Evaluation of the effectiveness of the M4 Cortex processor and Kinovea - through the analysis of Triple Jump

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Abstract

One problem that many athletes around the world today face is the startling lack of cheap, accessible and effective technology that they can use to analyse their performance, hindering their progress. In the Hwa Chong context, many coaches rely on pure observation or simply taking a video, which is inadequate in detecting nuances in technique. Synthesising 2 existing methods- video analysis technology and the Inertial Measurement Unit (IMU) allows for a more comprehensive study on Triple Jump. This method of analysis proved to be effective. It was found that a higher knee vs. heel percentage on the hop phase, a high ankle rotation speed, an overall short contact time is incremental to a good triple jump. Further comparison with professional athletes further shows that having balanced jump phases (equal phase distribution) is incremental to a good jump- it is found that the poorest jumps for both Hwa Chong athletes and professional athletes are the jumps which are heavily hop-dominated. This is one aspect that Hwa Chong Triple Jumpers can improve on.

1) Introduction

The triple jump is a track and field event in which a competitor runs down a track and performs three jumping phases, hop step and jump. As such, it is classified under the horizontal jumps category. According to IAAF (International Association of Athletics Federations) rules, the hop shall be made so that an athlete lands first on the same foot as that from which he has taken off in the step, he shall land on the other foot, from which, subsequently, the jump is performed. As of today, there is a lack of reliable technology accessible to coaches and athletes. Thus coaches and athletes have to rely on pure observation and their own knowledge of biomechanics in their sport to improve their athletes. In professional studies of Long Jump, some methods of analysis are thorough and perhaps reliable, but this is not easily available for everyone to use. Some examples are the force plate, video analysis, Inertial Measurement Unit (IMU) and Electromyography (EMG). A lack of proper coaching equipment results in the inability of coaches to accurately point out the factors that affect their athletes' performance, leading to poor performance. In light of a lack of efficient technological means to improve one's jump distance, a synthesis of two existing solutions- Inertial Measurement Unit (IMU) and video analysis software is proposed. This product will ultimately serve the purpose of a reliable source of technology, capable of providing efficient, accurate and analytical feedback to athletes and help to spot their areas of improvement to improve their performance.

2) Literature Review

As of today, some current methods of analysing Long Jump include: Force Plate, Video Analysis, IMU and EMG (Electromyography).

The Force Plate provides a direct measure of force. It is an electronic scale which measures the magnitude of the vertical and two horizontal forces (ground reaction forces), the torque about the vertical axis and the location of the resultant force acting on the platform, making it useful in jump analysis, gait analysis amongst other applications. However, it is very expensive, priced at 10,000 USD and hence inaccessible to many.

Video analysis software such as Kinovea allows for not only the measurement of lower limb angles via observation, but also distances as well as other parameters such as velocity, making it easy to discover an athlete's mistakes and inadequacies. Many studies around the world have taken to video analysis as a way to effectively analyse technique- this can be done through marking various points on the athlete's body and measuring observable parameters such as knee flexion. However, without a biomechanical model or other athletes to reference, the use of Kinovea may be inadequate- this is especially so when measuring biomechanical parameters such as movement of Center of Gravity (CG).

IMU measures a body's specific force, angular rates and velocities, amongst others, and processes the data in itself, allowing for detection of flaws in technique, and the prevention of injury. Researchers such as Marcus Schmidt[1] have conducted experiments using IMU to measure flight time, stance duration and center of mass, amongst other biomechanical parameters. However, it is prone to drift errors, meaning that errors can accumulate over time and affect data collected. In addition, magnometers embedded in these IMU are easily affected by magnetic

[1] Jaitner, Thomas & Schmidt, Marcus & Nolte, Kevin & Rheinländer, Carl & Wille, Sebastian & Wehn, Norbert. (2014). A Wearable Inertial Sensor Unit for Jump Diagnosis in Multiple Athletes. icSPORTS 2014 - Proceedings of the 2nd International Congress on Sports Sciences Research and Technology Support. 10.5220/0005145902160220.

fields.

