposition the STJ axis which effectively mimics a very small element of the range of functions of the Dynastat rearfoot platform or full system.

6.3.1 Strengths And Weakness Objective 1

The results have demonstrated that the rearfoot platform was a reliable and repeatable method of the assessment of rearfoot function and was key to the success of this study.

The ability to identify the “normal” weight-bearing rearfoot position, or to place the rearfoot in a position, considered by the clinician to represent the best functional position, on a device with reliable and repeatable measurements could quantify the “dose” of the orthosis prescription (Telfer et al., 2013). Thus, eliminating one of the major issues in clinical practice of bespoke orthosis production and research variables, and supporting the suggestion of Searle et al. (2018), that the weight-bearing position of the foot reflected the best assessment process. It also further eliminates the errors in the reliability and repeatability of goniometric measures found by Menz (1995) and Menadue et al. (2006).

Whilst the results demonstrate that the platform was able to reliably move to a given position, this does not necessarily mean that the foot actually moved to the same extent. As the starting position of the foot is not known it is possible that the foot may have been at its, or close to, end range of motion, and thus, not reflective of the true foot position. This may account for some of the different clusters produced in the cluster analysis.

6.4 Objective 2

The second objective was to combine the platform with an ultrasound probe so that weight-bearing measurements of the plantar fascia could be taken. This was successfully achieved using a 3D printed platform with additional clamps for posterior, medial and lateral supports to hold the foot on the platform and prevent slippage. Following this, a series of test measurements were undertaken in the frontal plane to establish the reaction of the plantar fascia to planal movements of the rearfoot. The results given in Figures 14 and 15 show that there was a relationship of the plantar fascia to frontal plane movement and, although only three measurements were taken, there was a strong linear correlation with PFT ($r^2 = .96$) and PFS ($r^2 = .94$), with both thickness and stiffness increasing as the rearfoot inverted. This indicated that the PF was indeed a reactive structure to rearfoot motion with a possible linear relationship.

6.4.1 Reliability And Repeatability (Internal Validity)

The next stage of objective 2 was to establish if repeated measurements using the developed protocol (Appendix 3) produced valid data (Section

5.2.1) that could be used to answer the main research question. This would validate the protocol and methodology for use in the main study and required five sets of analysis.

The first analysis compared repeated measurements for the PFT and PFS at zero degrees (RCSP) of the platform. The coefficient of variation (CoV) was good for the PFT showing good reliability, but the PFS had a high CoV showing that the data was variable between measurements. This was not surprising given that the PF is a dynamic structure and was likely to be reacting to a number of factors, such as static balance or intrinsic muscle function. Therefore, to reduce this variation the mean of three measurements was taken.

The analysis technique for collecting the PFT and PFS data was repeated five times on one frame, selected at random, which effectively would confirm if the selection process and tracing of the ellipse for analysis was repeatable. This produced no variation in the technique with the CoV at zero across the measurements. The protocol technique was also repeated on five separate frames from one clip and also showed good CoV across the PFT and PFS. However, the standard deviation and minimum measurements for the PFS had high a CoV which shows that there was a large variability between the participants.

6.4.2 Selection Of Probe Holder

The option of a fixed or flexible probe holder was also considered and assessed as part of objective 2. The results in Table 13 and Figures 17 and 18, showed that the PFS had a curvilinear relationship (polynomial, order 2) to the change in rearfoot frontal angle with increasing PFS with maximum rearfoot eversion (-8) and inversion (+8). The correlation was greater for the flexible probe ($r^2 = .94$) than the fixed probe ($r^2 = .79$) using a polynomial line of best fit, and consequently, it was selected for use in the main study. However, an independent t-test did not show any significant difference between the two groups of data for PFS in the frontal plane.

A similar result was obtained for the PFT with the flexible probe holder again having a higher correlation ($r^2 = .84$) than the fixed probe holder ($r^2 = .65$). The independent t-test also showed no significant difference between the PFT and the fixed or flexible probe.

The flexible probe holder was chosen for the main study given the high correlation values for PFT and PFS.

6.4.3 Comparison of Pilot and Study Data

The next stage of the study was a retro-investigation to assess if there was any comparison of the pilot data and data from the main study. The same participant was used for both assessments using the same protocol, but they were taken on different days. The data (Figures 19, 20, 21 & 22) were different for the pilot study and the main study data but the polynomial correlations for both pilot and study data were very strong in the sagittal plane for PFT ($r^2 = 1$) and PFS ($r^2 = 1$), with PFS also having very strong polynomial (order 2) correlations in the frontal plane ($r^2 = .94$). The PFT showed strong polynomial (order 2) correlation in the pilot data ($r^2 = .84$) but moderate polynomial (order 2) correlation in the study data ($r^2 = .28$). The overall difference in the PFT between both studies was 1.1mm (*study mean = .29, sd = .02; pilot = .40, sd .05*) and may be accounted for by the data being taken on different days, which may have resulted in the probe location not being consistent between assessments, or subjective interpretation of the PFT.

6.4.4 Strengths And Weakness Objective 2

The initial pilot data did demonstrate a relationship of the PFT and PFS to rearfoot movement and gave the foundation to the main study. However, only three data points were taken and were too few to establish a meaningful statistical relationship.

The ability to reliably perform a closed chain ultrasound assessment of the PF was a noteworthy achievement, and no evidence of this being performed before could be found in the literature. The protocol developed for the study does show a high internal validity given the meticulous testing of the data collected and is recommended for consideration in future studies of the plantar fascia, given that it gives a repeatable and standardised process for assessment of weight-bearing plantar fascia.

The mean of the overall PFT in this study was 3.5mm and compared to the findings of other studies that reported PFT of 4, 5 or 6mm (Baur et al., 2021; McMillan et al., 2009; McNally & Shetty, 2010). This variability of PFT may be accounted for by the lack of an agreed consensus on the measurement area or standardised process for assessment.

The range of the overall PFS in this study was left 24.5 to 800 KPa (*mean = 508.92, SD = 108.76*) and right 67.1 to 800 KPa (*mean = 489.89, SD = 99.17*) which does not compare well to the findings of other researchers. However, the findings for PFS given in the literature also vary considerably between researchers from 10 KPa to 152.88 KPa (Baur et al., 2021; Gatz et al., 2020; H. Zhang et al., 2020). This would suggest that the PFS varies according to the machine used and protocol for assessment.

Although, it may be argued that the PFS in this study demonstrated saturation on some of the participants given the high values obtained. However, the protocol use did not allow for variation of the settings and may be the result of thinner fat heel fat pads, instability of the participant or the use of intrinsic foot muscles.

The reliability, sensitivity and accuracy of SWE has been established previously (Gatz et al., 2020). The protocol used in this study for the collection of SWE, assumed that the probe was held at a perpendicular angle to the PF, as the rearfoot was moved through a range of angles. However, whilst the probe was positioned against the PF according to the protocol, there was still some variability in placement of the foot. The probe holder was designed to hold it in the same relative position to the

PF to prevent any parallax error and variation in angle to the PF, but this wasn’t assessed in the study and may be a consideration in the interpretation of the results. Although, the platform was moved through a range of angles, the foot would be expected to remain at a fixed angle to the probe. However, when movement in the sagittal plane was performed it was felt that the fixed probe holder may have the potential to provide increased reaction forces, and therefore, a flexible probe would be better for the assessment.

Furthermore, the potential variability in the angle of the probe meant that the SWE data may be inaccurate. However, it is very likely that this variation angle was less than 20 degrees to the perpendicular in this study, given the range of movement of the platform and the relationship of the foot to the probe. Therefore, the data collected would show, at most, a possible variance of 1.3% and given the range of values for SWE, it was considered well within tolerance (Miyamoto et al., 2015).

Whilst the pilot data and study data varied, it was felt this was likely due to a number of variables that could not be controlled. It was felt that this would not affect the results of the main study as all data for the participants was collected at the same time and represented an opportunistic sample.

6.5 Objective 3

The purpose of objective 3 was to assess if the PFT and PFS could be quantified based on the rearfoot position, age and BMI. Extensive analysis of the data is presented in the Results (Section 5) and is discussed with reference to the literature.

6.5.1 Cluster Analysis

This study has shown that whilst no significant relationship can be seen across the sample group, there is a definitive reaction of the PFT and PFS to changes in the rearfoot position. When the individual reactions of the sample group are considered, there are very strong correlations for PFT and PFS to the changes in the rearfoot position, more so in the sagittal plane. Some of these individual results (Appendix 9) can be shown to have similar patterns and were primarily visually analysed into clusters to assess for trends in the groups.

Tables 55 and 56 show that increases in both the frontal (eversion and inversion) and sagittal plane motion, generally have stronger increases in the PFT and PFS values, compared to decreased PFT and PFS values.

Furthermore, there is an important trend showing that the PFT increased as the PFS increased in the sagittal plane. However, the frontal plane has an equal number of participants with an increased and decreased PFS compared with an increased PFT. In other words, in some clusters an increased PFT and PFS were seen and in some clusters an increased PFT had a decreased PFS.

Further cluster analysis was performed in SPSS 27 (IBM Corp., 2020) to assess or support the visual cluster trends. A Two-Step analysis was performed on all variables which supported the GLM that BMI, weight, age and height were important predictors. When further analysis was performed to cluster the frontal or sagittal plane angles with the PFS and PFT, the frontal plane angle showed a cluster of 45.8% with a decreased PFT and PFS, with no clusters showing an increased PFS and PFT. However, when the analysis was performed in the sagittal plane and restricted to 3 clusters 65.8% of the clusters showed an increased PFS with increased PFT, but only 10% demonstrated this with an increased sagittal plane angle.

The PF is a complex collagen structure which behaves in a nonaffine manner with no general theory to predict the deformation (Picu, Deogekar, & Islam, 2018). Continuum elasticity theory suggests that two parameters can be used to characterise materials: Young’s modulus and Poisson’s ratio (Jadidi, Seyyed-Allaei, Tabar, & Mashaghi, 2014). Young’s modulus has been discussed in the introduction and is a constant that describes the elastic properties of a material under tension. The Young’s modulus has been used to calculate the stiffness of the material and is proportionally related to the area and length of the PF. Therefore, it could be expected to see an increased PFS as the foot lengthened, with the “lowered arch” in eversion (-8^0) (Fraser & Hertel, 2021; Maharaj, Cresswell, & Lichtwark, 2017). However, the results show that in some clusters the PFS actually increased in both eversion and inversion and more consistently increased with increased inclination of the calcaneus in the sagittal plane. This would support the histological findings in the literature that the PF has a varied cellular composition that may have different functional roles (J. Zhang et al., 2018).

The Poisson's ratio, is the ratio of expansion along one axis to contraction along the opposite axis when a material is subjected to tensile or compressive forces (Comet, 2021). Such that it can be explained by the formula:

$$v = -\frac{de\ trans}{de\ axial}$$

ε_{trans} = transverse strain

ε_{axial} = axial strain

Furthermore , the Poisson's ratio is also related to the Young's modulus (stress strain curve) of the material, and thus, the stiffness of the PF. Therefore, the PF can present with a varied Poisson's ratio given that it may be subject to an amalgamation of possible high stress but low strain or low stress and high strain.

The normal reaction of a tissue to stretching is to become thinner (Figure 60 B) but the negative Poisson's ratio (auxetic behaviour) will demonstrate a widening of the tissue to the stretching (Figure 60 A) and is accepted by classical elastic theory (Gatt et al., 2015).

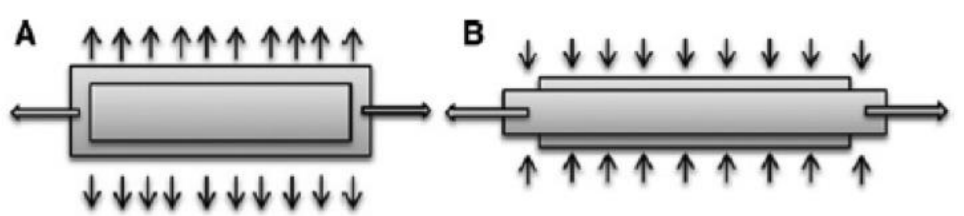


Figure 60: Auxetic and Non-Auxetic Behaviour of Materials (Comet, 2021).

This auxeticity has several benefits to tissues in that it can enhance the resistance to indentation and also the ability to form dome shaped surfaces (Evans, 1991). This ability to form a dome shape can be seen in the PF as biconvexity which presents as an extended area at the insertion, as seen by the circle in Figure 61, and it has been suggested in the literature that this finding may result in less response to tier 1 treatments that are based around mechanical support (Fleischer et al., 2015).

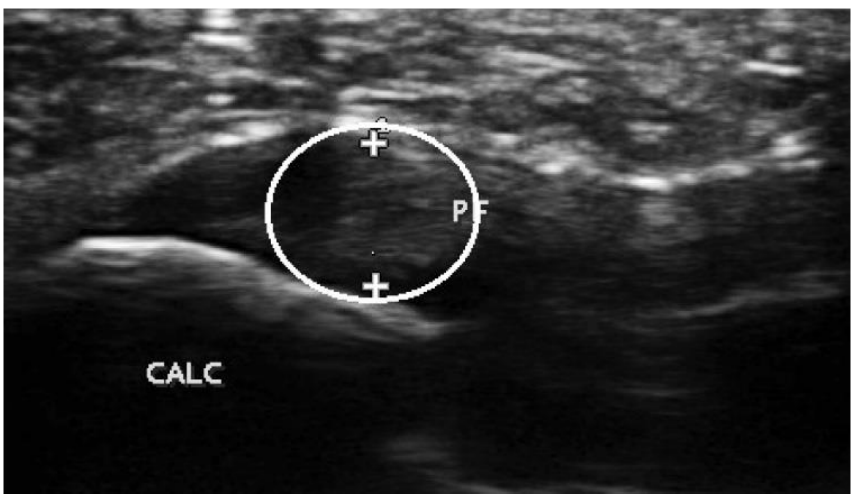


Figure 61: Biconvexity of The Plantar Fascia (Fleischer et al., 2015).

Thus, the normal Poisson's ratio would also expect the PF to become thinner as the length or strain (PFS) increased across the PF. This is seen in most of the frontal plane group trends, but a negative Poisson's ratio can be seen in 19% of this group. This is even more evident again in the sagittal plane angle where 38% of the group had an increased PFT with an increased PFS, on manual analysis, and 65.8% when subject to statistical cluster analysis. This can suggest that the PF is acting as an auxetic material, in that the PF is increasing in thickness with an increased PFS, as the rearfoot changes position, particularly with an increased inclination angle of the calcaneus. Ligaments and tendons are acknowledged to lose volume when stretched along the primary axis (Swedberg, Reese, Maas, Ellis, & Weiss, 2014) but this study has shown that this is not the case in a substantial number of participants. However, this could be argued to be due to the change in the viewed image from planal changes in the rearfoot probe position. However, the probe angle was maintained within 20 degrees, and therefore, unlikely to be greater than a 1.3% error (Miyamoto et al., 2015).

Whilst there was no direct reference for the negative Poisson’s ratio in the PF in the literature, Ostermann et al. (2020), did note that the PFT increased when subject to stretching. Therefore, they had identified but not acknowledged the negative Poisson’s ratio in the PF. Furthermore, they also concluded that the PFT was not related to perceived pain levels which was also in agreement with previous research.

This auxetic effect is dependent upon a linear, or possibly a torsional force, acting on the plantar fascia. Gefen (2003), demonstrated that the PF tension-deformation relationship is not constant throughout the gait cycle with different rates of elongation during the phases of gait. Although, the elongation of the medial arch with subtalar pronation, and the associated energy absorption and return within the PF has been questioned, this role may not fully define PF function and its relationship to the windlass mechanism (Welte, Kelly, Lichtwark, & Rainbow, 2018). Indeed, it has been suggested that the response of the PF is dependent upon the individual variation of foot structures but the cluster analysis seems to suggest that there may be "groups" of similar functioning feet (Kogler et al., 2016).

Additionally, it was also reported by Gatt et al. (2015), that the Achilles tendon also demonstrated a negative Poisson distribution. Whilst the anatomical relationship between the PF and the Achilles tendon is debated (Stecco et al., 2013), a functional relationship has been proposed by Singh et al. (2021), who also suggests an effective link between calf stretching and plantar heel pain treatment. This is supported by Cheung, Zhang and An (2006), who identified that increasing tension in the Achilles Tendon is coupled to increasing strain on the PF.

However, Stecco et al. (2013), have linked the PF more specifically to the paratendon of the Achilles Tendon, through the periosteum of the calcaneum. They also observed that little was known about the microscopic properties of the PF. This connection to the Achilles paratendon would also support the role of the PF in proprioception and peripheral motor coordination, given the presence of elastic fibres, Ruffini and Pacini corpuscles (Stecco et al., 2013).

Consequently, it could be proposed that the objective findings of PFT may well be related to the auxetic response of the PF which may have significant implications for the management of clinical presentations.

6.5.2 Plantar Fascial Response To Other Factors

There are a number of factors that may affect the Plantar Fascial response. Zhang et al. (2014) had considered the PFT and PFS relative to age and concluded that there was a difference for both variables between young and elderly participants (L. Zhang et al., 2014). A further influencing factor was the BMI of participants, and Taş et al (2017), had identified an increased PFT and decreased PFS with increased BMI. This was supported by other studies also supporting changes in PFT and body weight (Frey & Zamora, 2007; van Leeuwen et al., 2016). However, in this study the statistical analysis using ANOVA or t tests, did not show any significant relationship between the age and BMI of the participant and the PFT and PFS in the OGS or RCSP groups. However, the linear statistics used did not assume multiple modelling of the covariates, and Automatic Linear Regression Modelling was used to assess if the multiple covariates of Age, Height, Weight, PFT were predictors for PFS. In the left foot, the main predictor was age with height, weight and BMI having a lesser effect. In the right foot, the height, weight and BMI were the main predictors with age to a lesser extent. However, none of the predictors were significant. It may be assumed that the observations may not fit a normal distribution or linear coefficient, and therefore, a generalized linear model (GLM) was considered. The GLM allows other types of distribution to be assessed for between subjects where the coefficient is determined by the maximum likelihood (Wobbrock, 2019). This did support the findings of previous authors that height, weight and BMI were significant predictors for PFS but Age, PFT and angle of the rearfoot were not significant predictors. Although, this was not consistent between left and right feet.

In this study, measurements were dynamic and taken in the closed chain position, whilst in the other studies measurements were static and non-weight bearing and direct comparison is unreasonable. It was reported by Ostermann et al. (2020), that the PF was significantly thicker in the "stretched" foot (6mm) than the relaxed foot (5.8mm) especially in a symptomatic foot compared to a non-symptomatic foot (4.6mm). All of these measurements being higher than the PFT found in this study, but it does demonstrate that changes in the PF can occur on weight bearing, and further studies into comparative weight bearing (closed chain) and non-weight bearing measurements (open chain) would be recommended. The overall mean PFT for the left foot frontal plane was 3.4mm in the RCSP and in 3.5mm in the OGS, and in the sagittal plane the mean PFT for the left foot was 3.5mm and the right foot 3.6mm.

Furthermore, in this study no relationship was found between PFT and age or BMI, whereas Narindra et al. (2019), did find a close correlation with age and BMI and other factors in 226 feet. They also noted that the PFT was greater when stretched. Although, this study did not identify any significant difference between the PFT in the closed chain (OGS) compared to the RCSP. Therefore, the closed chain assessment of this study can be considered as providing a stretching force to the PF but the findings did not correlate with those of Narindra et al. (2019), and this may be due to the larger numbers in their study.

A further factor affecting the PFS is the menstrual state of the female participants which can result in hormonal related softening of the PF (Petrofsky & Lee, 2015). This study only had two female participants due to the sample selection, and therefore, was not considered in the analysis.

Moreover, Park et al. (2018), related the changes in the PF to abnormal foot function, although van Leeuwen et al. (2016), concluded that there was a lack of evidence for foot function as a risk factor for plantar fasciitis.

6.5.3 Parametric tests

The mean scores from each of the frontal and sagittal plane angles for PFT and PFS, at all the rearfoot angles, were all collated and the mean score taken to establish the Overall Group Score (OGS). This did not include the scores obtained at zero degrees (RCSP). Using a paired samples t-test, the OGS and the RCSP groups were compared for significant differences between the moved angles for PFT and PFS in both feet. There was no significant difference identified for both feet (Section 5.3.3) which was not surprising given that the OGS included interval changes for rearfoot motion of values of $+2^0$ or -2^0, which may have lessened the OGS results.

However, when the maximum degree of frontal plane motion of $+8^0$ or -8^0 was compared with the RCSP (three groups) using a one-way repeated ANOVA, there was also no significant difference noted for the frontal plane rearfoot positions in the PFT or PFS for both feet. The same finding was found using a paired t-tests for comparison of RCSP and $+8^0$ inclined in the sagittal plane and PFT and PFS.

Whilst it was clear that there were changes in the PFT and PFS with changes in the frontal and sagittal plane angles, the results of the main study indicate that the results were not significant. Therefore, the PF response as a group was not a consistent reaction, and therefore, it was likely that other factors may be affecting the PF response in some individuals.

6.5.4 Individual Participants

Whilst there was no significant statistical results for the group results, it was clear that the individual participant PFT and PFS data did show significant correlations for the movements in the frontal and sagittal planes (Appendix 9). Furthermore, they also demonstrated similar trends amongst clusters, and thus, proposed the further cluster analysis.

It is possible that the variation in results may be due to the starting point of the foot and a lack of range of motion within the rearfoot. Therefore, producing the discrepancy in results.

6.5.5 Strengths And Weakness Objective 3

The Two-Step Cluster Analysis within SPSS 27 (IBM Corp., 2020) uses an algorithm that identifies groups of cases that exhibit similar response patterns to several variables (Horn & Huang, 2016). The noise was specified at 25% which removed the data that did need not belong to any specific cluster, thus removing the main outliers. The data is initially allocated to smaller clusters (pre-clustering) before grouping them into larger similar clusters (hierarchical) whilst still employing Bayesian Information Criterion (BIC). BIC is one of the most widely known and used statistical modelling tools which is “derived from its computational simplicity and effective performance in many modelling frameworks” (Neath & Cavanaugh, 2012). In this study, the Two-Step clustering was selected as it is considered as the most reliable for the number of subgroups detected, classification probability of individuals to subgroups and reproducibility of findings (Benassi et al., 2020).

However, cluster analysis does have its limitations and the varying cluster methods can produce different results based on the criterion for the merging of the clusters. Also, the hierarchical nature of the analysis method means that “judgements” made at the start of the process cannot be rectified and may influence the outcomes.

The parametric statistical analysis did not show any significant relationships with the rearfoot angle moved and the PFT or PFS whether the data was analysed as a group or maximum range of rearfoot positions to a RCSP. This is likely due to the stating position of each foot not being standardised, such that, the foot may have been at an end range of motion, and therefore, the data would not be comparable. However, it was clear that the individual participant data and graphs (Appendix 9) did show groups of similar responses with some strong correlations amongst the individual participants.

