Cardiff School of Sport
DISSERTATION ASSESSMENT PROFORMA:
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Student name:	Luke Gareth Kinsey	***Student ID:***	St20004699
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Dissertation title:	What is the relationship between knee height in the leg cycle and force production during the stance phase whilst running at maximal velocity?		
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.
	Results and Analysis (15%) [2] To include: description and justification of data treatment/ data analysis procedures; appropriate presentation of analysed data within text and in tables or figures; description of critical findings.
	Discussion and Conclusions (30%) [2] To include: collation of information and ideas and evaluation of those ideas relative to the extant literature/concept/theory and research question/problem; adoption of a personal position on the study by linking and combining different elements of the data reported; discussion of the real-life impact of your research findings for coaches and/or practitioners (i.e. practical implications); discussion of the limitations and a critical reflection of the approach/process adopted; and indication of potential improvements and future developments building on the study; and a conclusion which summarises the relationship between the research question and the major findings.
	Presentation (10%) To include: academic writing style; depth, scope and accuracy of referencing in the text and final reference list; clarity in organisation, formatting and visual presentation

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CARDIFF METROPOLITAN UNIVERSITY
Prifysgol Fetropolitan Caerdydd

CARDIFF SCHOOL OF SPORT

DEGREE OF BACHELOR OF SCIENCE (HONOURS)

SPORT COACHING

2013-4

"What is the relationship between knee height in the leg cycle and force production during the stance phase whilst running at maximal velocity?"

(Dissertation submitted under the discipline of)

BIOMECHANICS

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CARDIFF METROPOLITAN UNIVERSITY

“WHAT IS THE RELATIONSHIP BETWEEN KNEE HEIGHT IN THE LEG CYCLE AND FORCE PRODUCTION DURING THE STANCE PHASE WHIST RUNNING AT MAXIMAL VELOCITY?”

Cardiff Metropolitan University

Prifysgol Fetropolitan Caerdydd

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ABSTRACT

The main aim of this study was to investigate the relationship between the maximum height of the knee during the leg cycle and the peak vertical ground reaction force from the forthcoming stance phase of the same leg. The other aims were to look at the relationship between knee height and maximal velocity, peak ground reaction force and maximal velocity, knee height and stride length and finally stride length and maximal velocity. Three University sports students with a mean age = 19.67 yr ± 1.53 yr, height = 1.76 m ± 0.10 m, mass = 76.67 kg ± 5.77 kg volunteered for the study. Four CODAmotion scanners (200 Hz) were positioned allowing for a capture range of approximately fifteen metres, with a force plate (1000 Hz) positioned approximately ten metres into this range. Kinematic and kinetic data was derived from each participant completing three successful maximal velocity trials, with the athletes sprinting for around thirty five metres. Knee height, peak vertical ground reaction force, stride length, stride frequency and running velocity were calculated. The findings from the study showed that there were significant relationships ($P<0.05$) for two of the athletes between their knee heights and stride lengths and two athletes were found to show a significant relationship ($P<0.05$) between stride length and velocity. No significant relationships ($P>0.05$) were found between knee height and peak vertical ground reaction force, peak vertical ground reaction force and velocity and knee height and velocity. These results can suggest that for athletes who want to improve their sprint performance, knee height and peak vertical ground reaction forces do not have a direct effect upon maximal velocity and should not be the main focus during training sessions. The proposed focus should be directed towards increasing stride length and exercises targeting improvements in joint flexibility are recommended.

CHAPTER 1

INTRODUCTION & LITERATURE REVIEW

1.1-Introduction:

Maximal velocity running is used in a wide range of sports, whether that is athletes in football, rugby and hockey running down the wings or in basketball when a team is on the counter attack. It is also classified as its own discipline, where athletes come to race one another over short distances (60 m, 100 m and 200 m) to see who can complete the distance in the shortest time. A factor in determining a successful sprint performance is an athlete’s velocity. Previous literature has identified that from a biomechanical viewpoint, sprint velocity is determined from multiplying the athlete’s step frequency and their step length together (Hunter et al. 2004). A step is defined as half of the natural running cycle, which is the distance covered from one foot touching the ground to the opposite foot touching the ground. A stride is defined as the distance produced from when one foot touches the ground, till that same foot touches the ground again (Cavanagh & Kram, 1989). Hay (1994) suggested there are many factors that determine an athlete’s step length and step frequency and also gave an insight into what they could optimally become due to training. Hay (1994) created two models one for step frequency and one for step length that explained these factors. The models have the potential to allow coaches to increase their athletes step frequency, step length or both (Hunter et al., 2004). The problem that coaches have is which attribute, if needed, they should try and increase. In theory by increasing one, it would have an impact on the other. For example by increasing an athlete’s step length, they would take fewer steps in a race which could increase that athlete’s velocity; just as long as that athlete’s step frequency does not have a detrimental reduction (Hunter et al., 2004). Within the literature if one attribute has been increased and the other decreased significantly, it is described as a ‘negative interaction’ (Hunter et al., 2004). Many authors have debated about which attribute is most prominent in successful performance.

1.2-Step Length vs Step Frequency:

Amongst the literature many authors have agreed with the relationships between step length and step frequency at submaximal velocities (Bezodis, 2012). With athletes demonstrating a greater step length at lower velocities and as velocity increases there is a change and step length remains the same but step frequency starts to increase (Luhtanen and Komi, 1978; Kuitunen *et al.,* 2002). At maximal velocity there is some dispute from source to source. Mero and Komi (1985) and Gajer *et al.* (1999) proposed that successful sprint performance was down to step length being the main influence, while Mann and

Herman (1985) and Ae *et al.* (1992) had previously stated that an athlete's step frequency was the most important factor leading to better performance. Hunter *et al.* (2004) proposed a study to look into the influences of step length and step frequency has on an athlete's velocity. They recruited thirty six athletes who were involved in sports that needed them to sprint to demonstrate successful performance. They asked them to perform a number of maximal effort sprints and recorded the data sixteen metres from the start line, with the performers travelling twenty five metres in total. From looking at other research this could be seen as a small distance to use if the authors were looking into the maximal velocity phase of the sprint. Krzysztof and Mero (2013) looked at the best sprint performances ever and it can be seen that the elite sprinters reached their maximal velocity around sixty metres into the hundred metre race. Hunter *et al.* (2004) found that as a result from their experiment, step length was significantly the main contributor to velocity rather than step frequency when analysing the group as a whole. They also looked at the influences of the attributes on an individual basis by comparing the athlete's fastest trial to their third fastest trial. The authors discovered that during this part of their study, there was not a significant difference between step lengths; but the athlete's step frequencies were much greater. This means that the athlete's performed their fastest performances with a higher step frequency rather than a longer step length (Hunter *et al.,* 2004). This study gives an insight to coaches and athletes into which attributes have a greater effect towards velocity. With this knowledge coaches could analyse their athlete's performance and break down their race and compare them to other athlete's or their own previous performances to see what the contributors were to that specific time. By doing this they could see if their athlete was more step length reliant or more step frequency reliant. This in turn would give the coach the opportunity to make training more specific and more individual and hopefully lead to successful performance. A factor that could have improved the Hunter *et al.* (2004) study could be the type of athletes they recruited; it may have been a good idea to focus on a certain sport to add to the validity of the paper.

Krzysztof and Mero (2013) analysed Usain Bolt's top three performances and compared them to the other competitors in those races. From looking at the data it shows that Usain's step frequency during his Olympic record performance in London 2012 showed no significant difference when compared with his other competitors. Usain's was 4.29 Hz and his opponents were 4.38 Hz. What is interesting is that there is a significant difference between Usain's step length (2.41 m) and his competitors step length (2.25 m) in the same race. This finding is also apparent for the Olympic final in Beijing 2008 and the

World Championships final in Berlin 2009. This could show that at elite level the performers nowadays have similar step frequencies but it is the athlete's that have the greater step lengths that produce the faster velocities. Although, this is only from the findings based on one athlete, so it cannot be generalised for the rest of the population. Other authors have looked into elite athletes and whether there is such thing as '*reliance*' towards step length or step frequency. Salo *et al.* (2011) studied numerous elite level male hundred meter races and focussed on eleven athletes to see what they individually relied on when they were travelling at maximal velocity. The authors discovered that out of all their participants only four showed a true reliance, with three showing that they are dependent on their step length and one showing that they rely on their step frequency. The others didn't show reliance either way. The authors (Salo *et al.,* 2011) concluded that this reliance should be taken into consideration when the athlete is training. This would allow the attributes to be improved and hopefully lead to an increase in a performer's maximal velocity. Certain types of training programmes can be substituted to help benefit athletes who are either step length or step frequency reliant (Salo *et al.,* 2011). For athletes who are step length reliant, training must consist of exercises that look to improve muscular and vertical ground reaction forces, whilst also looking at improving joint flexibility (Salo *et al.,* 2011). If the performers are step frequency reliant, then neural adaptation to encourage an increase in leg turnover is advised (Salo *et al.,* 2011). Furthermore it is also thought that the coach themselves can have an impact on which attribute individual athletes use more to contribute towards velocity, through their philosophy and their specific training styles (Bezodis, 2012).

