Biomechanics Research Project in the IAAF World Championships Daegu 2011

Korean Society of Sport Biomechanics

Biomechanics Research Project in the IAAF World Championships Daegu 2011

INDEX

Biomechanics Research Project Team in the IAAF World Championships Daegu 2011

- Chief Director :

  Young-Sang Bae

- Director :

  Eui-Hwan Kim · Jong-Jin Park · Young-Jin Park · Ji-Seon Ryu · Kyung-Ok Yi · Joong-Sook Lee Kyung-Jeong Choi · Cheong-Hwan Oh · Sang-Yron Woo · Young-Tae Lim · Kyung-Il Lee Woen-Sik Chae · Seung-Bum Park · Suk-Hoon Yoon · Jung-Sul Seo · Jae-Kyun Ryu Yong-Woon Kim · Ho-Mook Kim · Sang-Kyoon Park

- Researchers :

  Nam-Hee Kim · Sung-Mo Kang · Ji-Eun Kang · Moon-Seok Kwon · Ho-Jong Kill · Gun-Su Kim Ki-Man Kim · Dong-Soo Kim · Sung-Sup Kim · Sung-Jong Kim · Jong-Woo Kim · Joo-Yun Kim Jin-Hyuk Kim · Chang-Eun Kim · Eae-Sam Kim · Hye-Lim Kim · Ki-Jung Nam · Si-Hyeon Ryu Yong-Hyeon Park · Jung-Ho Park · Jae-Hee Bae · Eui-Su Shin · Hyung-Seung Ahn Ung-Ryang Wi · Chang-Jin Yoon · Chung-Gul Yun · Jeong-Min Lee · Jeong-Tea Lee Haeng-Seob Lee · Ik-Su Jeong · Sung-Bum Choi · Su-Nam Choi · Seul-Bi Choi · Sung-Hee Ha Wan-Ki Hong · Won-Sup Hwang

- International Cooperation Research Team(JAAF Biomechanics Team) :

  Ae Michiyoshi · Takashi Mochida · Hiroyuki Koyama · Koji Hoga-Miura Kazuhito Shibayama · Kadono Hirosuke · Tanji Hiroki

Biomechanics Research Project at IAAF World Championships in Athletics - Daegu

- Director :

  Young-Sang Bae(Keimyung University, Korea) · Young-Jin Park(Kyunghee University, Korea) Jong-Jin Park(Kyungsung University, Korea) · Joong-Sook Lee(Silla University, Korea) · Woen-Sik Chae (Kyungpook National University, Korea) · Seung-Bum Park(Busan Economic Promotion Agency, Korea)

Sport Biomechanics Research Project at IAAF World Championships Daegu 2011

Ⅰ. Introduction

The IAAF World Championships in Athletics is the greatest athletics championship game held by the IAAF biennially. The first game was held in Helsinki in 1983. The championships were held once 4 years until the Tokyo game, where after it has been held biennially. The 13th World Championships was successfully held in Daegu from August 27, 2011 to September 4, 2011 (IAAF, 2011). Sport biomechanics analyses have been widely utilized in various sports games. Various scientific analysis projects in vital dynamics, coaching and development areas using sport biomechanics were carried out at previous IAAF World Championships(Hommel, 1987).

The sport biomechanics project started first in the 2nd World Championships at Italy in 1987 followed by the projects for 1988 Seoul Olimpic Games, 1993 Stuttgart, Germany World Championships, 1995 Gothenburg, Sweden World Championships, 1997 Athens, Greece World Championships, 1999 Sevilla, Spain World Championships, 2005 Helsinki, Finland World Championships, 2007 Osaka, Japan World Championships, 2009 Berlin, Germany World Championships and 2011 Daegu, Korea World Championships in more various sports.

Sport biomechanic researches on the discus were performed at 1987 Rome World Championships (Moravec, Ruzicka, Susanka, Dostal, Kodejs & Nosek, 1988) and 1993 Stuttgart World Championships (Knicker, 1994) followed by research on the throwing at 1995 Gothenburg World Championships (Bartonietz, Best & Borgstrom, 1995) and on the 100 m, 200 m, 400 m, 110 m hurdles, 100 m hurdles, long jump, triple jump, high jump(men) and pole jump at 1997 Athens World Championships (Muller & Hommel, 1997). In 1999 Sevilla World Championships, the two-dimensional video system was introduced for the 100 m, 400 m and other sports researches (Ferro, Rivera, Pagola, Ferreruela, Martin & Rocandio, 2001). Same researches were carried out for the 100 m, pole jump, high jump, triple jump and javelin at 2005 Helsinki World Championships (Masatoshi, Satoru, Masaki, Juha, Pavo & Akira, 2006). In 2007 Osaka World Championships, the researches were carried out by Osaka University of Health and Sport Sciences, and various researches were carried out in 2009 Berlin World Championships (Hommel, 2009).

About 3,500 athletes and athletic officials including world record holders and Olympic medalists from 212 countries attended the Daegu World Championships to see who is the real world champion (Lee, 2010). 1,046 male and 899 female athletes representing 202 countries

finally competed to attract worldwide attention in the brilliant spotlights in the Championships. At the same time, scientific sport biomechanics researches were carried out by Korean Society of Sport Biomechanics under the support of the IAAF to generate scientific data of major athletic sports.

Domestic researches on the athletic sports by kinematics and biomechanics have been continuously carried out in various forms such as the researches related to starting elements in the 100-meter sprint including the variations of strides, starting methods and starting, records and response time, ground reaction forces, the effect of flexibility to the speed and the electromyogram at starting, and the researches on the sectional speeds in the 100 m (Ko, 1984) and the speeds at 30 m - 40 m section and 80 m - 90 m section (Eun, Chung & Bae, 1996; Jung & Lee, 1996). In other area of athletics, Lee and Ryu(2007) performed the analysis of variables of the 3rd hurdling motions of domestic and foreign elite 110 m hurdlers; Ryoo(2003) and Kim(2010) performed the researches on the pole jump; Lee, Back and Kim(2006) on the high jump; Bae(1994), Ko(2009), Lee, Min & Son(1994), Park, Kim & Ryu(2004), and Sung, Ryu & Lee(2003) on the run-ups and take-offs on the long jump; Ryu(2005), Ryu & Yoon(2001) and Yu(1999) on the triple jump; Jeong(2004), Ryu, Pak & Kim(2011) on the shop-put; and Kim(2003), Lee, Kim & Lee(2000) and Kim(1993) on the javelin. Korean athletes have not achieved the remarkable success in athletics except for the marathon, even in Asian Games where almost no medal has been won (Korea Association of Athletics Federations, 2007) and in 2011 Daegu World Championships as expected. Korea was pleased, however, to see its athletes listed in the final rounds of the male and female marathons, male and female 20 km walkings, male 50 km walking, male long jump, female 800 m wheel chair, and male 400 m wheel chair and to find new national records made in the male decathlon, male 1,600 m relay, male 400 m relay and male 50 km walking, which leaves the future possibility of medal winning.

This study aims to identify the measures to perform biomechanics researches more effectively to achieve better performance in the future athletics including the World Championships and to find out about the roles of the research for development of Korean athletics through analysing the process and results of the sport biomechanics research project performed successfully during 2011 Daegu World Championships. In addition, through these studies, the bases of enhancement of Korean athlete's performance may be established, the continuous endeavor for the research of coaching technology and strategies may be caused, and the measures to foster the development of Korean athletics and to promote people's attention to the athletics can be sought.

Ⅱ. Study Methods

The results of the sport biomechanics research projects of 2011 Daegu, 2005 Helsinki, 2007 Osaka and 2009 Berlin World Championships are analysed to establish better biomechanics research methods. <Table 1> shows the list of events to which sport biomechanics analyses are carried out and <Figure 1> shows the proceedings of the sport biomechanics research project at the 2011 Daegu World Championships as introduced in the home page of the IAAF.

Table 1. Biomechanics Research Event in the IAAF World Championships Daegu 2011

Gender			Events
Men's (8)	Track Events (2)	Sprints	100 m
		Hurdles	110 mH
	Field Events (6)	Jumps	Long Jump, High Jump, Triple Jump, Pole Vault
		Throws	Javelin Throw, Shot Put
Women's (8)	Track Events (2)	Sprints	100 m
		Hurdles	110 mH
	Field Events (6)	Jumps	Long Jump, High Jump, Triple Jump, Pole Vault
		Throws	Javelin Throw, Shot Put,

Figure 1. The IAAF World Championships Daegu 2011 homepage

Ⅲ. Results of the Research

1. Sport biomechanics research project at the 2011 Daegu World Championships

About 3,500 athletes and athletic officials, more than any attendants of previous World Championships, from 212 countries attended the Daegu World Championships, and 1,046 male and 899 female athletes, 1,945 athletes in total, representing 202 countries competed for championships.

For more than a year, the planning activities were carried out after the first proposal for sport biomechanics project was presented in Dec. 2009. Detailed implementation plan was established, necessary organization was formed, the analysis team and the photography team started practicing, and other preparation phase activities were carefully carried out after the approval of the proposal by the IAAF in Jul. 2011.

Table 2. Biomechanics Research Project on the proceedings in the IAAF World Championships Daegu 2011

Date	Proceeding
12. 2009.	2009 Autumn Conference of Korean Society of Sport Biomechanics and Proposal of KSSB Biomechanics Research Project in the IAAF WC Daegu 2011
3 ~ 4. 2010.	Biomechanics Research Project T/F Team Received
7. 2010.	11th IAAF World Championships in Athletics Osaka 2007 Report Received
8. 2010.	12th IAAF World Championships in Athletics Berlin 2009 Report Received
8. 2010.	2010 International Sports Science Congress and Biomechanics Research Project T/F Team Confirmed
11. 2010.	Biomechanics Research Project Plan for Proposal
1 ~ 2. 2011.	Organizing Committee for the IAAF World Championships Daegu 2011, Korea Association of Athletics Federations and IAAF to submit a proposal
4. 2011.	IAAF World Championships Daegu 2011 Workshop
5. 2011.	IAAF World Championships Daegu 2011 Rehearsal
5 ~ 7. 2011.	Biomechanics Research Project T/F Team Meeting
7. 2011.	IAAF Approved
8. 2011.	Extraordinary General Meeting and Biomechanics Research Project T/F Team Meeting Biomechanics Research Project T/F Team Rehearse
8. 2011.	IAAF World Championships Daegu 2011 Start

The Ministry of Culture, Sports and Tourism and the Korea Athletics Federation jointly formed the sport biomechanics team for increasing athletic capabilities of the athletes, respecting citizen's right to know, increasing viewing rate of mass media and responding the interests and concerns of the IAAF, organizing committee of 2011 IAAF World Championships and Korea Athletics Federation that regarded the sport biomechanics research as an important tool for increasing athletic capabilities of the athletes and promoting peoples's participation in athletics. Owing to this cooperation, the project team smoothly and effectively implemented systematic preparation including proper situation analyses. The joint research agreement made with Japan Association of Athletics Federations in 2007 was another element of successful endeavor where highly reliable and quantitative data and analysis methods were transmitted.

Variety of captioning approaches, real time scientific justifications, and quantitative and qualitative interpretations presented by the 2011 Daegu World Championships biomechanics project team through mass communication won positive responses from TV viewers and was evaluated as being a better and one-step advanced project than 2009 Berlin World Championships project. With these diverse camerawork and state-of-art analysis technology, biomechanics analyses and researches on various events were carried out. High-speed digital video cameras and Kwon 3D Program were used for 3 dimensional motion analysis, and the video images and data of individual motions of athletes were collected in real time, analysed in real time and documented in daily reports for immediate feedback (Figure 2).

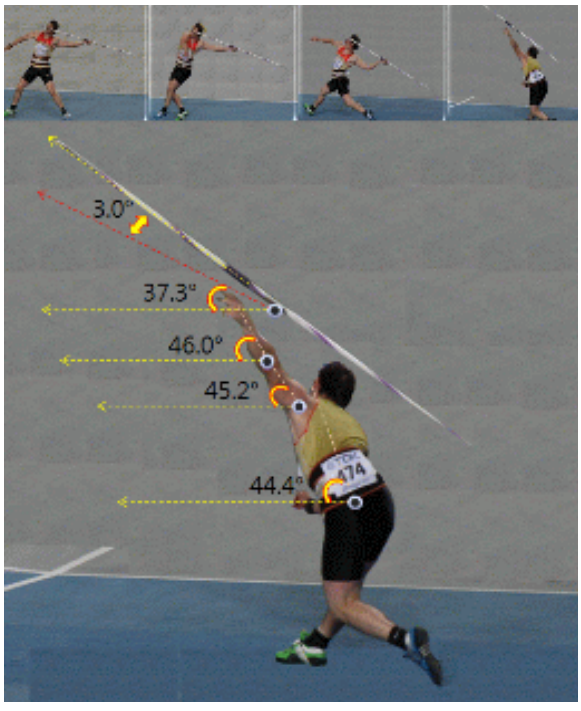


Figure 2. Videotaped using three high-speed cameras in IAAF World Championships Daegu 2011 (javelin throw)

The 8 events, male 100 m, female 100 m, 110 m Hurdle, pole vault, high jump, long jump, triple jump, shot put and javelin were analysed.

Figure 3. Calibrated area and set up for DLT structure

In the male and female 100 m finals, the acceleration section and running section for 4 male high rank players, and running section for 4 female high rank players were analysed. The hurdling technology at 5th and 6th hurdles of 4 male and 4 female high rank players at finals of the 110 m hurdles were analysed. In the male and female pole vaults, the motions at the approach run stage, jumping stage, pole bending stage and pole spreading stage of 8 male and 8 female high rank players were analysed. In the male and female high jumps, the speed of the middle of the body, leaping angle, the angle of the knee joint and the angle of the body slope at feet stamping of 3 male and 3 female high rank players were analysed through 4 high speed digital video camera. In the male and female long jumps, the approaching section, feet stamping section, flying section and landing section of the races of 8 male and 8 female high rank players were analysed. In the male and female triple jumps, the jumping distance of each section, COM jumping speed and jumping angle of the best records of 8 male and 8 female finalists were analysed. In the shot puts, the elapsed time of delivery, height of throw, angle of throw, throw speed, angular speed of the arm and hip, speed of the body center and trace of throw of the best records of 8 male and 8 female high rank players were analysed. In the male glide type shot put, the gliding and release motion of the Korean athlete, gold medalist and bronze medallist were analysed through 3 video cameras. Lastly, in the javelin throw, the release speed, release angle, angle of posture, attack angle, height of throw, slope angle of the body segment, sectional distance and timing element of 3 male and 3 female high rank players, and a Korean athlete were analysed.

Figure 4. Camera settings for the videotaping

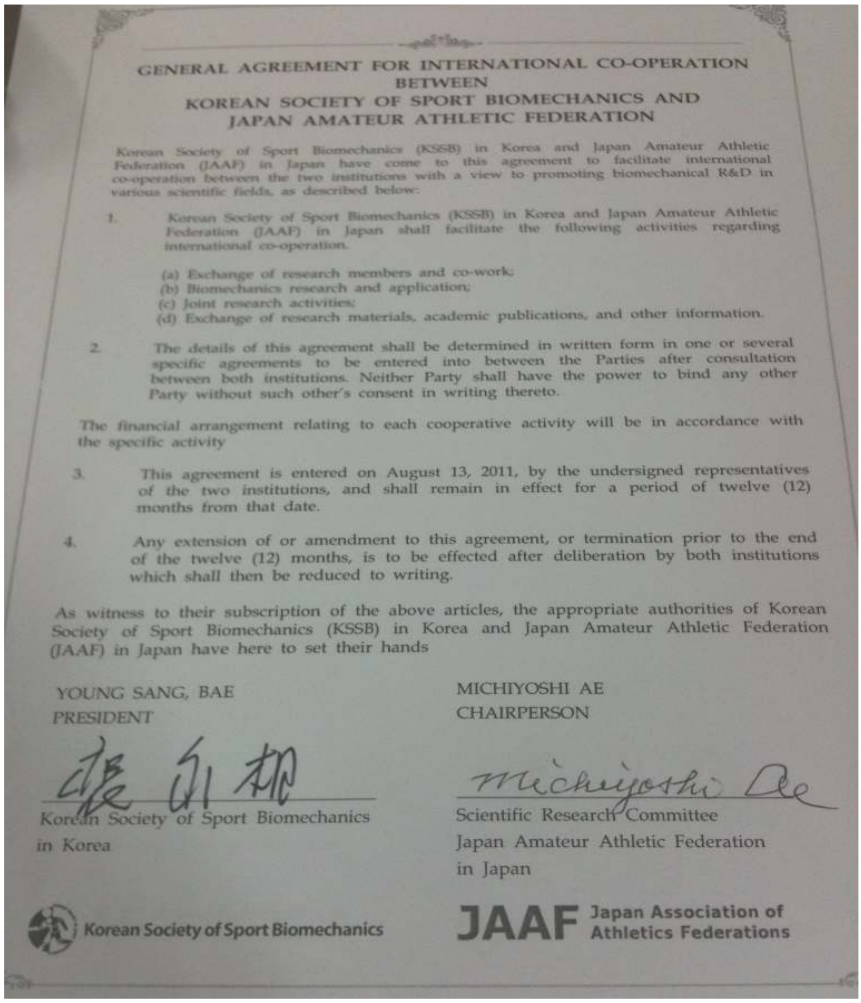
Figure 5. Biomechanical data analysis for daily report

Through these detailed biomechanics analyses, the motions of world-class athletes were analysed and translated into the quantitative and qualitative data that can significantly help the development of world's athletics technology and Korean athletics development and the higher level of Korean biomechanics analysis technology was well recognized worldwide.

2. Sport Biomechanics Projects at 2005 Helsinki, 2007 Osaka, and 2009 Berlin World Championships

1,668 athletes, from 191 countries, attended the 2005 10th World Championships in Helsinki. Scientific equipment was provided, by the Helsinki Athletics Federation, to the biomechanics team that was formed to improve athletic performance through quantitative data analysis. The team's effort to create diverse scientific video images taken by the GRF(ground reaction force system) installed on the ground before the Championships and to improve technology level of measuring ground reaction forces was evaluated as a significant advance. Analyses for the sprints, pole vault, long jump and high jump from various aspects were carried out to prepare a biodynamics performance evaluation report for performance improvement.

1,800 athletes from 197 countries attended the 2007 11th World Championships at Osaka. The sport biomechanics team was formed by the Japan Athletics Federation to respond the interests and concerns of the IAAF, the organizing committee of 2007 IAAF World Championships and Japan Athletics Federation that regarded the sport biomechanics research as an important tool for increasing athletic capabilities of the athletes and promoting peoples's participation in athletics. The results of the team's effort was evaluated as useful data for later sports science researches. As soon as an event was completed, the team issued the qualitative and the quantitative analysis report for improving the performance of the athletes attended the event, which was highly regarded by professionals and mass communication (Osaka, 2007; Alonso et al 2009; Graham-Smith, & Lees 2005; Muraki, Ae, Yokozawa, & Koyama, 2005; Burke, L., Maughan, & Shirreffs, 2007).



GENERAL AGREEMENT FOR INTERNATIONAL CO-OPERATION
BETWEEN
KOREAN SOCIETY OF SPORT BIOMECHANICS AND
JAPAN AMATEUR ATHLETIC FEDERATION

Korean Society of Sport Biomechanics (KSSB) in Korea and Japan Amateur Athletic Federation (JAAF) in Japan have come to this agreement to facilitate international co-operation between the two institutions with a view to promoting biomechanical R&D in various scientific fields, as described below:

1. Korean Society of Sport Biomechanics (KSSB) in Korea and Japan Amateur Athletic Federation (JAAF) in Japan shall facilitate the following activities regarding international co-operation.

(a) Exchange of research members and co-work;
(b) Biomechanics research and application;
(c) Joint research activities;
(d) Exchange of research materials, academic publications, and other information.

2. The details of this agreement shall be determined in written form in one or several specific agreements to be entered into between the Parties after consultation between both institutions. Neither Party shall have the power to bind any other Party without such other's consent in writing thereto.

The financial arrangement relating to each cooperative activity will be in accordance with the specific activity

3. This agreement is entered on August 13, 2011, by the undersigned representatives of the two institutions, and shall remain in effect for a period of twelve (12) months from that date.

4. Any extension of or amendment to this agreement, or termination prior to the end of the twelve (12) months, is to be effected after deliberation by both institutions which shall then be reduced to writing.

As witness to their subscription of the above articles, the appropriate authorities of Korean Society of Sport Biomechanics (KSSB) in Korea and Japan Amateur Athletic Federation (JAAF) in Japan have here to set their hands

YOUNG SANG, BAE
PRESIDENT
Korean Society of Sport Biomechanics
in Korea

MICHIYOSHI AE
CHAIRPERSON
Scientific Research Committee
Japan Amateur Athletic Federation
in Japan

Korean Society of Sport Biomechanics
JAAF Japan Association of Athletics Federations

Figure 6. MOU between Korean Society of Sport Biomechanics (KSSB) and Japan Association of Athletics Federations (JAAF)

1,994 athletes from 201 countries attended the 2009 12th Berlin World Championships. The sport biomechanics team was formed by the German Athletics Federation for increasing athletic capabilities of the athletes, respecting citizen's right to know and increasing viewing rate of the Championships. The team presented real time video images made by quantitative, qualitative and scientific analyses through mass media. The effort won popular acclaim and the technology used by the team was evaluated as being one step advanced from the analyses of the Osaka and Helsinki teams which were provided with some time-lag (Berlin, 2009a, 2009b). The hurdle, hammer throwing, races, long jump, triple jump and other various events were analysed using the state of the art scientific equipment including motion analysis cameras, ground reaction force equipment, super high-speed camera and velocity measuring device. The analyses reports full with quantitative and qualitative data were evaluated as being useful for the development world athletics, athletes abilities and athletic technology (Bouchouras, Moscha, Papaiakovou, Nikodelis, & Kollias, 2009; Hommel, 2009; Panoutsa kopoulos, & Kollias, 2007, 2009).

Ⅳ. Discussions

The results of the sport biomechanics research projects performed at the 2011 Daegu World Championships in Athletics and other previous Championships are analysed for identification of better and more effective measures of the research.

1. The sport biomechanics research project performed at the 2011 Daegu Championships

Figure 7. Biomechanics Research Project TF team in the IAAF World Championships Daegu 2011.

For the Daegu World Championships in Athletics, a joint research agreement made with Japan Association of Athletics Federations for highly reliable and quantitative data and analysis methods exchange. The research project team's effort including this joint agreement resulted from the agreement of the Ministry of Culture, Sports and Tourism and the Korea Athletics Federation, IAAF, organizing committee of 2011 IAAF World Championships and mass communication which regarded the research as an essential element for athletics development. The research agreement with the JAAF helped the Daegu team air more diverse video images with scientific justifications, and quantitative and qualitative interpretations to lead to much more positive responses from TV viewers than those of the Berlin Championships. Real time analyses of the finished events

were carried out to prepare daily reports that were distributed to mass media the next day for real time feedback. The higher level of quantitative and qualitative analysis data was included in the reports to be distributed to mass media to lead to the formation of a framework of future Korean athletics technology research. Especially, the consortium of the project team, mass media, IAAF, KAAF and organizing committee of 2011 Daegu World Championships in Athletics enabled to provide more effective stereo-scopic video images through scientific analyses using the state of the art 3-dimensional video technology, velocity measuring laser beam and ultra high-speed cameras.

The 14th IAAF World Championships is held at Moscow in 2013. Daegu city was designated as the City of International Athletics, for the successful hosting of 2011 Daegu World Championships in Athletics and its contribution to world athletics development, in the World Athletics Gala held by the IAAF. At least to respond this, continuous attention to and researches for sport biomechanics is needed for the development of Korean athletics, enhancement of domestic athletes abilities and winning medals in the Championships. Winning medals in the Championships and nurturing star players would be a catalyst for promotion of Korean athletics and creating citizen's interests. For decreased performance gap with the world top rank players and overcoming physical disadvantage, the sport biomechanics analyses should be applied to coaching technology and training strategies through continuous development and researches of the biomechanics. Continuous cooperation with the KAAF including awarding related MOU is also needed for continuous research. One of the regrets is that only 8 events were allowed for the analysis, and the attendance of the limited number of officials were granted while the capability of the research team exceeds it.

2. The sport biomechanics research projects performed at 2005 Helsinki, 2007 Osaka and 2009 Berlin Championships

The sport biomechanics research projects performed at 2005 Helsinki Championships resulted in more excellent effects than expected. This success of the research project team's effort resulted from the understanding and support of the Finland Athletics Federation, IAAF and organizing committee of the World Championships which regarded the research as a useful element for athletes ability development and creating citizen's interests. Proper preparation for the Championships including the installation of the ground reaction force measuring system in advance was an impressive factor. The ground reaction force measuring system is evaluated as leading the development of the ground reaction force measuring technology and signifies that proper preparation for measurement system with prior agreement is essential for successful provision of various data and development of world athletics. The sport biomechanics research team of Osaka was formed based on a science committee, which resulted from the opinion of the Japan Association of Athletics Federations, IAAF and organizing committee of the World Championships which regarded the scientific research as a useful element for athletes ability development and creating citizen's interests, which proved true. The

sport biomechanics research team of Berlin was formed for increasing athletic capabilities of the athletes, respecting citizen's right to know and increasing viewing rate of mass media. The team presented real time video images made by quantitative, qualitative and scientific analyses through mass media. The effort won popular acclaim and the technology used by the team was evaluated as being one step advanced from the analyses of the Osaka and Helsinki teams which were provided with some time-lag. This real time data provision is one of the most important elements modern mass media want to present to viewers who prefer quick feedback.

Ⅴ. Conclusion

This study aimed to identify the measures to perform biomechanics researches more effectively for development of the development of the Korean athletics through analysing the process and results of the sport biomechanics research project performed successfully during 2011 Daegu World Championships and the projects performed at previous Championships.

First, the preparation for measuring systems and surveys of the stadium prior to the Championships enabled to successfully provide correct and various information. Sufficient preparation for biomechanics research project including preparation for the measurement, rehearsals, and stadium surveys facilitates the use of more complex and various equipment that enables to create more various and precise scientific data and, in turn, to make the project more effective.

Second, it is necessary to promote more practical researches that can be utilized for athletics development and athlete's performance enhancement through data provision for coaching and establishing strategies, and application of the data to actual plays and feedback of the application.

Third, the consortium of the Daegu project team, mass media, IAAF, KAAF and organizing committee of 2011 Daegu World Championships in Athletics enabled the project team to provide the mass media with more effective stereo-scopic video images coupled by quantitative and qualitative information in real time through scientific analyses using the state of the art 2-dimensional and 3-dimensional video technology to lead to much more positive responses from TV viewers.

The sport biomechanics project team of the 2011 Daegu World Championships in Athletics proved that scientific analyses and resultant real time data play an important role in the athletics development, athlete's performance enhancement, scientific approach to sports and athletics technology development. It is hoped that this study can be assistance to coaching technology and strategy and cause wider attentions to scientific and biomechanics approaches in sports.

Biomechanics Analysis of the Men's 100 Meters Sprint during the IAAF World Championships, Daegu 2011

- Director :

  Ji-Seon Ryu(Korea National Sport University, Korea) · Jae-Kyun Ryu(Kyunghee University, Korea) Tae-Sam Kim(Korea National Sport University, Korea) · Young-Jin Park(Kyunghee University, Korea) Won-Seob Hwang(Korea National Sport University, Korea) · Suk-Hoon Yoon(Korea National Sport University, Korea) · Sang-Kyoon Park(Korea National Sport University, Korea)

- Researcher :

  Hiroyuki Koyama(Kyoto University of Education, Janpan) · Takashi Mochida(Yokohama Sports Association, Janpan) · Koji Hoga-Miura(Seikei University, Janpan) · Kazuhito Shibayama(University of Tsukuba, Janpan) · Kadono Hirosuke(University of Tsukuba, Janpan) · Tanji Hiroki(Kodaira City Kamishuku Primary School, Janpan)

1. Men's 100 Meters

The world record for the men's 100 meter race, 9.58 seconds, was set by Usain Bolt (JAM) at the IAAF Berlin World Championships (WC) 2009. Therefore, at the IAAF WC, Daegu 2011, people were anxious to see if he would break his world record. On the 28th of August, 2011, the men's 100 meter semi-finals and finals were held at 6 PM and 8:45 PM, respectively. During the IAAF WC, Daegu 2011, a team of biomechanics researchers was organized to analyze sprinting movement at the 100 meter final race (Figure 1).

Figure 1. Biomechanics research team for sprinting events

Measurement of running speed using the LAVEG system :

Three laser speed guns (LAVEG Sport, Jenoptik, Germany) were used to measure the sprinting speed (Figure 2). <Figure 2> shows the LAVEG system and the calibration process being done by two individuals in the 100 meter lane. The system measured an instant performance time at a given distance. Therefore, an instant speed of the sprinter was

Figure 2. LAVEG System calibration process (100 meter) / View from LAVEG System at the Stadium

calculated by dividing the distance by time. Data was sampled with a frequency of 100 frames per second and filtered with a low pass filter (cut off frequency: 0.5 Hz). Based on the records from the qualification rounds, three sprinters were selected for sprinting speed measurement.