6.6 Summary of Strengths and Weaknesses.

This study has developed a number of innovative techniques to assess the PF and the influence of the rearfoot motion upon it. The study has shown that the Dynastat platform is an accurate and consistent tool that could be a valuable instrument for moving the rearfoot through its range of motions. These could be as either separate component motions or as a single integrated three-dimensional movement (biaxial) which is reliable and repeatable.

The ability to change the platform to accommodate an ultrasound probe was not without obstacles, but it did allow the clear visualisation of the plantar fascia structure in the closed chain position of the foot. It could be argued that the movement of the platform may have changed the angle from which the PF is being viewed, and therefore, directly affect the measurements recorded. This may be shown in the high CoV that were obtained across the PFS measurements. However, the foot was held in position with clamps to prevent any medial or lateral deviation, and if any error was occurring, then it would have been consistent across all measurements. Furthermore, the angle of the probe was such that it was within the 20 degrees to the perpendicular, so that the SWE would produce data with a variance of less than 1.3%.

The other factor that may have influenced the results is the function of the intrinsic or extrinsic muscles. Changes in the rearfoot movement by an independent platform will naturally result in the participant knowingly, or unknowingly, holding or resisting the foot position. This could cause force changes in the PF and directly affect the results. To minimise this reaction the participant was allowed to settle before measurements were recorded. Unfortunately, this may not have been long enough in some measurements, and so other techniques may be required in the future to negate this risk. It could be achieved with electromyography to assess muscle activity or even a local anaesthetic block of the tibial nerve to prevent the intrinsic muscle activity.

The methodology may also have explained the lack of significant group results. The foot was placed on the platform at the participants relaxed normal closed chain position. Therefore, the starting point was not consistent for the taking of measurements, and so, the relative positions of $+8^{o}$ or -8^{o} would not be the same relative position of the foot for each participant. This may mean that the results obtained may have been similar or significant had the foot been set in the same relative “neutral position” as proposed by Root et al. (1977) in his original concept of normalcy. However, the concept, location and ability to obtain this STJ neutral position has been questioned in the research (Mcpoil & Cornwall, 1994; Sobel & Levitz, 1997). To expand this, it is possible that a participant in the relaxed position may already have been at or close to their maximum end range of motion (i.e. -8º or +8º) and so any further motion in the same direction may not have produced any changes in the PFT or PFS, as no or little further motion occurred in that direction. This may account for the differences in the group analysis and was not, unfortunately, considered at the start of the study.

This ability to locate the controversial subtalar joint neutral position may also have been helpful in this study. It is proposed that the results may have been more consistent had this neutral position been implemented. However, the ability to achieve this with the platform was not considered until the device was used and its ability recognised. This is certainly worthy of further quantification in the future.

Operator bias is always a risk to research, and it was not possible to blind the researcher in this study. However, the data validation process and repeating of measurements did provide some defence to the accuracy and reliability of the results.

6.7 Future Research

This study has shown that it is possible to develop a platform for controlling, or adjusting, rearfoot function and position and this has many implications for future research, whether the single or multiple plane function is used. Furthermore, the potential to be able to move the rearfoot and assess its effects on the leg and back is very encouraging.

Moreover, the ability to be able to isolate and manipulate the motion of the rearfoot in a closed chain position could also have significant value in research of the rearfoot function. The Dynastat will allow the researcher to move the rearfoot through its range of motion, and therefore, determine a relative "neutral position" using biaxial co-ordinates. Using Root theory (Root, Orien, et al., 1977) and other qualitative foot position indices, such as the Foot Posture Index (Redmond et al., 2008), would allow better approximation of the STJ normal position of the rearfoot. Therefore, this study's methodology and findings may have developed a reference point for a "true STJ neutral position" rather than the RCSP and make a significant contribution to future research. This ability to locate the "STJ neutral" when combined with a Vicon Motion Analysis ((Vicon Motion

Systems, 2021) may produce further information to the true function of the foot.

Further research into the PF function can also be developed from this study. The concept of assessing the PF in the closed chain position has now been presented and this concept may be expanded to develop further studies to assess the PF using a forefoot platform to control the foot motion across other functional joints of the foot. The protocol developed by this study had a high internal validity and can be considered as the initial protocol for the assessment of the weight-bearing PF.

The negative Poisson effect of the PF reaction to changes in rearfoot position is also very worthy of further study, as this may account for the thickening seen in pathology. Therefore, this thickening may be representative of the function of the foot and not as a result of the healing process previously suggested in the literature (Cardinal et al., 1996).

6.8 Summary Of Discussion

In summary, the study has not identified a significant relationship of the PFT or PFS to the changes in the rearfoot angle in the frontal or sagittal planes. It has, however from the cluster analysis, suggested that there is a much more complex relationship of the PFT and PFS particularly to changes in the sagittal plane. The auxetic changes may link the PF more closely to the function of the Achilles tendon and its auxetic properties.

Clinically, the study has introduced the concept of being able to manipulate the rearfoot in a closed chain position and this could expand research into many new fields. This could have substantial implications for the treatment of painful foot and lower limb pathologies. It has also shown that is possible to assess the PF in a loading bearing position and this may lead to the development of further clinical assessment, and tools for the treatment of painful PF.

Chapter 7. Conclusion

This study's main objective has been found to not show any significant parametric statistical relationship for the plantar fascial thickness or stiffness with changes in the rearfoot position. It has shown that there are clusters of participants in which there is a definitive reaction of the PFT and PFS to changes in the rearfoot position and that the PF is, therefore, a dynamic and reactive structure.

Furthermore, it has had a number of very beneficial outcomes and results. It has shown that it is possible to develop a unique three-dimensional closed chain platform for use in the clinical setting, and for the assessment of foot function for the production of foot orthosis. It has also demonstrated the ability to adapt the platform to perform closed chain ultrasound assessments and this is also a unique outcome of the study. Hopefully, this will encourage the further assessment of the PF function from this weight-bearing position, using the developed protocol..

The study has some weakness in the methodology due to the unique concepts being developed but where possible these have been mitigated. The results of the main objective of the study, were disappointing for not showing a significant outcome for the group, but it has shown some excellent individual and cluster results for further research.

7.1 Recommendations for Clinical Practice.

The study has produced several interesting findings that could be used in the management of a range of foot pathologies, but may require further research to accomplish them.

1. The first recommendation would be the use of the rearfoot platform, and its further developed prototype, that could be used to assess the static foot more accurately and reliably. The ability to develop a biaxial co-ordinate position of the foot could have a significant impact in the future production of clinical foot orthosis. The ability to reliably and repeatedly set the clinical foot position, scan the foot and produce a 3d printed orthosis, based on the values obtained, is now a distinct prospect.
2. The platform could also allow the assessment and reaction of other joints in the leg and spine to deviations in foot position. This was also noted incidentally by some participants who noted changes in posture as the rearfoot was manoeuvred.
3. The platform may also help in the development of clinical knowledge in a number of related fields. The ability to set the foot to a "neutral position" would be invaluable in establishing the

concept of “normalcy”. Furthermore, the feet are the foundations of the body and an understanding of the foot position, or changes to it, may have substantial benefits to diabetic foot management, neurological foot pathology, sports injuries or prevention and the obvious general everyday foot pathologies.

4. The protocol developed by the study also gives the ability to assess the PF in the weight-bearing position, and will also allow future research to establish the reactions of this complex structure to changes in foot or leg position or BMI.
5. The auxetic changes noted in the PF may also explain the PFT seen in plantar heel pain pathologies. This has significant implications for clinical treatment programmes and may help explain the varied outcomes of extracorporeal shock wave therapy, steroid injections and foot taping techniques.

Chapter 8. Reflective Analysis

This study has been a difficult process given the effects of the SARS2-Covid 19 pandemic. Assess to the Biomechanics Laboratory and University was difficult, and obtaining a suitable sample for assessment was challenging. I was well supported throughout the module by the University staff, namely Prof Naemi and Mark Young, who managed to recruit volunteers from the those allowed into the University, whilst adhering to the UK Government protocols.

The study was a complicated study and to some extent it developed into a much larger study than I anticipated. I have learnt a lot about applying a rigours process to the methodology, to ensure that data collection is kept consistent and reliable. I have also had to learn several new skills in mechanics, soft development, 3D printing and computer skills, especially in software use. However, without the assistance and skills of colleagues and the extraordinary abilities of Tom Price, this study would not have been viable.

I am very pleased, and proud, to have completed this study and have achieved some unique and valuable achievements, which I hope can be shared with the wider research community to improve our knowledge, clinical skills and patient care. It is entirely possible that the study may lead to a new system of assessing foot function, but this will require more validation.

The module has certainly improved my overall understanding of research and the need for more forward planning. Had I known the results of this study, I would have focused the study on assessing the range of motion of the rearfoot to establish a relative “neutral” rearfoot position which may have improved the outcome of the study. Hindsight!

> “Science walks forward on two feet, namely theory and experiment.”
>
> Robert Andrews Millikan (Todayinsci, 2021)

Chapter 9. References

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Chapter 10. Appendices

Appendix 1: Excel Spreadsheet Data Collection From Systematic Review

Author	paper title	year	study type	thickness	stress	foot function	control	study no.	male / female	age range	mean	treatment	outcomes	
Petrofsky, J., & Lee, H.	Greater Reduction of Balance as a Result of Increased Plantar Fascia Elasticity at Ovulation dur	2015	pros cohort	yes	elatocity			15	female	18 -30		no	change in thickness related to menstrual, 0.187mm during 0.164mm at ovulation. Si	
Calvo-Lobo, Cesar	Rehabilitative ultrasound imaging of the bilateral intrinsic plantar muscles and fascia in post-s	2018	case-control observa	yes	no			60	not given	18+		no	thinner in pes plannus & spasticc and otehtr foot compared to healthy. No descripti	
Wu, Chueh-Hung	Plantar fascia softening in plantar fasciitis with normal B-mode sonography	2015		yes	yes			50				no	softer in patients with typical clinical manifestations of plantar fasc	
Welk, Aaron B.	Use of High-Resolution Ultrasound to Measure Changes in Plantar Fascia Thickness Resulting F	2015	pros cohort	yes	yes			61	32 m 29 f	21-51	25.7	yes	compares run & walk for creep and thickness. No change	
Carlo Gamba	Relationship of Plantar Fascia Thickness and Preoperative Pain, Function, and Quality of Life ir	2018	trans sescriptive	yes	no			35		18+	49.1		thickness not related to pain, fucntion, Q function ot foot movement	
Fabrikant, Jerry M.	Plantar fasciitis (fasciosis) treatment outcome study: Plantar fascia thickness measured by ult	2011	prospective	yes	no			61	29m 34f	57.14tt 58.55cont		yes	pf < with varied tt+ inj & biom (various orhtosis	
Lee, S.-Y	Ultrasound elastography in the early diagnosis of plantar fasciitis. Clinical Imaging, 38(5), 715–	2014	retro	yes	yes		18 9r 9l	18	?	45+-11		no	thick not sign, Softening sign between group & control not age related. Thick > in ol	
McMillan, A. M	Ultrasound guided corticosteroid injection for plantar fasciitis: randomised controlled trial. Bl	2012	reject tt											
Angin, S.	Ultrasound evaluation of foot muscles and plantar fascia in pes planus. Gait & Posture, 40(1), 4	2014	propective	yes	no	pes planus	49 (29 m 2	49	29m 20 f	18-44	24.1 (Con 23.4	no	compares PF muscle in norm and flat feet. PF thinner in flat ? <load	GIVES REC
Taş, S	Effects of morphological and mechanical properties of plantar fascia and heel pad on balance	2018	prospective	yes	yes	balance +fpi	0	37	37 f	19-35	22		PF thick and stiff related to sw; > sway with > thick and stiff	
Ieong, E	Ultrasound scanning for recalcitrant plantar fasciopathy. Basis of a new classification. Skeletal	2013	prospective	yes	no	no		96 (125 fe	39M 57F	22-82	55	No	82 insert thick, 9 distal disease, mixed 28 thick +fibroma	
Fleischer, A. E.	Prognostic Value of Diagnostic Sonography in Patients With Plantar Fasciitis. Journal of Ultras	2015	prospective	yes	no	foot supports	0	63		25-75	49		bioconexity of PF. Thickness not related to pain	
Chen, H	Association Between Plantar Fascia Vascularity and Morphology and Foot Dysfunction in Indiv	2013	sing cohort	yes	no	pain + FFI	21	38	24F 14 M (Con 9F 12M)		45.2 (Con 45.1	no	PF > vas and thick on affected side + controls. Thick and vasc assc FFI	
Fernández-Lao, C.	Analysis of Pressure Pain Hypersensitivity, Ultrasound Image, and Quality of Life in Patients w	2016	prospective	yes	no	SP36 +FAAM	22	22	11m 11f	27-73		no	PF= thicker, <QOL, > sensitivity.	
Gao, L.,	Imaging of the elastic properties of tissue—A review. Ultrasound in Medicine & Biology, 22(8)	1996	reject review											
Jarvis, H. L.	Inter-assessor reliability of practice based biomechanical assessment of the foot and ankle. Jc	2012	reject biom only										Static biomechanical assessment of the foot, leg and lower limb is an important prc	
Bishop, C.,	Custom foot orthoses improve first-step pain in individuals with unilateral plantar fasciopathy	2018	RCT	yes	no	orthosis cust, sl	20	40(20& 20	con13f 7m, shoe 12f8m, ort 14f6m		con44.4, sh 44.9, orth 44.		orth < 1st step pain @4&12/52. orth<PF@12/52	
Bisi-Balogun, A.	Clinical Utility of Ultrasound Measurements of Plantar Fascia Width and Cross-Sectional Area.	2017	reject technique										width & CSA helpful	
Abul, K.,	Detection of Normal Plantar Fascia Thickness in Adults via the Ultrasonographic Method. Jourr	2016	reject US only										<4mm in non pf	
Radwan, A.	ULTRASONOGRAPHY, AN EFFECTIVE TOOL IN DIAGNOSING PLANTAR FASCIITIS: A SYSTEMATIC I	2016	reject	syst review to proves US good										
Skovdal Rathleff, M.	Intra- and interobserver reliability of quantitative ultrasound measurement of the plantar fas	2011	reject us tech										ablel to measure changes over0.6mm	
Ahn, J. H.	Ultrasonographic examination of plantar fasciitis: a comparison of patient positions during exa	2016	reject technique										can do in any position	
Granado, M. J.	Metatarsophalangeal joint extension changes ultrasound measurements for plantar fascia thi	2018	cohort	yes	no	1st tmpj	20	20		18-65	44.8	no	PF thicker than cont and vried by mtp position	
Wearing, S. C.	Plantar Enthesopathy. The American Journal of Sports Medicine, 38(12), 2522–2527. https://dc	2010	casecontrol	yes	yes	no	9	9				no	fat pad thicker in symp v non symp v control. No stress. Fat pad dissipates energy	
Mohseni-Bandpei, M. A.	Application of Ultrasound in the Assessment of Plantar Fascia in Patients With Plantar Fasciitis	2014	reject tecl	sys review of us and pf reliable										

Appendix 2: CASP Assessment Example

CASP
Critical Appraisal
Skills Programme

Paper for appraisal and reference: Metatarsophalangeal joint extension changes ultrasound

Section A: Are the results of the study valid?

1. Did the study address a clearly focused issue?

Yes ☑
Can't Tell ☐
No ☐

HINT: A question can be 'focused' In terms of
- the population studied
- the risk factors studied
- is it clear whether the study tried to detect a beneficial or harmful effect
- the outcomes considered

Comments: Yes it assess the relationship of the PF and 1st mtpj.

2. Was the cohort recruited in an acceptable way?

Yes ☑
Can't Tell ☐
No ☐

HINT: Look for selection bias which might compromise the generalisability of the findings:
- was the cohort representative of a defined population
- was there something special about the cohort
- was everybody included who should have been

Comments: Good inc and exc criteria. Doesn't say where they recruited from. Sample were evenly distributed.

Is it worth continuing?

CASP
Critical Appraisal
Skills Programme

3. Was the exposure accurately measured to minimise bias?

Yes	✔
Can't Tell	
No	

HINT: Look for measurement or classification bias:
- did they use subjective or objective measurements
- do the measurements truly reflect what you want them to (have they been validated)
- were all the subjects classified into exposure groups using the same procedure

Comments: Good structure to research. Systematic process. Weakness examiner not experienced?

4. Was the outcome accurately measured to minimise bias?

Yes	✔
Can't Tell	
No	

HINT: Look for measurement or classification bias:
- did they use subjective or objective measurements
- do the measurements truly reflect what you want them to (have they been validated)
- has a reliable system been established for detecting all the cases (for measuring disease occurrence)
- were the measurement methods similar in the different groups
- were the subjects and/or the outcome assessor blinded to exposure (does this matter)

Comments: Blinding of examiner to the groups but not to the position of the toes. Good systems.

Appendix 3: Protocol For Sonography

1. Place foot on platform and locate probe in-line with second toe and beneath heel.
2. The probe should be covered by the heel and gel medium used.
3. Observe the B wave image to ensure the medial tuberosity of the calcaneus is clearly visible and the plantar fascia. Adjust the plate position or foot until correct visualisation.
4. Once visualization is achieved the foot can be held in place with the locating clamps.
5. To achieve measurement with Sonoelastography:
    a. Select Shear wave assessment from machine.
    b. Set region of interest box as small as possible (size?)
    c. Place ROI box 20mm from highest point of the medial tuberosity from proximal margin of box.
    d. The upper edge of the box should be inline or just above the plantar fascia.
    e. Depth of box should be approx. 10mm. This should give a shear wave reading just off the anterior edge to the calcaneus. This edge will not be visible through variation of angles.

   f. Select the shear wave that gives the most coverage within the region of interest.

6. To obtain the area of interest.
   a. Select measurement tools.
   b. Select ellipse and locate approx. 5mm from proximal edge of the region of box and at the upper margin of the plantar fascia.
   c. Adjust the position to locate the plantar margin of the plantar fascia. Press select.
   d. Adjust the width of the ellipse to set a fixed width of 15mm.
   e. Select Q-box trace and zoom to area of interest (ellipse).
   f. Draw around the ellipse with the pen tool to obtain the shear wave readings within the area of interest.
7. Press select, exit and save image. Record the image number and assessment image number on the spreadsheet against the appropriate foot and angle.
8. Repeat 3 times for each angle and move platform according to the next angle on list.
9. Export the images for input onto spreadsheet.

Appendix 4: Patient Information Leaflet
Version Number 13/10/2020

INFORMATION SHEET FOR PARTICIPANTS

Title of study

Does a change in foot position have an effect on the thickness and stiffness of the plantar fascia of the foot?

Invitation Paragraph

I would like to invite you to participate in this research project which forms part of my Professional Doctorate research. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me if there is anything that is not clear or if you would like more information.

What is the purpose of the study?

The study will aim to move the back of the foot through its normal range of movement and at certain angles measure the thickness and stiffness of a band of tissue in the heel (Plantar Fascia). This is done using an ultrasound machine which uses sound waves to measure the structure. This will be done for both feet.

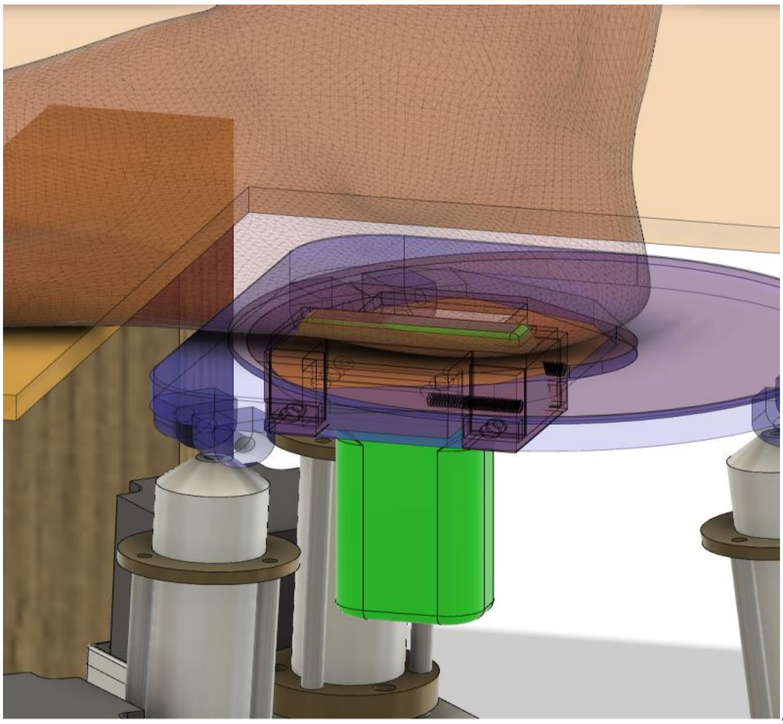
Why have I been invited to take part?

You have been chosen to take part because you are over 18 and able to stand freely unaided on the device. The study hopes to complete this for 15 participants.

You cannot take part if you have any foot pain or medical conditions that may cause inflammation or are receiving or recently had any steroid treatment. This is because they may cause changes to the Plantar Fascia.

<u>What will happen if I take part?</u>

After you have completed the questionnaire and consent form, you will be asked to stand on the platform and device. Your heel will have a water-based gel applied and the probe positioned against your foot to identify the plantar fascia. The foot will then be moved to certain angles and the measurements recorded to look for any correlation between the angle of the foot and thickness and density of the Plantar Fascia. The Diagram below shows how the foot and probe will be placed on the platform. The other foot will be on a supporting platform.



The Biomechanics Laboratory is located in The Science Centre within Staffordshire University Leek Road Campus (ST4 2DF). It is estimated that the tests will take about 30 minutes to complete.

The questionnaire data is only necessary to make sure that you have not had any conditions that could cause the Plantar Fascia to be inflamed or thickened which could cause abnormal results. The thickness and density of the Plantar Fascia will be recorded on a table and you will only be identified by a number. No personal identifiable data will be recorded.

Do I have to take part?

Participation is completely voluntary. You should only take part if you want to and choosing not to take part will not disadvantage you in anyway. Once you have read the information sheet, please contact us if you have any questions that will help you make a decision about taking part. If you decide to take part we will ask you to sign a consent form and you will be given a copy of this consent form to keep.

What are the possible risks of taking part?

The sound waves are completely harmless, and you will not feel anything. The movement of the foot is within your normal range of movement and is not painful. This is done on a device that is designed to move the heel to the required positions. You will be required to step up on to the platform and use the platform and device to support you weight.

What are the possible benefits of taking part?

By taking part in this study, you will allow me to collect data about the plantar fascia and the way it responds to the different movements of the foot. This can then be used to help in the treatment of many foot problems such as plantar fasciitis.

Data handling and confidentiality

Your data will be processed in accordance with the data protection law and will comply with the General Data Protection Regulation 2016 (GDPR).