Lastly, Electromyography allows for monitoring of muscular activity through tracking electrical pulses, making it possible to determine parameters such as quadricep vs calf propulsion. A study published on the Journal of Sports Science by Jarmo Perttunen and other researches used electromyography[2] to assess neuromuscular function and impact loads in the triple jump with a specific focus on the interaction between ground reaction forces, plantar pressures, and muscle electromyographic (EMG) activities and their interactions in the triple jump. However, analysis of this is intensive, and is also extremely expensive- most coaches would not have the means to use this technology.

3) Solution Design

A new form of analysis- hybrid analysis is proposed. This involves the use of video software and IMU- in our case, Kinovea and the M4 cortex processor, provided by our external vendor, Aerspace. Kinovea is a video player for sport analysis. It provides a set of tools to capture, slow down, study, compare, annotate and measure technical performances.

For the IMU, the M4 context processor has key features such as on-board memory, BLE communication. Coupled with edge computing, this enables this small light product to upload data to the cloud real-time. It is such able to measure parameters such as the movement of center of mass as well as lower limb dynamics- the angle of contact, angular velocity at ankle, etc.

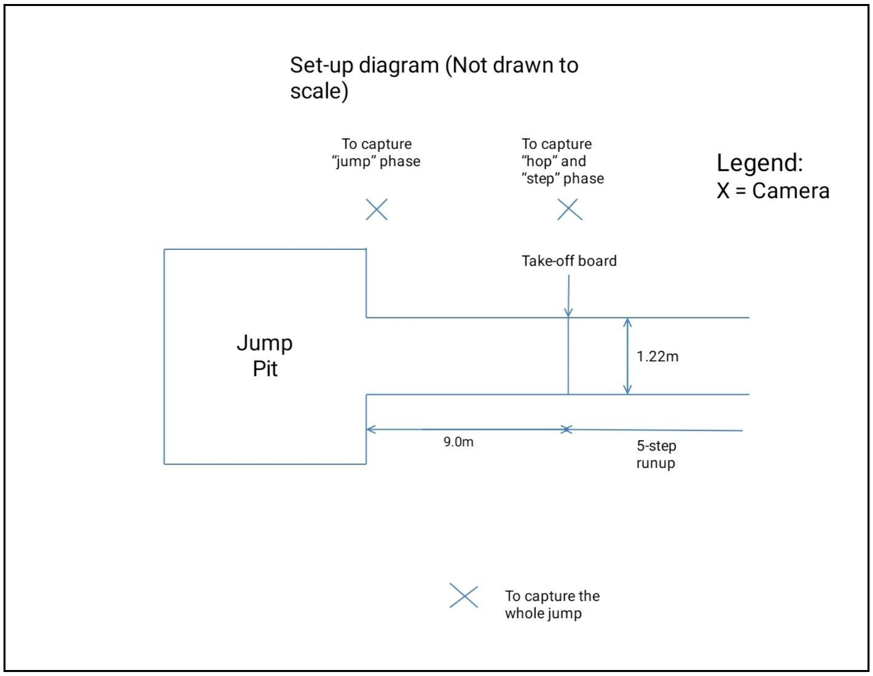
Experiments will be conducted using each separate technology with experiments using the IMU having it secured to the knee and ankles of jumpers to collect data of jumps. Experiments carried out using Kinovea will be done with cameras recording jumps and then exporting the video to the software for analysis. This will enable the comparison of data between the two technologies to come up with a reliable and accurate model for jumpers to follow or identify the areas of improvements to improve their jumps and reach their full potential.

[2] Čoh, Milan & Matjačić, Zlatko & Peharec, Staniaslav & Bačić, Petar & Rausavjević, Nikola & Krzysztof, Maćkała. (2015). Kinematic, Dynamic and EMG Analysis of Drop Jumps in Female Elite Triple Jump Athletes. Collegium antropologicum. 39 Suppl 1. 159-66.