Step length and step frequency is worked out from the performer completing what is known as a step cycle. Each one of these leg cycles consists of a contact phase and a flight phase (Exell, 2010). The stage when the foot is in contact with the ground is also defined as the stance phase (Heise *et al.,* 2011). This phase can be broken up into the touchdown distance, foot movement distance and take-off distance (Hay, 1994). With all these phases added together creating the stance distance. The latter phase (flight) is when both feet are off the ground and the leg that wasn't in contact with the ground during the stance phase is coming through for touchdown. This leg cycle is a main part of the sprinting technique.

1.3-Sprint Technique:

Jones *et al.* (2009) and Thompson *et al.* (2009) interviewed expert coaches within sprinting to see how they (the coaches) defined good sprinting form during maximal velocity running. From both articles, some of the coaches describe how they wanted to see a ‘high hip position’. Their rationale for wanted this was because it led to the centre of mass of the athlete remaining high, which then allowed the desirable step length to be produced as the knees were able to come up and through (Thompson *et al.,* 2009). The same coach stated that if the athlete didn’t keep a high hip position they would end up ‘running into the ground’ (Thompson *et al.,* 2009). Within Biomechanics there have been studies that have looked into the height of the centre of mass of the athlete. Hinrichs *et al.,* (1987) reported that arm action could influence the height at which the centre of mass could reach. Others previously (Mann and Herman, 1985) suggested that an athlete’s touchdown distance related to their centre of mass. There are other factors that play an equal part in determining good form, especially during the maintenance phase of a sprint performance. The coaches described the importance for good posture, arm action and relaxation (Jones *et al.,* 2009). Two of the experts offered to explain good posture, one of them suggested that “Correct posture is having the total body control to maintain the optimum sprinting action for the whole duration of the run” (Thompson *et al*., 2009, pg. 857). While the other talked about viewing the torso as the central hub for movement, with the arms and legs rotating about the trunk. They then described how the trunk needed to be able to support all these extremities and if it wasn’t strong then the sprint technique would appear weak (Thompson *et al.,* 2009). Other key points that came from questioning the coaches on posture were core strength and core stability. The coaches’ ideas were very similar to those discussed in Kibler *et al.* (2006) and Novak and Mackinnon (1997) which explains that if an athlete has their posture in an optimal position it can have a positive effect on their production of muscular force and muscular efficiency. The sprint coaches identified the importance of arm action in describing efficient sprinting movement. They believed that the elbow joint should be at around 90 degrees of flexion and the arms should move in the sagittal plane, trying to avoid the arms coming across the body (Jones *et al.,* 2009). Both of the arms should do the same thing but at opposite times, as one arm is coming forward, the arm is coming back (Jones *et al.,* 2009). These key points have been discussed and previously approved in Jarver’s (1984) paper, but the literature is limited on the subject as a whole. It was then brought up by one of the other coaches that by doing this the arms can be seen as balancing the trunk, which in turn adds to the points discussed about posture (Jones *et al.,* 2009). Other authors (Mann, 1981; Mann & Herman, 1985) have previously stated that from a biomechanical viewpoint the arms do not serve much purpose in successful sprint performance other than somewhat help the performer maintain balance. The coaches finally stated how they wanted to see total relaxation in their performers when they are travelling at maximum velocity (Jones *et al.,* 2009). They suggested that the upper torso, neck and jaw need to be relaxed when running to avoid the shoulders being raised as a result of tensed muscles (Jones *et al.,* 2009). Within other literature the view of being relaxed while sprinting has been agreed. Carr (1999) had stated that facial muscles need to be relaxed when sprinting. Frye (1999) also agreed with the statement and believed that performers should have relaxed shoulders, neck and face. Although it is widely recognised that athletes will perform better if they stay relaxed, there is little or no scientific research that has looked into the effects relaxation and tensing has on a sprint performance. As well as all the points spoken with regard to a coach's desired sprint technique, there is still a need for kinematic and kinetic characteristics of the lower limbs which could be used in explaining further what good sprinting form is.

1.4-Sprint Kinematics and Kinetics:

Referring back to Hay's (1994) models for step length and step frequency, an athlete's stance distance has been mentioned as a contributor towards identifying both step length and step frequency. There are many kinematic and kinetic studies that have looked into the stance phase, as well as the swing phase. In reference to the stance phase there are two elements of horizontal ground reaction force that occur at the driving phase of the stance (Hay, 1994); one at the early stage of the phase (braking ground reaction force) and the other at the latter stage of the phase (propulsive ground reaction force) (Hunter *et al.,* 2005). Traditionally sprinters have been advised that during the maximal velocity phase of the sprint it would be better for their performance if they decrease their braking ground reaction force (Mero & Komi, 1986; Mero *et al.,* 1992; Wood, 1987) and focus on increasing their propulsive ground reaction force (Mero *et al.,* 1992). Other authors have discussed how this can be done. Mann & Sprague (1983) and Mann *et al.* (1984) suggested that the velocity of hip extension needed to be high and the velocity of knee flexion also needed to be high at the moment of touchdown when trying to decrease an athlete's braking ground reaction force. To increase the propulsive ground reaction force, the performer needs to make sure they have a large angular velocity at the hip joint (Mann & Sprague, 1983; Mann *et al.,* 1984; Wiemann & Tidow, 1995). They also need to make sure there is a triple extension of the ankle, knee and hip at the take-off phase of the stance (Hunter *et al.,* 2005).

Hunter *et al.* (2005) proposed a study to look into these theories at the drive phase of the stance. They got their participants to sprint from a standing start for around twenty five metres and they collected their data sixteen metres into the sprint. Their findings showed that the faster athletes of the study did not always have a lower relative braking impulse. However they found that the quicker performers did engage in greater magnitudes of propulsive impulsive. With regards to the theories in how to decrease and increase braking and propulsion ground reaction forces the authors suggested that a high velocity of hip extension and knee flexion wasn't supported for a decrease in braking ground reaction force. What was supported was the idea of having an active touchdown phase and a small touchdown distance when wanting to decrease braking ground reaction force (Hay, 1994; Mann & Sprague, 1983; Mero *et al.,* 1992; Wood 1987). The theories with reference to increasing propulsive ground reaction force were also partly disproved. With the notion of triple extension at the ankle, knee and hip at take-off, not being supported and a larger velocity of hip extension only partially being proved (Hunter *et al.,* 2005). These theories could have been disproved because their study was looking into the acceleration phase of the sprint and the theories could have more closely linked to the maximal velocity phase (Hunter *et al.,* 2005). That being said, other authors have reported that elite sprinters do not obtain the triple extension (Kunz & Kauffman, 1981; Mann & Herman, 1985). Mann and Herman discovered that the top three sprinters in the two hundred metre race at the 1984 Olympics did not have full extension at their knee and hip joints at about one hundred and twenty metres into the race. The average for the hip joint was one hundred and sixty eight degrees and the average for the knee was one hundred and fifty seven degrees. Another paper linked to ground reaction forces and sprint performance was the study conducted by Weyand and colleagues (Weyand *et al.,* 2000). They recruited thirty three sprint athletes and got them to run at their top speed on a treadmill. They concluded that faster runners produce greater forces into the ground compared to slower runners.

Closely linked to braking and propulsive ground reaction forces is the notion of contact time. Many authors have assessed contact time and linked it to braking and propulsion forces as well as running velocity. Luhtanen and Komi (1978) looked into the relationship, if any, between contact time and the flight time of a running step. They discovered that as running velocity increased contact time decreased and flight time was larger than contact time for all but one of the velocities tested (3.90 m/s), which was the lowest velocity that the authors tested for. Although there wasn’t a relationship throughout all the velocities, it does show that there is a relationship between contact time and flight time once the athlete has travelled over 3.90 m/s and is starting to demonstrate a transition from a jog to a sprint. These findings have been reinforced by other authors (Bushnell & Hunter, 2007; Mann & Herman, 1985). Kunz and Kaufmann (1981) reported that elite sprinters have shorter contact times compared with decathletes. They also tended to have longer step lengths which led to the assumptions that elite sprinters can produce greater propulsive forces in less time.