The data collected will not contain any personal identifiable details only a unique reference number such as participant No 2. It will not be shared with anyone other than the research team for the purpose of statistical analysis. It is intended to publish the results of the study in an appropriate academic journal and again not identifiable data will be published.

Data Protection Statement

The data controller for this project will be Staffordshire University. The University will process your personal data for the purpose of the research outlined above. The legal basis for processing your personal data for research purposes under GDPR is a ‘task in the public interest’ You can provide your consent for the use of your personal data in this study by completing the consent form that has been provided to you.

You have the right to access information held about you. Your right of access can be exercised in accordance with the General Data Protection Regulation. You also have other rights including rights of correction, erasure, objection, and data portability. Questions, comments and requests about your personal data can also be sent to the Staffordshire University Data Protection Officer. If you wish to lodge a complaint with the Information Commissioner’s Office, please visit www.ico.org.uk

What if I change my mind about taking part?

You are free withdraw at any point of the study, without having to give a reason. Withdrawing from the study will not affect you in any way. You are able to withdraw your data from the study up until **1/12/2020**, after which withdrawal of your data will no longer be possible due to the being processed and submitted as part of the dissertation.

If you choose to withdraw from the study we will not retain any information that you have provided us as a part of this study.

How is the project being funded?

The project is being funded by the researcher.

What will happen to the results of the study?

The results are part of my professional doctorate and will be published in appropriate journals and presented at relevant conferences.

Who should I contact for further information?

If you have any questions or require more information about this study, please contact me using the following contact details:

Mark Price Mobile: 07772805458 Email: dynastat@sky.com Or

C/O Prof N Chockalingham at Staffordshire University: Email n.chockalingam@staffs.ac.uk

What if I have further questions, or if something goes wrong?

If this study has harmed you in any way or if you wish to make a complaint about the conduct of the study you can contact the study supervisor or the Chair of the Staffordshire University Ethics Committee for further advice and information:

Dr Tim Horne

Director of Research

Staffordshire University

Mobile: +44 (0) 7584 460785

Email: tim.horne@staffs.ac.uk

Thank you for reading this information sheet and for considering taking part in this research.

Appendix 5: Participant Consent Form

SPORT AND EXERCISE: PRE-TEST QUESTIONNAIRE & INFORMED CONSENT

Name: ____

D.O.B: _______ / _______ / _______ Age: _______

For your health and safety please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you are fit and healthy enough to participate in this laboratory research project.

ALL INFORMATION YOU PROVIDE WILL REMAIN CONFIDENTIAL

Do you have any medical condition that can affect your balance, such as neurological conditions (Parkinson's, multiple sclerosis etc) or ear related problems (Vertigo, Meniere's or Labyrinthitis) ?

Yes No

Please give details

____

Do you suffer, or have you suffered from any form of heart condition or problems with blood pressure?

Yes No

Please give details

____

Do you have any arthritis in your feet, knees or hips that limits your movement or causes any balance problems?

Yes No

Please give details

____

Have you ever had any periods of falling or tripping?

Yes No

Please give details

____

Do you need to use a stick or walking aid?

Yes No

Please give details

____

Are you currently taking any form of medication?

Yes (please give details below) No

____

Do you have any known allergies?

Yes (please give details below) No

____

Have you suffered any form of viral or bacterial infection in the last two weeks?

Yes No

Please give details

____
___

Do you have any form of muscle, bone, or joint injury?

Yes (please give details below) No

____
____
____

Do you know of any other reason why you should not be able to complete the tests that have been outlined to you?

Yes (please give details below) No

____
____
____

Are you currently suffering from a foot fracture or swelling of the foot?

Yes No

For UBIS use only:

The UBIS should not be used on any participants under the age of 5 years

Do you currently have any broken or cracked skin on your feet?
Yes No

INFORMED CONSENT

I understand that the information provided on the pre-test questionnaire is confidential.

The full details of the tests have been explained to me. I am clear about what will be involved, and I am aware of the purpose of the tests and the potential risks.

Any questions that I have about the tests or my participation in them have been answered to my satisfaction.

I know that I am not obliged to complete the tests. I am free to stop the test at any time and for any reason.

I have no injury or illness that will affect my ability to successfully complete the tests.

The test results will only be communicated to members of the research team for the purpose of analysing the data.

Having read the above I agree to participate in the testing.

Signature of Participant: ________________________ Date: ______ / ______ / ______

Signature of Supervisor:________________________ Date: ______ / ______ / ______

Appendix 6: Risk Assessment

Severity multiplied by **Likelihood** equals

Risk Rate.

		Severity / Likelihood	Insignificant (1)	Minor (2)	Moderate (3)	Serious (4)	Fatal / Critical (5)
School/Service: Psychology, Sport and Exercise							
Task/Activity/Area: R004 (Sport and Exercise Labs)		Almost Certain (5)	5	10	15	20	25
Collecting Data with Dynastat 2 device: "Does a change in foot position have an effect on the thickness and stiffness of the plantar fascia of the foot?"		Likely (4)	4	8	12	16	20
Assessed By: Mark Young	Signature:	Possible (3)	3	6	9	12	15
Supervisor:	Signature:	Unlikely (2)	2	4	6	8	10
Date of Assessment: 08-09-20	Review Date: 08-09-21	Rare (1)	1	2	3	4	5

Description / Activity / Procedure:

Subjects aged 18+ will complete a pre-test questionnaire and consent form prior to taking part. Anybody who does not meet the requirement will be excluded from taking part in the study. The subject will be required to stand upon the Dynastat unit bare footed with both feet on the unit (One foot over the Probe's cut out and the other foot on a support platform. Where the foot position will be altered to various positions (The foot will be moved in the frontal plane to +2, +4,+6 +8 & -2, -4, -6, -8 degrees and also the sagittal plane 5, 10, 15, 20, 25 degrees). Adjustment to the Dynastat will be applied via a computer connected to the system, with the researcher operating from at least 2m away from the subject and each other.

		Severity multiplied by **Likelihood** equals **Risk Rate**.

Testing will take approx. 20 mins in total, but the subject will be able to ask for a pause to relax after completing one set of measurement. Data collection will be for 1 complete set of frontal planes and 1 set of sagittal planes as described above.

Whilst this is happening the plantar fascia tendon will be scanned with an ultra-sound probe connected to the Supersonic Image Aixplorer (ShearWave Ultra-Sound machine) which will be mounted underneath the unit plate. The Ultrasound gel will be used and applied to the probe only prior to the subject standing on the unit, this will only be a small amount to enhance recordings. The platform has shaped sides and a slight roughened surface which will prevent slippage and the platform cleaned after each trial. Angles which the platform is moved to are not excessive to cause significant foot movement. If the Ultrasound gel does fall onto the Dynastat base, any spillage will be cleaned up straight away.

The height of the Dynastat unit is fixed at 30cm with a step set at 15cm to assist the participant in getting onto the platform. The Dynastat platform will only tilt in the frontal and sagittal plane, it will not be raised in this test. The opposing or supporting foot will be on a platform set at the same height as the Dynastat platform. There is no change in the height only a change in the angle of the rearfoot platform There will be a handrail for support which will be place in front and to the sides of the unit to provide the subject support should they loss balance, they are not to use the handrail during testing for balance. There is sufficient length of cable to prevent any strain on the probe or alter its position whilst the test is being carried out.

To ensure UK Government and University social distancing guidance is always adhered to other than when contact is required with the subject. This will be for no more than a five-minute period. All researchers present will be required to wear PPE (Face Guards or Masks, Aprons and Gloves) when in contact with the subject. The subject will also be asked to wear masks. The subject will not touch any of the operating equipment.

STAFFORDSHIRE UNIVERSITY		**Severity** multiplied by **Likelihood** equals **Risk Rate**.

There will be up to 3 researchers operating the equipment plus the subject present during this data collection session. The same researcher will operate the same specific piece of equipment during the test session, which will be positioned as far away from the subject as possible. They will be responsible for setting up and cleaning of their own equipment both before and after the data collection session and between subjects. All other lab users will ensure that they always adhere to social distancing as per signage within the lab. All equipment which has been used during the session will be cleaned with materials provided.

If the equipment is setup and dismantled by someone other than the researcher, it should be sanitised prior to and after the researcher touches it.

NB This risk assessment will be used in conjunction with the 'HCS Labs COVID-19' risk assessment. Everyone involved with this activity should ensure that they read and familiarise themselves with the hazards and control measures of both risk assessments.

	Activity/Process/ Mechanism	Hazzard	Persons at Risk	Measures/Comments	Severity 1-5	Likelihood 1-5	Risk Rate	Result
1	Setting up and Operating Equipment	Setting up, operating and cleaning equipment Potential risk of exposure to COVID-19	All Present	Where possible one individual (researcher. technician, academic, or student) must be responsible for setting-up, operating, sterilising and the dismantling the equipment before, during and after the activity. If the equipment is setup and dismantled by someone other than the researcher, it should be sanitised prior to and after the researcher touches it. The operator will sanitise their hands before the start of the test/data collection session and then wipe the equipment before and after use. During data collection activities, to reduce the amount of time the equipment is wiped down, where possible it should be operated by the same person throughout the data collection session. Where this is not possible the equipment should be sanitised before any other individual touches the operating equipment. Upon completion of the test / data collection activity the operator will clean their hands with soap and water or hand sanitising gel.	3	1	3	T

	Activity/Process/ Mechanism	Hazzard	Persons at Risk	Measures/Comments	Severity 1-5	Likelihood 1-5	Risk Rate	Result
2	Moving around lab.	Slip/ Trip/ Fall	All Present	Precautions will be taken to make sure that the floor is clean, and the lab space is kept tidy to avoid any risks of slip or trip. Any hazards will be sorted prior to activities taking place. Any trailing equipment cables will be secured and will be located outside the capture space.	2	1	2	T
3	Subject preparation	Potential risk of exposure to Covid-19	Participant	Subjects will need to arrive in suitable clothing i.e. shorts or will have to roll up their trousers for the session. There will be no sharing of clothing between subjects. Anyone without suitable clothing will not be able to take part in the session. They will have to remove their socks and shoe. Their feet will be wiped with Anti-bacterial wipe prior to then stepping upon the device. The Device will also be wiped both before and after the testing.	3	1	3	T
4	Data Collection Activities	Not Being able to to adhere to social distancing guidance Potential risk of exposure to COVID-19	All Present	Due to not being able to adhere to social distancing guidance the researchers will wear gloves, mask and face visor throughout the activity and they will sanitise their hands prior to setting up the participant on the equipment. The participant will wear a face mask during the activity.	3	3	9	A

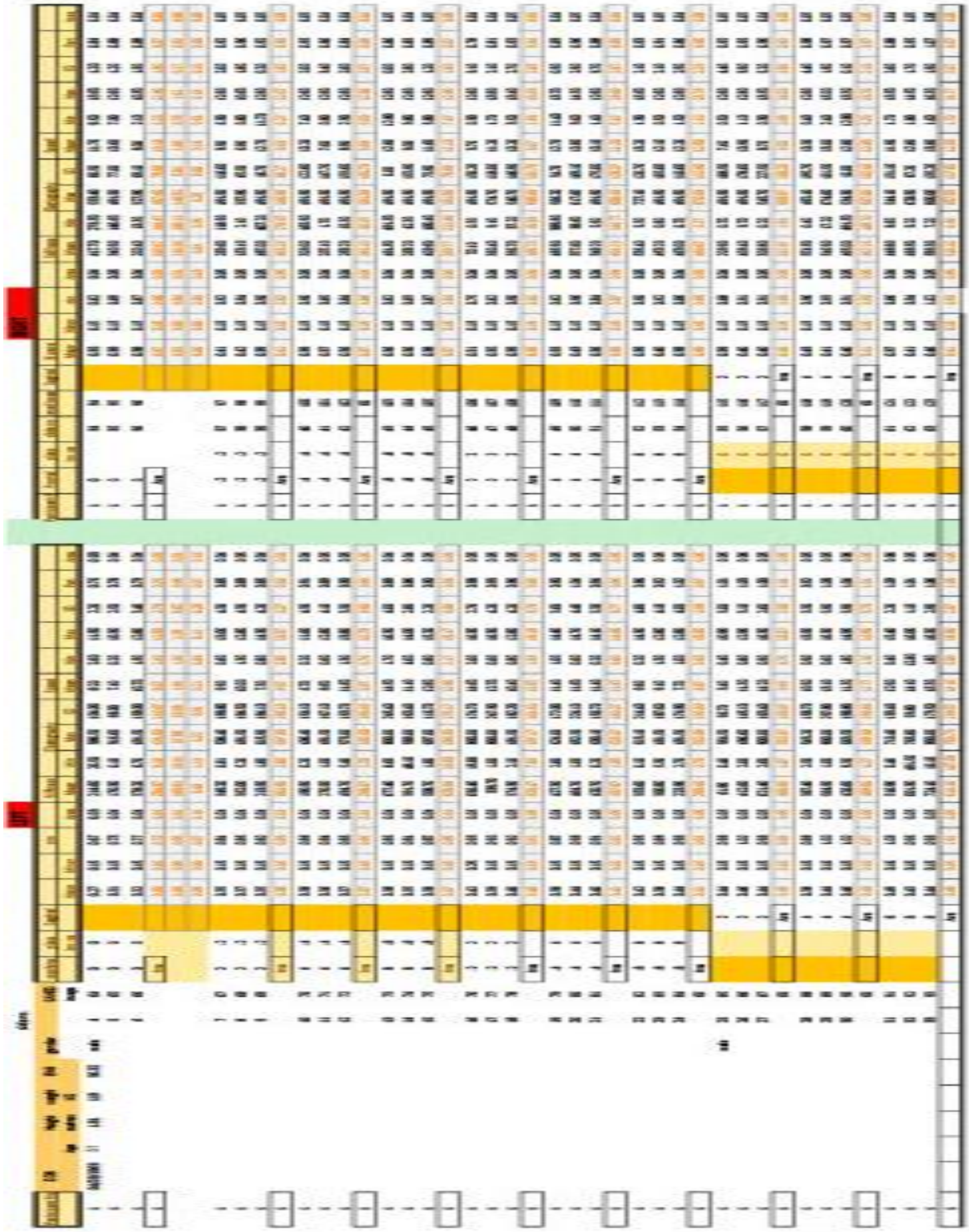
	Activity/Process/ Mechanism	Hazzard	Persons at Risk	Measures/Comments	Severity 1-5	Likelihood 1-5	Risk Rate	Result
5	Use of Gloves	Allergy	Participants	Participants will be asked if they have any known allergy before starting any testing via pre-test questionnaire. Nitrile, latex and powder free gloves used. Failing this, they will be excluded from the trials.	2	1	2	T
6	Taking part in test	Slipping on Dynastat Unit	Participants	Precautions will be taken to make sure that the foot plate is clean, and dry. Any spillage of Ultrasound Gel will be clean straight away. All trailing equipment cables will be secured and will be located outside the capture space.	2	1	1	T
7	Taking part in test	Loss of Balance	Subject	There will be a handrail set up. To aid the subject should the start to loss balance, due to standing still for a period. This is not to be used during the testing phase. This will be cleaned down between each subject.	3	1	3	T

Other special conditions specified as part of the permissions to carry out the work / activity / procedure and actions needed to minimise risk:

All participants must complete a pre-test questionnaire and informed consent form excluding those medically unfit to perform the exercise test, SE001, before participating.
A first aider must be available during the test. The first aider will have access to disposable gloves and a fluid-repellent face mask to wear if treatment is needed.
The experiment/procedure will cease immediately if the participant reports that they feel any discomfort, unwell, if an accident occurs, or if the fire alarm sounds.
All accidents, near misses, and injuries, however slight, must be reported to the technician and supervisor immediately, appropriate forms must be completed.
Operators will be told who to contact in an emergency, will be given a list of first aider contacts, and will be instructed to obey the fire orders.
Operator will to be trained up to a competent level by an experienced member of staff before being allowed to use the equipment.
Undergraduates may use the equipment on an individual basis i.e. dissertation work, thus they will receive training, assessment, and supervision.

Operator must read relevant safety notes and guidelines in the operations manuals.
Operators must report to the technician if they suspect that the equipment may be malfunctioning, faulty, or not working correctly.
The equipment is PAT tested annually and a visual inspection of the cables and equipment should be carried out prior to use.

Appendix 7: Excel Data Sheet Example.



Appendix 8: Ethics approval

Life Sciences and Education

PROPORTIONATE REVIEW APPROVAL FEEDBACK

Researcher name: Mark Price

Title of Study: Does a change in foot position have an effect on the thickness and stiffness of the plantar fascia of the foot?

Status of approval: Approved

Thank you for addressing the committee's comments. Your research proposal has now been approved by the Ethics Panel and you may commence the implementation phase of your study. You should note that any divergence from the approved procedures and research method will invalidate any insurance and liability cover from the University. You should, therefore, notify the Panel of any significant divergence from this approved proposal.

You should arrange to meet with your supervisor for support during the process of completing your study and writing your dissertation.

When your study is complete, please send the ethics committee an end of study report. A template can be found on the ethics BlackBoard site.

Signed: Date: 29th October 2020

Prof. Peter Kevern

pp. Dr Roozbeh Naemi Chair of the LSE Ethics Panel

Life Sciences and Education

Appendix 9: Report on Individual Participants

5.4.1 Participant 1

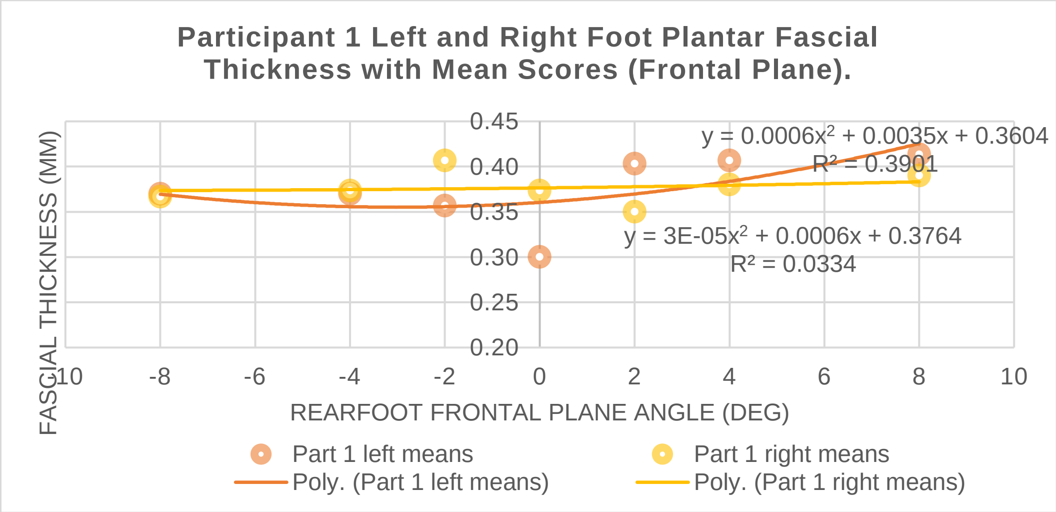


Figure 62: Graph Showing PFT And Frontal Plane – Participant 1.

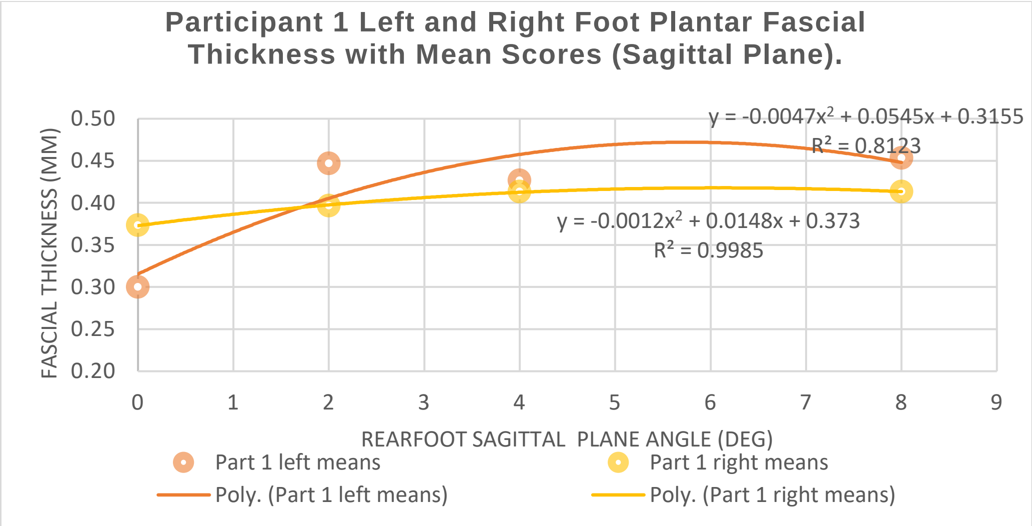


Figure 63: Graph Showing PFT And Sagittal Plane – Participant 1.

Participant 1 shows poor polynomial (order 2) correlation for plantar fascial thickness (PFT) with a change in the rearfoot frontal plane angle in both feet (*Left* r^2 *= .39, Right* r^2 *= .03*) but good polynomial (order 2) correlation in the sagittal plane (*Left* r^2 *= .81, Right* r^2 *= .99*).

The PFT increases as the foot moves into inversion (+8) and eversion (-8) in the frontal plane and as the sagittal plane angle increased.

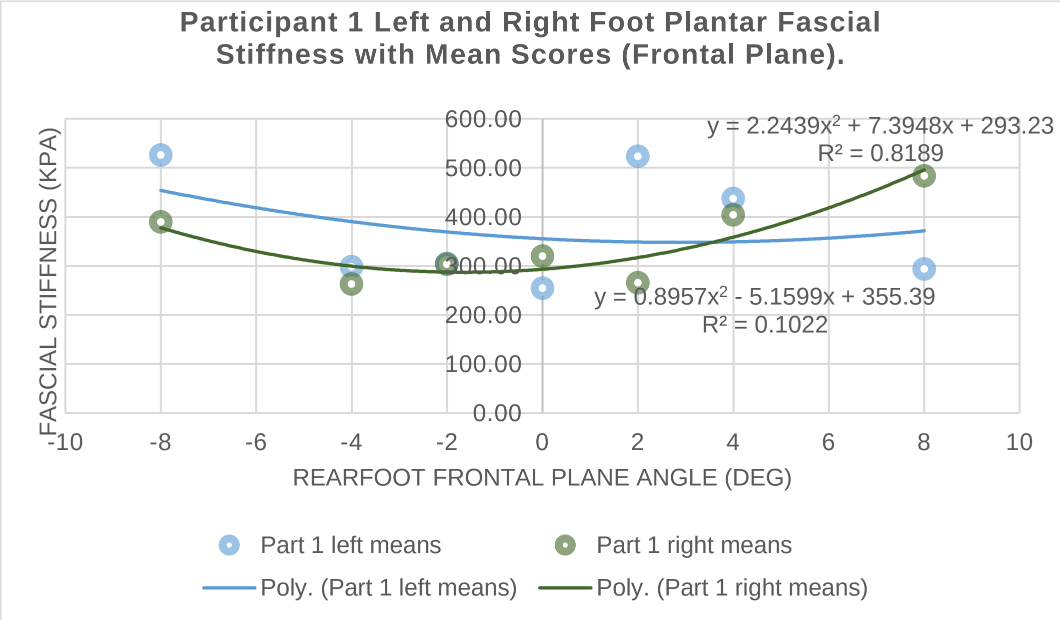


Figure 64: Graph Showing PFS And Frontal Plane – Participant 1.

