Cardiff School of Sport

DISSERTATION ASSESSMENT PROFORMA:

Empirical [1]

Student name: Matty Patel	***Student ID:*** St20000594
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Dissertation title: How the rate of force development at the start of the block affects the speed of release during a Javelin throw.	
Supervisor: Dr Ian Bezodis	

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.
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CARDIFF SCHOOL OF SPORT

DEGREE OF BACHELOR OF SCIENCE (HONOURS)

SPORT COACHING

2013-4

How the rate of force development at the start of the block affects the speed of release during a Javelin throw.

(Dissertation submitted under the discipline of

Biomechanics)

Matty Patel

St20000594

How the rate of force development at the start of the block affects the speed of release during a Javelin throw.

Cardiff Metropolitan University

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Abstract

During a javelin throw, research suggests that 70% of the release speed is provided during the point of foot contact with the ground at the start of the block and the point of release, yet this only lasts one tenth of a second. This study was designed to analyse this short period of time; more specifically, whether the rate of force development exerted into the ground during the block directly linked to speed of release? Three elite throwers were used as participants and were studied over six trials each. CODA motion analysis system (200 Hz), a force plate (1000 Hz) and a video camera (50 Hz) were used to conduct a 3D analyses of the participants' block.

No definitive correlation was found between rate of force development and the speed of release (correlations of 0.39, -0.48 and 0.44 for participants one, two and three respectively) however after including other factors a strong relationship was found between the two variables. To enhance speed of release the amount of time the force is applied on the object and the magnitude of this force needs to be optimised. An effective block increased the time between the point of foot contact and release (the time the force was acting on the object), as well as increased the magnitude of the force by increasing the separation angles between joints, thus increasing the torque; however movements became slow (reducing the force) if the time continued to increase. An effective block also aided momentum transfer into the hip strike, further increasing the magnitude of the force.

The findings suggested that an effective block is vital in optimising the speed of release. This entails achieving the highest rate of force development possible during the block (found to be highly dependent on an individual's optimal run up speed)

Chapter 1

Introduction and Literature review

When analysing javelin technique, the blocking phase, in which the athlete plants their heel into the ground on their last step before the throw is vital as it causes a transfer of momentum from the lower body up and into the throw (Trower, 2000). However there are different techniques to achieve this. For example the traditional, more widely used technique (Trower, 2000) involves an almost straight knee during the block phase, in which the leg does not flex from when the heel is planted until the javelin is released. However some athletes have a slightly bent knee when they block which visibly flexes throughout. This technique obviously works for come athletes, such as the American Breaux Greer who he is the current American record holder and has been ranked world number one in the past. Yet differences in throwing technique will show variations in performance outcome (Muhmud, 2010). Because javelin throwing is so technical over such very short period of time, biomechanics analyses is an effective way of gaining a greater understanding of what is needed for an optimal throw (Morriss, 2000).

Javelin technique

There are a number of different phases that make up a javelin throw. Firstly there is the run up in which the athlete runs facing forwards lasting roughly eight to twelve strides (Johnson, 1987). This is where the majority of their speed is gained (Johnson, 1987) and when carried out well, should be relaxed and controlled (Trower, 2000). Speed and tempo are important during the approach and are relative to the technical and physical proficiencies of the performer (Trower, 2000).

The next phase is the cross overs in which the athlete turns sideways and withdraws the javelin. This is where the remainder of their speed is gained (Johnson, 1987). Timing of the transition between these two phases is crucial to retain all forward momentum built in the run up and transfer it into a side on running style (Trower, 2000). The torso should remain upright, whilst the shoulders and javelin remain relatively parallel (Johnson, 1987; Trower, 2000). The throwing arm should be extended putting maximum distance between the javelin and the release point (Trower, 2000). This lengthens the contact time with the javelin, increasing the potential impulse that can be put on the object. During this phase, the more accurately a performer can set and retain the javelin in a position to be thrown, the more controlled the release will be (Trower, 2000).

The next phase is referred to as the impulse stride or the cross step. This is the penultimate stride that sets up the block. Its purpose is to place the throwing side foot ahead of the body's centre of mass causing a backwards tilt along the performer's coronal plane (Trower, 2000). The cause of this tilt must be due to the throwing side's foot positioning and not just the leaning back of the torso (Trower, 2000). Where this phase ends and the block begins is unclear between researchers. Some believe this point to be when the throwing side foot meets the ground after the impulse stride, however in the UK it is believed to be one step later, once the non-throwing side foot comes into contact with the ground (Trower, 2000).

The next and most important phase is the block because it includes the release of the javelin. After the throwing side foot has hit the ground, in order to prevent any deceleration, the leg must remain passive until the centre of mass has passed over (Johnson, 1987; Trower, 2000). Then it drives forward whilst the non-throwing side leg is out stretched waiting for the ground to come to meet it (Johnson, 1987). At this point the hips should begin to strike (Trower, 2000). The hip strike refers to the very rapid rotational path the hips take, around the non-throwing side hip (Trower, 2000). Once the non-throwing side foot meets the ground (believed to be the official start of the block in the UK), for the most effective transfer of momentum, the leg should be kept as straight as possible to create a block for the throwing side hip to rotate around, reducing almost all horizontal velocity, and rapidly increasing the rotational velocity of the hips (Johnson, 1987; Trower, 2000). The shoulders should still be parallel to the runway and this large difference in alignment between the hips and shoulders stretches the muscles down the throwing side of the body, creating pre-tension which is essential for the development of torque (Johnson, 1987; Trower, 2000). The non-throwing shoulder becomes the focal point with the throwing shoulder rotating around it, powered by the torque created by the pre-tension of the muscles, until it is over the blocking foot. At this point the javelin is still trailing behind the body. Then the shoulder, elbow and wrist strike to complete the movement (Trower, 2000). The striking of the shoulder, elbow and wrist refers to the very rapid motion taking place at each joint. At the shoulder this motion is circumduction, in which the arm goes form a position of retraction to protraction. At the elbow, this motion is flexion as the elbow is brought over the shoulder then extension. In the case of the wrist, this motion is a combination of wrist flexion and pronation.

The block involves sequential movements in which the hips lead the shoulders, the shoulders lead the elbow, and the elbow leads the hand (Johnson, 1987; Trower, 2000). Mero, Komi, Korjus, Navarro, and Gregor (1994) reported an orderly progression in peak speeds from larger to smaller body segments within the block. These sequential movements should be completed as one smooth unit with no single element stressed more than another.

The final phase is the recovery. During the final acts of throwing, the performer rides up over the blocking leg. Whilst keeping this leg grounded, the other leg is brought past to cushion the action (Johnson, 1987). An additional step may be required depending on the effectiveness of the block.

Previous biomechanical analysis of Javelin

It is agreed amongst coaches that at the highest level, technique is the discriminating factor between athletes (Trower, 2000). Therefore understanding the way in which a performer's movement affect the throw is vital to their success.

There have been a number of studies carried out on javelin in the past and release velocity seems to be the single most vital factor that can affect the overall distance thrown (Leigh et al, 2010). Zhiheng, Yongdong and Zaiping (1991) found that there is a significant positive correlation between throwing distance and release velocity, as long as the results of other factors, such as release angle, altitude angle, height of release and the unknown wind factor, are also taken into account. The altitude angle, or angle of attack, refers to the angle the javelin is pointing in at release. For optimum performance, the angle of attack is equal to the path of the javelin; however this can change depending on wind conditions. Zhiheng et al. (1991) found no significant correlation between release parameters and throwing distance in their previous studies because they failed to take into account these extra variables. This would suggest that although release speed is the most prolific contributing factor for the overall performance, as a coach other factors need to be included when it comes to increasing distance thrown.

Viitasalo, Mononen and Norvapalo (2007) carried out a study comparing different variables correlation with distance thrown and their results backed up Zhiheng et al. (1991) study. Viitasalo et al. (2007) set out to investigate the how release speed, release angle and uncorrected angle of attack measured at the foul line affected the distance thrown. They found that release speed had the highest correlation with the official throwing distance. They discovered that increasing the release speed by 1 $m.s^{-1}$ from 29 $m.s^{-1}$ to 30 $m.s^{-1}$ would increase the distance thrown by between 2.12m to 6.14m (Viitasalo et al., 2007) for male throwers. For female throwers an increase in release speed from $24m.s^{-1}$ to $25m.s^{-1}$ increased the official result by 2.25m to 3.68m.

Morriss (2000) found a similar direct correlation. He was able to devise an equation to describe the relationship between them. It stated that an increase of speed of release squared, equalled the increase in distance:

$$(\text{Increase in speed})^2 = \text{Increase in distance}$$

Because the speed is squared, a minor change in speed of release will have a major change in distance thrown.

Although Viitasalo et al. (2007) and Zhiheng et al. (1991) agree with Morriss (2000) that an increase in speed of release results in an increase in distance thrown, their findings do differ. Viitasalo et al. (2007) and Zhiheng et al. (1991) found that other factors, as mentioned above, are needed in order for a correlation to exist; in other words a set increase in speed of release can have a varied increase in distance thrown. However, Morriss (2000) found a correlation between the two so high that he could form an equation, as shown above, to describe the relationship between them. This disagreement causes implications for performers trying to improve their performance. If they were to follow Morriss (2000) view, they could just aim to increase their speed of release. On the other hand if they were to follow Viitasalo et al. (2007) and Zhiheng et al. (1991), increasing speed of release would aid performance but the inclusion of other factors would be needed.

One study carried out during competition by Mero et al. (1994) agreed with Morriss (2000) correlation. They investigated body segment contribution to javelin throwing during the final thrust phase, in other words, the block. A kinematic 3-d analysis was carried out on the 1992 Barcelona Olympic finals by videoing the athletes from the right side of the throwing area using two NAC high speed cameras operating at 100 frames per second.

