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Cardiff School of Sport

DISSERTATION ASSESSMENT PROFORMA:

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Student name:	Ella Nicole Taylor
Student ID:	ST20005365
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Dissertation title:	The variability of lower extremity mechanics in gymnastic landings on different mat materials
Supervisor:	Marianne Gittoes

Comments	Section
	Title and Abstract (5%) Title to include: A concise indication of the research question/problem. Abstract to include: A concise summary of the empirical study undertaken.
	Introduction and literature review (25%) To include: outline of context (theoretical/conceptual/applied) for the question; analysis of findings of previous related research including gaps in the literature and relevant contributions; logical flow to, and clear presentation of the research problem/ question; an indication of any research expectations, (i.e., hypotheses if applicable).
	Methods and Research Design (15%) To include: details of the research design and justification for the methods applied; participant details; comprehensive replicable protocol.
	Results and Analysis (15%) [2] To include: description and justification of data treatment/ data analysis procedures; appropriate presentation of analysed data within text and in tables or figures; description of critical findings.
	Discussion and Conclusions (30%) [2] To include: collation of information and ideas and evaluation of those ideas relative to the extant literature/concept/theory and research question/problem; adoption of a personal position on the study by linking and combining different elements of the data reported; discussion of the real-life impact of your research findings for coaches and/or practitioners (i.e. practical implications); discussion of the limitations and a critical reflection of the approach/process adopted; and indication of potential improvements and future developments building on the study; and a conclusion which summarises the relationship between the research question and the major findings.
	Presentation (10%) To include: academic writing style; depth, scope and accuracy of referencing in the text and final reference list; clarity in organisation, formatting and visual presentation

[1] This form should be used for both quantitative and qualitative dissertations. The descriptors associated with both quantitative and qualitative dissertations should be referred to by both students and markers.

[2] There is scope within qualitative dissertations for the RESULTS and DISCUSSION sections to be presented as a combined section followed by an appropriate CONCLUSION. The mark distribution and criteria across these two sections should be aggregated in those circumstances.

CARDIFF METROPOLITAN UNIVERSITY
Prifysgol Fetropolitan Caerdydd

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THE VARIABILITY OF LOWER EXTREMITY MECHANICS IN GYMNASTIC LANDINGS ON DIFFERENT MAT MATERIALS

BIOMECHANICS

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THE VARIABILITY OF LOWER EXTREMITY MECHANICS IN GYMNASTIC LANDINGS ON DIFFERENT MAT MATERIALS

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Notes:

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Acknowledgements

Above all I would like to thank my dissertation supervisor Dr Marianne Gittoes for helping me throughout the dissertation process, I really appreciate all the time she gave me answering my many questions and without her this study wouldn't have been possible. Her support and feedback has been invaluable. I would also like to thank my parents for the support they have given me through my university life. Finally, I want to thank my boyfriend for his support and help throughout this process and putting up with all the stress that I came with, you helped me through it all immensely.

Abstract:

This investigation was conducted to investigate the influence different gymnastic mat materials have on the kinetic, kinematic and variability of the lower extremity mechanics during gymnastic landing movement. Three injury-free female gymnasts who had familiarity with the dismount were asked to perform ten backward tucked somersault dismounts off the beam onto three different mats (hard, medium and soft). Kinetic and kinematic data were recorded during each performance. Overall, participants landing on the soft mat experienced decreased vertical ground reaction forces. They also experienced decreased amount of flexion at the ankle and increased flexion at the hip when landing on the softer mats. The variability was high overall across all the mats, except force variables for the soft mat and the minimum angles variability for the hard mat. Therefore it was concluded that variability was highest within the medium mat and the kinetic and kinematic variables were in the safest parameters within the softest mat which could lead to a decrease in the overuse injury potential.

CHAPTER I

INTRODUCTION

1.0 Introduction

The objective for gymnastics is to perform each routine or skill whilst minimising technical errors and the highest amount of artistic imprint (Miller, 2011). Females try to satisfy this prerequisite across four pieces of apparatus: vault, asymmetric bars, floor exercise and balance beam. The balance beam can prove a difficult piece for most gymnasts, as it is performed on a surface only 10cm wide (Coulton,1988). Beam dismounts are vital within the routine to showcase intricate technical moves while sticking the landing.

Within gymnastics, the majority of research studies have conducted into the assessment of landings. Mechanical research has been conducted into landings due to the fact every exercise in artistic gymnastics ends with a landing (Cuk and Marinsek, 2013). Previous research has indicated that gymnasts can experience forces that exceed nine bodyweights when landing (McNitt-Gray *et al.,* 1993). Karacsony and Cuk, 2005 also supported this finding, stating that acrobatic moves within the gymnastics created 13.9 multiples of bodyweight vertical landing forces. The combination of the frequency of landings gymnasts have to perform after every move coupled with the forces they experience are what can often lead to lower extremity overuse injury.

Research into overuse injury potential of gymnastic landings have taken many different avenues. Many previous studies have looked into various landing stratagies (McNitt-Gray *et al.,* 1993; McNitt-Gray *et al.,* 1994 and Mills *et al.,* 2009) including diverse heights (McNitt-Gray, 1991; McNitt-Gray, 1993 and Seegmiller and McCaw, 2003), lower extremity landing technique (DeVita and Skelly, 1992; Zhang *et al.,* 2000 and Yeow *et al.,* 2009) and different mat material (Mills *et al.,* 2006 and Pérez-Soriano et al., 2010).

The use of different mat materials within gymnastic landings is a relatively new aspect into biomechanical research. Mills *et al.,* 2010 found that the use of a soft landing mat reduces external forces (for example vertical ground reaction force) which can help to reduce the risk of stress fractures. Overall it has been found that the softer the mat has a higher functional benefit as it’s got greater energy absorption (Perez-Soriano *et al.,*2010). However with the vast knowledge within gymnastic landings, gymnasts are still experiencing overuse injuries linked with landings. This expresses the need for a new direction of biomechanical research to be developed.

Mechanical variability is not recent to biomechanics; however the view that it is beneficial to performance and injury rather than being damaging is an advanced concept (Bartlett *et al.,* 2007). This concept was researched into by Heiderscheit (2000), he hypothesised that mechanical variability within locomotion has a positive relationship with the decrease in overuse injury. Gymnastic landings and mechanical variability are both related to overuse injury. Therefore the aim of this study was to investigate the influence different gymnastic mat materials have on the kinetic, kinematic and variability of the lower extremity mechanics during gymnastic landing movement. The research objectives were to:

1) Assess the key kinetic and kinematic variables such as peak vertical ground reaction force and minimum angles across the different mat conditions to see if this influences overuse injury potential
2) Evaluate the variability of the landing movements across the different mat conditions to see if this influences overuse injury potential

The overall purpose was to assess each of the landing mat conditions, using key kinematic, kinetic variables and variability values to further the knowledge of overuse injury potential of each mat condition and which mat can be deemed appropriate for training to decrease overuse injuries. This study hypothesised that:

1) The softest mat will create more variability within the landings then the other two mats.
2) The softest mat will hold the optimum force and angles to reduce injury in landings.

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CHAPTER II

LITERATURE REVIEW

2.1 Injury Perspective Within Gymnastics

2.1.1 Injury in Gymnastic Dismounts

Biomechanics should pursue injury prevention, given the increased and repetitive biomechanical demands a gymnast receives (Preatoni *et al*., 2012).

Rapid and excessive impact forces experienced in landings have been associated with a high number of lower extremity injuries (Devita & Skelly, 1992). It has been reported that the lower extremity is the most injured, comprising of 54–70% of all injuries (Andrish, 1985; Jensen, 1998; McAuley *et al*., 1987; Meeusen and Borms, 1992; Snook, 1979). Caine *et al.,* (1988), highlighted that 36% of all injuries sustained by gymnasts occurred during dismount landings. Dismount landings comprises of an aerial phase and landing, where the gymnasts loses contact with the apparatus or floor and then gain contact with the landing surface (Gervais and Dunn, 2003).

The high level of injuries linked to the knee and lower extremities can be classified due to the frequency and force produced from each landing. Gymnasts can be exposed to these high vertical ground reaction forces which can exceed nine bodyweight (McNitt-Gray *et al.,* 1993) within landings in excess of 200 times a week (Ozguven and Berme, 1988). Females involved in these high landing sports for example gymnastics are up to six times more likely to sustain a serious knee injury than males (Hewett, 2000). The landing errors observed by McNitt-Gray (2000) indicated that gymnasts have difficulty when attempting to satisfy both safety and performance objectives.

Most biomechanical investigations of gymnastic-style impact landings have looked to enhance insight into the mechanisms that can influence loading and the physical demands incurred (Gittoes & Irwin, 2012). They have also tried to distinguish the differences between gymnast landings compared with other athletes (McNitt-Gray, 1993; Seegmiller and McCaw, 2003). Seegmiller and McCaw (2003) studied the differences between gymnasts and recreational athletes landing forces. They concluded that drop landings performed by female gymnasts exhibited higher peak vertical force magnitude 32.84±7.81 N/Kg than drop landings performed by female recreational athletes 24.00± 5.85 N/Kg. High ground reaction forces experienced by gymnasts may contribute to the occurrence of lower extremity injuries. McNitt-Gray (1993) contended with this study that gymnasts exhibited higher ground reaction forces. McNitt-Gray (1993) stated that the greater stress placed on the ankle and hip extensors by the gymnasts, as compared to the recreational athletes, may be explained by the need to sustain balance during competitive gymnastics landings. This contributed to the knowledge that gymnastic landings are of a high importance when focusing on the forces experienced in the body and holds the greatest overuse injury potential.

2.1.2 Landing Strategies in Gymnastic Landings

Landing strategy can be defined as how a gymnast lands in respect to their kinematic patterns to satisfy a 'stuck' landing. Federation Internationale de Gymnastique (F.I.G) set out strict rules in accordance to gymnastic landings which has changed the way gymnasts may land. The gymnast must adhere to this criterion, such as landing without maximised knee flexion to minimize score deduction (Gittoes *et al.,* 2013). McNitt-Gray (1993) studied the landing strategy of a gymnast, he found that gymnasts chose to use larger ankle and hip extensor moments to satisfy higher impact velocities, which suggest they used less hip and ankle flexion which created larger ground reaction forces. These high moments and ground reaction forces can be a reason to increased lower extremity injuries. This lead research to assess how to change landing strategies while still satisfying the F.I.G landing parameters.

Mills *et al.,* 2009 looked to determine landing strategies that minimise ground reaction forces (GRF) and internal forces. They found that it is feasible for a gymnast to modify their landing strategy in order to minimise internal forces and lower GRF. However, changing landing strategy to reduce GRF as a foundation for a reduction in injury potential may not be suitable since internal loading can increase. These findings had major implications on the direction of future research and the way coaches examined safe landing procedures. However research conducted needed to be brought into sport specific environments, and landings needed to be tested on different mat materials.

2.1.3 Injury Through Gymnastic Mats

Landing mats that can experience a great amount of area deformation are now vital for the safe completion of gymnastic landings (Mills *et al.,* 2006). Arampatzis *et al*., (2002) confirmed this by finding the functional benefit of using a softer mat is higher energy absorption. Despite the use of landing mats, a high rate of injuries to the lower extremities arises from performing dismounts in competitive gymnastics (Arampatzis *et al.,* 2002; Mills *et al.,* 2006).

The interaction between a gymnast and the landing mat is crucial for maximising performance. Most of the gymnast's landings are from dismounts off apparatus in which a mat would be used both in practise and competition. Therefore the gymnast will aim to meet strict marking criteria when landing on a mat, marking criteria is set out by F.I.G (2009) on landing which stipulates that the gymnast must land with a single foot placement. From practise to competition it is known that gymnasts use progressively harder mats. This lead to Mills *et al*., (2010) to look at the effect of different mats on ground reaction forces and internal loading. They found that the optimisation of the landing mat parameters was characterised by minimal changes to the landing mat's stiffness (<0.5%) but increased damping (20%). This decreased the peak external forces however it increased internal loading of the gymnast when landing. This decrease of external forces to the musculo-skeletal system could help to reduce the injury risk connected with landing (McNitt-Gray, 2000). This was supported by Beck (1998) who stated that the major factor associated with bone stress injuries was repeated mechanical loading. These findings contributed to the knowledge of coaches and gymnasts in which mat to use to decrease the forces experienced in the body and therefore holds the lowest injury potential.

2.2 Biomechanics of a Gymnast

2.2.1 Landing/Dismount Mechanics

Dismounting is a vital element in gymnastic beam routines and the mastering of fundamental dismount skills has been considered advantageous in providing a foundation for the progression of more complex skills (Takei, Nohara, & Kamimura, 1992). Dismounts are fundamental in daily training of most gymnastics routines, (Perez-Soriano *et al.,* 2010), especially beam.

The backward somersault dismount skill, distinguished by the requirement for a greater whole-body moment of inertia in the tucked position (Sanders & Gibson, 2003), may be considered as a fundamental skill for competitive gymnasts to master. In performing the backward tucked dismount skill, gymnasts are challenged with two crucial aims. First, the rotation of the body orientation in flight must be adapted with reduced peripheral vision in the late stages of the aerial phase, to ensure the feet plant the ground. Second, a safe, aesthetic, and well-executed landing must be achieved (Gervais & Dunn, 2003) to complete the dismount at a high standard. Dismounts are split into two key phases, flight and landing.

Landing is of high importance to the success within gymnastic dismounts (Marinšek, 2011), thus making landing an important determinant of the overall score and execution level within a beam routine/dismount. Judging criteria for landings in gymnastics specify that gymnasts must land with a single placement of the feet with the centre of mass over the base of support (Mills *et al.,* 2009).

Federation Internationale de Gymnastique, 1984, described the mechanical goal of a gymnastics landing as the reduction of the total body vertical, horizontal and angular momentum at touchdown without moving the feet.

2.2.2 Kinematic Changes Through Different Gymnastic Mats

As seen is section 2.1.2 it is a main concern within gymnastics to see which mat is deemed the most safe for the performance of dismounts/landings, to decrease the level of injury. F.I.G mat recommendations for beam dismount landings are for a carpet surface landing mat which is manufactured from a core of foam layers to provide the rebound and deflection characteristics, with standard dimensions 3mx2m (Federation Internationale de Gymnastique, F.I.G., 2013). An important factor within this is looking how the mechanics of the lower extremities change with different landing mats. It is vital that even within practise onto different mats the gymnast covers the judging criteria. Any arm swings, legs apart on landing or falls and steps on landings can deduct 0.10 to 1.00 or more from a gymnasts overall score (Federation Internationale de Gymnastique, F.I.G., 2013).