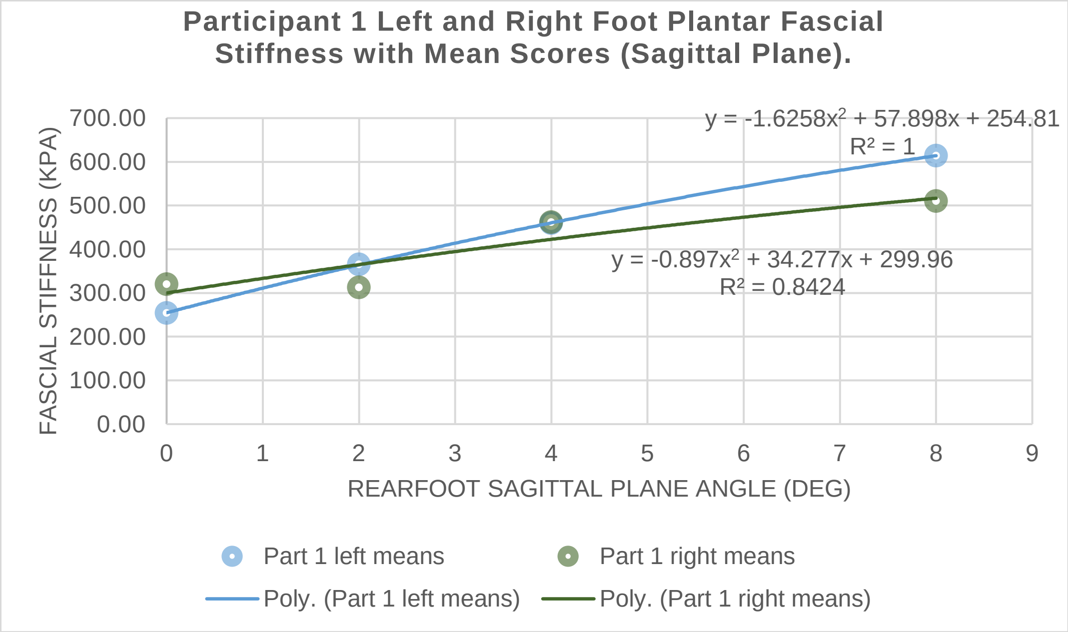


Figure 65: Graph Showing PFS And Sagittal Plane – Participant 1.

The Plantar Fascial Stiffness (PFS) shows a strong polynomial (order 2) correlation in the right foot (*Left* r^2 = *.10, Right* r^2 = *.82*). for the frontal plane angle and very strong polynomial (order 2) correlation in the sagittal plane for both feet *(Left* r^2 = *1.0, Right* r^2 = *.84*). The PFS also increased as the frontal plane angle moved into inversion and eversion. The PFS also increased as the sagittal plane angle increased.

5.4.2 Participant 2

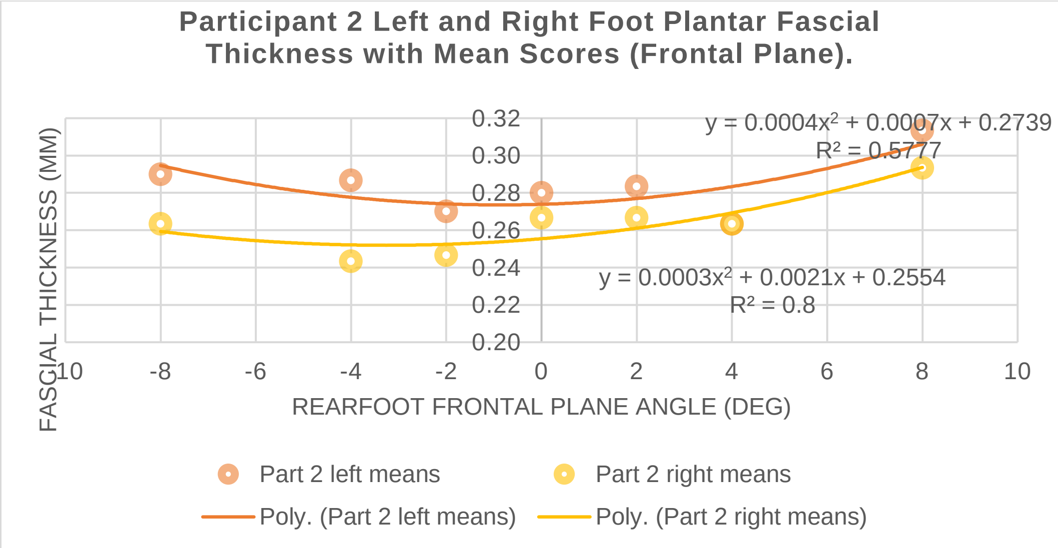


Figure 66: Graph Showing PFT And Frontal Plane – Participant 2.

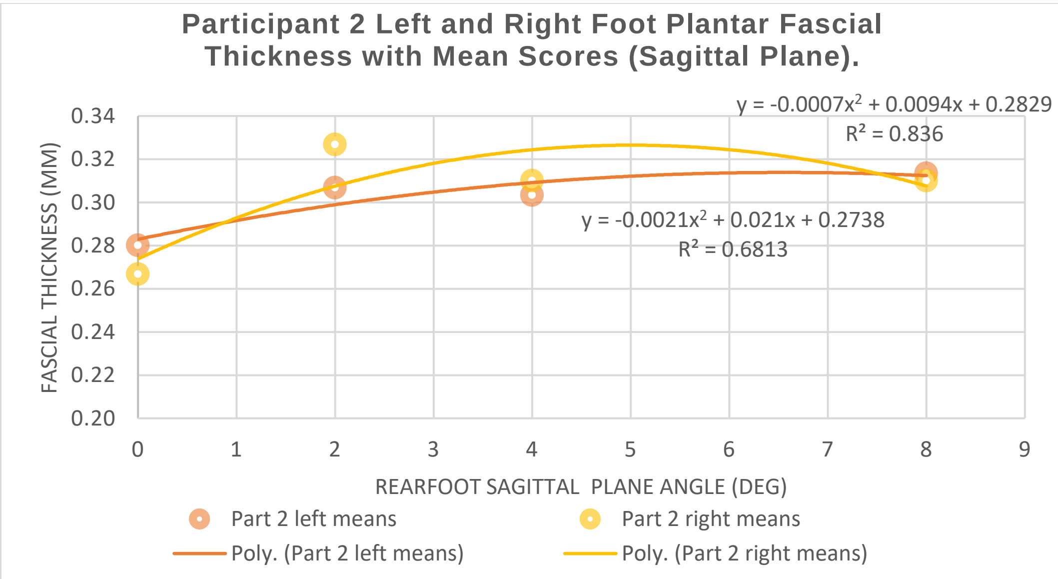


Figure 67: Graph Showing PFT And Sagittal Plane – Participant 2

Participant 2 shows similar pattern to participant 1 with the PFT showing stronger corelation (*Left r^2 = .68, Right r^2 = .84*). The right foot shows a drop in the PFT after an initial increase in the sagittal plane angle.

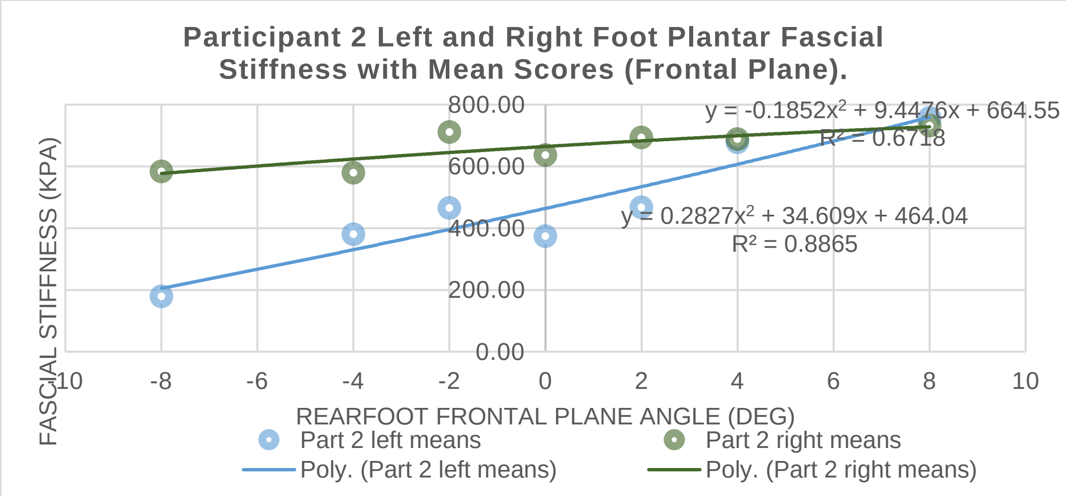


Figure 68: Graph Showing PFS And Frontal Plane – Participant 2.

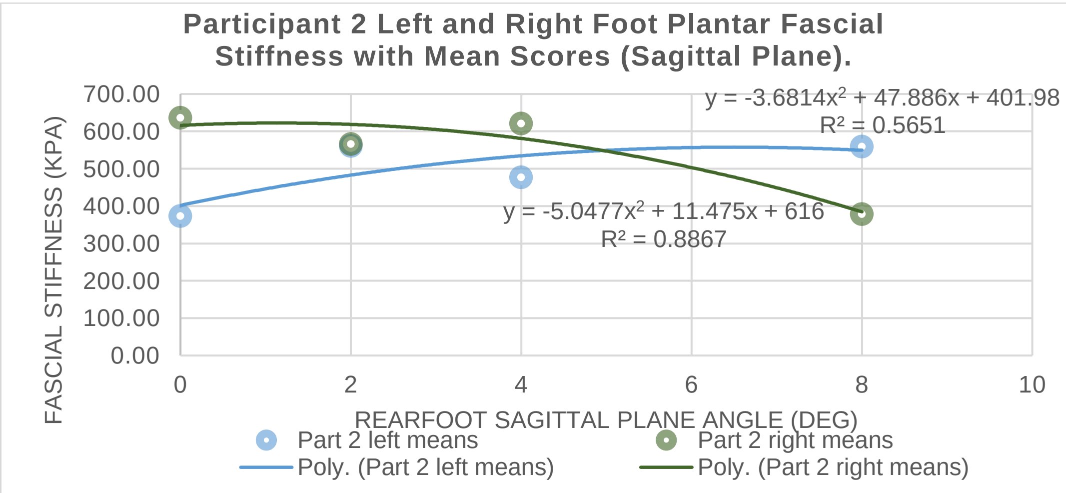


Figure 69: : Graph Showing PFS And Sagittal Plane – Participant 2.

The Plantar Fascial Stiffness was a strong polynomial (order 2) correlation in both feet (*Left* r^2 = *.67, Right* r^2 = *.89*). for the frontal plane angle and strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left r^2 = .89, Right r^2 = .57)* but stronger in the right. The right foot also shows the same pattern of decreasing PFS as the PFT decreased.

5.4.3 Participant 3

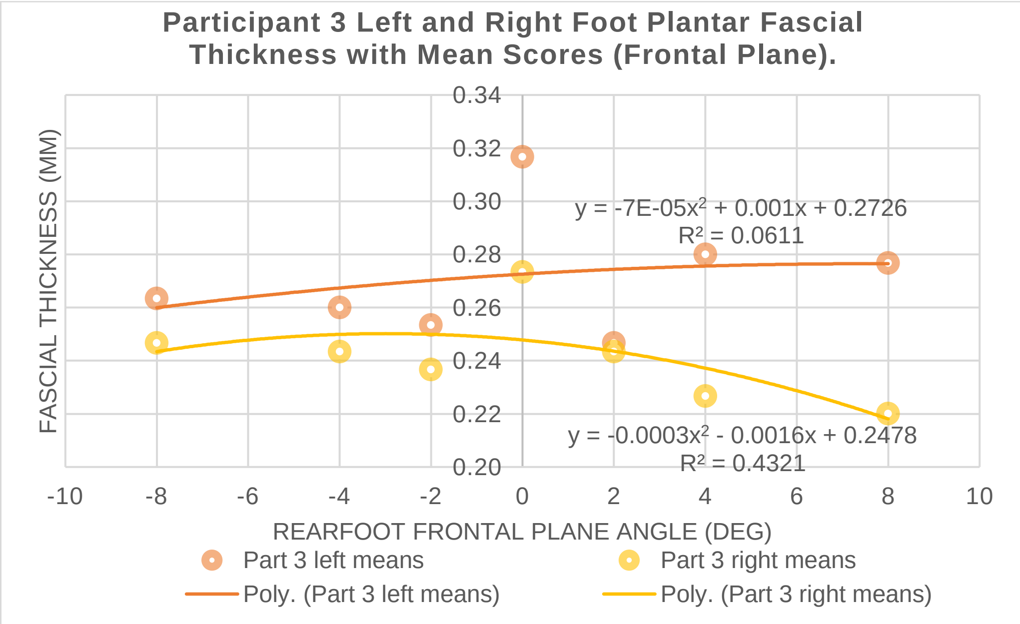


Figure 70: Graph Showing PFT And Frontal Plane – Participant 3.

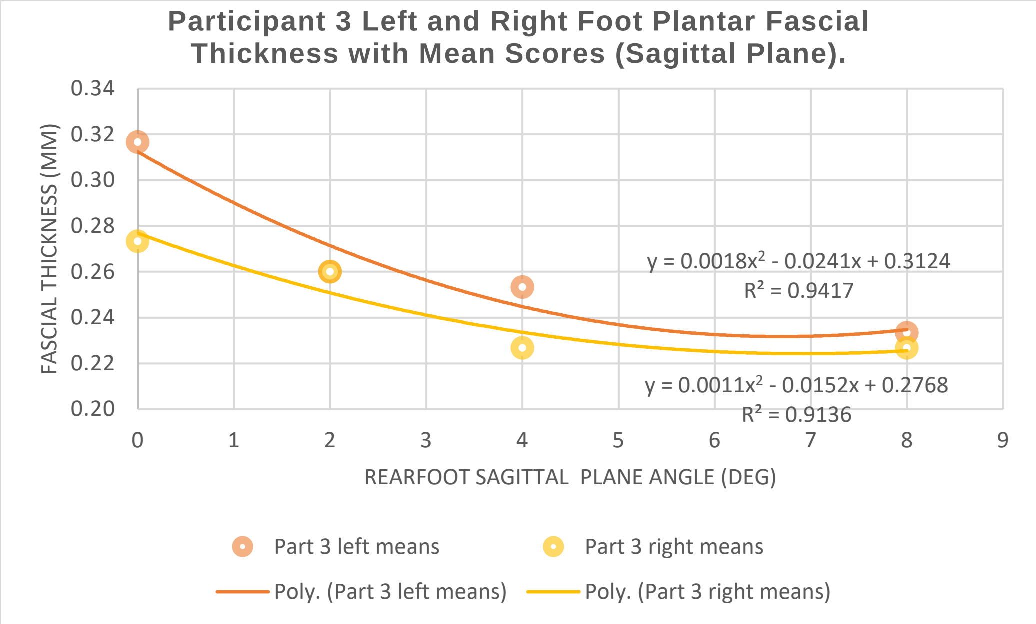


Figure 71: Graph Showing PFT And Sagittal Plane – Participant 3.

Participant 3 shows similar pattern on the left foot but an inverse relationship on the right foot with the PFT showing moderate polynomial (order 2) corelation on the right and weak polynomial (order 2) correlation on the left (*Left r^2 = .06, Right r^2 = .43*). Both feet show a drop in the PFT with an initial increase in the sagittal plane angle with strong polynomial (order 2) correlation (*Left r^2 = .94, Right r^2 = .91*).

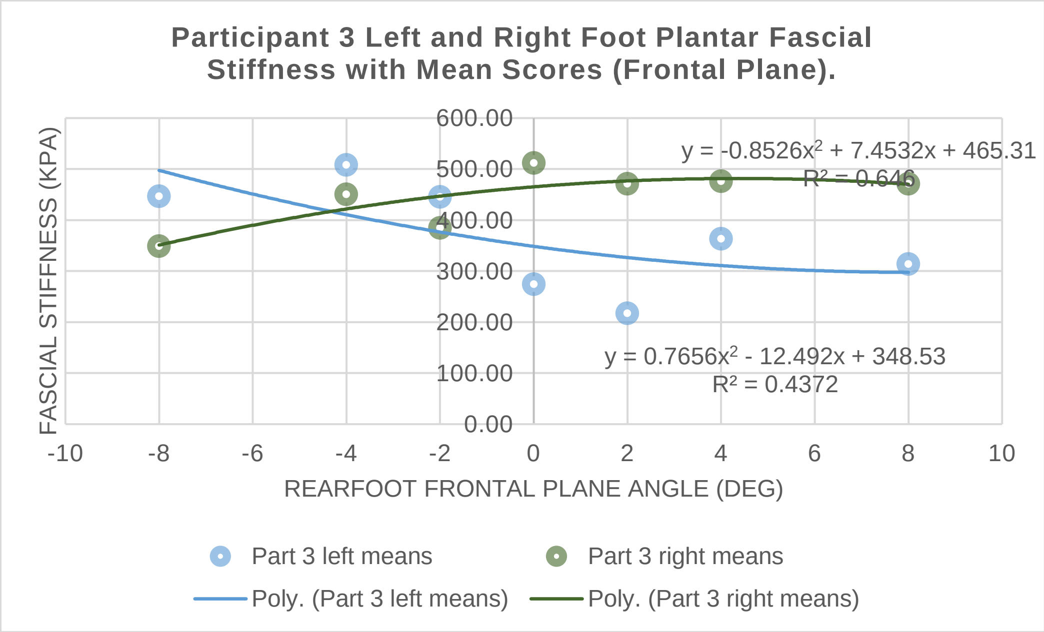


Figure 72: Graph Showing PFS And Frontal Plane – Participant 3.

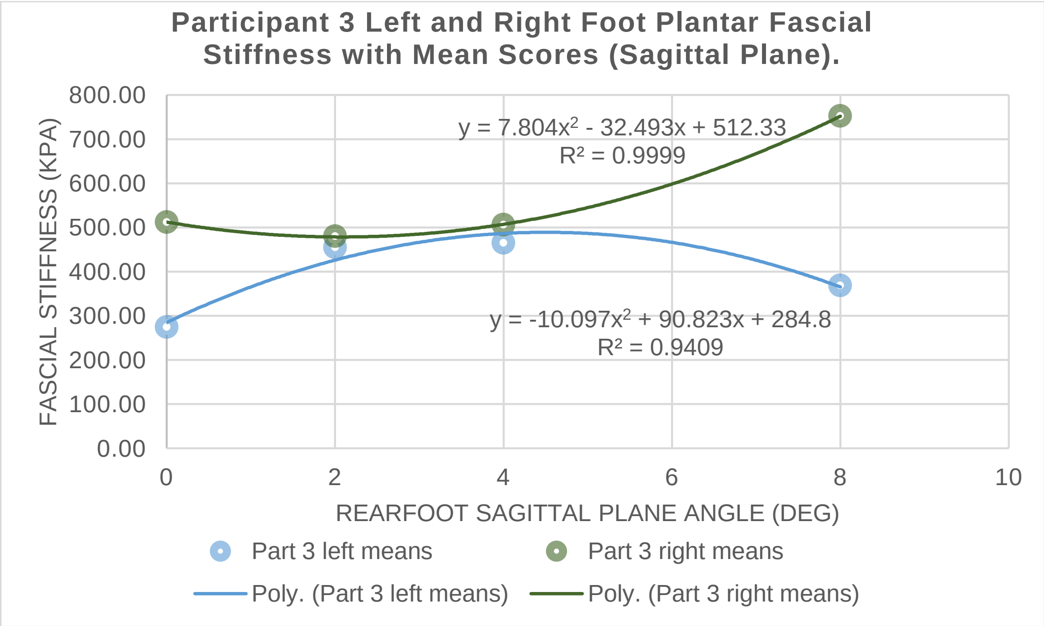


Figure 73: Graph Showing PFS And Sagittal Plane – Participant 3.

The Plantar Fascial Stiffness was a moderate polynomial (order 2) correlation in both feet (*Left* r^2 *= .65, Right* r^2 *= .44*). for the frontal plane angle but an inverse relationship between left and right. There was a strong polynomial (order 2) correlation in the sagittal plane for both feet *(Left* r^2 *= .99, Right* r^2 *= .94*) but the left also shows a decrease in PFS after 4^0 of sagittal plane motion.

5.4.4 Participant 4

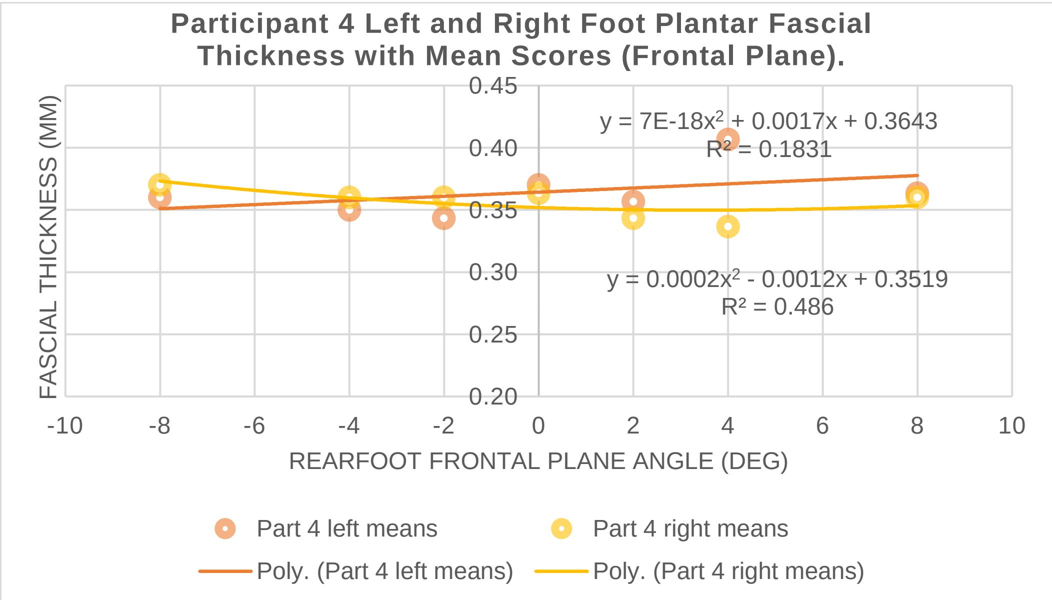


Figure 74: Graph Showing PFT And Frontal Plane – Participant 4.

