MODELLING BADMINTON MOVEMENT FOR INJURY PREVENTION AND PERFORMANCE ENHANCEMENT

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This report details the progress of the Badminton World Federation (BWF) Research Grant project "Modelling Badminton Movement for Injury Prevention and Performance Enhancement" from July 2020 – November 2021. The study is a collaborative investigation between the University of the Witwatersrand and Badminton South Africa (SA), funded by the BWF Research Grant. The aim of the study is to investigate the jump-smash manoeuvre to determine the landing characteristics in several landing positions and their effect on the performance of the smash and the risk of injury as a result of the landing mode.

The study was affected by the SARS-CoV-2 pandemic resulting in project delays due to the postponement of events in accordance with national regulations. Data collection took place during the Badminton SA training camps in December 2020 and February 2021, with the participation of 15 participants. Participants executed the jump smash and landed in four modes: (1) their natural landing (on the ball of the foot), (2) forced toe-first landing, (3) forced heel-first landing and (4) forced flat-footed landing.

It was found that landing toe-first or heel-first following a badminton jump smash could pose increased risk of injury due to higher vertical ground reaction forces and joint stiffness. Training should focus on ensuring landing on the ball of the foot following the jump smash.

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1. STUDY SUMMARY

Biomechanical modelling in sports is an effective tool for modelling the internal forces within the muscles and joints of an athlete when undertaking sport movement. These models are useful to sports scientists, physiotherapists, coaches and participants in predicting and preventing injury as well as finding an “optimal” state for the movement. The study will provide scientific basis to involved parties that was not previously available and promote applied research in badminton.

The landing post badminton jump smash has been identified as the primary interest of the study. This movement was identified due to its competitive performance benefits and its predisposition to injury given that a quick return to base is required following the movement and a stable landing is key to the follow-through of the movement.

It was determined that in order to accurately assess the performance of the smash, additional data collection would need to take place. Due to time and regulation constraints, this was postponed and the study was focused on assessing the risk of injury in the various landing modes, namely: (1) their natural landing (BF), (2) forced toe-first landing (TF), (3) forced heel-first landing (HF) and (4) forced flat-footed landing (FF). The athletes were found to land on the ball of the foot (BF) when landing without a prescribed technique i.e. in their natural landing technique, thus it is referred to as such hereafter.

From the collected data, the phases of the jump smash were identified such that the data could be segmented by phase and the landing identified. The Preparation Phase (PP), Backswing Phase (BSP), Follow-through Phase (FTP) and Forward-swing Phase (FSP) were identified.

To analyse the effect of different landing positions, the vertical ground reaction force and biomechanical response of the ankle, hip and knee joints for each participant were determined. The joint stiffness was used as a measure of biomechanical response based on literature that supports the statement that increased joint stiffness is correlated to increased ground reaction forces and risk of injury.

A one-way repeated measure analysis of variance (ANOVA) test was conducted to evaluate the different landing techniques. The VGRF, joint stiffnesseses, incident angles in the sagittal plane, and range of motion (ROM) in the sagittal and frontal planes were assessed across the four landing techniques.

It was found that landing toe-first or heel-first following a badminton jump smash could pose increased risk of injury due to higher vertical ground reaction forces and joint stiffness. Training should focus on ensuring landing on the ball of the foot following the jump smash.

2. OBJECTIVES OF THE RESEARCH

The study analyses the biomechanics of the jump smash with the aim of producing results which can be implemented in coaching of the participants of Badminton SA to improve the effectiveness of the jump smash as well as reduce the injury risk associated with landing. While this will benefit the competitiveness of the South African National Teams, the results will also provide insights to participants and coaches worldwide and contribute towards the increased knowledge on performance and safety internationally, as is the aim of BWF.

3. PROGRESS SUMMARY

The sections below detail the progress of the study from July 2020 to November 2021.

3.1 Data Collection

Data collection for the study involves on-court data capture using the XSens MVN Link inertial measurement system. The XSens suit is donned by the participant and inertial movement sensors are attached to the suit. The participant then executes the shot while the movement is captured in real-time via the sensors.

Since the study involves human participants, ethics clearance was first obtained for the study from the University of the Witwatersrand Human Research Ethics Committee (Medical). Ethics clearance was obtained in November 2020. Data collection was originally scheduled to occur during the Badminton SA training camp in November 2020, however, due to national regulations as a result of the SARS - CoV - 2 pandemic, the camp was postponed.

Data collection was rescheduled to December 2020 and February 2021. A total of 15 players participated (10 males and 3 females). The results from two female participants were excluded since the participants did not execute the smash with a jump and so the subsequent landing, which is the focus of the study, could not be assessed.

Participants donned the XSens MVN Link suit and were served a shuttlecock which they returned with a jump smash, the shot was then returned to the participant to allow for an assessment of the recovery from the smash. Participants were also asked to perform a box jump on a force plate for data verification.