To produce a stuck landing the gymnast needs the ability to absorb impact forces at landing and maintain balance. This is achieved by the movements made during landing, the position the gymnast is in at touchdown and the properties of the landing mat (Brian *et al*., 2001; Pérez *et al*., 2008). Arampatzis *et al*., (2002) showed that changing the properties of the landing mat will initiate a different landing strategy adopted by the gymnast which will then influence the kinematics at the mid and forefoot. This is supported by Ozguven and Berme, (1988) who observed a change in landing strategy of less joint flexion in the lower extremity when landing on less firm surfaces. Major findings came from

McNitt-Gray *et al*., (1994) when she conducted a study on different landing strategies used by gymnasts on different surfaces. It was found that significantly longer landing phase times, and greater knee and hip flexion were detected between the no mat condition and the mat conditions. Knee flexion was also significantly greater for landings on the stiff mat than those on the soft mat. These results indicate that with the presence of a mat, the gymnast landing mechanics change. This was also the case from a soft to hard mat. These results showed that landing on different mat conditions changed the landing strategies which still adhered to the landing parameters set out by the F.I.G code of points for competition landings (i.e. no excess movement, or excessive flexion causing a deep squat).). With the vast knowledge within gymnastic dismounts and landings, gymnasts are still experiencing overuse injuries linked with landings. This expresses the need for a new direction of biomechanical research to be developed.

2.3 Mechanical Variability

Mechanical variability is a characteristic within human movement that happens innately (Kong and Candelaria, 2009). . Movement variability always occurs when biomechanical demands and actions such as landings are repeated and even the elite athlete cannot reproduce identical motor patterns (Bartlett, *et al*., 2007). Variability research is relatively new within sports biomechanics and has started assessing variability within gate, however variability within gymnastics and gymnastic landings has not yet been explored.

Movement variability occurs every time we replicate the same movement, changes may be seen in the repetitive actions, regardless of expertise with the movement (Preatoni *et al.,* 2013).Sports biomechanists tended to presume that intra-individual variability in movement patterns was “noise”, and not an imperative issue in measurement (Bartlett *et al.,* 2007). Clinical research was first to look into variability conducting their studies with participants with Parkinson’s disease (Hamill, van Emmerik, Heiderscheit and Li, 1999) it suggested that variability plays a functional role in movement execution, this was then drew into a sporting context by Van Emmerik and van Wegnen (2000).

Movement variability reflects the inherent functional features of the neuromuscular system and may contain important information that should not be neglected (Preatoni, E. *et al.,* 2012). Movement variability was associated with a decrease in performance due to a lack of consistency (Knudson & Blackwell, 2005; Salo & Grimshaw, 1998). Only recently the insight into variability in sports biomechanics has changed that it now shows to have positive effects on performance, and has been suggested as a factor contributing to injury (James, 2004; McLean, Lipfert and van Den Bogert, 2004). James (2004) believed that variability within repeated actions may play a vital role in preventing overuse injury by altering the magnitude, direction, rate or frequency of acting forces and creating a larger distribution of stresses. However Hamill *et al.,* (2000) refutes this suggesting larger variability may be a response to the alteration to an unfamiliar task.

As research into the association between injury and variability develops, it appears that variability research within sporting environments is weak. Bartlett, Wheat and Robins, (2007) believe that this is down to sport biomechanists lack of awareness around the subject until recently. The understanding in sports biomechanics and landing strategy variability is relatively sparse. Most variability research has looked into the differences in landing variability of healthy individuals and individuals with lower extremity injures (Roger *et al.,* 2000; Brown *et al.,* 2012; Kipp & Palmieri-Smith, 2012). Hamill *et al.,* 1998 published a key kinematic variability paper looking at the dynamical system approach to lower extremity running injuries. The paper concluded that individuals with patellofemoral pain showed reduced variability in the continuous relative phase of the lower extremities then the subject with no injuries. This research was a major finding within movement variability. It concluded that individuals with ankle instability and that are injury prone in the lower extremities have less variability, indicating a relationship between variability and lower extremity overuse injury (i.e. patellofemoral pain). With the connection made between variability and overuse injury research can start taking shape in sporting applied settings.

When considering gymnastics, variability research can now take place looking into mechanical variability of landings in different condition (i.e. mat use). This would expand the knowledge of gymnastic landings and progress the research on within sports biomechanics.

2.4 Methods of Approach

2.4.1 Research Design

The Validity of results from a study include whether the results represent the true response for the study conditions (Mullineaux *et al*., 2001). Within a study design that observes the differences within a group of performers, individual differences can be concealed (Michaels and Beek, 1996), specifically to the study multiple single-subject design should be used as they look into the individualised signatures of movement (Bartlett *et al*., 2007). When using a multiple single-subject design trial and sample sizes become increasingly important. Bates *et al*., (1992) recommended that for a statistical power of 90% trial sizes of 10, 5 and 3 should be used of samples sizes of 5, 10 and 20, respectively.

2.4.2 Data Collection Issues

Lower extremity mechanic values can be derived from the data obtained from Cartesian Optoelectronic Dynamic Anthropometer (CODA) motion analysis system and force plate analysis. For the analysis of kinematic variables within a landing, CODA motion analysis has been used in many studies, such as that of Gittoes, Irwin and Kerwin (2013) and McNitt-Gray (2000), demonstrating to be a prevalent method.

The use of force plates to observe kinetic variables has also proved to be a popular method over time within biomechanics testing with McNitt-Gray (1993) compiling his study with the use of a force plate along with more recently Brown, Bowser and Simpson (2012). Literature around gymnastic landings is highly diverse using both theoretical simulation modelling studies (Mills *et al*., 2008; Mills *et al*., 2009) and laboratory based studies (Seegmiller and McCaw 2003; McNitt-gray *et al*., 1993). Using a theoretical simulation model you have the potential of the study to lack realism to an actual human performer. Therefore sticking with a laboratory study can gain an improved real life insight into how the performer’s variability adjusts to the different gymnastic mats.

2.4.3 Methods of Processing and Analysis

There are three common types of variability, inter-condition, intra- condition and intra-subject. Within the current study main focus will be placed on inter-condition (between condition) variability as it will consider the differences between the three different types of mat. Intra-condition (within condition) analysis will also be performed for all three of the mats; this is to provide a better insight of how the conditions differ and how variable the mats are irrespectively of another mat.

2.5 Summary

Based on the review of literature it has become apparent that dismounts in gymnastics is an important area of injury perspective research. However a new contemporary direction needs to be taken. The aim of this study was investigate the influence different gymnastic mat materials have on the kinetic, kinematic and variability of the lower extremity mechanics during gymnastic landing movement. The research objectives were to:

1) Assess the key kinetic and kinematic variables such as peak vertical ground reaction force and minimum angles across the different mat conditions to see if this influences overuse injury potential
2) Evaluate the variability of the landing movements across the different mat conditions to see if this influences overuse injury potential

The study hypothesised that:

1) The softest mat will create more variability within the landings then the other two mats.
2) The softest mat will hold the optimum force and angles to reduce injury in landings.

CHAPTER III

METHODOLOGY

3.1 Participants

Three injury-free, female gymnasts from Cardiff Metropolitan University volunteered to take part in the current study. The mean ± standard deviations (*SD*) for the subject's age, height, and mass were: 20.3±1.53years; 57.3±2.07kg; 159.5±3.09cm respectively. The participants would be currently training and competing for the university gymnastics team or for an outside gymnastics squad. The selected participants will have trained the skill to compete it in past competition(s), and have used it as a progressive skill for more advanced dismounts, for example round-off back somersault. Through the use of a participant information sheet (appendix A), a detailed explanation of the test protocol was disclosed to the athletes before they agreed to take part in the study. Those willing to participate then gave written informed consent (appendix B) for the study. Ethical approval was gained from the Cardiff School of Sport Research Ethics Committee (CSSREC) (appendix C). The research method used a multiple single subject design.

3.2 Protocol

Completed at an earlier date the pilot study which aimed to evaluate and improve the method used for collection, the outcome of the pilot study was that the mats and marker set up needed to be changed (appendix D).

The participants were asked to attend the testing session wearing their usual leotards and shorts. Each participant was firstly asked to perform a warm up of what they would usually do in training, containing a heart raising activity and stretching. The participants were then asked to complete a test trial in which they performed a backward tucked somersault off the beam onto the soft mat, to familiarise themselves to the testing procedure. During the trial, no data were collected; its purpose was: a) to assess how far the beam had to be to accommodate the gymnast landing on the force plate and b) to see if all markers were in view of the scanners during the landing phase on all of the mats.

During the collections participants were required to perform three sets of ten backward tucked somersault off a standard balance beam (Figure 1) set at 125cm (competition height) which is measured from the floor to the top of the beam.. Each set required a different mat to allow the comparison of lower extremity mechanics at landing. Three types of mats, all FIG approved (appendix E) that are commonly used for practise of the skill and competition were used that can be categorised as soft mat, medium mat and hard mat. In order to eliminate a fatigue factor, the participants were allowed a 5 minute rest between each mat change. The gymnasts were instructed to perform a well-executed backward somersault which allowed them to land safely, stable and aesthetic. A successful trial/dismount was determined by full foot placement on the force place at landing and full viewing of the markers during landing.

Figure 1: Standard balance beam at competition height (125cm)

3.3 Data Collection

The set-up of the equipment for the data collection session is demonstrated in Figure 2 and 3. Four CODA motion Cx1 units operating at 400Hz (Charnwood Dynamics Ltd., Leicestershire, UK) and one Kistler force plate (9287BA, Kistler, Switzerland), operating at 1000Hz were used to obtain kinetic and kinematic data from each trial. After every trial force profiles from their landings were collected along with the marker positions during the backward somersault and landing phase. The CODA scanners were positioned to provide optimum capture of all active markers in the impact/landing phase. Mondo (Mondo, Warwiskshire, UK) was placed over the Kistler force plate.

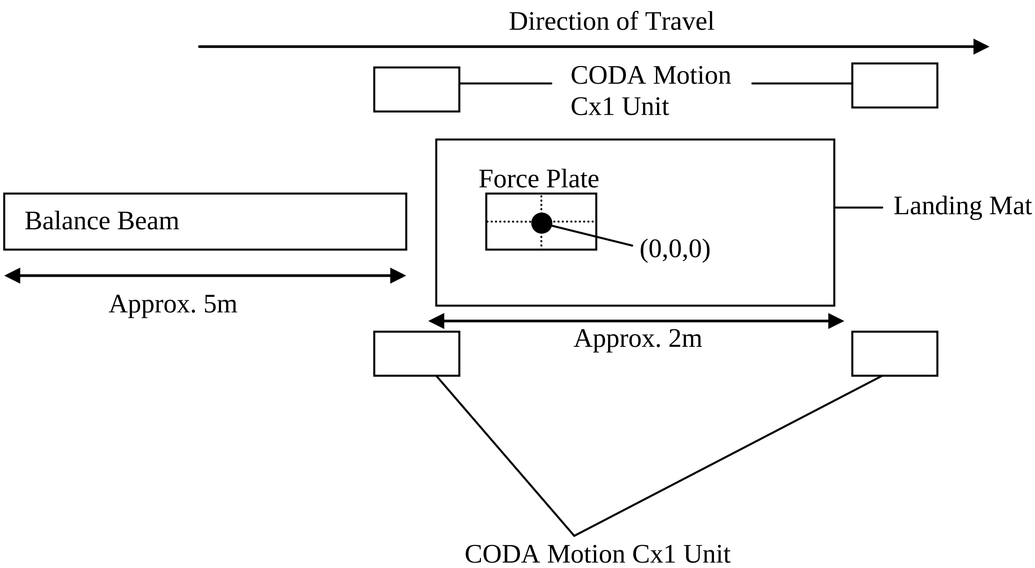
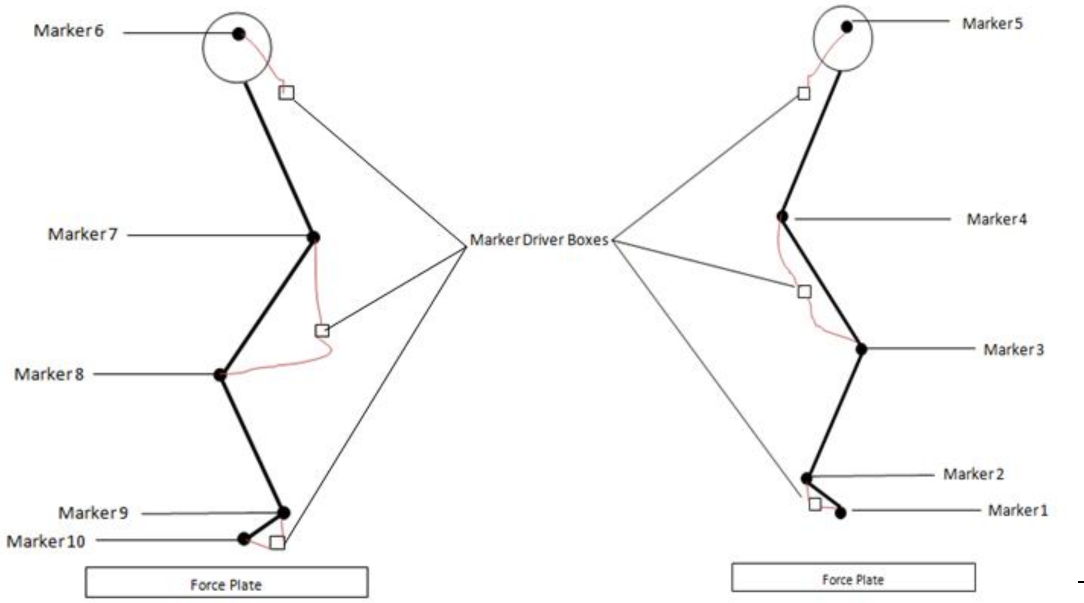


Figure 2: Set-up of equipment for data collection session

Figure 3: Photo set-up of equipment for data collection session

Before testing was carried out, it was essential to carry out the CODA alignment procedure. A central measure was calculated from both sides of the force plate and lasers were then used to identify the origin of the force plate. CODA markers were used to align the axis identified by the right-handed global coordinate system. The x-axis was vertical, the y-axis was the direction of movement/anterior-posterior and the z-axis was medio-lateral (Winter, 2009). This alignment of the CODA markers ensured the integration of both CODA and the force plate, the origin formed a (0,0,0) reference frame.