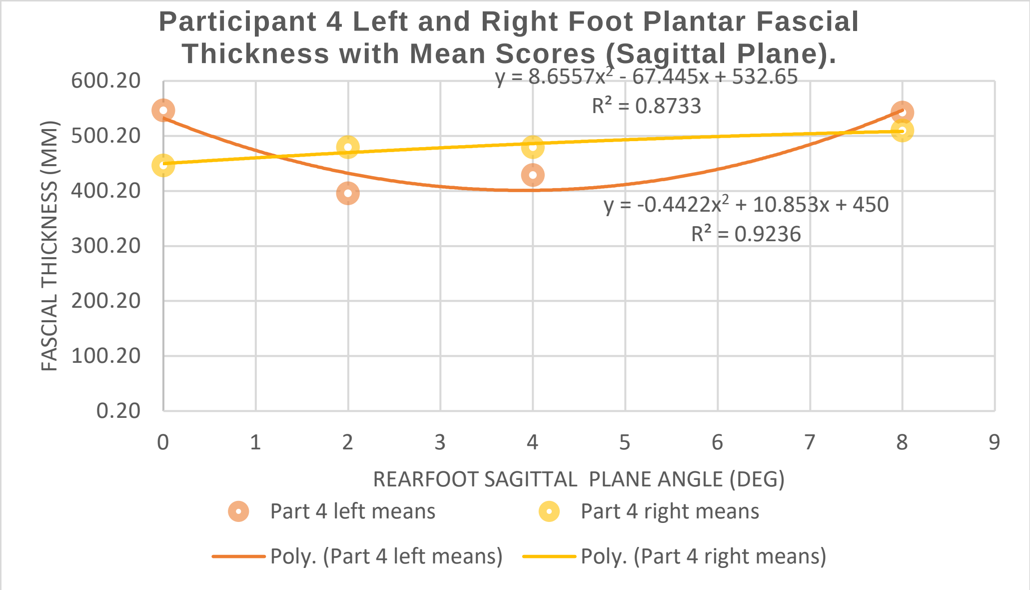


Figure 75: Graph Showing PFT And Sagittal Plane – Participant 4.

Participant 4 shows similar pattern on both feet for the PFT and shows weak to moderate corelation with right better than the left (*Left* r^2 *= .18, Right* r^2 *= .49*). Both feet show a relatively flat graphical appearance with little change in the PFT in the frontal plane angle. The sagittal plane shows increasing PFT with a change in sagittal plane angle, but the left foot RCSP was high. There was a strong polynomial (order 2) correlation for an increase in PFT and increase in the sagittal plane angle (*Left* r^2 *= .87, Right* r^2 *= .92*).

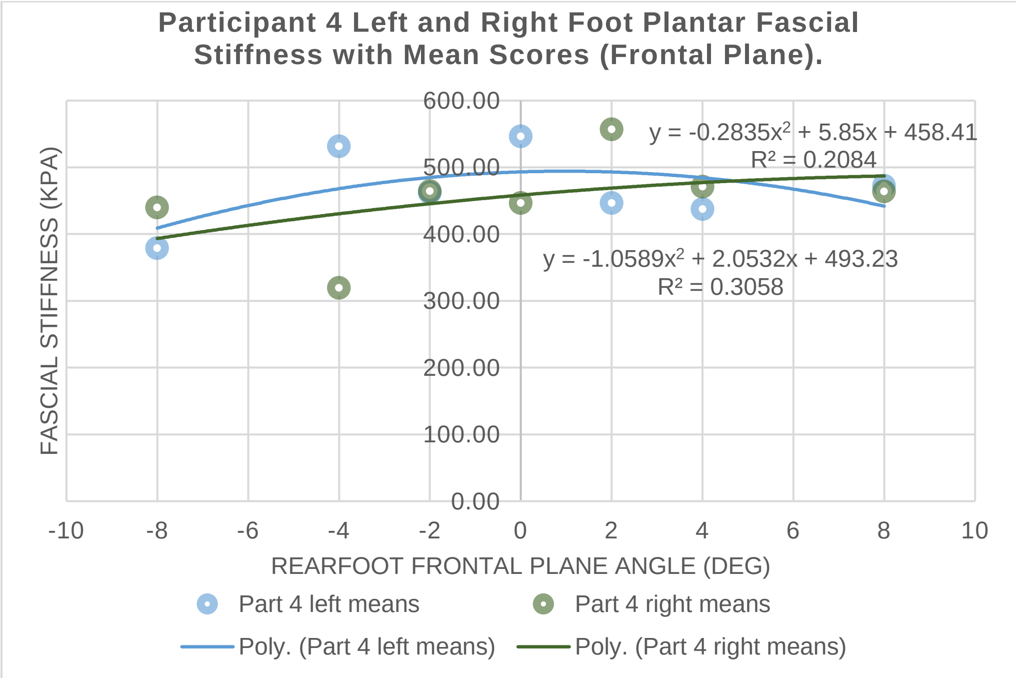


Figure 76: Graph Showing PFS And Frontal Plane – Participant 4.

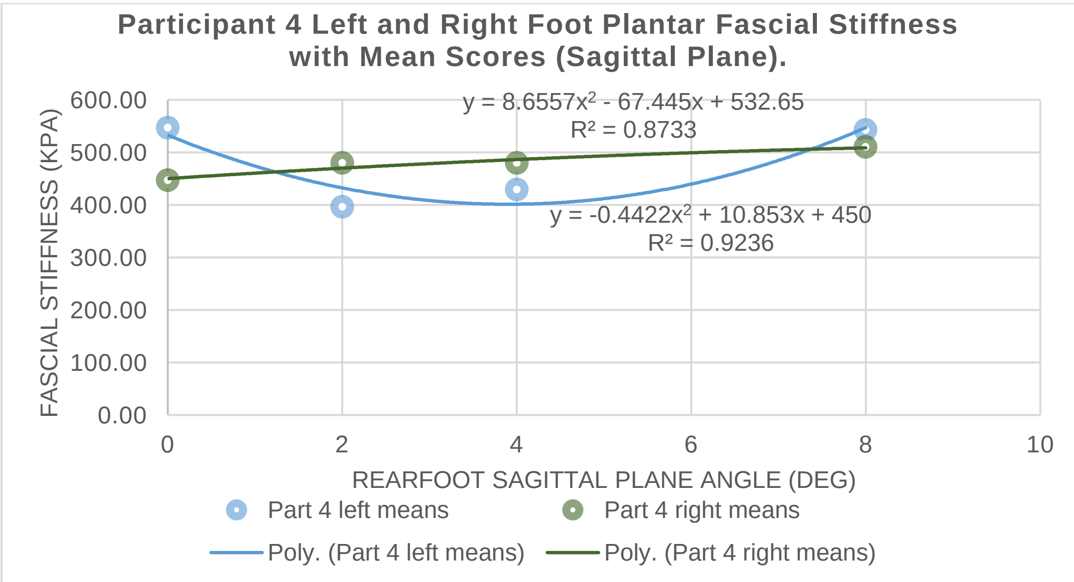


Figure 77: Graph Showing PFS And Sagittal Plane – Participant 4.

The Plantar Fascial Stiffness was a moderate polynomial (order 2) correlation in both feet (*Left* $r^2 = .31$, *Right* $r^2 = .21$) for the frontal plane angle but an inverse relationship between left and right. There was a strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left* $r^2 = .92$, *Right* $r^2 = .87$) but the left also shows a high RCSP.

5.4.5 Participant 5

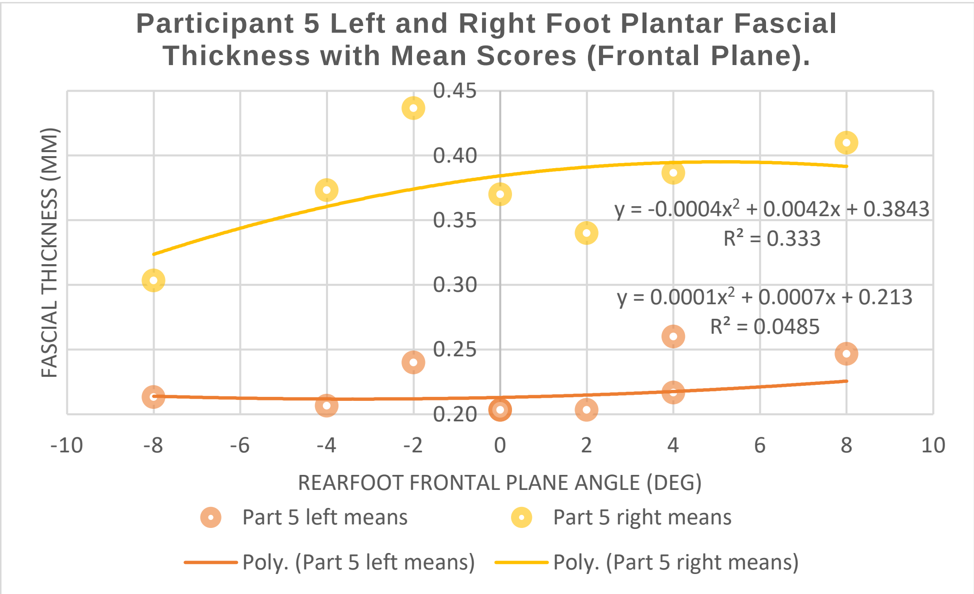


Figure 78: Graph Showing PFT And Frontal Plane – Participant 5.

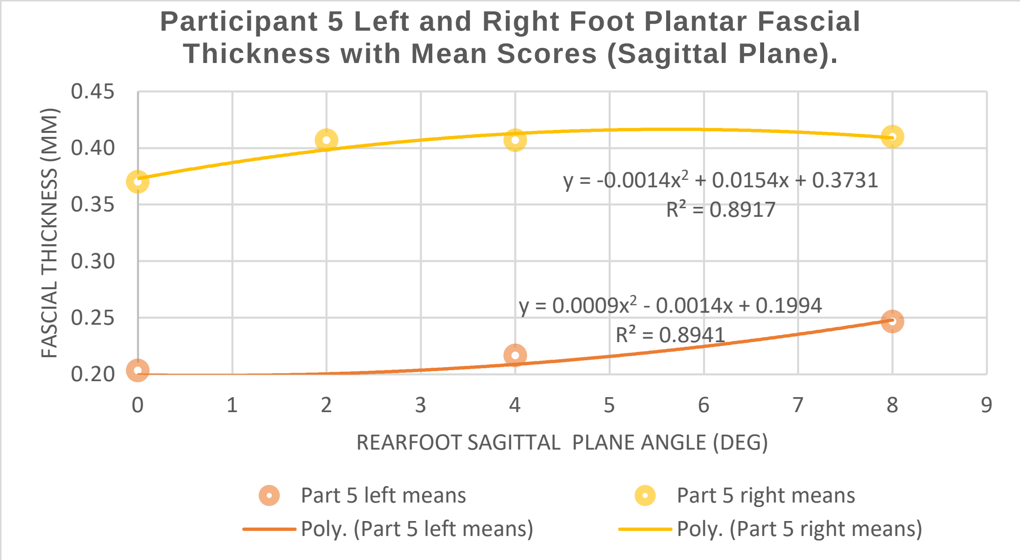


Figure 79: Graph Showing PFT And Sagittal Plane - Participant 5.

Participant 5 shows similar pattern on both feet for the PFT and shows weak polynomial (order 2) correlation with the right better than the left (*Left* r^2 = *.33, Right* r^2 = *.05*). Both feet show relatively variable data with a large difference between the left and right foot in the PFT in the frontal plane angle. The sagittal plane shows increasing PFT with a change in sagittal plane angle, but the right foot PFT was thicker than the left. The polynomial (order 2) correlation was strong for an increase in PFT and increase in the sagittal plane angle (*Left* r^2 = *.89, Right* r^2 = *.89*).

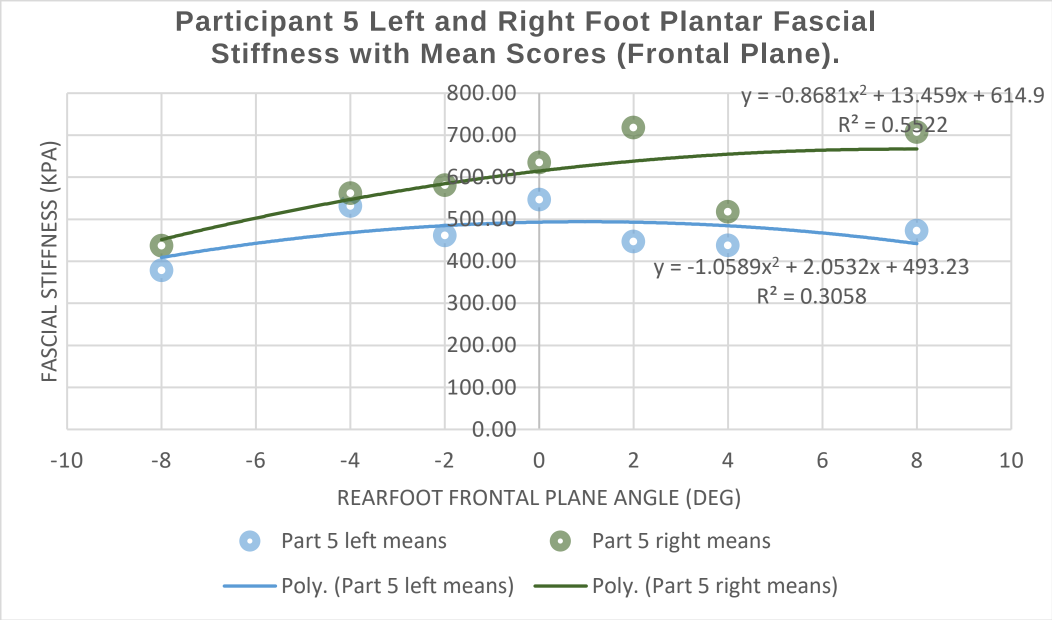


Figure 80: Graph Showing PFS And Frontal Plane – Participant 5.

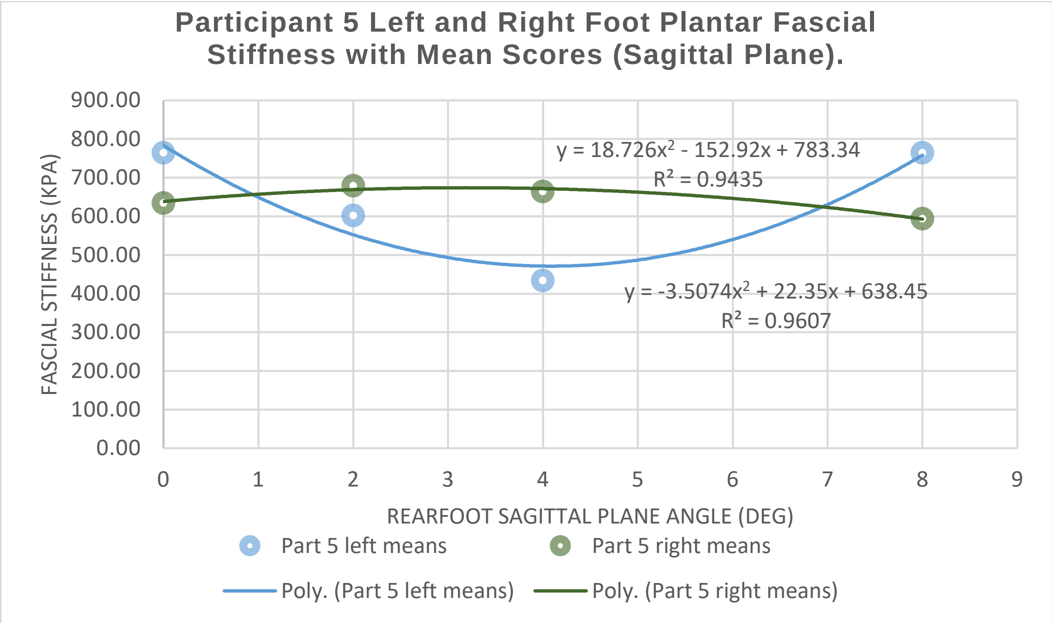


Figure 81: Graph Showing PFS And Sagittal Plane – Participant 5.

The Plantar Fascial Stiffness was a moderate polynomial (order 2) correlation in both feet (*Left* r^2 *= .31, Right* r^2 *= .52*) for the frontal plane angle but an inverse relationship between left and right. There was a strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left* r^2 *= .96, Right* r^2 *= .96*) but the left also shows an inverse relationship.

5.4.6 Participant 6

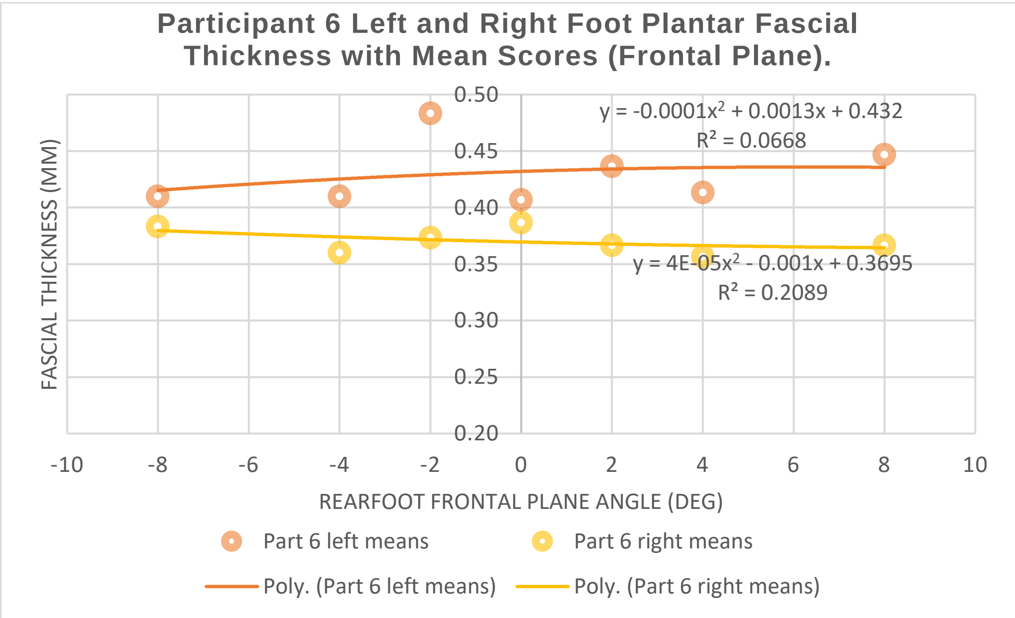


Figure 82: Graph Showing PFT And Frontal Plane – Participant 6.

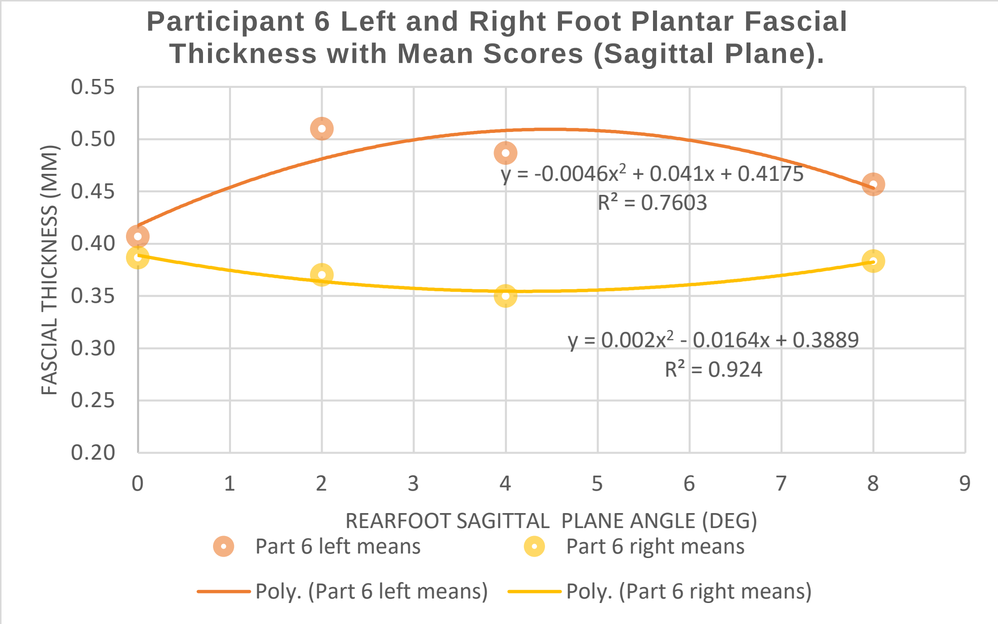


Figure 83: Graph Showing PFT And Sagittal Plane – Participant 6.

Participant 6 shows similar pattern on both feet for the PFT and shows weak polynomial (order 2) correlation with right better than the left (*Left* r^2 *= .22, Right* r^2 *= .07*). The sagittal plane shows increasing PFT with a change in sagittal plane angle, but the left foot PFT was thicker than the right. The polynomial (order 2) correlation was strong for an increase in PFT and increase in the sagittal plane angle (*Left* r^2 *= .92, Right* r^2 *= .76*), but the right foot showed initial reduction in PFT.

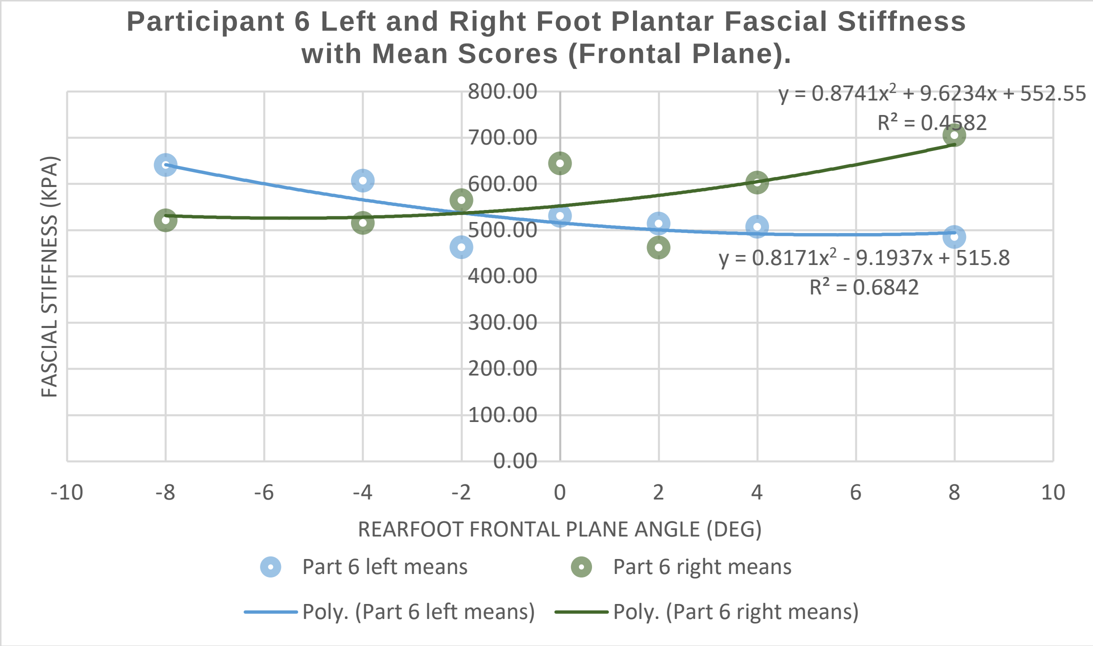


Figure 84: Graph Showing PFS And Frontal Plane – Participant 6.