One of their findings demonstrated that the speed of release significantly correlated with throwing distance for both females and males.

Mero et al. (1994) and Morriss (2000) are in agreement with Zhiheng et al. (1991) and Viitasalo et al. (2007) studies, as discussed earlier, even if their views on how strong the correlation is differ. Therefore, an increase in speed of release will have a positive effect on the distance thrown.

Research has shown that for elite throwers, the delivery, between the blocking foot's contact with the ground and the release of the javelin, provides 70% of the release speed yet only lasts one tenth of a second (Trower, 2000). Therefore analysing what goes on in this very short period of time is vital when investigate optimal performance.

As mentioned earlier, Mero et al. (1994) examined body segment contribution during the block. They discovered that the body segments had to follow a specific sequence of movements, roughly the same as mentioned above in javelin technique, in order to optimise distance thrown.

Lui, Leigh and Yu (2010) carried out a kinematic study of the javelin throw. The aim of the study was to define the general sequences of upper and lower extremity motions of elite throwers for both males and females. They collected three dimensional kinematic data for a total of 62 javelin throwers (32 females and 30 males) during competition. Sequences of lower and upper extremity motions were determined through statistical analysis (Lui et al., 2010). They discovered that lower and upper extremity motion sequences did not follow a specific sequence as previously suggested in the literature. They found that elite javelin throwers, both female and male, employed different sequences for lower and upper extremity motions (Lui et al., 2010).

The findings of Lui et al. (2010) prove that javelin throwers throw with varied techniques from one another. But even if there are various techniques employed by elite athletes, there could possibly be a specific way to carry out certain sections of technique in order to optimise performance.

Salo, Ihalainen, Korjus and Viitasalo (1993) believed this to be correct and tried to pin point certain aspect of technique used by more advanced throwers that allowed them to throw further. They carried out a biomechanical study comparing elite javelin throwers with elite decathletes. The throwing distances for the throwers ranged from 75.80 m to 86.72 m. The throwing distances for the decathletes ranged from 52.34 m to 65.70 m. They found the main differences to be that the throwers had a much faster run up into the throw; and during their last step (the block) their support leg was more extended making the whole final step take place over a further distance. This allowed them to decrease the speed of the non-throwing side of their body much faster, creating more torque on their throwing side than the decathletes were able to. Therefore indicating that the throwers were able to transfer their run up speed and momentum into the javelin through their body segments much more effectively (Salo et al., 1993). This caused a larger maximal linear velocity of the throwing side of the body and subsequently, a greater release speed of the javelin (Salo et al., 1993).

Salo et al. (1993) study indicates how different techniques affect momentum transfer and subsequently the speed of release of the javelin and the overall distance thrown. This study suggests that a higher rate of ground reaction force development exerted throw the blocking foot after the run up, will increases the speed of release due the increased momentum of the throwing side of the body and the transfer of force through the body segments and into the javelin.

Lui et al. (2010) study, mentioned earlier, backed up this idea when they looked at the relationship between release speed and javelin throwing technique. They found the best way to increase speed of release was to increase the speed of their run up and effectively transfer the run up speed and momentum into release speed. Lui et al. (2010) found trunk lean to be an important factor for an effective block. It was discovered that if the trunk lean was too far forward it could absorb some of the momentum built up in the run up and prevent it from being transferred into the javelin, affectively decreasing the speed of release. Trunk lean needed to be slightly backwards at initial foot contact in order to optimise the momentum built up in the run up and transfer it into the javelin.

Looking at these studies, it starts to become clear how technical aspects should be performed in order to achieve optimal performance. However none of these studies carry out a kinetic analysis, they all just use kinematics. As mentioned earlier, both Salo et al (1993) and Lui et al (2010) studies state that a higher run up speed increases speed of release, suggesting that an increase ground reaction force at the block, required to sufficiently decelerate the performer, would have a large positive effect on the speed of release. However neither of these studies includes kinetic analysis. Nevertheless, there is very little biomechanical research on javelin throwing that has included kinetics. The researcher for this study was unable to find any.

Therefore this study will carry out a kinematic and kinetic analysis of a javelin throw. Its question shall be: is the rate of force development exerted into the ground during the block directly linked to speed of release?

CHAPTER 2

METHODS

The testing took place in NIAC (National Indoor Athletics Centre). Three elite athletes javelin throwers a (age 22 ± 1 years, height 1.84 ± 0.07 m , mass 88kg ± 6 kg, PB 56. 43 m ± 13.46 m), from Cardiff Metropolitan University provided voluntary informed consent to participate in the study. The criteria for the required participants entailed they be elite athletes, with no recent injuries or musculoskeletal limitations that would put them at risk of injury during the study or prevent them from performing optimally. Elite was categorised as having competed in one or more international competitions, be it at a junior or a senior level.

Procedure

Before the throws took place, each participant went through their own warm up of their choice. What was required of them during the study was no different to what the participants would do as part of their training, so they had a good understanding of how best to prepare themselves for it. After the markers were placed on the participant, it was recommended that participants briefly warm up again to insure their muscles hadn't cooled, preventing stiffness and injury.

The participants' role entailed them running off a full run-up, blocking onto a force plate and throw an 800g ball (the same ball they would use in training, the same weight as a javelin) into a net, just as they would throw a javelin. The participants were required to perform six throws; during which all the CODA markers had to be tracked correctly as well as the blocking foot landing completely on the force plate. If a marker was tracked incorrectly or the force plate was missed, the trial was redone. If the performer aimed to land on the force plate, hindering their technique and preventing optimal release speed, the trial was redone. The throw had to be as smooth and as realistic as it would be in competition. The participants were allowed as much recovery time as they liked between throws, during which they were advised to stay warm.

The mass and height of the participants were taken on the same day as their trials, using a set of calibrated scales (Kistler 5233A, Kistler, Winterthur, Switzerland) and a stadiometer (Harpenden 602, Holtain Ltd, Pembrokeshire, UK). This data was recorded by the same person for each participant. Objectivity or rater reliability is the amount separate observers agree on a measurement (Atkinson and Nevill, 1998) therefore using the same individual to record data across all participants would have reduced systematic error.

Data collection

The force plate (Kistler 5233A, Kistler, Winterthur, Switzerland) sampling at a rate of 1000 Hz was used to produce the kinetic data during the block (defined from when the foot made contact with the ground during the final stride, to when that foot left the ground during the follow through). CODA motion analysis system (CODAmotion V6.78.2, Charnwood Dynamics Ltd, Leicestershire, UK) operating at a rate of 200 Hz was used to determine the kinematic data from the end of the impulse stride through to the end of the follow through. Four motion sensors were placed in a square around the force plate, as shown in figure 1. Four sensors were used with the hope that throughout the movement, each marker would be tracked by at least one sensor and would not be obscured from view.

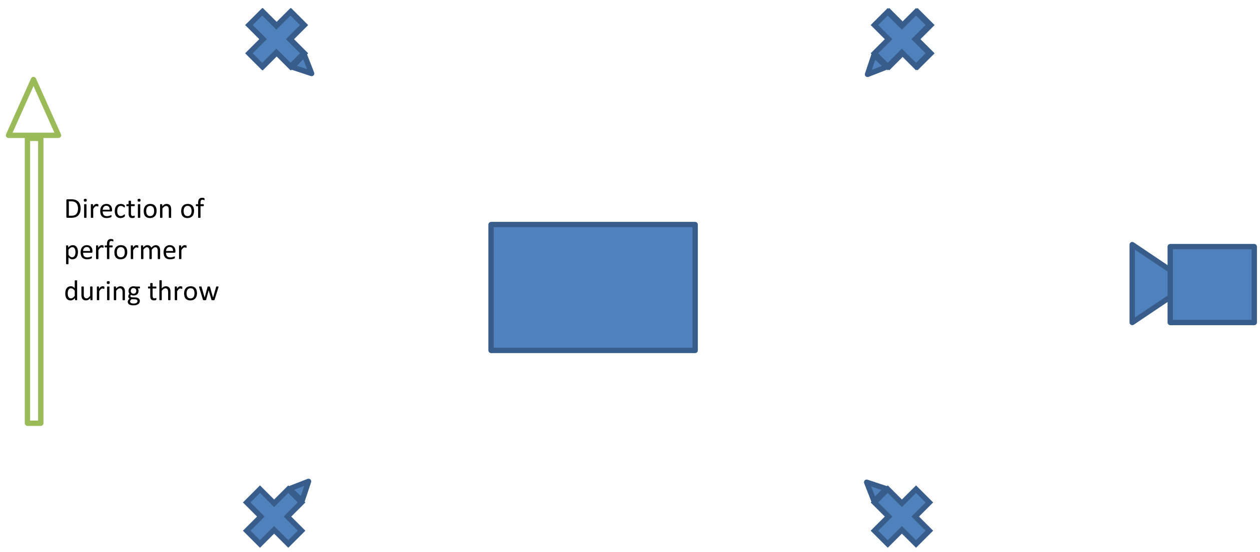

Figure 1. Shows the positioning of the Coda sensors and video camera relative to the force plate from a bird's eye view. Force plate represented by . Sensors represented by . Camera represented by 

18 markers were placed on each participant by the same person to reduce systematic error (Atkinson and Nevill, 1998). They were placed on the joint centre of the lateral side of the toe, ankle, knee and hip, on both legs; one on each of the lateral side of the shoulder,

elbow and wrist of the non-throwing arm; and one on each of the medial and lateral side of the wrist and elbow of the throwing arm. The last three markers were placed on the shoulder of the throwing arm; one on the lateral side, with the last two each on the posterior and anterior sides of the shoulder. Finally one video camera (Sony HVR-Z1E, Sony, Japan) operating at 50Hz, iris at F 1.8, shutter at 1/300 and focus at 4.9 m, was used to recorded data along the sagittal plane, as shown in figure 1. It was set up on a tripod five meters from the force plate, exactly perpendicular to the participants' run up.