Once the foot has pushed off the ground it begins a transition from the drive phase of the stance and enters the recovery phase which is part of the flight phase (Hay, 1994). During this phase the upper leg rotates backwards slightly and then forwards about the hip, this allows the lower leg to flex, which results in the heel coming close the Gluteus Maximus (Hay, 1994). Once the performer’s thigh segment has rotated forward about the hip and their knee has reached its highest point, the lower leg (shank segment) can come through at the knee and then the whole leg segment makes its way down for the touchdown phase (Hay, 1994). The idea of looking at human locomotion and finding attributes that differ from fast athletes to slower athletes can be dated way back to the early twentieth century. Fenn (1930) proposed a study to look into how much and athlete works against gravity and works due to velocity changes in running movements of their centre of gravity. The findings of the experiment were that the quicker runners from the population had greater knee height and longer step lengths. Later Fred and Ecker (1962) agreed with what had previously said by Fenn (1930) and commented that if an athlete wanted to produce a desirable stride length, they would need to produce a high knee lift in the latter stage of the leg cycle. Deshon and Nelson (1964) also conducted a study to look at the relationships between running velocity and a number of variables, with one of the variables tested being the angle of leg lift. They tested nineteen University runners of various abilities and concluded that the angle of leg lift did have an impact on the velocity that an athlete was traveling at. Another study that looked into distance runners was Sinning and Forsyth (1970). They took seven autonomous distance runners and got them to run on a treadmill at different velocities. They discovered that as the velocity increased so did the angle of hip flexion. While these two studies (Deshon and Nelson, 1964; Sinning and Forsyth, 1970) did show similar findings to the other studies, they have to be treated with caution when referencing them within sprinting technique. This is due to the fact that they used distance runners as their participants rather than sprinters. More recently there has been a study that has looked into the angle of hip flexion within sprinters. Guex *et al.,* (2012) used ten national sprinters for their data collection, which consisted of the athletes taking part in various hip flexing exercises at different degrees of flexion (0°, 30°, 60° and 90°) and looking at peak muscle torques which occurred at each degree of flexion. They noticed that as the degree of flexion increased so did the peak hamstring torque. They had also commented earlier in their paper that sprinters traditionally have a high angle of hip flexion (around 80°) which could explain why sprinters are more at risk at getting hamstring injuries. This study could have been improved if they had included the athletes taking part in maximal velocity sprints. They then could have tested to see if the sprinters did have a high degree of hip flexion while running and could have seen if there was any link towards hip flexion and performance.

1.5-The Research Proposal:

The current study was specifically looking at the influence between optimal knee height from the leg that was rotating at the hip during the recovery phase and the peak vertical ground reaction force created during the forthcoming stance phase of the same leg. The expected finding for the study was to show that as knee height increases so does force production. Another area that was looked into was suggestions made by Weyand *et al.* (2000) that implied faster athletes tend to apply greater forces into the ground. It was also proposed to look further into the works of Deshon and Nelson (1964) and Sinning and Forsyth (1970) to see if knee height could have an effect on a sprint athlete’s velocity. Going further into this area, the workings from Fenn (1930) were investigated, to see if the quicker athletes had higher knee heights and longer stride lengths. The final part of the study was to at the findings from Mero and Komi (1985) and Gajer *et al.* (1999) to see if stride length effected an athlete’s velocity.

CHAPTER 2

METHODOLOGY

2.1-Research Design:

The design for the current study followed a cross sectional format as all the data was collected within one session. For all the participants involved in the experiment, the measures were repeated to guarantee a fair test. The data was analysed as a multi-individual study.

2.2-Participants:

The three male participants (Table 1.) were University students all studying at Cardiff Metropolitan University. They all volunteered to take part in the study and were accepted as they had met the criteria to participate. The criteria was to be free from any injury for at least six months and to be actively training in any given sprint event or sport that has a part within it where athletes are required to sprint at maximal velocity. Once they had been accepted to take part, the performers provided written consent that showed they understood what they were being asked to do and what the information was going to be used for. For the project to be initiated, it had to be ethically approved. This was granted by the ethics committee at Cardiff Metropolitan University.

Table 1. Participant Information including Age, Height and Mass.

Participant	Age	Height (m)	Mass (kg)
1	21	1.65	70
2	18	1.84	80
3	20	1.80	80

2.3-Protocol:

The athletes were given sufficient time to warm up and cool down. They were asked to do both (warm up and cool down) exactly how they would in training or before competition. They were then asked to complete a minimum of three successful trials. A successful trial was identified as the athlete being at their maximal velocity once they had reached the twenty metre marker and then continued this speed until they had made a correct step onto one of the two force plates (Kistler 9287B, Winterthur, Switzerland) with the foot that was being analysed. The right side of the body was being analysed for all of the participants and had five markers positioned at each of the joints centre of rotation (Fig. 1.).

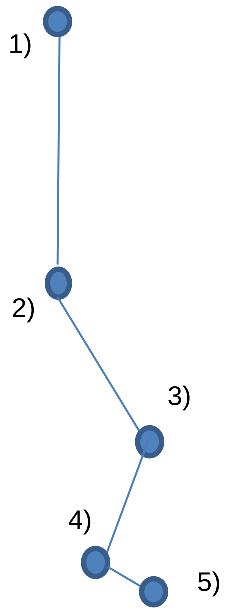

Fig. 1. Positioning of CODA markers, 1-Shoulder, 2-Hip, 3-Knee, 4-Ankle and 5-MTP (Metatarsophalangeal joint).

2.4-Data Collection:

Once the performers had been marked up they were able to start their trials. All the trials were completed on a Mondo track surface (Warwickshire, UK) in the National Indoor Athletics Centre (Cardiff, UK). The athletes were asked to start from a marker and begin to sprint and by the time they had reached the second marker (twenty metres down the track, Fig. 2.) they had to be at top speed. From the second marker they had to carry on at maximal velocity until they had made a successful foot contact with one of the force plates (Refer to Fig. 2.) that were being captured at 1000 Hz. After the participants had completed their twenty metre run in phase, kinematic coordinate data (3D but was reduced to 2D in the sagittal plane) that was being captured at 200 Hz, was collected for the rest of the run. Four CODA scanners (Charnwood Dynamics Ltd, Leicestershire, UK) were used for the optimal capture distance (15 m approx.) available. The scanners were placed three and a half metres apart and three metres away from the centre of the lane on the track (See Fig. 2.). In the pilot study the scanners were placed four metres apart and two metres away from the centre of the lane on the track, this led to there being a slight distance in between the scanners where no movement was being picked up. It was agreed that it would be better to move the scanners slightly closer together and further back. The scanners and force plates were synchronised to a CODA CX1 Motion Analysis System (Charnwood Dynamics, UK).

Due to some of the athletes struggling to make a correct foot strike onto either force platform because of their natural stride length, the starting marker was moved slightly back or slight forward depending on what each athletes specific needs were; the marker was never moved more than a metre either way. To try and minimise how much the athlete was targeting the force plate a marker was placed a few metres after the force plates and they were asked to focus on running past that marker. Once each participant had completed three successful trials then they were free to cool down and leave.

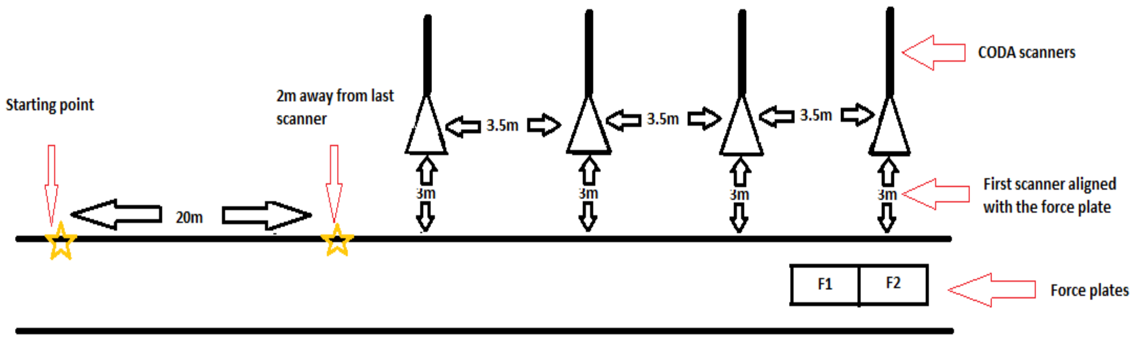

Fig. 2. Practical set up for the study.

2.5-Data Processing:

Once all the data had been collected it was filtered using a Butterworth low-pass digital filter. The residual analysis approach (Winter, 2005) was adopted to calculate the optimal cut-off frequency for the data. The cut-off frequency came out at 11 Hz and this was used for each of the trials analysed.

2.6-Data Analysis:

The data was analysed as a multi-individual study and the variables that were being considered were, maximum knee height, peak vertical ground reaction force, stride length, stride frequency and how all of these have affected each athlete’s velocity (performance).

For each of the variables means and standard deviations were calculated from the three successful trials each athlete performed, using Microsoft Excel.

Knee height was calculated by tracking the vertical displacement of the knee marker for each participant and finding the point at which the marker was at its highest (Using CODAmotion V6.78.2 software, Charnwood Dynamics Ltd, Leicestershire, UK). As each participant completed more than one stride, an average was taken for all peak knee heights during each trial. After this the mean and standard deviation were calculated, resulting in an average knee height for each participant. The means were then divided from each performer's body height for a normalised figure that was used to compare between performers.