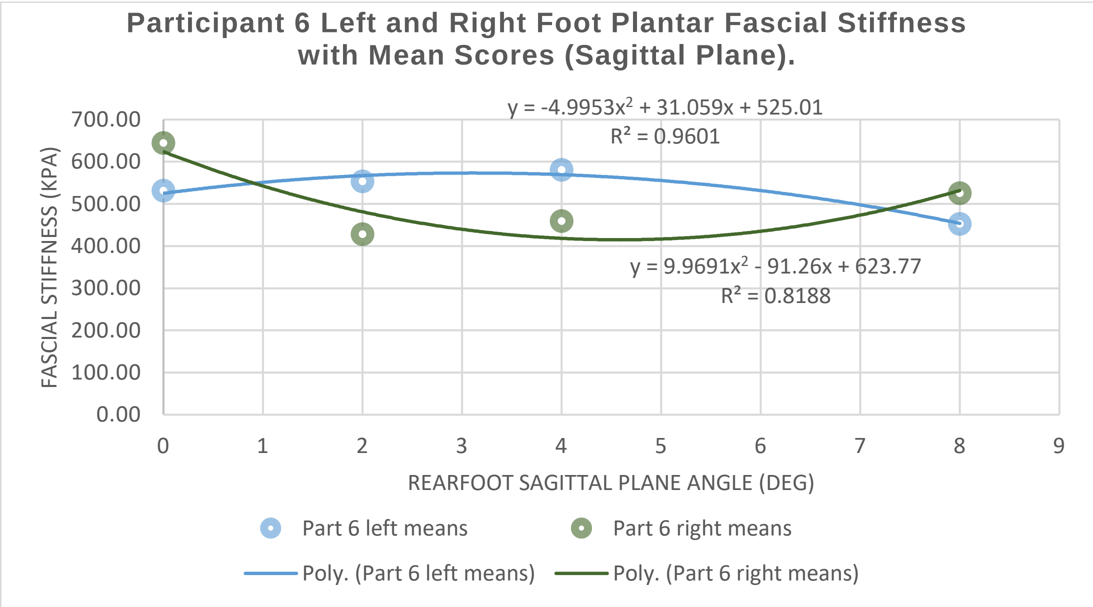


Figure 85: Graph Showing PFS And Sagittal Plane – Participant 6.

The Plantar Fascial Stiffness was a moderate polynomial (order 2) correlation in both feet (*Left r^2 = .68, Right r^2 = .46*) for the frontal plane angle but an inverse relationship between left and right. There was a strong polynomial (order 2) correlation in the sagittal plane for both feet (Left r^2 = .96, Right r^2 = .81) but the left also shows an inverse relationship.

5.4.7 Participant 7

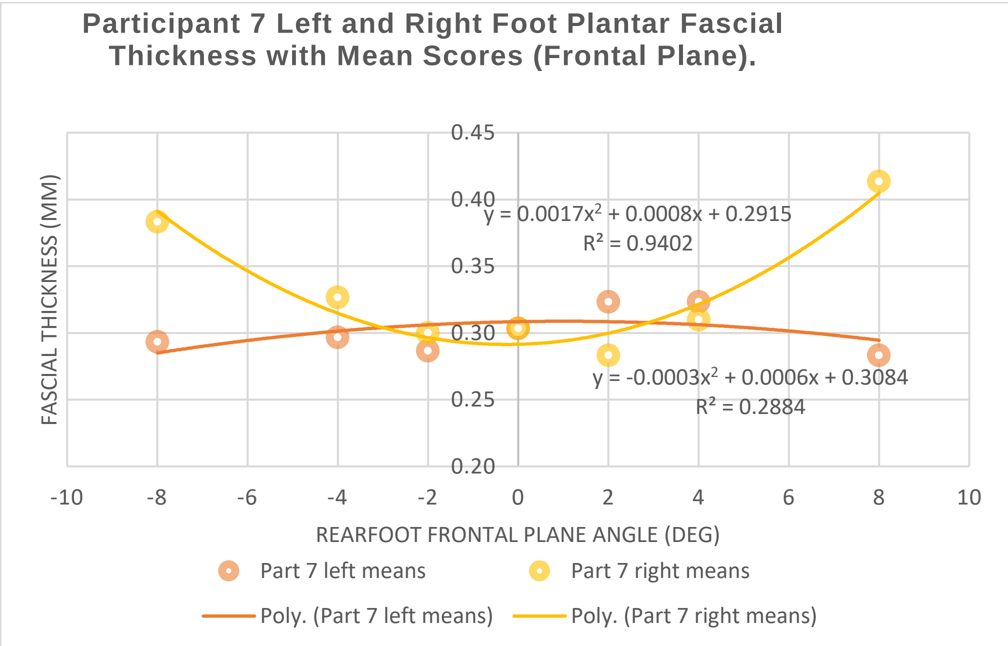


Figure 86: Graph Showing PFT And Frontal Plane – Participant 7.

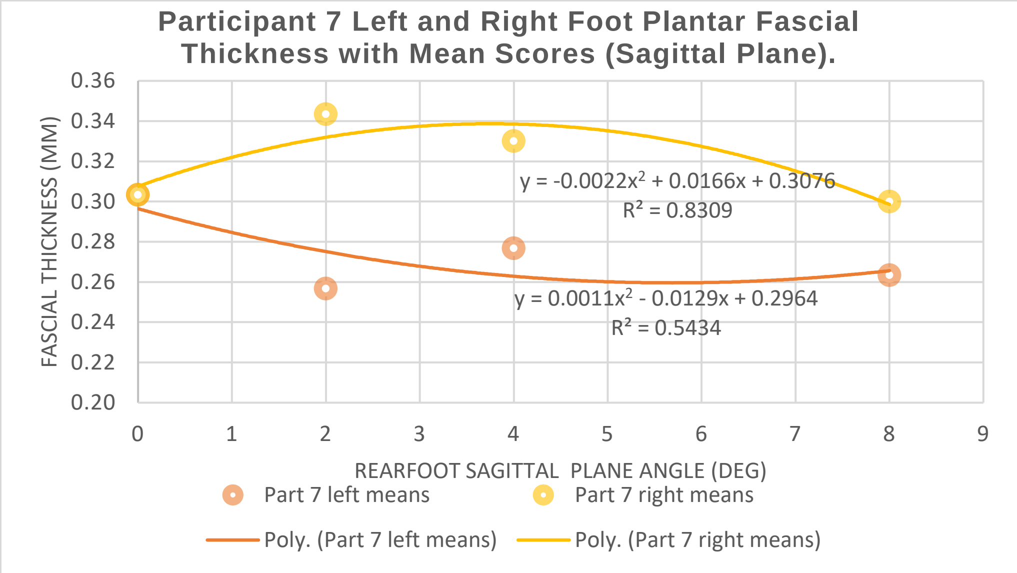


Figure 87: Graph Showing PFT And Sagittal Plane – Participant 7.

Participant 7 shows a different pattern on both feet for the PFT with the right showing an inverse relationship to the left with strong polynomial (order 2) correlation on the right and moderate on the left (*Left* r^2 = *.29, Right* r^2 = *.94*). The sagittal plane shows increasing PFT initially with the right foot before decreasing. The left foot shows an inverse relationship to the right in sagittal plane angle, but the left foot PFT was thicker than the right. There was a strong polynomial (order 2) correlation for PFT in the right and moderate in the left in the sagittal plane angle (*Left* r^2 = *.54, Right* r^2 = *.83*).

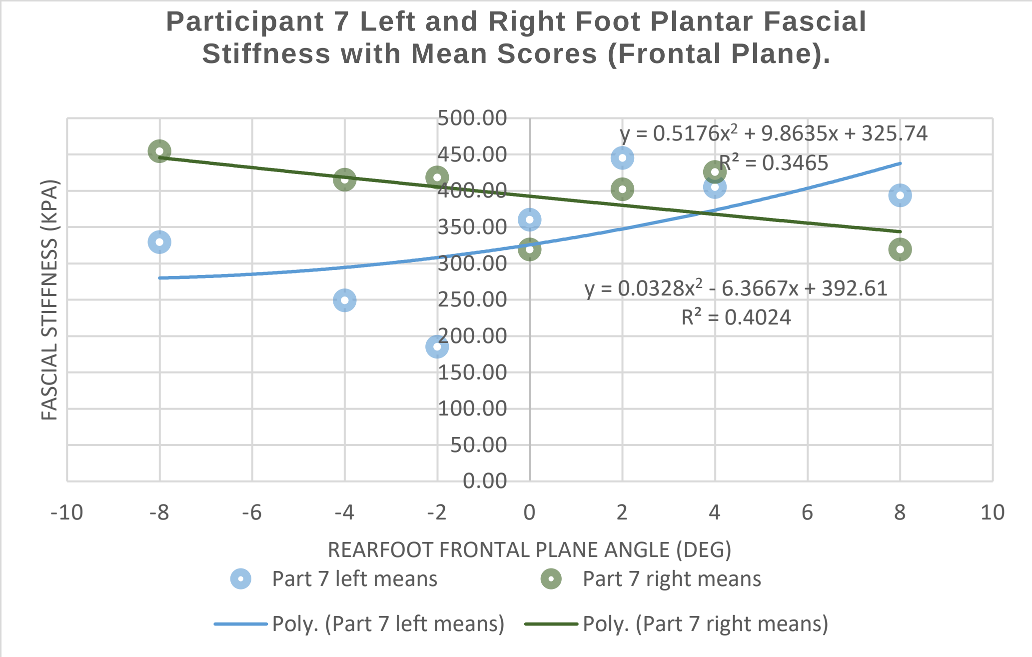


Figure 88: Graph Showing PFS And Frontal Plane – Participant 7.

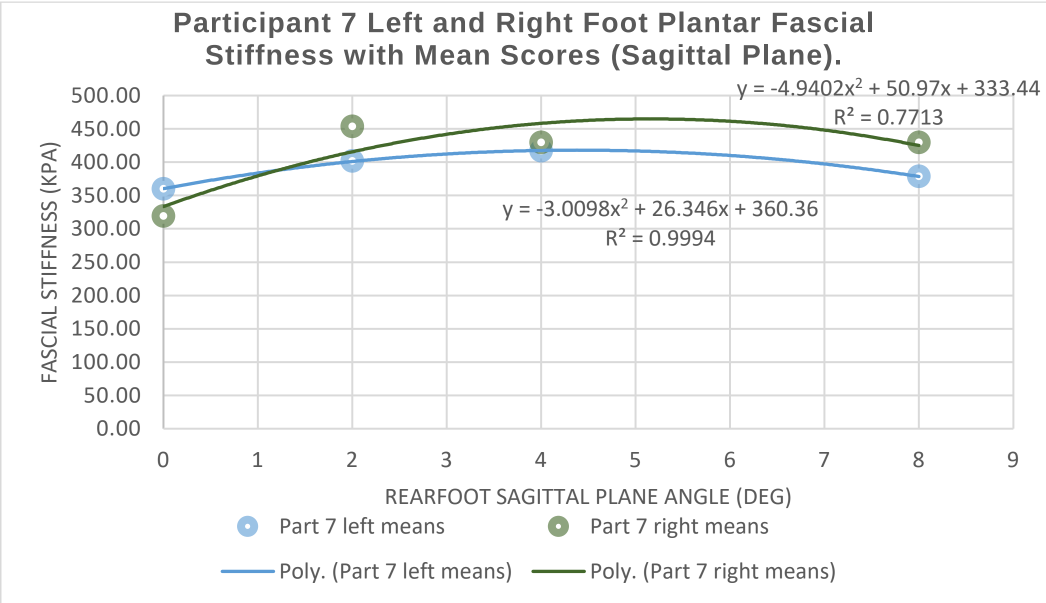


Figure 89: Graph Showing PFS And Sagittal Plane – Participant 7.

The Plantar Fascial Stiffness was a moderate polynomial (order 2) correlation in both feet (*Left* $r^2 = .35$, *Right* $r^2 = .40$) for the frontal plane angle but an inverse relationship between left and right. There was a strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left* $r^2 = .99$, *Right* $r^2 = .77$) with a similar relationship between with the feet.

5.4.8 Participant 8

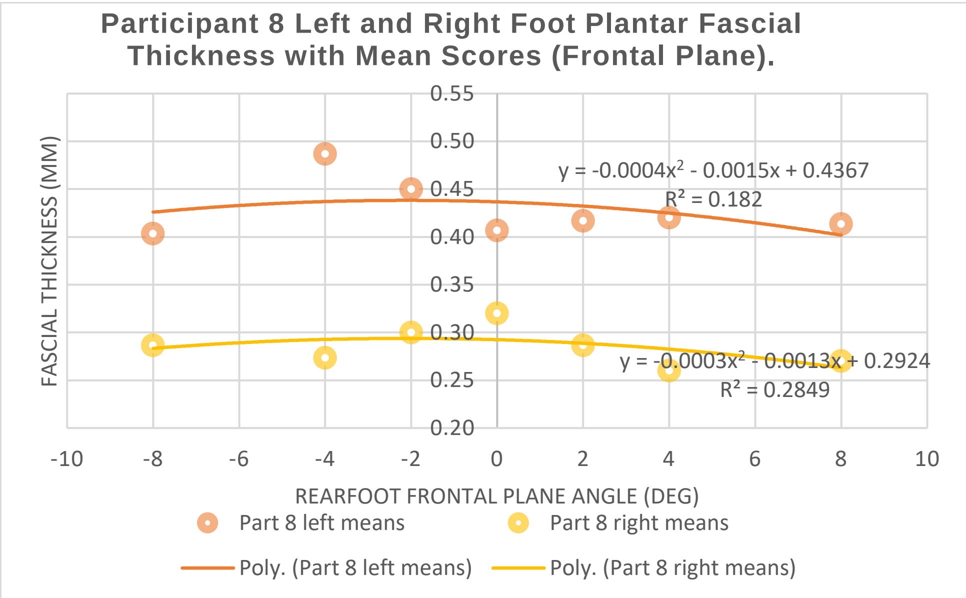


Figure 90: Graph Showing PFT And Frontal Plane – Participant 8.

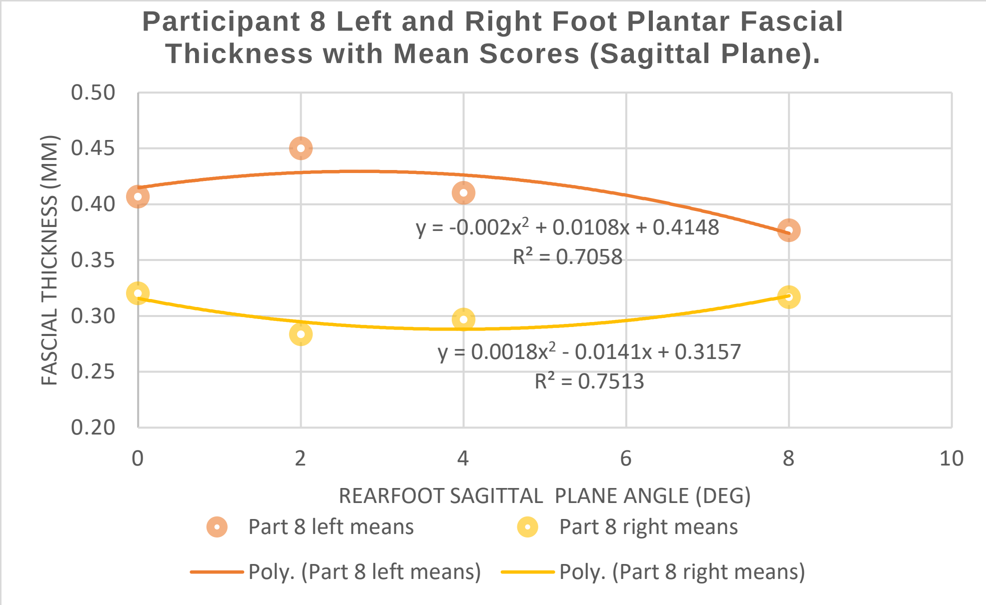


Figure 91: Graph Showing PFT And Sagittal Plane– Participant 8.

Participant 8 shows a similar pattern on both feet for the PFT with the left showing a greater thickness with weak polynomial (order 2) correlation on the left and moderate on the right (*Left r^2 = .18, Right r^2 = .28*). The sagittal plane shows increasing PFT initially with the left foot before decreasing. The right foot shows an inverse relationship to the left in sagittal plane angle, but the left foot PFT was thicker than the right. There was a strong polynomial (order 2) correlation for PFT in both feet in the sagittal plane angle (*Left r^2 = .71, Right r^2 = .75*).

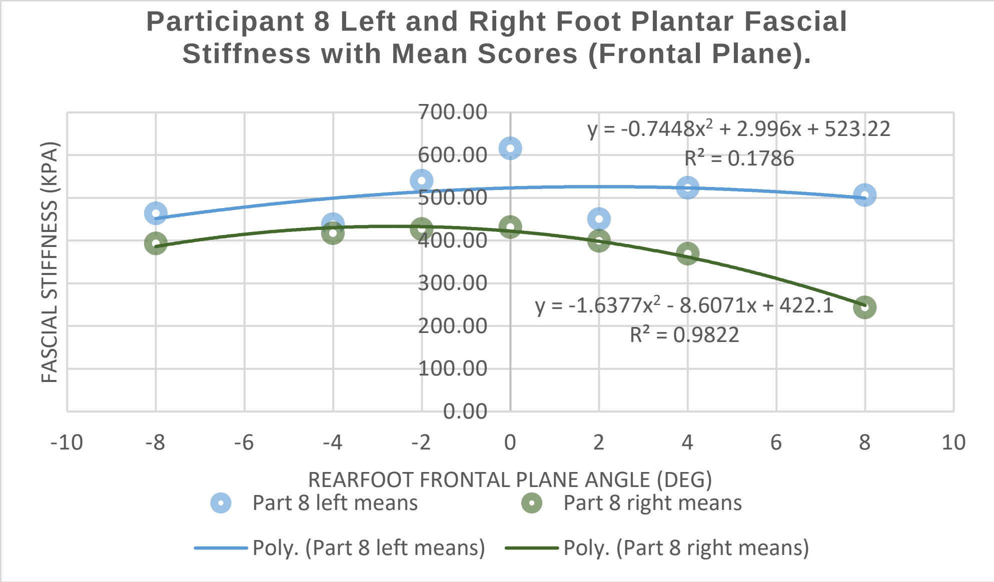


Figure 92: Graph Showing PFS And Frontal Plane – Participant 8.

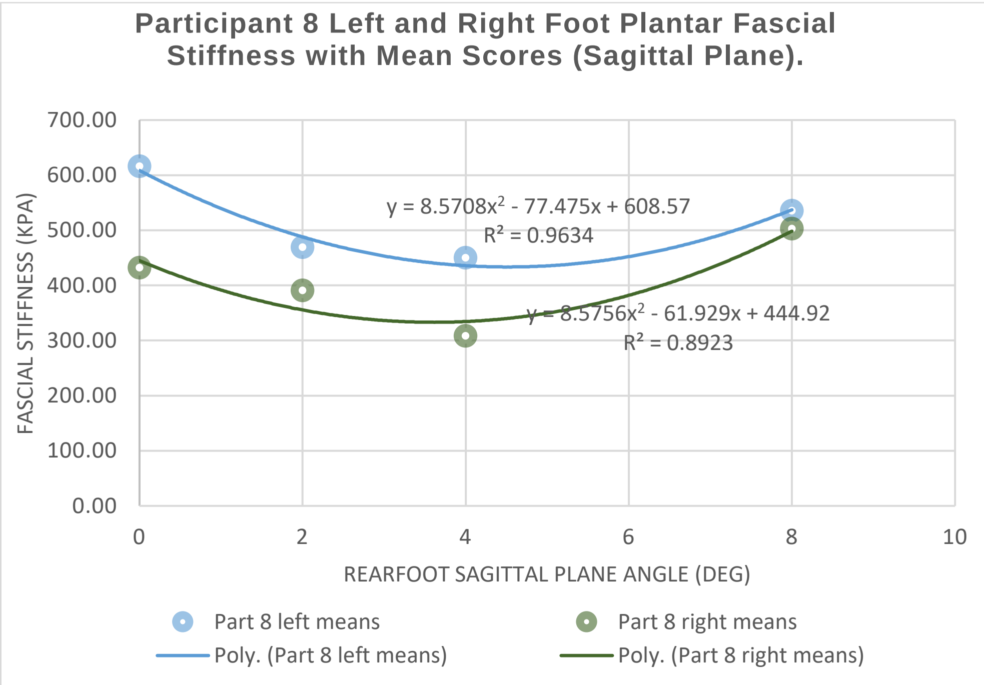


Figure 93: Graph Showing PFS And Sagittal Plane – Participant 8.

The Plantar Fascial Stiffness was a weak polynomial (order 2) correlation in the left foot but very strong in the right (*Left r^2 = .18, Right r^2 = .98*) for the frontal plane angle but an inverse relationship between left and right. There was a strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left r^2 = .96, Right r^2 = .89*) with a similar relationship between with the feet.