The measurement of sprinting characteristics by high-speed cameras

The panning technique (Chow, 1993) was applied to capture the selected sprinting characteristics of the sprinters during the race. This method is recognized as an effective way to photograph a fast moving object using high-speed cameras. Five high-speed cameras (Casio EX-F1, Japan) operated by individuals from the research team were located in the spectator's area on the second floor of the stadium and were aligned with the 13, 30, 47, 64 and 81 meter lines (Figure 3, 4). Video imagery with a sampling frequency of 300 Hz was synchronized to the signal of the start gun. Once all the images were collected from the five cameras, software (Vegas, Sony, Japan) was used to calculate an average speed (m/sec), the number of steps (n), stride length (meter), and stride frequency (m/sec). The number of steps was visually counted from the images and, in particular, the last step was calculated from the number of sampled images at the finish line. Step length was calculated by dividing the performance distance, 100 meters, by the number of steps. Step frequency was calculated by dividing the number of steps by the performance time. The correlation coefficients between the performance time and each variable were calculated using Matlab (MathWorks, USA) with an alpha level of 0.05.

Figure 3. The locations of each high-speed camera in the stadium

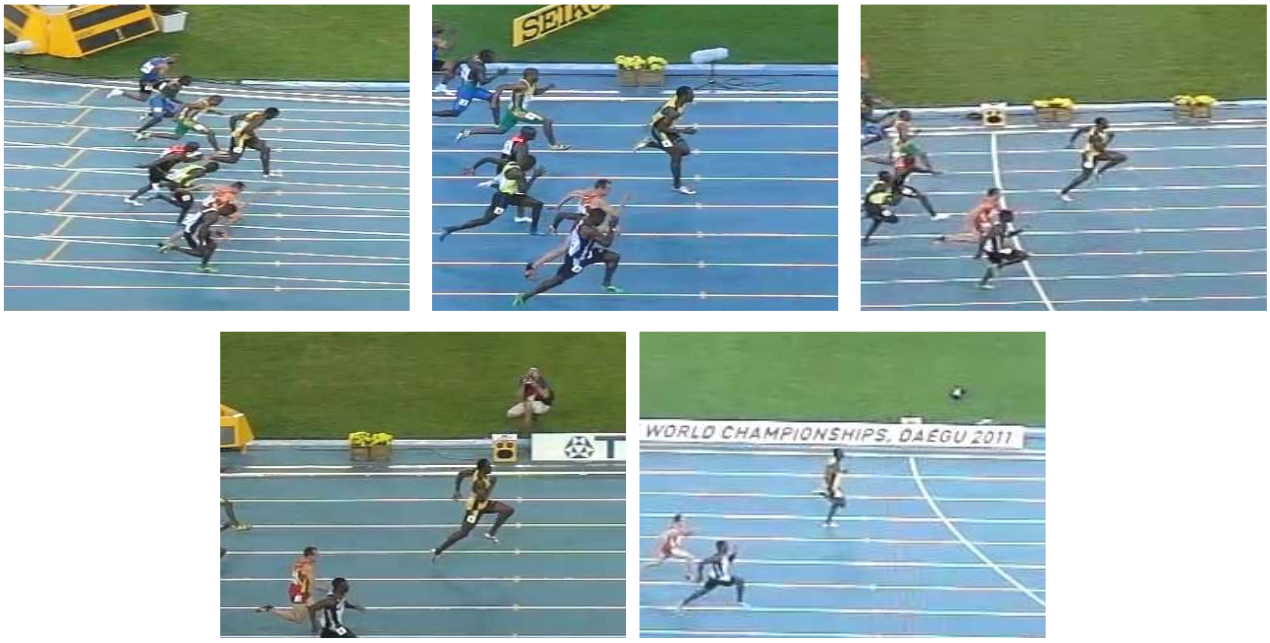


Figure 4. Camera view from the stadium (cameras 1 to 5 from the top left to right)

Usain Bolt's (JAM) qualification rounds

Usain Bolt (JAM) participated in one of the seven qualification rounds held on the 27th of August 2011. He won the race with a performance time of 10.10 seconds and with a reaction time of 0.153 seconds. His reaction time was the third best among the eight sprinters(mean : 0.167 ± 0.021 seconds) and his average number of steps was 40, which was four to thirteen less than the other sprinters (Table 1).

Table 1. Biomechanical Analysis of Men's 100 Meters Sprint (Round 1, Heat 6)

Rank	Name	Finish Time (sec)	Reaction Time(sec)	Total Steps	Avg. Step Length(m)			Avg. Step Frequency(m/sec)		
					0-47m	-64m	-100m	0-47m	-64m	-100m
1	Usain BOLT (JAM)	10.10	0.153	40	2.24	2.83	2.71	3.96	4.02	3.86
2	Dwain CHAMBERS (GBR)	10.28	0.171	44	2.04	2.43	2.71	4.24	4.58	3.90
3	Angel David RODRIGUEZ (ESP)	10.37	0.172	47	1.96	2.27	2.38	4.41	4.82	4.41
4	Simon MAGAKWE (RSA)	10.53	0.150	50	1.74	2.13	2.71	4.84	5.09	3.88
5	Nilson ANDRE (BRA)	10.54	0.146	53	1.68	2.13	2.11	4.96	5.16	5.00
6	Gerald PHIRI (ZAM)	10.60	0.211	47	1.88	2.27	2.71	4.48	4.74	3.77
7	Abdouraim HAROUN (CHA)	10.72	0.179	46	1.96	2.43	2.38	4.28	4.30	4.29
8	Moudjib TOYB (COM)	11.12	0.157	48	1.88	2.27	2.38	4.32	4.45	4.07

<Table 2> shows the changes in Usain Bolt’s sprinting speed compared to the first place sprinters in groups 5 and 7. Usain Bolt's maximum speed was 11.64 m/sec at a distance of 55.27 meters. <Table 2> indicates that Usain Bolt reacheds his maximum speed at a later stage of the race in comparison to Michael Frater (JAM) and Nester Carter (JAM), who won the first rounds in groups 5 and 7, respectively(Figure 5).

Table 2. Changes in Sprint Speed During the Men's 100 Meter Qualifying Rounds (first place in round 1, groups 5, 6 and 7, on, August 27th, 2011)

	Group/ Rank/ Lane	10m Avg. Speed (m/sec)	20m Avg. Speed (m/sec)	30m Avg. Speed (m/sec)	40m Avg. Speed (m/sec)	50m Avg. Speed (m/sec)	60m Avg. Speed (m/sec)	70m Avg. Speed (m/sec)	80m Avg. Speed (m/sec)	90m Avg. Speed (m/sec)	100m Avg. Speed (m/sec)	Max Speed (m/sec)	Distance at Max Speed	Total Time (sec)
Usain Bolt	6/1/4	5.30	9.63	10.78	11.31	11.59	11.64	11.59	11.38	10.94	10.12	11.64	55.27	10.10
Michael Frater	7/1/5	5.17	9.48	10.59	11.15	11.35	11.40	11.32	11.11	10.74	10.31	11.42	50.61	10.26
Nester Carter	5/1/3	5.33	9.57	10.69	11.12	11.25	11.29	11.21	11.00	10.66	10.17	11.31	54.55	10.26

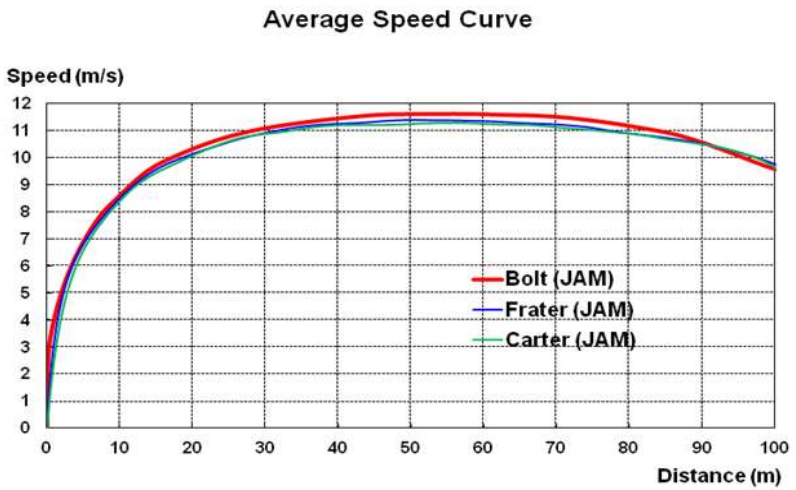


Figure 5. Average speed curve of three top sprinters in the first round of the men's 100 meter sprint

Table 3. Changes in Usain Bolt's (JAM) speed during the 100 meter sprint (Round 1 and Semi-Finals, August 27-28th, 2011)

	Rank/ Lane	Reaction Time (sec)	10m Avg. Speed	20m Avg. Speed	30m Avg. Speed	40m Avg. Speed	50m Avg. Speed	60m Avg. Speed	70m Avg. Speed	80m Avg. Speed	90m Avg. Speed	100m Avg. Speed	Max speed (m/sec)	Distance at Max Speed	Total Time (sec)
Usain Bolt(JAM) -Round 1	1/6	0.153	5.30	9.63	10.78	11.31	11.59	11.64	11.59	11.38	10.94	10.12	11.64	55.27	10.10
Usain Bolt (JAM)- Semi Final	1/3	0.164	5.30	9.58	10.71	11.32	11.58	11.71	11.71	11.61	11.25	10.15	11.72	56.17	10.05

Comparison of Usain Bolt's first round and semi-final times

When comparing the differences in magnitude and distance of maximum speed between the first round and the semi-finals, Usain Bolt's (Table 3) reaction time of 0.164 seconds in the semi-final was slower than his reaction time (0.153 seconds) in the first round but an overall maximum sprinting speed was faster in the semi-finals. His maximum speed, in the semi-finals was, 11.72 m/sec, observed at a distance of 56.17 meters, while his maximum speed in the first round of 11.65 m/sec was observed at a distance of 55.27 meters. Therefore, Usain Bolt showed a 0.05 seconds faster performance time in the semi-finals(10.05 seconds vs. 10.10 seconds).

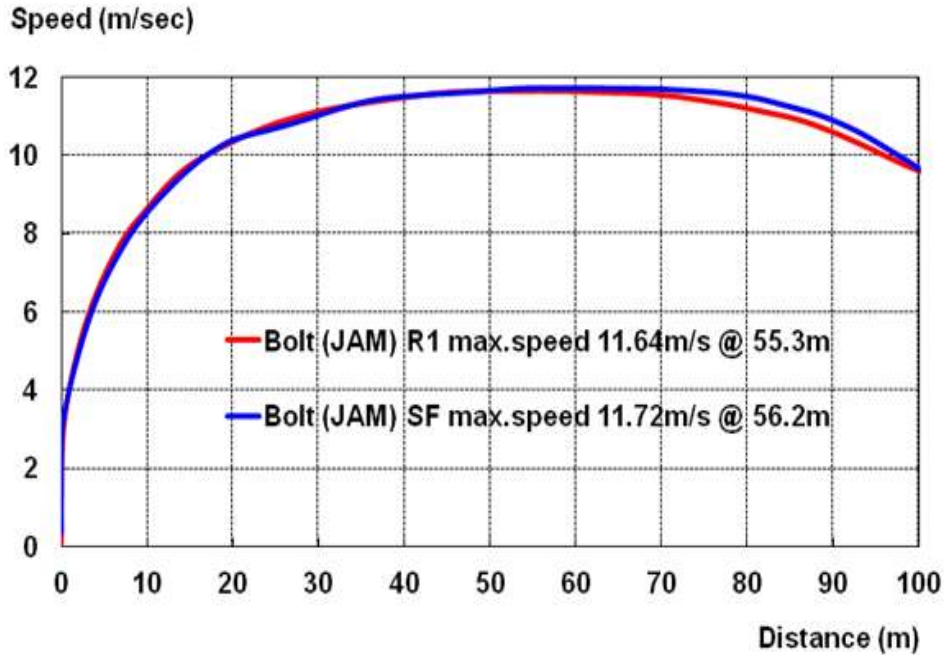


Figure 6. Average Speed Curve of Usain Bolt's Round 1 and Semi-Final

The results of the men's 100 meter finals

At the men's 100 meter finals on August 28th, 2011, Usain Bolt (JAM) had a false start which was 0.104 seconds earlier than the start gun al. His, teammate, Yohan Blake (JAM) won the race with a time of 9.92 seconds. His maximum speed was 11.75 m/sec at the distance of 57.9 meters in the finals (Table 4, Figure 7).

Table 4. Changes in Yohan Blake's Speed During the 100 Meter Sprint (Finals, August 28th, 2011)

	Rank/ Lane	10m Avg. Speed (m/sec)	20m Avg. Speed (m/sec)	30m Avg. Speed (m/sec)	40m Avg. Speed (m/sec)	50m Avg. Speed (m/sec)	60m Avg. Speed (m/sec)	70m Avg. Speed (m/sec)	80m Avg. Speed (m/sec)	90m Avg. Speed (m/sec)	100m Avg. Speed (m/sec)	Max Speed (m/sec)	Distance at Max Speed	Total Time (sec)
Yohan Blake (JAM)- Final	1/6	5.35	9.76	10.84	11.32	11.62	11.74	11.71	11.63	11.49	11.29	11.75	57.9	9.92

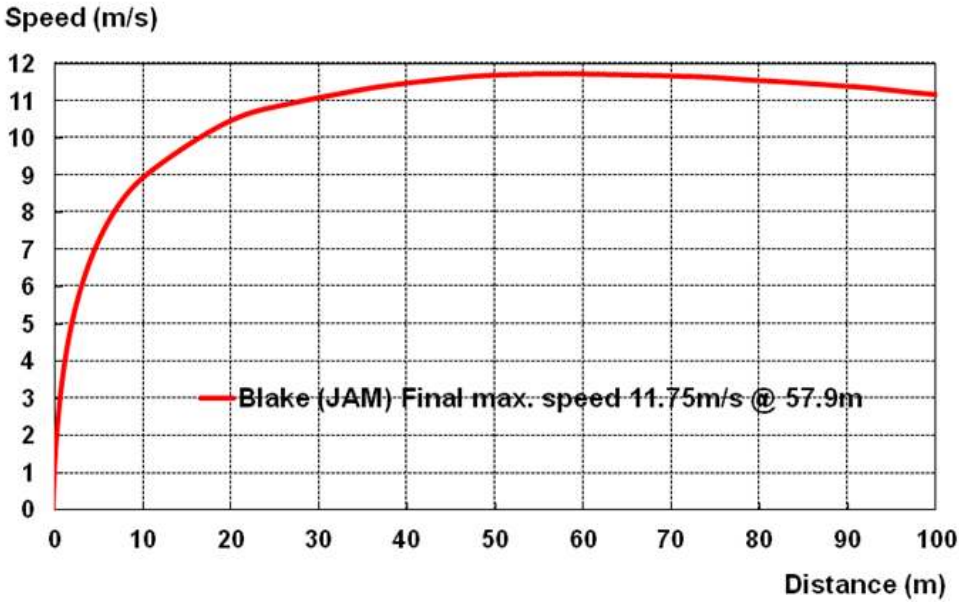


Figure 7. Average Speed Curve of Yohan Blake's 100 Meter Finals

In the final race of the men's 100 meter event, Yohan Blake's (JAM) a reaction time was of 0.174 seconds which is slower than the other sprinters but he reached his fastest sprinting speed after 30 meters, finishing the race in first place. He Took 47 steps during the race. which was similar to the average of the other sprinters, steps in the final: 46.71±2.75 (Table 5). Furthermore, Yohan Blake (JAM) showed the an ability to maintain his maximum sprinting speed until the end of the race (Figure 8).

Table 5. Biomechanical Analysis of the Men's 100 Meter Finals (Finals, August 28th, 2011)

Rank /Lane	Name	Finish Time (sec)	Reaction Time (sec)	Total Steps	Avg. Step Length (m)			Avg. Step Frequency		
					0-47 m	-64 m	-100 m	0-47 m	-64 m	-100 m
1/ 6	Yohan BLAKE (JAM)	9.92	0.174	47	1.88	2.43	2.38	4.69	4.88	4.65
2/ 4	Walter DIX (USA)	10.05	0.175	49	1.81	2.27	2.38	4.78	5.18	4.58
3/ 3	Kim COLLINS (SKN)	10.10	0.155	49	1.81	2.27	2.38	4.88	5.03	4.49
4/ 8	Christophe LEMAITRE (FRA)	10.14	0.179	41	2.14	2.62	3.17	4.03	4.38	3.40
5/ 2	Daniel BAILEY (ANT)	10.14	0.165	48	1.88	2.27	2.38	4.58	4.99	4.47
6/ 1	Jimmy VICAUT (FRA)	10.32	0.162	46	1.96	2.27	2.71	4.42	4.96	3.86
7/ 7	Nesta CARTER (JAM)	10.49	0.154	47	1.96	2.27	2.38	4.28	4.67	3.76
8/ 5	Usain BOLT (JAM)	DQ	-0.104							

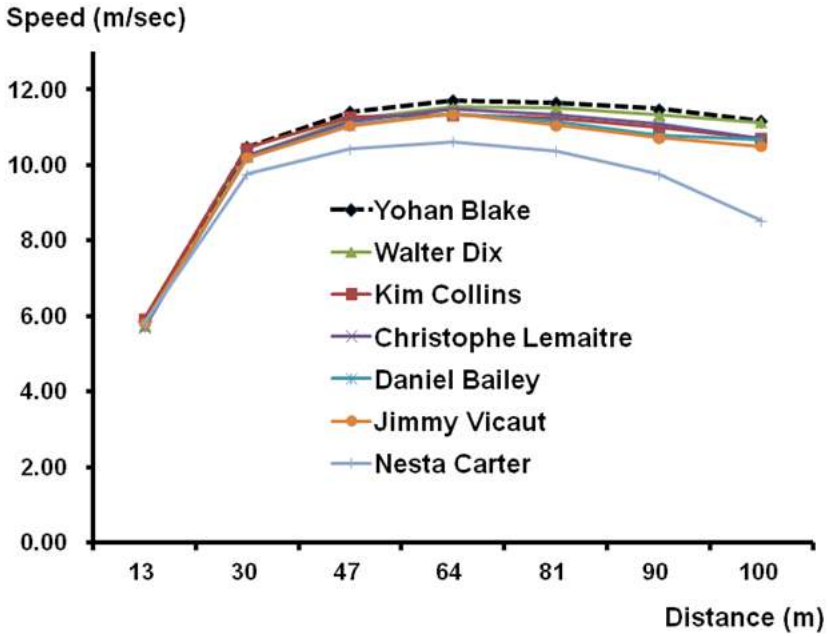


Figure 8. Average Speed Curve of the Men's 100 Meter Finals

Analysis

At the IAAF WC Daegu 2011, Yohan Blake (JAM) won the men's 100 meter finals with a time of 9.92 seconds. His performance time is not better than Tyson Gay's 9.85 seconds in the IAAF WC Osaka 2007 or Usain Bolt's 9.58 seconds in the IAAF WC Berlin 2009.

The first to third place sprinters had reaction time of 0.137 to 0.145 seconds at the IAAF WC Osaka 2007 while a reaction time of 0.137 seconds to 0.146 seconds were observed at the IAAF WC Berlin 2009. However, the three top finishers in Daegu had a reaction times of 0.155 to 0.174 seconds which were slower than those of previous competitions. In particular , Yohan Blake's reaction time of 0.174 seconds was slower than the winner of Berlin WC, Usain Bolt's 0.146 seconds and the winner of the Osaka WC, Tyson Gay's 0.143 seconds.

When comparing the maximum sprinting speed of the competitions, we find that Tyson Gay's (USA) maximum speed of 11.83 m/sec at 65 meters at the IAAF Osaka WC 2007 was faster than Yohan Blake's (JAM) maximum speed of 11.75 m/sec at 57.9 meters at the IAAF Daegu WC 2011.

References

Chow, J. W.(1993) Panning video graphic technique to obtain selected kinematics characteristics of the stride in sprint hurdling. *Journal of Applied Biomechanics*, 9(2).149-159.

Biomechanical Analysis of the Women's 100 Meters Sprint at the IAAF World Championships Daegu 2011

• Director :

Ji-Seon Ryu(Korea National Sport University, Korea) · Jae-Kyun Ryu(Kyunghee University, Korea) Tae-Sam Kim(Korea National Sport University, Korea) · Young-Jin Park(Kyunghee University, Korea) Won-Seob Hwang(Korea National Sport University, Korea) · Suk-Hoon Yoon(Korea National Sport University, Korea) · Sang-Kyoon Park(Korea National Sport University, Korea)

• Researcher :

Hiroyuki Koyama(Kyoto University of Education) · Takashi Mochida(Yokohama Sports Association) Koji Hoga-Miura(Seikei University) · Kazuhito Shibayama(University of Tsukuba)
Kadono Hirosuke(University of Tsukuba) · Tanji Hiroki(Kodaira City Kamishuku Primary School)

2. Women's 100 Meters

The women's 100 meter world record of 10.49 seconds was set by Florence Griffith-Joyer (USA) in the quarter-finals of the US Olympic Trials and has not been broken for over 20 years. Camelita Jeter (USA) or Veronica Campbell-Brown (JAM) were predicted to win the women's 100 meter event at the IAAF Daegu World Championships (WC) 2011. Carmelita Jeter had recorded the fastest time for the season, while Veronica Campbell-Brown had the fastest qualifying time in Daegu. After the qualification rounds for seven groups followed by three semi-final races, the eight finalists were selected for competing at the final race on the evening of the 29th of August, 2011. Carmelita Jeter had recorded the fastest time for the qualification rounds for seven groups followed by three semi-final races, the eight competitors were selected to compete at the final race on the final race on the evening of August 29th, 2011. Carmelita Jeter (USA) won the race with a time of 10.90 seconds, followed by Veronica Campbell-Brown (JAM) and Kelly-Ann Baptiste (TRI), with times of 10.97 seconds and 10.98 seconds, respectively.

The biomechanics research team, supported by the IAAF has been actively involved in the scientific support of world class competitions since the Rome WC in 1987 and the 1988 Seoul Summer Olympic Games. The purpose of the biomechanics project during the IAAF WC, Daegu 2011 was, to analyze the sprinting characteristics of the finalists in the women's 100 meter event.

Methods

Biomechanical analysis was conducted to capture the movements of the eight finalists(mean age: 26.38 ± 2.92 years, mean height : 168.75 ± 7.05 cm, mean weight: 56.50 ± 5.76 kg) in the women's 100 meter final event (Table 1).

Table 1. Eight finalists in the women's 100 meter final event

Rank	Name	Country	Lane	Results (sec)
1	Carmelita Jeter	USA	4	10.90
2	Veronica Campbell-Brown	JAM	8	10.97
3	Kelly-Ann Baptiste	TRI	5	10.98
4	S.A. Fraser-Pryce	JAM	3	10.99
5	Blessing Okagbare	NGR	2	11.12
6	Kerron Stewart	JAM	6	11.15
7	Ivet Lalova	BUL	1	11.27
8	Marshevet Myers	USA	7	11.33

Laser gun(Laveg Sport, Jenoptik, Germany) was used to measure the speed of sprinting. The system measured an instant performance time at a given distance, therefore, an instant speed of the sprinter was calculated by the distance divided by time. Data was sampled with a frequency of 100 frames per second and filtered with a low pass filter (cut-off frequency : 0.5 Hz).

Panning technique (Chow, 1993) was applied to capture the selected sprinting characteristics of the sprinters during the race. This method is known as an effective way to photograph a fast moving object with a fast shutter speed. Five high speed cameras operated by each individual from the team were located at the spectator's area on the second floor of the stadium (Figure 1). The video image with a sampling frequency of 300 Hz was synchronized to the sign of the start gun going off near the start line. Once all the images were collected from the five cameras, software (Vegas, Sony, Japan) was used to calculate an average speed (m/sec), the number of steps (n), stride length (meter), and stride frequency (m/sec). The number of steps is visually counted from the image and, especially, the last step was calculated from the number of sampled images at the finish line. The step length is calculated by the performance distance, 100 meter, divided by the number of steps. The step frequency is calculated by the number of steps divided by the performance time. The correlation coefficients between the performance time and each variable were calculated using Matlab program (Math Works, USA) with an alpha level of 0.05.

Figure 1. High speed camera (Casio, EX-F1, Japan) and the locations of each camera at the stadium

Results

Carmelita Jeter (USA) won the race with a record of 10.90 seconds. She reached maximum speed of 10.54 m/sec at the distance of 58.4 meters in the final (Figure 2, Table 2).

Table 2. Changes in speed of Carmelita Jeter's 100meter sprint in the final

	Rane / Lane	10m Avg. speed (m/sec)	20m Avg. speed (m/sec)	30m Avg. speed (m/sec)	40m Avg. speed (m/sec)	50m Avg. speed (m/sec)	60m Avg. speed (m/sec)	70m Avg. speed (m/sec)	80m Avg. speed (m/sec)	90m Avg. speed (m/sec)	100m Avg. speed (m/sec)	Max speed (m/sec)	Distance (m) at Max Speed	Total Time (sec)
Carmelita JETER (USA)	1/4	5.16	8.99	9.95	10.39	10.51	10.53	10.43	10.25	10.12	9.83	10.54	58.4	10.90

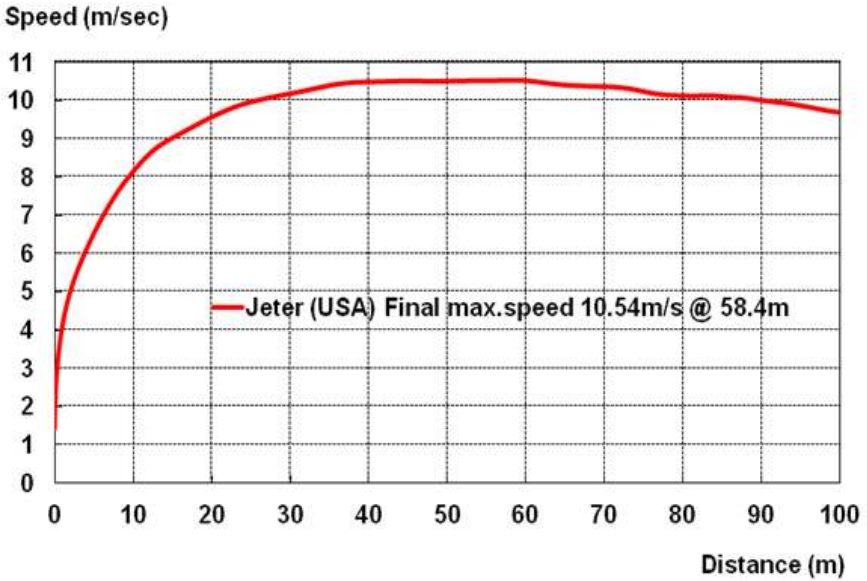


Figure 2. Average speed curve of Carmelita Jeter's (USA) 100 meters final

Carmelita Jeter (USA) and S.A. Fraser-Pryce (JAM) were competing first place between 50 meters and 80 meters but Carmelita Jeter was able to maintain a high level of sprinting speed during the last 10 meters (Table 3).

Table 3. Biomechanical Analysis of 100 meter women's sprint

Rank/ Lane	Name	Parameter	0-13m	-30m	-47m	-64m	-81m	-89.5m	-100m	Total teps	Avg. SL	Avg. SF
1/ 4	Carmelita JETER (USA)	Lap time (sec)	2.32	4.11	5.73	7.35	8.97	9.80	10.90	50.5	1.98	4.63
		Avg. Speed (m/s)	5.60	9.53	10.47	10.52	10.45	10.32	9.52			
2/ 8	Veronica CAMPBELL - BROWN (JAM)	Lap time (sec)	2.39	4.17	5.81	7.42	9.03	9.85	10.97	49.6	2.02	4.52
		Avg. Speed (m/s)	5.44	9.57	10.34	10.54	10.60	10.37	9.35			
3/ 5	Kelly-Ann BAPTISTE (TRI)	Lap time (sec)	2.20	4.11	5.76	7.39	9.02	9.85	10.98	50	2.00	4.55
		Avg. Speed (m/s)	5.92	8.87	10.32	10.43	10.41	10.24	9.32			
4/ 3	S. A. FRASER - PRYCE (JAM)	Lap time (sec)	2.32	4.10	5.73	7.35	8.98	9.85	10.99	50	2.00	4.55
		Avg. Speed (m/s)	5.60	9.53	10.47	10.45	10.43	9.85	9.18			
5/ 2	Blessing OKAGBARE (NGR)	Lap time (sec)	2.36	4.14	5.84	7.49	9.15	9.99	11.12	47.4	2.11	4.26
		Avg. Speed (m/s)	5.50	9.59	10.00	10.30	10.24	10.12	9.26			
6/ 6	Kerron STEWART (JAM)	Lap time (sec)	2.38	4.18	5.84	7.50	9.14	9.98	11.15	47	2.13	4.22
		Avg. Speed (m/s)	5.47	9.41	10.24	10.28	10.32	10.20	8.95			
7/ 1	Ivet LALOVA (BUL)	Lap time (sec)	2.38	4.22	5.94	7.60	9.27	10.12	11.27	50	2.00	4.44
		Avg. Speed (m/s)	5.46	9.24	9.90	10.20	10.22	9.92	9.16			
8/ 7	Marshevet MYERS (USA)	Lap time (sec)	2.41	4.25	5.94	7.62	9.28	10.14	11.33	47.6	2.10	4.20
		Avg. Speed (m/s)	5.39	9.26	10.04	10.14	10.22	9.96	8.80			

Based on the results, there was a tendency to show the relationship between the sprinters' performance time and their physical characteristics. Lighter weight and shorter height seen to be positively related with performance time based on the correlation analysis, but it was not statistically significan t(Figure 3).