Once each participant's average knee height had been found, their peak vertical ground reaction force was assessed. The CODAmotion V6.78.2 software (Charnwood Dynamics Ltd, Leicestershire, UK) was used to identify the peak vertical ground reaction force. The means and standard deviations were then found and these figures were then normalised to the athletes body weight, by multiplying their body mass by 9.81 (gravity), then dividing that figure from the mean peak vertical ground reaction force.

The final variable to work out was each athlete's sprint velocity. For this to be calculated, stride length and stride frequency needed to be identified using the CODAmotion V6.78.2 software (Charnwood Dynamics Ltd, Leicestershire, UK). For stride length, a method was adapted from the work published by Bezodis *et al.* (2007) that took into account the acceleration of the MTP marker to identify touchdown. A graph for the acceleration of the MTP marker was created and it was agreed that as the graph suddenly peaked, the highest point of the peak meant the athlete was in contact with the ground. Another graph was created (Marker displacement of the MTP marker) and at the same point in time as on the acceleration graph the position in millimetres was noted. This method was repeated for each of the major peaks on the acceleration graph and stride lengths were calculated from finding the differences between the positions of the marker that were noted down. Once the stride lengths had been calculated for each trial, an average stride length was found using the same format as the other variables. Each performer's stride frequency was calculated using the number of strides taken in the trial that was analysed and dividing that number by the time it took to take those strides. Means and standard deviations were found in the same manner as the other variables. The average stride length and average stride frequency for each participant were then multiplied together and the product was equal to the athlete’s average velocity over the three trials. Once all the variables had been calculated, a statistical regression test was employed using Microsoft Excel to investigate the relationships between variables and to test for significance. The tests looked into the relationships between; knee height and peak vertical ground reaction force, peak vertical ground reaction force and velocity, knee height and velocity, knee height and stride length and finally, stride length and velocity. The best performance from the study was determined by the athlete who achieved the greatest velocity during the trials.

CHAPTER 3

RESULTS

3.1-Main Findings:

The main findings from this study have shown that for the athletes used in the study, there was a significant relationship ($P<0.05$) between how high the athlete’s knee goes (Knee Height) in the leg cycle to how much force is produced in the forthcoming touchdown (Peak Force) (Fig. 3.a and b). Once the same data had been normalised (Fig. 3.b) to each athlete’s body height (BH) and body weight (BW), it showed that there was not a significant relationship ($P>0.05$) between knee height and peak force. It was also found that there were no significant relationships ($P>0.05$) between peak force and velocity (Fig. 3.c and d), and also between knee height and velocity (Fig. 5.a, b and c) for all the participants.

3.2-Knee Height vs Peak Force and Peak Force vs Velocity:

With reference to Fig. 3.(a), a significant relationship ($P<0.05$) was found between knee height and peak force. This showed that as knee height increased, peak force decreased. Although statistical there was found to be a relationship between the two variables, the regression test resulted in there being a weak association between knee height and peak force ($R^2 = 0.475$). It can clearly be seen that Athlete 1 produced the greatest peak vertical ground reaction forces for each of their trials, whilst producing the smallest knee heights for each trial (Fig. 3.a). Although for the majority of the trials Athlete 2 and Athlete 3 produced similar knee heights, there was a difference in the peak force produced (Fig. 3.a). This is also replicated in Table 2, where it shows that Athlete 1’s mean peak force was 3226 N ± 250 N. The table (Table 2.) also emulates the finding that on average Athletes 2 and 3 produced similar knee heights (0.71 m ± 0.01 m for both the participants), but there was a difference between peak forces (Athlete 2 = 2637 N ± 189 N, Athlete 3 = 2961 N ± 78 N). Once the values were normalised (Table 2.), there was seen to only be 1% of a body height between each of the athlete’s knee heights (Athlete 1 = 0.38 BH ± 0.01 BH, Athlete 2 = 0.38 BH ± 0.01 BH, Athlete 3 = 0.39 BH ± 0.01 BH). Whereas there was still a large difference between peak forces, with Athlete 1 producing the greatest mean force (4.70 BW ± 0.36 BW) and Athlete 2 producing the smallest mean force (3.36 BW ± 0.24 BW) (Table 2.).

It was also apparent from looking at the graphs (Fig. 3.c and d) and the table (Table 2.) that Athlete 1 produced the greatest velocity (mean velocity = 9.21 m/s ± 0.48 m/s) (Table 2.) and thus deemed to achieve the best performance out of the three participants. Athlete 2 produced the second quickest velocity (9.05 m/s ± 0.18 m/s) and Athlete 3 producing the slowest velocity (8.82 m/s ± 0.39 m/s) (Table 2.). Athlete 1 created their velocity by producing a greater mean stride frequency figure compared to the other athletes (Athlete 1 = 2.53 Hz ± 0.11 Hz, Athlete 2 = 2.13 Hz ± 0.04 Hz, Athlete 3 = 2.14 Hz ± 0.13 Hz). Athlete 2 and Athlete 3 produced similar stride frequencies but their differences in sprint velocity came from their differences in stride length (Athlete 2 = 4.25 m ± 0.14 m, Athlete 3 = 4.12 m ± 0.08 m), which allowed for Athlete 2 to create the quicker velocity out of the two athletes. As it was stated earlier, there was no significant relationship (P>0.05) found between peak force and velocity (Fig. 3.c and d).

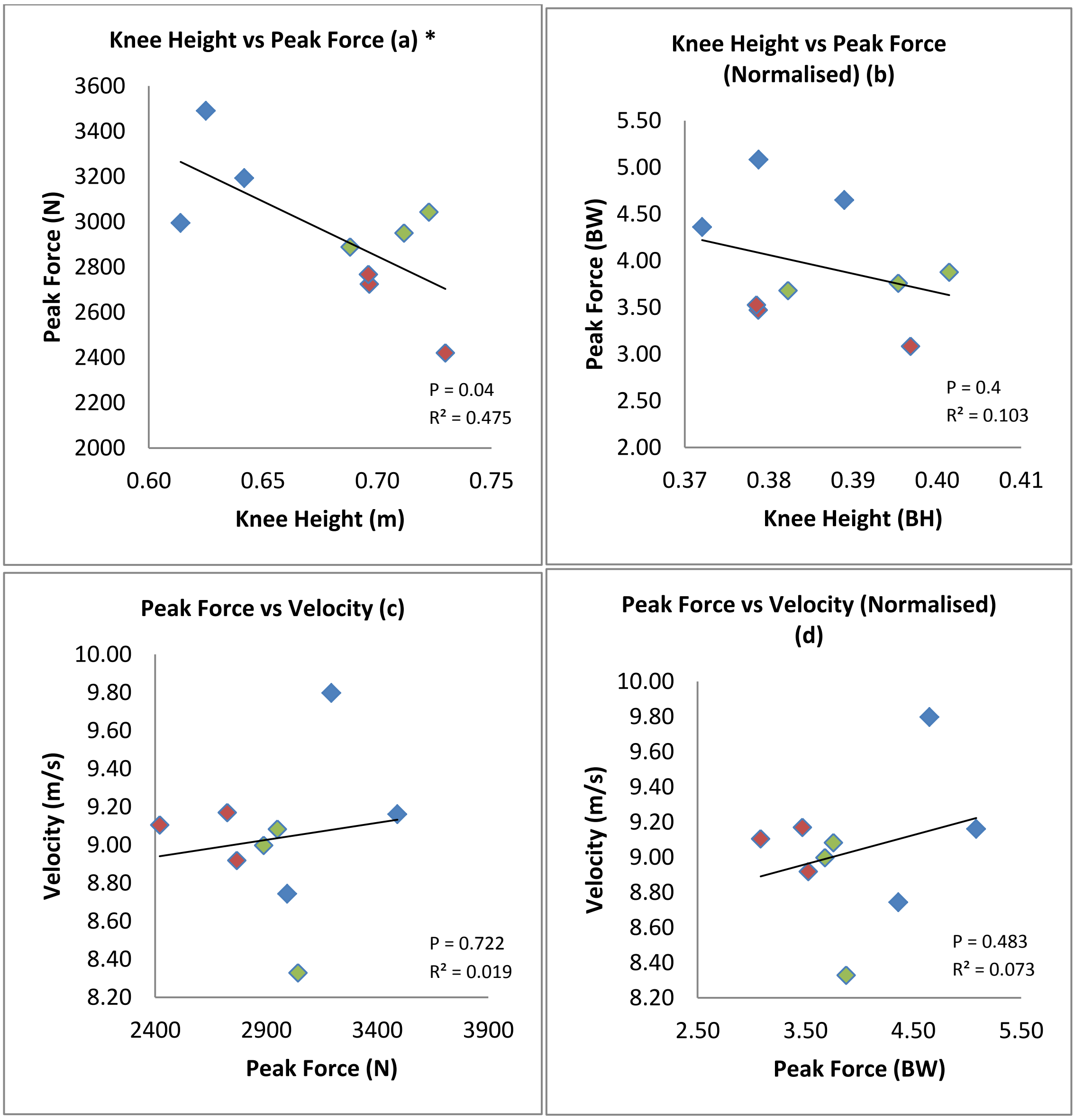

Fig. 3.(a, b, c and d). Data vs Normalised Data for two set of graphs, including P and R² values. Knee Height vs Peak Vertical Ground Reaction Force (Peak Force) and Peak Force vs Velocity. Blue markers = Athlete 1, Red markers = Athlete 2 and Green markers = Athlete 3. * = Significant relationship (P<0.05).