Ten active CODA markers were placed unilateral for each side of the gymnast's body, corresponding to the landmarks outlined in Figure 4 in order to obtain lower-body joint kinematic profiles. These markers were placed to identify the key joints which face injury during landings. Markers were placed on both sides of the body to increase the marker visibility due to different participants favouring weight balance on one side of the body when landing, therefore loosing the visibility of the MTP marker. Before each participant started testing a simple protocol was used to evaluate the CODA markers visibility; this consisted of the gymnast standing on the force plate with the CODA markers placed on their body. After, each gymnast's height and mass data measures were taken using a stadiometer (Holtain, Pembrokeshire, UK) and a set of scales (Seca, Germany) (Appendix F).



Marker 1 = Right MTP (Tuberosity of the fifth metatarsal)
Marker 2 = Right Ankle (Lateral malleolus)
Marker 3 = Right Knee (Lateral femoral condyles)
Marker 4 = Right Hip (femoral head)
Marker 5 = Right Temple
Marker 6= Left Temple
Marker 7 = Left Hip (femoral head)
Marker 8 = Left Knee (Lateral femoral condyles)
Marker 9 = Left Ankle (Lateral malleolus)
Marker 10 = Left MTP (Tuberosity of the fifth metatarsal)

Figure 4: A diagram representing the anatomical marker positions

All active markers and marker drive boxes were placed and secured by tape (Figure 5) to each gymnast by one researcher to ensure consistency of the joint centre identification.

Figure 5: The marker set up on one side of the body for one participant

Each trial was recorded for ten seconds to ensure full capture of the backward somersault and landing. Visual monitoring assessed whether the landing was safe and stable and to assure full foot contact at landing took place on the force plate. A successful trial was deemed as full foot placement on the force plate at landing and sufficient viewing of markers at touchdown and landing.

3.4 Data Processing

The 2-Dimensional marker and horizontal and vertical ground reaction force data were filtered through Winter's Residual Analysis (2009) using a customised Butterworth filter, which identified to optimum cut-off frequency as 4Hz (Appendix G). The data set was normalised to 100 points by linear interpolation this is in correspondence to Lees *et al* (2004). The optimum cut-off frequency was decided through residual analysis completed on the three trials of the left ankle x-displacement during the entire movement for a) one hard mat landing b) one medium mat landing c) one soft mat landing. These three trials were selected at random; the entire recording of kinematic movement was used for analysis, not just the landing phase. Landing was defined as the instant at touchdown to a stable, steady position. Instant at touchdown was identified as the instant of force less than 30N but higher then 0N and steady position was when the gymnasts force stayed constant for over 1 second.

3.5 Data Analysis

3.5.1 Discrete Variables

The key discrete variables assessed can be seen below in Table one.

Table One: Discrete Variables

Discrete Variable	Description
Minimum joint angles (Hip, knee and ankle)	Joint angles were defined; a graph was created for each of the joint angles over time. Angle data was transfer each into excel, minimum angles for the multiple trials for each gymnast was calculated
Peak joint angular velocities in flexion (Hip, knee and ankle)	Joint angles were defined; a graph was created for each of the joint angular velocities over time. Angle data was transfer each into excel, minimum angles for the multiple trials for each gymnast was calculated.
Peak vertical force	Force over time graph in CODA was constructed; peak vertical force was the highest point of the graph.
Time to peak force	Force over time graph in CODA was constructed, time to peak force was the point of the graph where the force is below 30N and above 0N before peak force
Loading rate	Peak vertical force/time to peak force

The variables were selected in conformity to previous studies of the identification of key variables within injury (McNitt-Gray, 1993; McNitt-Gray *et al.,* 1993; Mills *et al.,* 2009; Marinsek, 2011). Half of the variables were assed directly through the CODA motion software, these variables included; minimum joint angle for the hip, knee and ankle and peak joint angular velocities. Before the data was analysed the marker visibility during every trial was viewed for each participant, the anatomical side with the best marker visibility for each participant was then chosen and the data was analysed from that side of the body. Participant one – Left side of the body, Participant two – Right side of the body and Participant three – Left side of the body. Within CODA motion analysis system the joint angles were calculated by the active markers being defined (i.e MTP, Knee) then the markers were linked to define the joint angles. Joint angles were defined as follows: MTP and knee (ankle), ankle and hip (knee) and knee and temple (hip). The other discrete variables were obtained from the kinetic data, collected from the Kistler force plate; these variables consisted of peak vertical force and time to peak vertical force. These variables were used to calculate the loading rate (Peak force divided by the time to peak force). These values were then exported into Microsoft Excel (Microsoft, USA).

To obtain the mean response for the gymnasts' trials for each of the discrete variables, an overall mean for each of the multiple trials for each gymnast was taken for each of the mat condition. Then the variability for each mat was found for each discrete variable through the calculation of the coefficient of variation (%) (CV). To calculate the CV, the following equation was used:

$$\text{Coefficient of variation (\%)} = s/x * 100$$

s= standard deviation

x = mean

The mean was calculated by the overall average of every trial within the group condition on the specific mat, the standard deviation was calculated in the same way. If the CV value was less than 10%, the variable was considered to have low variability (Menz *et al.,* 2004).

3.5.2 Continuous Variables

The continuous variables, angles, vGRF time profile and angular velocities were also selected based on previous research findings of key injury variables (McNitt-Gray *et al., 1992;* McNitt-Gray, 1993). The variables selected were joint angle (knee, hip, and ankle) profiles, joint angular velocity profiles and landing phase time. The data was firstly selected from CODA motion analysis system then exported into a Microsoft Excel document. When exported to Excel the data was normalised to time and 100 data points were selected. The mean was taken for the multiple trials for each of the gymnast on each mat condition. The Root Mean Squared Difference (RMSD) was calculated between the overall averages of each different mat to examine the variability of the continuous data. All graph outputs were obtained in Excel spreadsheet

3.5.3 Statistics

After analysis was completed a normality test (Shapiro Wilk) on all of the discrete data was carried out in the Statistical Package for the Social Sciences software (SPSS inc, 17.0, Chicago, IL). This was in order to state whether the use of a parametric or a nonparametric test should be used to test the significance of the data. The findings of the Shapiro-Wilk test showed the data was non-normal ($P<0.05$) thus the non-parametric Friedman test was carried out on the discrete data.

CHAPTER IV
RESULTS

4.1 Discrete Variables

4.1.1 Ground Reaction Forces

As illustrated in Figure 6, the hard mat produced a greater peak vertical ground reaction force (vGRF) than the medium and soft mat, the difference between peak vGRF in mat hard and soft 35.85% and medium and soft 32%, showing the biggest difference in vGRF between hard and soft mat, significant difference was found between the hard and soft mat and the medium and soft mat ($P<0.05$). Participant one and two showed individual differences compared to the group. They showed the peak vGRF on the medium mat was largest followed by the hard then soft, where as the group showed the highest vGRF on the hard mat followed by the medium then soft mat. Figure 7 showed time to peak vGRF was greater in the medium mat than the hard and soft mat. All mat conditions showed a significant difference ($p \leq 0.05$). Time to peak vGRF was similar for each participant compared to group data showing a longer time to reach peak vGRF in the medium mat, followed by the soft mat then hard mat, however participant 1 showed a slight difference in the soft and medium mat taking the same time to reach the peak at 0.057s. Peak loading rate is shown in Figure 8. It shows a significant difference between hard and medium mat and hard and soft mat ($P<0.05$). The peak loading rate was greater in the hard mat condition for every participant and the group and showed a 36.61% and 54.83% group difference between the hard mat compared to medium and soft mat respectively. Participant three showed a slight difference from the other participants and group data between the medium and soft mat. They showed a larger loading rate in the soft mat then the medium mat (7.26% increase) compared to the group data which showed a smaller loading rate in the soft mat then the medium mat (40.34% decrease).

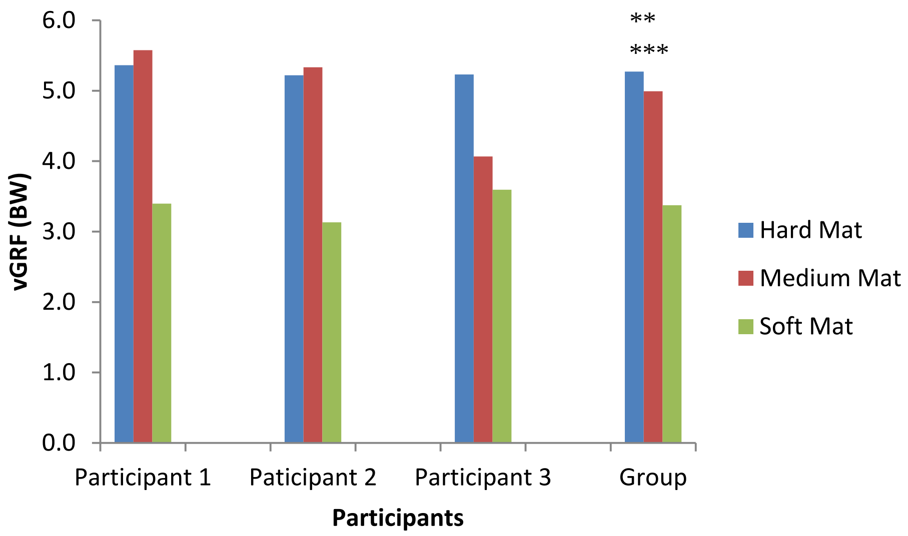


Figure 6 – Peak vGRF for each mat condition shown for each participant and the overall group. ** Significant difference between hard mat and soft mat at the group level (P<0.05). *** Significant difference between medium and soft mat at the group level (P<0.05).

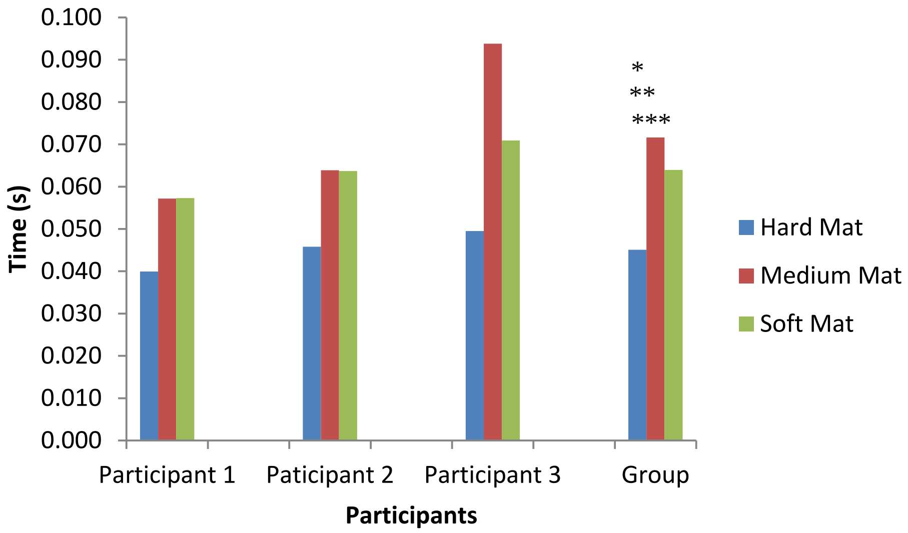


Figure 7 – Time to peak vGRF shown under each mat condition for each participant and overall group. * Significant difference between hard and medium mat at the group level (P<0.05). ** Significant difference between hard and soft mat at the group level (P≤0.05). *** Significant difference between medium and soft mat at the group level (P<0.05).

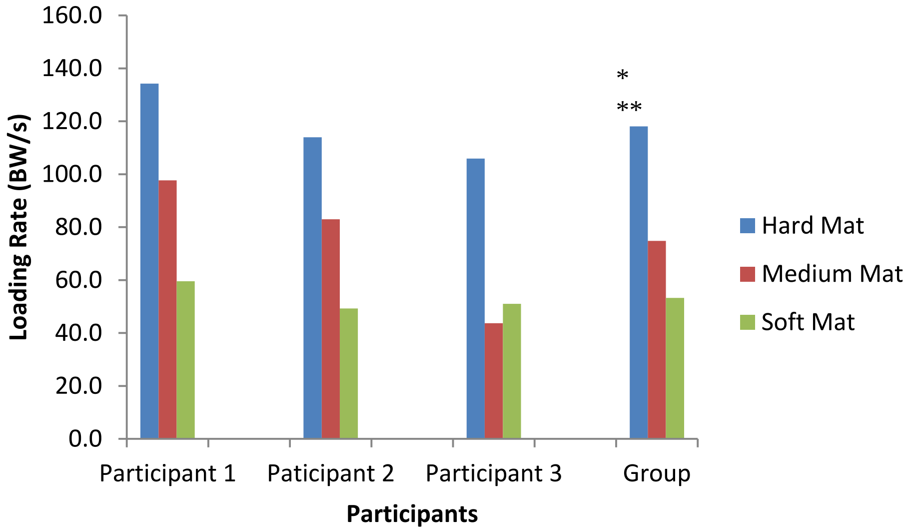


Figure 8 – Peak loading rate shown for each participant and overall group data under each mat condition. * Significant difference between hard mat and medium mat at the group level (P<0.05). ** Significant difference between hard mat and soft mat at the group level (P<0.05).

4.1.2 Kinematic Data

Figure 9, 10 and 11 shows the minimum flexion-extension angles for the ankle, knee and hip during the landing phase respectively. The ankle angle was greatest under the hard mat condition (78.27°) then the soft mat (75.30°) and medium mat (54.81°). The ankle angle showed significant difference across the medium and soft mat (P<0.05). The knee angle showed no significant differences between the mat conditions (P<0.05). The participants overall pattern differed to the overall group except participant one. The group and participant one showed a smaller angle on the medium mat followed by the hard then soft mat where-as participant two who showed a smaller angle on the medium followed by the soft then hard mat and finally participant three differed from the group with the smallest angle being shown on the soft mat followed by the medium then hard mat. Figure 11 showed the minimum hip angle in the landing phase, significant differences were found between landing on the hard mat compared to the medium mat and the medium mat compared to the soft mat (P<0.05). Figure 11 also showed that the hip angle was greatest in the medium mat compared to the hard and soft with differences of 8.87% and 9.79% respectively. Only participant one showed a different minimum hip angle pattern compared to the other participants and overall group. Participant one's hip angle was greatest on the soft mat (93.08°) when compared to the medium mat (83.85°) and hard mat (80.14°).