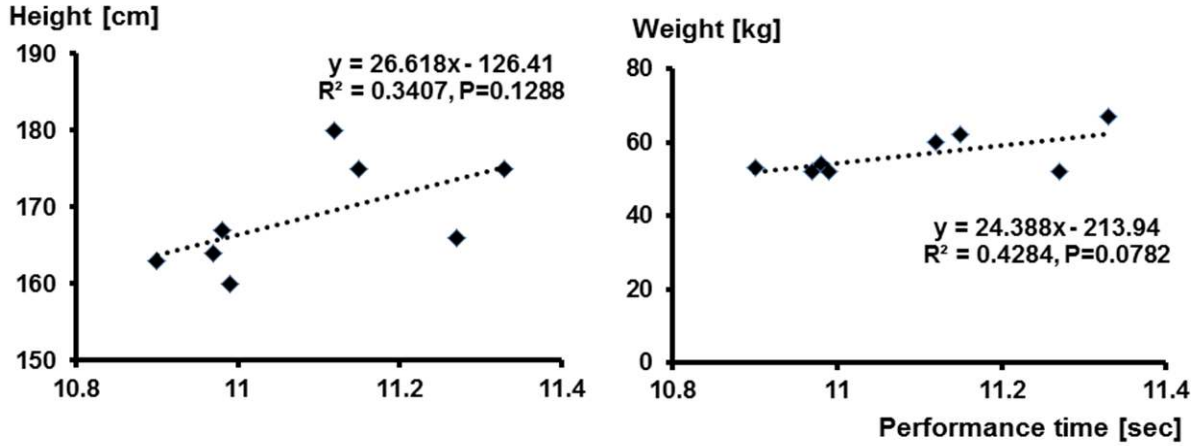


Figure 3. Correlation coefficients between the performance time and sprinters' height and weight

<Table 4> shows the sprinters sprinting characteristics such as reaction time, the number of steps, step length, and step frequency. Performance time ranged from 10.90 seconds to 11.33 seconds with a range of 0.147 seconds and 0.234 seconds of reaction time. The number of steps ranged from 47.00 steps to 50.50 steps with a range of 1.98 meter and 2.13 meter in step length. The first place sprinter showed the highest step frequency with the highest number of steps and the shortest step length among the eight finalists.

Table 4. Descriptive data of eight sprinters during women's 100 meter final

Rank	Time (sec)	Reaction time (sec)	# of steps (n)	Step length (meter)	Step frequency (# of steps/sec)
1	10.90	0.167	50.50	1.98	4.63
2	10.97	0.234	49.60	2.02	4.52
3	10.98	0.151	50.00	2.00	4.55
4	10.99	0.194	50.00	2.00	4.55
5	11.12	0.147	47.40	2.11	4.26
6	11.15	0.212	47.00	2.13	4.22
7	11.27	0.156	50.00	2.00	4.44
8	11.33	0.164	47.60	2.10	4.20
Mean ± SD	11.09 ± 0.15	0.178 ± 0.032	49.01 ± 1.42	2.04 ± 0.06	4.42 ± 0.17

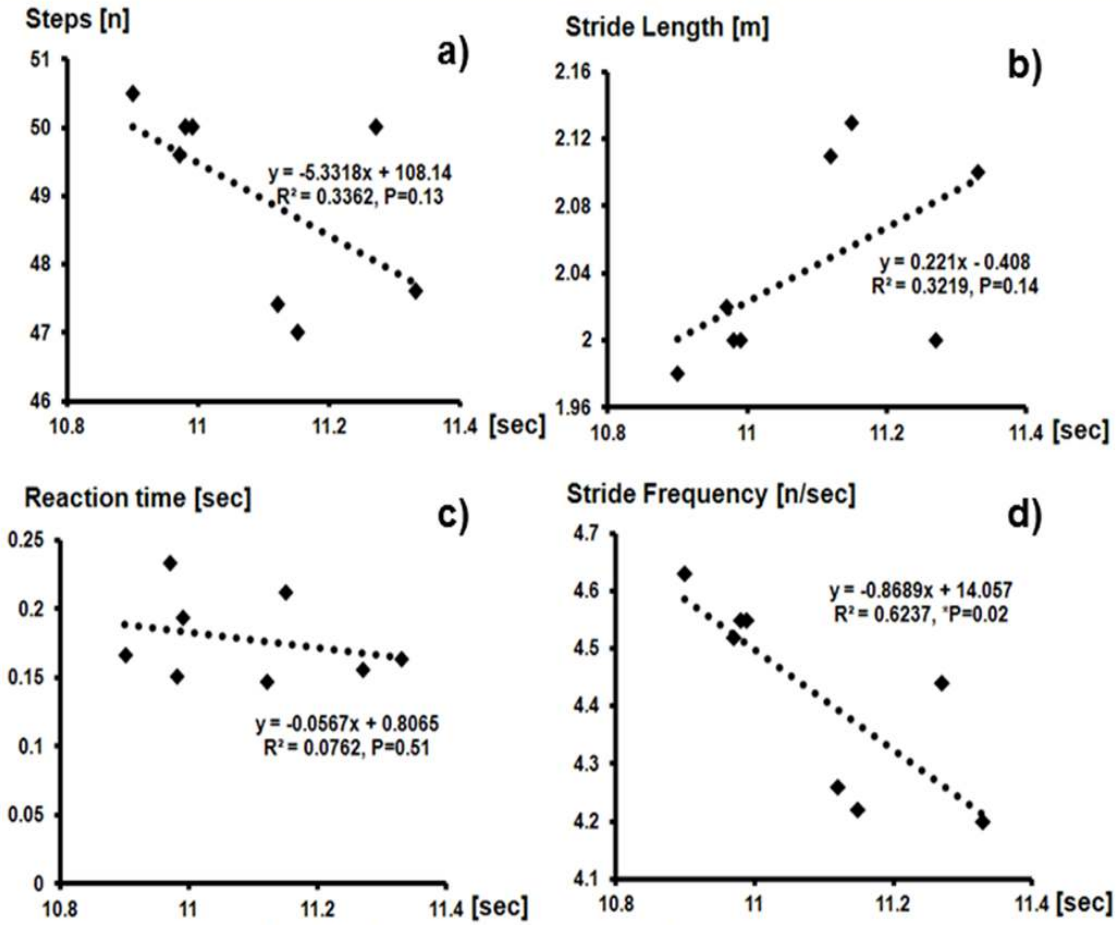


Figure 4. Correlation coefficients between the performance time and the sprinting characteristics (a: # of steps, b: stride length, c: reaction time, and d: stride frequency)

<Figure 4> shows the linear relationship between performance time and sprinting characteristics. There was a trend that showed a significant correlation between the sprinters' sprinting characteristics and their performance time. Especially, a faster stride frequency has a positive impact on performance time (R=0.7897, P=0.02). Furthermore, a higher number of steps and shorter stride length seemed to be related with the faster performance time but was not significant. The reaction time and performance time of the sprinters were not related.

Conclusion

A mathematical model proposed by Peronnet & Thibault (1989) has predicted that the ultimate performance time of a 100 meter sprinting would be 9.37 seconds for men and 10.15 seconds for women. In Berlin WC 2009, Usain Bolt (JAM) in the men's 100 meters event broke the world record with a record of 9.58 seconds but no strong female sprinters has stepped up to break Florence Griffith-Joyner's (USA) current record, 10.49 seconds for over 20 years. This research was conducted during the 100 meter women's event in the IAAF

Daegu 2011 and aimed to provide useful information to track and field coaches and athletes through the analysis of sprinting strategies of today's top female sprinters.

It is generally accepted that a quicker reaction time to start the 100 meter sprint is critical to perform the best race. When Veronica Campbell-Brown (JAM) won the race with a record of 11.01 seconds in Osaka WC 2007, her reaction time was 0.167 second and the second place, Williams (USA)'s reaction time was 0.145 seconds (JAAF, 2007). On the other hand, Fraser Shelly-Ann (JAM) won her race with a record of 10.73 seconds and with a reaction time of 0.146 seconds in Berlin WC 2009. Finally, in Daegu WC 2011, the reaction time of the top three sprinters was 0.167 seconds, 0.234 seconds, and 0.151 seconds, respectively. Carmelita Jeter (USA) who won the women's 100 meter final race with a record of 10.90 seconds, showed a reaction time of 0.167 seconds. This was slower than her reaction time of 0.160 seconds in Berlin WC 2009. However, there was no direct relationship found between reaction time at the start and final performance time of the race.

Based on the relationship between performance time and the sprinters' physical characteristics, the lighter and shorter sprinters seem to perform better among the eight finalists. It was found that top four sprinters' physical characteristics were ranged from 160 cm to 167 cm in height and 52 kg to 54 kg in weight. On the other hand, heavier sprinters seem to perform better but the height of the sprinters does not seem to be related to performance time when analyzing the men's 100 meter final event at Daegu WC 2011. There would be an existing gender difference between men and women but further investigation would be required to find the exact relationships between performance and physical characteristics based on the higher number of the top sprinters in the analysis.

There was a tendency to show a better performance time with a higher number of steps and a shorter stride length among the eight sprints. Furthermore, stride frequency and performance time were negatively correlated, as a higher stride frequency had a positive impact on performance time. Therefore, female sprinters using a short step length and a fast stride cycle during their sprints would see a positive impact on their performance. Furthermore, the unpublished data of men's sprinting characteristics in 100 meter in Dague 2011 also show a similar trend between sprinting characteristics and performance time but the relationship was weaker than women sprinters'.

A previous study investigated the sprinting strategies of male sprinters who have an average record of 11.09±0.15 seconds (Mackala, 2007). The study suggested that an appropriate adjustment of step frequency and step length in the first 10 to 20 meters of a race is important to perform the best in a 100 meter race. Therefore, how the sprinters change sprinting characteristics such as stride length and frequency during acceleration, mid-race, and finish phases would be required to understand the sprinting strategy of today's top class

sprinters in the women's 100 meter.

References

Chow, J. W. (1993). Panning video graphic technique to obtain selected kinematics characteristics of the stride in sprint hurdling. *Journal of Applied Biomechanics*, 9(2), 149-159.

JAAF (2007). *Biomechanics report of Japan biomechanics research project in IAAF World Championships in athletes for the 2007 Osaka WC*(Edited by Ae, M.), Japan Association of Athletes Federations.

Mackala, K. (2007). Optimisation of performance through kinematic analysis of the different phases of the 100 metres. *New Studies in Athletes*, 22(2), 7-16.

13th IAAF World Championships, Daegu 2011 Final Report : Men's Pole Vault

- Director :

  Kyoo Jeong Choi (Korea Institute of Sport Science (KISS))

  Ok Kyung Yi (Professor, Ewha Woman's University, Korea)

- Researcher :

  Nam Hee Kim(Ewha Woman's University Doctoral Candidate, Korea) · Ji Eun Kang (Ewha Woman's University Doctoral Candidate, Korea) · Hye Lim Kim (Ewha Woman's University Master's Candidate, Korea)

3. Men's Pole Vault

At the 2011 Daegu World Track and Field Competition, five sets of video cameras were used to analyze male pole vaulters during the preliminary (28 competitors) and final (8 competitors) competitions. There were two staggered, parallel pole vault pits operating during the competition. Camera three recorded a frontal view of vaulters at pit A. Camera four captured a frontal view of vaulters at pit B. In the sagittal plane two cameras were used to record movement for both pits. Camera one covered the vaulter's initial approach, while camera two recorded the final approach and vault. The fifth camera was used to record statistical information about the vaulters on the stadium's display screen (Figure 1). DLT sets were used for two-dimensional analysis (Figure 2). Analytical variables included total approach distance, number of steps, mean step length, approach position, and average velocity from 6~11 meters away from the pole box.

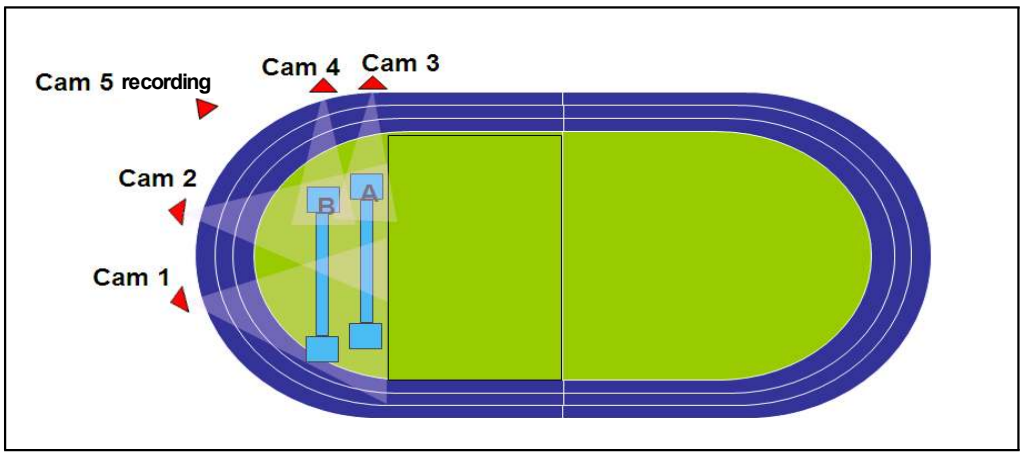


Figure 1. The layout of cam 1-5 for recording pole vault competition

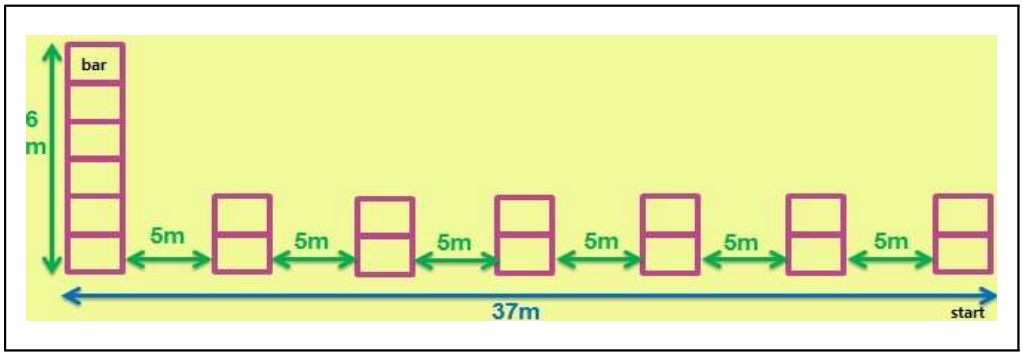


Figure 2. The layout of DLT for calibration

Preliminary competition began at 10:38 AM on a calm morning on August 27th, 2011. 28 athletes were separated into group A and group B. The two groups included seven of the IAAF's top-ten rated pole-vaulters. The opening height for the preliminary rounds in Daegu

was 5.20 m, 0.5 m higher than at the 2009 Berlin International Track & Field Competition, but 0.5 m lower than at the 2008 Beijing Olympics. Qualification height was preset at 5.70 m lower than the preset qualifying height for Beijing and Berlin by 0.5 m. From 5.20 m, qualifying heights increased to 5.35 m, 5.50 m, and 5.60 m, with the field being set at 5.65 m. 16 athletes qualified for the championship round. In Beijing, preliminary competition began at 5.15 m, increasing to 5.30 m, 5.45 m, and 5.55 m, with the field being set at 5.65 m. 12 athletes qualified for the championship round. In Berlin, qualifying rounds started at 5.25 m, increasing to 5.40 m, and 5.55 m, with the field being set at 5.65 m. 11 athletes qualified for the championship round. At all three events, the final qualifying height for the championship round was reset to 5.65 m after the field narrowed down.

The championship rounds for pole vault started at 7:25 PM on August 29th, 2011. The average age of the 16 finalists was 26.5 similar to the mean age of the 12 pole vault finalists in Beijing (26.2), but a year younger than the mean age of the 11-man field in Berlin (27.6). During the championship rounds two competitors achieved their season's best vaults (M. Mohr and K. Fillippidis), while two other vaulters set personal records (L. Borges and L. Michalski) (Table 1).

Table 1. Competition results in relation to 2011 season's best (before the World Championships)

Athlete	Rank	SB 2011 (m)	IAAF WCh Daegu 2011 (m)	Difference (%)
Wojciechowski, P. (POL)	1	5.91	5.90	-0.2
Borges, L. (CUB)	2	5.75	5.90	+2.6
Lavillenie ,R. (FRA)	3	5.90	5.85	-0.8
Michalski, L. (POL)	4	5.75	5.85	+1.7
Mohr, M. (GER)	5	5.81	5.85	+0.7
Filippidis, K. (GRE)	6	5.73	5.75	+0.3
Didenkow, M. (POL)	7	5.75	5.75	0.0
Silva, F. (BRA)	8	5.80	5.65	-2.6

Results for analytic variables

Analytic variables for the pole vault, such as total run up distance, number of steps, average step length, and ratio (%) were measured (Table 2). Due to pole vaulting equipment left on the field, the first two steps for four of the eight finalists could not be clearly recorded. Consequently, the information for the first two steps for these four competitors could not be included into the analysis, resulting in an slight decrease in total run up distance, along with as light increase in average step length, and ratio.

Total run up distance averaged 34.0 m. Total number of steps averaged 17.5.

These numbers were slightly lower than the 2009 Berlin results. Average step length was 2.10 m, while the ratio of average step length to height was 114.5%.

Table 2. Analytical Variables: Athlete´s height, total run-up distance, number of run-up steps, average step length and the ratio to his height

Athlete	Height (m)	Total Run-up Distance (m)	# of Steps (step)	Average Step Length (m)	Ratio (%)
Wojciechowski, P. (POL)	1.85	33.34	16(SS)***	1.96	106.0
Borges, L. (CUB)	1.78	34.04*	20	2.27**	127.5
Lavillenie, R. (FRA)	1.76	33.59*	18	2.10**	119.3
Michalski, L. (POL)	1.89	34.20*	18(SS)***	2.14**	113.2
Mohr, M. (GER)	1.92	35.62	16	2.23	116.2
Filippidis, K. (GRE)	1.88	37.35	18	2.08	110.6
Didenkow, M. (POL)	1.80	33.42	16(SS)***	1.97	109.4
Silva, F. (BRA)	1.78	30.43*	18	2.03**	114.0
Average	1.83	34.00	17.5	2.10	114.5

*the total run-up distance is not exactly accurate due to interference with the filming of first 1-2 steps
**average step length has obtained except the first 1-2 step, so slightly higher than real
***additional 1 short step for preparation first step

Step analysis was divided into three sections: early (the final 15th-11th steps), middle (the final 10th-6th steps), and final (the last 5 to the final step).

Early average step length was 2.07 m (step length / height ratio: 112.8%), increasing during middle average step length to 2.21 m (120.8% ratio), and decreasing during final average step length to 2.12 m (115.9% ratio). Figure 3 shows the average step length according to all three stages for Poland's P. Wojciechowski, the first place vaulter in Daegu.

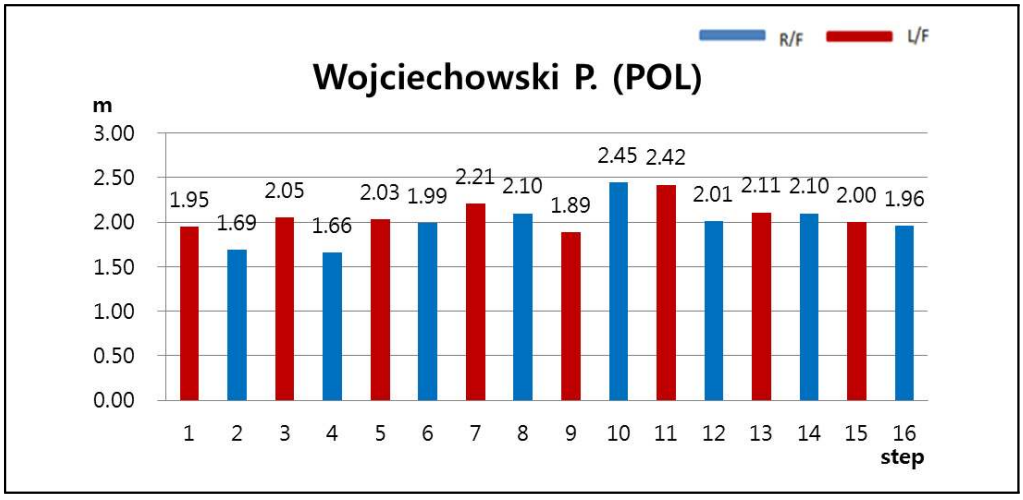


Figure 3. Each step length for run-up (P. Wojciechowski)

Table 3. Average step length for the 15-11 step, 10-6 step and 5-1 step sections

(unit : m)

Athlete	Height	Average step length (*)		
		Last 15 - 10 step	Last 10 - 6 step	Last 5 - 1 step
Wojciechowski P. (POL)	1.85	1.88 (101.6)	2.21 (119.5)	2.04 (110.3)
Borges L. (CUB)	1.78	2.42 (136.0)	2.24 (125.8)	2.15 (120.8)
Lavillenie R. (FRA)	1.76	2.05 (116.5)	2.17 (123.3)	2.09 (118.8)
Michalski L. (POL)	1.89	2.09 (110.6)	2.20 (116.4)	2.20 (116.4)
Mohr M. (GER)	1.92	2.25 (117.2)	2.31 (120.3)	2.19 (114.1)
Filippidis K. (GRE)	1.88	2.00 (106.4)	2.26 (120.2)	2.21 (117.6)
Didenkow M. (POL)	1.80	1.90 (105.6)	2.20 (122.2)	2.07 (115.0)
Silva F. (BRA)	1.78	1.94 (109.0)	2.11 (118.5)	2.04 (114.6)
Average	1.83	2.07 (112.8)	2.21 (120.8)	2.12 (115.9)

(*) represents the ratio of step length to his height

Table 4 shows the results for vault height (m), number of steps (step), velocity or VA (m/s)(at 11 m-6 m from pole box), and approach position or AP (m) (distance from pole box and final foot strike) from the 2009 World Championships in Berlin alongside the results from Daegu in 2011.

The average vault height for competitors in 2011 at Daegu was 5.81 m, an increase from the 2009 World Championships in Berlin (5.75 m) and the 2008 Olympics in Beijing (5.73 m) by 6 cm and 8 cm respectively. Approach velocity increased by 0.08 m/s in Daegu (9.26 m/s), compared to 9.18 m/s in 2009 in Berlin. Approach position increased as well by 0.22 m in Daegu (4.44 m) compared to Berlin (4.22 m). A trend emerges when comparing the 2009 Berlin results with the 2007 results from Stuttgart. Athletes increased their approach position by 0.23 m, indicating a higher grip or a longer pole. R. Lavillenie of France increased his approach position more than any other athlete. In Berlin, his approach position averaged 4.65 m from the pole box, while in Daegu, his approach position averaged 4.79 m, an increase of 14 cm. Not surprisingly R. Lavillenie (FRA) employed the free-take off technique in both competitions.

Table 4. Jumping height, run-up velocity V_A in section 11-6 m, number of run-up steps and take-off position AP

IAAF WCh Berlin 2009					IAAF WCh Daegu 2011				
Athlete	Records (m)	# of Steps (step)	V_A (m/s)	AP (m)	Athlete	Records (m)	# of Steps (step)	V_A* (m/s)	AP** (m)
Hooker, S. (AUS)	5.90	18	9.24	4.35	Wojciechowski, P. (POL)	5.90	16(SS)***	9.05	4.50
Mesnil, R. (FRA)	5.85	18	8.99	4.15	Borges, L. (CUB)	5.90	20	9.48	4.55
Lavillenie, R. (FRA)	5.80	20	9.54	4.65	Lavillenie, R. (FRA)	5.85	18	9.63	4.79
Mazuryk, M. (UKR)	5.75	18	9.12	4.30	Michalski, L. (POL)	5.85	18(SS)***	9.09	4.51
Gripich, A. (RUS)	5.75	16	8.73	4.25	Mohr, M. (GER)	5.85	16	9.05	4.47
Dossevi, D. (FRA)	5.75	20	9.35	3.60	Filippidis, K. (GRE)	5.75	18	9.34	3.80
Gibilisco, G. (ITA)	5.65	18	9.07	4.25	Didenkow, M. (POL)	5.75	16(SS)***	9.09	4.48
Straub, A. (GER)	5.65	18	9.35	4.20	Silva, F. (BRA)	5.65	18	9.31	4.45
Lewis, S. (GBR)	5.65	18	9.24	4.25					
Average	5.75	18.22	9.18	4.22	Average	5.81	17.50	9.26	4.44

* the velocity has analyzed in the run-up section between 11-6 m from the pole box

**AP has analyzed the distance between cut-in box and the last heel strike

***additional 1 short step for preparation first step

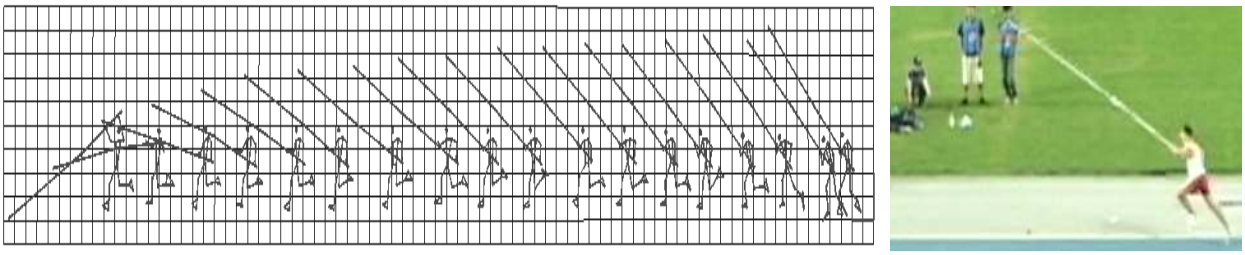


Figure 4 Stick Figure and photo of Wojciechowski P. (POL)

To summarize, the results for men's pole vault run up variables at the Daegu 2011 World Track and Field Competition show a steady increase when compared to results from the 2009 World Championships in Berlin. Specifically, run up velocity and approach position increased. This increase in approach position can also indicate that vaulters took a higher grip position than before, requiring athletes to increase their power. Consequently, run up speed and approach position have proven to be crucial variables when evaluating pole vault performance. However, the run up speed and approach position for the first place finisher were relatively low compared to other top performers, indicating that some other variables outside of this study must account for his winning performance. In order to continue to develop the research around pole vault performance, future studies should expand their variables to include previously excluded factors such as other stages of the vault like plant and take off, swing up, extension, etc.

13th IAAF World Championships, Daegu 2011 Final Report : Women's Pole Vault

- Dircector :

  Kyoo Jeong Choi(Korea Institute of Sport Science (KISS))

  Ok Kyung Yi(Professor, Ewha Woman's University, Korea)

- Researcher :

  Nam Hee Kim(Ewha Woman's University Doctoral Candidate, Korea) · Ji Eun Kang(Ewha Woman's University Doctoral Candidate, Korea) · Hye Lim Kim Ewha Woman's University Master's Candidate, Korea)

4. Women's Pole Vault

At the 2011 Daegu World Championships, five sets of video cameras were used to analyze female pole vaulters (9 competitors) during the final competition. There were two staggered, parallel pole vault pits operating during the competition. Camera three recorded a frontal view of vaulters at pit A. Camera four captured a frontal view of vaulters at pit B. In the sagittal plane two cameras were used to record movement for both pits. Camera one covered the vaulter's initial approach, while camera two recorded the final approach and vault. The fifth camera was used to record statistical information about the vaulters on the stadium's display screen (Figure 1). DLT sets were used for two-dimensional analysis (Figure 2). Analytical variables included total approach distance, number of steps, mean step length, approach position, and average velocity from 6~11 meters away from the pole box.

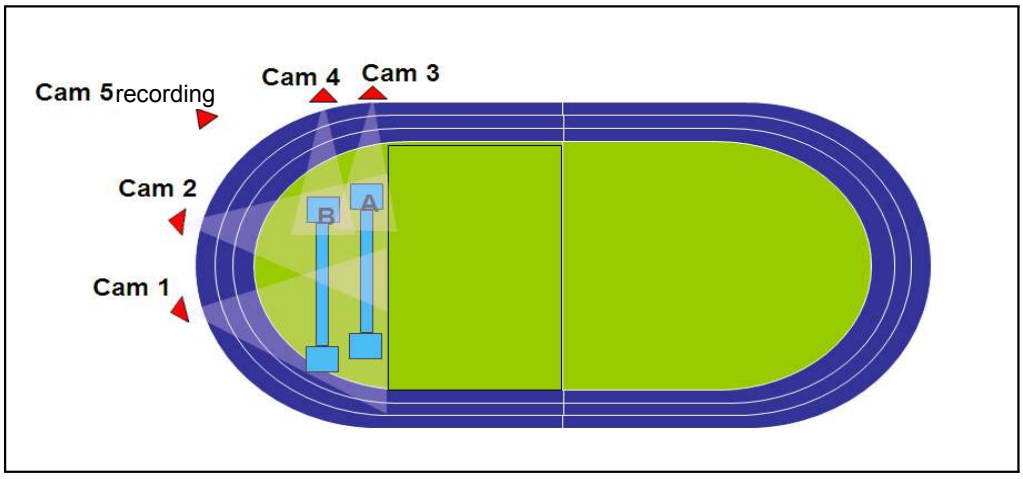


Figure 1. The layout of cams 1-5 for recording pole vault competition

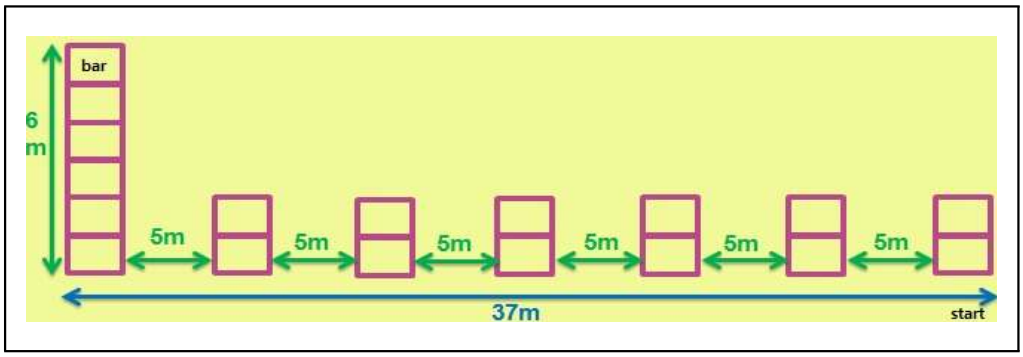


Figure 2. The layout of DLT for calibration

Preliminary competition began on a calm morning on August 28th, 2011. 34 athletes were separated into group A and group B. The two groups included all ten of the IAAF's top-ten rated female pole-vaulters, compared to the 2009 Berlin competition, where only eight of the IAAF's

top-ten competed. Nine of those top ten athletes moved on to the final round of competition.