Table 2. Means and Standard Deviations of the key variables analysed.

	Stride Length (m)	Stride Frequency (Hz)	Velocity (m/s)	Knee Height (m)	Knee Height (BH)	Peak Force (N)	Peak Force (BW)
Athlete 1	3.64 ± 0.10	2.53 ± 0.11	9.21 ± 0.48	0.63 ± 0.02	0.38 ± 0.01	3226 ± 250	4.70 ± 0.36
Athlete 2	4.25 ± 0.14	2.13 ± 0.04	9.05 ± 0.18	0.71 ± 0.01	0.38 ± 0.01	2637 ± 189	3.36 ± 0.24
Athlete 3	4.12 ± 0.08	2.14 ± 0.13	8.82 ± 0.39	0.71 ± 0.01	0.39 ± 0.01	2961 ± 78	3.77 ± 0.10

3.3-Knee Height vs Stride Length:

Another part of the study was looking at knee height and stride length. For two of the participants (Athlete 2 and Athlete 3) a significant relationship was discovered ($P<0.05$) between the two variables, with Athlete 3 demonstrating more of a relationship than Athlete 2 (Athlete 3, $P = 0.032$ and Athlete 2, $P = 0.049$). Of these two performers, both showed that there was a positive correlation ($R>0.8$) between the max height of their knee in the leg cycle and the length of the stride (Fig. 4.b and c), which meant as knee height increased so did stride length. A high value of the relationship between the variables was also shown to be explainable ($R^2>0.65$) for both of the athlete’s and showed that there was a strong linear association between knee height and stride length. With regards to Athlete 1, they showed no significant relationship between the variables ($P>0.05$) (Fig. 4.a). As seen in Table 2, Athlete 2 produced the largest mean stride length (4.25 m ± 0.14 m) and Athlete 1 produced the smallest mean stride length (3.64 m ± 0.10 m). What’s key is that Athlete 2 had a larger mean stride than Athlete 3 by over 10 centimetres (Athlete 3 = 4.12 m ± 0.08 m), but it was identified in Table 1 that at the time of testing they were both measured and found to be similar heights (1.80 m).

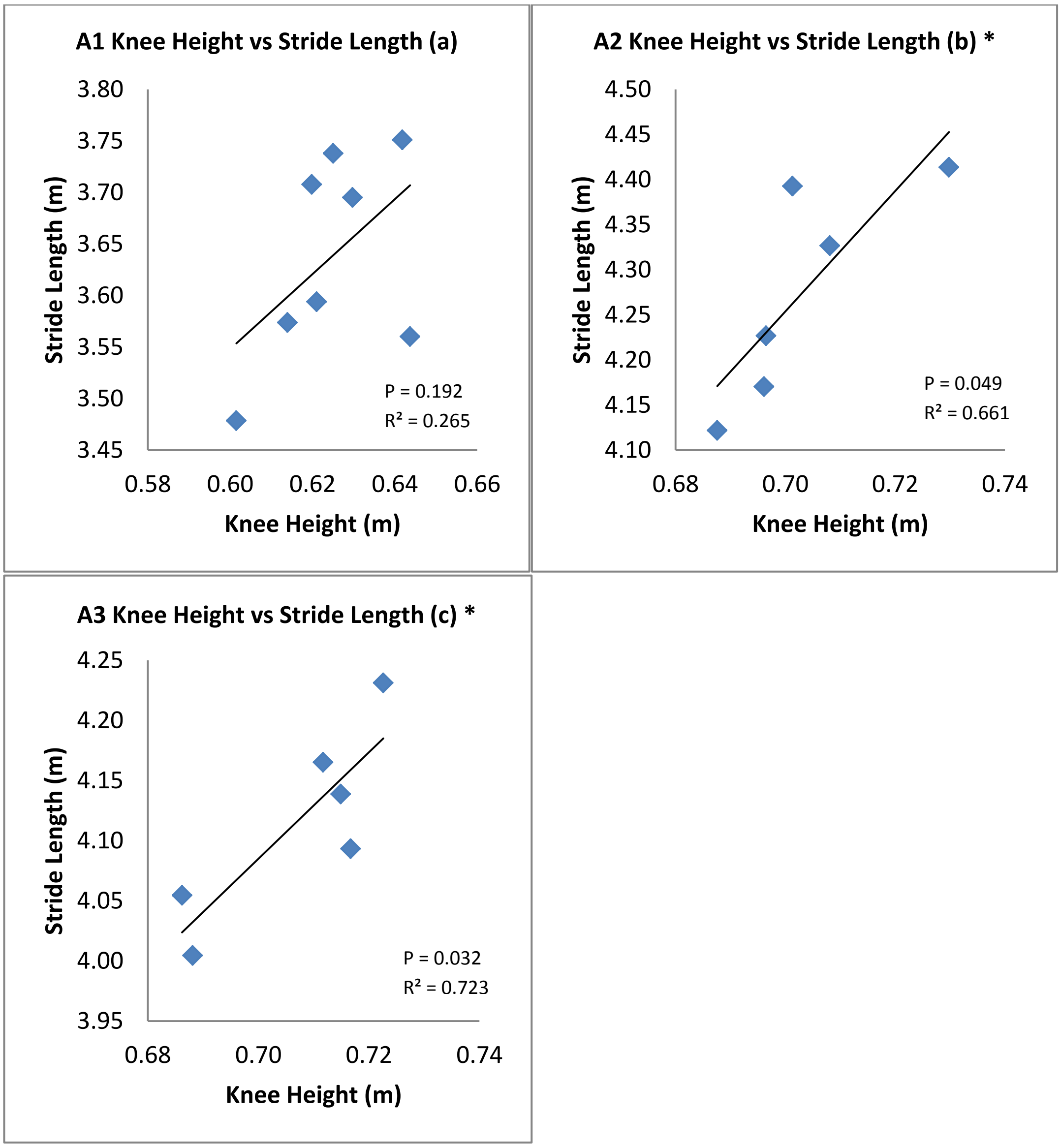

Fig. 4.(a, b and c). Each athlete's Knee Height vs Stride Length graphs, including P and R^2 values. * = Significant relationship ($P<0.05$).

3.4-Knee Height vs Velocity:

As two of the three participants experienced a significant relationship between knee height and stride length, the next part of the study was to see if either variable had an influence on velocity. As seen in Fig. 5.(a, b and c), the first of those was to see if there was a relationship between knee height and velocity. The entire sample showed no significant relationships ($P>0.05$) between knee height and velocity. Athlete 1 created their fastest velocity (9.87 m/s) when adopting a higher knee height (0.64 m) but they also created their slowest velocity (8.61 m/s) when they used a similar knee lift (0.64 m) (Fig. 5.a). As for Athlete 2, they created their quickest velocity (9.35 m/s) when they did not produce their highest knee lift (0.7 m) but they did however produce their slowest velocity

(8.93 m/s) when they used their smallest knee height (0.69 m) (Fig. 5.b). Athlete 3 was at their fastest (9.2 m/s) when they adopted a similar knee height to Athlete 2 (0.71 m) and a similar thing that occurred with Athlete 1, Athlete 3 was at their slowest (8.24 m/s) when they were using a similar knee height to their fastest trial (0.71 m).