Data Analysis

A range of variables were calculated with the data provided by the force plate, the video footage and the 3D kinematic data captured from the CODA markers. Before any data was taken from CODA, a cut off frequency was calculated using residual anaylses (Winters, 2009) which resulted in a cut off frequency of 7 Hz. The variables concerned regarded the run up speed, the knee angle of the blocking leg, the trunk angle, the rate of ground reaction force development during the block and the speed of the ball at release.

The run up speed was defined as the performers' horizontal velocity in the X direction (the direction of the run up and the throw) at the point of foot and ground contact at the block. This was calculated by taking the velocity of the non-throwing side hip marker at the point of foot contact with the ground. The point the foot struck the ground was defined as when the vertical ground reaction force exceeded 20 N.

The change in knee angle of the blocking leg was observed and tracked from the start of the block, when the foot struck the ground; up until the point of release of the ball. The knee angle was calculated using the CODA markers for the hip, knee and ankle. Two lines were created, one between the hip and knee, to represent the thigh; and the second between the knee and ankle, to represent the shank. Then an angle was taken between the two lines, giving the knee angle. The point the ball was release was determined in CODA by discovering the frame in which foot contact took place in the video footage and the frame in which the ball is released in the footage using visual identification; working out the time in between the two frames; and then adding that time to the point in which the vertical force exceeded 20 N (point of foot contact) in the CODA data.

Much like the knee angle, the change in trunk angle was tracked over the same period of time. However in order to get the trunk angle in the sagittal plane, virtual markers were created in order to ignore the rotation of the torso. Two markers were created, one in the middle of the two hip markers and one in the middle of the two lateral shoulder markers. A line was formed between the two and an angle taken from the difference of this line and the vertical Z line.

The rate of force development was calculated for the vertical ground reaction force at the block. This was defined as the change in force over the time taken. The change in force was taken from the peak force, and the time was taken from the point of touchdown (Vertical force > 20 N) to the point of the peak force.

The contact point between the foot and the ground during the block was observed, to see whether contact is first made with the toe. This was observed using the slow motion video footage. A possible cause for reduced force development could be due to the contact between the foot and the ground taking place at the toe.

Finally, the speed of the ball at release was discovered by digitising the video footage using the software Peak (Peak Motus 9.0, Vicon, Los Angeles, California, USA). For each trial, the ball was digitised for five frames before the point of release plus any frames after being released when the ball remains in frame, and from this the software calculated the speed at release.

Statistical Analysis

All statistical analysis was carried out using Microsoft Excel. The software was used to calculate means, standard deviations and correlations for a number of different variables. The mean and standard deviation were found for each participant for the speed of release, run up speed and rate of force development. Correlations for each participant were found between rate of force development and speed of the ball at release, final knee angle and the speed of release, final trunk angle and the speed of release, the time between touch down and point of release and ball speed at release, the time between touch down and point of release and rate of force development, the time between touch down and point of release and the final angle of the knee; and finally the time between touch down and point of release and the final angle of the trunk. The correlations were interpreted using the guidelines proposed by Fallowfield et al. (2005). A strong correlation occurred when the values were greater than 0.7, between 0.45 and 0.7 showed a moderate correlation, from 0.2 to 0.45 showed a week correlation and between 0.0 and 0.2 showed no correlation.

CHAPTER 3

RESULTS

Participant One

Participant one's average speed of release was 23.62 $m.s^{-1}$ and a standard deviation of 0.19 $m.s^{-1}$ shows performance was consistent between trials. The highest speed of release took place in trial six, 23.81 $m.s^{-1}$ and therefore would have achieved the furthest distances thrown (Mero et al, 1994; Zhiheng et al, 1991; Trower 2000; Viitasalo et al, 2007).

Participant one's average run up speed before blocking was 3.88 $m.s^{-1}$. Once again performance was consistent with a standard deviation of 0.05 $m.s^{-1}$. Trial two had the highest run up speed of 3.97 $m.s^{-1}$.

The average rate of force development for participant one is 3015.55 $N.s^{-1}$ across the six trials. A standard deviation of 1090.75 $N.s^{-1}$ would suggest inconsistency between trials for this variable. This is back up when noticing a difference of 2385.15 $N.s^{-1}$ between participant one's highest and lowest trial, trial five and trial six respectively.

Table 1. Participant one's recorded data over the six trials.

Trial	Ball speed ($m.s^{-1}$)	Run up speed ($m.s\text{-}^{1}$)	Rate of force development ($N.s^{-1}$)
1	23.74	3.90	4012.37
2	23.61	3.97	3548.76
3	23.57	3.81	1997.55
4	23.28	3.84	2160.51
5	23.72	3.87	4379.65
6	23.81	3.90	1994.50
Mean	23.62	3.88	3015.55
Standard deviation	0.19	0.05	1090.76

Table 2. Correlations between variables for participant one.

	Correlation
Force development, Ball speed	0.39
Force development, Run up	0.47
Run up, Ball speed	0.41

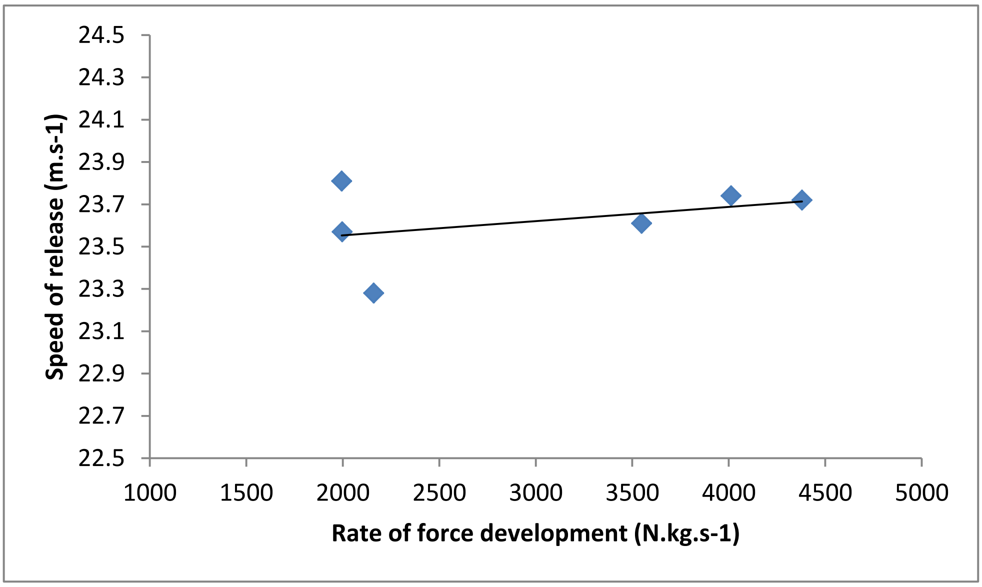

Figure 2. Correlation between rate of force development and speed of release for participant one.

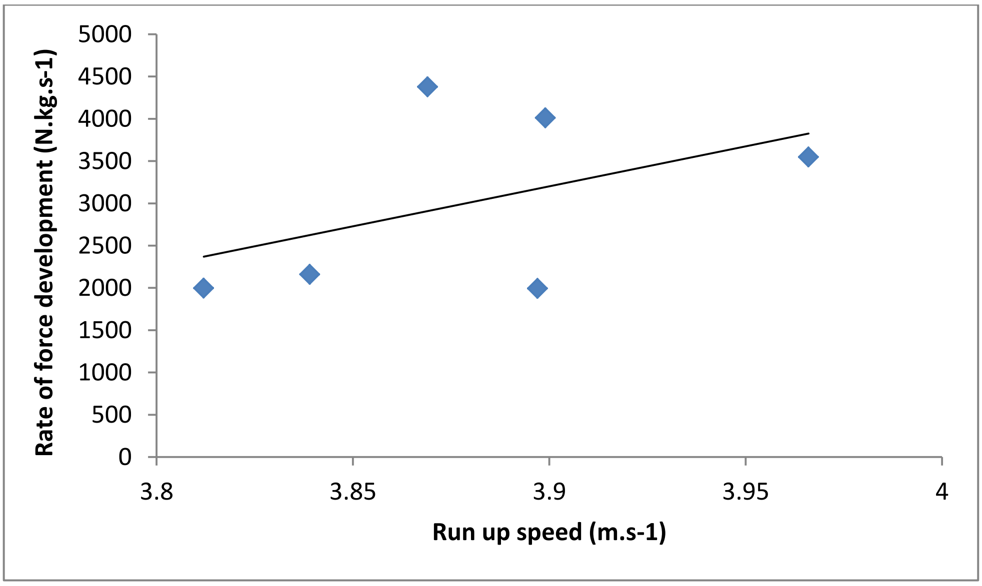

Figure 3. Correlation between run up speed and rate of force development for participant one.