4) Procedure

To evaluate the effectiveness of IMU and Kinovea, we would be conducting experiments to prove the relationship of 3 variables on overall jump distance: Knee to Heel ratio, Ankle Rotation Speed and Contact time. We will also be comparing the data collected to that of professional athletes.

Set-up



Independent variable	**Dependent Variable**	**Controlled variables**
Knee vs. Heel[3] Ratio	Angle of take-off (per phase)	Jumper, experiment location, camera position, jumper's runup length
	(indirect) Distance of each jump phase	
Ankle Rotation Speed	Distance of each jump phase	
Contact time	Distance of each jump phase	

[3] Note: Knee: Heel ratio is the proportion of vertical force to horizontal force. Higher ratio means more upward force while a lower ratio means more horizontal force. The knee is the main contributor to the conversion of vertical force given that it initiatives the main braking mechanism.

5) Results & Discussions

Part 1: Relationship of variables to overall jump distance

Variable 1: Knee to Heel Ratio

Table 1: Optimum Knee to Heel Percentage (Jumper A)				
		Heel vs Knee Percentage		
Variables	Jump Distance	Hop (contact)	Step (contact)	Jump (contact)
Jump 1	12.4m	84% Knee	52% Knee	51% Knee
Jump 2	13.21m	68% Knee	56% Knee	57% Knee

From the data above, it can be concluded that takeoff angles for the hop phase must be as flat as possible to maximise the horizontal velocity of a jump. The second jump is the better one with a longer jump distance of 13.21m as compared to the first jump with a distance of 12.4m. This can be attributed to the flatter or smaller heel vs knee percentage of 68% which is less than that of 84% in the take-off phase. The lower the knee-to-heel percentage, the flatter the takeoff (smaller take-off angle). As a result, it can be seen that the knee-to-heel percentages for Jump 1 in the Step and Jump phase are significantly lower than that in Jump 2, indicating a lack of vertical height in those 2 phases.

Table 2: Optimum Knee to Heel Percentage (Kinovea) (Jumper B)				
		Heel vs Knee Percentage		
Variables	Jump Distance	Hop (Contact)	Step (Contact)	Jump (Contact)
Jump 1	12.96m	67% Knee	83% Knee	69% knee
Jump 2	12.5m	73% Knee	87% Knee	78% knee

Jump 3	12.54m	70% Knee	88% Knee	73% knee

From the data above, it can be concluded that takeoff angles must be as flat as possible to maximise the horizontal velocity of a jump. The first jump is the best one with the longest jump distance of 12.96. This can be attributed to the flatter or smaller heel vs knee percentage of 67% which is less than that of 73% for second jump and 70% for third jump in the take-off phase. Similarly, the first jump has the smallest ratio of 83% on the hop phase and 69% in the step phase.

Table 3: Optimum Knee to Heel Percentage (Kinovea) (Jumper C)				
		Heel vs Knee Percentage		
Variables	Jump Distance	Hop (Contact)	Step (Contact)	Jump (Contact)
Jump 1	11.46m	85% Knee	81% Knee	65% knee
Jump 2	11.50m	85% Knee	87% Knee	54% knee
Jump 3	11.59m	63% Knee	88% Knee	60% knee

From the data above, it can be concluded that takeoff angles must be as flat as possible to maximise the horizontal velocity of a jump. The third jump is the best one with the longest jump distance of 11.59. This can be attributed to the flatter or smaller heel vs knee percentage of 63% for the third jump which is less than that of 85% for first jump and second jump in the take-off phase. Similarly, the third jump has the highest ratio of 88% in the step phase, indicating that the distance across the step phase was maximised.

Analysis

The knee is responsible for the creation of 60% of vertical velocity[4]. A flatter heel to knee

[4] Lees, A., Graham-Smith, P., & Fowler, N. (1994). A Biomechanical Analysis of the Last Stride, Touchdown, and Takeoff Characteristics of the Mens Long Jump. Journal of Applied Biomechanics, 10(1), 61-78. doi:10.1123/jab.10.1.61

percentage for the hop phase (a flatter take-off angle) results in reduced knee flexion and hence reduced vertical height in the hop phase. It hence minimises braking on the step phase, hence minimising the stress to the knee due to high ground reaction forces and maximising the distance across the step phase. The knee requires a flat take-off angle in order to react to the stress upon landing[5]. In addition, having a flat take-off angle ensures minimum loss in horizontal velocity[6] (Lee et al, 1993). To achieve the best jump possible, athletes should strive for the lowest knee to heel ratio for the hop phase- as this affects the step phase and jump phase of the jump. This corresponds to reduced knee flexion in the hop phase as the knee bends in order to propel the jumper upward.

There appears to be no correlation between overall jump distance and the knee-to-heel ratio of the jump phase.

Variable 2: Ankle rotation speed

Table 4: Optimum ankle rotation speed (Jumper A)				
		Ankle Rotation Speed (deg/sec)		
Variables	Jump Distance	Hop (Contact)	Step (Contact)	Jump (Contact)
Jump 1	12.4m	120.86	210.22	502.44
Jump 2	13.21m	142.27	635.56	572.44

From the data shown above, it can be concluded that ankle rotation speed should be as fast as possible to maximise the horizontal jump distance of a jump. The second jump is the better jump with a jump distance of 13.21m as compared to jump 1 with a 12.4m. This can be attributed to the faster ankle rotation speed in Jump 2. Jump 2 has a faster ankle rotation speed of 142.27 deg/sec as compared to 120.86 deg/sec in the hop phase. Similarly, Jump 2 has a much faster ankle rotation speed of 635.56 deg/sec in the step phase, which is about 400 deg/sec more

5 Antonini, Stefano. (2015). Biomechanics of the triple jump: technical, coordinative and muscular aspects. Scienza e sport.

6 Lees, A., Graham-Smith, P., & Fowler, N. (1994). A Biomechanical Analysis of the Last Stride, Touchdown, and Takeoff Characteristics of the Mens Long Jump. Journal of Applied Biomechanics, 10(1), 61-78. doi:10.1123/jab.10.1.61

than Jump 1. The same trend can be determined for the Jump phase. It can then be determined that better jumps tend to have high ankle rotation speed which is termed as a fast pawing motion in sports. The clawing action generates a stronger contact force which then converts into more energy to bring the body forward. Therefore, jumps with stronger pawing motion tend to have a longer horizontal jump distance.

Furthermore, the faster ankle rotation speed is correlated to a shorter contact time as this action minimises forward anteroposterior velocity loss[7] which translates to a shorter contact time with the ground (Koh and Hay, 1990). The pawing motion of the foot creates a backward velocity of the landing leg and thus helps to maintain the forward horizontal velocity of the body. Less energy is lost through the swaying of the body sideways and more is converted into a maximum jump distance before the jump phase. Thus, a faster ankle rotation speed helps to increase the ground reaction force needed for a longer jump.

Variable 3: Optimal contact time

Table 5: Optimum contact time (Jumper A)					
		Contact time[8] vs flight[9] time			
Variables	Jump Distance	Hop	Step	Jump	Contact time vs flight time
Jump 1	12.4m	18%	39%	47%	39%
Jump 2	13.21m	20%	27%	57%	29%

From the data shown above, it can be concluded that contact time should be as short as possible to maximise the horizontal jump distance of a jump. The second jump is the better jump with a jump distance of 13.21m as compared to jump 1 with a 12.4m which can be attributed to

[7] Lees, A., Graham-Smith, P., & Fowler, N. (1994). A Biomechanical Analysis of the Last Stride, Touchdown, and Takeoff Characteristics of the Mens Long Jump. Journal of Applied Biomechanics, 10(1), 61-78. doi:10.1123/jab.10.1.61

[8] Contact time is the period in which the feet are in contact with the ground.

[9] Flight time is the period in which the jumper is suspended in the air above the ground.

the shorter contact time vs flight time. Jump 2 has an overall smaller percentage of contact time vs flight time at 29% as compared to 39% in jump 1. It is worth noting that most of the contact time comes from the jump phase, followed by the step phase. The contact time for the hop phase is the shortest.

Extension

According to a research paper titled biomechanical loading in the triple jump published on the Journal of Sports Science, the paper revealed that elite triple jumpers could achieve a staggering 0.139s for the step phase and 0.177s for the jump phase while Jumper A can only achieve 0.16s for the step phase and 0.32s for the jump phase. The huge difference may be due to Jumper A's inadequacies in his technique.

Table 6: Optimum contact time (Kinovea) (Jumper B)

		Contact time vs flight time			
Variables	Jump Distance	Hop	Step	Jump	Contact time vs flight time
Jump 1	12.96m	26%	38%	37%	29%
Jump 2	12.5m	30%	40%	30%	37%
Jump 3	12.54m	29%	30%	41%	35%

From the data shown above, it can be concluded that contact time should be as short as possible to maximise the horizontal jump distance of a jump. The first jump is the best jump with a distance of 12.96m as compared to 12.5m for the second jump and 12.54 for the third jump. This difference in jump distance can be attributed to the shorter contact time vs flight time. Jump 1 has an overall smallest percentage of contact time vs flight time at 29% as compared to 37% in jump 2 and 25% for jump 3.

Table 7: Optimum contact time (Kinovea) (Jumper C)					
		Contact time vs flight time			
Variables	Jump Distance	Hop	Step	Jump	Contact time vs flight time
Jump 1	11.46m	26%	37%	37%	39%
Jump 2	11.50m	33%	28%	39%	36%
Jump 3	11.59m	26%	34%	37%	29%

From the data shown above, it can be concluded that contact time should be as short as possible to maximise the horizontal jump distance of a jump. The third jump is the best jump with a distance of 11.59m as compared to 11.50m for the second jump and 11.46m for the first jump. This difference in jump distance can be attributed to the shorter contact time vs flight time. Jump 3 has an overall smallest percentage of contact time vs flight time at 29% as compared to 36% in jump 2 and 39% for jump 1. It is worth noting that generally most of the contact time comes from the jump phase, followed by the step phase. The contact time for the hop phase is the shortest.

Analysis

The jump phase would generally have a higher contact time than the step phase. Reasons for this is due to the decrease in horizontal velocity during this phase and this allows for braking which equates to more vertical velocity and hang time[10] (Aagaard et al., online). This means there will be a higher take-off angle for the jump phase as well to maximise the jump distance.

A smaller contact time results in a longer jump distance because it means the jumper has greater explosiveness, thus more energy is converted to propel the body forward instead of being lost to contact force with the ground. Since less time is wasted on the ground, there will be

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[10] Hardbound, S. A. (2010). Optimisation of performance in the triple jump using computer simulation (Master's thesis). Thesis / Dissertation ETD.

greater take-off velocity. The shorter braking time would help to reduce the amount of vertical force generated. This would lengthen the duration of the step phase and maximise the jump distance.

It is also worth noting that the jump phase is generally the phase with the highest contact time (save for Jumper B). In order to maximise the distance across the jump phase into the sand, the jumper must gain a certain amount of vertical velocity (similar to a long jump takeoff). This means that there must be a certain amount of knee flexion to gain the vertical velocity, amounting to a long contact time in order to exert a force on the ground that (by Newton's 3rd Law) would eventually propel the jumper upward. Similarly, the contact time for the hop phase is the lowest in order to ensure that the least amount of horizontal velocity is lost.

Part 2: Comparison to elite triple jumpers

Variable: Jump phase proportion

Name	The proportion of jumping on one foot %	Stride jump proportion %	Jump proportion %	Achievement (m)
Schmidt	35.2	29.5	35.3	17.03
Banks	35.2	27.6	37.2	17.97
Edwards	33.1	28.5	38.4	18.28
Conley	32.0	30.0	38.0	18.17
Saneyev	37.0	29.0	34.0	17.39

Table 8: Elite triple jumpers jump phase proportion

Table 9: Jump proportions (Jumper B + Jumper C)				
Variables	Hop proportion (%)	Step proportion (%)	Jump proportion (%)	Jump distance (m)
Jump B (1)	37.5%,	30.9%,	34.5%	12.95

Jump B (2)	34.5%,	28.0%,	35.3%	12.46
Jump B (3)	36.9%,	29.6%,	33.5%	12.50
Jump C (1)	38.4%	33.5%	28.0%	11.46
Jump C (2)	37.9%,	30.1%,	32.0%	11.50
Jump C (3)	35.2%,	30.2%,	34.5%	11.59

It can be seen that in general, the proportion for all triple jump phases for our Hwa Chong athletes are quite similar to that of triple jumpers. The sheer difference in distance may be due to our athletes lacking the speed and power to match up to Olympic athletes. This could also be due to the fact that both athletes did a 5-step runup (instead of the conventional 15-19 step) because both were mildly injured and had just returned to the Triple Jump scene. Strength training might be an area for future research, given that there appears to be a gap between our athletes and professional athletes.

It is also interesting to note that: First, the jumps of Hwa Chong athletes are hop-dominated, meaning that the hop takes the highest percentage of the jump. Second, it is generally around 5% higher compared to professional athletes. While this does not lead to a decrease in the proportion in the step phase (it is similar to elite triple jumpers at around 30%), it may lead to a corresponding decrease in the proportion of the jump phase. An area for consideration for these athletes might be how to make take-off angles flatter in order to maximise the distance into the step phase

Finally, it can be noted that in general, the proportion of the jump phases for our Hwa Chong athletes are around 3% lower than that of elite athletes (32% to 35%). While minute, it indicates that our Hwa Chong athletes may need to shift their focus slightly to also train their non-dominant leg to ensure that they are able to maximise their distance into the jump phase.

6) Conclusion and recommendations

1) The lower the knee to heel ratio for the hop phase, the further the jump.
2) The higher the ankle rotation speed in all phases, the further the jump.
3) The shorter the contact time in general, the further the jump.
4) The jump phase typically has the longest contact time, followed by the step phase and lastly the hop phase.

When compared with elite triple jumpers, Hwa Chong jumpers appear to have hop-dominated jumps, perhaps over-emphasising the hop phase and neglecting the jump phase. Training for the non-master leg and achieving flatter take-off angles may be a good course of action to take for these athletes.

Thus, our recommendation for jumpers is to focus on jumping further and not higher by adopting a clawing action. This pawing action will help force jumpers to exert their momentum forward and thus more force is used to propel the body forward instead of upwards. This would translate to a maximised horizontal jump distance. Jumpers should also focus on training their explosiveness as this would help to reduce their contact time. When less time is spent on the ground, flight time is increased. At the same time, the pawing action will then enable less energy to be used on braking and instead used to increase the contact force and propel the body forward for longer jump.

7) Limitations

Firstly, the jumper might tire out in between his jumps. This can be mitigated by allowing him to take periodic breaks to fully recover. In addition, only 3-4 jumps were taken for each jumper, hence this was not very intensive to a jumper used to rigourous workouts per se.

Second, we experienced a limited sample size due to the fact that most of the triple jumpers in both the High School and JC team were either partially injured or completely out of action. To mitigate this, we made use of past videos in order to increase our sample size- but this was unfeasible as the camera angle was not suited. In the end, we had to make do with 3 jumpers and 8 jumps to analyse.

Finally, our external vendor Aerspace withdrew from our project, resulting in us being unable to conduct any testing necessary for the success of our project. The data they provided for us to analyse was incomplete, and the corresponding video for one jumper's jumps was cut off at the jump phase, hence we were unable to analyse the data of the fourth jumper (hence, we only had 3 test subjects). We had to make do with using Kinovea, and we were still able to analyse some of the data they had collected earlier in the year using the IMU. However, this meant that we were unable to comment on user feedback and give our comments as to how to improve this technology- which was the main aim of our project. Our title could not be changed in time as they only withdrew in end-June.

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simulation (Master's thesis). Thesis / Dissertation ETD.

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