Qualification height was preset at 4.60m the same as the preset qualifying height for Beijing and Berlin. From 4.10m, qualifying heights increased to 4.25 m, 4.40 m, 4.50 m, and 4.55 m. 12 athletes qualified for the championship round. In Beijing, preliminary competition began at 4.00 m, increasing to 4.15 m, 4.30 m, 4.40 m and 4.50 m. In Berlin height progression was the same as in Daegu.

The pole vault championship rounds started at 7:05PM on August 30th, 2011. The average age of the 9 finalists was 27.9 slightly older than the pole vault finalists in Beijing (26.7) and Berlin (26.7). During the championship rounds three competitors achieved their season's best vaults (F. Murer; S. Feofanova; J. Ptacnikova), while two other vaulters set personal records (M. Sturutz; Y. Silva) (Table 1).

Table 1. Competition results in relation to season's best 2011(before the World Championships)

Athlete	Rank	SB 2011 (m)	IAAF WCh Daegu 2011 (m)	Difference (%)
Murer, F. (BRA)	1	4.71	4.85	+3.0
Sturutz, M. (GER)	2	4.78	4.80	+0.4
Feofanova, S. (RUS)	3	4.71	4.75	+0.8
Suhr, J. (USA)	4	4.91	4.70	-4.3
Silva, Y. (CUB)	5	4.66	4.70	+0.9
Isinvaeva, E. (RUS)	6	4.76	4.65	-2.3
Ptacnikova, J. (CZE)	7	4.60	4.65	+1.1
Kiriakopoulou, N. (GRE)	8	4.71	4.65	-1.3

Results for analytic variables

Analytic variables for the women's pole vault finalists, such as total run up distance, number of steps, average step length, and ratio (%) were measured. (Table 2).

Average height of the finalists was 1.69 m. Total run up distance averaged 30.54 m. The total number of steps averaged 16.25. These numbers was slightly higher than the 2009 Berlin results (15.88). Average step length was 1.87 m, while the ratio of average step length to height was 110.8%.

Table 2. Athlete´s height, total run-up distance, number of run-up steps, average step length and the ratio to her height

Athlete	Height (m)	Total Run-up Distance (m)	# of Steps (step)	Average Step Length (m)	Ratio (%)
Murer, F. (BRA)	1.72	33.19	18	1.84	107.0
Sturutz, M. (GER)	1.60	30.42	16(SS)*	1.79	111.9
Feofanova, S. (RUS)	1.63	29.54	16	1.85	113.5
Suhr, J. (USA)	1.83	32.27	18	1.79	97.8
Silva, Y. (CUB)	1.61	28.22	14	2.02	125.5
Isinvaeva, E. (RUS)	1.74	31.29	16	1.96	112.6
Ptacnikova, J. (CZE)	1.74	29.22	16	1.83	105.2
Kiriakopoulou, N. (GRE)	1.67	30.20	16	1.89	113.2
Average	1.69	30.54	16.25	1.87	110.8

*additional 1 short step for preparation first step

Step analysis was divided into three sections: early (the final 12th-9th steps), middle (the final 8th-5th steps), and final (the last 4 to the final step) (Table 3). Since the average number of steps for women (16.25) was 1.25 less compared to male pole vaulters (17.50), and since the least amount of steps for competitor (Y. Silva) was 14, the analytic phases for women's steps were divided into three stages, with four steps for each stage.

Early average step length was 1.93 m (step length / height ratio: 114.4%), increasing during middle average step length to 1.94 m (114.9% ratio), and decreasing during final average step length to 1.92 m (113.3% ratio). Figure 3 shows the average step length according to all three stages for Brazil's F. Murer, the first place vaulter in Daegu.

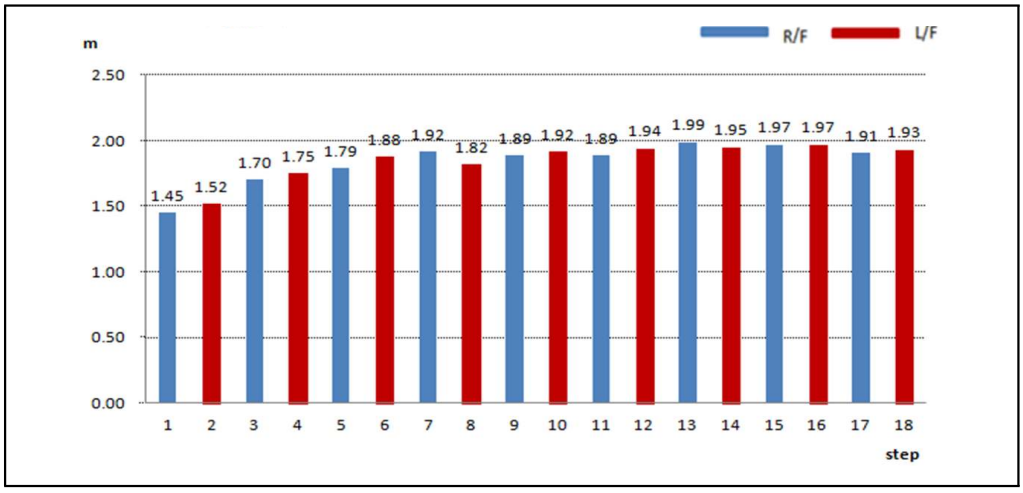


Figure 3. Each step length for run-up (P. Murer)

Table 3. Average step length for the section of 12-9 step, 8-5 step and 4-1 step (unit : m)

Athlete	Height	Average step length (*)		
		Last 12 - 9 step	Last 8 - 5 step	Last 4 - 1 step
Murer, F. (BRA)	1.72	1.89 (109.9)	1.94 (112.8)	1.95 (113.4)
Sturutz, M. (GER)	1.60	1.87 (116.9)	1.77 (110.6)	1.75 (109.4)
Feofanova, S. (RUS)	1.63	1.91 (117.2)	1.80 (110.4)	1.93 (118.4)
Suhr, J. (USA)	1.83	1.91 (104.4)	1.97 (107.7)	1.91 (104.4)
Silva, Y. (CUB)	1.61	2.07 (128.6)	2.11 (131.1)	2.01 (124.8)
Isinvaeva, E. (RUS)	1.74	2.08 (119.5)	2.09 (120.1)	1.94 (111.5)
Ptacnikova, J. (CZE)	1.74	1.82 (104.6)	1.95 (112.1)	1.91 (109.8)
Kiriakopoulou, N. (GRE)	1.67	1.91 (114.4)	1.91 (114.4)	1.92 (115.0)
Average	1.69	1.93 (114.4)	1.94 (114.9)	1.92 (113.3)

(*) represents the ratio of step length to her height

<Table 4> shows the results for vault height (m), number of steps (step), velocity or V_A(m/s)(at 11m-6m from pole box), and approach position or AP (m) (distance from pole box and final foot strike) from the 2009 World Championships in Berlin alongside the results from Daegu in 2011.

The average vault height for competitors in 2011 in Daegu was 4.72 m, a 14 cm increase from the 2009 World Championships in Berlin (4.58 m) and a 2cm decrease the 2008 Olympics in Beijing (4.74 m). Approach velocity was the same as 2009 in Berlin at 8.23 m/s. Approach position was the same as well at 3.62 m.

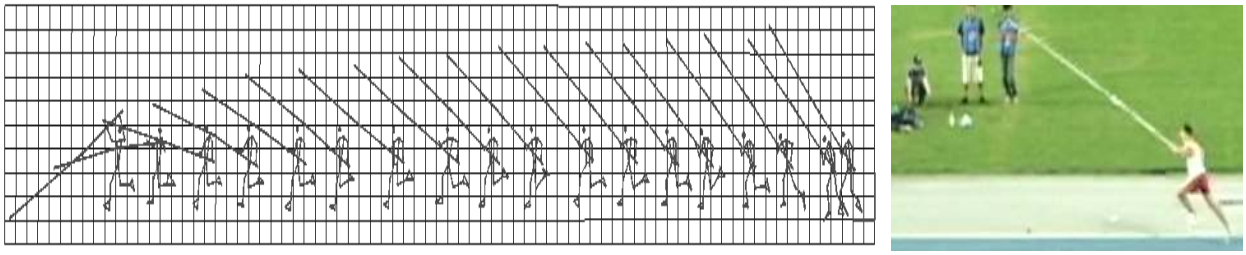


Figure 4 Stick figure and photo of Murer F. (BRA)

To summarize, the women at the Daegu 2011 World Track and Field Competition achieved higher average heights than their counterparts at the 2009 World Championships in Berlin. In terms of run up variables, the number of steps increased, and the approach position for the first and second place finishers was approximately 0.4 m larger than the average in Berlin. Thus, number of steps and approach position can be considered as crucial variables for women's pole vault performance. In order to continue to develop the research around pole vault performance, future studies should expand their variables to include previously excluded factors such as other stages of the vault like plant and take off, swing up, extension, etc.

Table 4. Jumping height, run-up velocity V_A in section 10-5 m, number of run-up steps and take-off position AP

IAAF WCh Berlin 2009					IAAF WCh Daegu 2011				
Athlete	Records (m)	# of Steps (step)	V_A (m/s)	AP (m)	Athlete	Records (m)	# of Steps (step)	V_A* (m/s)	AP** (m)
Rogowska, A. (POL)	4.75	16	8.68	3.45	Murer, F. (BRA)	4.85	18	8.27	4.04
Johnson, C. (USA)	4.65	16	8.32	3.35	Sturutz, M. (GER)	4.80	16(SS)***	8.23	4.10
Pyrek, M. (POL)	4.65	16	7.92	3.75	Feofanova, S. (RUS)	4.75	16	8.30	3.40
Spiegelburg, S. (GER)	4.65	16	8.33	3.80	Suhr, J. (USA)	4.70	18	8.30	3.54
Murer, F. (BRA)	4.55	16	8.26	3.85	Silva, Y. (CUB)	4.70	14	8.15	3.69
Dennison, K. (GBR)	4.55	14	8.24	3.40	Isinvaeva, E. (RUS)	4.65	16	8.27	3.46
Polnova, T. (RUS)	4.40	17	7.68	3.80	Ptacnikova, J. (CZE)	4.65	16	8.20	3.39
Battke, A. (GER)	4.40	16	8.43	3.55	Kiriakopoulou, N. (GRE)	4.65	16	8.13	3.35
Average	4.58	15.88	8.23	3.62	Average	4.72	16.25	8.23	3.62

* the velocity has analyzed in the run-up section between 10-5 m from the cut-in box

**AP has analyzed the distance between cut-in box and the last heel strike

***additional 1 short step for preparation first step

Men's High Jump Men - Biomechanics Research Report from the IAAF World Championships, Daegu 2011

• Dircector :

Eui-Hwan Kim(Yongin University, Korea) · Young-Sang Bae(Keimyung University, Korea)

• Researcher :

Sung-Sup Kim(Yongin University, Korea) · Moon-Seok Kwon(Yongin University, Korea) Ung-Ryang Wi(Yongin University, Korea) · Ki-Man Kim(Polytechnic College University, Korea) Jeong-Min Lee(KeimyungUniversity, Korea)

Abstract

The purpose of this study was to analyze the takeoff techniques of the world's leading male high jumpers (men's high jump medalists) at the 2011 IAAF Championships in Daegu (2011. 8. 27 - 9. 4). Three-dimensional coordinate methods were used to analyze the athletes' last three strides before touchdown, touchdown techniques, and movements after takeoff toward the bar.

First, data analysis showed that gold medalist, J. Williams, used single arm form, while other medalists used double arm form. Second, the difference between knee joint angles upon touchdown and toe-off was 10°. Third, J. Williams achieved a maximum CM height after takeoff (1.26 m) through maximum flexion of his knee joint. Fourth, A. Dmitrik's duration of foot contact (0.11 sec.) was the shortest among the medalists, and his ratio of transformation of horizontal velocity toward vertical velocity was the greatest (75.25%). Lastly, T. Barry's maximum CM height was the greatest and his foot contact duration was the longest among the medalists.

5. Biomechanicals Analysis of the Men's High Jump Finals

J. Williams (U.S.A.), who holds this year's best jump of 2.37 meters, won the men's high jump event at the 2011 IAAF World Championships in Daegu (Figure 1).

Figure 1. J. Williams (USA)

J. Williams, a 27 year-old American athlete, made this year his best by clearing all attempts before the 2.37 meter jump. As a result, he took the gold medal with a height of 2.35 meters. A. Dmitrik (RUS) earned the silver. A. Dmitrik cleared 2.35 meters as Williams did, but as he cleared 2.29, 2.32, and 2.35 meters on his second attempt, he could not defeat Williams, placing him at second place. T. Barry from the Bahamas won the bronze with the height of 2.32 meters, which was his personal best.

To analyze the men's high jump competition, we placed two high-speed video cameras (Casio EX-F1 Exilim, JPN, 300 frames/sec, shutter speed 1/1000 sec) at the takeoff point and at the landing area. Before videotaping the movement of the athletes, a bar with a control point was fixed to the 14th point to calibrate three-dimensional coordinates(Figures 2, 3).

Video images of the top three athletes were used for analysis. The variables were foot contact time at takeoff, maximum height of CM, horizontal velocity of CM, horizontal and vertical velocity of CM at takeoff, angle at takeoff, body lean angle, backward lean angle, and knee joint angle at takeoff.

Side camera view

Back camera view

Figure 2. Camera Calibration

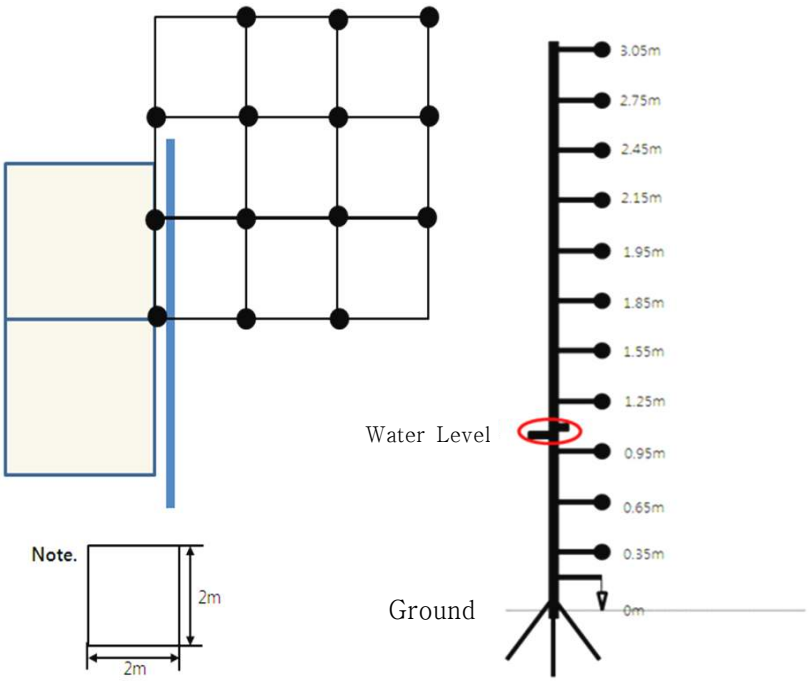


Figure 3. Camera Calibration Methods

According to the men's finals results, the average jump height of the top three athletes was 2.34 ± 0.02 m, and the average maximum CM height was 2.65 ± 0.01 m. The average time

of foot contact at takeoff was 0.15 ± 0.04 seconds. The average takeoff angle toward the bar was 48.7 ± 1.6°. The average horizontal CG velocity at the actual takeoff was 7.97 ± 0.41 m/s. The mean horizontal and vertical velocities of the jumpers' CM at the touchdown phase were 4.31 ± 0.21 m/s and 4.91 ± 0.05 m/s. The average angle of backward body lean at the moment of touchdown was 34.6 ± 2.5°, inward body lean angle averaged 27.4 ± 2.5°, and body trunk lean angle averaged 32.8 ± 8.8°. The mean knee joint angle at the last stride was 143.1 ± 4.7° but it decreased to 140.9 ± 7.2° at touchdown; the average angle of the knee joint was 170.8 ± 8° but it increased to 172.8 ± 3.2° at touchdown. The lowest mean of the knee joint angle was 138.5 ± 14.8°.

In high jump competitions, the jumpers are categorized into Single-Arm (S) and Double-Arm (D) types according to their arm actions at touchdown. Categorizations of Bend (B) and Half-Bend (HB) are used according to how the jumpers swing their leading legs at touchdown (Ae, 1990). At the 2011 IAAF World Championships in Daegu, the arm action of J. Williams, the gold medalist, was of the Single-Arm type while the arm actions of A. Dmitrik (silver medalist) and T. Barry (bronze medalist) were of the Double-Arm type. In addition, the leading leg action of J. Williams was of the Half-Bend type, while that of the other medalists was of the Bend type. It can be concluded that the efficient kinematic matching of arm actions and the actions of leading legs at touchdown are S-HB and D-B.

There was not a big difference between the takeoff body angles of the gold medalist J. Williams (49.8°) and of the bronze medalist T. Barry (49.4°), but the takeoff body angle of A. Dmitrik (46.9°), the silver medalist, was significantly lower than the others'. In addition, among the vertical and horizontal CM velocities, the horizontal velocity of A. Dmitrik was comparably higher than the other medalists. Though the maximum CM height of A. Dmitrik, 2.64 meters, was the same as that of the gold medalist, J. Williams, this result demonstrates the added difficulty in clearing the bar due to the low takeoff angle. In the case of the bronze medalist T. Barry, he recorded the greatest maximum CM height at 2.66 meters, but his horizontal velocity (7.51 m/s) was slower than that of the gold medalist (8.32 m/s) and the silver medalist (8.07 m/s). In 2007 Osaka competition, D. Thomas won the gold medal with the result of 2.35 m and 7.87 m/s for horizontal velocity. Hence, for a better result, it is necessary to increase the horizontal velocity. Moreover, J. Williams cleared 2.34 meters, which was the same as the results of D. Thomas and Y. Rybakov at the 2007 Osaka competition.

Table 1. Kinematic data of Men's High Jump finals, IAAF W.C., Daegu 2011

Rank	Athlete	Analysed attempt	Result (m)	Foot contact time (ms)	Peak CM height (m)	Peak Horizontal CM Velocity (m/s)	Takeoff angle (deg)	CM Velocity at takeoff (m/s)		Body lean at takeoff foot touchdown (deg)			Knee joint angle at takeoff phase(deg)				
													Last Stride		Takeoff		
								Horizontal	Vertical	Back ward	Inward	Trunk	on	off	on	max flexion	off
1	Jesse Williams (USA)	5	2.35	0.14	2.64	8.32	49.8	4.2	4.97	37.4	29.7	36.9	145.4	147	161.7	127.2	171.5
2	Aleksey Dmitrik (RUS)	8	2.35	0.11	2.64	8.07	46.9	4.56	4.88	33.5	17.6	23.3	146.2	142.7	174.1	155.3	176.4
3	Trevor Barry (BAH)	3	2.32	0.19	2.66	7.51	49.4	4.18	4.88	32.8	34.8	38.3	137.7	132.9	176.7	133.1	170.5
Mean			2.34	0.15	2.65	7.97	48.7	4.31	4.91	34.6	27.4	32.8	143.1	140.9	170.8	138.5	172.8

Gold medalist J. Williams' maximum horizontal and vertical velocities at the end of the takeoff phase were 8.32 m/s and 4.97 m/s, which were greater than the velocities of D. Thomas (7.57 m/s, 4.64 m/s) and Y. Rybakov (7.57 m/s, 4.45 m/s). However, the duration of J. Williams' foot contact was 0.14 sec, which was shorter than those of D. Thomas (0.18 sec) and Y. Rybakov (0.192 sec). This means that J. Williams might have had a better result if he had taken more time at foot contact, which would have transformed the horizontal energy into vertical movement.

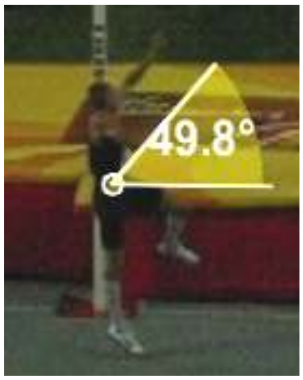
In this competition, the average backward body lean angle at the point of touchdown was 34.6 ± 2.5°, which was lower than those of the athletes at the 2007 Osaka event, 42.3 ± 2.02°. It can be said that the difference between backward body lean angles was influenced by the maximum horizontal velocity and the horizontal velocity after touchdown of the medalists in the 2011 Daegu IAAF Championships. The velocities of the athletes in Daegu were higher than the velocities of the athletes at the 2007 Osaka competition. Moreover, the average physical height of the athletes at the 2007 Osaka event (1.94 ± 0.04 m) was greater than that of the medalists at the 2011 Daegu event. J. Williams and A. Dmitrik are both 1.84 m. Because of their shorter stature, they achieve a greater horizontal velocity causing a lower backward body lean angle at the point of touchdown. This allowed them to perform much better than the athletes in earlier competitions.

At touchdown, J. Williams' knee joint angle was 161.7°, A. Dmitrik's was 174.1° and T. Barry's was 176.7°. After touchdown, J. Williams' knee joint angle was 171.5°, A. Dmitrik's was 176.4° and T. Barry's was 170.5°. In 2007, D. Thomas recorded touchdown and post touchdown angles of 161° and 171°, while Y. Rybakov had angles of 170° and 174°. The gold medalists, J. Williams in 2011 and D. Thomas in 2007, had the same value of knee joint angles at and after touchdown. Moreover, the difference between the knee joint angles from the moment of touchdown to when foot lost contact was about 10° for both athletes. Compared to the two gold medalists, the knee joint angles of the other athletes were very different. In particular, their knee joint angles at the point of touchdown were greater than those of the gold medalists. The two gold medalists most actively used their knee joints at the moment of touchdown. This means that their body movements were efficient enough to transform their horizontal movement into increased vertical movement after takeoff. Moreover, their active knee joint movement at the moment of touchdown led kinetic energy originated by touchdown toward potential energy. Hence, it can be concluded that their active knee joint movement contributed to their gold medal performances.

Side view

Back view

Backward angle



Takeoff angle

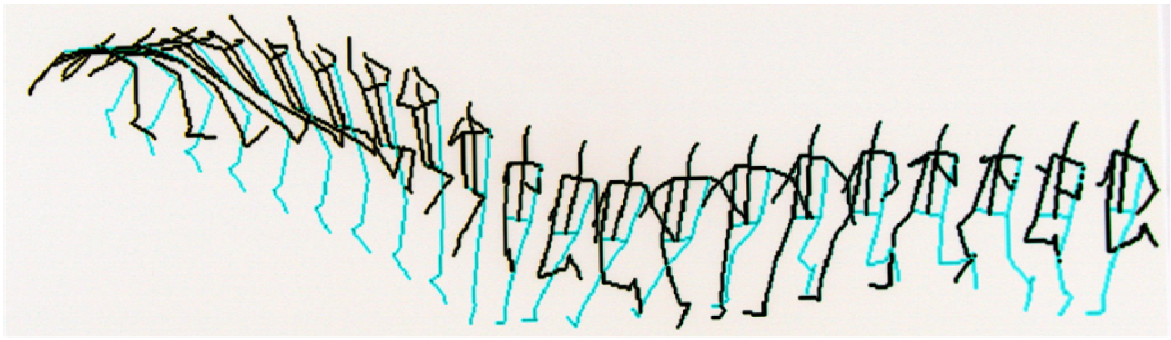
Takeoff on

Takeoff max

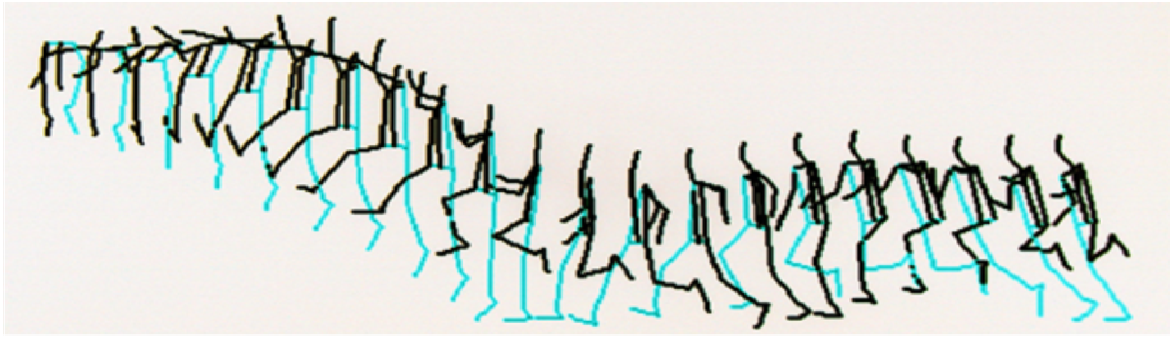
Takeoff off

Knee Joint Angles

Figure 4. J. Williams (USA)



Side view



Back view

Takeoff angle

Backward angle

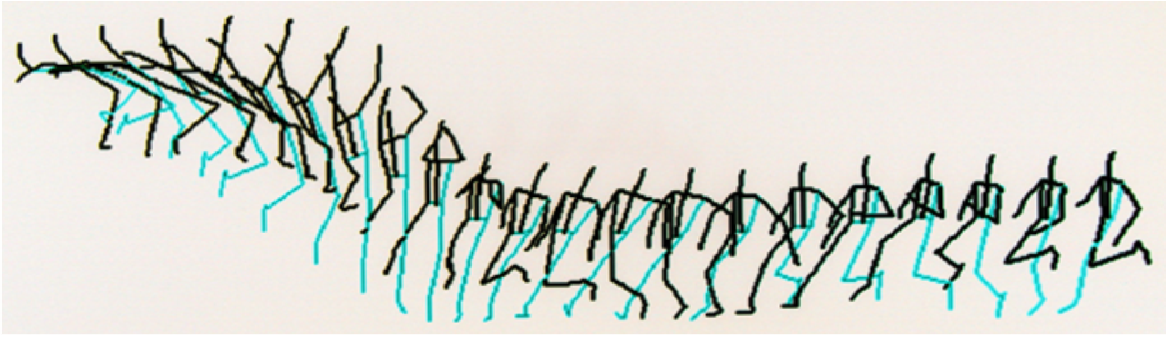
Takeoff off

Takeoff max

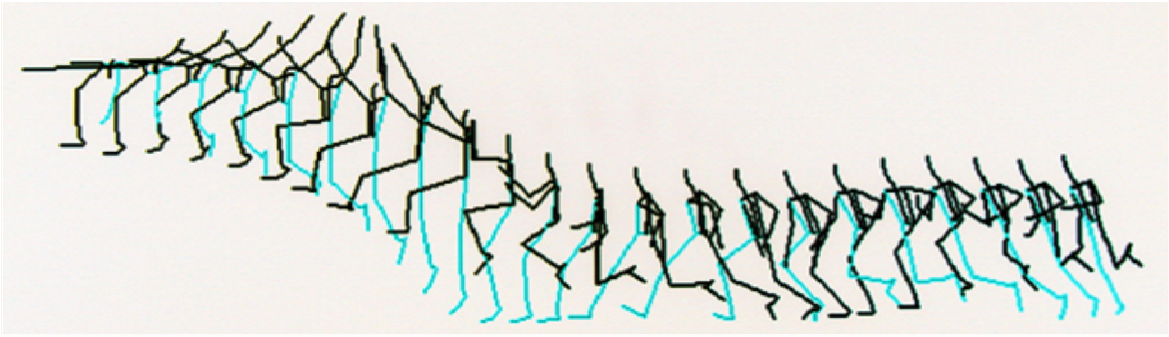
Takeoff on

Knee Joint Angles

Figure 5. A. Dmitrik (RUS)



Side view



Back view

Takeoff angle

Backward angle

Takeoff off

Takeoff max

Takeoff on

Knee Joint Angles

Figure 6. T. Barry (BAH)

Table 2. Results of Men's High Jump, IAAF W.C., Daegu 2011

(unit: cm)

Place	Name	Country	220	225	229	232	235	237
1	Jesse Williams	USA	○	○	○	○	○	×××
2	Aleksey Dmitrik	RUS	○	○	×○	×○	×○	×××
3	Trevor Barry	BAH	○	○	-	○	×××	
4	Jaroslav Baba	CZE	○	○	××○	○	×××	
5	Ivan Ukhov	RUS	○	○	○	××○	×××	
5	Dimitrios Chondrokoukis	GRE	○	○	○	××○	×××	
7	Mutaz Essa Barshim	QAT	○	×○	×○	××○	×××	
8	Aleksandr Shustov	RUS	○	×○	○	×××		
9	Raul Spank	GER	○	○	×○	×××		
10	Zhang Guowei	CHN	×○	○	×××			
11	Donald Thomas	BAH	○	×××				
12	Darvin Edwards	LCA	×○	×××				
12	Dmytro Dem'yanyuk	UKR	×○	×××				

Women's High Jump Biomechanics Research Report from the IAAF World Championships, Daegu 2011

- Director :

  Young-Sang Bae(Keimyung University, Korea) · Eui-Hwan Kim(Yongin University, Korea)

- Researcher :

  Ki-Man Kim(Polytechnic College University, Korea) · Jeong-Min Lee(Keimyung University, Koea) Sung-Sup Kim(Yongin University, Korea) · Moon-Seok Kwon(Yongin University, Korea) Ung-Ryang Wi(Yongin University, Korea)

Abstract

The purpose of this study was to perform kinematic analysis of the top three women's high jumpers at the IAAF World Championships in Athletics, Daegu 2011. This study also examined the current techniques of the world's top women high jumpers. It is notable that competitor Antonietta Di Martino, despite her shorter height, secured a spot among the top three athletes by maximizing her movement in her take-off technique. This included her single arm swing with a half flexed lead leg swing, as well as using a deep arch to clear the bar. The study also showed that the world's top athletes used the techniques to jump with no decrease in run-up velocity on the take-off. Furthermore, it appeared that the angle of the knee joint at take-off directly affected the body position at take-off (H1).