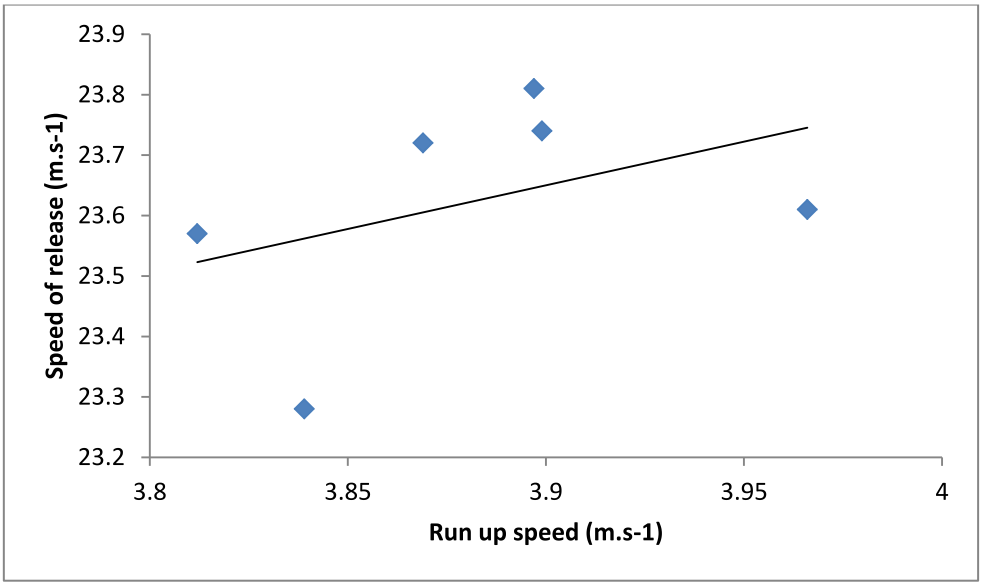

Figure 4. Correlation between run up speed and speed of release for participant one.

When looking at the change in knee angle during the block, it is clear that the path of knee flexion follows consistent timings; however the amount of knee flexion varies up to 15^{o} between trials. The average knee flexion at the point of contact between the foot and the ground was 149^{o}. It then flexes roughly 15^{o} before it extends up until the ball is released. The most knee flexion takes place in trial four, the same trial with the smallest speed of release. There is a moderate positive correlation of 0.68 between the angle of the knee at release and the speed of the ball at release. Subsequently a strong positive correlation of 0.90 is found between the final angle of the knee and the time between the point of contact of the foot and the point of release.

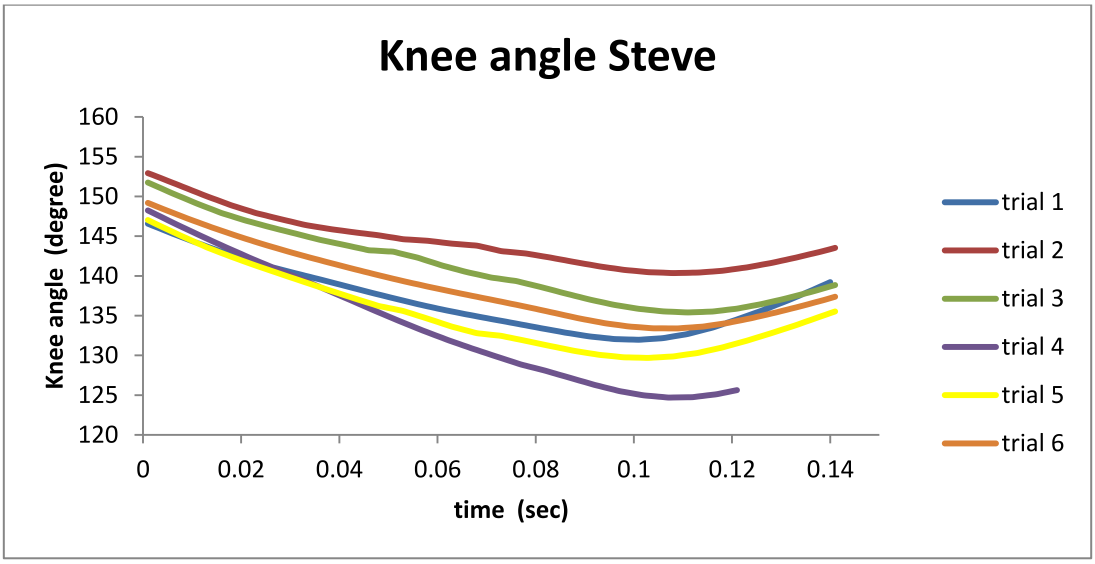

Figure 5. The left (non-throwing side) knee angle for participant one, between the point of contact between the foot and the ground at the block, up until the point the ball is released from the hand.

At foot contact, the trunk was leant slightly backwards along the sagittal axis, with an average of 79.04^{o}, as shown in figure six. The average trunk angle at release was 114^{o} after the shoulders had travelled over the hips. There was a strong positive correlation of 0.83 between trunk angle at release and ball speed of release. Also a strong positive correlation of 0.98 was evident between the final angle of the trunk and the length of time between the point of contact of release and release.

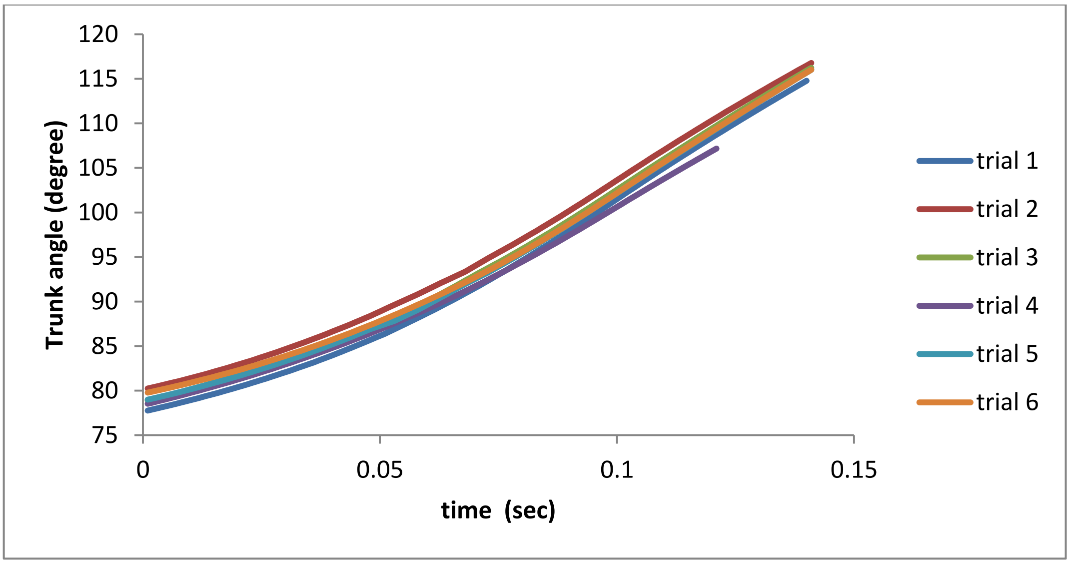

Figure 6. Shows the change in trunk angle for participant one, between the point of contact between the foot and the ground at the block, up until the point the ball is released from the hand.

Participant Two

Participant two has the lowest P.B of the three participants; therefore as expected, had the lowest average speed of release, 20.63 $m.s^{-1}$ (Mero et al., 1994; Zhiheng et al., 1991; Trower 2000; Viitasalo et al., 2007). There was also a lot of disparity in the performance over the six trials, with a standard deviation of 2.01 $m.s^{-1}$; and a difference of almost 5 $m.s^{-1}$ between his best and worse throw, trial one and trial four respectively.

Participant two had the highest average run up speed, 4.43 $m.s^{-1}$ between participants. There is also high consistency in run up speeds; with a standard deviation of 0.11 $m.s^{-1}$ between trials, unlike the highly varied speed of release. There is a weak positive correlation of 0.21 between the run up speed and the speed of the ball at the point of release.

Participant two's average rate of force development was 1260 $N.s^{-1}$ across the six trials. There is also high consistency with a standard deviation of 135.29 $N.s^{-1}$. There is a weak negative correlation of -0.31 between rate of force development and the run up speed. Subsequently there is a moderate negative correlation of -0.48 between the rate of force development and the speed of the ball at release.

Table 3. Participant two's recorded data over the six trials.

Trial	Ball speed ($m.s^{-1}$)	Run up speed ($m.s^{-1}$)	Rate of force development ($N.s^{-1}$)
1	22.75	4.47	1210.42
2	21.67	4.31	1354.72
3	22.13	4.43	1180.85
4	17.99	4.29	1255.99
5	18.34	4.50	1471.14
6	20.92	4.57	1089.02
Mean	20.63	4.43	1260.36
Standard deviation	2.01	0.11	135.29

Table 4. Correlations between variables for participant two.

	Correlation
Force development, Ball speed	-0.48
Force development, Run up	-0.31
Run up, Ball speed	0.21

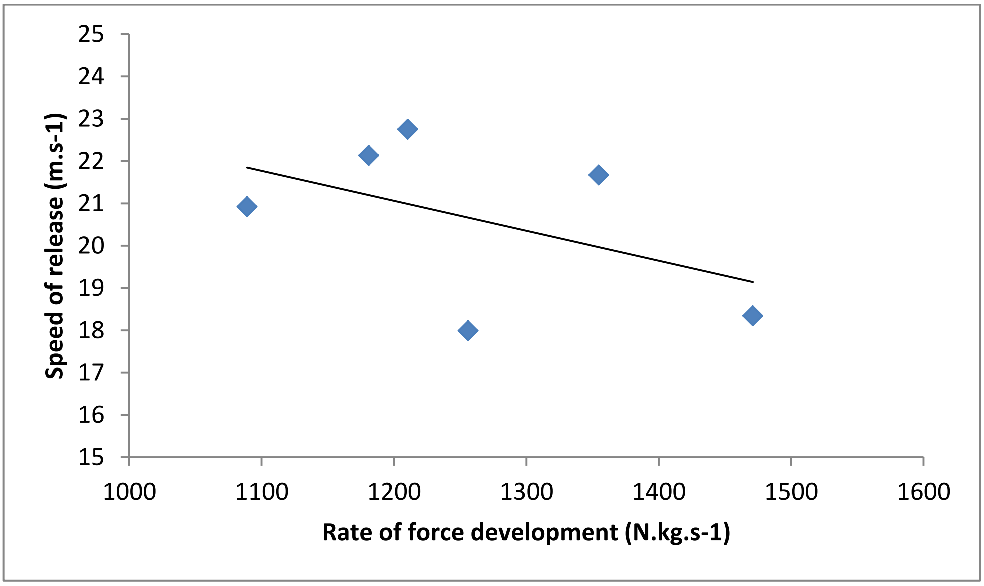

Figure 7. Correlation between rate of force development and speed of release for participant two.