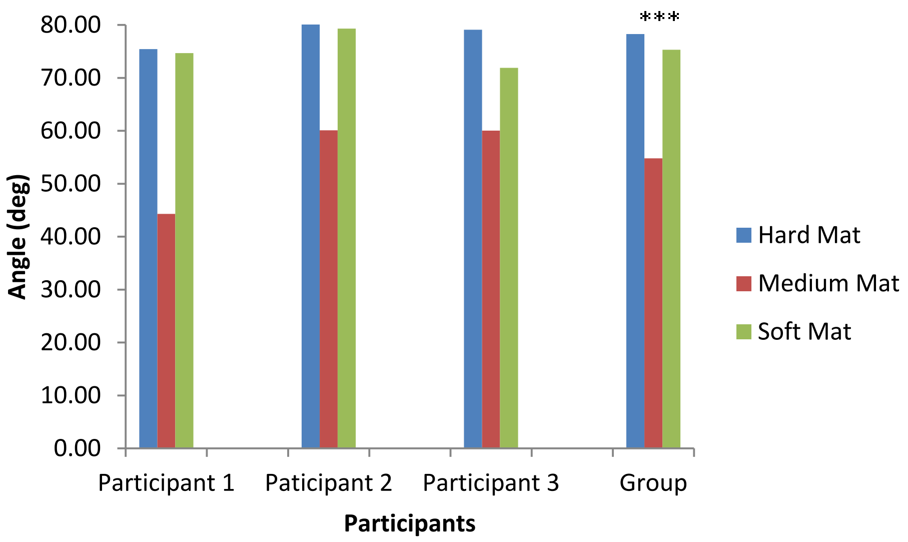


Figure 9 – Minimum ankle angle in the landing phase shown for each participant and as a overall group under all mat conditions. *** Significant difference between the medium and soft mat at the group level (P<0.05).

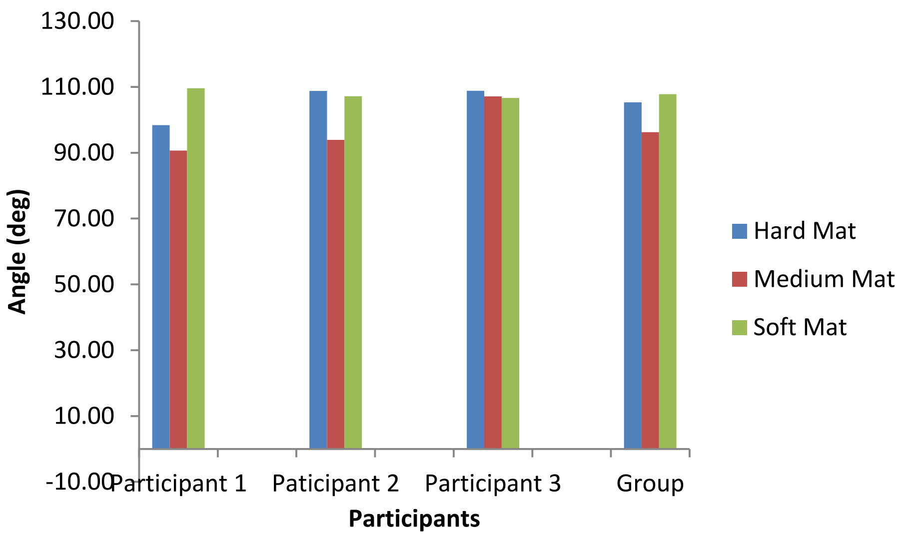


Figure 10 - Minimum knee angle in the landing phase shown for each participant and as a overall group under all mat conditions.

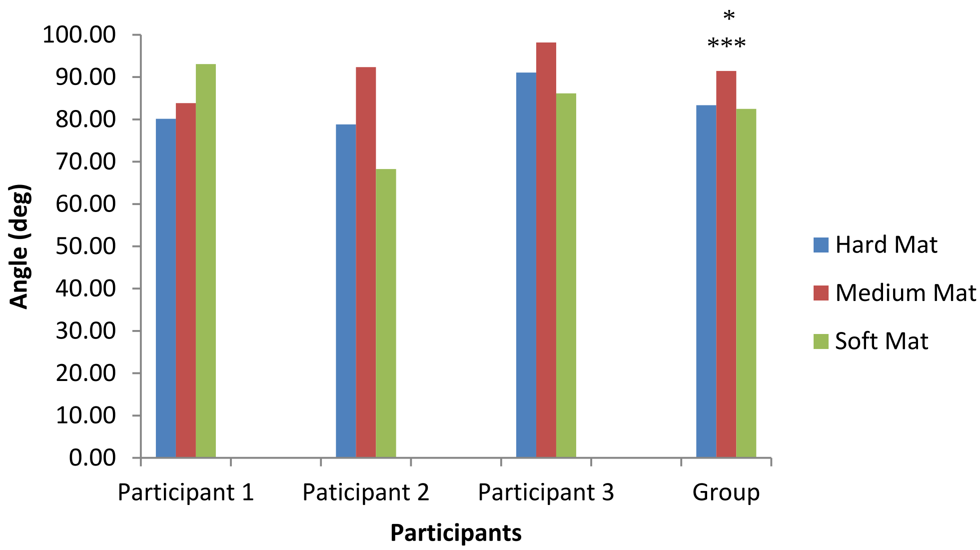


Figure 11 – Minimum hip angle in the landing phase shown for each participant and as a overall group under all mat conditions.* Significant difference between the hard and medium mat at the group level (P<0.05). *** Significant difference between the medium and soft mat at the group level (P<0.05).

Figure 12, 13 and 14 show the peak angular velocities through flexion at the ankle, knee and hip respectively. The negative values show the joint in flexion, where-as they would be positive if the joint was in extension. The peak ankle angular velocity showed no significant difference was found between all mat conditions (P<0.05). Every participant bar participant three showed a different pattern when compared to the overall group. Participant one showed a difference between the hard and soft mat, where the hard mat produced the lowest angular ankle velocity (-185.45°/s) and the hard mat exhibited the largest angular ankle velocity (-419.89°/s). Where-as participant two showed a difference within the soft mat, where the ankle angular velocity was largest (-577.68°/s), this shows individual responses to peak angular velocity. Figure 13 displayed the peak angular velocity within the knee joint. No significant difference was found between all the mat conditions (P<0.05). Participant one displayed a different pattern with the knee angular velocity being greatest under the medium mat condition (-250.56°/s). The peak hip angular velocity showed similar patterns to the ankle and knee angular velocity showing no significant difference between any of the mat conditions (P<0.05). All participants showed a different pattern within the peak angular velocity at the hip when compared to the overall mean data.

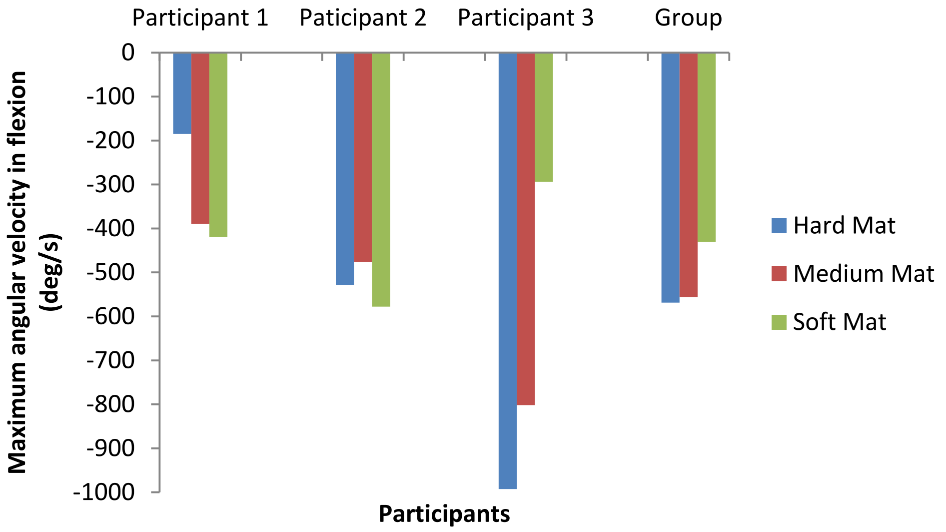


Figure 12 – Peak ankle angular velocity in the landing phase shown for each participant and as an overall group under all mat conditions.

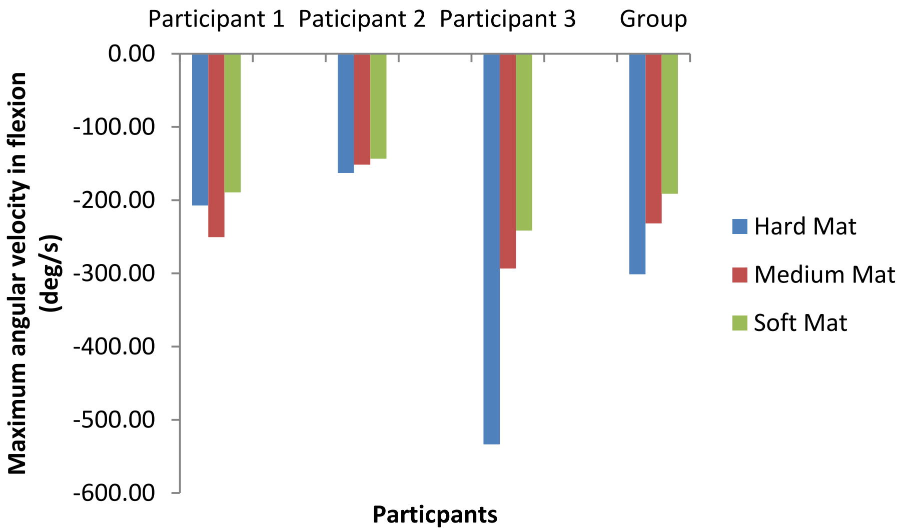


Figure 13 – Peak knee angular velocity in the landing phase shown for each participant and as an overall group under all mat conditions.

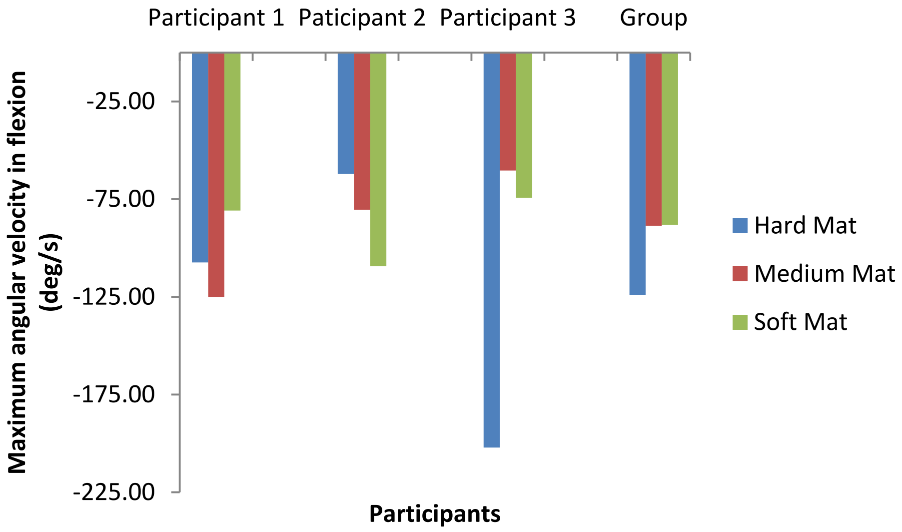


Figure 14 – Peak hip angular velocity in the landing phase shown for each participant and as an overall group under all mat conditions.

4.2 Continuous Data

4.2.1 Continuous Kinetic Phase Time Profiles

Figure 15 illustrates the vGRF-time profile for the landing phase onto the hard, medium and soft mat conditions. As seen from the graph, there was a tendency for the hard mat condition to produce higher levels of peak VGRF just after touchdown (0%-20%) when compared to the medium and soft mat condition. The vGRF-time profile for the hard mat condition differed largely when compared with the soft mat condition which can be seen in the graph and also coincides with table two with a RMSD value of 9.58%.

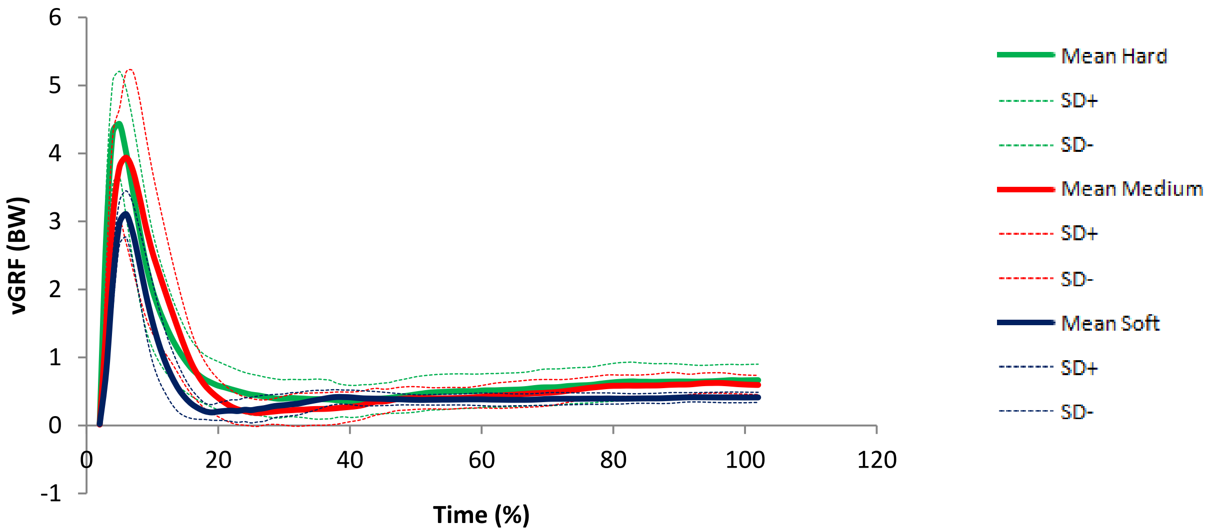


Figure 15 – A force-time graph demonstrating the vertical ground reaction force profile for the hard, medium and soft landing mat conditions.

4.2.2 Continuous Flexion-Extension Joint Kinematics

Figure 16, 17 and 18 represent the continuous time profiles for the ankle, knee and hip angles. A decrease in the curves represents flexion and an increase in the curve represents extension. All the curves represented in figure 16 initially show a sudden decrease in the ankle angle, followed by an increase and slight fluctuations before the curve comes to a plateau. At touchdown (0%) the ankle angle seems to be consistent throughout all landing mat conditions. The standard deviations for all mats are wider distributed to the actual angles created, suggesting variability within the landings is present. It is recognised that the standard deviations become wider apart and the point where the ankle angle reaches its minimum.