6. Biomechanical Analysis of the Women's High Jump Finals

At the women's high jump finals at the IAAF World Championships, Daegu 2011, the 2011 world record holder Anna Chicherova from Russia won the gold medal. She cleared every single height on her first attempt, with a range of 1.89 m to 2.03 m. It was her first gold medal at the IAAF World Championships (Figure 1).

Figure 1. A. Chicherova (RUS)

Blanka Vlasic from Croatia, who had won two earlier IAAF Championships, was rumored not to appear at the IAAF World Championships in Daegu due to an injury, but in the end, she was able to participate in the event. Vlasic cleared 2.00 m and then 2.03 m on her second attempt, but she still needed to clear 2.05 m to defeat Chicherova. However, after three

attempts she failed to cross the bar, which her competitor Chicherova successfully did. The bronze medal was awarded to Antonietta Di Martino from Italy, who held the national record. She cleared 2.00 m on her second attempt.

To analyze the women's high jump competition, we placed two high speed video cameras (Casio EX-F1 Exilim, JPN, 300 frames/sec, shutter speed 1/1000 sec) at the take-off point and at the landing area. Before videotaping the motions of the athletes, a bar with a control point was fixed to the 14th point to calibrate three-dimensional coordinates (Figure 2, 3).

Video images of the top three athletes were used for the analysis. The variables were foot contact time at take-off, maximum height of CM, horizontal velocity of CM, horizontal and vertical velocity of CM at take-off, angle at take-off, body lean angle, backward lean angle, and knee joint angle at take-off.

Side camera view

Back camera view

Figure 2. Camera Calibration

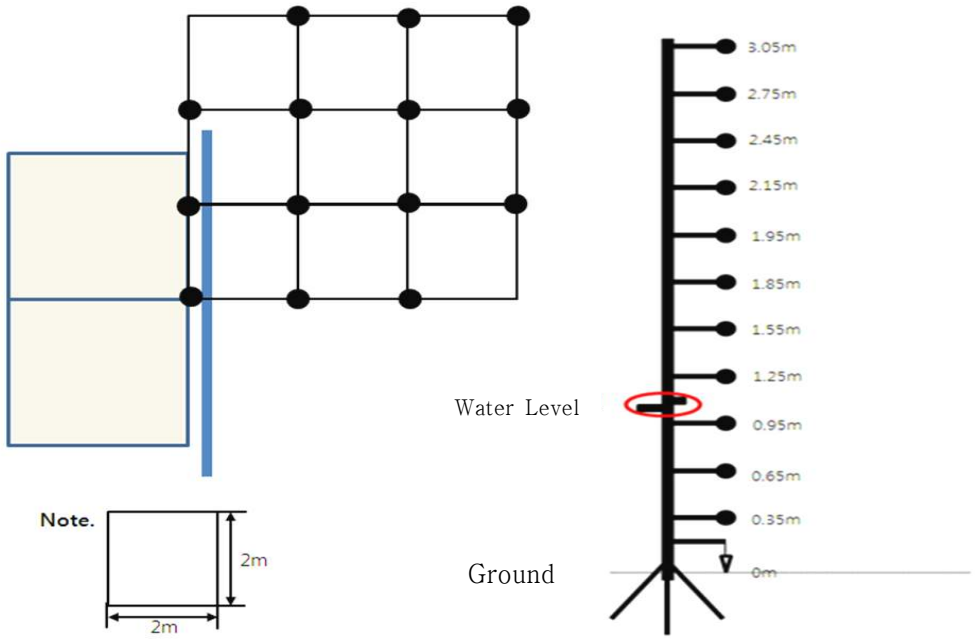


Figure 3. Camera Calibration Methods

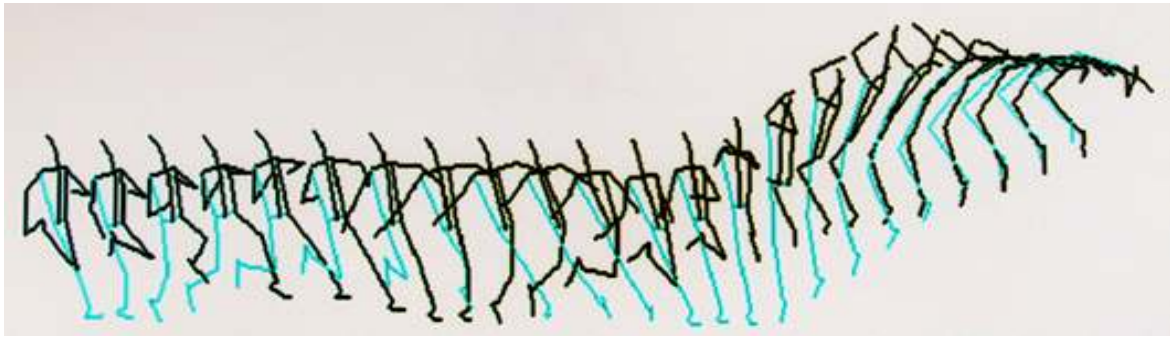
The average of the top three athletes' final results was 2.12 ± 0.02 m, and the mean of the maximum CM height was 2.12 ± 0.18 m. The average time of foot contact at take-off was 0.16±0.01 sec. The average take-off angle toward the bar was 48.6 ± 3.2°. At the point of take-off, the average horizontal velocity of the jumpers' CM was 6.99 ± 0.33 m/s. The mean horizontal and vertical velocities of the jumpers' CM at the point of touchdown phase were 3.66 ± 0.45 m/s and 4.13 ± 0.07 m/s. The average backward body lean angle at touchdown was 30.5 ± 4.6°, the average inward body lean was 34.3 ± 5.6°, and the average angle of the trunk of the body was 36.9 ± 5.3°. The mean of the knee joint angle at the last stride was 142.9±6.2°, but it increased to 150.4 ± 9°at touchdown. At touchdown, the angle of the knee joint was 171 ± 7°, but it decreased 168.7 ± 3.3° upon touchdown. The lowest mean of the knee joint angle was 144.5 ± 10.2°.

The gold medalist, A. Chicherova, recorded a longer foot contact time (0.16 sec.) than B. Vlasic, the silver medalist, and A. Di Martino, the bronze medalist. Also, the maximum height (2.22 m) of A. Chicherova's CM and her maximum horizontal velocity (7.37 m/s) when crossing the bar were higher than the other competitors'. The bronze medalist, A. Di Martino, cleared 2 m even though she is shorter (1.69 m) than the others. It is notable that she brought her CM to a maximum height of 1.97 m when she cleared 2 m. The medalists' body angles toward the bar after take-off were 46.6° (A. Chicherova), 46.9° (B. Vlasic), and 52.2° (A. Di Martino). They all recorded take-off angles greater than 45°. It appears that A. Di Martino's take-off angle was higher than the others'. After take-off, the mean body angle of the women high jump medalists was similar to that of the men medalists, 48.7°. But at the take-off phase, the body angles of the women gold and silver medalists were 3° smaller than the men medalists'. In addition, when their touchdown foot lost contact with the ground, the medalists' mean horizontal velocity was over 3 m/s, and their vertical velocity was over 4 m/s. In particular, A. Chicherova's vertical velocity was 4.18 m/s greater than those of B. Vlasic and A. Di Martino. Also, the gold medalist's, A. Chicherova's, maximum horizontal velocity was 7.37 m/s, which was greater than other two medalists' horizontal velocities. This meant that A. Chicherova's body movements were efficient enough to transform her horizontal movement at touchdown into a better vertical movement than those of B. Vlsasic and A. Di Martino.

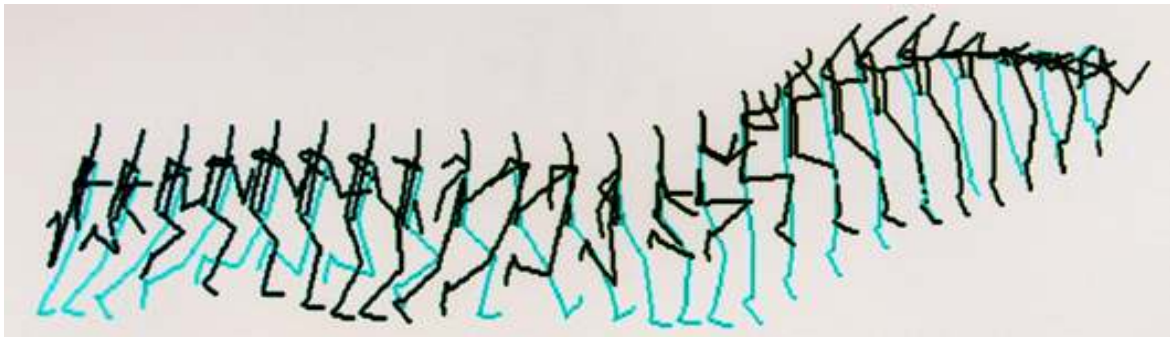
Table 1. Kinematic data of Women's High Jump of finals, IAAF W.C., Daegu 2011

Rank	Athlete	Analysed attempt	Result (m)	Foot contact time (ms)	Peak CM height (m)	Peak Horizontal CM Velocity (m/s)	Takeoff angle (deg)	CM Velocity at takeoff (m/s)		Body lean at takeoff foot touchdown (deg)			Knee joint angle at takeoff phase (deg)				
								Horizontal	Vertical	Backward	Inward	Trunk	Last Stride		Takeoff		
													on	off	on	max flexion	off
1	Anna Chicherova (RUS)	5	2.03	160	2.22	7.37	46.6	3.59	4.18	33.2	29.9	33.1	138.2	153.3	163.0	133.4	172.3
2	Blanka Vlasic (CRO)	7	2.03	150	2.17	6.87	46.9	3.89	4.15	25.2	32.4	34.7	140.7	157.5	174.1	146.9	165.8
3	Antonietta Di Martino (ITA)	6	2.00	140	1.97	6.74	52.2	3.14	4.05	33.1	40.6	42.9	149.9	140.3	175.9	153.3	168.0
Mean			2.02	150	2.12	6.99	48.6	3.66	4.13	30.5	34.3	36.9	142.9	150.4	171.0	144.5	168.7

In the women's competition, the mean backward body lean angle at touchdown was 30.5 ± 4.6° which is smaller than that of the male competitors, which was 34.6 ± 2.5°. In particular, B. Vlasic, the former champion, had a similar take-off angle to A. Chicherova, but Vlasic's maximum horizontal velocity, maximum CM height, and vertical velocity after take-off were lower than those of A. Chicherova. It can be said that her backward body lean angle (25.2°) was not enough to efficiently transform horizontal movement to vertical movement. Also notable in A. Chicherova's performance was that her knee joint angle at the point of touchdown and after touchdown was almost same as J. Williams', the men's high jump champion in Daegu, and D. Thomas', the men's champion at the 2007 Osaka competition. Moreover, the difference between the maximum and minimum flexion in the knee of Chicherova's take-off leg was about 9°. Female competitors' knee flexion was as great as the male gold medalists. Lastly, the knee joint angles of B. Vlasic and A. Di Martino at take-off were greater than the actual toe take-off point. In comparison, A. Chicherova's knee joint angle at the actual toe take-off was greater than it was for J. Williams and D. Thomas. Hence, this difference in knee joint angle at take-off helped A. Chicherova to receive her gold medal at the IAAF World Championships, Daegu 2011.



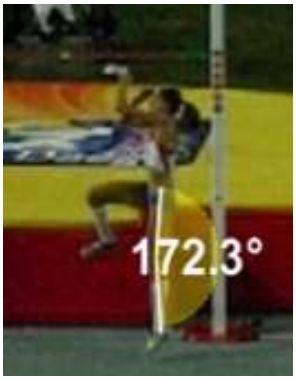
Side view



Back view

Takeoff angle

Backward angle



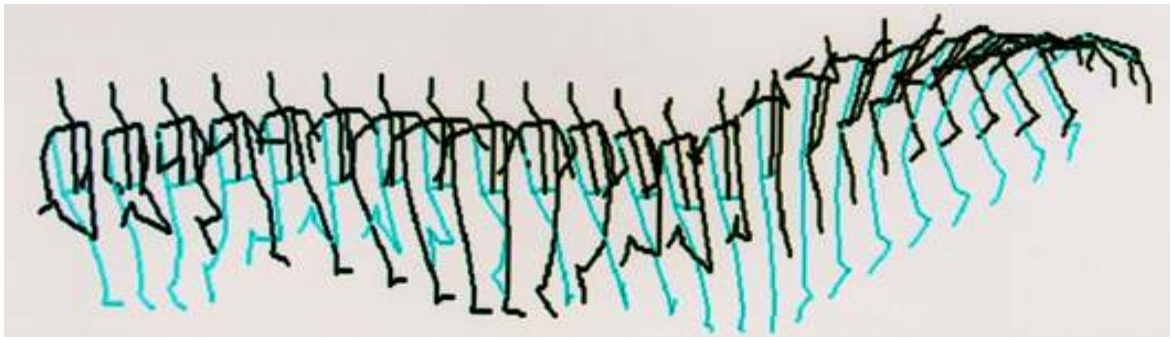
Takeoff off

Takeoff max

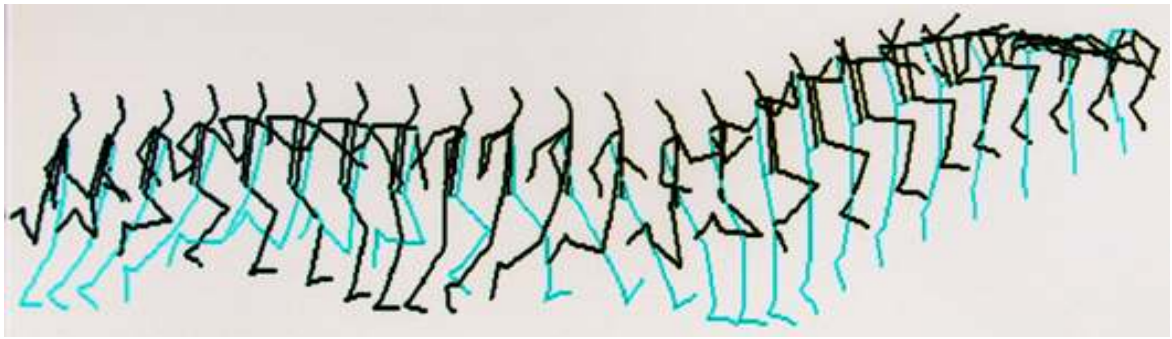
Takeoff on

Knee Joint Angles

Figure 4. Chicherova (RUS)



Side view

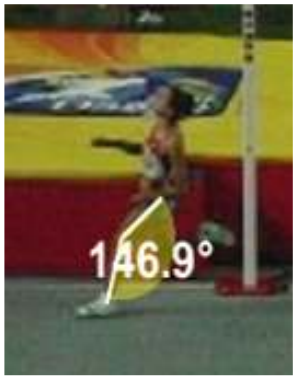


Back view

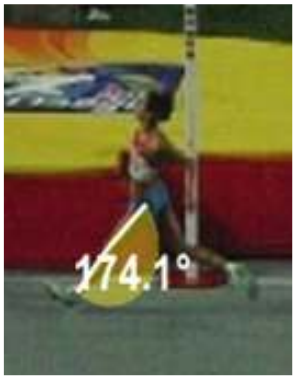
Takeoff angle

Backward angle

Takeoff off



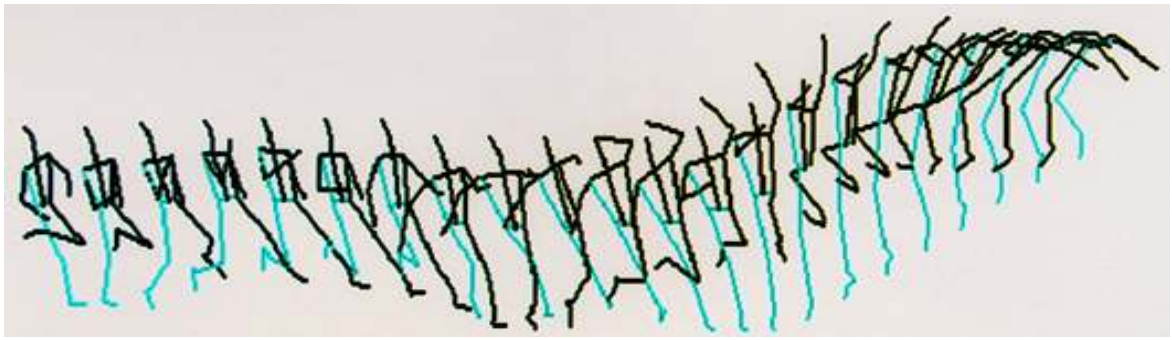
Takeoff max



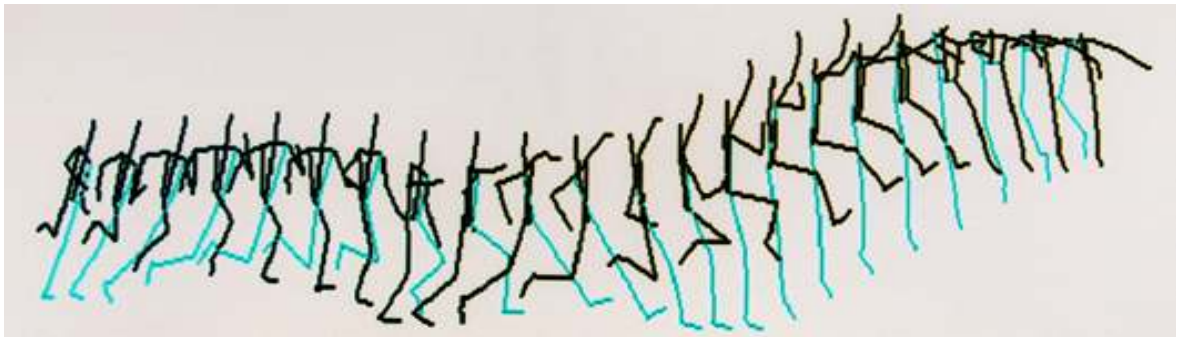
Takeoff on

Knee Joint Angles

Figure 5. B. Vlasic (CRO)



Side view



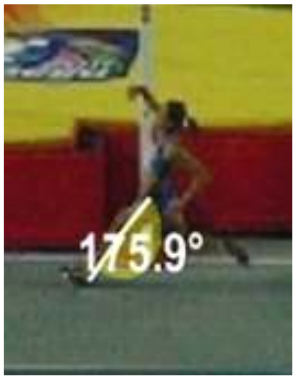
Back view

Takeoff angle

Backward angle

Takeoff off

Takeoff max



Takeoff on

Knee Joint Angles

Figure 6. A. Di Martino (ITA)

Table 2. Women's High Jump Results, IAAF W.C., Daegu 2011

(unit: cm)

Place	Name	Country	189	193	197	200	203	205
1	Anna Chicherova	RUS	○	○	○	○	○	×××
2	Blanka Vlasic	CRO	○	○	○	×○	×○	×××
3	Antonietta Di Martino	ITA	○	○	○	××○	×××	
4	Elena Slesarenko	RUS	○	×○	○	×××		
5	Svetlana Shkolina	RUS	○	○	××○	×××		
6	Zheng Xingjuan	CHN	×○	○	×××			
6	Deirdre Ryan	IRL	×○	○	×××			
8	Svetlana Radzivil	UZB	×○	×○	×××			
8	Doreen Amata	NGR	×○	×○	×××			
10	Brigetta Barrett	USA	○	××○	×××			
11	Emma Green Tregaro	SWE	○	×××				
12	Anna Iljustsenko	EST	×○	×××				

2011 IAAF World Championships, Daegu KSSB Project Final Report Men's Long Jump Finals

• Director :

Jung-Suk Seo(Wonkwang Universit, Korea) · Ho-Mook Kim(Soonchunhyang Universit, Korea)

• Researcher :

Sang-Yeon Woo(Soonchunhyang University, Korea) · Yong-Woon Kim(Kyungnam University, Korea)
Ki-Jeong Nam(Seoul National University, Korea) · Yong-Hyun Park(Seoul National University, Korea)
Sung-Bum Choi(Soonchunhyang University, Korea) · Jin-Hyuk Kim(Soonchunhyang Universit, Korea)

7. Biomechanical Analysis of the Men's Long Jump Finals

D. Phillips won the gold for the men's long jump in Daegu in 2011 with a leap of 8.45 m (Figure 1). During the Championships in Daegu, Phillips was assigned the bib number 1111. After winning, Phillips proudly pointed to his number, which was appropriate for finishing in first place in four World Championships. These finishes firmly place him among the event's all-time greats.

Figure 1. Dwight Phillips (USA) (taken from http://daegu 2011.iaaf.org)

In order to conduct a three-dimensional analysis of the long jump competition, seven digital cameras (Sony vx2100, Sony Fx, JPN, 60 fields / sec) were installed in the stands. Providing protection for the cameras from the spectators was essential, so a warning line was used. The performance distance used for the analysis of the men's long jump was 20 m, which was comparable with the 2009 IAAF Berlin World Championships reports. The performance distance consisted of three zones of 7 m. Each zone was covered by two cameras (Figure 2). An additional camera was used to record the total area in order to verify what happened during competition.

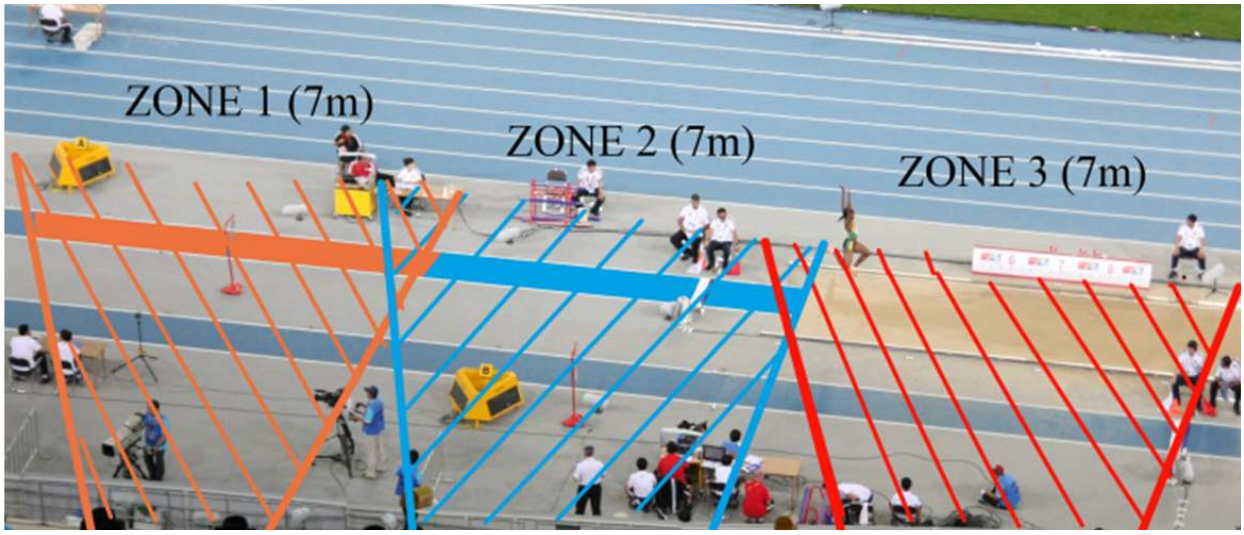


Figure 2. Three zones for camera recordings of long jump performances

Before the beginning of the daily competition, three control objects (2 m x 1 m x 1 m) that covered each zone (7 m) had to be set up to find control points. This calibration procedure was repeated in each zone. The control points were used to calculate DLT parameters for 3-D analysis. Kwon 3D ver. 3.0 was operated to analyze the athletes' performances in three-dimensional space. The events and phases that were analyzed for the long jump competition encompassed the final three steps before take-off and landing (Figure 3).

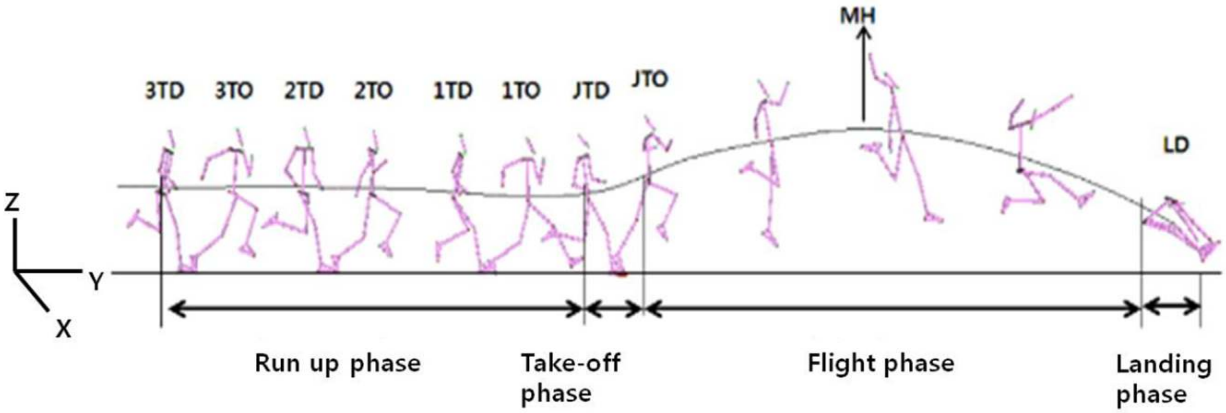


Figure 3. Main events and phases of long jump

The men's long jump qualifying rounds began on September 1st, 2011 at 11:32 AM. The temperature was 28°C with a humidity of 70%. The athletes were divided into group A (18 athletes) and group B (17 athletes). Athletes with a qualification distance over 8.15 m and the top 12 jumpers advanced to the next round. Out of the 35 athletes, three athletes were disqualified. The 32 remaining athletes had an average distance of 7.86 ± 0.32 m and only 2 of them had a distance greater than this. The cut off line for advancement was 8.10 ± 0.08 m.

The men's long jump finals began at 19:17 on September 2nd, 2011. The temperature was 27°C with a humidity of 64%. There was a 0.02 m difference between the average distance for the top eight ranked long jump athletes at the 2011 Daegu World Championships and the average at the 2009 Berlin World Championships. The average in Daegu was 8.26 ± 0.09 m, while the average in Berlin was 8.24 ± 0.19 m.