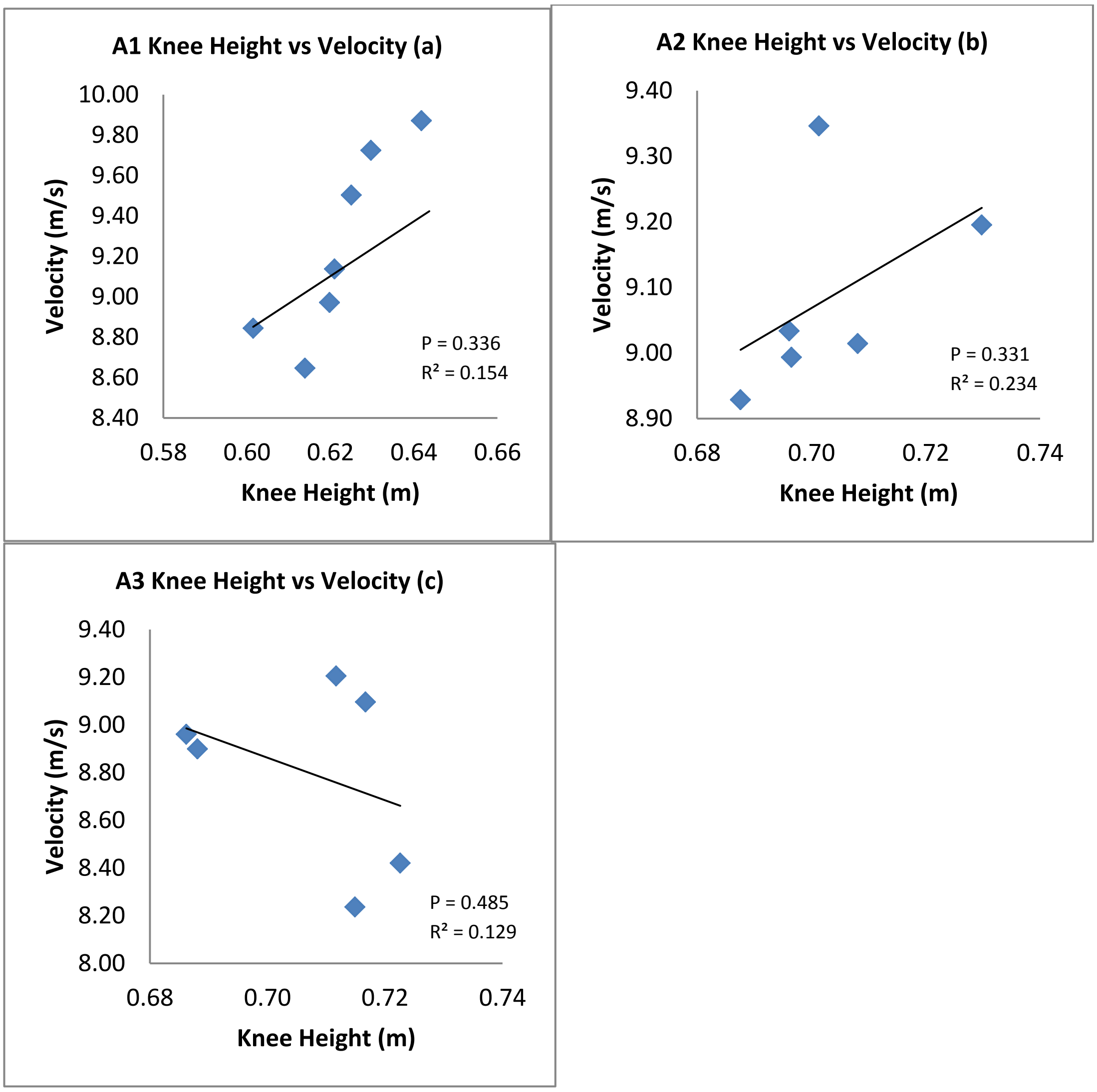

Fig. 5.(a, b and c). Each athlete's Knee Height vs Velocity graphs, including P and R^2 values.

3.5-Stride Length vs Velocity:

The final variables analysed were stride length and velocity for each of the athlete's (Fig. 6.a, b and c). The findings showed that for two of the performers (Athlete's 1 and 2), there was a significant relationship ($P<0.05$) between stride length and velocity (Fig. 6.a and b) with Athlete 1 demonstrating a better relationship ($P = 0.023$) than Athlete 2 ($P = 0.049$). This was also confirmed by both of the athlete's demonstrating a positive correlation ($R>0.8$), meaning as stride length increased as did sprint velocity. There also was a high linear association between the two variables (stride length and velocity) for Athlete's 1 and 2 ($R^2>0.6$). As for Athlete 3 (Fig. 6.c), they did not show any significance relationship between stride length and velocity. It can be seen in Fig. 6.(a) that Athlete 1 produced their longest stride length (3.75 m) when they were travelling at their fastest velocity (9.87 m/s). Athlete 2 produced their fastest velocity (9.35 m/s) when they used their second longest stride length (4.39 m) which was only a couple of centimetres shorter than their longest stride length (4.41 m). Although there was only a small margin between their longest and second longest stride length, Athlete 2 did show that there was a noticeable difference between the velocity they were travelling (9.35 m/s) when they used their second longest stride length (4.39 m), compared to the velocity they ran at (9.20 m/s) when they used their longest stride length (4.41 m). Athlete 3 also travelled at their fastest velocity (9.2 m/s) when using their second longest stride length (4.17 m). What is interesting is from looking at the different variables that have an effect on velocity, Athlete 2 was the only participant to show a significant relationship and positive correlation for both knee height against stride length and stride length against velocity.

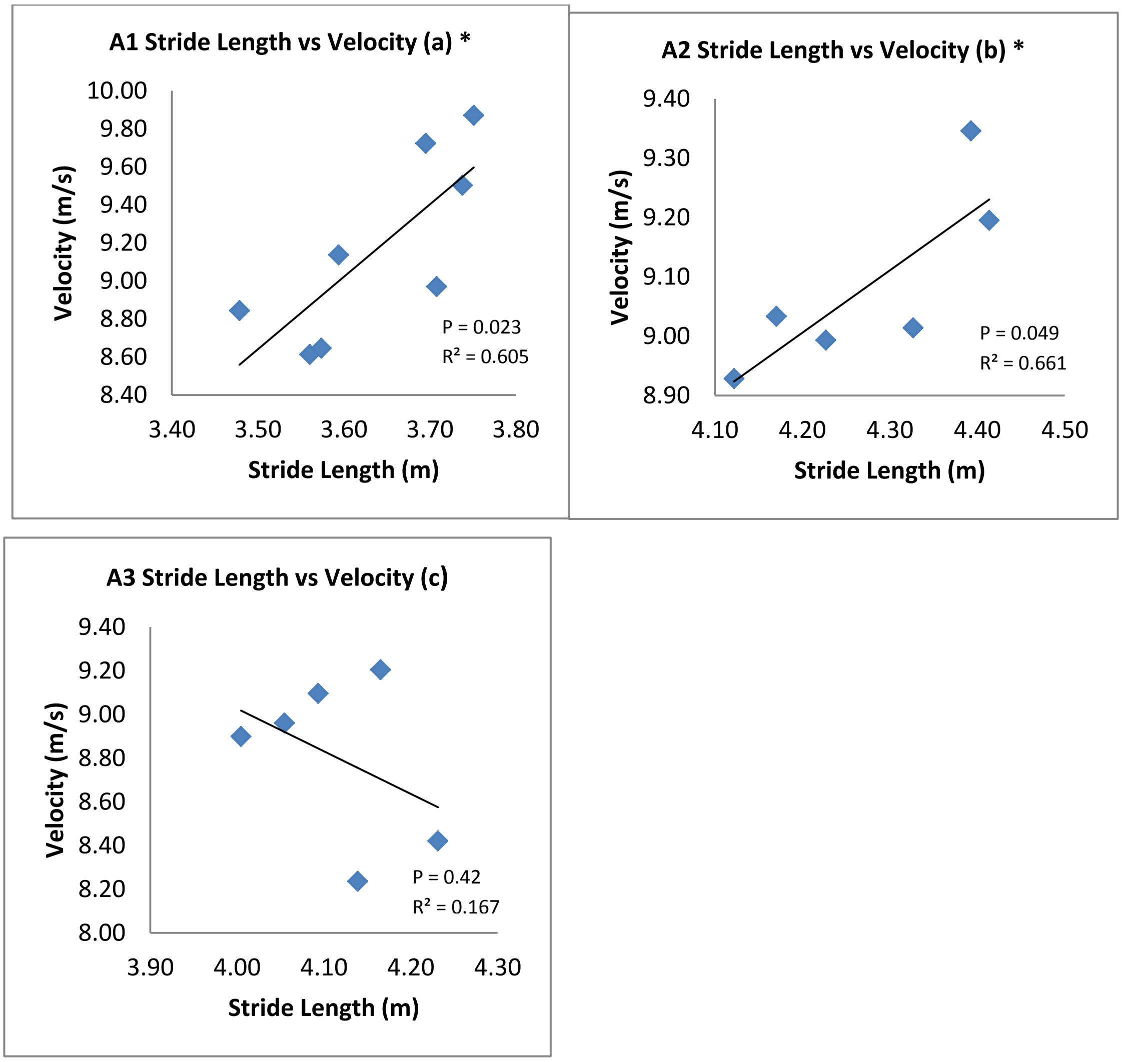

Fig. 6.(a, b and c). Each athlete's Stride Length vs Velocity graphs, including P and R^2 values. * = Significant relationship ($P<0.05$).

CHAPTER 4

DISCUSSION & CONCLUSION

The aims of the study were, firstly look at the influence of knee height during the leg cycle and peak vertical ground reaction force at the forthcoming stance phase of the same leg. Secondly, to look into the works of Weyand *et al.* (2000) with regards to the relationship between ground reaction forces and maximal velocity. Thirdly, to see if the findings from Deshon and Nelson (1964) and Sinning and Forsyth (1970) had the same effect on sprint athletes that it had on distance runners. Fourthly, to revisit the suggestions made by Fenn (1930) and Fred and Ecker (1962), that faster athletes tend to have a higher knee height and a longer step length. Then finally, to see if there was any relationship found between stride length and velocity, referring to the results from Mero and Komi (1985) and Gajer *et al.* (1999).