Figure 17 conveys the knee angle throughout the landing phase. All curves show a decrease after touchdown followed by a steady increase. The curves for each of the mat conditions have a similar distribution which shows little variability between the knee angle curves during landing.

The hip angle shown in Figure 18 shows a slight altered pattern for the hard mat. The hip angle decrease straight after touchdown (0%) and then increases until coming to a slight plateau. Where-as the hip angles on the medium and soft mat increase slight straight after touchdown then decrease before increasing again and coming to a slight plateau. This suggests that on the medium and soft mat the participant is still extending from the tucked somersault position when hitting the mat before then adjusting to land without steps.

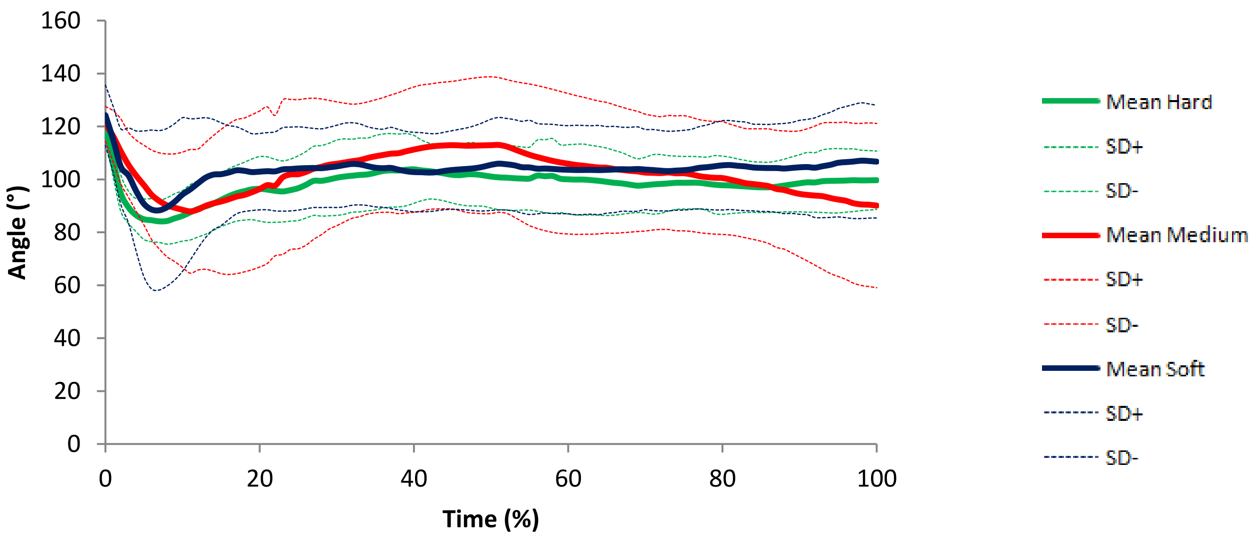


Figure 16 - The flexion-extension ankle angles throughout landing phase for each mat condition.

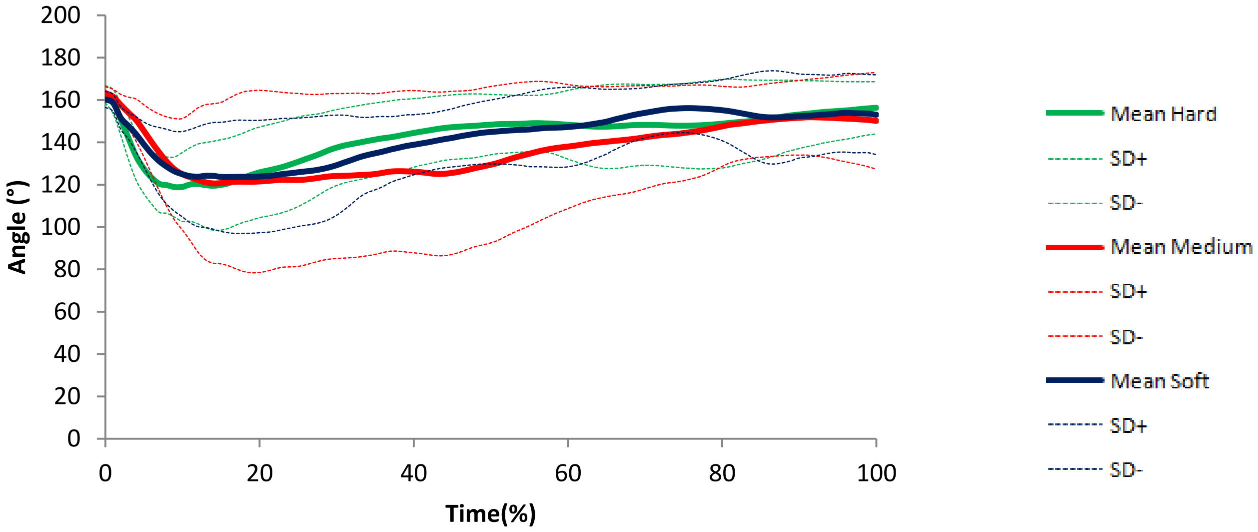


Figure 17 – The flexion-extension knee angles throughout the landing phase for each mat condition.

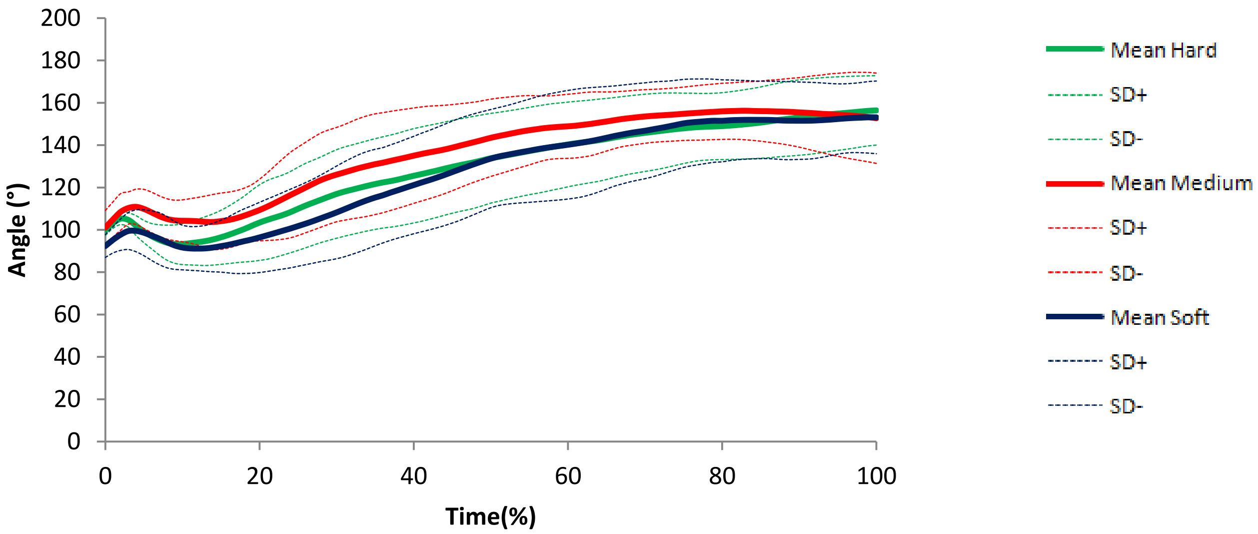


Figure 18 – The flexion-extension hip angles throughout the landing phase for each mat condition.

The graphs presented in figure 19, 20 and 21 show the continuous time profiles for the angular velocity of the ankle, knee and hip. The positive values show the joint extending and the negative values the joint in flexion. Figure 19 shows the continuous time profile for the angular velocity of the ankle. This mat condition can be recognised to attribute less variation then the other mat conditions due to the smaller distributed standard deviations compared with the actual angular velocity curve. Each mat condition produced a similar pattern, where the angular velocity shows multiple actue extension and flexion movements. Figure 20 shows the angular velocity pattern across the knee joint while landing on the different mat conditions. The hard mat condition produces the largest angular velocity in flexion at approximately -180°/s. It also produces the largest angular velocity in extension at approximately 80°/s. This suggests the knee when landing on the hard mat goes through the largest range of motion and just after touchdown (0%). The variation within the curves all differ, suggesting different angular velocity patterns on each of the different mat conditions. Within the mat conditions the standard deviation lines are widely distributed, suggesting high variability within the landings on the mats. The angular velocity across the hip joint is shown in figure 21. Each curve presents the same pattern of movement within the angular velocity of the hip. The hard mat produces the largest angular velocity in flexion, however the medium mat produces the largest angular velocity in extension at touchdown.

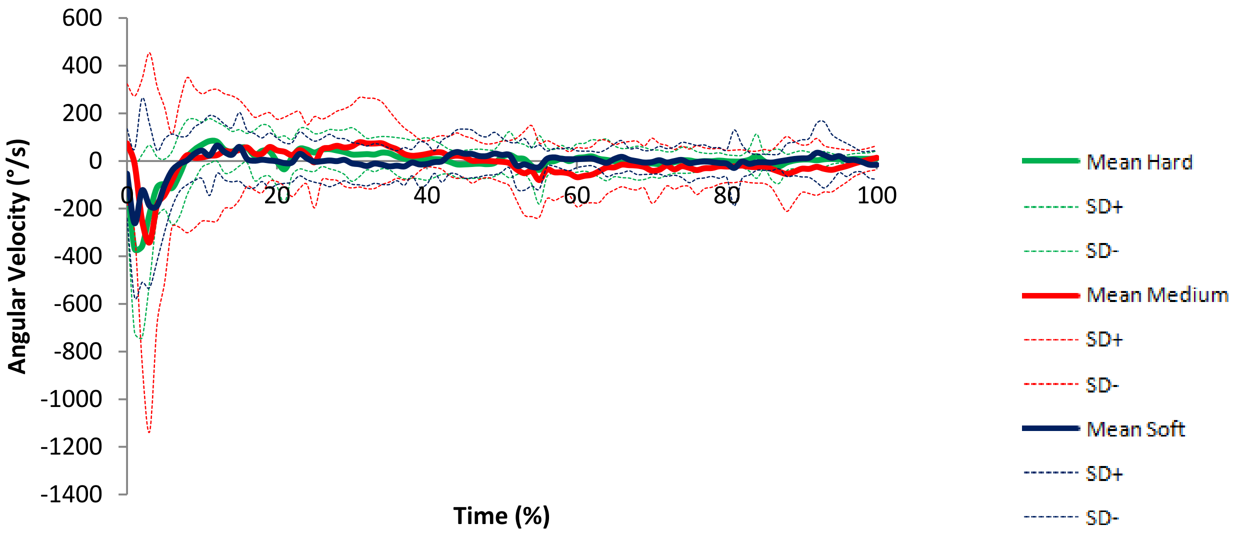


Figure 19 - The angular velocity across the ankle joint throughout the landing phase for each mat condition.

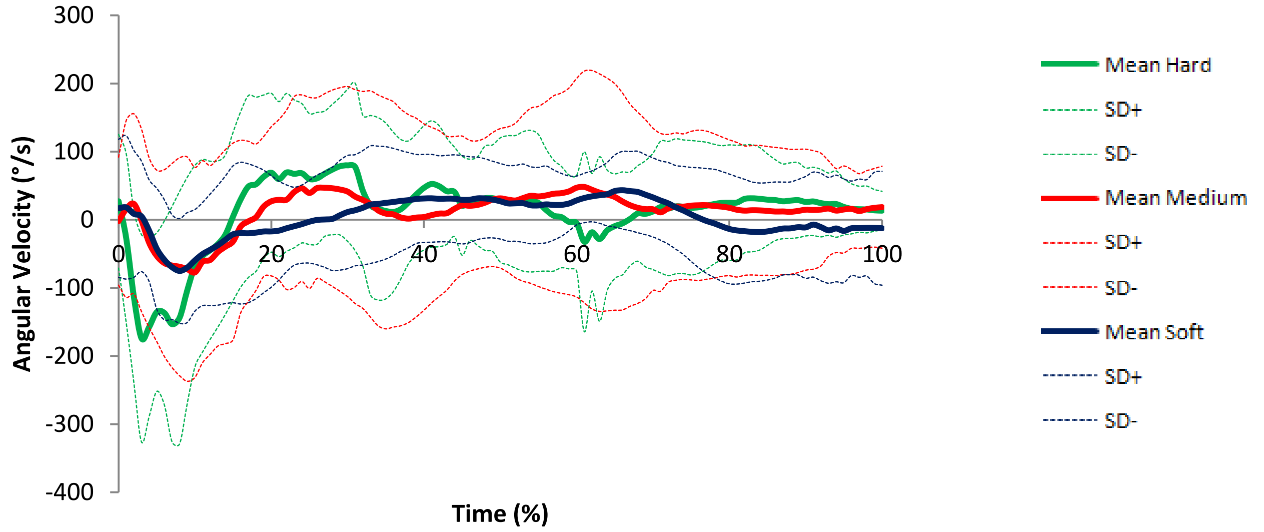


Figure 20 - The angular velocity across the knee joint throughout the landing phase for each mat condition.

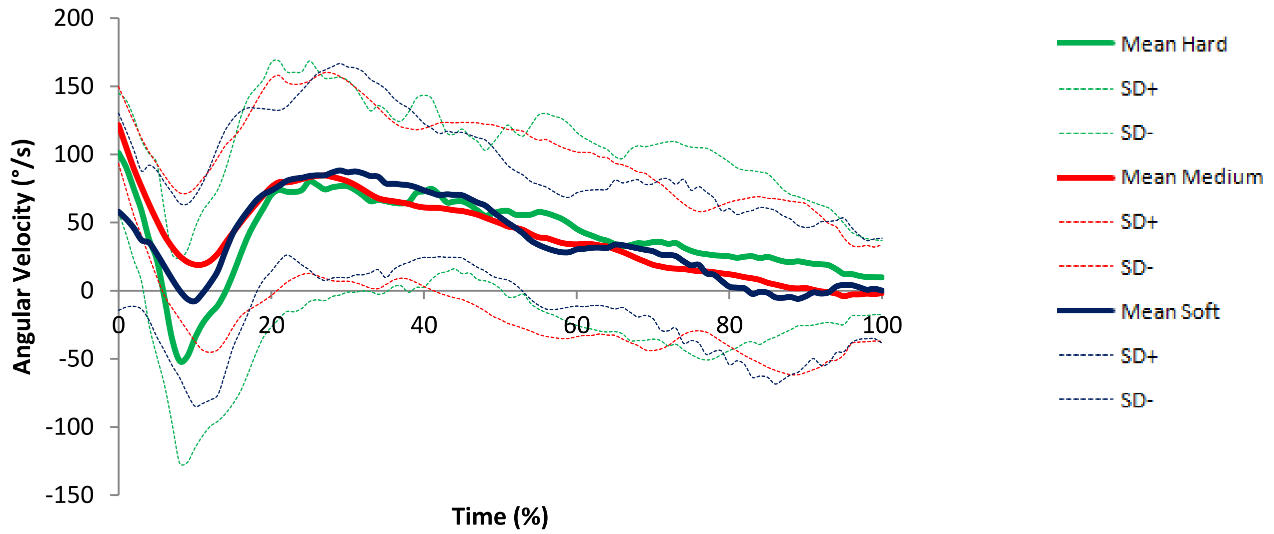


Figure 21 – The angular velocity across the hip joint throughout the landing phase for each mat condition.

4.3 Mechanical Variability

Variability calculated is only for the group response the individual data has been ignored, due to the aim being to look into the differences of the mats as a whole and not the individual differences.

4.3.1 Discrete Variability

Table two summarises the groups landing variability onto the different landing surfaces. Within the kinetic variables, time to peak presented low variability throughout each mat condition, 8.8% for the soft mat, 7.9% for the medium mat and 5.1% for the hard mat. Peak vGRF and loading rate both showed the same pattern within the CV value. The soft mat showed the lowest variability followed by the hard mat and the highest variability being shown on the medium mat landings. There was no noticeable trend when considering the variability change in angle variability on each of the mats. Minimum angle of the hip and ankle however displays low variability while landing on the hard mat condition, showing a CV level of 9.6% and 8.1% respectively. All of the peak angular velocities display high variability being above 10% on each mat condition.

Table two - The mean ± standard deviation and coefficient of variation values of discrete mechanical measures for hard mat, medium mat and soft mat landing conditions at the group level where N=30 for each condition. Coefficient of variation = Group intra-condition differences.

	Soft Mat		Medium Mat		Hard Mat	
	Mean±SD	Coefficient of Variation (CV) %	Mean±SD	Coefficient of Variation (CV) %	Mean±SD	Coefficient of Variation (CV) %
Peak vGRF (BW)	3.37±0.29	8.6	4.99±0.78	15.7	5.27±0.58	10.9
Time to Peak (s)	0.06±0.01	8.8	0.07±0.01	7.9	0.05±0.002	5.1
Loading Rate (BW/s)	53.3±5.11	9.6	74.8±12.01	16.1	118.0±11.82	10.0
Minimum ϴ Ankle (°)	75.30±23.05	30.6	62.9±24.35	38.7	78.27 ±15.54	8.1
Minimum ϴ Knee (°)	107.81 ±25.09	23.3	96.23 ±42.16	43.8	105.32 ±15.54	14.8
Minimum ϴ Hip (°)	82.51±10.75	13.0	91.46±12.09	13.2	83.35±7.97	9.6
Peak ω Ankle (°/s)	-430.56± 206.68	48.0	-555.83± 349.33	62.8	-568.71 ±387.55	68.1
Peak ω Knee (°/s)	-191.41 ±86.08	45.0	-231.82 ±149.02	64.3	-301.2 ±154.14	51.2
Peak ω Hip (°/s)	-88.18 ±64.80	73.5	-88.61 ±60.47	68.2	-123.9 ±61.11	49.3

Note. SD = Standard Deviation, vGRF = Vertical ground reaction force, BW = Body Weights, ɷ = Angular Velocity, ϴ = Angle, ° = Degree.

4.3.2 Continuous Variability

RMSD was used to present the overall group variability this was used to assess the differences between one mat condition compared to the other mat condition. Table three summarises the RMSD between each of the mats. The RMSD for the vGRF time profiles was lowest between the hard and medium mat (5.76%) suggesting a similar vGRF profile. Comparing the hard mat and soft mat there was the largest (9.58%) difference between the vGRF profiles however this value is still small and suggests little variability between the mats. This is also shown in Figure 6 with a 5.66% difference between the peak vGRF for the hard and medium mat and a 35.85% difference between hard and soft mat.

The RMSD for the angle profiles were high overall showing different patterns within the angle profiles for each of the mat conditions. The hip angle change is large when landing on the hard mat compared to the medium mat (24.97%) and the medium mat compared to the soft mat (19.78%). The ankle angle showed high RMSD values when comparing the minimum ankle angle across the different mats, the largest difference being between the minimum ankle angle on the medium mat compared to the soft mat (20.22%). This is also represented in Figure 12 where the minimum ankle angle difference is largest between the medium and soft mat (29.18%).

RMSD for the peak angular velocity occurring at the ankle are relatively similar between the hard mat compared to the medium and soft 12.05% and 11.84% respectively. Between the medium and soft mat there was little change within the peak angular velocity at the ankle (7%). This was similar when looking at the peak angular velocity at the knee with a small difference of 9.27% between the medium and soft mat. The peak angular velocity at the hip showed high differences between all the mats. The largest difference of peak angular velocity at the hip was between the hard mat and soft at a value of 25.33%.

Table three - The RMSD values of continuous mechanical measures for hard mat, medium mat and soft mat landing conditions

	Hard mat versus Medium mat	Hard mat versus Soft mat	Medium mat versus Soft Mat
	RMSD (%)	RMSD (%)	RMSD(%)
vGRF Time Profile (BW)	5.76	9.58	8.15
Minimum Ө Ankle (°)	19.19	16.72	20.22
Minimum Ө Knee (°)	24.97	11.59	19.78
Minimum Ө Hip (°)	12.50	6.53	16.71
Peak ω Ankle (°/s)	12.05	11.84	7.00
Peak ω Knee (°/s)	15.49	19.20	9.27
Peak ω Hip (°/s)	13.56	25.33	18.64

CHAPTER V
DISCUSSION

5.0 Discussion

The aim of this study was to investigate the influence different gymnastic mat materials have on the kinetic, kinematic and variability of the lower extremity mechanics during gymnastic landing movement. In order to address the study aim, kinematic and kinetic variables of the gymnastics were firstly examined, followed by an assessment of mechanical variability; this was completed for all of the mat conditions. The objectives were to assess the key kinetic and kinematic variables across the different mat conditions to see if this influences overuse injury potential and to evaluate the variability of the landing movements across the different mat conditions to see if this influences overuse injury potential.

5.1 Kinetic-Kinematic Responses

It was hypothesised that the softest mat will hold the optimum force and angles to reduce injury in landings. To address this, the first objective of this study was to understand how the key kinetic and kinematic variables of the gymnastic landing changes across the mat conditions. Peak vertical ground reaction force for the group was greater in the hard mat (5.1BW) and lowest in the soft mat landing (3.37BW). There were significant differences between the hard and soft mat and the medium and soft mat condition ($P<0.05$). Mills *et al.,* (2010) also found that increasing the dampness in the mat lowered the external ground reaction forces. McNitt-Gray *et al.,*(1993) agreed on this finding significant differences between the hard and soft mat's peak vertical force. However a study by Arampatzis *et al.,*(2002) found no significant difference in peak vertical forces between the three types of mats. Ground reaction force is a display of the amount of stress on the human system (i.e. lower extremities) during ground contact (McClay *et al.,* 1994). Therefore, with the soft mat having significantly lower peak vertical ground reaction force when compared to the hard and medium mat, it can be assumed that the lower extremities of the body are put through less stress. Vertical ground reaction force during landing can be modified by either technique used and/or the properties of the mat, as shown by the result of this study with a 35.85% reduction between the hard and soft mat.

When examining the minimum angles of the ankle knee and hip across the different mats, no significant differences were found across the knee joints, this suggested that overall the gymnasts elicited their hip and ankle angles to suffice the landing parameters. Significant differences were found on the minimum hip angle when comparing to the landings on the hard and medium mat and the medium and soft mat. These results conflict to McNitt-Gray *et al.,* (1993) who found that significantly smaller knee angles were found when landing on the harder mat, and no significant differences were found across the hip angles across the two mat conditions. The minimum angle at the hip on the soft mat was shown to have the lowest minimum angle value at 82.51°. This suggests that when landing on the soft mat the hip angle goes through the largest range of flexion when compared to the medium mat condition. This suggests that the overall landing strategy used was to decrease the hip angle when landing on the soft mat condition in order to control the amount of peak vertical ground reaction force experienced. One possible explanation for this change in the hip angle is that it will influence the moment arm of the external vertical ground reaction force and of the ligaments and muscles, thus changing the loading experienced by the lower extremities (Dixon *et al.,* 2005).

Many studies (Lees 1981; Dufek and Bates, 1990; Irvine *et al.,* 1992) also found that the landing strategies that favoured greater degrees of joint flexion at a specific lower extremity joint created a reduced peak vertical reaction force. Myers *et al.,* (2011) found that stiff landings, which can be defined as lower joint flexion angles, causes significantly greater peak ground reaction forces. This is agreed upon within the study's results which showed a significantly greater peak vertical ground reaction force on the medium mat compared to the soft mat which may be due to the significantly increased hip angle experienced on the medium mat when compared to the soft. Therefore the increased joint flexion angles at the hip on the soft mat can cause the peak ground reaction force to decrease which could reduce the overuse injury potential. Shock attenuation could mechanical explain the increased hip flexion and decreased peak ground reaction forces. Shock attenuation is accomplished by reactive structures (i.e. Hip joint) absorbing the impact energy by activating movement (i.e. increasing flexion). With the conflicting results around the minimum knee and hip angles this study brings about new knowledge of group responses onto different landing mats. It suggests that overall landing strategies change gymnast to gymnast and they can adapt a specific joint angle allowing an effective landing strategy for the individual which allows satisfaction of the landing constraints and decreases the forces experienced.

The significant difference seen in Figure 9 of the minimum ankle angle between the medium and soft mat, shows a decrease in flexion as the mat hardness decreases from medium to soft. The individual responses shown in figure 9 also allay the same pattern of a decrease in flexion on the soft mat. Therefore this suggests that the kinematic landing strategy for landing on a soft mat is a reduction in flexion at the ankle joint. This is supported by Ozguven and Berme, (1988); McNitt-Gray *et al., (*1993) and McNitt-Gray *et al.,* (1994) who observed less joint flexion in the lower extremity when landing on less firm surfaces. Robbins and Waked (1997) also found that landing on soft surfaces causes the participant to decrease the flexion of the lower extremities. This may be due to the participants' perception of the damping of the mat and assumed the mat would attenuate the force.

As the mat softness increases so does the instability of the ankle joint (Arampatzis *et al.,* 2002; Perez *et al.,* 2008). This instability of the ankle joint may cause ankle sprains after a prolonged time. Therefore softer mats may not always be the safest option because of the decreased peak vGRF due to the instability properties it contains. Looking at the flexion-extension angles for the ankle alone isn't sufficient. Future directions can look into the different movement planes of the lower extremity joint (i.e. eversion-inversion) when looking into landing on different mat materials to give a wider insight of the kinematic movement that occur and how they affect injury.

An examination of the minimum angles of the knee did not bring about significant difference. However when looking into the individual responses of the knee joint angle they are all greatly extended (>90°) just after touchdown. Devita and Skelly (1992) defined a stiff knee landing as the maximum knee flexion angle over 90°. This result may be an effect of the experience of the gymnast who knows any extraneous segment motion will result in a reduction of performance score (FIG, 2013). Therefore, it should be noted that the findings from the current study are relative to a small sample size and a specific population who have great familiarity with the backward tucked somersault dismount and the required landing needed to satisfy a 'stuck' landing this has also been found by (McNitt-Gray *et al.*, 1993). An explanation for the observed stiffer knee angles was put forward by McNitt-Gray (1993) who stated that decreased knee joint flexion angles suggest the gymnast is aware of a specific landing procedure which permits greater ability to accommodate for any unexpected events in which they can then accommodate with more flexion at the knee. These decreased knee joint flexion angles observed across all of the mats for each individual landing response could contribute to an increase in injury potential of overuse knee injuries upon landings at each mat condition.

In conjunction with these stiff knee angles and changes in the minimum hip angle the mats' energy absorption rates may have a part to play in these decreased peak vertical ground reaction forces. Many studies have found that the more elastic deformation a mat has, the better capabilities of reducing the rate of loading (Mills *et al.,* 2006; Perez-Soriano *et al.,* 2010). Rate of loading was shown to be significantly decreased between the hard and medium mat and hard and soft mat ($P<0.05$). Therefore rate of loading was significantly smaller in the medium and soft mats when compared to the hard mat condition, this may be due to the increased elastic deformation the medium and soft mat may exhibit. This study didn't measure the mats characteristics and most importantly the shock absorption of the mat. Future directions could take place in the form of not only testing the participant's kinetic and kinematic variables on the mats but also test the mats capacity for shock absorption and elastic deformation, this would help to conclude why the soft mat and medium mat produces a decrease rate of loading, and why the soft mat demonstrates significantly lower peak vertical ground reaction forces.

5.2 Mechanical Variability

It was hypothesised that the softest mat will create more variability within the landings then the other two mats. To address this, the second objective was to assess the variability of the landing movements across the different mat conditions to see if this influences overuse injury potential. When looking into the variability of the kinetic and kinematic values it is important to understand that if the CV value was less than 10%, the variable was considered to have low variability (Menz *et al.,* 2004). A contemporary dynamical systems perspective suggests that in the execution of athletic task movement variability is set to have a practical role (Hamill et al.,1999; van Emmerik et al., 2005). However due to the set landing parameters by F.I.G, a stable kinematic response across all mats was expected.

When looking into the CV for the specific mats for the minimum angles most were above 10%. However the knee angle and hip angle on the hard mat showed to have low variability at 8.1% and 9.6% respectively. This suggests that the hard mat produces lower variability within the joint angles when compared to the soft and medium mat. This lower variability can be a possibility of higher overuse injury potential, due to invariable patterns on stress distribution which could lead to the collapse of lower extremity structures (Pollard *et al.,* 2005). Though, Mclean *et al.,* (2005) contradicted this in suggesting that reduced variability is innate with greater experience. This study has contradicted this statement due to high variability level found within the medium and soft mat with greater experienced gymnasts.

This greater level of variability found within the soft and medium mat may be beneficial to the potential for overuse injury. However, it has been suggested that larger variability may be a response to the alteration to an unfamiliar task (Hamill *et al.,* 2000). This may be true within the present study as gymnasts utilize the use of harder mats to prepare for true competition requirements, therefore landing on the softer mats have brought about unfamiliarity and change within the landing strategies. Therefore it would be beneficial for a compensation period in where the gymnasts used the softer mats for landings within practise to become familiar with the landing properties.

Within the kinetic variables the variability within the soft landing mat conditions were the lowest at 8.6% for peak vGRF and 9.6% for the loading rate. The medium mat produced higher variability within the kinetics of the landing at 15.7 % for peak vGRF and 16.1% for the loading rate. These variations on the medium mat are set to be functional and healthy (Hamill *et al.,* 2012) and can demonstrate reduction in overuse injuries of the lower extremities (James, 2004). Within the soft mat and the reduction in variability across the kinetic variables it is said to cause the forces to distribute across a small surface area which can then result in possible overuse injuries to the lower extremities (Hamill *et al.,* 2012). As no variability research has been examined in the gymnastic field, this has added to the knowledge of the variability patterns in relation to gymnastic landings on different mat conditions.

From an injury perspective it has been previously stated that through the research of individuals with ankle instability and that are injury prone, the lower extremities have less variability, indicating a relationship between variability and overuse injury (Roger *et al.,* 2000; Brown *et al.,* 2012; Kipp & Palmieri-Smith, 2012). Therefore with the medium mat having highest variability within the kinematic and kinetic variables while still satisfying the landing parameters can hold the highest potential for decreasing overuse injury potential. However more in-depth future research would be necessary to accept this hypothesis.

CHAPTER VI
CONCLUSION

6.0 Conclusion

The study found that the key kinetic variables were in the safest parameters on the softest mat condition, and the kinematic variables displayed an optimum landing strategy on the soft mat with reduced flexion of the ankle and increased flexion to the hip. The study also found the variability across the mats were relatively high except when looking at force variables for the soft mat and the minimum angles variability for the hard mat, This suggested the medium mat has the optimum variability parameters for gymnastic landings. The study was set to look into the basic kinematic, kinetic and variability variables and didn't look into the mat characteristics, therefore it would be beneficial to widen the scope of the kinematic variables (i.e. different movement planes) and mechanically test the mat characteristics. The study does posses limitations however it does confirm at the basic levels that variability was highest within the medium mat and the kinetic and kinematic variables were in the safest parameters within the softest mat which could lead to a decrease in the overuse injury potential. Therefore effort for gymnast's and their coaches should take future direction of using a medium to soft mat for landing when in practise.

CHAPTER VII
REFERENCE LIST

Reference list

Arampatzis, A. Bruggemann, G. P. Klapsing, G. M. and Wiehn, M. A. (2002). Three dimensional lower leg-foot model to determine the influence of various gymnastic mats on foot during landings*. Medicine & Science in Sports & Exercise*. 34, pp. 130–138.

Andrish, J.T. (1985). Knee injuries in gymnastics. *Clinics in Sports Medicine*. 4, pp.111–121.

Bartlett, R. Wheat, J. and Robins, M. (2007). Is movement variability important for sports biomechanics? *Sports biomechanics.* 6(2), pp. 224-243.

Bates, B. T., Dufek, J. S. and Davis, H. P. (1992). The effect of trial size on statistical power. *Medicine and Science in Sports and Exercise*. 24, pp. 1059-1068.

Beck, B. (1998). Tibial stress injuries: An aetiological review for the purposes of guiding management. *Sports Medicine*, 26, pp. 265–279.

Brian, P. Self, P. and Paine, D. (2001). Ankle biomechanics during four landing techniques. *Medicine and Science in Sports and Exercise.* 14, pp. 1338-1344).

Brown, C. Bowser, B. Simpson, K. J. (2012). Movement variability during single leg jump landings in individuals with and without chronic ankle instability. *Clinical biomechanics.* 27, pp. 52-63.

Caine, D. Cochrane, B. Caine, C. and Zemper, E. (1988). An epidemiologic investigation of injuries affecting young competitive female gymnasts. *The American Journal of Sports Medicine*. 17, pp. 811-820.

Coulton, J. (1988). *Women's Gymnastics.* 2nd edition, London: A & C Black.

Cuk, I. And Marinsek, M. (2013). Landing quality in artistic gymnastics is related to landing symmetry. *Biology of Sport*. 30, pp. 29-33.

Devita, P. and Skelly, A.W. (1992) Effects of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and science in sport and exercise*. 24(1), pp.108-115.

Dixon, S.J. Collop, A.C. and Batt, M.E. (2005). Compensatory adjustments in lower extremity kinematics in response to a reduced cushioning of the impact interface in heel-toe running. *Sports Engineering.* 8 (1), pp. 47-55.

Dufek, J. S. and Batel, B. T. (1990). The evaluation and prediction of impact forces during landings. *Medicine and Science in Sports and Exercise.* 22, pp. 370-377.

Federation Internationale de Gymnastique (1984). *Code of points.* International Gymnastics federation, Bericht:West Germany.

Federation Internationale de Gymnastique F.I.G. (2001). *Code of Points*. Men's Artistic Gymnastics. F.I.G. Switzerland.

Federation Internationale de Gymnastique F.I.G. (2013). *Code of Points*. Womens Artistic Gymnastics. F.I.G. Switzerland.

Gervais, P., & Dunn, J. (2003). The double back salto dismount from the parallel bars. *Sports Biomechanics*, 2, pp. 85–101.

Gittoes, M.R., Irwin, G., Mullineaux, D.R. and Kerwin, D.G. (2011). Whole-body and multi-join kinematic control strategy variability during backward rotating dismounts from beam. *Journal of Sport Science,* 29(10), pp. 1051-1058.

Gittoes, M. R. and Irwin. G. (2012). Biomechanical approaches to understanding the potentially injurious demands of gymnastic-style impact landings. *Sports medicine, arthroscopy, rehabilitation, therapy & technology.* 4(4), pp. 1-9.

Gittoes, M. R., Irwin, G. and Kerwin, D. G. (2013). Kinematic Landing Strategy Transference in Backward Rotating Gymnastic Dismounts. *Journal of Applied Biomechanics*. 29, pp. 253-260.

Karacsony, I. Cuk, I. (2005). Floor exercises – Methods, Ideas, Curiosities, History.

Hamill, J. van Emmerik, R. E. Heiderscheit, B. C. and Li, L. (1999). A dynamical systems approach to lower extremity running injuries. *Clinical Biomechanics*, 14, pp. 297–308.

Hamill, J. Haddad, J. M. McDermott, W. J. (2000). Issues in quantifying variability from a dynamical systems perspective. *Journal of Applied Biomechanics.* 16, pp.407–418.

Hamill, J. Palmer, C. andvan Emmerik, R. E. A. (2012). Coordinative variability and overuse injury. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology.* 4(45), pp 1-9.

Heiderscheit, B. C. (2000). Movement variability as a clinical measure for locomotion. *Journal of Applied Biomechanics*, 16, pp.419-427.

Hewett, T. E. (2000). Neuromuscular and hormonal factors associated with knee injuries in female athletes. *Sports Medicine*, 29(5), pp.313-327.

Irvin, D. M. E. McNitt-Gray, J. I. Munkasy, B. A. Barbieri, C. A. and Welch, M. D. (1992) Muscle activity and kinetics during landings with reduced vertical reaction forces. In: *Proceeding of the CVIIth American Society of Biomechanics (ASB) Meeting,* pp. 111-112.

James, C.R. 2004. Considerations of movement variability in biomechanics research. In: Stergiou, N. (Ed.), Innovative Analyses of Human Movement. Human Kinetics, Champaign, IL, pp. 29–62.

Jensen, J.E. (1998). Stress fracture in a world-class athlete: a case study. *Medicine and Science in Sports and Exercise* 30, pp. 783–787.

Kipp, K. and Palmieri-Smith, R. (2012). Principal component based analysis of biomechanics inter-trial variability in individuals with chronic ankle instability. *Clinical biomechanics.* 27, pp. 706-710.

Kong, P.W. and Candelaria, N.G. (2009). Spanning set many not be appropriate for measuring knee kinematic variability for the entire gait cycle during over-ground barefoot running. *Journal of Applied Biomechanics*. 25, pp. 258-264.

Knudson, D., & Blackwell, J. (2005). Variability of impact kinematics and margin for error in the tennis forehand of advanced players. *Sports Engineering, 8*(2), pp. 75-80.

Lees, A. (1981). Methods of impact absorption when landing from a jump. *Engineering in Medicine.* 10(4), pp. 207-211

Lees, A. Vanrenterghem, J. and Clercq, D. (2004). Understanding how an arm swing enhances performance in the vertical jump. *Journal of Biomechanics*. 37 (12), 1929-1940.

Marinsek, M. (2011). Basic landing characteristics and their application in artistic gymnastics. *Science of Gymnastics.* 2(2), pp. 59-67.

MacLean, S.G., Lipfert, S.W. and Van Den Bogert, A.J. (2004). Effect of gender and defensive opponent on the biomechanics of sidestep cutting. *Medicine and Science in Sports and Exercise.* 36(6), pp. 1008-1016.

McAuley, E., Hudash, G., Shields, K., Albright, J., Garrick, J., Requa, R., Wallace, R. (1987). Injuries in women's gymnastics. *The American Journal of Sports Medicine* 15, pp. 558–566.

McClay, I. Robinson, J. Andriacchi, T. Frederick, E. Gross, T. Martin, P. Valiant, G. Williams, K. R. and Cavamagh, P. R. (1994). A profile of ground reaction forces in professional basketball. *Journal of Applied Biomechanics*. 10, pp. 222-236.

Mclean, S. G. Walker, K. B. van den Bogert, A. J. (2005). Effect of gender on lower extremity kinematics during rapid direction changed: an integrated analysis of three sports movement. *Journal of Science and Medicine in Sport*. 8, pp.411-422

Mcnitt-Gray, J. L. (1991). Kinematics and impulse characteristics of drop landings from three heights. *International journal of Sport Biomechanics*. 7, pp. 201-224.

McNitt-Gray, J. L. (1993). Kinetics of the lower extremities during drop landings from three heights. *Journal of biomechanics*. 26(9), pp. 1037-46.

McNitt-Gray, J. L., Yokoi, T. and Millward, C. (1994). Landing strategies used by gymnasts on different surfaces. *Journal of Applied Biomechanics.* 10, pp 237-252.

McNitt-Gray, J. L., Yokoi. T. and Millward. C. (1993). Landing strategy adjustments made by female gymnasts in response to drop height and mat composition. *Journal of Applied Biomechanics.* 9, pp.173-190.

McNitt-Gray, J.L. (2000). Musculoskeletal loading during landing. In: Zatsiorsky, V. (Ed.), *The Encyclopaedia of Sports Medicine*: Biomechanics in Sport. IOC, Blackwell Science, pp. 523–549.

Meeusen, R., Borms, J. (1992). Gymnastic injuries. *Sports Medicine.* 13, pp. 337–356.

Menz, H. B. Latt, M. D. Tiedemann, A. Mun San Kwan, M. Lord, S. R. (2004). Reliability of the GAITRite walkway system for the quantification of temporo-spatial parameters of gait in young and older people. *Gait Posture*. 20(1), pp.20–25.

Michaels, C. F. and Beek, P. (1996). The state of ecological psychology. *Ecological Psychology.* 7, pp. 259-278.

Miller, S. (2011) Coaching Youth Gymnastics. Leeds: Human Kinetics, p. 20.

Mills, C. Pain, M. T. G. and Yeadon, M. R. (2006). Modeling a viscoelastic gymnastics landing mat during impact. *Journal of applied biomechanics*. 22, pp. 103-111.

Mills, C., Pain, M. T. G. and Yeadon, M. R. (2008). The influence of simulation model complexity on the estimation of joint loading in gymnastics landings*. Journal of Biomechanics*. 41, pp.620-628.

Mills, C. Yeadon, M. R. and Pain, M. T. G. (2009). Reducing ground reaction forces in gymnastics' landings may increase internal loading. *Journal of biomechanics.* 42, pp. 671-678.

Mills, C. Yeadon, M. R. and Pain, M. T. G. (2010) Modifying landing mat material properties may decrease peak contact forces but increase forefoot forces in gymnastic landings. *Sports biomechanics.* 9(3), pp. 153-164.

Mullineaux, D. R., Bartlett, R. M. and Bennett, S. (2001). Research design and statistics in biomechanics and motor control. *Journal of Sports Sciences.* 19, pp. 739-760.

Myers, C. A. Torry, M. R. Peterson, D. S. Shelburne, K. B. Giphart, J. E. Krong, J. P. Woo, S. L-Y. And Steadman J. R. (2011). Measurements of tibiofemoral kinematics during soft and stiff drop landings using biplane fluoroscopy. *The American Journal of Sports Medicine*. 39(8), pp. 1718-1722

Ozguven, H. H. and Berme, N. (1988). An experimental and analytical study of impact forces during human jumping. *Journal of Biomechanics*. 21, pp 1061-1066.

Perez-Soriano, P. Llana-Belloch, S. Morey-Klapsing, G. Perez-Turpin, J. A. Cortell-Tormo, J. M. and Tillaar, R. V. D. (2010). Effects of mat characteristics on plantar pressure patterns and perceived mat properties during landing in gymnastics. *Sports Biomechanics.* 9(4), pp. 245-257.

Pérez, P. Llana, S. and Alcantara, E. (2008). Standard test ability to measure impact forces reduction on mats. *International Journal of Sport Science and Engineering.* 2, pp. 162-168.

Pollard, C. D. Heiderscheit, B. C. van Emmerick, R. E. A., and Hamill, H. (2005). Gender Differences in Lower Extremity Coupling Variability during and Unanticipated Cutting Maneuver. *Journal of Applied Biomechanics.* 21, pp.143-152.

Preatoni, E. Hamill, J. Harrison, A. J. Hayes, K. Van Emmerik, R. E. A. Wilson, C. and Rodano, R. (2012). Movement variability and skills monitoring in sports. *Sports Biomechanics. 12(2), pp. 69-62*

Robbins, S. and Waked, E. (1997). Balance and vertical impact in sports: Role of shoe sole materials. *Archives of Physical Medicine and Rehabilitation,* 78(5), pp. 463-467.

Roger, J. C. Dufek, J. S. and Bates, B. T. (2000). Effects of injury proneness and task difficulty on joint kinetics variability. *Medicine & Science in sports & exercise.* 32(11), pp. 1833-1844.

Salo, A., & Grimshaw, P.N. (1998). An examination of kinematic variability of motion analysis in sprint hurdles. *Journal of Applied Biomechanics, 14*(2), pp. 211-222.

Sanders, R., & Gibson, B. (2003). Technique and timing in women's backward two and one half somersault tuck (205C) and the men's backward two and one half somersault pike (205B) 3m springboard dives. *Sports Biomechanics*, 2, pp. 73–84.

Seegmiller, J. G. and McCaw, S. T. (2003) Ground reaction forces among gymnasts and recreational athletes in drop landings. *Journal of athletic training.* 38(4), pp. 311-314.

Snook, G.A. (1979). Injuries in women's gymnastics. *The American Journal of Sports Medicine*. 7, pp. 242–244.

Takei, Y. Nohara, H. and Kamimura, M. (1992). Techniques used by elite gymnasts in the 1992 Olympic compulsory dismount from the horizontal bar. *International Journal of Sport Biomechanics*, 8, pp. 207–232.

van Emmerik, R. E. A. Hamill, J. and McDermott, W. J. (2005). Variability and coordinative function in human gait. *Quest*. 57, pp.102–123.

Winter, D.A. (2009). *Biomechanics and motor control of human movement* (4th Edition). New Jersey: John Wiley & Sons.

Yeow, C. H. Lee, P. V. S. and Goh, J. C. H. (2009). Regression relationships of landing height with ground reaction forces, knee flexion angles, angular velocities and joint powers during double leg-landing. *The Knee*. 16, pp. 381-386.

APPENDICES

APPENDIX A

A participant information sheet given to each gymnast to inform them on what the study entails

Cardiff School of Sport Ethics Committee
Research Participant Information Sheet

Project Title: The variability of lower extremity mechanics in gymnastic landings on different mat materials.

The purpose of this document is to assist you in making an *informed* decision about whether you wish to be included in the study, and to help with the research required.

1) Background and aims of the research

There has been little research into variability in gymnastic landings. This study will examine the variability of lower extremity mechanics in gymnastics landings on 3 different mats. This research will be focusing on Kinematic (movement patters) and Kinetics (forces) variables and how they vary between three different mats. This will show the optimum mat to use to decrease injury potential, as low variability has been linked to overuse injury.

2) My role as the researcher:

The project involves me (Ella Taylor), the researcher to conduct a motion and force analysis from a gymnastics beam landing, for each mat.

3) Your role as a participant:

Your role is to complete five backward tucked somersaults on each of the three different mats (fifteen overall). You will be expected to land onto a mat covered force plate and have CODA markers attached to the relevant joints. The results will then be analysed to see the variability of the lower limb mechanics. As a participant you can withdraw from this study without question whenever you want to.

4) Benefits of taking part:

The information obtained from this study will allow a better insight into how lower limb mechanics vary from a soft, medium and hard mat. From this study I will aim to understand how the variability contributes to injury, and which mat can therefore be distinguished as the safest/ has the least injury potential when used. I will be happy to share this information to any of the participants. I can provide you with your own variability scores for each variable observed.

5) How data will be collected:

The kinematics data will be collected using CODA markers places on the relevant areas to give coordinate data for the hip, knee and ankle. The kinetic data will be collected by using a force plate underneath each mat to record the impact and balance phase of each landing.

6) How the data / research will be used:

If you agree to be a voluntary participant, you will allow me to use your results and see how the variability in your lower extremity mechanics change from mat to mat and then compare your results with other participants. This will allow me to see if which mat should be used frequently within gymnastics practice to lower injury potential. Your personal data will remain anonymous and will not be reported alone.

Your rights

Your right as a *voluntary* participant is that you are free to enter or withdraw from the study at any time. This simply means that you are in full control of the part you play in informing the research, and what *anonymous* information is used in its final reporting.

Protection to privacy

As you can see, everyone working on the study will respect your privacy. We have taken very careful steps to make sure that you cannot be identified from any of the information that we have about you.
All the information about you will be stored securely away from the consent and assent forms. At the end of the evaluation study we will destroy the information we have gathered about you. We will only keep the consent and assent forms with your name and address. We keep these for ten years because we are required to do so by UWIC.

Contact

If you require any further details, or have any outstanding queries, feel free to contact me on the details printed below.

Miss Ella Nicole Taylor

Email: ST20005365@outlook.cardiffmet.ac.uk

APPENDIX B

A participants informed consent form which they sign before they take part in the study

CARDIFF METROPOLITAN
INFORMED CONSENT FORM

CSS Reference No:
Title of Project: The variability in lower extremity mechanics in gymnastic landings on different mat materials

Name of Researcher: Ella Nicole Taylor

Participant to complete this section: Please initial each box.

1. I confirm that I have read and understand the information sheet dated ……….......
for this human study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that it is possible to stop taking part at any time, without giving a reason.

3. I also understand that if this happens, our relationships with the Cardiff Metropolitan University, or our legal rights will not be affected

4. I understand that information from the study may be used for reporting purposes, but I will not be identified.

5. I agree to take part in this study on.......................

____
Name of Participant

______________________________ _______________
Signature of Participant Date

______________________________ _______________
Name of person taking consent Date

____
Signature of person taking consent

* When completed, one copy for participant and one copy for researcher's file

APPENDIX C
ETHICS APPROVAL LETTER

Cardiff Metropolitan University
Prifysgol Fetropolitan Caerdydd
UWIC

Date: October 2013

To : Ella Taylor

Project reference number: (13/10/05U)

Your project was recommended for approval by myself as supervisor and formally approved at the Cardiff School of Sport Research Ethics Committee meeting of 16th October 2013.

Yours sincerely

Dr Marianne Gittoes

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APPENDIX D

Details of the pilot study

The purpose of the pilot study was to be made apparent of any faults within the data collection procedure; thus the aim of the pilot study is to evaluate and improve the method used for collection. One participant was used within the pilot study who also partook in the actual data collection, hence satisfying all the conditions set out (age, experience, injury free). The pilot study took place in the National Indoor Athletics Centre at Cardiff Metropolitan University over a two hour slot. The pilot study made apparent of two main changes, mat use and CODA set-up. Firstly the mats used at first were too soft which caused increased damping and lost the marker visibility. This was modified by using a harder mat on top to decrease damping and increasing marker visibility. Another key modification was changing from two to four CODA motion Cx1 units, increasing the number of units also meant adding more markers. Markers originally were on one side of the body, MTP, ankle, knee, hip and temple this was then extended to the other side of the body in the same layout. Running through the full data collection procedure allowed time analysis to be recognised and how much time each participant would be needed for in the actual data collection.

APPENDIX E

Mat information used in data collection

Mat Specification

Hard mat – Carpet Surface competition landing mat. The mat has a core of foam layers. Standard dimensions: 3m x 2m.

Medium mat - Carpet Surface competition landing mat. The mat has a core of foam layers. Standard dimensions: 3m x 2m, with a soft complimentary landing mat over the top. This mat is 100mm thick absorbent foam with a PVC cover, Dimensions 2m x 2m.

Soft Mat – Safety crash mat. The mat has a combustion modified foam core with the dimensions of 1.8m x 1.2m x 100mm, with a soft complimentary landing mat over the top. This mat is 100mm thick absorbent foam with a PVC cover, Dimensions 2m x 2m.

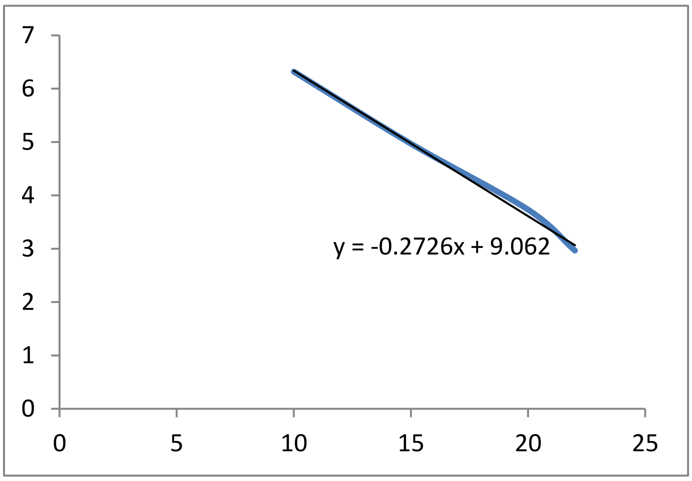
APPENDIX F

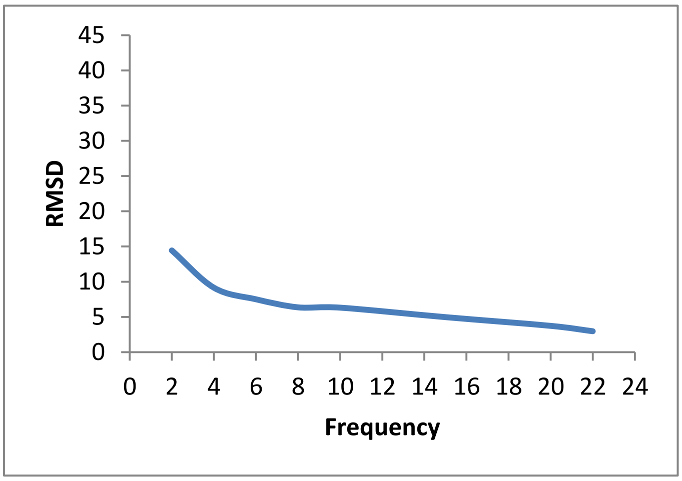
Each gymnast's anthropometric data measures

Participant	Age (years)	Mass (kg)	Height (cm)
1	22	55.4	157.3
2	20	57.0	153.4
3	19	59.5	167.7
Mean	20.3	57.3	159.5
Standard Deviation	1.53	2.07	3.09

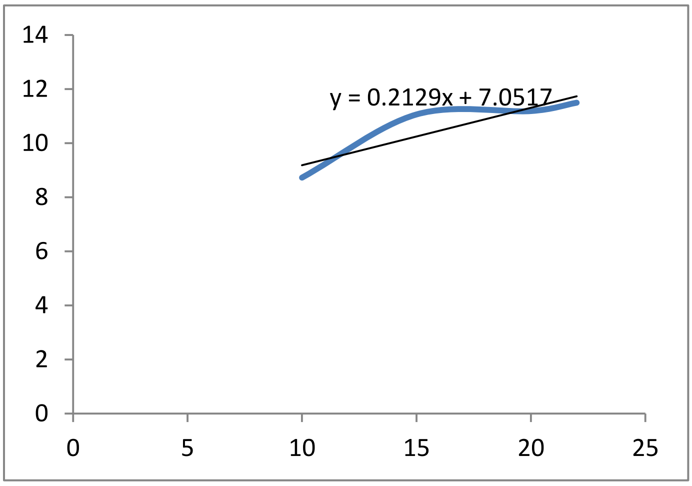
APPENDIX G

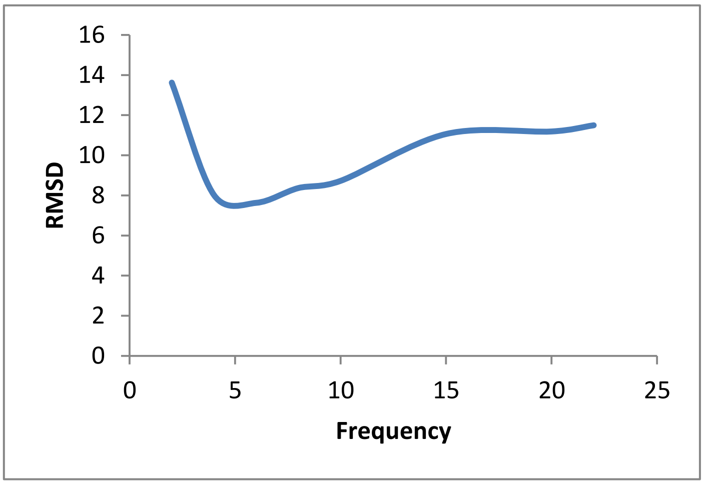
WINTERS RESIDUAL ANALYSIS



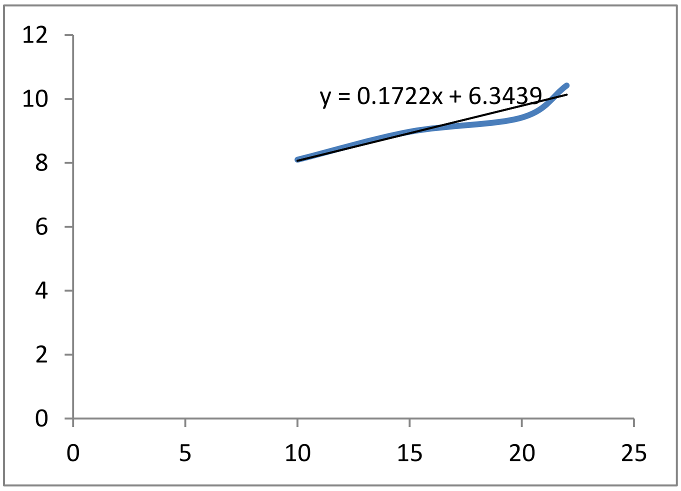


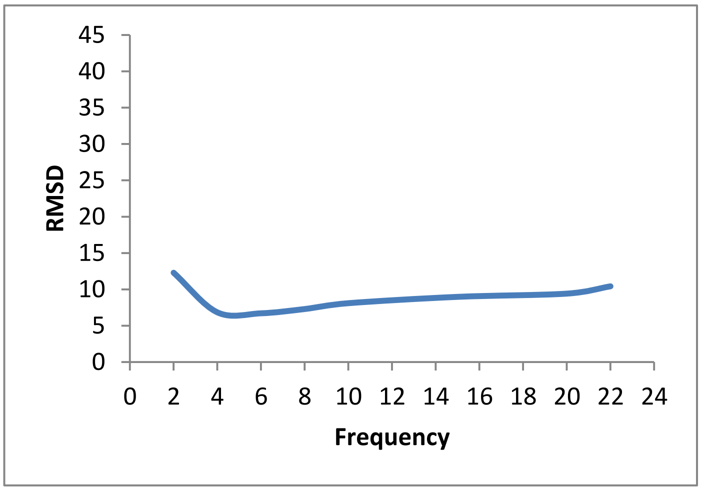
Winters residual analysis; participant 1 hard mat trial 1 of the ankle.





Winters residual analysis; participant 2 medium mat trial 3 of the ankle.





Winters residual analysis; participant 3 soft mat trial 8 of the ankle

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Participant 1 hard mat	4.1
Participant 2 medium mat	5.0
Participant 3 soft mat	3.9
Average	4.3

This table shows the average cut off frequency and 4Hz was found as the cut-off point to filter the data.