Table 1. Competition results in relation to 2011 season's best (before the World Championships)

Name	Rank	SB 2011 (m)	IAAF WC Daegu 2011 (m)	Difference (%)
Phillips, D.(USA)	1	8.32	8.45	1.6
Watt, M.(AUS)	2	8.54	8.33	-2.5
Makusha, N.(ZIM)	3	8.40	8.29	-1.3
Berrabah, Y.(MAR)	4	8.37	8.23	-1.7
Manyonga, L.(RSA)	5	8.26	8.21	-0.6
Menkov, A.(RUS)	6	8.28	8.19	-1.1
Tomlinson, C.(GBR)	7	8.35	8.19	-1.9
Bayer, S.(GER)	8	8.17	8.17	0.0

Table 2. Kinematic data of men's long jump finals

Name/Attempt	Distance (m)				Stride length (m)			Relative length (%)	
	Officially measured	Real distance	Loss at take-off (toe-to-board)	Loss by landing	3last	2last	1last	2last/3last	1last/2last
Phillips, D./2nd	8.45	8.48	0.03	0	2.15	2.36	1.99	110	84
Watt, M./2nd	8.33	8.36	0.03	0	2.34	2.53	2.42	108	96
Makusha, N./1st	8.29	8.42	0.13	0	2.22	2.57	2.22	116	86
Berrabah, Y./2nd	8.23	8.23	0.00	0	2.23	2.62	2.24	117	85
Manyonga, L./1st	8.21	8.24	0.03	0	2.14	2.26	2.27	106	100
Menkov, A./2nd	8.19	8.22	0.03	0	2.21	2.34	2.01	106	86
Tomlinson, C./2nd	8.19	8.25	0.01	0	2.28	2.75	2.34	121	85
Bayer, S./1st	8.17	8.30	0.13	0	2.07	2.24	2.06	108	92
Mean ± S.D	8.26 ± 0.09	8.31 ± 0.10	0.05 ± 0.05	0 ± 0.00	2.21 ± 0.08	2.46 ± 0.18	2.19 ± 0.16	112 ± 5.71	89 ± 6.02

Name/Attempt	Lowering of CM	Velocity of CM (m/s)					
		3last	2last	1last	Take-off instant	Loss at take-off	Vertical velocity at take-off
Phillips, D./2nd	0.12	10.81	10.09	11.08	9.27	1.81	2.92
Watt, M./2nd	0.09	10.46	9.77	10.82	8.39	2.43	3.60
Makusha, N./1st	0.08	10.60	9.76	11.12	9.66	1.46	2.70
Berrabah, Y./2nd	0.06	10.16	9.31	10.56	8.78	1.78	3.20
Manyonga, L./1st	0.10	9.73	9.17	10.22	8.85	1.37	3.05
Menkov, A./2nd	0.10	10.49	9.87	10.62	8.93	1.69	3.05
Tomlinson, C./2nd	0.06	10.40	9.70	10.59	9.07	1.52	2.89
Bayer, S./1st	0.09	10.29	9.34	10.49	9.06	1.43	2.94
Mean ± S.D	0.09 ± 0.02	10.37 ± 0.32	9.63 ± 0.32	10.69 ± 0.30	9.00 ± 0.37	1.69 ± 0.34	3.04 ± 0.27

Name/Attempt	Take-off						Lead leg		Landing			
	Duration (s)	Inclination angle (°)	Trunk-angle (°)	Trunk rotation (°)	Minimal knee-angle (°)	Angle of take-off (°)	Thigh-angle at take-off (°)	Average velocity (°/s)	Distance (m)	Trunk angle (°)	Knee angle (°)	Hip angle (°)
Phillips, D. 2nd	0.11	31	90	9	152	17.3	-22	863	0.45	32	152	77
Watt, M. 2nd	0.11	23	87	11	161	22.8	-19	708	0.44	62	144	72
Makusha, N. 1st	0.10	31	90	15	151	15.3	-12	811	0.59	85	138	86
Berrabah, Y. 2nd	0.13	32	86	10	167	20.0	2	950	0.53	94	108	104
Manyonga, L. 1st	0.15	33	81	25	153	18.8	-7	778	0.48	72	110	90
Menkov, A. 2nd	0.13	34	87	14	160	18.6	-18	683	0.50	69	131	84
Tomlinson, C. 2nd	0.13	29	99	17	163	17.2	-8	730	0.61	96	139	83
Bayer, S. 1st	0.13	27	88	8	149	17.6	-11	728	0.47	61	164	80
Mean ± S.D	0.12 ± 0.02	30 ± 3.59	89 ± 5.10	14 ± 5.55	157 ± 6.57	18.5 ± 2.24	-12 ± 7.65	781 ± 89.86	0.51 ± 0.06	71 ± 20.93	136 ± 19.19	85 ± 9.58

The men's mean final results were as follows: officially measured distance 8.26 ± 0.09 m, real distance 8.31 ± 0.10 m, and loss at take-off distance 0.05 ± 0.05 m. The mean stride lengths were as follows: 3last 2.21 ± 0.08 m, 2last 2.46 ± 0.18 m, and 1last 2.19 ± 0.16 m. Moreover, relative landing stride length had mean results of 2last/3last 112 ± 5.71% and 1last/2last 89 ± 6.02%. Additionally, lowering of center of mass (CM) had a mean length of 0.09 ± 0.02 m.

Mean velocities of the CM were as follows: take-off instant 9.00 ± 0.37 m/s; loss at take-off 1.69 ± 0.34 m/s; and vertical velocity at take-off 3.04 ± 0.27 m/s. Moreover, take-off duration had a mean time of 0.12 ± 0.02 s.

At take-off, the mean relative angles of body segments were as follows: inclination angle 30 ± 3.59°, trunk angle 89 ± 5.10°, trunk rotation 14 ± 5.55°, minimal knee angle 157 ± 6.57°, and angle of take-off 18.5 ± 2.24°. Additionally, the mean landing distance was 0.51 ± 0.06 m.

The defending champion in Daegu was D. Phillips. He had won the 2009 Berlin World Championships with a distance of 8.54 m. He maintained his position in Daegu with a performance of 8.45 m, 0.09 m shorter than his winning performance in Berlin. Two athletes (D. Phillips & S. Bayer) performed their season's best in Daegu. S. Bayer took 8th place in this competition. However, most of the athletes, excluding two, underperformed by 0.10 m when compared to their season's best.

All of the medalists had a 2last stride length greater than their 3last and 1last stride lengths. When comparing the stride lengths of the male medalists to the female athletes at the 2011 IAAF World Championships, Daegu, we found that the women also had a 2last stride length greater than their 3last and 1last stride lengths. This result implies that relative 2last stride length is an important factor in achieving greater distance. This pattern of stride lengths results in a relatively high vertical CM during the 3last and 1last strides and a lower CM for the 2last stride, which creates a ramp effect to aid in projecting the CM upward for take-off.

When looking at the kinematic variables of the three men's long jump medalists at the 2011 IAAF World Championships, we found that gold medalist D. Phillips' take-off horizontal velocity was higher than what he achieved at the Berlin competition by 0.04 m/s. Even though the long jump distance is highly correlated to the take-off velocity, he was not able to achieve a further distance with higher horizontal velocity.

D. Phillips, who won gold, achieved a longer jump (0.12 m) in comparison to the second place finisher. This was greater than the Berlin competition by 0.06 m. Furthermore, the 3 medalists' average knee angle of 154° at take-off was 4° less than the non-medalists. In order to get a medal, the other athletes would have needed greater knee flexion at take-off.

In contrast to the average landing distance of 0.51 m for the 8 finalists, gold medalist D.

Phillips and silver medalist M. Watt achieved landing distances of 0.45 m and 0.44 m respectively.

Figure 4. American gold medalist Dwight Phillips (C), poses on the podium with Australian silver medalist Mitchell Watt (L) and Zimbabwean bronze medalist Ngonidzashe Makusha (R) during the award ceremony for the men's long jump event

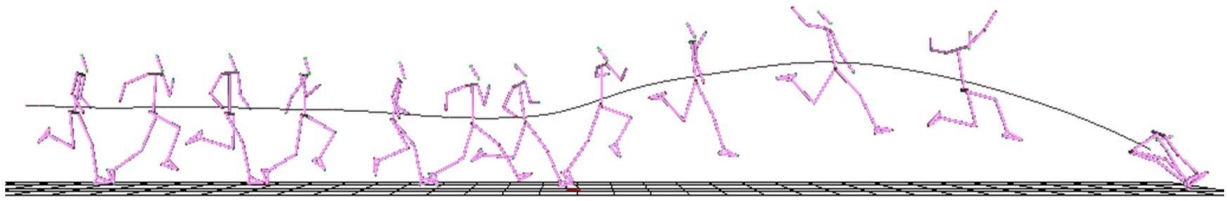


Figure 5. Phillips, D. 2nd Attempt (8.45 m)

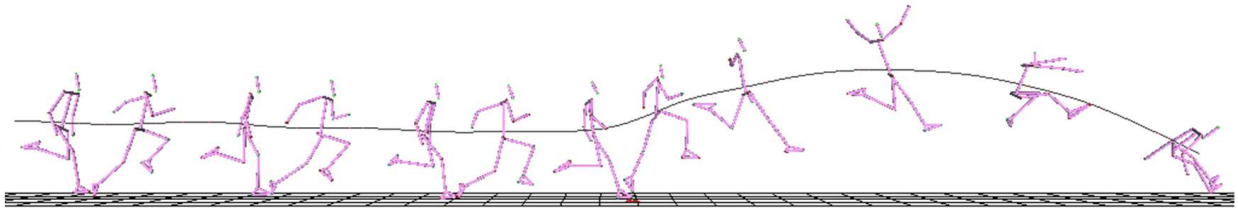


Figure 6. Watt, M. 2nd Attempt (8.33 m)

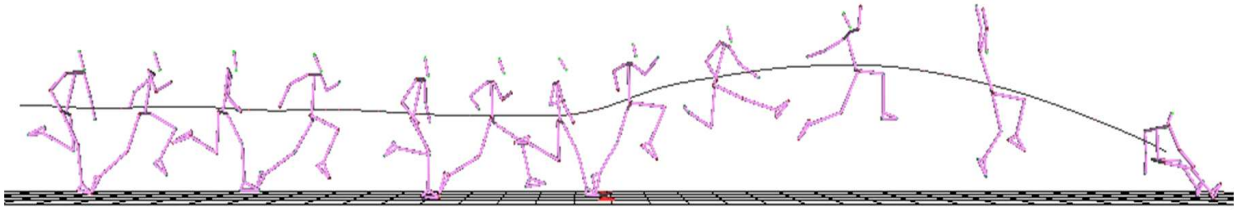


Figure 7. Makusha, N. 1st Attempt (8.29 m)

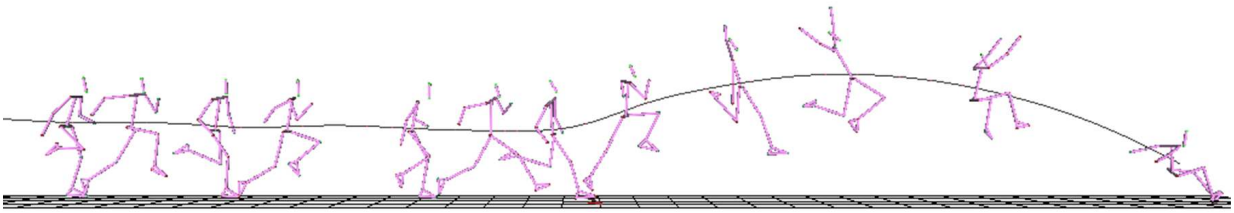


Figure 8. Berrabah, Y. 2nd Attempt (8.23 m)

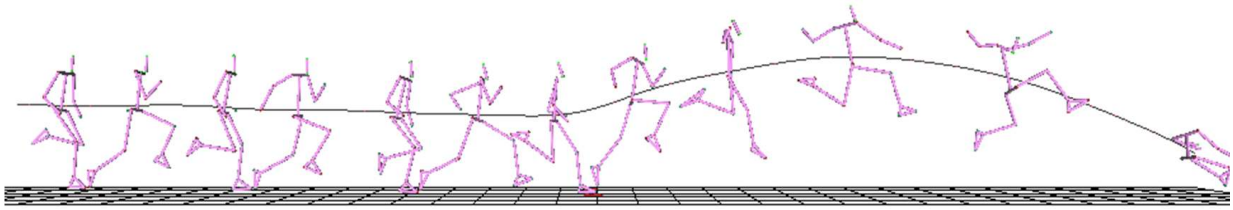


Figure 9. Manyonga, L. 1st Attempt (8.21 m)

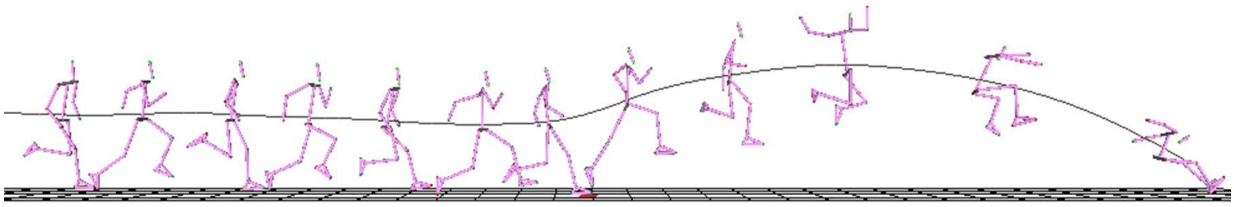


Figure 10. Menkov, A. 2nd Attempt (8.19m)

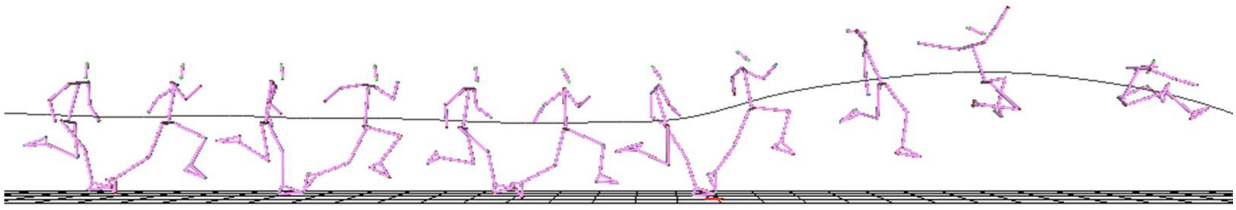


Figure 11. Tomlinson, C. 2nd Attempt (8.19 m)

Figure 12. Bayer, S. 1st Attempt (8.17 m)

2011 IAAF World Championships, Daegu KSSB Project Final Report Women's Long Jump Finals

- Director :

  Jung-Suk Seo(Wonkwang University, Korea) · Ho-Mook Kim(Soonchunhyang University, Korea)

- Researcher :

  Sang-Yeon Woo(Soonchunhyang University, Korea) · Yong-Woon Kim(Kyungnam University, Korea) · Ki-Jeong Nam(Seoul National University, Korea) · Yong-Hyun Park(Seoul National University, Korea) · Sung-Bum Choi(Soonchunhyang University, Korea) · Jin-Hyuk Kim(Soonchunhyang University, Korea)

8. Biomechanical Analysis of the Women's Long Jump Finals

With only one valid jump in the women's long jump finals, B. Reese took the gold medal at the 2011 IAAF World Championships in Daegu. In the final round, she made her successful initial leap of 6.82 m and five invalid attempts. It was an odd situation because this was the first case of the World Championships women's long jump final being captured during a finalist's first and only jump.

Figure 1. Brittney Reese (USA) (taken from http://daegu2011.iaaf.org)

In order to conduct a three - dimensional analysis of the long jump competition, seven digital cameras were installed (Sony vx2100, Sony Fx, JPN, 60 fields / sec) at the stands. Providing protection for the cameras from spectators was essential, so a warning line was used. The performance distance used for the analysis of the women's long jump was 18 m which was comparable with the 2009 IAAF Berlin World Championship reports. The performance distance (18 m) consisted of three zones. Each zone was covered by two cameras (Figure 2). An additional camera was used to record the total area in order to verify what happened during competition.

Before the beginning of the daily competition, three control objects (2 m x 1 m x 1 m) that covered each zone (6~7 m) had to be set up to find control points. This calibration procedure was repeated in each zone. The control points were used to calculate DLT parameters for 3-D analysis. Kwon 3D ver. 3.0 was operated to analyze the athletes' performances in three dimensional space. The events and phases that were analyzed for the long jump competition encompassed the final three steps before take-off and the landing (Figure 3).

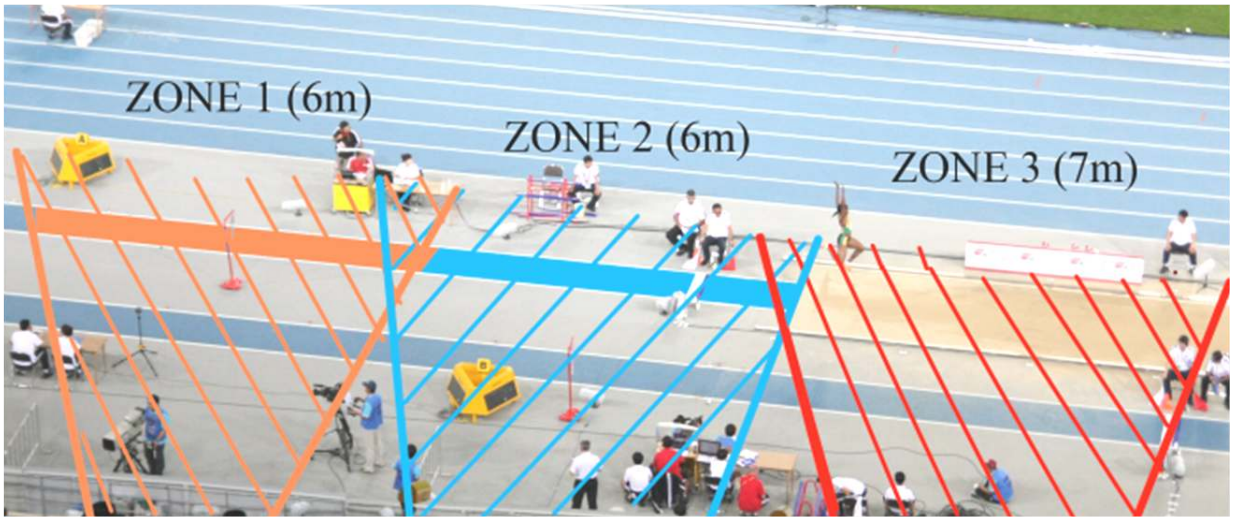


Figure 2. Three zones for camera recordings of long jump performances

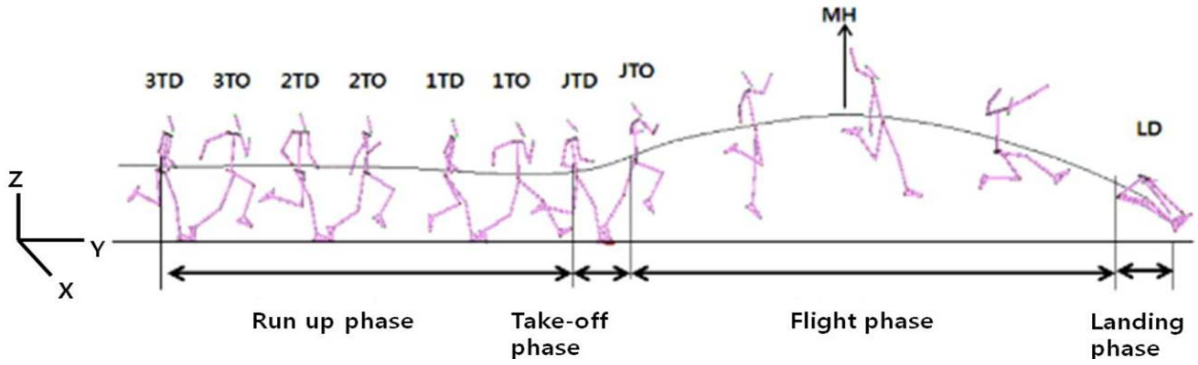


Figure 3. Main events and phases of long jump

The women's long jump qualifying round began on August 27th 2011 at 21:11. The temperature was 25°C and the humidity was 68%. The athletes were divided into group A(17 athletes) and group B(18 athletes). Athletes with a qualification record over 6.75m and the top 12 finishers advanced to the next round. Out of the 35 athletes, one athlete was disqualified. The 34 remaining athletes had an average distance of 6.38 ± 0.31 m, and only 5 of them had a distance over this. The cut off line for advancement was 6.67 ± 0.12.

The women's long jump finals began at 18:08 on August 28th, 2011. The temperature was 26°C with a humidity of 67%. There was a 0.22 m difference between the average distance for the top eight ranked long jump athletes at the 2011 Daegu World Championships (IAAF WC) and the average at the 2009 Berlin World Championships. The average in Daegu was 6.64 ± 0.14 m, while the average in Berlin was 6.86 ± 0.16 m.

Table 1. Competition results in relation to 2011 season's best (before the World Championships)

Name	Rank	SB 2011 (m)	IAAF WC Daegu 2011 (m)	Difference (%)
Reese, B. (USA)	1	7.19	6.82	-5.1
Kucherenko, O. (RUS)	2	6.86	6.77	-1.3
Radevica, I. (LAT)	3	6.60	6.76	2.4
Mironchyk-I, N. (BLR)	4	6.85	6.74	-1.6
Kluft, C. (SWE)	5	6.73	6.56	-2.5
Deloach, J. (USA)	6	6.99	6.56	-6.2
Klishina, D. (RUS)	7	7.05	6.50	-7.8
Mey Melis, K. (TUR)	8	6.66	6.44	-3.3

Table 2. Kinematic data of women's long jump finals

Name/Attempt	Distance (m)				Stride length (m)			Relative length (%)	
	Officially measured	Real distance	Loss at take-off (toe-to-board)	Loss by landing	3last	2last	1last	2last/3last	1last/2last
Reese, B./1st	6.82	6.93	0.11	0.00	1.98	2.41	1.95	122	81
Kucherenko, O./4th	6.77	6.82	0.05	0.00	2.12	2.33	2.21	110	95
Radevica, I./6th	6.76	6.85	0.07	0.00	2.16	2.41	2.18	112	90
Mironchyk-I, N./3rd	6.74	6.79	0.05	0.00	2.14	2.34	2.15	109	92
Kluft, C./3rd	6.56	6.65	0.09	0.00	2.12	2.13	2.00	100	94
Deloach, J./6th	6.56	6.80	0.24	0.00	2.20	2.31	2.18	105	94
Klichina, D./5th	6.50	6.61	0.11	0.00	2.28	2.32	1.96	102	84
Mey Melis, K./2nd	6.44	6.54	0.10	0.00	2.11	2.21	2.16	105	98
Mean ± S.D.	6.64 ± 0.14	6.75 ± 0.13	0.10 ± 0.06	0.00 ± 0.00	2.14 ± 0.09	2.31 ± 0.10	2.10 ± 0.11	108 ± 6.92	91 ± 5.78

Name/Attempt	Lowering of CM	Velocity of CM (m/s)					
		3last	2last	1last	Take-off instant	Loss at take-off	Vertical velocity at take-off
Reese, B. /1st	0.12	9.71	9.69	9.56	7.82	1.74	3.05
Kucherenko, O./ 4th	0.05	9.20	9.28	9.48	7.72	1.76	3.07
Radevica, I./ 6th	0.07	9.17	9.12	9.44	7.87	1.57	2.95
Mironchyk-I, N./3rd	0.03	9.08	9.12	9.41	8.10	1.31	2.94
Kluft, C./ 3rd	0.05	9.26	8.31	9.51	7.81	1.70	2.78
Deloach, J./ 6th	0.09	9.21	9.26	9.47	7.57	1.90	2.99
Klichina, D./ 5th	0.07	9.24	9.15	9.50	7.82	1.68	2.75
Mey Melis, K./ 2nd	0.07	8.91	9.05	9.15	7.70	1.45	3.14
Mean ± S.D.	0.07 ± 0.03	9.22 ± 0.23	9.12 ± 0.38	9.44 ± 0.13	7.80 ± 0.15	1.64 ± 0.19	2.96 ± 0.14

Name/Attempt	Take-off						Lead leg		Landing			
	Duration (s)	Inclination angle (°)	Trunk-angle (°)	Trunk rotation (°)	Minimal knee-angle (°)	Angle of take-off (°)	Thigh-angle at take-off (°)	Average velocity (°/s)	Distance (m)	Trunk angle (°)	Knee angle (°)	Hip angle (°)
Reese, B. /1st	0.13	28	80	14	133	21.0	-19	694	0.53	75	136	83
Kucherenko, O./4th	0.13	29	103	12	156	21.9	-21	673	0.58	98	120	94
Radevica, I./6th	0.11	27	89	13	154	20.4	-12	726	0.55	77	144	71
Mironchyk-I, N./3rd	0.11	27	102	9	146	20.0	-21	684	0.54	76	141	72
Kluft, C./3rd	0.13	29	91	7	163	19.1	-7	761	0.51	75	136	83
Deloach, J./6th	0.11	26	88	15	156	21.3	-29	591	0.34	33	126	80
Klichina, D./5th	0.13	30	97	15	151	20.0	-11	699	0.49	68	114	96
Mey Melis, K./2nd	0.11	27	90	12	150	22.1	-8	755	0.47	87	134	80
Mean ± S.D.	0.12 ± 0.01	28 ±1.36	92 ± 7.88	12 ± 2.85	151 ± 8.89	20.7 ± 1.03	-16 ± 7.57	698 ± 53.69	0.50 ± 0.07	74 ± 18.75	131 ± 10.45	82 ± 9.03

The women's mean final results were as follows: officially measured distance 6.64 ± 0.14 m, real distance 6.75 ± 0.13 m, and loss at take-off distance 0.10 ± 0.06 m. The mean stride lengths were as follows: 3last 2.14 ± 0.09 m, 2last 2.31 ± 0.10 m, 1last 2.10 ± 0.11 m. Moreover, relative landing stride length had mean results of 2last/3last 108 ± 6.92%, and 1last/2last 91 ± 5.78%. Additionally, lowering of center of mass (CM) had a mean length of 0.07 ± 0.03 m.

Mean velocities of the CM were as follows: take-off instant 7.80 ± 0.15 m/s, loss at take-off 1.64 ± 0.19 m/s, and vertical velocity at take-off 2.96 ± 0.14 m/s. Moreover, take-off duration had a mean time of 0.12 ± 0.01 s.

At the take-off, the mean relative angles of body segments were as follows: inclination angle 28 ± 1.36°, trunk angle 92 ± 7.73°, trunk rotation 12 ± 2.85°, minimal knee angle 151 ± 8.89°, and angle of take-off 20.7 ± 1.03°. Additionally, the mean landing distance was 0.50 ± 0.07 m.

The defending champion in Daegu was B. Reese. She had won the 2009 Berlin World Championships with a distance of 7.10 m. She maintained her position in Daegu with a performance of 6.82 m, 0.28 m shorter than her performance in Berlin. Only I. Radevica had a season's best performance of 6.76 m. She took third place in this competition. Every athlete, excluding I. Radevica, underperformed by 0.27 m compared to their season's best score.

Out of the three medalists, B. Reese and I. Radevica had the greatest 2last stride lengths. In addition, B. Reese had the greatest 2last/3last ratio and the least 1last/2last ratio. When comparing the stride length of the female medalists to those of the male medalists at the 2011 IAAF World Championships Daegu, both groups had a 2last stride length greater than their 3last and 1last stride lengths. This result implies that relative 2last stride length is an important factor in achieving greater distance.

When looking at the kinematic variables of the three women's long jump medalists at the 2011 IAAF World Championships, Daegu, gold medalist, B. Reese's, take-off horizontal velocity was lower than what she achieved at the Berlin competition by 0.49 m/s. Her distance in Daegu was 0.28 m shorter than in Berlin. Because the long jump is highly correlated to the take-off velocity, she was not able to achieve a longer distance with lower velocity.

B. Reese, who won gold, achieved a greater lowering of CM (0.12 m) compared to the other athletes. This distance was greater than her lowering of CM in the Berlin competition by 0.03 m. Considering that the average lowering of CM for the best performance of the 8 finalists was 0.07 m, this was a prominent difference.

Furthermore, B. Reese's minimal knee angle at take-off was 133°, 18° less than the average of the 8 finalists' best performances. In order for her to win the gold medal, she needed to have the greatest angle of knee flexion at take-off.

O. Kucherenko, who won silver, recorded the greatest landing distance of 0.58 m. Gold medalist B. Reese and bronze medalist I. Radevica achieved landing distances of 0.53 m and 0.55 m, respectively. Considering the average landing distance of the best performances of the 8 finalists was 0.50 m, all the medalists had a greater landing distance than average.