4.1-Main Finding:

The main finding from the study was that there failed to be a significant relationship (P>0.05) between knee height and peak vertical ground reaction force produced once the data had been normalised. To the authors knowledge exploring the relationship between these two variables had not been considered up to the start of data collection. It is an area that could be of interest to coaches and athletes as there has been literature linking peak vertical ground reaction force to velocity as well as knee height to velocity. What the finding shows is that although both may have an effect on an athlete’s velocity, they do not have an effect on one another. The perfect example from the study came from Athlete 1, who had a similar normalised mean knee height to the other two athlete’s (0.38 BH ± 0.01 BH), but created a normalised mean peak vertical ground reaction force much higher than the others (4.70 BW ± 0.36 BW) (Table 2.).

4.2-Aims of the Study:

There was found to be no significant relationship (P>0.05) between peak vertical ground reaction force and maximal velocity amongst all the athlete’s. What is apparent and can be seen in Fig. 3.(c and d), is that Athlete 1 ran their fastest velocity (9.80 m/s) when they produced a large force (3193 N, 4.65 BW). They also ran the third quickest velocity out of the three athletes (9.16 m/s) when they produced their greatest peak vertical ground reaction force (3491 N, 5.08 BW) (Fig. 3.c and d). As no significant relationship (P>0.05) was discovered, the study has to partly disagree with suggestions made by Weyand *et al.* (2000) that as velocity increases so does ground reaction forces. The study only partly disagreed with the findings from Weyand *et al.* (2000) as Athlete 1 did show that the quicker athlete’s tend to produce more force into the ground. Although, Athlete 2 was the second quickest out of the three athletes (9.05 m/s ± 0.18 m/s), they produced the smallest peak vertical ground reaction force (2637 N ± 189 N, 3.36 BW ± 0.24) compared to the others (Table 2.). What can be taken from the current study is that the findings from Weyand *et al.* (2000) may have to be viewed with caution as some athletes may produce higher ground reaction forces to increase velocity, whereas other athletes may depend on other variables to increase their velocity.

The third part of the study looked at the relationship between knee height and maximal velocity. There was found to be no significant relationship between the two variables (P>0.05) for all the three athlete’s involved. This finding fails to agree with the statements made by both Deshon and Nelson (1964) and Sinning and Forsyth (1970), who found that as velocity increased in their athletes so did their knee height. The finding showed that this relationship does not have the same effect on sprint athletes that it had on distance runners. This may have been because the current study was only looking at the maximal velocity phase of the sprint, and there wasn’t much variation amongst the velocities that the performers ran at (Athlete 1 = 9.21 m/s ± 0.48 m/s, Athlete 2 = 9.05 m/s ± 0.18 m/s, Athlete 3 = 8.82 m/s ± 0.39 m/s) (Table 2.), which differs with the way the Sinning and Forsyth (1970) study took fold. In the Sinning and Forsyth (1970) study, the athletes ran on a treadmill at different velocities and the authors studied the change in mechanics of the athletes.

As there was no obvious relationship between knee height and velocity, knee height was then matched up against stride length to see if there was any relationship between the two. Of all the participants tested, two showed that there was a significant relationship (P<0.05) between the height of their knee and the length of their stride (Athlete 2 and 3). It can clearly be seen in Fig. 4.(b and c) that the athletes showed a strong correlation between the variables, with both their smallest knee heights (Athlete 2 = 0.69 m, Athlete 3 = 0.69 m) causing the athletes to produce their smallest stride lengths (Athlete 2 = 4.12 m, Athlete 3 = 4.00 m). The increase between the two variables (Knee Height and Stride Length) carried on with the athletes producing their longest stride lengths (Athlete 2 = 4.41 m, Athlete 3 = 4.23 m) when they adopted their highest knee height (Athlete 2 = 0.73 m, Athlete 3 = 0.72 m). This finding agrees with statements made by Fenn (1930) and Fred and Ecker (1962) that to produce the optimal stride length the athlete is going to have to lift their knee high in the latter stage of the swing phase. What is interesting is that the athletes showed a large difference between their smallest stride lengths recorded and their greatest stride lengths recorded, by only increasing their knee heights by a few centimetres. As all of the performers did not express this relationship the finding has to be viewed with caution, and cannot be generalised for a whole population.

Once it was clear that for some of the performers there was a relationship between knee height and stride length, the final aim was to look into the relationship between stride length and velocity. Two of the participants (Athlete 1 and 2) demonstrated a significant relationship ($P<0.05$) between their stride length and their velocity. This is partly in agreement with the findings from Mero and Komi (1985), Gajer *et al.* (1999) and Hunter *et al.* (2004) that all suggested stride length is an important factor in sprint velocity. It can be seen in Fig. 6.(a and b) that Athlete's 1 and 2 showed a strong correlation between the variables, with Athlete 1 producing their fastest velocity (9.87 m/s) when they were applying a longer stride length (3.75 m). Athlete 2 on the other hand produced their quickest velocity (9.35 m/s) when they demonstrated their second longest stride length (4.39 m), although it was only a couple of centimetres shorter than their longest stride length (4.41 m). As the present study did not look into stride frequency it cannot be stated that stride length is the most important factor in sprint velocity but it does show that there is a relationship. This finding can suggest that coaches and athletes may need to make time for improving stride length and to make it a focus within their sessions. Athletes can be advised to take part in joint flexibility exercises to improve their stride length (Salo *et al.,* 2011). There was only one athlete (Athlete 2) in the sample that showed a significant relationship between their knee height and stride length and also stride length and velocity. Although statistically there was not a significant relationship found between knee height and velocity, Athlete 2 shows that there could be some truth within the findings of Deshon and Nelson (1964) and Sinning and Forsyth (1970) who suggested that as they increased the velocity the athlete's ran at, they demonstrated an increase in knee height. More recently Exell (2010) analysed sprint athletes during the maximal velocity phase. He looked at knee height amongst other variables, and it was found that the quicker athlete's possessed higher knee heights and longer step lengths than the other participants.

4.3-Limitations and Future Research:

Although the current study revealed some interesting results, there were a number of limitations that need to be addressed that could have made for a better study. There was a small sample size (three participants) used, which has hindered the validity of the results found. Also due to lack of availability of designated areas, data collection was made a lot shorter than anticipated which resulted in the participants having limited trials. This has decreased the reliability of the results, as only three successful trials were recorded for each participant. As stated earlier the current study did not look into relationships between stride frequency and other variables, this was mainly because there was not enough stride frequencies recorded due to the low number of trials per athlete to produce a reliable test.

Going forward within the same area, future research may want to further look into the influence the height of the knee has on different running velocities to see if there is a more conclusive relationship between knee height and running velocity. Another area that could be of interest is the influence of vertical and horizontal ground reaction forces and the effects they have on stride lengths and stride frequencies. This would link in nicely with suggestions made by Salo *et al.* (2011) that athletes who are step length reliant should take part in exercises that improve ground reaction forces. It would also be interesting to compare the variables analysed from the amateur athletes that have been used in the current study to elite performers to see if there are relationships between the variables discussed in the study at the top level. The answers to these future directions of study would open doors for new information for coaches and athletes to prepare better for sprint competitions, with either different types of training methods or key points to focus on when trying to maximise sprint performance being uncovered.

4.4-Conclusion:

The most significant finding from the study was that there was a significant relationship for two athletes, between knee height and stride length and also stride length and running velocity but there failed to be a significant relationship between knee height and velocity. Suggestions can be made that knee height and peak vertical ground reaction force do not have a linear association with maximal sprint velocity but could have an effect on other variables such as stride length and stride frequency that have been noted to have relationships with sprint velocity. These findings could be used by athletes or coaches to try and improve sprint technique. Athletes would not need to focus on applying vertical ground reaction force to try and improve their maximal velocity phase of the sprint but would be advised to focus on improving their stride length. A type of exercise that would improve stride length is joint flexibility exercises (Salo *et al.,* 2011), and it can be proposed that these types of exercises make their way into a sprint athletes training regime. Further directions for this area of research would need to look into the relationships between knee height and different running velocities to see if there is a more conclusive relationship.

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APPENDICES

APPENDIX A: ETHICS STATUS

Name of applicant:	Luke Gareth Kinsey
Supervisor (if student project):	Ian Bezodis
School:	School of Sport
Student number (if applicable):	St20004699
Programme enrolled on (if applicable):	HND Sports Development and Sports Coaching
Project Title:	What is the relationship between knee height in the leg cycle and force production during the stance phase whilst running at maximal velocity.
Expected Start Date:	23/09/2013
Approximate Duration:	1 year
Funding Body (if applicable):	None
Other researcher(s) working on the project:	None
Will the study involve NHS patients or staff?	No
Will the study involve taking samples of human origin from participants?	Yes

In no more than 150 words, give a non technical summary of the project
The project is going to look at the relationship between, how much force a sprinter puts onto the ground relative to how high that same legs knee lifts during the swinging phase of the leg during a maximal effort sprint. This is an area that has not been well researched and the findings could influence different training for athletes. For example if the study shows there is a positive relationship between ground reaction force and knee height then coaches may want to try and increase their athletes strength and power to increase the force they can produce onto the ground meaning a higher knee lift.