5.4.9 Participant 9

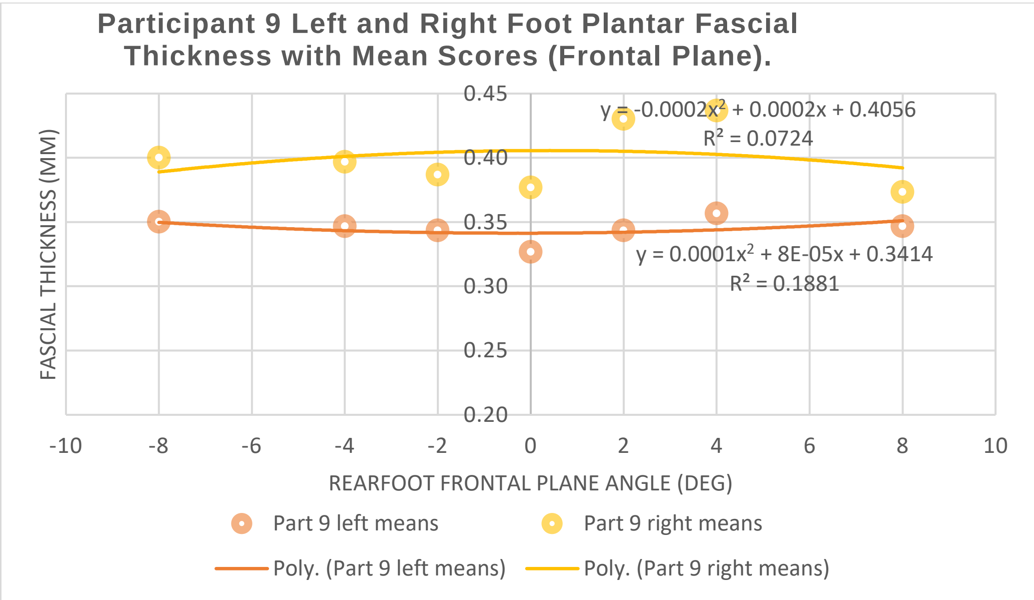


Figure 94: Graph Showing PFT And Frontal Plane – Participant 9.

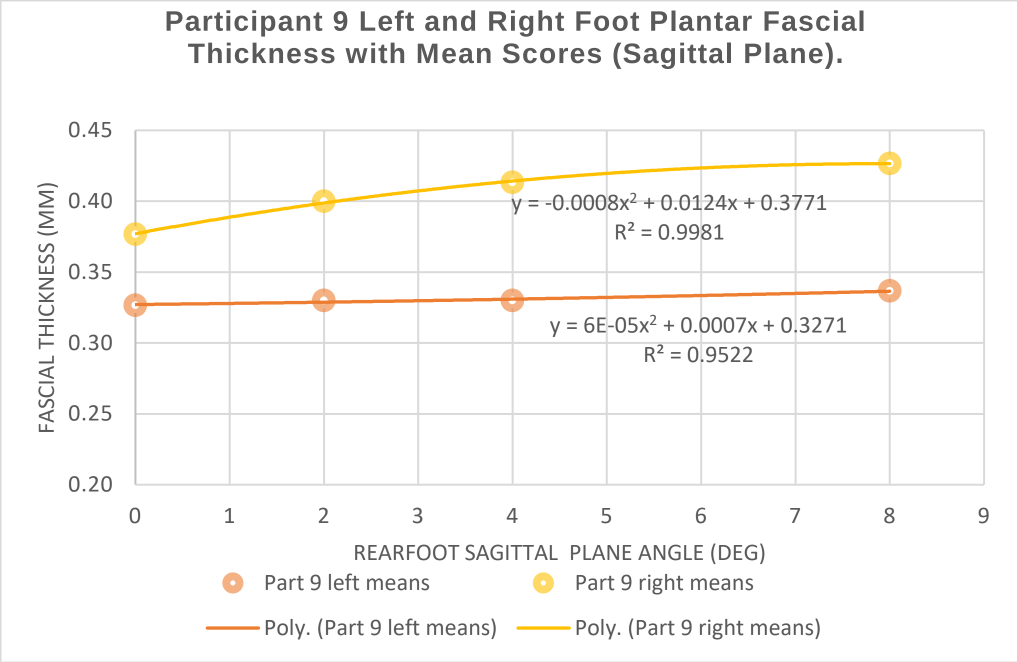


Figure 95: Graph Showing PFT And Sagittal Plane – Participant 9.

Participant 9 shows a similar pattern on both feet for the PFT with the right showing a greater thickness with weak polynomial (order 2) correlation on both feet (*Left* r^2 = *.19, Right* r^2 = *.07*). The data was variable for the right foot. The sagittal plane shows increasing PFT with both feet with the right thicker than the left. There was a strong polynomial (order 2) correlation for PFT in both feet in the sagittal plane angle (*Left* r^2 = *.95, Right* r^2 = *1*).

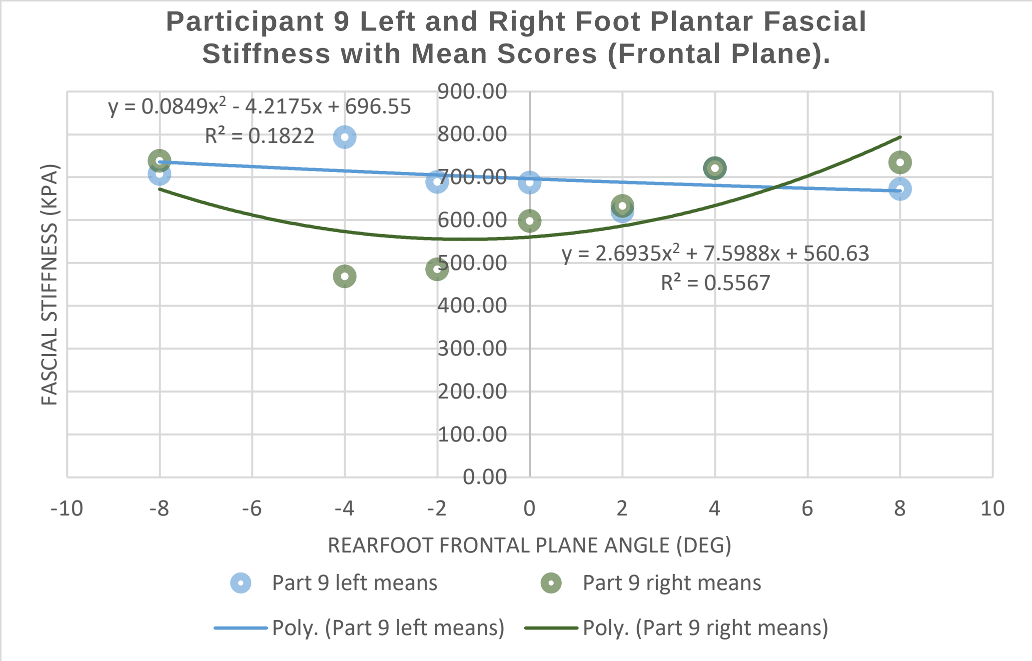


Figure 96: Graph Showing PFS And Frontal Plane – Participant 9.

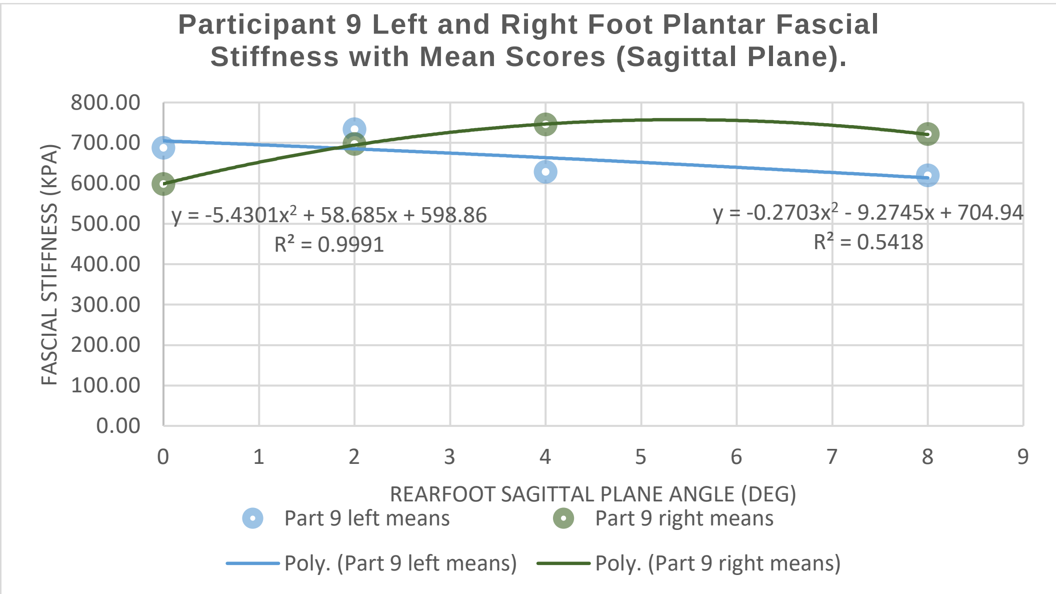


Figure 97: Graph Showing PFS And Sagittal Plane – Participant 9.

The Plantar Fascial Stiffness was a weak polynomial (order 2) correlation in the left foot but moderate in the right (*Left* r^2 *= .18, Right* r^2 *= .56*) for the frontal plane angle, but an inverse relationship between left and right. There was a very strong polynomial (order 2) correlation in the sagittal plane for the right foot and a moderate for the left (*Left* r^2 *= .54, Right* r^2 *= 1*) with an inverse relationship between with the feet.

5.4.10 Participant 10

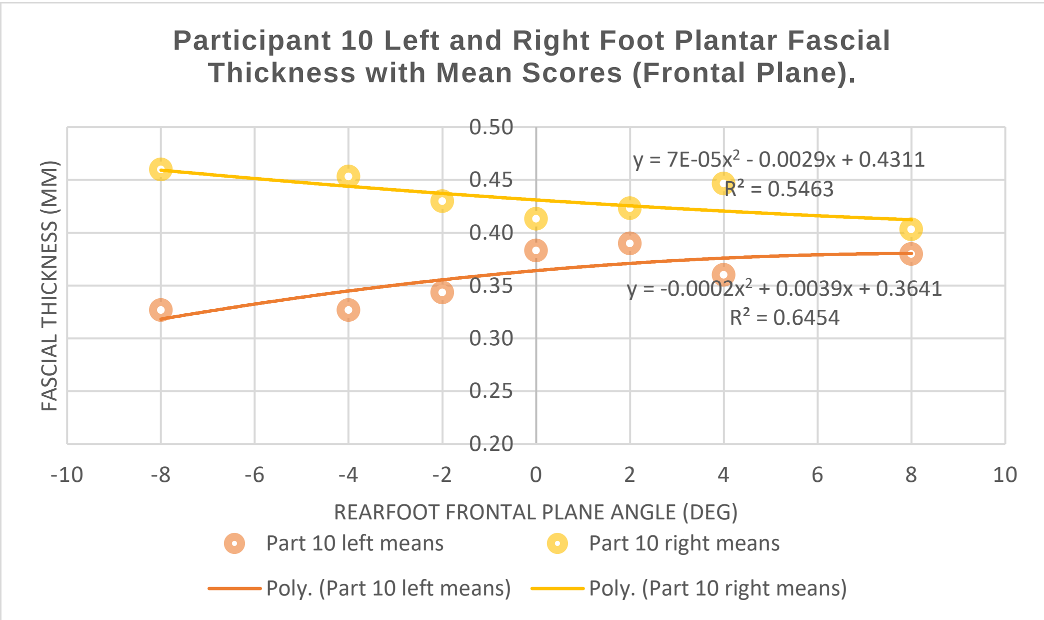


Figure 98: Graph Showing PFT And Frontal Plane – Participant 10.

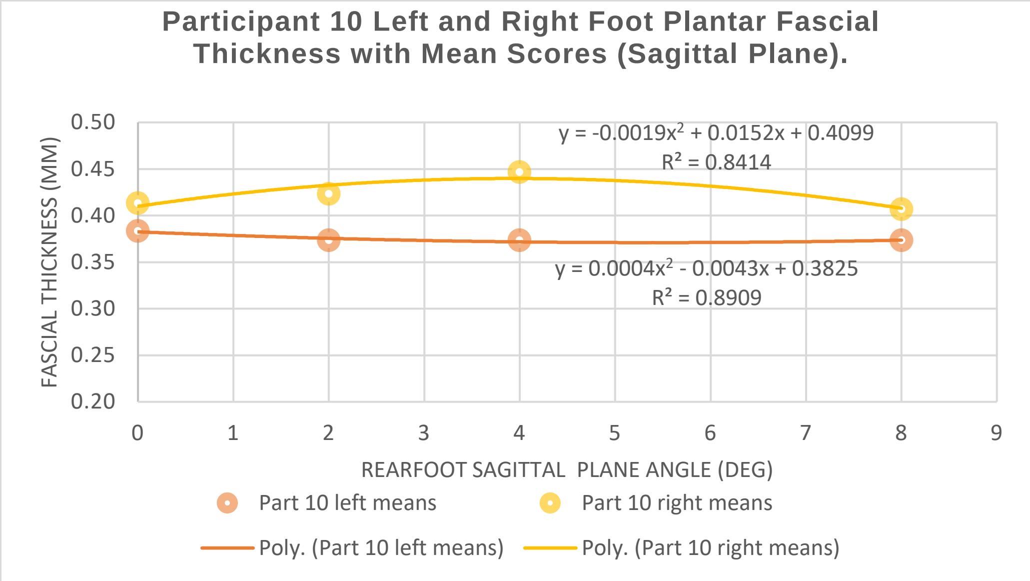


Figure 99: Graph Showing PFT And Sagittal Plane – Participant 10.

Participant 10 shows a different pattern on both feet for the PFT with the left showing a greater thickness with moderate polynomial (order 2) correlation on both feet (*Left r^2 = .64, Right r^2 = .55*). The left has an inverse relationship to the right. The sagittal plane shows increasing PFT on the right foot before decreasing, with the left having little change. The right was thicker than the left. There was a strong polynomial (order 2) correlation for PFT in both feet in the sagittal plane angle *(Left r^2 = .89, Right r^2 = .84*).

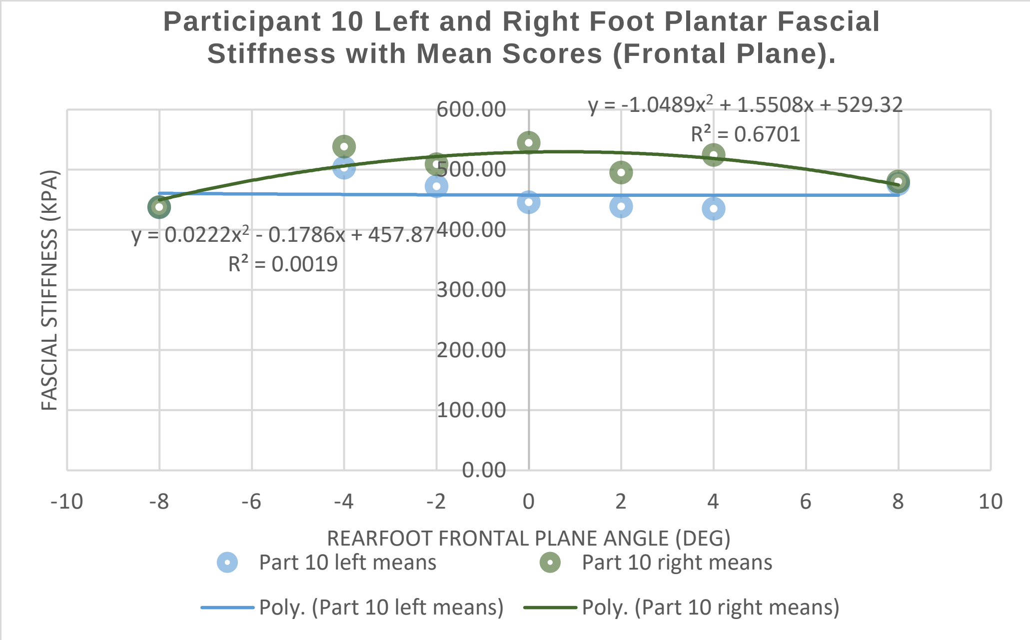


Figure 100: Graph Showing PFS And Frontal Plane – Participant 10.

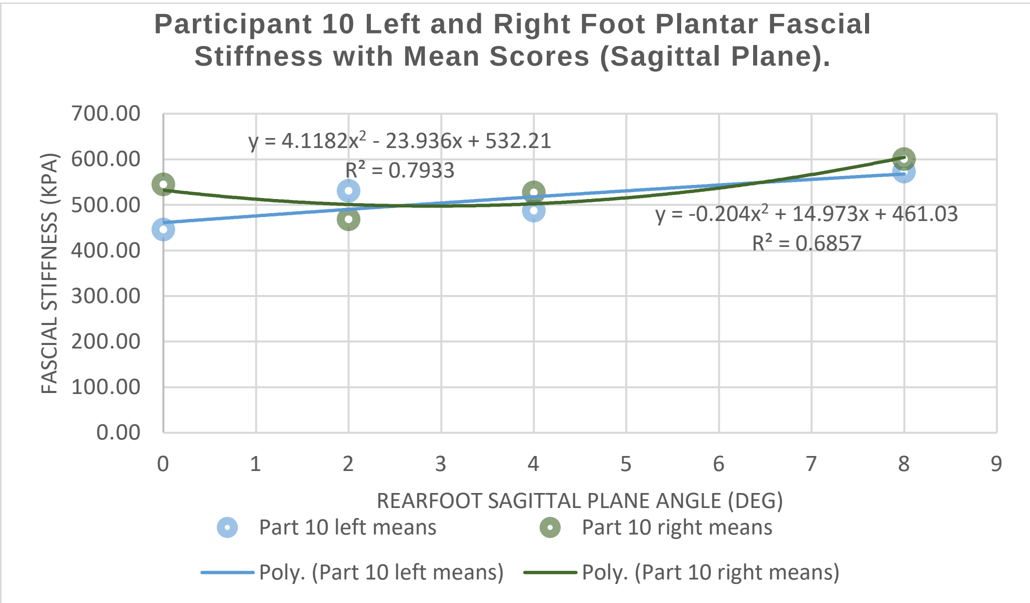


Figure 101: Graph Showing PFS And Sagittal Plane – Participant 10.

The Plantar Fascial Stiffness was a weak polynomial (order 2) correlation in the left foot but strong in the right (*Left* r^2 *= .0, Right* r^2 *= .67*) for the frontal plane angle but an inverse relationship for the right foot. There was a very strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left* r^2 *= .69, Right* r^2 *= .79*) with an increasing relationship to the increase in the sagittal plane angle.

5.4.11 Participant 11

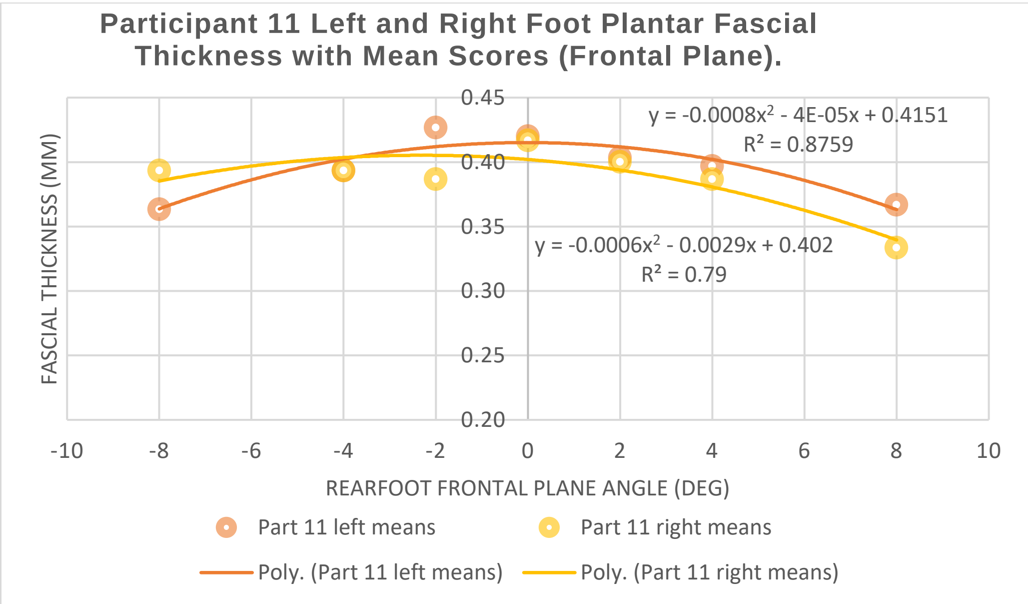


Figure 102: Graph Showing PFT And Frontal Plane – Participant 11.

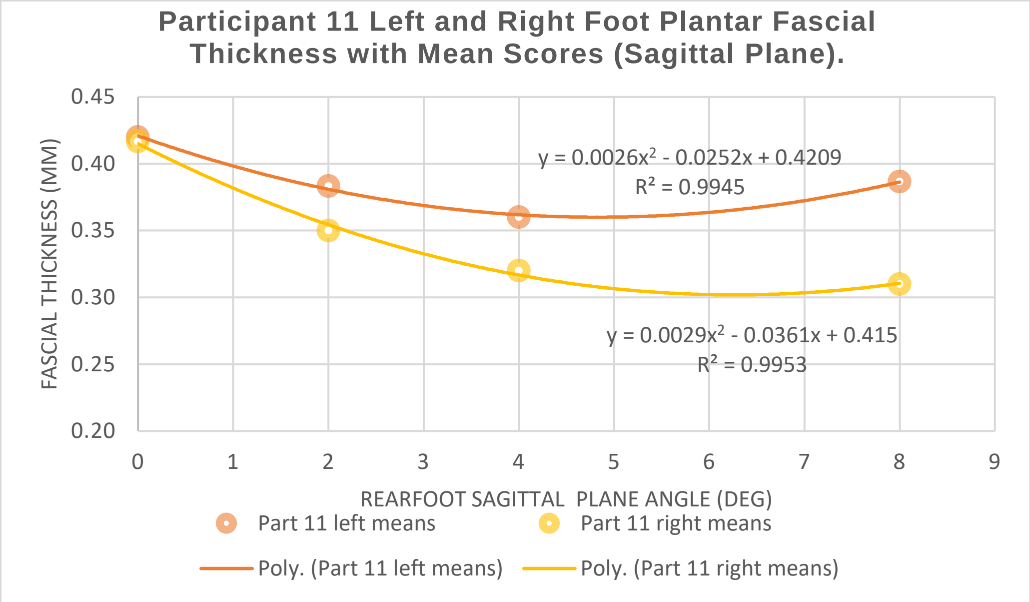


Figure 103: Graph Showing PFT And Sagittal Plane – Participant 11.

Participant 11 shows an inverse pattern on both feet for the PFT with the right showing a slighter greater thickness, with strong polynomial (order 2) correlation on both feet (*Left r^2 = .79, Right r^2 = .88*). The sagittal plane shows decreasing PFT on both feet. The right was thicker than the left. The was a strong polynomial (order 2) correlation for PFT in both feet in the sagittal plane angle (*Left r^2 = .99, Right r^2 = .99*).

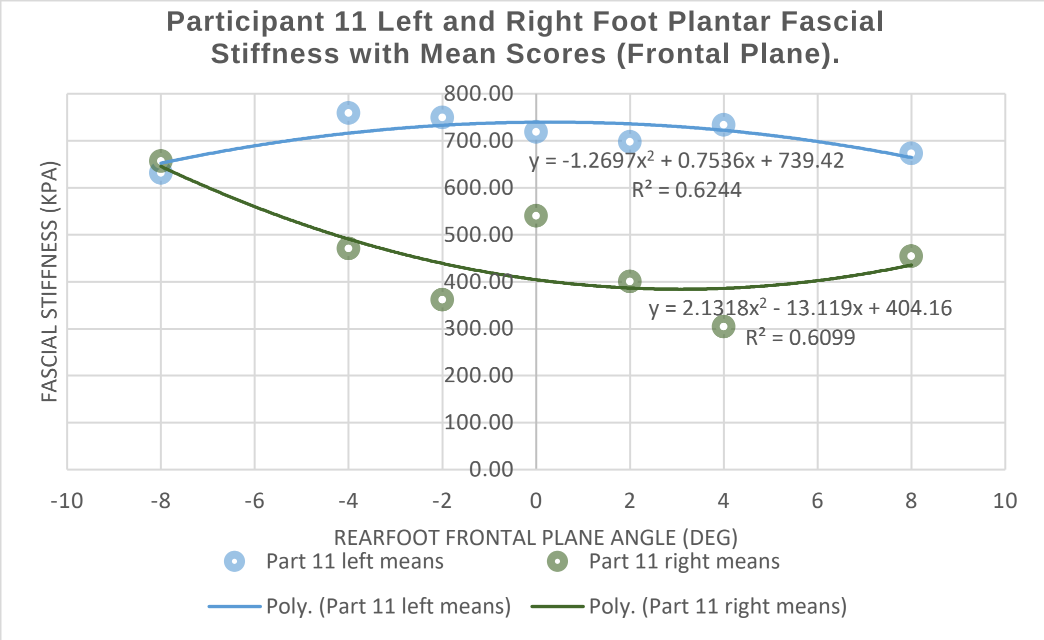


Figure 104: Graph Showing PFS And Frontal Plane – Participant 11.

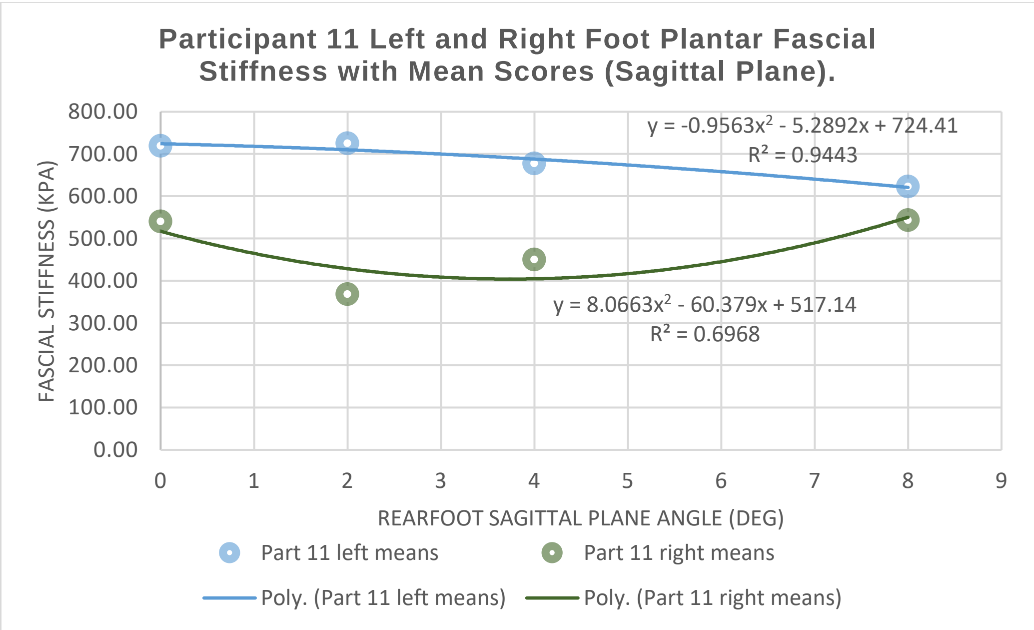


Figure 105: Graph Showing PFS And Sagittal Plane – Participant 11.

The Plantar Fascial Stiffness was a moderate polynomial (order 2) correlation in both feet (*Left* r^2 *= .62, Right* r^2 *= .61)* for the frontal plane angle but an inverse relationship for the right foot. There was a very strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left* r^2 *= .94, Right* r^2 *= .70*) with an increasing relationship on the right and decreasing stiffness to the increase in the sagittal plane angle.

5.4.12 Participant 12

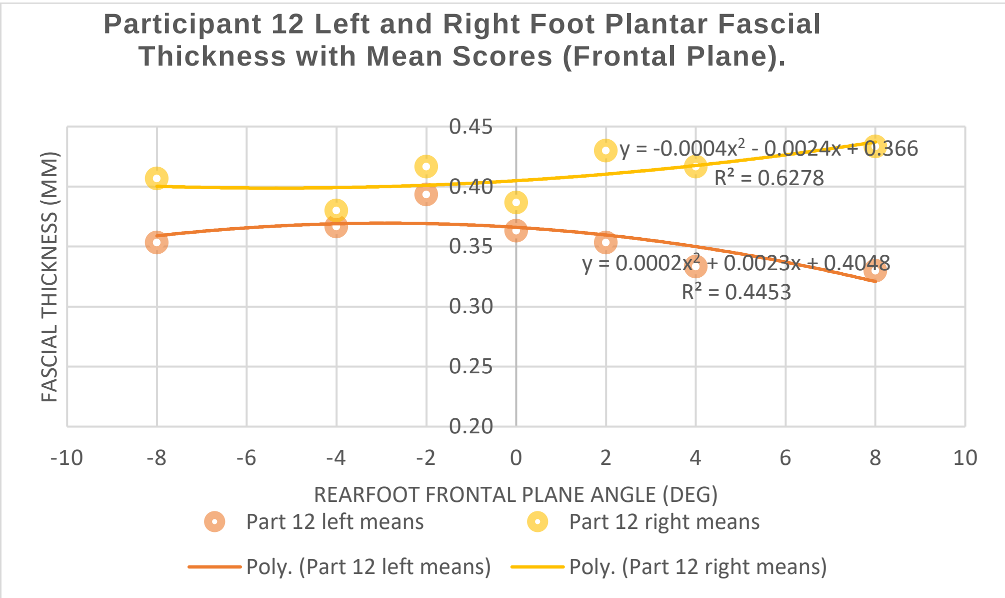


Figure 106: Graph Showing PFT And Frontal Plane – Participant 12.

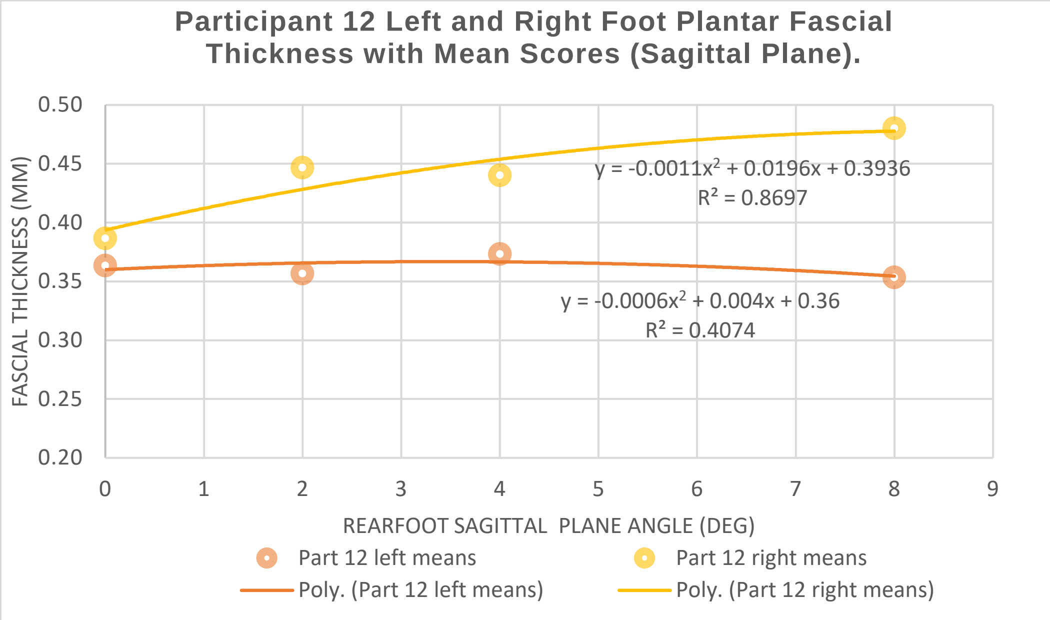


Figure 107: Graph Showing PFT And Sagittal Plane – Participant 12.

Participant 12 shows an inverse pattern on the left foot for the PFT with the right showing a greater thickness with strong polynomial (order 2) correlation on the left foot and moderate on the left foot (*Left* r^2 *= .63, Right* r^2 *= .44*). The sagittal plane shows an increasing PFT on the right foot and flat on the left foot. The right was thicker than the left. There was a strong polynomial (order 2) correlation for PFT on the right foot in the sagittal plane angle and moderate on the left (*Left* r^2 *= .41, Right* r^2 *= .87*).

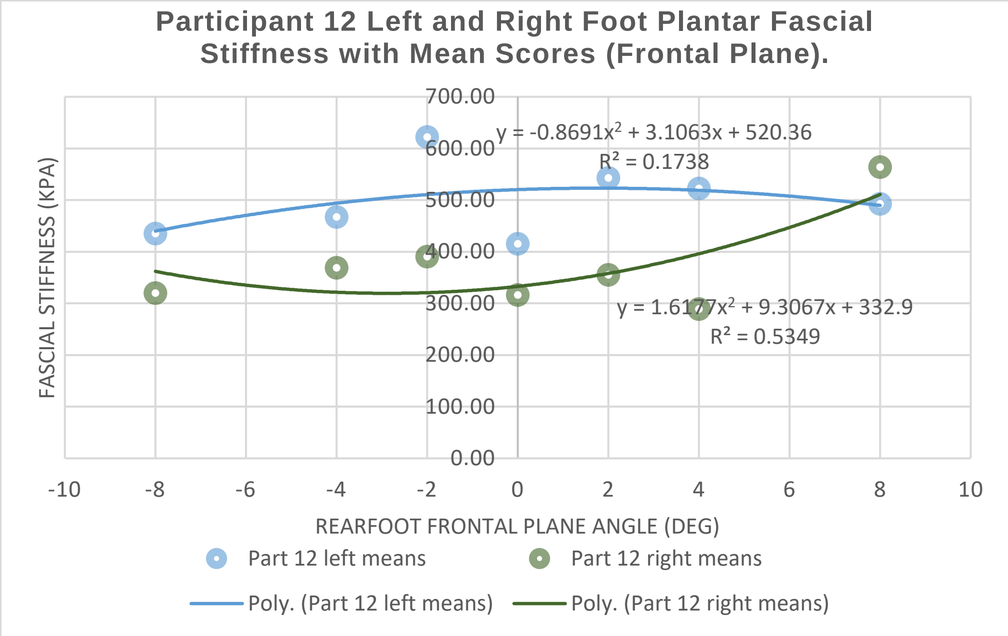


Figure 108: Graph Showing PFS And Frontal Plane – Participant 12.

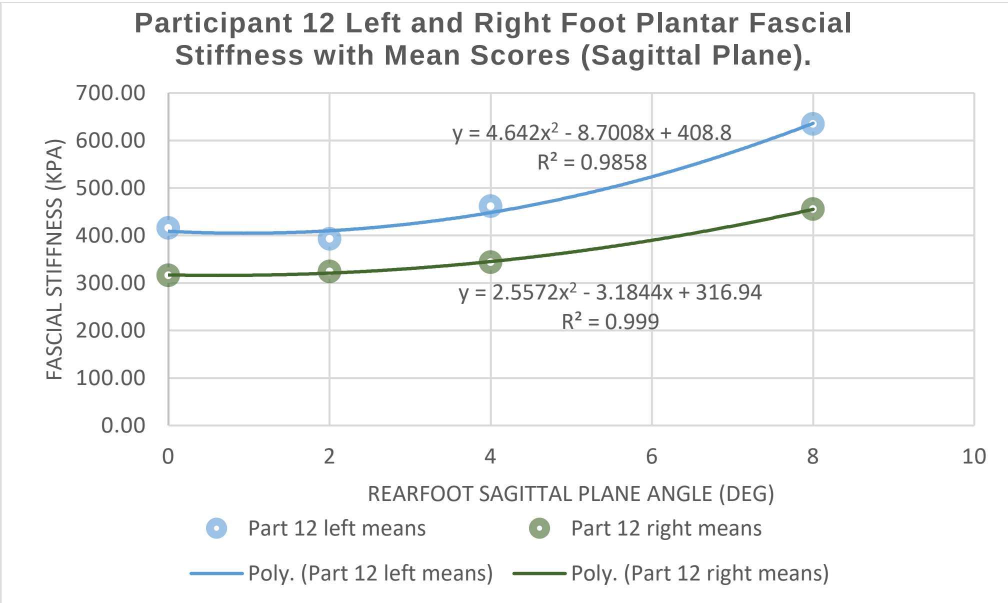


Figure 109: Graph Showing PFS And Sagittal Plane – Participant 12.

The Plantar Fascial Stiffness was a moderate polynomial (order 2) correlation on the right foot and weak on the left foot (*Left* r^2 *= .17, Right* r^2 *= .54*) for the frontal plane angle but an inverse relationship for the right foot. There was a very strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left* r^2 *= .99, Right* r^2 *= 1*) with an increasing relationship on both feet in the sagittal plane angle.

5.4.13 Participant 13

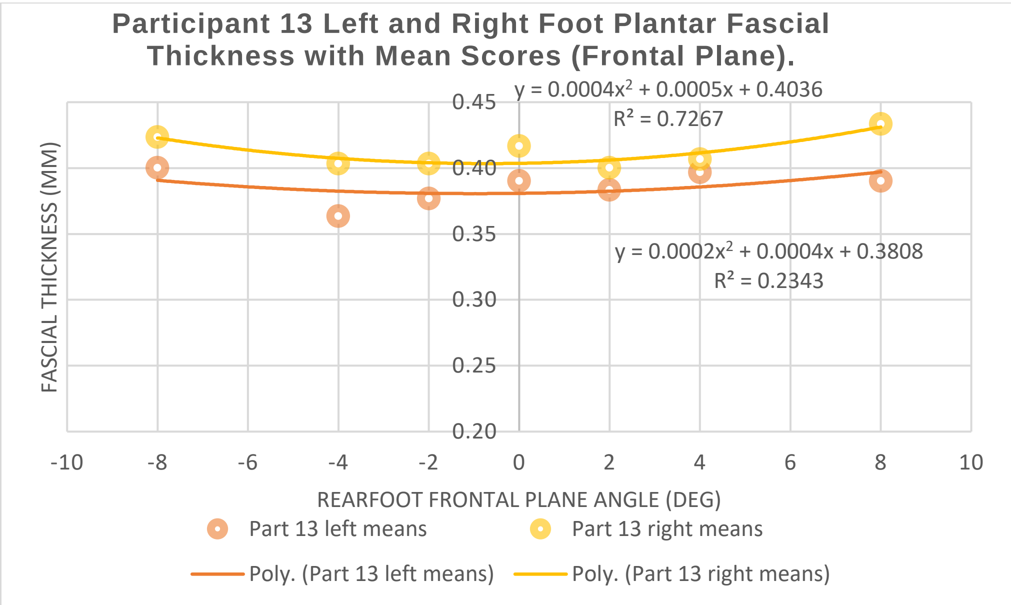


Figure 110: Graph Showing PFT And Frontal Plane – Participant 13.

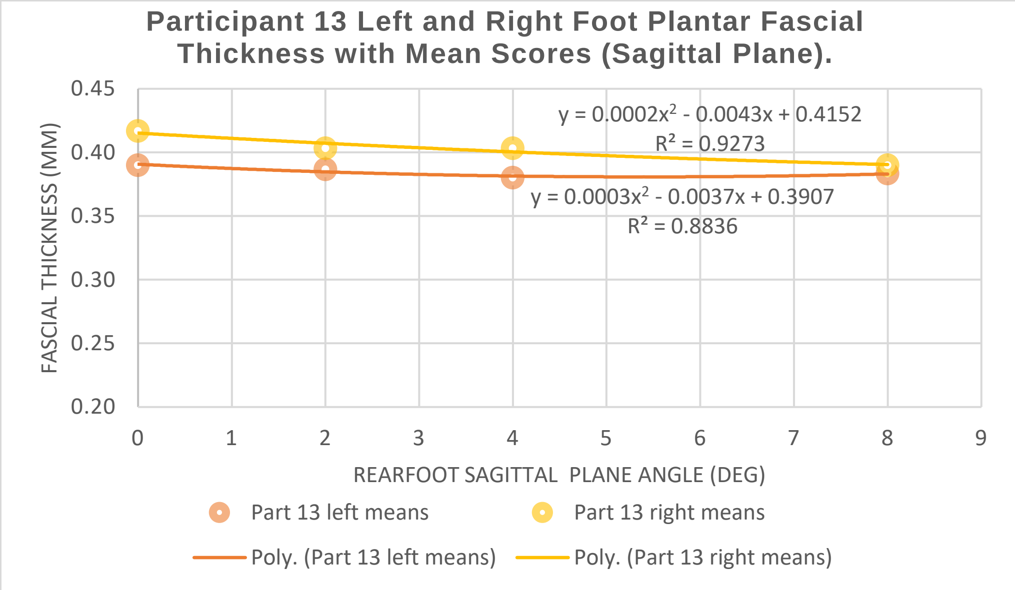


Figure 111: Graph Showing PFT And Sagittal Plane – Participant 13.

Participant 13 shows a similar pattern on both feet for the PFT with the right showing a greater thickness with strong polynomial (order 2) correlation then on the left foot (Left r^2 = .23, Right r^2 = .73). The sagittal plane shows a decreasing PFT on the right foot and relatively flat on the left foot. The right was slightly thicker than the left. There was a very strong polynomial (order 2) correlation for PFT on both feet in the sagittal plane angle (Left r^2 = .88, Right r^2 = .93).

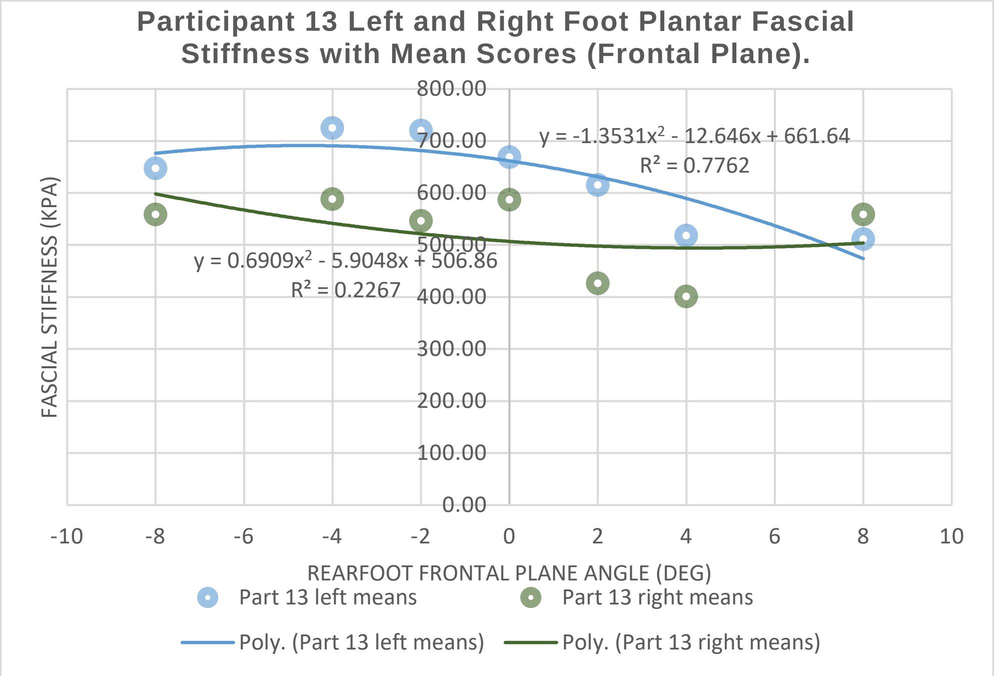


Figure 112: Graph Showing PFS And Frontal Plane – Participant 13.

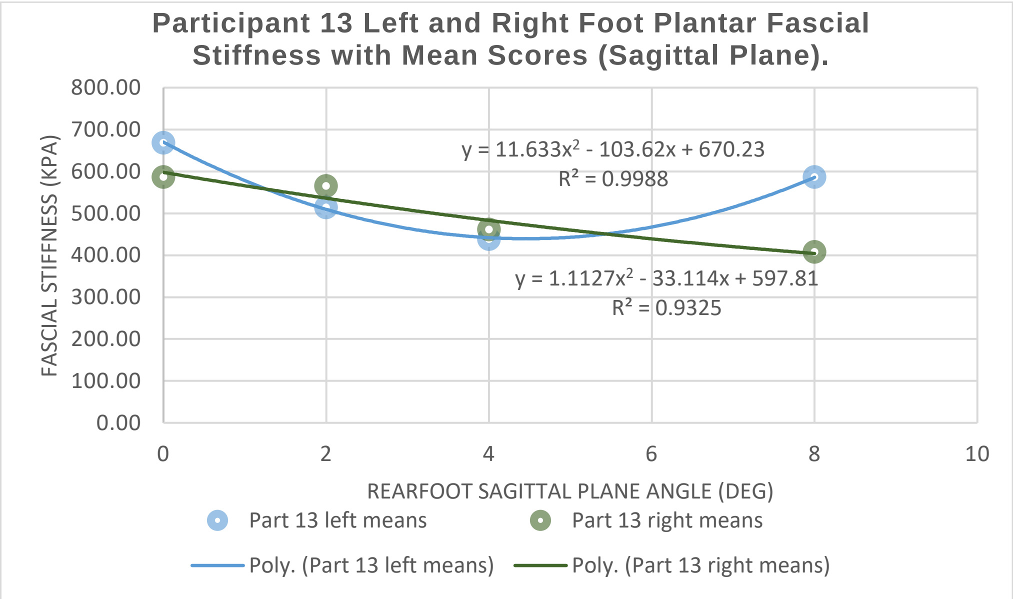


Figure 113: Graph Showing PFS And Sagittal Plane – Participant 13.

The Plantar Fascial Stiffness was a moderate polynomial (order 2) correlation on the right foot and strong on the left foot (*Left* $r^2 = .78$, *Right* $r^2 = .23$) for the frontal plane angle but an inverse relationship for the left foot. There was a very strong polynomial (order 2) correlation in the sagittal plane for both feet (*Left* $r^2 = 1$, *Right* $r^2 = .93$) with an increasing relationship on the left but decreasing PFS on the right foot in the sagittal plane angle.