Figure 4. Gold medalist Brittney Reese of the U.S. (C), silver medalist Olga Kucherenko of Russia (L) and bronze medalist Ineta Radevica of Latvia (R) pose with their medals (taken from http://www.daylife.com)

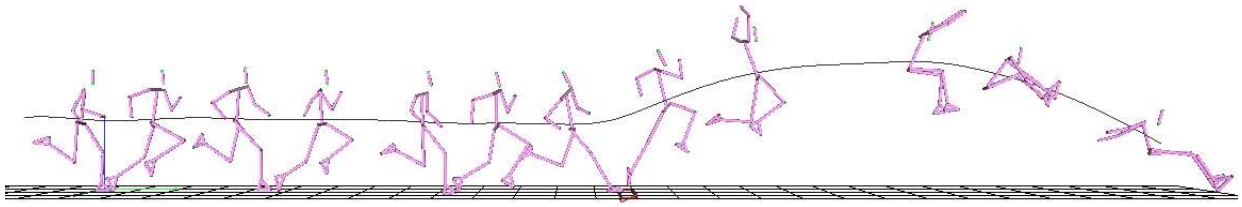


Figure 5. Reese, B. 1st Attempt (6.82 m)

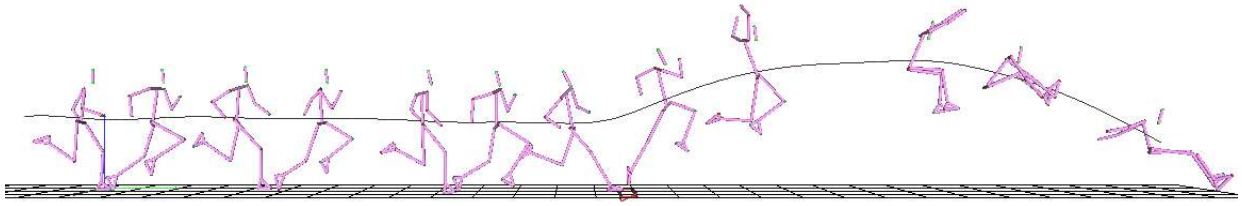


Figure 6. Kucherenko, O. 4th Attempt (6.77 m)

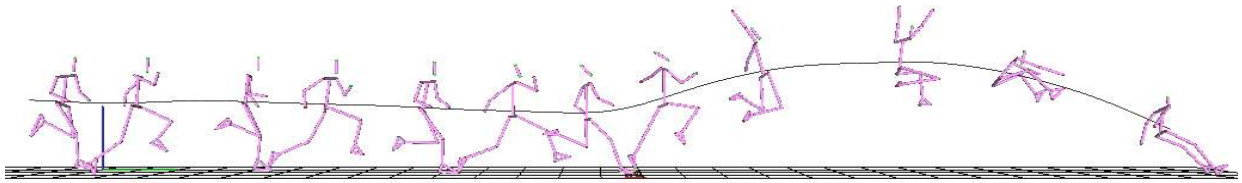


Figure 7. Radevica, I. 6th Attempt (6.76 m)

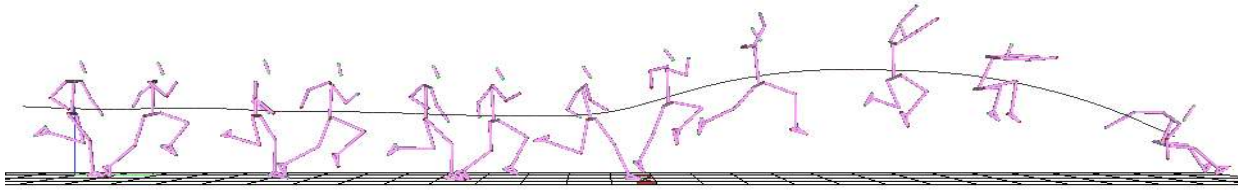


Figure 8. Kluft, C. 3rd Attempt (6.56 m)

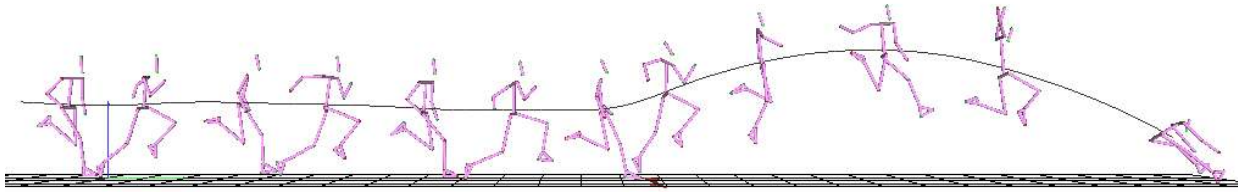


Figure 9. Deloach, J. 6th Attempt (6.56 m)

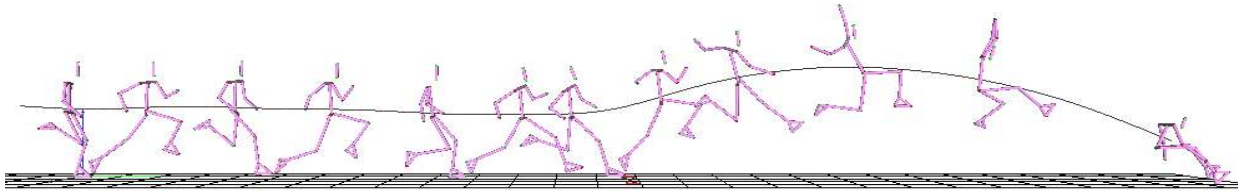


Figure 10. Klichina, D. 5th Attempt (6.50 m)

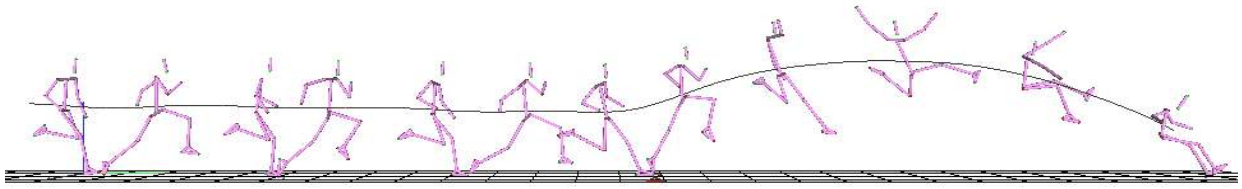


Figure 11. Mey Melis, K. 2nd Attempt (6.44m)

Men's Triple Jump Biomechanics Research Report from the IAAF World Championships Daegu, 2011

• Director :

Sang-Yeon Woo, Ph.D(Soonchunhyang University, Korea)

Yong-Woon Kim, Ph.D(Kyungnam University, Korea)

• Researcher :

Jung-Suk Seo, Ph.D(Wonkwang University, Korea) · Ho-Mook Kim, Ph.D(Soonchunhyang University, Korea) · Ki-Jeong Nam(Seoul National University, Graduate School, Korea) · Yong-Hyun Park(Seoul National University, Graduate School, Korea) · Sung-Bum Choi(Soonchunhyang University, Graduate School, Korea) · Jin-Hyuk Kim(Soonchunhyang University, Graduate School, Korea)

9. Biomechanical Analysis of the Men's Triple Jump Finals

13th IAAF World Championships in Athletics, Daegu on September 4th, 2011

The young athlete Christian Taylor (USA), 21 years old, won the gold medal at the men's triple jump event with a spectacular performance of 17.96 m (Figure 1). As a result, defending world champion Phillips Idowu was left with the silver.

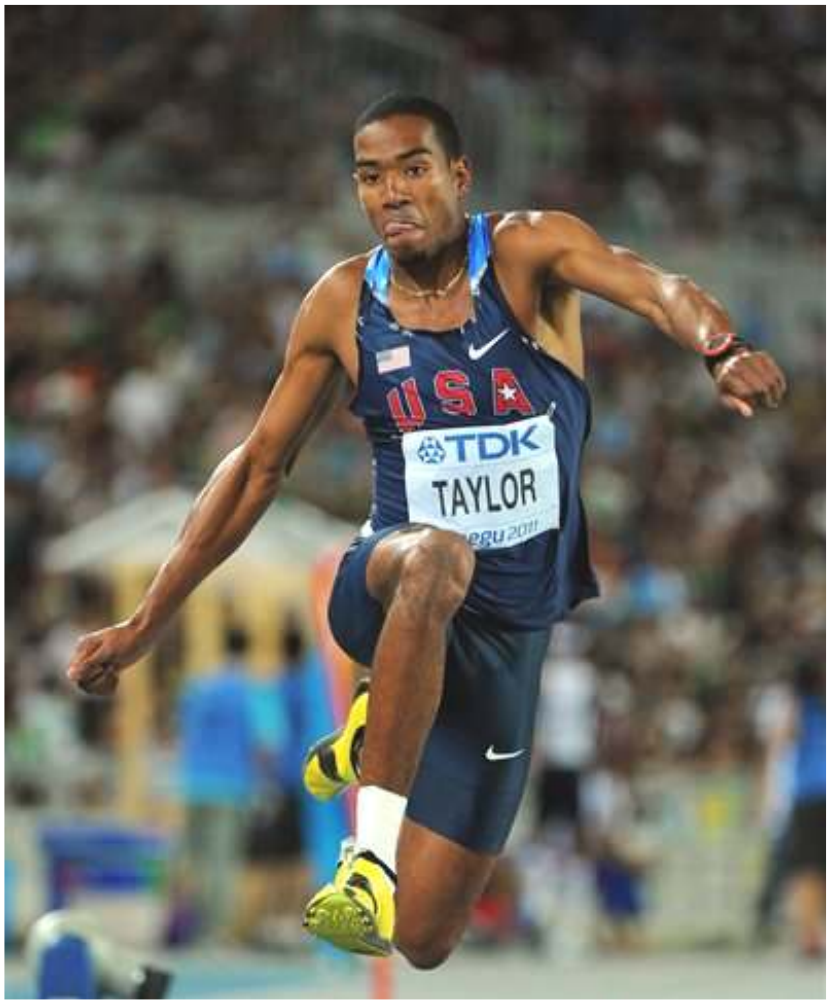


Figure 1. Christian Taylor (USA) (taken from http://daegu2011.iaaf.org)

Before the start of the competition, four control boxes (1 m × 1 m × 2 m) were set up to calibrate the three dimensional coordinates (Figure 2).

In order to conduct a three dimensional analysis of the triple jump competition, seven digital cameras with a shutter speed of 1/1000 sec (Sony vx2100, Sony Fx, JPN, 60 fields/sec) were installed at the stands. Protecting the cameras from the spectators was essential, so a warning line was used. The performance distance used for the analysis of the men's triple jump was 26 m, which was comparable with the 2009 IAAF Berlin World Championships

reports. The performance distance consisted of three zones (9 m, 9 m, 9 m). A 0.5 m overlap occurred between zones 1 and 2 and between zones 2 and 3 (Figure 3). Each zone was covered by two cameras (Figure 2). An additional camera was used to record the total area in order to verify what happened during competition.

Temporal variables; hop, step and jump time; spatial variables; horizontal and vertical velocity at landing and take-off; and hop, step and jump distances for each trial were calculated.

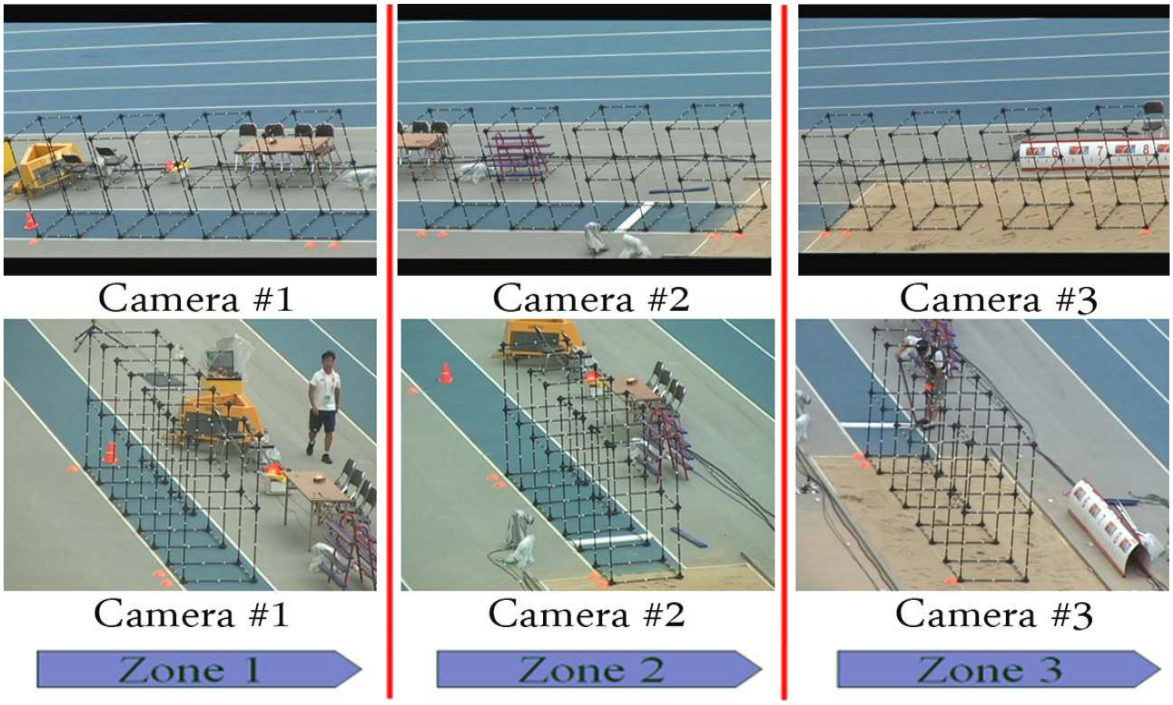


Figure 2. Set-up of control frames & cameras

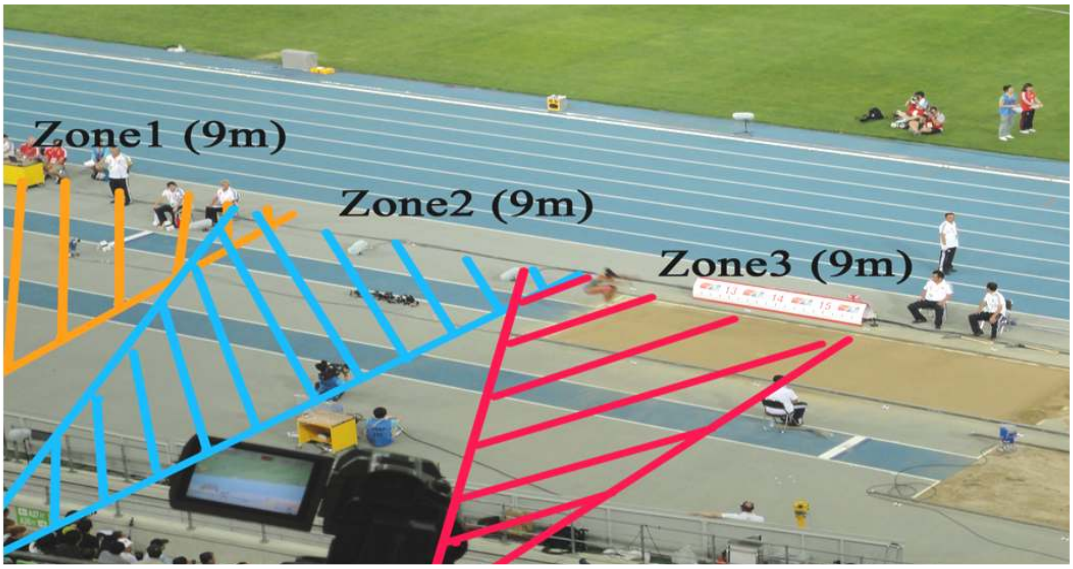


Figure 3. Three zones for recording triple jump performances

1. Kinematic variables of the top 8 athletes - 1

Name / Attempt	Jump distance (m)			Stride length (m)				
	off.	real	loss	2L	1L	Hop	Step	Jump
Taylor C. 4th	17.96	18.10	0.14	2.40	2.37	6.19	5.29	6.62
Idowu P. 4th	17.77	17.77	0.14	2.52	2.24	6.67	5.64	5.60
Claye W. 3rd	17.50	17.67	0.17	2.42	2.31	5.77	5.43	6.47
Copello A. 5th	17.47	17.62	0.15	2.51	2.35	6.40	5.38	5.84
Evora N. 1st	17.35	17.46	0.11	2.39	2.25	6.44	5.18	5.84
Olsson C. 1st	17.23	17.45	0.22	2.63	2.54	6.37	5.09	5.99
Sandsa L. 5th	17.21	17.59	0.38	2.59	2.41	6.63	4.77	6.19
Compaore B. 3rd	17.17	17.48	0.31	2.62	2.59	6.32	5.23	5.93

Name / Attempt	Relative distance (%)			Horizontal velocity (m/s)				
	Hop	Step	Jump	2L	1L	Hop	Step	Jump
Taylor C. 4th	34	29	37	10.25	10.57	9.70	8.61	7.33
Idowu P. 4th	37	32	31	10.36	10.62	9.65	8.11	6.53
Claye W. 3rd	33	31	36	10.08	10.27	9.77	8.57	7.33
Copello A. 5th	36	31	33	9.99	9.94	8.14	7.96	6.71
Evora N. 1st	37	30	33	10.16	10.19	9.49	8.35	6.67
Olsson C. 1st	37	29	34	9.95	10.16	9.35	8.07	7.33
Sandsa L. 5th	38	27	35	10.18	10.28	9.36	8.43	7.50
Compaore B. 3rd	36	30	34	10.43	10.66	9.71	8.26	6.91

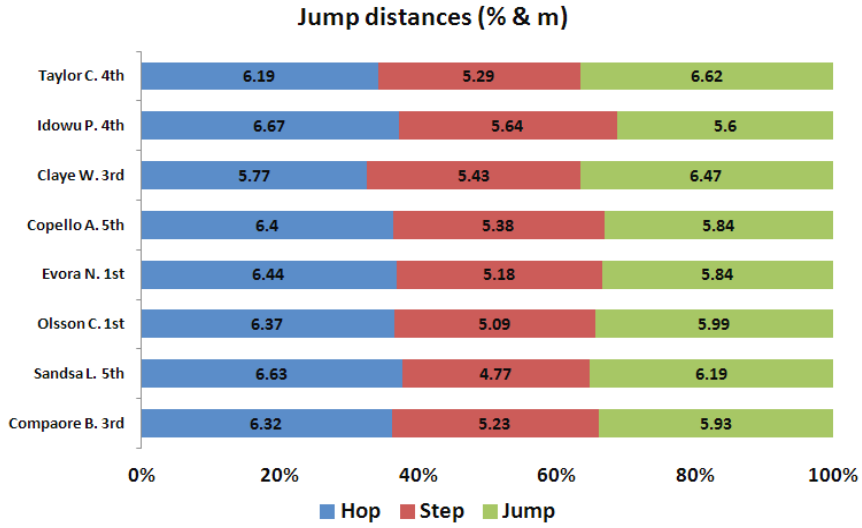
Name / Attempt	Loss of horizontal velocity (m/s)			Vertical velocity (m/s)			Angle of take-off (°)		
	Hop	Step	Jump	Hop	Step	Jump	Hop	Step	Jump
Taylor C. 4th	0.87	1.09	1.28	1.78	1.92	2.43	10.3	12.6	18.3
Idowu P. 4th	0.97	1.54	1.58	2.15	2.05	2.6	12.6	14.3	21.8
Claye W. 3rd	0.50	1.20	1.24	1.85	1.99	2.76	10.7	13.1	20.8
Copello A. 5th	1.80	0.18	1.25	1.88	2.05	2.59	14.1	14.6	21.3
Evora N. 1st	0.70	1.14	1.68	2.27	1.89	2.45	13.4	12.8	20.2
Olsson C. 1st	0.81	1.28	0.74	2.13	1.87	2.16	12.8	13.1	16.5
Sandsa L. 5th	0.92	0.93	0.93	2.2	1.68	1.81	13.2	11.4	13.9
Compaore B. 3rd	0.95	1.45	1.35	1.97	2.04	2.18	11.6	13.8	18.4

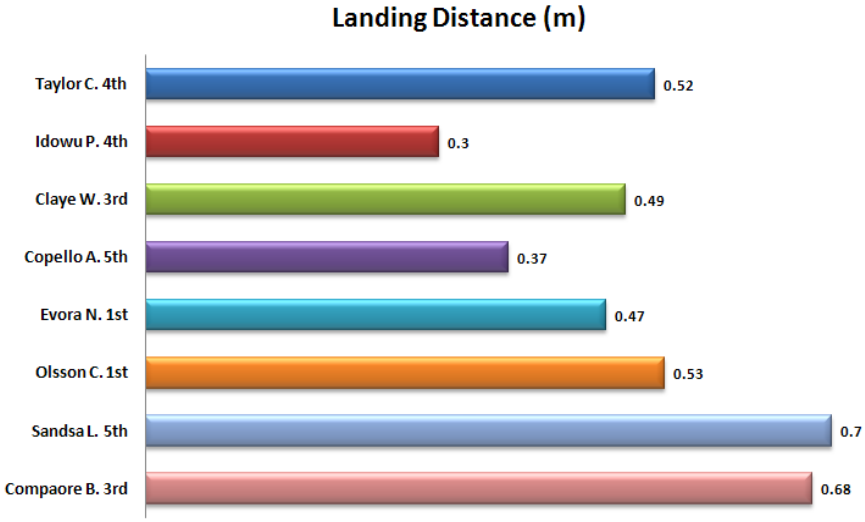
2. Kinematic variables of the top 8 athletes - 2

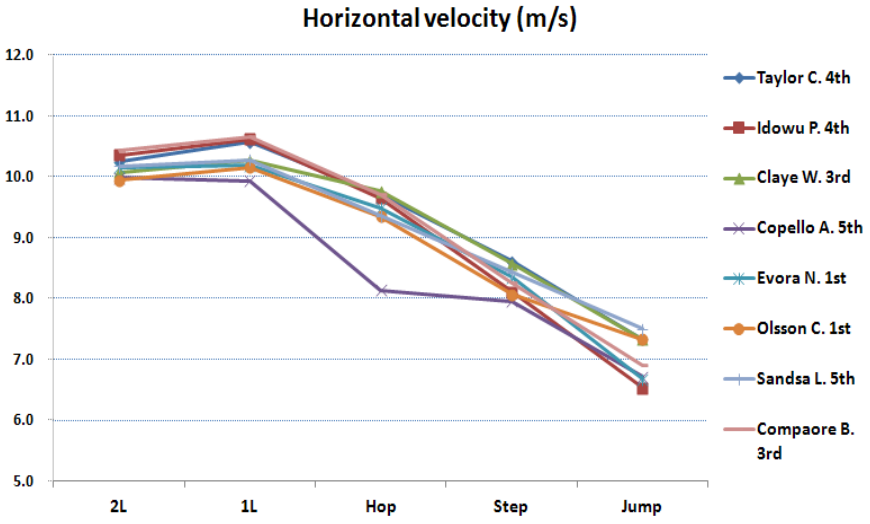
Name / Attempt	Duration of the support phase (s)			Minimal knee angle (°) at contact phase		
	Hop	Step	Jump	Hop	Step	Jump
Taylor C. 4th	0.13	0.17	0.18	149	139	133
Idowu P. 4th	0.13	0.17	0.18	137	140	133
Claye W. 3rd	0.13	0.17	0.17	146	139	149
Copello A. 5th	0.15	0.18	0.20	137	132	139
Evora N. 1st	0.13	0.17	0.20	147	145	138
Olsson C. 1st	0.13	0.18	0.20	152	137	143
Sandsa L. 5th	0.13	0.18	0.18	146	136	141
Compaore B. 3rd	0.13	0.17	0.18	147	142	149

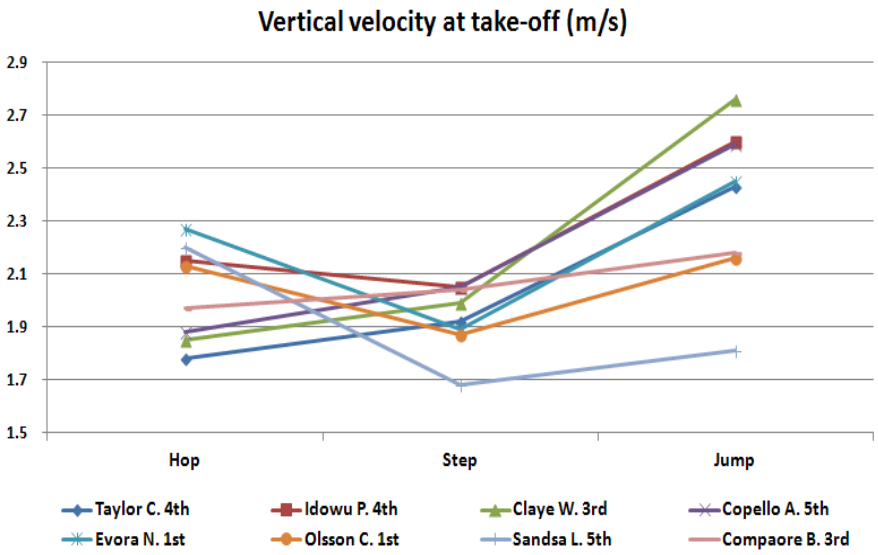
Name / Attempt	Inclination angle at touch-down (°)			Trunk angle (°)					
	Hop	Step	Jump	Hop ↓	Hop ↑	Step ↓	Step ↑	Jump ↓	Jump ↑
Taylor C. 4th	15	20	21	88	88	93	80	88	77
Idowu P. 4th	21	21	24	93	91	92	78	88	66
Claye W. 3rd	16	20	20	84	87	90	88	87	84
Copello A. 5th	19	21	20	88	88	93	82	86	70
Evora N. 1st	21	18	26	87	86	85	78	80	72
Olsson C. 1st	19	23	23	90	80	90	77	86	74
Sandsa L. 5th	17	24	17	88	87	85	81	86	83
Compaore B. 3rd	15	21	19	90	88	92	87	89	74

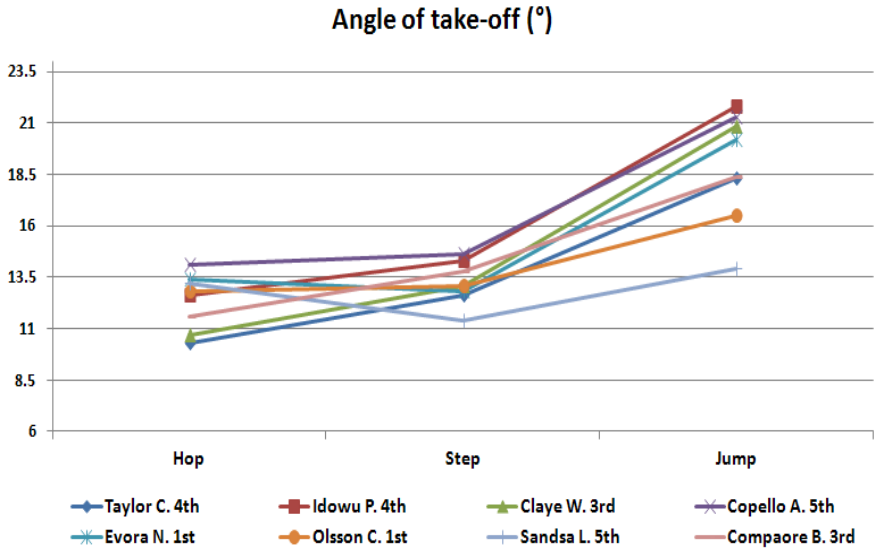
Name / Attempt	Average velocity of the lead leg (°/s)			Landing			
	Hop	Step	Jump	dist. (m)	knee angle (°)	hip angle (°)	trunk angle (°)
Taylor C. 4th	614	571	465	0.52	133	82	63
Idowu P. 4th	582	527	481	0.30	168	48	60
Claye W. 3rd	556	593	516	0.49	147	74	34
Copello A. 5th	627	585	466	0.37	115	92	66
Evora N. 1st	522	449	502	0.47	142	75	28
Olsson C. 1st	508	491	488	0.53	158	65	44
Sandsa L. 5th	664	525	511	0.70	151	77	81
Compaore B. 3rd	571	550	482	0.68	121	91	94

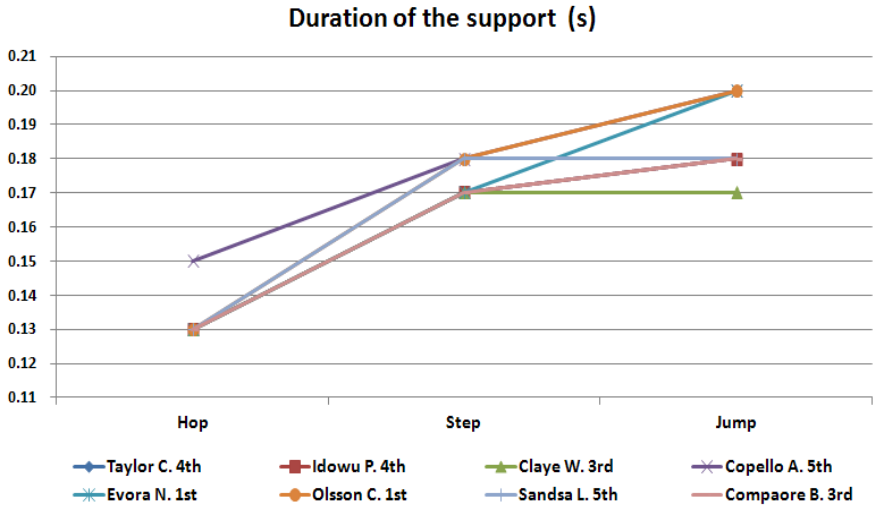

Jump distances (% & m)
Taylor C. 4th
6.19
5.29
6.62
Idowu P. 4th
6.67
5.64
5.6
Claye W. 3rd
5.77
5.43
6.47
Copello A. 5th
6.4
5.38
5.84
Evora N. 1st
6.44
5.18
5.84
Olsson C. 1st
6.37
5.09
5.99
Sandsa L. 5th
6.63
4.77
6.19
Compaore B. 3rd
6.32
5.23
5.93
0%
20%
40%
60%
80%
100%
Hop
Step
Jump


Landing Distance (m)
Taylor C. 4th
0.52
Idowu P. 4th
0.3
Claye W. 3rd
0.49
Copello A. 5th
0.37
Evora N. 1st
0.47
Olsson C. 1st
0.53
Sandsa L. 5th
0.7
Compaore B. 3rd
0.68


Horizontal velocity (m/s)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
2L
1L
Hop
Step
Jump
Taylor C. 4th
Idowu P. 4th
Claye W. 3rd
Copello A. 5th
Evora N. 1st
Olsson C. 1st
Sandsa L. 5th
Compaore B. 3rd


Vertical velocity at take-off (m/s)
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
Hop
Step
Jump
Taylor C. 4th
Idowu P. 4th
Claye W. 3rd
Copello A. 5th
Evora N. 1st
Olsson C. 1st
Sandsa L. 5th
Compaore B. 3rd


Angle of take-off (°)
23.5
21
18.5
16
13.5
11
8.5
6
Hop
Step
Jump
Taylor C. 4th
Idowu P. 4th
Claye W. 3rd
Copello A. 5th
Evora N. 1st
Olsson C. 1st
Sandsa L. 5th
Compaore B. 3rd


Duration of the support (s)
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
Hop
Step
Jump
Taylor C. 4th
Idowu P. 4th
Claye W. 3rd
Copello A. 5th
Evora N. 1st
Olsson C. 1st
Sandsa L. 5th
Compaore B. 3rd

The triple jump event for male qualifiers began at 10:26 AM. on September 2nd, 2011. The temperature was 25° Celsius with a humidity of 74%. There were two groups of athletes, with 16 athletes in group A and 15 athletes in group B.