From the data collection process, orientation, position, velocity, acceleration and angular acceleration for each body segment was collected for the duration of the movement for each participant. This data is further processed to assess the effect of each landing technique.

3.2 Data Processing

The original data files were saved in ".mvnx" format. Initially this file format can only be read in XSENS software, but the file can be imported into MATLAB as a structured array containing all the recorded data. Each individual jump smash was loaded into MATLAB, processed and the results written to an excel spreadsheet for further data analysis.

By observing the centre of mass data, changes in the height allow the identification of the Preparation Phase (PP), Backswing Phase (BSP) and the Follow-through Phase (FTP). Shortly after the BSP, sudden changes in the racquet hand angular velocity allow for the identification of the Forward-swing Phase

(FSP). Indexing these phases, it is possible to obtain the frame when these phases occur and consequently, the corresponding ankle, knee and hip angles can be identified and compared for each landing technique.

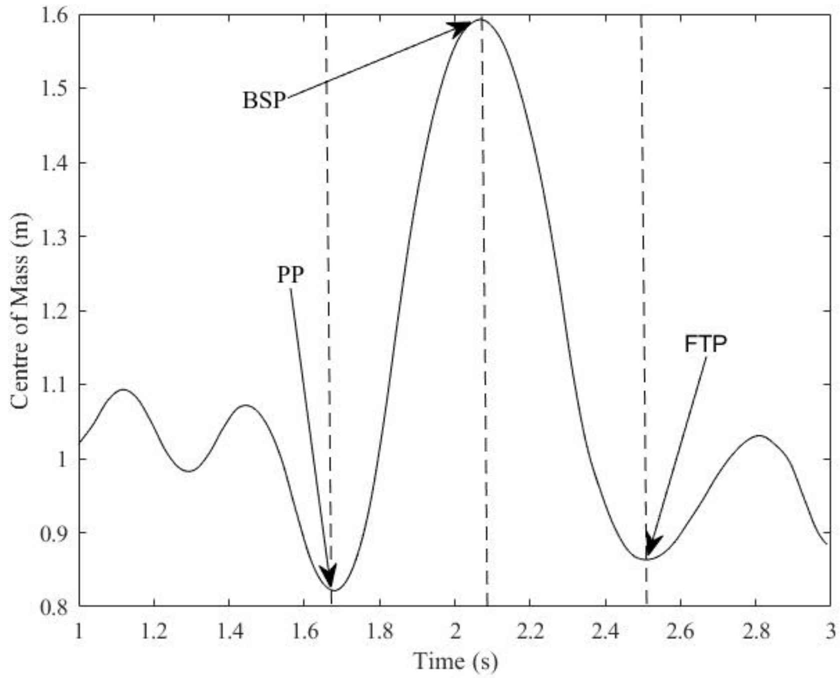

Figure 1: Centre of Mass vs Time plot

3.2.1 Reference Angles

The ankle, hip and knee joints are to be analysed to determine the angles of the joints during the different phases of the jump. More importantly, the joint incident angles need to be determined (angles of joints during initial ground contact upon landing) in order to compare the biomechanical response of these joints to the different landing techniques. The 0° reference angle corresponds to when the subject is standing as normal.

For the sagittal plane when the foot is pointed upwards for dorsiflexion, this is considered a positive angular displacement of the ankle. A negative angular displacement is reference for plantarflexion. Bending the knee and hip joints under flexion is considered the positive displacement and extension of the knee and hip are referenced as negative angular displacement.

For the frontal plane, eversion of the ankle is given a positive displacement whilst inversion is given a negative displacement. For hip and knee joints, abduction is referenced as a positive displacement whilst adduction is a negative displacement.