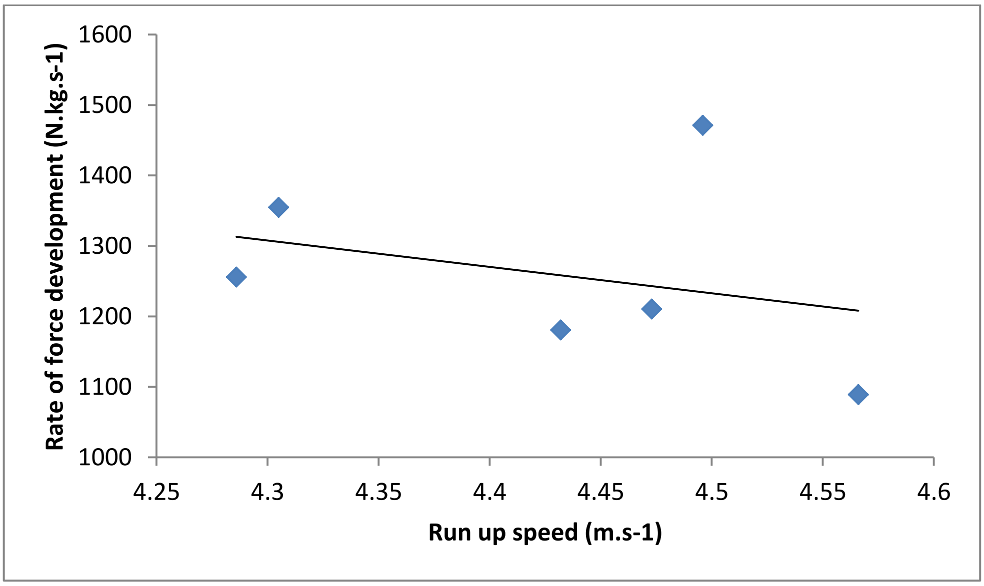

Figure 8. Correlation between run up speed and rate of force development for participant two.

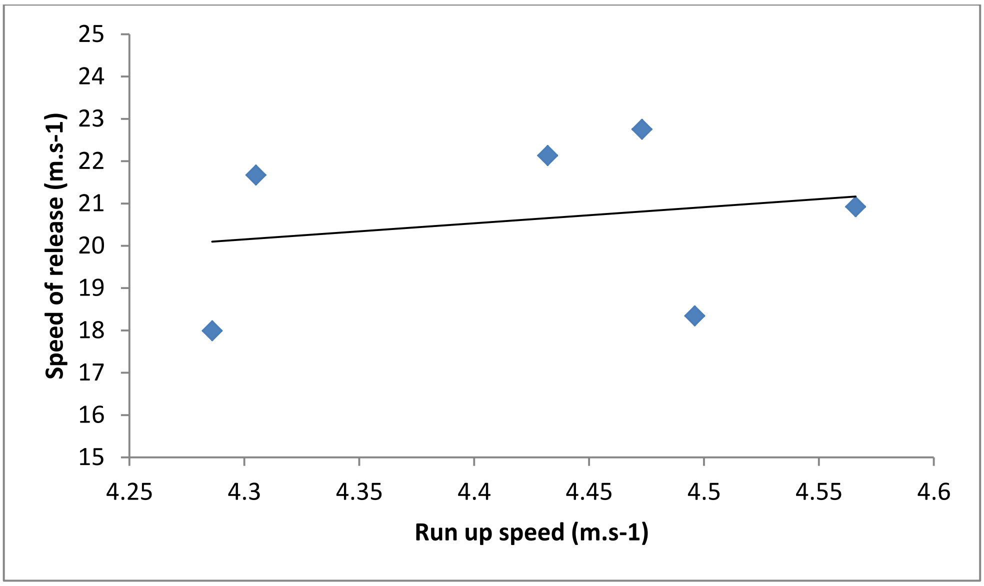

Figure 9. Correlation between run up speed and speed of release for participant two.

Participant two had an average knee angle of 141^{o} at the point of foot contact. It is clear that participant two's knee flexes a great amount during the block, and similar to participant one, this participant's knee starts to extend before the point of release, to an average of 120^{o}. When looking at trial four, participant two's lowest speed of release, the knee flexes more than it does in any other trial, and extends the least leading to the point of release. During trial six, one of the highest trials for speed of release, leading to the point of release the most amount of knee extension takes place. However a correlation value of -0.05 would indicate a negligible correlation between knee angle at release and the speed of the ball at release. Yet a strong correlation of 0.81 was found between the knee angle at release and the length of time between the point of contact and the point of release.

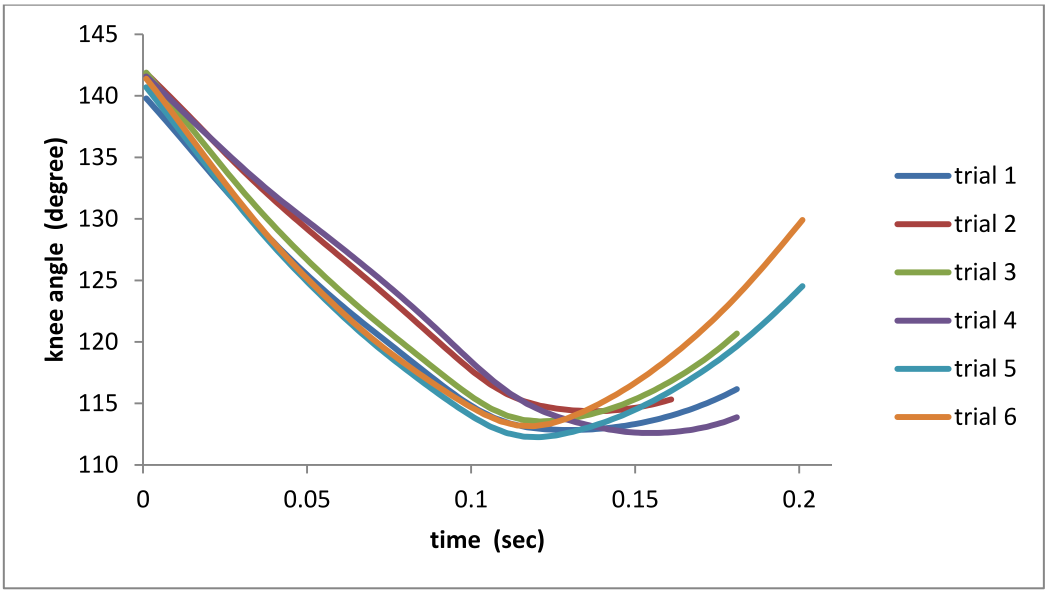

Figure 10. The left (non-throwing side) knee angle for participant two, between the point of contact between the foot and the ground at the block, up until the point the ball is released from the hand.

When looking at the trunk angle, as shown in figure 11, it is clear that the trunk is leant backwards along the sagittal plane during the point of foot contact with the ground at the start of the block; an average of 77^{o}. When looking at the trunk angle at the point of release, there is a high amount of deviation between trials. However there is a negligible correlation of 0.03 between the angle of the trunk at the point of release and the speed of the ball at release. Yet a strong positive correlation, 0.78, was discovered between the final angle of the trunk and the length of time between the point of contact and the point of release.

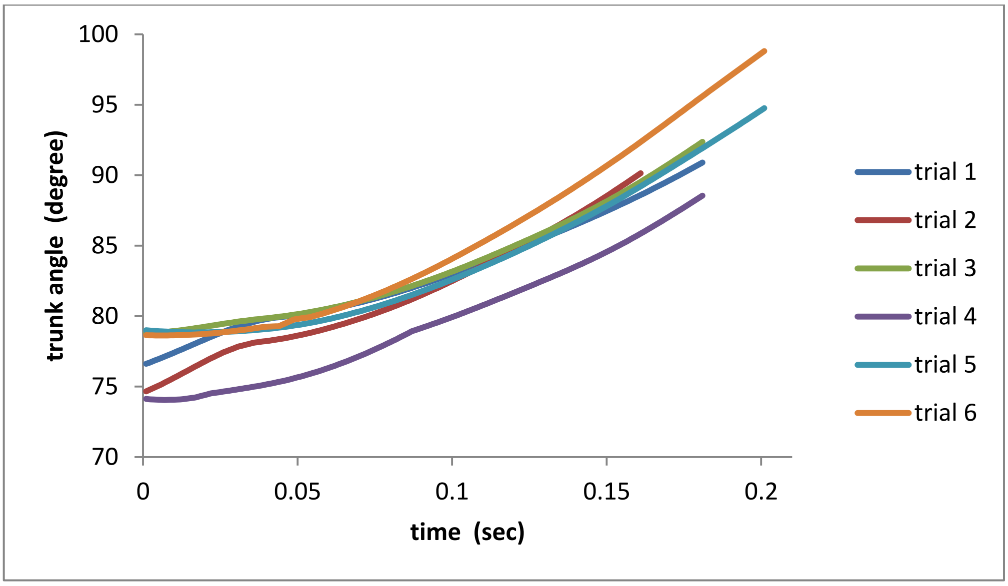

Figure 11. The trunk angle for participant two, between the point of contact between the foot and the ground at the block, up until the point the ball is released from the hand.

Participant Three

Participant three's average ball speed at release was 22.29 m.s^{-1} and a standard deviation of 0.43 m.s^{-1} proves that the trials remained consistent. During trial five, the highest speed was recorded for participant three, 22.82 m.s^{-1}, and therefore this trial would have achieved the furthest distance when throwing a javelin (Mero et al., 1994; Zhiheng et al., 1991; Trower 2000; Viitasalo et al., 2007).

Participant three's average run up speed was 4.12 m.s^{-1} and the standard deviation was 0.37 m.s^{-1} between trials. Also there is a moderate negative correlation of -0.57 between run up speed and the speed of the ball at the point of release.

Participant three's average rate of force development was 1400.44 N.s^{-1} with a standard deviation of 495.87 N.s^{-1}. There was a strong negative correlation, -0.95, between run up speed and rate of force development. However, a correlation of 0.44 shows a weak positive correlation between rate of force development and speed of release.

Table 5. Participant three's recorded data over the six trials.

Trial	Ball speed ($m.s^{-1}$)	Run up speed ($m.s^{-1}$)	Rate of force development ($N.s^{-1}$)
1	21.62	4.42	968.58
2	22.46	4.04	1630.99
3	22.31	4.24	1343.54
4	21.98	4.44	1096.54
5	22.82	4.16	1074.79
6	22.53	3.43	2288.22
Mean	22.29	4.12	1400.44
Standard deviation	0.43	0.37	495.87

Table 6. Correlations between variables for participant three.

	Correlation
Force development, Ball speed	0.44
Force development, Run up	-0.95
Run up, Ball speed	-0.57

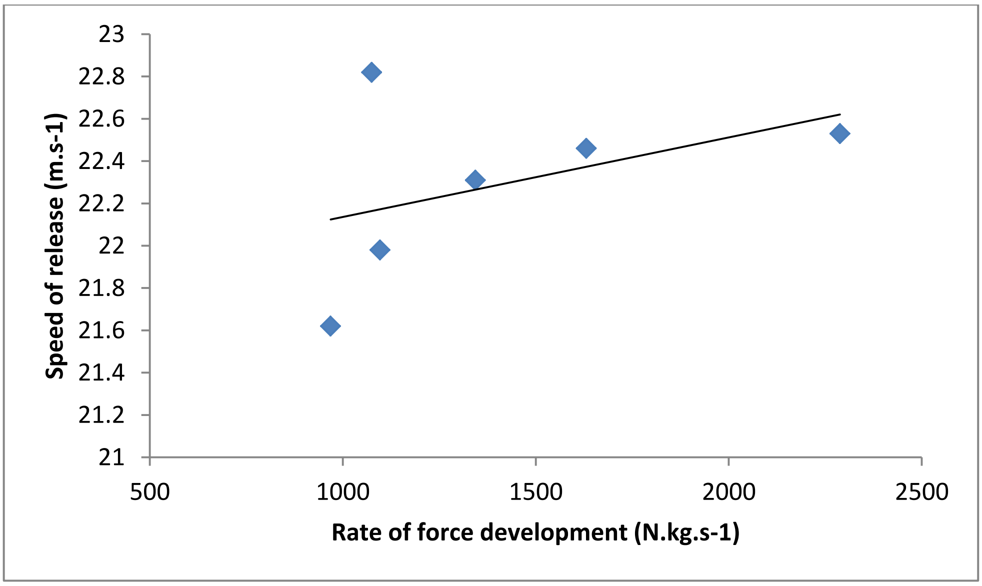

Figure 12. Correlation between rate of force development and speed of release for participant three.

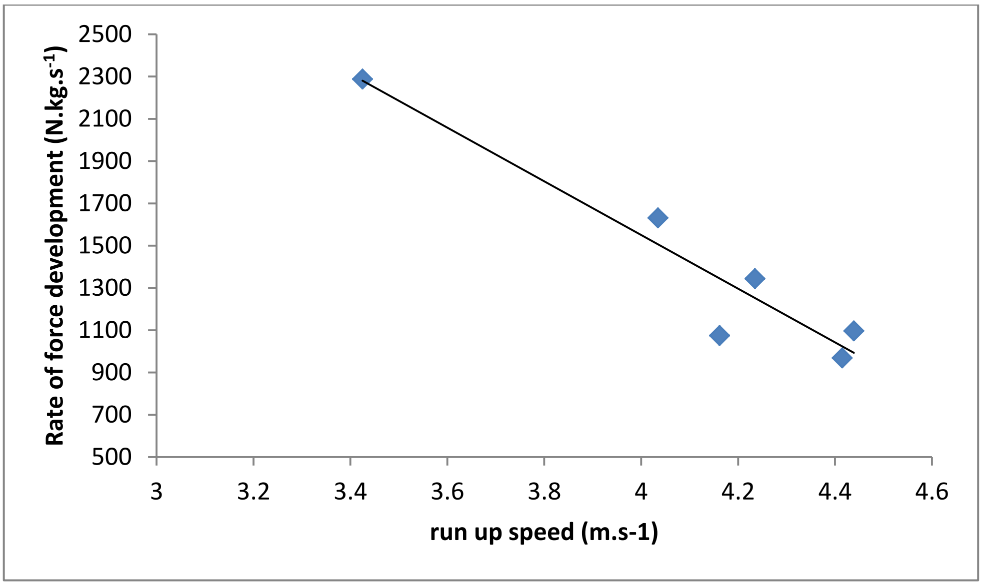

Figure 13. Correlation between run up speed and rate of force development for participant three.

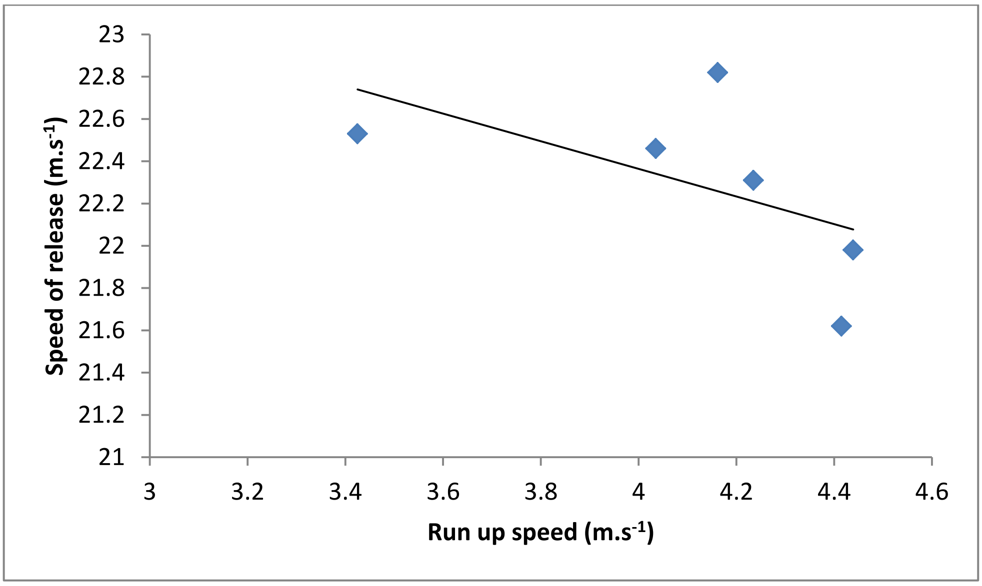

Figure 14. Correlation between run up speed and speed of release for participant three.

At foot contact during the start of the block, participant three's average knee angle was 156^{o}. It then flexes greatly, roughly 25^{o}, and much like the other participants, extension of the knee occurs just before the release in the majority of trials but this does vary. There was a negligible correlation, 0.11, found between the final knee angle and the ball speed at release. And no correlation, 0.00 was found between the final knee angle and the length of time between the point of contact and the point of release.

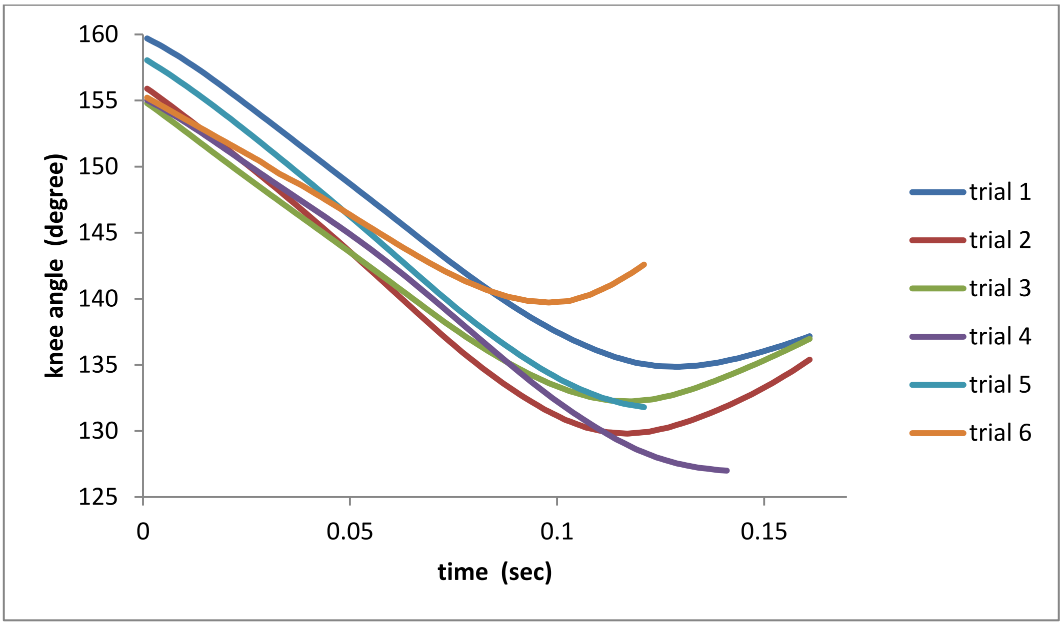

Figure 15. The left (non-throwing side) knee angle for participant three, between the point of contact between the foot and the ground at the block, up until the point the ball is released from the hand.