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: Luke Kinsey	Date: 26/04/2013
FOR STUDENT PROJECTS ONLY	
Name of supervisor: Ian Bezodis	Date: 29/04/2013
Signature of supervisor: Ian Bezodis	

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	
The research will follow a quantitative design. The method of data collection will be done by testing the athletes while they complete maximal effort sprints, each participant will complete five maximal sprint efforts (around 40 metres). The athletes will have markers on their Ankle, Knee, Hip and shoulder. The reason the markers will be placed in the areas so the kinematic data can be collected from looking at the angles created between the markers. The kinetic data will be collected from a force plate that will be placed under the Mondo track, the participants will need to step onto the force plate during their trials for the data to be collected. With the nature of study focusing on sprinting, only participants who are training as sprinters will be used and they will be recruited from the athletics union at Cardiff Metropolitan University. The study is needed as this area hasn't been looked at in great depth and it is an important to look at this relationship as it will give coaches a good insight in to how they can condition their athletes better. The study will take place in the N.I.A.C and each session will take an hour maximum. The participants will	

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[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

only need to attend one session, dates and times will be given to the participants once the term has started. To analyse the data the computer programme SPSS will be used to see if there a relationship between the two attributes that will be looked at.

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?

The previous experience I have gained is from my second year Biomechanics module, where we have dealt with CODAmotion and also force plates. For my coursework in this module I used a force plate to gain kinetic data from a performer complete a series of drop landings in shoes and bare feet onto different types of surfaces. Also within the lab practical's for the module data was collected and then analysed using CODAmotion.

B2 **Student project only**

What previous experience of research involving human participants relevant to this project does your supervisor have?

Click here to enter text.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.

C POTENTIAL RISKS

C1 What potential risks do you foresee?

The athletes could gain an injury while performing the sprints.
The athletes may not want their details to go out into the public domain.
The equipment needed for the study may not be working.

C2 How will you deal with the potential risks?

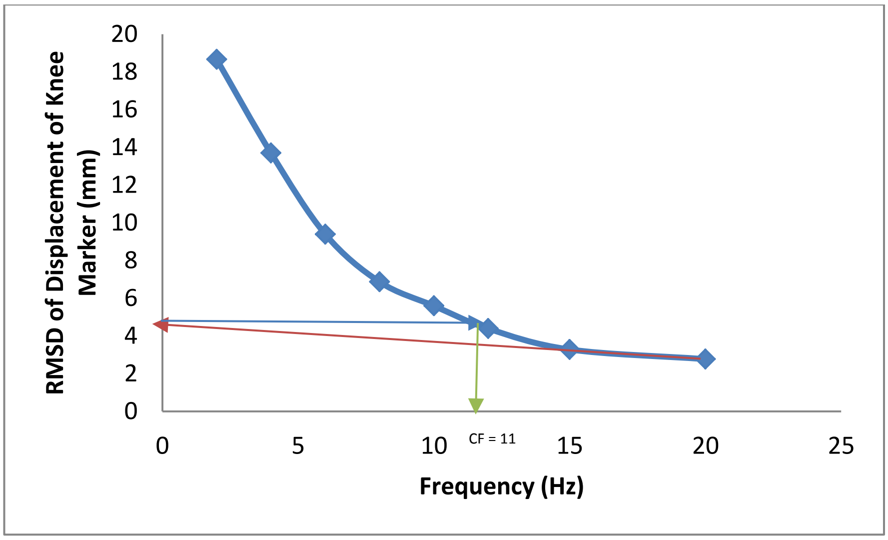
The athletes will complete a thorough warm-up that would have been taken from a leading sprinting coach or a leading sprinting document. The athletes used will be performers that have not suffered from a major injury within the last year.
The identities of the participants will stay strictly confidential.
With regards to the equipment, if it stops working the participant will be asked to return on another session to complete their trials.

APPENDIX B: RESIDUAL ANALYSIS

The table below shows the root mean squared difference results of the knee marker at various frequencies.

Frequency (Hz)	2	4	6	8	10	12	15	20
RMSD Knee	18.66	13.70	9.39	6.87	5.59	4.39	3.28	2.77

The graph below shows the residual analysis method of calculating the optimal cut off frequency. The result came out at 11 Hz (green arrow).



APPENDIX C: REGRESSION TEST VALUES

The table below shows the results from the regression tests, to test for significance. R value demonstrated the strength of the correlation (-1,1), R^2 showed the linear association between x and y (0,1) and P showed the relationship between x and y (significant relationship = $P<0.05$ and no significant relationship = $P>0.05$).

	R value	R^2 value	P value
Knee Height vs Peak Force	0.689	0.475	0.040
Knee Height vs Peak Force (normalised)	0.321	0.103	0.400
Peak Force vs Velocity	0.139	0.019	0.722
Peak Force vs Velocity (normalised)	0.269	0.073	0.483
Athlete 1, Knee Height vs Stride Length	0.515	0.265	0.192
Athlete 2, Knee Height vs Stride Length	0.813	0.661	0.049
Athlete 3, Knee Height vs Stride Length	0.850	0.723	0.032
Athlete 1, Knee Height vs Velocity	0.392	0.154	0.336
Athlete 2, Knee Height vs Velocity	0.484	0.234	0.331
Athlete 3, Knee Height vs Velocity	0.359	0.129	0.485
Athlete 1, Stride Length vs Velocity	0.778	0.605	0.023
Athlete 2, Stride Length vs Velocity	0.813	0.661	0.049
Athlete 3, Stride Length vs Velocity	0.409	0.167	0.420

APPENDIX D: PARTICIPANT INFORMATION SHEET & PARTICIPANT CONSENT FORM

PARTICIPANT INFORMATION SHEET

Project title: What is the relationship between knee height in the leg cycle and force production during the stance phase whilst running at maximal velocity?

It has to be made clear that all participants for this study are strictly volunteers and that you have agreed to take part in this study.

The aims for this project is to look at the relationship between how high your knee lifts in the latter stages of your sprint running leg cycle and how much force is produced during the stance phase. The benefits that can come from this study is to show how athletes could change their conditioning to maybe try and improve the amount of force an athlete puts onto the ground. It may also give an athlete an insight into other areas they could improve such as flexibility to improve their knee height.

If you wish to take part in this study, will only need to attend one of sessions unless some of your sprint trials are not to the standard that is required, where you will asked to attend another session. The sessions will last for around an hour, and you will be tested during a maximal effort sprint, which will be around 40 metres, you will complete five sprint trials. Within the trials five markers will be placed on one side of you, one on your shoulder, hip, knee and ankle. During your sprint trial you will need to try and make sure that you step onto the force plate which will collect your ground reaction forces during you sprint. After you have hit the force plate the CODAmotion scanner will detect the markers that have been placed on you and will collect the kinematic data needed for the study.

With sprinting being the main focus of this project being on sprinting, you will only be able to take part in the study if you are currently a trained sprinter or sprinting is a main part of your sport, for example if you’re a winger in rugby or a wide player in football.

There should not be able risks within this study, but with the trials be at maximal effort there could be a chance that you could get injured during the session. The way to overcome or reduce this risk is to complete a good warm up before the trials and to complete a good cool down after the trials have been completed.

Early on in this form there were benefits that could come from this study. The results can have a major effect on how you or your coach could condition you in the future. For example if the study shows there is a positive relationship between the amount of force you produce onto the ground to how high your knee reaches during your leg cycle then you may want to try and develop your power and strength so that you can then create more force into the ground and then your knee should be able to lift higher.

If you do wish to take part in this study then you do not need to worry about your personal details going out into the public domain. Your details will be kept strictly confidential but your results might get published into the public but they will never be able to get traced back to you.

If you wish to ask any questions that have not be answered in the information above then do not hesitate to contact myself.
Luke Kinsey (Researcher): lukekinsey@yahoo.co.uk.

PARTICIPANT CONSENT FORM

Reference number:
Participant name:
Title of project:
Name of researcher:

Participant to complete this section: Please signature each box.

1)I confirm that I have read and understand the information for the study. I have been able to talk to the researcher about the study and all the necessary questions have been answered. ☐

2)I understand that my participation in this study is strictly voluntary and I can withdraw from the study at any time. ☐

3)I agree to take part in the study. ☐

4)I also understand that the results from this study will be used and could possibly be published, your personal details will be kept strictly confidential. ☐

Signature of participant: Date:

Signature of researcher: Date: