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AFFSECT COUPLING IN THE LOWER EXTREMITY JOINTS HAS ON THE CONSISTANCY OF THE STEP CHARACTERISTICS IN THE EARLY ACCELERATION PHASE OF THE SPRINT RUNNING
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Acknowledgements

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Abstract

Purposes: This study was conducted to develop the understanding of the influence variability in the coordination between the lower extremity joints in the support leg have on the consistency of the step characteristics in the early accelerating phase of sprint running.

Methods: Five well-trained male sprinters performed eight maximal effort sprints over 10 meters. The kinematic data for the first three steps of the sprint where captured using automatic motion analysis system CODA CX1. Step velocity, step length and step frequency where found for each subject. The coefficient of variation in step velocity, step length and step frequency was found for each subject. The variability in the continuous joint angle profile differences in the lower extremity where found to show the joint coupling and plotted against the variability in the step characteristics using a linear correlation and regression graphs to test for a linear relationship.

Results: The variability in the coupling of the ankle – knee had a strong positive correlation $r = 0.91$ with step frequency variability and $r = 0.49$ with step velocity variability. The variability in the coupling of the ankle – hip was shown to have a strong positive correlation $r = 0.79$ with step frequency variability, step length variability $r = 0.68$ and step velocity variability $r = 0.94$. Indicating these couplings are indicative of the consistency of the step characteristics.

Conclusion: The ankle joint was found to have a significant role in enabling consistent performance in the step characteristics by coordinating its movement with the knee and the hip joint.
CHAPTER I

INTRODUCTION
1.0 Introduction

1.1 Variability in sprinting

Variability is inherent within all human movement (Newell et al., 2006). This is apparent in the fact that it is impossible for a person to repeat the exact same movement. However in sprint running as with many sports low outcome variability (step velocity) is indicative of greater skill learning and outcome performance. Bradshaw et al., (2007) stated that high outcome movement consistency of the step is viewed as beneficial to performance and increased ability in sprint running because it determines our ability to perform intentional modulations of the stride. This importance of consistency in the step is a reflection of the aim in sprint running, which is to repeat the optimum step velocity for each step of the sprint. Hunter et al., (2004) has implied that repeatability of the step velocity indicates greater optimisation of the step length, step frequency relationship. Danion et al., (2003) found that stride frequency and length are two fundamental parameter determining the variability of the stride. These findings suggest that repeatability of the step velocity indicates greater optimisation of the step length, step frequency relationship. An increase in either step length or step frequency will result in an increase in step velocity as long as the other factor does not undergo a proportionate or greater decrease (Hunter et al., 2004). This relationship between step length and step frequency is flexible allowing for adaptations to performance constraints, meaning that if the step length is decreased, step frequency could be increased to allow a consistent outcome of the step velocity. (Hunter et al., 2004) has indicated this flexible relationship between the two indicating that in the acceleration phase of the sprint step length produces the majority of the step velocity, while in the maximal velocity phase of the sprint step frequency has the biggest affect on step velocity. This indicates that in the early acceleration phase of the sprint the variability in the step length will have the biggest affect on the step velocity.

The first three steps of the sprint start (early acceleration phase) has been shown to have the highest levels of intra-subject variability in the step characteristics (Thomson et al., 2007). This is largely down to the fact that this is the area of the race there is the greatest change in vertical velocity, indicating changes in the step velocity. Thomson et al., (2007) found a higher coefficient of variation in both step length and step frequency within the first three steps, with the variability decreasing as the athlete progressed from the start. This would
suggest that the early acceleration phase of the sprint would see the greatest improvement due to increased movement co-ordination, enabling increased consistency of the step length, step frequency and overall consistency in the step velocity.

### 1.2 Coordination between joints

Joint variability has been shown to produce a flexible coping strategy allowing increased coordination between the joints (Hamill et al., 1999). The joints are able to offer a flexible coping strategy to movement constraints as the hip joint increase its movement the knee would also adjust its movement to allow for the correct coordination sequence between the two (Bradshaw et al., 2007). This flexibility in the joints allows for increased coordination of the movement. Haddad et al., (2006) researched the adaptations both within segment coordination (intralimb) and between segment coordination (interlimb) to asymmetric loading. This study found that adaptation changes in interlimb coordination were greater than the changes observed in intralimb coordination; this suggests that it is the interlimb coordination that is high in variability to allow for flexible coping strategies. This is in agreement with Whitall and Caldwell., (1992) which found that intralimb coordination is more stable than interlimb coordination, indicating that the interlimb coordination is adaptable to overcome constraints imposed on it. These findings indicate that the coupling between intralimb joints should remain constant to allow for increased consistency of the outcome. Bradshaw et al., (2007) found that while the biological movement variability associated with the sprint start was generally low, the joint rotation measures were high, alluding to a flexible movement coordination strategy. This shows how the variability at the joints is important in increasing movement coordination.

In sprinting it is essential that the joints are able to have variability and have a flexible range of motion to enable stability and control. Butler et al., (2003) found that as greater forces are imparted on the body, greater resistance to move in the joints is needed in order to produce controlled movements. In sprinting Stefanyshyn and Nigg., (1998) have found significant increases in the ankle joint stiffness with increases in running speed. This may suggest that as the joints which produce the movement increase their range of motion the ankle joint decreases it movement. This is an example of joint coupling in sprinting.
1.3 Rational for study

While it is apparent that joint coordination is needed in sprint running, it is still largely unclear how these certain joint coordination’s affect the step characteristics. The aim of this present study will be to investigate the role that coordination between lower extremity joints has on the consistency of the step characteristics.
CHAPTER III

METHODOLOGY
3.0 Methods

3.1 Introduction

The performance outcome variability that will be discussed involves finding the coefficient of variation in step length, step frequency and step velocity for each subject. A step was defined as touchdown to next touchdown of the opposite foot. The continuous joint angle profile differences were taken from the stance phase of the step which was defined from touchdown to takeoff of the same foot. The difference between the continuous joint angle profiles of the ankle – knee, ankle – hip and knee – hip where found using root mean square difference (RMSD). This difference between these continuous joint angles where then analysed to see if they had any correlation with the variability in the performance outcome variability.

3.2 Participants

The study was given ethical approval. Every participant that took part in the study signed an informed consent indicating that they knew what to expect from the study and that their data and any images or video collected of them during the data collection could be used in the study. This study used 5 male sprinters (mean ± S.D: Body mass = 83 kg ± 11.2 kg height = 1.81 m ± 0.10 m), all the athletes are members of the university sprint team at the University of Wales Institute Cardiff. These sprinters where all at a sub-elite level and aged between 18 and 25. All athletes where currently injury free at time of data collection, as it was made clear in the consent form that the athlete had to be injury free to participate in the data collection. The reason for using male sub-elite performers aged between 18 and 25, that where injury free was to reduce the amount of between subject variability.

3.3 Protocol

Each participant was informed that they were required to complete eight, ten meter sprints accelerating maximally from a block start. There was plenty of rest between each trial to ensure that there was no fatigue affect that would influence the data. Markers where required to be on the athlete while they performed the sprints, so CODA could collect the necessary movements of the performance, the athletes was informed that they should wear shorts and a vest or tight fitting under top. The estimated time involved with each athlete was about an hour, this involved placing markers on the subject and running the subject through 8 trials.
The athlete was informed in the consent form and verbally before data collection that they were free to drop out at any point.

3.4 Data collection

The data collection took place at the National Indoor Athletics Centre at the University of Wales Institute Cardiff. Kinematic data was collected during the first three steps of the sprint (early acceleration phase) at a frequency of 400 Hz using the automatic analysis system CODA CX1. Four CODA CX1 systems where set up, two either side of the 10 meter running lane to capture the early acceleration phase of the sprint as illustrated in Figure 3. The set up will allow the first 3 steps from the starting blocks to be captured (2 from one foot and 1 from the other foot). From the diagram in Figure 3 you can see that the CODA systems where situated 3.17 meters from the centre of the lane and 4 meters from each other to make sure that the filed of view of each system overlapped and the signal from the markers where able to be clearly picked up by the CODA CX1 systems for the whole of the early acceleration phase of the sprint. There was approximately 7.5 meters field of view with 6 meters of the early acceleration phase after the block start being captured. Video of the subjects was also collected using standard two-dimensional videographey (60Hz).

Figure 3: Set up of the CODA CX1 units during data collection
Figure 4 shows that the CODA CX1 markers were situated on the outside of both sides of the body at the metatarsal phalanges of the second toe and little toe, ankle joint, knee joint, hip joint, wrist joint, elbow joint and shoulder joint on the right and left side of the body. This was repeated for each subject.

**Figure 4: Marker set up on both sides of the body**

The markers were situated at the functional centre of all joints, this is illustrated in Figure 5. The functional joint centre of the joint was found by getting the subject to move at the joint and the functional joint centre was the point that the movement pivoted around. Two marker drive boxes were used; these boxes contain the battery and optical synchronisation for up to two markers. Markers are time-multiplexed by these boxes so when the marker set ups are inputted into CODA each marker has a unique identity and relationship with the other markers allowing recognition of different joints and how they should look on the stick figure view in coda. Figure 5 shows that the boxes were placed around mid–segment, with different length wires allowing the makers to be situated at the functional joint centres of each joint.
3.5 Data Processing

The raw data of the ankle, knee and hip joint angles collected contained additive noise, this noise will result in random error in the converted data (Winter., 1990). This is why it was essential that the raw data was filtered. To choose the best cut of frequency residual analysis was used (Winter., 1990), this method analyses the difference between the filtered and unfiltered signals over a wide range of cutoff frequencies. This means the filter is specific to the characteristics of the data collected. The raw three-dimensional kinematic data was reduced to two-dimensions (2D) (z-vertical and y-anterior-posterior). Residual analysis was used on the ankle, knee and hip markers on the leg that was in contact with the ground in each of the first three steps of the sprint. This was performed for two different subjects over two trials to enable an accurate reflection of the whole data set. The RMSD of different frequency filters from 0Hz to 16Hz where found; this data was formatted into graphs to show where the correct data filter lied this is illustrated in Figure 6. Figure 6 represent that from the analysis of all the graphs the cut off frequency found in the support phase during the first three steps of the sprint was 12Hz.
3.6 Data Analysis

3.6.1 Performance outcome variability

To analyses the step performance outcome variability, the definition of a step first had to be decided. In this study the term step will refer to touchdown of foot to next touchdown of the opposite foot, other research (e.g. Hunter et al., 2003; Thomson et al., 2007; Gittoes and Wilson., 2008) has tended to use this definition of a step also. The step length and frequency was found in CODA by analysing the touchdown to touchdown data of the marker on the top of the second toe. Touchdown was defined using the force plate data, the height of the marker on the top of the second toe was found at point of touchdown. This height measurement at touchdown (z-vertical) of the marker on the top of second metatarsal tip (2nd TT) was used for a subject to define the point of touchdown over all trials and for both feet, as the marker was situated on the 2nd TT for both feet the height (z-vertical) would be almost exactly the same. This method of calculating touchdown and takeoff was chosen based on Bezodis et al., (2007) study that highlighted the benefits of using specific forefoot markers when identifying touchdown and takeoff.

The outcome variability of step length, step frequency and step velocity where found for each subject by calculating the coefficient of variation in each. The coefficient of variation is equal to the standard deviation divided by the mean, multiplied by 100.

Figure 6: RMSD in the different frequency filters
The coefficient of variation represents the ratio of the standard deviation to the mean, and it is useful for comparing the degrees of variation from one data series to another, even if the means are very different (Mullineaux et al., 2001). The coefficient of variation in the step length and step velocity and step frequency and step velocity where plotted in a linear correlation and regression graph to test for linear relationships.

3.6.2 Continuous joint angle profile differences

The continuous joint angle profile differences where found in the support leg in the stance phase of each step. The stance phase of the step was defined as touchdown of foot to takeoff of the same foot. To find the continuous joint angle profile differences for the ankle – hip, knee – hip and ankle – knee the joint angle of the ankle, knee and hip had to first be defined in CODA. Each joint angle was defined in CODA and the vector angles of each was taken at 100 points per second from touchdown too takeoff of the support leg in each step. The continuous joint angles, of the stance phase of each step was pulled out of the rest of the data by using the definition of the stance phase explained earlier. These vector angles were pasted into excel where the RMSD of ankle – knee, ankle – hip and knee – hip was found by taking the angle of one joint away from the other giving the difference between the ankle – knee, ankle – hip and knee – hip joints the square root of the mean difference between the ankle – knee, ankle – hip and knee – hip where then found. This method gives continuous joint angle profile differences for each subject.

The coefficient of variation was then found for each subject during the whole of the continuous joint angle profile differences in the support leg in the stance phase. The purpose of finding the coefficient of variation was to assess the variability in the difference of two joint, assessing how in phase each was with the other. The coefficient of variation in the continuous joint angle profile differences for each subject was then plotted against the coefficient of variation in step length, step frequency and step velocity to assess whether there was a correlation between the continuous joint angle profile differences of the ankle – knee, ankle – hip and knee – hip and the variability in the performance outcomes. The strength of these correlations where found using Pearson r correlation coefficient, this shows

\[
C.V. = \frac{S}{X} \times 100
\]

\(C.V. = \) Coefficient of variation
\(S = \) Standard deviation
\(X = \) mean
the strength and direction of the correlation. A positive correlation is shown by an r greater than zero and a negative correlation by r less than zero. The strength of the correlation is shown by how close r is to 1 or -1 if the correlation is negative (Hinton., 2001). Because a correlation between two sets of data is being analyzed, the explained variance provides an appropriate measurement of the size of the effect. The explained variance was found by quantifying the correlation coefficient squared (r²), this value would indicate the amount of variance in the dependent variable that can be explained by the variance in the independent variable (Mullineaux et al., 2001).
CHAPTER IV

RESULTS
4.0 Results

4.1 Performance variables for step length, step frequency and step velocity

The step length, step frequency and step velocity mean ± SD where found for each subject and for across the whole group (table 2). From table 2 it is clear that the performers that had the highest combination of the step length and step frequency had the highest mean step velocity, this is evident from subject 4 (SF = 4.2 ± 0.25; SL = 1.3 ± 0.14; and SV = 5.5 ± 0.68), this is a reflection of step velocity being the sum of the step length X step frequency.

Step velocity is shown from table 2 to be the overall outcome variable and is a reflection of the displacement and time taken to perform the step. Comparing between subjects in table 2, subject 4 had the highest mean step velocity (SV = 5.5 ± 0.68) 0.4 m/s above the mean step velocity for the group, indicating that he had a higher average speed and subject 1 had the lowest mean step velocity (SV = 4.6 ± 0.57) 0.5 m/s below the mean step velocity for the group.

Table 2: Performance variables for each subject (Mean ± SD) for step length, step frequency and step velocity

<table>
<thead>
<tr>
<th>Subject</th>
<th>SF (Hz)</th>
<th>SL (m)</th>
<th>SV (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.2 ± 0.24</td>
<td>1.1 ± 0.11</td>
<td>4.6 ± 0.57</td>
</tr>
<tr>
<td>2</td>
<td>3.7 ± 0.24</td>
<td>1.3 ± 0.16</td>
<td>4.8 ± 0.73</td>
</tr>
<tr>
<td>3</td>
<td>3.5 ± 0.29</td>
<td>1.4 ± 0.15</td>
<td>5.0 ± 0.74</td>
</tr>
<tr>
<td>4</td>
<td>4.2 ± 0.25</td>
<td>1.3 ± 0.14</td>
<td>5.5 ± 0.68</td>
</tr>
<tr>
<td>5</td>
<td>3.6 ± 0.20</td>
<td>1.5 ± 0.11</td>
<td>5.4 ± 0.58</td>
</tr>
</tbody>
</table>

4.2 Relationship between the continuous joint angle profile differences and step velocity

Figure 7 indicates that there is a correlation between step velocity and the variability in the coupling of the knee – hip joint angle and the ankle – hip joint angle. This indicates that as the variability in difference between the knee and the hip and the ankle and the hip joint angles is reduced the step velocity is increased. This suggests that the coupling variability of these joints has a negative correlation with step velocity, because as the variability increases the step velocity decreases. Figure 7 indicates that there is no relationship between the variability of the difference between the ankle and knee joints and step velocity.
Figure 7: The relationship between step velocity performance (m/s) and continuous joint angle profile differences of the Knee – Hip (Red), Ankle – Hip (Green) and Ankle – Knee (Blue)

4.3 Relationship between step length, step frequency and step velocity variability

Both step length and step frequency variability have a strong positive correlation with step velocity variability indicated by the r values of 0.86 for step length variability and 0.77 for step frequency variability. As the variability in step length and step frequency is reduced the variability in step velocity is also reduced (figure 8). From Figure 4 it is evident that step length variability ($R^2 = 0.73$) has a greater effect on step velocity variability than step frequency variability does ($R^2 = 0.59$).

The $R$ squared values for step length and step frequency variability are both high indicating that a high percentage of the variance in step velocity is a result of the variance in step length and frequency. The $R$ squared values indicate that 59% of the variance in step frequency can be explained by the variance in step velocity and 74% of the variance in step length can be explained by the variance in step velocity, indicating a greater correlation in step length variability and step velocity variability. Figure 8 suggests that most of the variability in step velocity is a result of the variability in step length and step frequency.
Figure 8: step length (Blue) and step frequency (Red) variability relationship with step velocity variability.

4.4 Relationship between continuous joint angle profile differences and step frequency variability

The relationship between step frequency variability and continuous joint angle profile difference shown in Figure 9 indicates that as the difference between the angle profiles at the ankle and hip and between ankle and knee is reduced the step frequency variability is reduced; this shows there is a positive relationship. However there seems to be no relationship between the continuous joint angle profile differences in knee and hip with regards to step frequency variability, this is indicated by the r squared value showing a value of 0.04% indicating that none of the variance in step frequency can be explained by the variance in the continuous joint angle profile difference of the knee – hip.
Figure 9: The relationship between step frequency variability and continuous joint angle profile differences of the Knee – Hip (Red), Ankle – Hip (Green), and Ankle – Knee (Blue)

4.5 Relationship between the continuous joint angle profile differences and step length variability

Figure 10 showing the relationship between step length variability and the continuous joint angle profile difference indicated that the difference between the ankle and the hip joint angle has a positive relationship with step length variability. When the difference between the ankle and hip is low the variability is step length is low. The difference between the knee and hip joints angles and the difference between ankle and knee joint angles show no correlation with step length variability.
Figure 10: The relationship between the step length variability and continuous joint angle profile differences of the Knee – Hip (Red), Ankle – Hip (Green), and Ankle – Knee (Blue)

4.6 Relationship between the continuous joint angle profile differences and step velocity variability

The variability in step velocity and the continuous joint angle profile in Figure 11 indicate that the variance in difference between the angles at the ankle and hip joints can be mostly explained by the variance in step velocity. This is shown by the r squared value which indicates that 88% of the variance in the difference between the ankle and hip can be explained by the variance in step velocity. The difference between the ankle and knee only indicates a small percentage of 24% the variance being explained by the variance in step velocity and none of the variance seen in the continuous joint angle profile differences of the knee – hip can be explained by the variance in step velocity.
Figure 11: The relationship between step velocity variability and continuous joint angle profile differences of the Knee – Hip (Red), Ankle – Hip (Green) and Ankle – Knee (Blue)
CHAPTER VI

CONCLUSION
6.0 Conclusion

To finalise, the step length and step frequency variability was shown to be strongly related with the step velocity variability. The current study found that the step length variability had a stronger relationship with step velocity variability than step frequency variability in the early acceleration phase of sprint running.

The hip joint was shown to be the main contributing factor to step velocity performance in the stance phase. This was suggested to be down to the forward acceleration in sprint running being caused by the extension of the hip in the support phase.

The study showed that the coupling of the ankle – knee is crucial in reducing the variability in the step frequency and as a result step velocity, while the coupling of the ankle – hip is crucial in reducing the variability in the step frequency, step length and as a result step velocity. From these findings consistent sprint running performance was related to the coordination of the ankle joint in relation to the hip and the knee joints.

It was concluded that the hip joint extension is responsible for the propulsion in the stance phase of the step. In addition, the ankle joint coupling with the hip was shown to significantly reduce variability in the step characteristics leading to increased consistency in performance.
REFERENCES


APPENDICES
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**Consent Form**

**Project title:** Lower joint kinematic variability during the early acceleration phase of sprint running.

**Researcher:** Joshua Hatton

**Supervisor:** Marianne Gittoes

I have read and understand the information sheet and the verbal instructions I have been given, and what is required of me in completing the study. There is no medical or injury reason why I should not participate in the study. I understand that I am free to leave the study at anytime.

Signed                                Date
............................................  ............................................

I give permission for my data and any images derived from the study to be used in the research and presentations and to be held at the University of Wales Institute Cardiff.

Signed                                Date
............................................  ............................................

Name:.............................................

Age:.............................................

Contact no:.....................................
APPENDIX B
Appendix A: coefficient of variation in step characteristics and continuous joint angle profile differences.