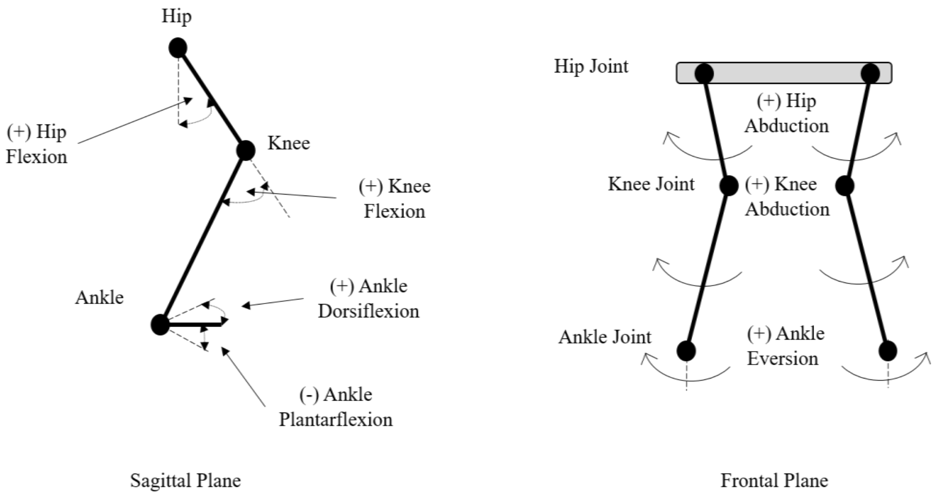

Figure 2: Ankle, Knee and Hip reference angles in the Sagittal and Frontal Plane

3.2.2 Vertical Ground Reaction Force

The vertical ground reaction force experienced during the PP and FTP was modelled as a multi-segment of rigid bodies. Each body segment can be classified as a rigid link with its own mass and connected to other segments (links) at joints. Each segment contributes its own force to the overall ground reaction force.

$$VGRF = \sum_{i}^{n} F_i = m_i \ddot{a}_i \qquad (1)$$

Where $F_i$the force of the segment is, m_i is the weight of the segment and a_i is the acceleration of the segment. The VGRF was normalised to bodyweight in order to have comparable results amongst all the athletes with different bodyweights [1].

Body segment data was obtained from a study conducted by P. de Leva [2]. In this study, the different segment weights are reported as a percentage of the total body weight for both male and female subjects.

3.2.3 Joint Stiffness

The joint stiffness during the instant of the peak VGRF can be used as a Biomechanical Performance Indicator in order to show how the different landing techniques may impact the joint stiffness. Previous studies have suggested that a stiffer landing strategy will contribute to increased ground reaction forces and thus an increased risk of injury [3]. The lower limb joints in the landing leg were modelled as torsional springs undergoing angular displacement under torsional loading from the reaction moment [4].

The reaction forces calculated in each segment were used in conjunction with the body measurements taken for each participant to calculate the reaction moments experienced by the knee, hip and ankle joints. The stiffness of the joints in the landing leg were then calculated with:

$$k_{joint} = \frac{M_{joint}}{\theta_{joint}} \qquad (2)$$

Where k_{joint} is the normalised stiffness of the joint in question (Nm /kg rad), M_{joint} is the normalised reaction moment experienced by the joint (Nm/kg) and θ_{joint} is the angular displacement (rad) of the joint at the moment of the peak VGRF in the sagittal plane.

3.2.4 Statistical Analysis

In order to assess the differences between the different landing techniques, a one-way repeated measure analysis of variance (ANOVA) test was conducted. This is a statistical test to determine whether there is any statistical significance between the means of the results obtained from the different landing techniques.

Different variables for the ball of the foot (BF), toe first (TF), flat footed (FF) and heel first (HF) were tested during the Follow-through phase. The variables tested were:

1. The maximum Vertical Ground Reaction Force (VGRF)
2. The ankle, knee and hip joint stiffness
3. The ankle, knee and hip incident angles in the sagittal plane upon landing
4. The ankle, knee and hip ranges of motion (ROM) in the sagittal plane during the FTP
5. The ankle, knee and hip ranges of motion (ROM) in the frontal plane during the FTP

The level of significance was set to $a = 0.05$.

The analysis determines a p – value which is the probability that an observed difference may have occurred at random. The statistical significance is greater the lower the p-value.

A p-value that is less than a will void the null hypothesis. In the case of this study the null hypothesis is "The different landing techniques do not have any effect on the vertical ground reaction force (VGRF) and biomechanical response.

3.2.5 Vertical Ground Reaction Force Validation

Certain jump tests were conducted with the XSens suit and on force plates in order to assess the validity of the VGRF model that was developed as well as the validity of the suit.

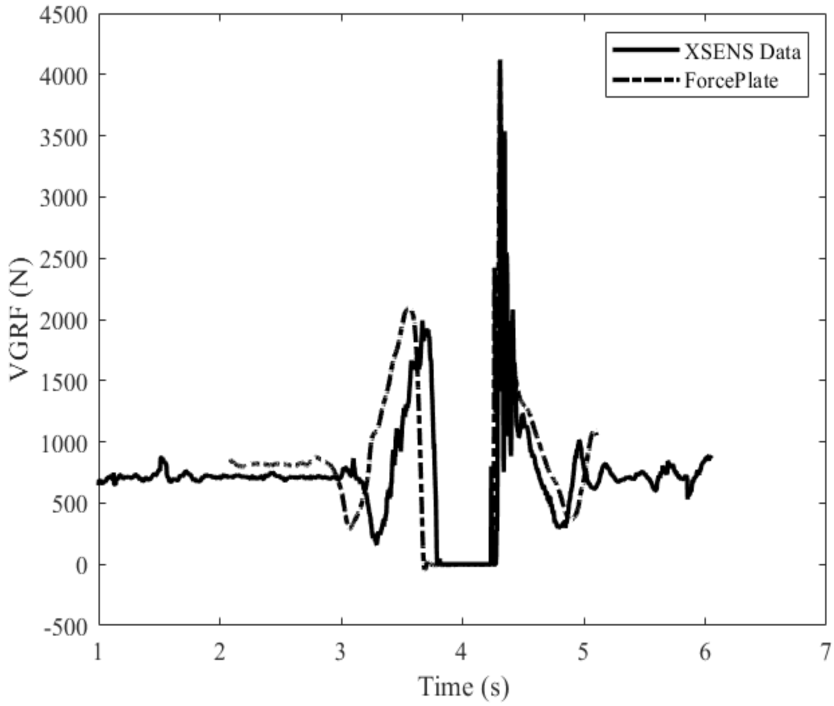

Figure 3: VGRF comparison between XSENS data and data collected from a force plate for a given jump smash

In the Preparation Phase of the jump smash, the calculated VGRF with the XSENS data matches the force plate data with differences as little as 7%. However, during impact upon landing, certain tests experienced differences as large as 36%. On average, for the VGRF on impact, there was an average difference of 16% (±10%) between the data obtained from the force plate and the calculated VGRF. This difference could be associated with the VGRF model's use of published segment weight data since it is not possible to determine the segment weight for the athletes. Equipment sensitivity may also contribute to the variation. The data trend between the results remains consistent, thus the results obtained from the XSens suit can be used for analysis.

3.3 Results

Table 1 summarises the VGRF and joint stiffness for the various landing techniques. The TF and HF landing strategies experience the highest VGRF. The BF and FF landing strategies exhibit the lowest VGRF.

The highest ankle stiffness is experienced during the HF landing technique whilst the TF landing strategy experiences the lowest ankle stiffness and the BF and FF experience moderate ankle stiffness values. The ankle stiffness data suggests that shifting the landing towards a heel dominant landing strategy will result in an increase in the ankle joint stiffness.

The highest knee stiffness is experienced during the HF and TF landing strategies and the BF and TF landing strategies result in the highest hip joint stiffness. Shifting to a toe dominant strategy may have lower ankle stiffness but the data suggests there is larger hip joint stiffness.
The TF and HF landing techniques could possibly be more prone to injury due to the large VGRF values as well has high hip stiffness.

Table 1: Mean ± SD for VGRF and joint stiffness for the different landing strategies

BPI	BF	TF	FF	HF	P-value
VGRF (BW)	5.93 (±1.71)	7.91 (±1.86)	5.17(± 1.22)	7.54 (±2.00)	0.0106
Ankle Stiffness (Nm/kg rad)	1.36 (±2.74)	0.03 (±4.93)	1.61 (±1.08)	2.87 (±3.61)	0.0205
Knee Stiffness (Nm/kg rad)	3.08 (±1.61)	4.00 (±1.62)	2.31 (±1.00)	4.37 (±1.65)	0.0196
Hip Stiffness (Nm/kg rad)	6.70 (±3.69)	7.33 (±3.54)	3.17 (±1.29)	4.25 (±1.43)	0.0155

Figure 4 illustrates the relationship between the VGRF and the ankle stiffness for the different landing strategies. There is a low correlation between an increase in ankle stiffness and the VGRF. The steeper gradients for the HF and FF landing techniques suggest that the ankle stiffness will influence the VGRF more than the TF strategies and this could have a higher risk of lower limb injury.

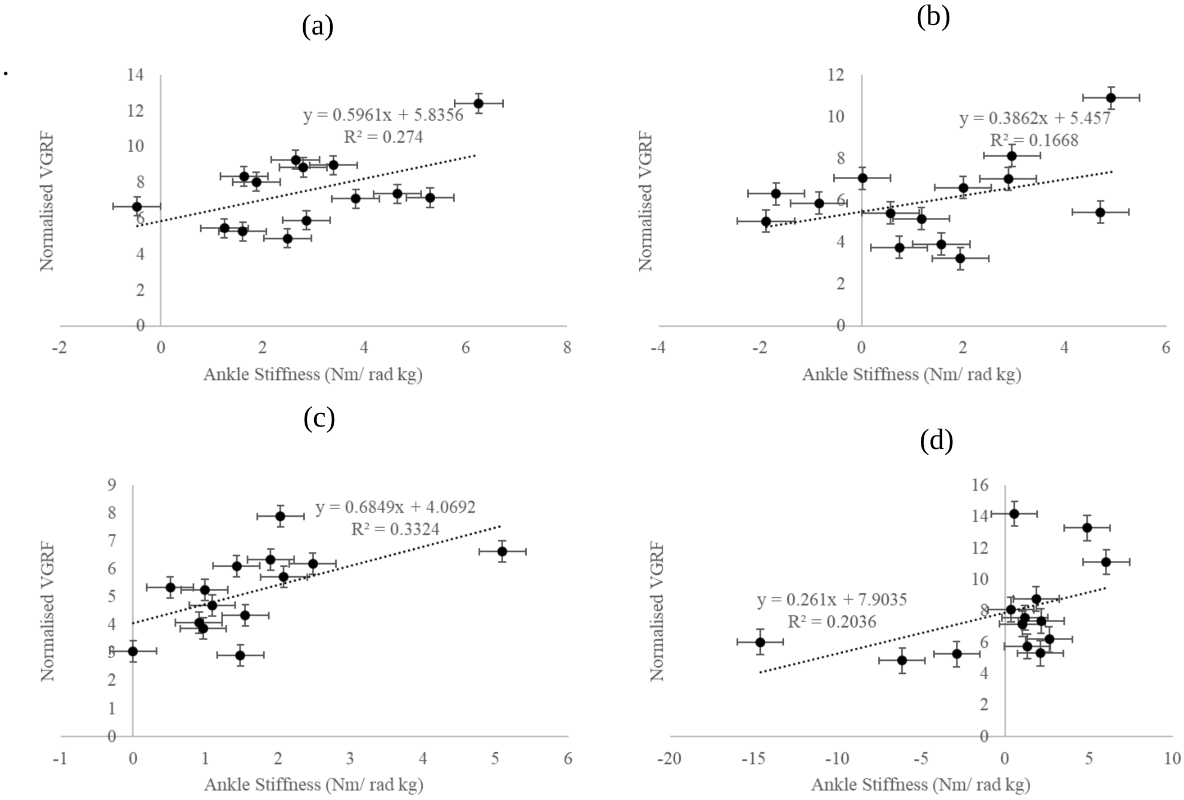

Figure 4: VGRF vs Ankle Stiffness for (a) HF, (b) BF, (c) FF, (d) TF

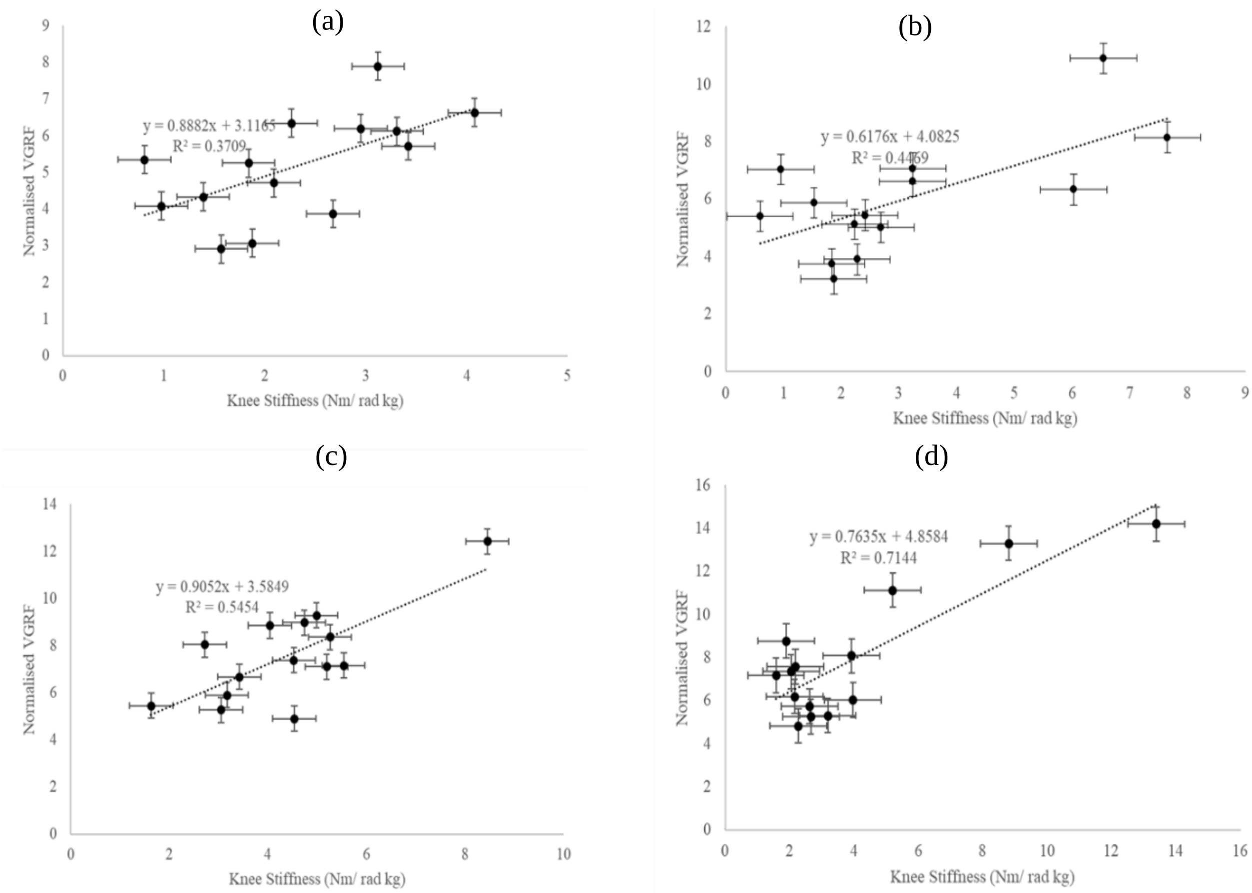

Figure 5: VGRF vs Knee Stiffness for (a) FF, (b) BF, (c) HF, (d) TF.

Figure 5 illustrates the relationship between the knee stiffness and the VGRF for the different landing techniques. There is a higher positive correlation between knee stiffness and VGRF on landing. The HF and TF landing strategies have the steepest gradients in comparison with the BF and FF landing strategies.

Figure 6 illustrates the relationship between the hip joint stiffness and the VGRF for the different landing techniques. There is a low correlation between the hip joint stiffness and the VGRF on landing. The steep gradients of the HF and FF landing strategies as well as the higher correlation values in relation to the other two landing techniques suggest that the joint stiffness will significantly influence VGRF.

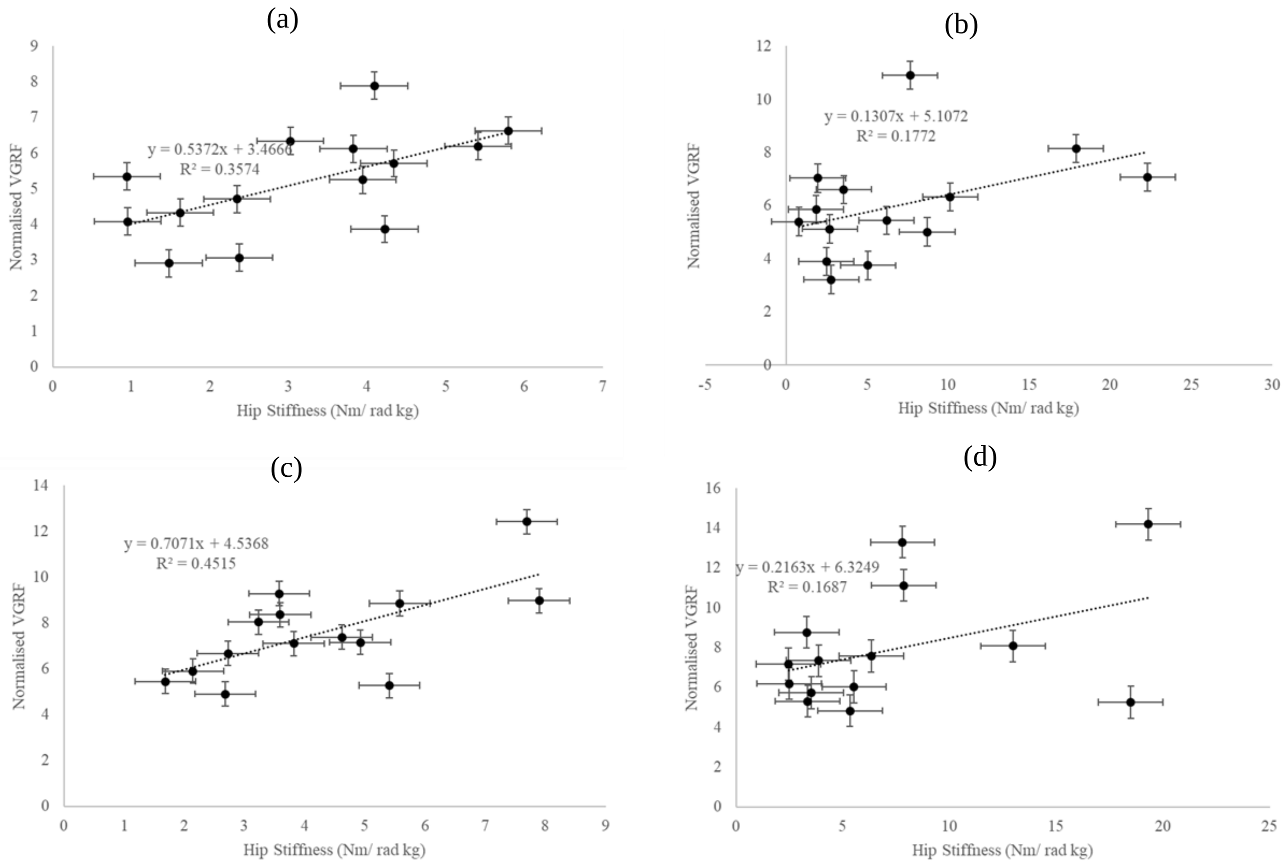

Figure 6: VGRF vs Hip Stiffness for (a) FF, (b) BF, (c) HF, (d) TF.

Table 2 summarises the joint data range of motion for the different landing techniques during the follow through phase. The HF landing technique experiences significantly less ankle rotation during the follow through phase. This is to be expected since in order to land heel first the foot needs to be in a dorsiflexion position. This is confirmed by the ankle incident angle which has the highest mean flexion angle of 15.73° (±18.81).

The BF and FF landing techniques again exhibit similar results, with the ankle ROM and ankle incident angles are statistically indifferent in the two landing techniques. For these techniques, the foot is in a plantar flexion position upon landing. During data collection, the participants reported difficulty in landing completely flat footed, many stating that at times the balls of their foot made contact first before the heels, similar to their normal landing technique. The techniques differ at the knee and hip incident angles. The FF strategy has a 7.6% and 26.77% increase in knee and hip flexion respectively upon landing. This is possibly an attempt from the athletes to try and land as flat footed as possible.

For the TF landing position, the ankle incident angle is almost at the reference angle point with the mean value 0.711° (±22.37). This landing technique was expected to experience the highest plantarflexion, however the increase flexion in the hip and knee joints upon landing in comparison with the BF suggests that in order to compensate for landing on their toes, the participants would bend the hip and knee joints further before landing rather than extending the foot.

Large standard deviations are reported for all joint angle data in the sagittal plane, possibly due to the variations in the jump smash between participants. Although the landing technique was being controlled, there were still variables left uncontrolled that affected the results. For example, it was difficult to serve the shuttlecock exactly the same for each jump smash. This would result in athletes having to adjust and position themselves differently for each jump smash which will have affected the results.

Table 3 summarises the ROM data of the ankle, knee and hip joint in the frontal plane for the different landing techniques. For the BF and FF strategies, the ankle experiences large eversion rotation in the frontal plane during the follow-through phase. The low ROM in the frontal plane for the TF and HF landing technique could contribute to increase VGRF due to less energy dissipation as well as the potential for the ankle experience inversion rather than eversion. This would suggest that landing using the TF and HF strategies could have increased risk in ankle injury due to potential for ankle inversion. There is very little knee rotation in the frontal plane, however, the TF landing strategy experiences the most rotation in the form of knee abduction (valgus). This landing strategy also experiences the least hip adduction, perhaps contributing to the increase in VGRF due to less energy dissipation.

Table 2: Mean ± SD for ankle, knee and hip joint incident angles and ranges of motion (ROM) in the sagittal plane.

BPI	BF	TF	FF	HF	P-value
Ankle ROM (°)	44.64 (±21.67)	34.71 (±22.11)	43.65 (±23.16)	8.22 (±13.25)	0.011
Knee ROM (°)	36.85 (±17.18)	39.69 (±14.10)	38.49 (±22.32)	36.62 (±16.92)	0.022
Hip ROM (°)	13.70 (±23.02)	5.98 (±22.37)	21.60 (±19.75)	25.49 (±18.81)	0.012
Ankle Incident Angle (°)	-13.06 (±23.03)	0.711 (±22.37)	-15.20 (±19.75)	15.73 (±18.81)	0.0064
Knee Incident Angle (°)	28.63 (±23.02)	29.13 (±22.37)	30.98 (±19.75)	23.25 (±18.85)	0.0202
Hip Incident Angle (°)	24.29 (±23.02)	33.97 (±22.37)	33.17 (±18.81)	30.85 (±19.75)	0.0196

Table 3: Mean ± SD for ankle, knee and hip joint ranges of motion in the frontal plane.

BPI	BF	TF	FF	HF	P-value
Ankle ROM(°)	4.30 (±7.39)	0.43 (± 4.42)	2.20 (±5.86)	-0.59 (±6.93)	0.0198
Knee ROM (°)	3.37 (±2.38)	4.21 (±2.78)	3.51 (±3.00)	2.64 (±3.11)	0.021
Hip ROM (°)	-24.10 (±5.12)	-15.89 (±4.50)	-20.81 (±4.35)	-22.90 (±5.511)	0.021

Figure 7 illustrates a low correlation between the ankle incident angle and the normalised VGRF. An increase in the ankle incident angle means that the landing strategy is shifting from a toe dominant landing strategy (TF) towards a heel dominant landing strategy (HF). Figure 7 shows that by shifting the landing strategy towards the heel, the athlete will consequently experience greater VGRF and thus there is a greater risk of injury.