Technical issues with CODA markers prevented discovering the change in trunk angle between the point of foot contact and the point of release. However it was possible to collect some data for the trunk angle at the point of release for all six trials. The average trunk angle at release was 100^o; and there was a negligible correlation, -0.14 between the trunk angle at the point of release and the speed of the ball at release.

CHAPTER 4

DISCUSSION

The aim of this study was to investigate what takes place in the short period of time between foot contact and point of release during the block in a javelin throw; more specifically, how the rate of force development during the start of the block affected the speed of the ball at release. It carried out a kinematic and kinetic analysis on three elite throwers, looking into a number of variables.

A correlation between the rate of force development and the speed of release was discovered but this correlation differed greatly between participants. Participants one and three had a weak positive correlation of 0.39 and 0.44 respectively; whereas participant two, the thrower with the lowest average speed of release showed a moderate negative correlation of -0.48 between rate of force development and speed of release. These finding obviously contradict one another therefore looking into other factors is needed in order to fully explain the relationship between the two.

When looking at the run up speeds before the block, it is clear that the participants differ from one another. Participant one, the thrower with the highest average speed of release, had the slowest average run up speed of 3.88 $m.s^{-1}$ but the highest average rate of force development, 3016 $N.s^{-1}$ However, participant one had weak positive correlation (0.41 $m.s^{-1}$) between run up speed and ball speed at release. In other words, the speed of the ball at release was likely to increase if the participant's run up speed increased. During trial six participant one achieved his highest speed of release, 23.81 $m.s^{-1}$. The participant's run up speed was also amongst the highest between his trials.

Participant two, the participant with the lowest average speed of release was found to have the highest average run up speed (4.43 $m.s^{-1}$) but then the lowest rate of force development (1260 $N.s^{-1}$). The participant was found to have a weak almost negligible correlation of 0.21 $m.s^{-1}$ between the speed of release and the run up speed. During trials one and five, the participant had very similar running velocities, 4.47 $m.s^{-1}$ and 4.50 $m.s^{-1}$; however the speed of release during trial one was 22.75 $m.s^{-1}$ whereas the speed of release for trial five was 18.34 $m.s^{-1}$; a difference of over 4 $m.s^{-1}$ between the two. To bring this into context regarding distance thrown, Viitasalo et al. (2007) found that an increase of 1 $m.s^{-1}$ in the speed of release for male throwers could increase the distance thrown by up to 6.14 m. For participant two, this would suggest a possible difference of up to 24.54 m between these two trials.

Participant three, the median participant for average speed of release, run up speed and rate of force development, was found to have a moderate negative correlation of -0.57 $m.s^{-1}$ between the two variables. In other words, the speed of release is likely to increase if the participant's run up speed is reduced. This is backed up when looking at trials one and six. The speed of release in trial six (22.53 $m.s^{-1}$) is just under 1 $m.s^{-1}$ higher than in trial one 21.62 $m.s^{-1}$); yet the run up speed during trial six (3.43 $m.s^{-1}$) is just under 1 $m.s^{-1}$ lower than it trial one (4.42 $m.s^{-1}$).

If you were to bring this information together it would suggest that for each individual, there is an optimum speed that a thrower should achieve before blocking. Participant one had the highest average speed of release as well as the highest rate of force development at the start of the block; yet had the slowest average run up speed. Participant two had the highest average run up speed yet had the lowest average rate of force development and speed of release. This agrees with Trower (2000) who stated that the speed of a performer before blocking is relative to the technical and physical proficiencies of that individual performer. Participant one had not reached the optimum run up speed at which his technical and physical proficiencies could still block effectively; hence the weak positive correlation (0.41 $m.s^{-1}$) between run up speed and speed of release. Participant three was exceeding his optimal run up speed, hence the moderate negative correlation (-0.57 $m.s^{-1}$).

Participant two however had a weak positive correlation of 0.21 $m.s^{-1}$ between run up speed and speed of release, even though the participant had the highest average run up speed and the lowest average speed of release in the study. Yet the amount of this correlation needs to be taken into account, 0.21 $m.s^{-1}$. According to the guidelines set by Fallowfield et al. (2005) this is 0.01 $m.s^{-1}$ from showing no correlation. This weak (almost no) correlation can be explained when looking at the consistency of participant two's throws. A standard deviation for speed of release of 2.01 $m.s^{-1}$ (compared to participant one, 0.17 $m.s^{-1}$; and participant three, 0.43 $m.s^{-1}$) between the six trials shows that participant two's throws were highly inconsistent. Bringing this information together would suggest that participant two was greatly exceeding his optimal run up speed, making his block highly ineffective, causing great inconsistency between trials.

The relationship between run up speed and speed of release can further be explained mechanically using Newton's second law of motion. Optimal javelin technique requires the performer to rapidly reduce almost all horizontal velocity with the blocking leg, transferring the momentum into the hip strike (Johnson, 1987; Trower, 2000). Salo et al. (1993) found that a greater decrease in speed of the non-throwing side of the body, created more torque on the throwing side. Newton's second law of motion states that force equals mass times by acceleration. The mass of the performer and the javelin remain constant throughout, therefore a large force is required to decelerate the performer during the block. (Although deceleration is the negative of acceleration, the force applied by the performer during the block goes against the direction they are travelling in making the force negative as well, hence why the equation F=ma remains positive throughout.) The faster the performer is travelling before the block, the more deceleration is needed and the higher the blocking force is required to be. However, the maximum amount of force an individual can produce during the block will depend on the technical and physical proficiencies of that performer, thus, in accordance to Trower (2000), giving an optimal run up speed. Running faster than this optimal speed will result in insufficient deceleration and ineffective momentum transfer into the hip strike. When relating this to participants two and three, their technical and physical proficiencies were not sufficient enough to apply the required force (hence the low rate of force development compared to participant one) to decelerate themselves effectively off the speed they were running in at, thus restricting the transfer of momentum and limiting the speed of release.

The implications of this from a researcher's point of view is that it would suggest that there is a positive correlation between rate of force development during the block and the speed of the ball at release, providing the performer does not exceed their optimal run up speed. The implications for coaches would be finding the optimal run up speed for their athletes and ensuring they do not exceed it. Changing the length of the run up is an easy way to control this (Tower, 2000); a technique already used by coaches to ease athletes back into throwing after injury or a long break.

The main limitation to these findings are that even if this explanation is proved by the three participants in this study, external validity is still questionable. Further research is needed with a much larger number of throwers to make these findings externally valid.

Another limitation to this study is the lack of physical proficiency testing. The study uses the work of Trower (2000) to help explain the findings; each performer has an optimal run up speed that is depended on their technical and physical proficiencies. This study included a technical analysis, however did not include any form of physical make-up testing. To enhance further research, including physical proficiency tests, such as strength or power tests, may allow researchers to develop a more detailed understanding of the association between technique and power; and how they interact to form an individual's optimal run up speed. From this the relationship between the rate of force development at the block and the speed of release should become easier to understand.

Another mechanical theory worth considering when analysing the results is the impulse momentum relationship. It states that impulse (force*time) must remain equal to momentum (mass*velocity) (therefore Ft = mv). Relating this to this study, the mass of the ball remains constant; therefore increasing the impulse will increase the velocity (speed of release). One way to increase the impulse would be to increase the length of time the force is acting on the ball, in this case, the length of time between the point of foot and ground contact at the start of the block to the point of release. Another way to increase the impulse would be to increase the amount of force acting on the ball. From a technical point of view, extending the time between the point of contact and release gives the hips longer to rotate before the shoulders start to turn (evident with participant one). Consequently increasing the separation angle between the hips and shoulders and therefore increasing the pre-tension in the muscles, causing an increased production of torque (Johnson, 1987; Trower, 2000); thus increasing the amount of force acting on the ball. Of course there is a limit to how much you can increase this length of time before the movement becomes slow reducing the production of force. But increasing the time between the point of contact and release (up until a certain point) would drastically increase the impulse because not only does in allow the force to act on the object longer, it also increases the production of force.

This is evident as participant one had a strong positive correlation of 0.89 between this amount of time and the speed of the ball at release. Therefore the trials in which participant one had increase this time were also the trials which had the highest speeds of release.

However this is not evident with participant two or three who both had negative correlations between the length of time and the speed of release (-0.40 and -0.59 respectively). This would suggest that as the length of time between the point of contact and release slowly increased, the amount of force applied to the ball rapidly decreased. Therefore during the study, it was beneficial for these two participants to reduce this length of time; thus increasing the speed of release. The reason for this most likely leads back to the earlier point regarding the participants' run up speeds; the two participants' run up speeds were too high and they were unable to decelerate sufficiently to form an effective transfer of momentum (Johnson, 1987; Trower, 2000; Salo et al., 1993). Because of the inefficient deceleration, the two participants were travelling too fast after the point of contact and were rushed to release the ball before they had passed a position for an effective point of release. An effective deceleration at the start of the block to a sufficiently low speed would have allowed the two participants to spend longer applying the force before the release point. With regards to the force, the fact that the participants did not slow themselves down effectively greatly hindered their hip strike, greatly decreasing the speed of the hip strike and reducing the separation angle that causes muscle pre-tension. Both of which meant a great reduction in the production of torque, and limited the amount of force that can be put on the ball.

The implication for researchers is that this would suggest that there is an optimum time between the point of contact and release to complete the block for each performer. In order to achieve the highest speed of release achievable, this length of time is required to be as long as possible up until the point where force production reduces due to the movements becoming slow. The main contributing factor to controlling this variable would be the run-up speed, thus increasing the importance for a coach to perfect a performer's speed before blocking.

Finally, returning to this study's specific question regarding the relationship between rate of force development and speed of release; the findings above keep referring back to the requirement of an effective block to rapidly decelerate the performer. In order to do this a large rate of force development is required. However the amount required depends on the speed of the performer before blocking. Running in too slow would reduce the amount of deceleration, whereas running in too fast would cause an ineffective block, insufficiently reducing the participants speed. To optimise performance a performer is required to run in at a speed that would allow them to produce the highest rate of force development possible, causing the largest amount of deceleration for the reasons discussed above. This suggests that there is a strong relationship between the rate of force development and the speed of release.

The main limitation to this explanation is varied and inconsistent trials for participant two and three. This made the external validity of any explanation slightly questionable. For this study, elite competitors were used as participants. The criteria for elite used in this study was someone who had competed at a national level at any age group. However, some participants had not competed nationally for a number of years now. Therefore there was a large difference in performance and personal best throwing distances between the three paerticipants. Future studies should categories the term ‘elite’ better, possibly using a certain range for season best throws. Using season best throws rather than personal best throws would be more beneficial because it tells the researcher about the athlete’s current form and how they are likely to perform during the study. Including more participants in future studies and splitting throwers into homogenous groups when analysing the throws would benefit the study as it would produce more trials to compare with each other as well as between homogenous groups. This would allow for more reliable results, making discoveries and explanations more valid.

Another limitation is the lack of previous research. The researcher for this study was unable to find any previous studies that go into detail over the short time between the point of contact and the point of release. This means the validity and reliability is slightly uncertain as there is nothing to compare the results to.

There were also limitations with the equipment and data processing. CODA markers placed on soft tissue move and do not remain on the joint centres. The data was filtered but this is not accurate enough to remove all noise from the data. Also there is a high chance of human error when digitising video footage, even if the same individual carried out the whole process. There were also technical issues that limited the study. A problem with participant three’s left shoulder marker made it impossible to find the trunk angle at the point of foot contact with the ground at the start of the block.

Conclusion

This study found no direct correlation between rate of force development and speed of release that was the same for all participants. Another variable was required to fully understand the relationship between the rate of force development and speed on release. This factor was run up speed as it had great effects on what took place between the point of contact and release. In agreement with previous studies, this study found there was an optimal run up speed for each performer, however this study identified the causes of this optimum speed.

The two main factors to consider when optimising release speed were the length of time the force was acting on the ball and the magnitude of this force. Increasing the time between the point of contact and release automatically increased the time the force was acting on the object. An effective block was required to decelerate the performer to allow for more time before the participant reached an effective position to release the ball. The length of this time also had an effect on the magnitude of the force. Increasing this time would allow the hips to rotate further before the start of the shoulders strike, thus increasing muscle pre-tension and therefore increase torque and the force acting on the ball. However if this time continued to increase, the movements would become slow, reducing the production of force; thus creating an optimal length of time between the point of contact and release.

Rapid decelerates of the participant at the point of contact also allowed a large transfer of momentum into the hip strike (Johnson, 1987; Trower, 2000; Salo et al., 1993) increasing the production of torque and consequently further increasing the magnitude of the force acting on the ball. This rapid deceleration could only be caused with an effective block, once again highlighting its importance.

As explained above, rapid deceleration is key to optimising the speed of release. This the performer has run in at their optimal speed (too slow limits the transfer of momentum and the production of torque; too fast and insufficient deceleration takes place) and to block effectively resulting in the highest rate of force development achievable for that individual; Thus suggesting that optimising rate of force development is required to optimise the speed of the release.

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APPENDIX A

ETHICS STATUS

The Ethics committee approved this study before it started. Below is a copy of the ethics form sent to them:

When undertaking a research or enterprise project, Cardiff Met staff and students are obliged to complete this form in order that the ethics implications of that project may be considered.

If the project requires ethics approval from an external agency such as the NHS or MoD, you will not need to seek additional ethics approval from Cardiff Met. You should however complete Part One of this form and attach a copy of your NHS application in order that your School is aware of the project.

The document ***Guidelines for obtaining ethics approval*** will help you complete this form. It is available from the Cardiff Met website.

Once you have completed the form, sign the declaration and forward to your School Research Ethics Committee.

PLEASE NOTE:
Participant recruitment or data collection must not commence until ethics approval has been obtained.

PART ONE

Name of applicant:	Matty Patel
Supervisor (if student project):	Dr Ian Bezodis
School:	School of Sport
Student number (if applicable):	St20000594
Programme enrolled on (if applicable):	Sports Coaching
Project Title:	To observe the relationship between a change in knee angle and the rate of force development experienced during the block in a javelin throw. And subsequently, to observe the relationship between the rate of force development, during the block, and the speed of the hand at release.
Expected Start Date:	9/2013
Approximate Duration:	5 months
Funding Body (if applicable):	

Other researcher(s) working on the project:	
Will the study involve NHS patients or staff?	No
Will the study involve taking samples of human origin from participants?	No

In no more than 150 words, give a non technical summary of the project
Biomechanical analysis of a javelin throw. It will use 4 – 6 participants all of whom are trained javelin throwers. It will use CODA motion analysis with markers placed on the toe, ankle, knee, hip, shoulder and hand. The throwers will block onto a force plate and throw an 800g ball into a net. This is no different to what the throwers carry out in training. They shall also be filmed using a video camera.

Does your project fall entirely within one of the following categories:	
Paper based, involving only documents in the public domain	No
Laboratory based, not involving human participants or human tissue samples	No
Practice based not involving human participants (eg curatorial, practice audit)	No
Compulsory projects in professional practice (eg Initial Teacher Education)	No
If you have answered YES to any of these questions, no further information regarding your project is required. If you have answered NO to all of these questions, you must complete Part 2 of this form	

DECLARATION: **I confirm that this project conforms with the Cardiff Met Research Governance Framework**	
Signature of the applicant: Matty Patel	Date: 1/5/13
FOR STUDENT PROJECTS ONLY	
Name of supervisor:	Date:
Signature of supervisor:	

Research Ethics Committee use only	
Decision reached:	Project approved ☐ Project approved in principle ☐ Decision deferred ☐

	Project not approved ☐ Project rejected ☐
Project reference number: Click here to enter text.	
Name: Click here to enter text.	Date: Click here to enter a date.
Signature:	
Details of any conditions upon which approval is dependant: Click here to enter text.	

PART TWO

A RESEARCH DESIGN	
A1 Will you be using an approved protocol in your project?	No
A2 If yes, please state the name and code of the approved protocol to be used[3]	
Click here to enter text.	
A3 Describe the research design to be used in your project	
Analyses of a javelin throw using 4 – 6 javelin throwers or decathletes, all currently carrying out some form of javelin training. They will perform 6 trials in which they will run off a full run up and throw an 800g ball. Exactly the same to what they would carry out in training. CODA motion analysis will be used and markers will be placed on the toe, ankle, knee, hip, shoulder and hand. The throwers will block onto a force plate and throw the ball into a net. They shall also be filmed using a video camera.	
A4 Will the project involve deceptive or covert research?	No
A5 If yes, give a rationale for the use of deceptive or covert research	
Click here to enter text.	

B PREVIOUS EXPERIENCE
B1 What previous experience of research involving human participants relevant to this project do you have?
For our biomechanics course work we carried out a study much like this one but looked at cutting movements and how they affect the forces experienced through our joints.
B2 **Student project only** What previous experience of research involving human participants relevant to this project does your supervisor have?
Dr Ian Bezodis has been conducting research into the biomechanics of sport and exercise in humans for the past 14 years. In this time he has produced 21 published research articles, 17 conference abstracts and five invited conference presentations. He has experience of conducting studies into the kinematics and kinetics of human movement, using many motion analysis systems, including standard 50 Hz and high speed video, as well as the automatic systems, Vicon and CODA, alongside force platforms and pressure-sensing insole devices. He has worked with participants ranging from elite Olympians and Paralympians, to recreational sports people, and elderly participants with conditions such as cardiac problems or undergoing recovery from joint replacement surgery. He has been a member of the CSS Research Ethics Committee since 2008.

[3] An Approved Protocol is one which has been approved by Cardiff Met to be used under supervision of designated members of staff; a list of approved protocols can be found on the Cardiff Met website here

C POTENTIAL RISKS
C1 What potential risks do you foresee?
Athletes could get injured during the experiment, most likely injury would be a sprained ankle when blocking but other injuries could occur.
C2 How will you deal with the potential risks?
As stated earlier, what the athletes do for this study is no different to what they do in training therefore if injuries do occur they would be because of a freak accident. Because of this it is impossible to prevent it from occurring.

When submitting your application you **MUST** attach a copy of the following:

- All information sheets
- Consent/assent form(s)

Refer to the document ***Guidelines for obtaining ethics approval*** for further details on what format these documents should take.

APPENDIX B

RESULTS FOR RESIDUAL ANALYSIS

Joint	Participant	Trial for participant	Cut-off frequency
Elbow	1	2	8
Elbow	2	5	8
Elbow	3	10	8.5
Knee	1	2	7.5
Knee	2	4	6.5
Ankle	1	8	7.5
Ankle	3	11	6.5

Average	**7**