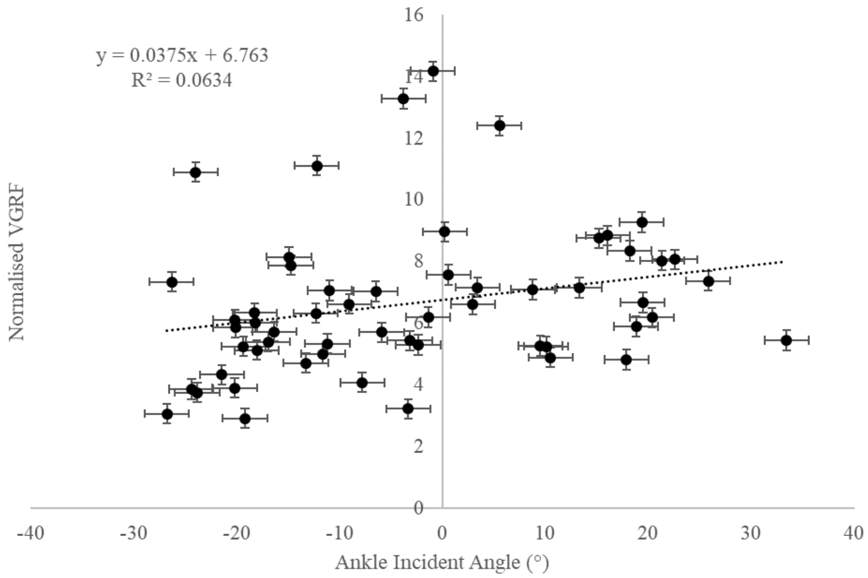

Figure 7: Normalised VGRF vs Ankle Incident

3.4 Conclusions

A biomechanical analysis of the landing following the badminton jump smash was conducted on 14 badminton athletes by studying the effect of various landing techniques. Four different landing techniques were tested: (1) natural landing (on the ball of the foot), (2) forced toe-first landing, (3) forced heel-first landing and (4) forced flat-footed landing.

The dominant natural landing mode across athletes is landing on the ball of the foot. The TF technique is described as landing on the toes first, the FF technique is defined as landing on both the toes and heel at the same time and the HF technique is defined as landing on the heel first.

The TF and HF landing techniques experience the highest VGRF with a mean normalised VGRF of 7.91 and 7.54 respectively. Excessive ligament strain and damage can be caused by increased ground reaction forces, therefore the TF and HF landing techniques experience an increased risk of injury.

The increase in VGRF can be attributed to the decrease in joint rotation during the landing phase. The HF landing technique experiences almost no ankle dorsiflexion under loading and the TF technique experiences decreased hip rotation. Ground reaction forces can be reduced by greater energy absorption and this is achieved by increased joint rotation.

There is a positive correlation between the knee stiffness and the VGRF. A low correlation between the ankle and hip joints vs the VGRF. The TF and HF landing strategies experience the greatest knee stiffness values, which further substantiates that these landing strategies may contribute to increased risk of injury.

The data shows a low correlation relationship between the ankle incidence angle and the VGRF. As the ankle incidence shifts from plantarflexion to dorsiflexion (shifting towards heel dominant landing technique) the VGRF will also increase.

It was hypothesised that the FF landing technique would experience less joint rotation and therefore increase reaction forces, however the data suggests that FF landing technique is similar to the BF technique. The participants have reported that they found it difficult to land completely flat footed. At times they would land on the balls of their feet first which the similarity can be attributed to.

The BF technique experiences the lowest ground reaction forces due to the increase rotation of the ankle, hip and knee joints in the sagittal plane. The BF also experiences moderate ankle and knee stiffness which are proportionally related to the VGRF. The hip stiffness is considerably high in comparison to the other joints, however large hip joint stiffness does not impact the VGRF as significantly as the knee stiffness. An incorrect landing on the toes or heel could pose a significant injury risk and training should emphasise the importance landing on the ball of the foot following the badminton jump smash.

3.5 Recommendations and Future activities

Future activities could involve the assessment of the performance of the jump smash and an assessment of the effect of landing on this performance. To achieve this, and inertial sensor placed on the racket should be used in conjunction with the suit when executing the movement to allow for the determination of the shuttlecock speed on impact, which is a commonly used measure of performance of the smash. Alternatively, motion capture cameras could be used in conjunction with the XSens suit for this purpose.

Although a relationship can be defined between the landing technique and the VGRF, the correlation is low and the ROM data experiences large standard deviations. This could be attributed to sensor drift which could be addressed by using a larger sample size.

The variation in results between male and female participants could not be studied due to the low number of female participants. It is recommended that more female participants are included in subsequent data collection.

A journal publication based on the outcome of this study titled “The landing biomechanics of the badminton jump smash” is being drafted for submission to an appropriate journal.

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