Athletes with a qualification distance of over 17.10 m and the top 12 qualifiers advanced to the next round. Of the 31 athletes, 5 were disqualified. The 26 who remained had an average distance of 16.69 ± 0.44 m. Only 7 of these athletes had a distance greater than this. The cut off line for advancement was 17.07 ± 0.16 m, which was only 0.38 m longer than the average distance. Alexis COPELLO (CUB) was ranked first, Nelson EVORA (POR) was ranked second, and Will CLAYE (USA) was ranked third. These three athletes had an average distance of 17.23 ± 0.07 m, which was 0.16 m longer than the qualification distance and 0.54 m longer than the average distance of the other qualifying athletes.

The finals of the men's triple jump began at 7:02 AM. on September 4th, 2011. The temperature was 27° Celsius with a humidity of 54%.

There was a 0.18 m difference between the average distance of the top eight finishers at the 2011 Daegu World Championships and the average distance of the top eight finishers at the 2009 Berlin World Championships. The average from the Daegu World Championships was 17.46 ± 0.28 m, while the average from the Berlin World Championships was 17.28 ± 0.29 m.

Number one ranked Christian TAYLOR's (USA) distance of 17.96 m from the Daegu World Championships was 0.23 m longer than Phillips IDOWU's (GBR) Berlin distance of 17.73 m. The top four athletes at the 2009 Berlin World Championships were Phillips IDOWU (GBR), Nelson EVORA (POR), Alexis COPELLO (CUB), and Leevan SANDS (BAH), who were ranked second, fifth, fourth and seventh respectively at the Daegu World Championships.

The hop, step and jump phases with the stride length relative distance were classified into the hop-dominated technique, the balanced technique and the jump-dominated technique. Number one ranked Christian TAYLOR (USA) and number three ranked Will CLAYE (USA) used the relatively jump-dominated technique, while the remaining top athletes used the relatively hop-dominated technique.

The horizontal velocity at take-off of the top eight finishers at the 2011 Daegu World Championships averaged: 2L (10.18 ± 0.17 m/s), 1L (10.34 ± 0.26 m/s), Hop (9.40 ± 0.53 m/s), Step (8.30 ± 0.24 m/s), and Jump (7.04 ± 0.38 m/s). All of these averages were high when compared to the 2009 Berlin World Championships, where the averages were: 2L (10.13 ± 0.23 m/s), 1L (10.14 ± 0.21 m/s), Hop (9.38 ± 0.20 m/s), Step (8.29 ± 0.14 m/s), and Jump (6.99 ± 0.22 m/s).

The vertical velocity at take-off for the top eight ranked athletes at the 2011 Daegu World Championships averaged: Hop (2.03 ± 0.18 m/s), Step (1.94 ± 0.13 m/s), and Jump (2.37 ± 0.31 m/s). All of these averages were low when compared to the 2009 Berlin World

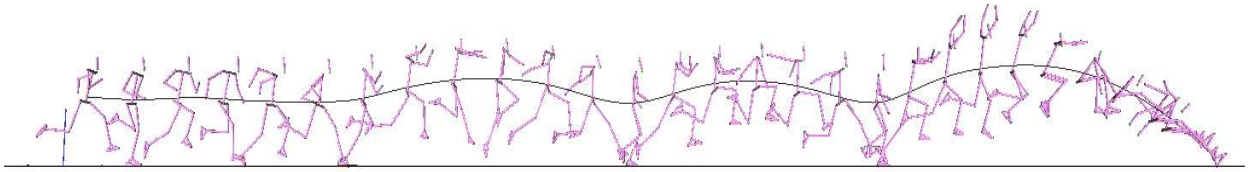
Championships, where the averages were: Hop (2.48 ± 0.13 m/s), Step (2.06 ± 0.19 m/s), and Jump (2.63 ± 0.23 m/s).

The take-off angle for the top eight ranked athletes at the 2011 Daegu World Championships for each phase averaged: Hop (12.34 ± 1.34°), Step (13.21 ± 1.02°), and Jump (18.90 ± 2.69°). The averages at the 2009 Berlin World Championships were: Hop (14.75 ± 1.04°), Step (14.00 ± 1.51°), and Jump (20.63 ± 2.39°), which were all higher for all phases than at the Daegu Championships.

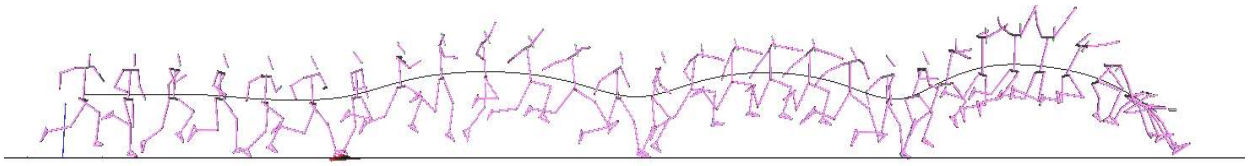
Finally, the duration of the support phase for the top eight ranked athletes at the 2011 Daegu World Championships was: Hop (0.13 ± 0.01 s), Step (0.17 ± 0.01 s), and Jump (0.19 ± 0.01 s). The average for the 2009 Berlin World Championships was: Hop (0.12 ± 0.01 s), Step (0.15 ± 0.01 s), and Jump (0.17 ± 0.01 s), all of which increased at the Daegu Championships for all phases.

3. Stick figures of the top 8 athletes

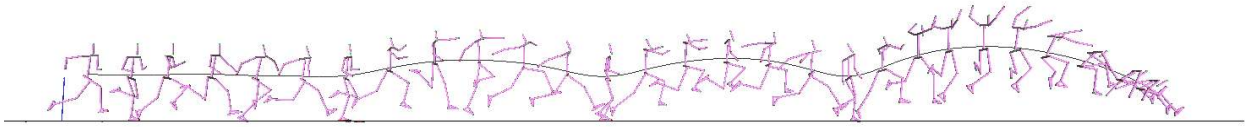
Rank 1 : Taylor C. 4th 17.96 m



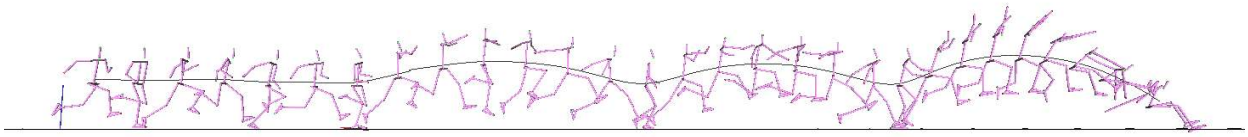
Rank 2 : Idowu P. 4th 17.77 m



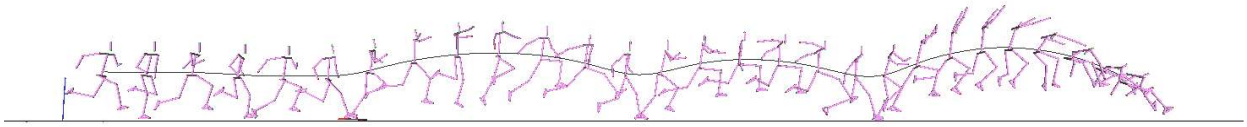
Rank 3 : Claye W. 3rd 17.50 m



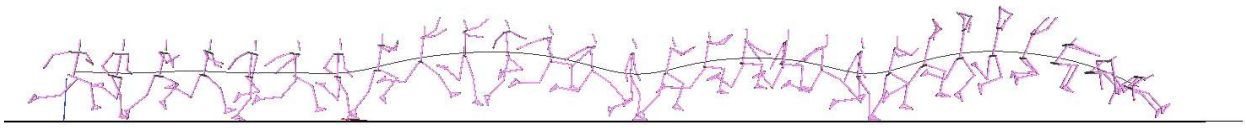
Rank 4 : Copello A. 5th 17.47 m



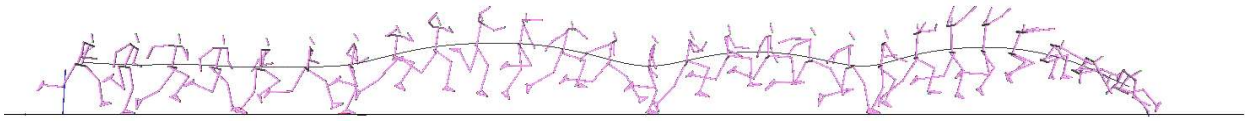
Rank 5 : Evora N. 1st 17.35 m



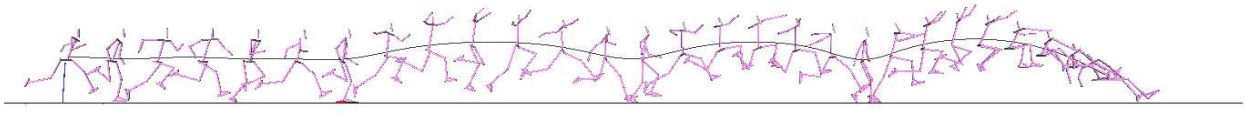
Rank 6 : Olsson C. 1st 17.23 m



Rank 7 : Sandsa L. 5th 17.21 m



Rank 8 : Compaore B. 3rd 17.17 m



Women's Triple Jump Biomechanics Research Report from the IAAF World Championships Daegu, 2011

• Director :

Sang-Yeon Woo(Soonchunhyang University, Korea)

Yong-Woon Kim(Kyungnam University, Korea)

• Researcher :

Jung-Suk Seo(Wonkwang University, Korea) · Ho-Mook Kim(Soonchunhyang University, Korea) Ki-Jeong Nam(Seoul National University, Graduate School, Korea) · Yong-Hyun Park(Seoul National University, Graduate School, Korea) · Sung-Bum Choi(Soonchunhyang University, Graduate School, Korea) · Jin-Hyuk Kim(Soonchunhyang University, Graduate School, Korea)

10. Biomechanical Analysis of the Women's Triple Jump Finals

13th IAAF World Championships in Athletics - Daegu on September 4, 2011

Olha Saladuha won the gold medal in the women's triple jump in Daegu in 2011 with a distance of 14.94 m (Figure 1). Surprisingly, she continues on post-childbirth to secure her second big title. Following the birth of her daughter in 2009, Saladuha has shown the best form of her career. Before 2009, Saladuha had consistently improved as a jumper but had not won a big title. However, last year she won the European title. Her win in Daegu was her first global title.

Figure 1. Olha Saladuha (Ukraine) (taken from http://daegu 2011.iaaf.org)

Before the start of the competition, four control boxes (1 m × 1 m × 2 m) were set up to calibrate the three dimensional coordinates (Figure 2).

In order to conduct a three dimensional analysis of the triple jump competition, seven digital cameras with a shutter speed of 1/1000 sec (Sony vx2100, Sony Fx, JPN, 60 fields/sec) were installed at the stands. Protecting the cameras from the spectators was essential, so a warning line was used. The performance distance used for the analysis of the women's triple jump was 23 m, which was comparable to the 2009 IAAF Berlin World Championships reports. The performance distance consisted of three zones (9 m, 7 m, 8 m respectively). A 0.5 m overlap occurred between zones 1 and 2 and between zones 2 and 3 (Figure 3). Each zone was covered by two cameras (Figure 2). An additional camera was used to record the total area in order to verify what happened during competition.

Temporal variables; hop, step and jump time; spatial variables; horizontal and vertical velocity at landing and take-off; and hop, step and jump distances for each trial were calculated.

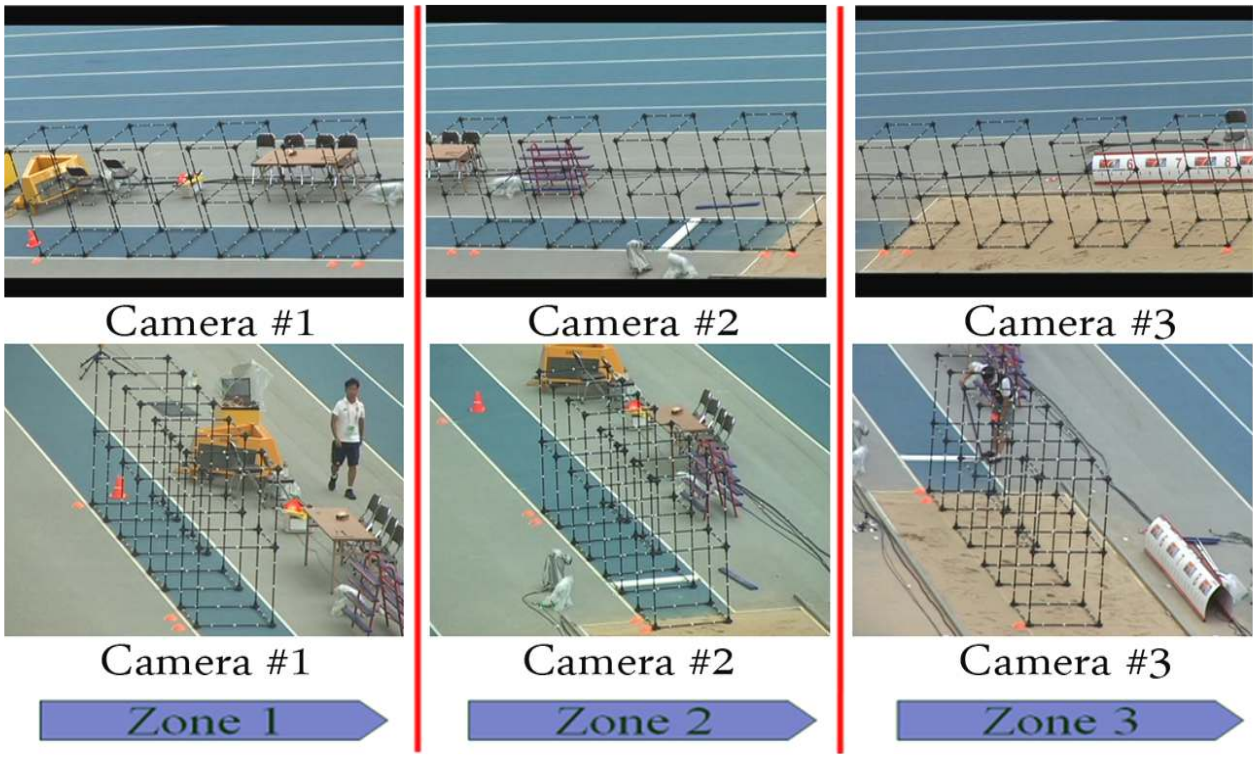


Figure 2. Set-up of control frames & cameras

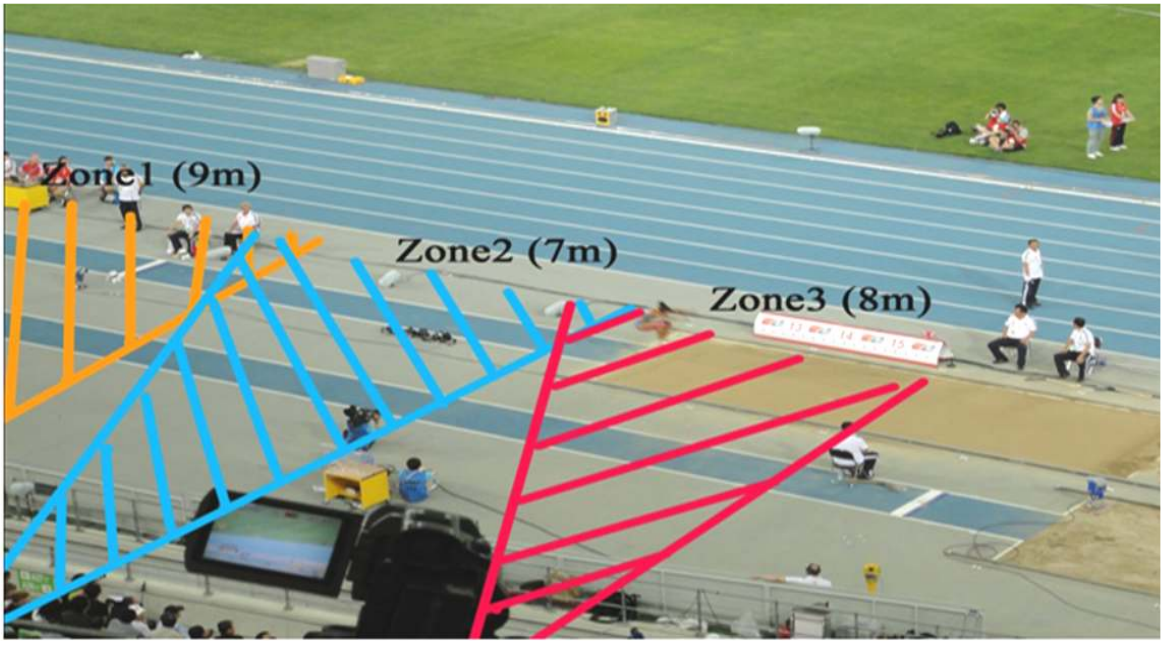


Figure 3. Three zones for recording triple jump performances

1. Kinematic variables of the top 8 athletes - 1

Name / Attempt	Jump distance (m)			Stride length (m)				
	off.	real	loss	2L	1L	Hop	Step	Jump
Saladuha O. 1st	14.94	15.04	0.10	2.25	2.21	5.73	4.15	5.16
Rypakova O. 5th	14.89	15.14	0.25	2.48	2.71	5.38	4.23	5.53
Ibarguen C. 5th	14.84	14.89	0.05	2.20	2.14	5.48	4.19	5.22
Gay M. 5th	14.67	14.92	0.25	2.39	2.11	5.55	4.33	5.04
Aldama Y. 1st	14.50	14.62	0.12	2.21	2.10	5.62	4.49	4.51
Savigne Y. 1st	14.43	14.59	0.16	2.19	2.09	5.18	3.82	5.59
Kuropatkina A. 2nd	14.23	14.23	0.00	2.10	2.28	5.03	4.18	5.02
Rahouli B. 3rd	14.12	14.26	0.14	2.24	2.05	4.95	4.23	5.08

Name / Attempt	Relative distance (%)			Horizontal velocity (m/s)				
	Hop	Step	Jump	2L	1L	Hop	Step	Jump
Saladuha O. 1st	38	28	34	9.09	9.04	8.31	7.14	5.9
Rypakova O. 5th	35	28	37	9.44	9.45	8.51	7.79	6.99
Ibarguen C. 5th	37	28	35	9.72	9.47	8.64	7.91	6.22
Gay M. 5th	37	29	34	8.88	8.95	7.73	6.98	5.85
Aldama Y. 1st	38	31	31	8.94	8.99	7.92	6.4	5.43
Savigne Y. 1st	36	26	38	9.16	9.20	8.24	8.18	7.00
Kuropatkina A. 2nd	35	30	35	8.70	8.72	7.60	7.17	6.11
Rahouli B. 3rd	35	30	35	8.81	8.9	8.15	7.47	6.45

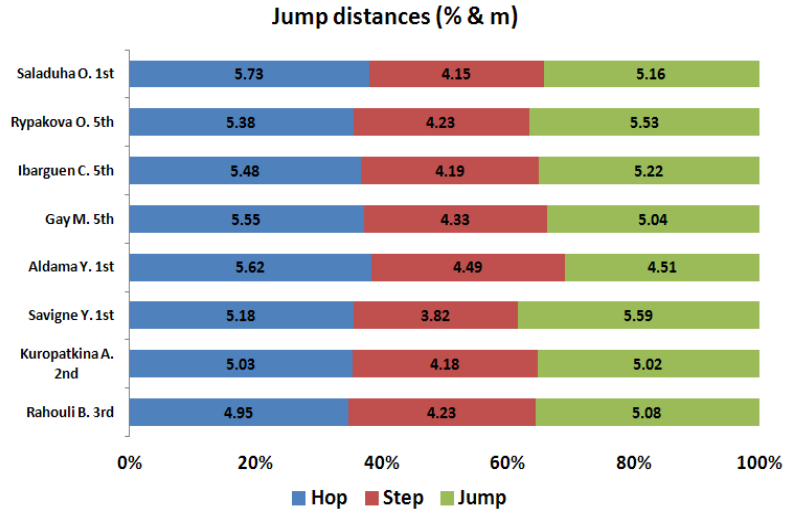
Name / Attempt	Loss of horizontal velocity (m/s)			Vertical velocity (m/s)			Angle of take-off (°)		
	Hop	Step	Jump	Hop	Step	Jump	Hop	Step	Jump
Saladuha O. 1st	0.73	1.17	1.24	2.22	1.62	2.29	15.1	12.8	21.2
Rypakova O. 5th	0.94	0.72	0.8	2.03	1.51	2.13	13.4	11.0	17.1
Ibarguen C. 5th	0.83	0.73	1.69	2.13	1.72	2.5	14.1	12.1	22.1
Gay M. 5th	1.22	0.75	1.13	1.98	1.57	2.28	14.4	13.0	21.6
Aldama Y. 1st	1.07	1.52	0.97	2.19	2.03	2.17	15.4	17.7	22.0
Savigne Y. 1st	0.96	0.06	1.18	1.79	1.00	2.03	12.2	6.7	16.1
Kuropatkina A. 2nd	1.12	0.43	1.06	1.78	1.62	2.30	13.1	12.7	20.7
Rahouli B. 3rd	0.75	0.68	1.02	1.71	1.67	1.99	11.8	12.6	17.2

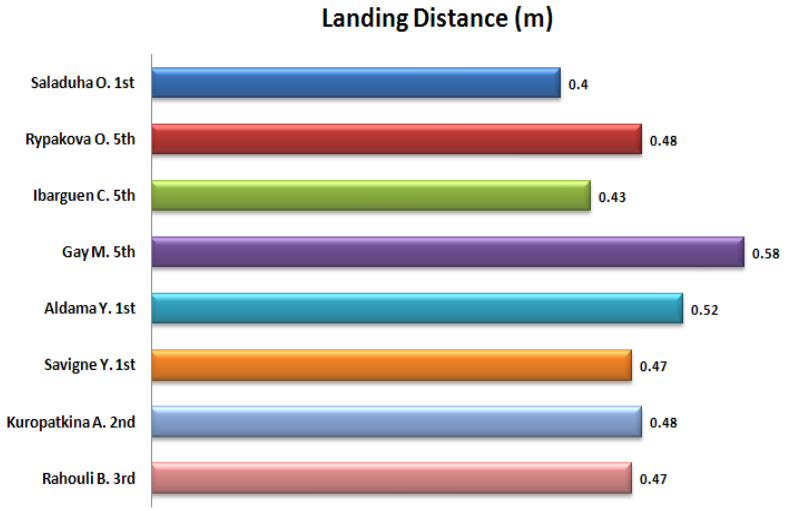
2. Kinematic variables of the top 8 athletes - 2

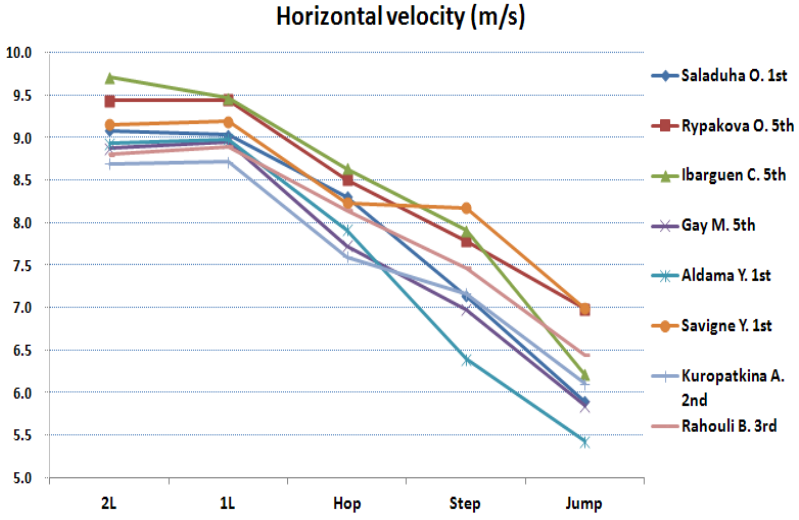
Name / Attempt	Duration of the support phase (s)			Minimal knee angle (°)at contact phase		
	Hop	Step	Jump	Hop	Step	Jump
Saladuha O. 1st	0.15	0.17	0.17	147	140	144
Rypakova O. 5th	0.13	0.17	0.17	150	145	148
Ibarguen C. 5th	0.13	0.15	0.18	143	156	142
Gay M. 5th	0.17	0.18	0.20	140	137	143
Aldama Y. 1st	0.12	0.17	0.20	149	136	143
Savigne Y. 1st	0.13	0.15	0.17	133	144	138
Kuropatkina A. 2nd	0.15	0.17	0.20	146	136	141
Rahouli B. 3rd	0.15	0.17	0.20	148	144	147

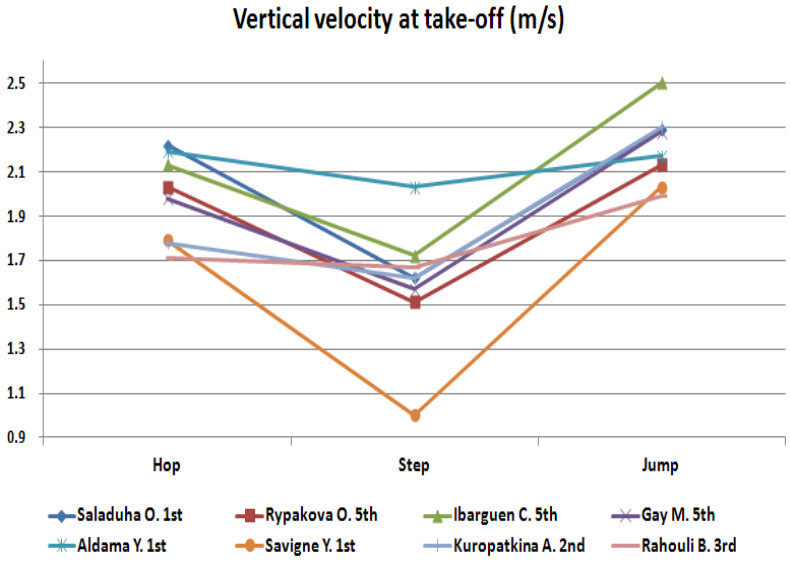
Name / Attempt	Inclination angle at touch-down (°)			Trunk angle (°)					
	Hop	Step	Jump	Hop ↓	Hop ↑	Step ↓	Step ↑	Jump ↓	Jump ↑
Saladuha O. 1st	21	14	16	92	84	88	73	93	89
Rypakova O. 5th	17	12	13	84	84	83	80	91	84
Ibarguen C. 5th	21	18	23	92	79	92	75	80	81
Gay M. 5th	21	19	22	91	89	88	80	85	75
Aldama Y. 1th	13	14	21	87	86	86	73	80	69
Savigne Y. 1st	13	11	21	88	88	91	89	87	89
Kuropatkina A. 2nd	19	12	22	87	91	86	80	83	84
Rahouli B. 3rd	18	17	19	88	88	88	87	84	78

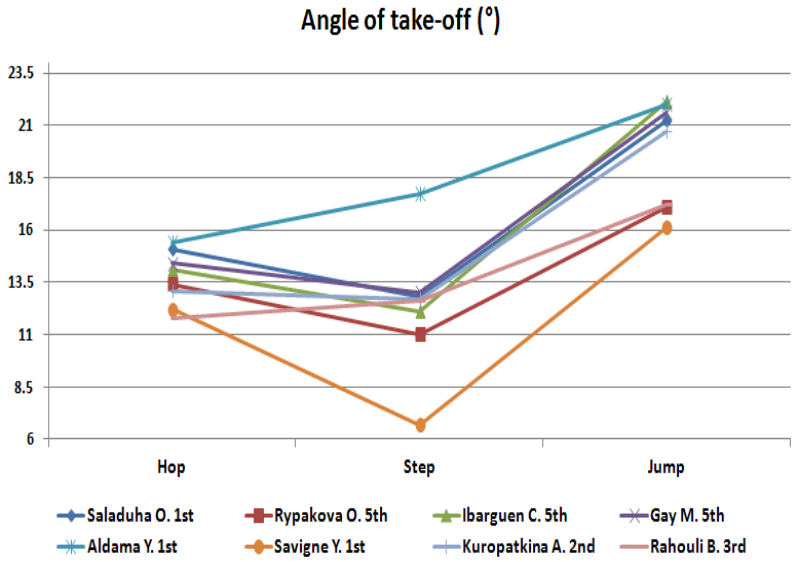
Name / Attempt	Average velocity of the lead leg (°/s)			Landing			
	Hop	Step	Jump	dist. (m)	knee angle (°)	hip angle (°)	trunk angle (°)
Saladuha O. 1st	561	540	401	0.40	124	77	77
Rypakova O. 5th	603	487	479	0.48	129	85	62
Ibarguen C. 5th	662	528	596	0.43	145	69	46
Gay M. 5th	496	498	400	0.58	154	71	40
Aldama Y. 1st	523	477	418	0.52	154	75	52
Savigne Y. 1st	552	478	511	0.47	123	89	93
Kuropatkina A. 2nd	449	482	432	0.48	138	78	50
Rahouli B. 3rd	514	474	427	0.47	156	67	71

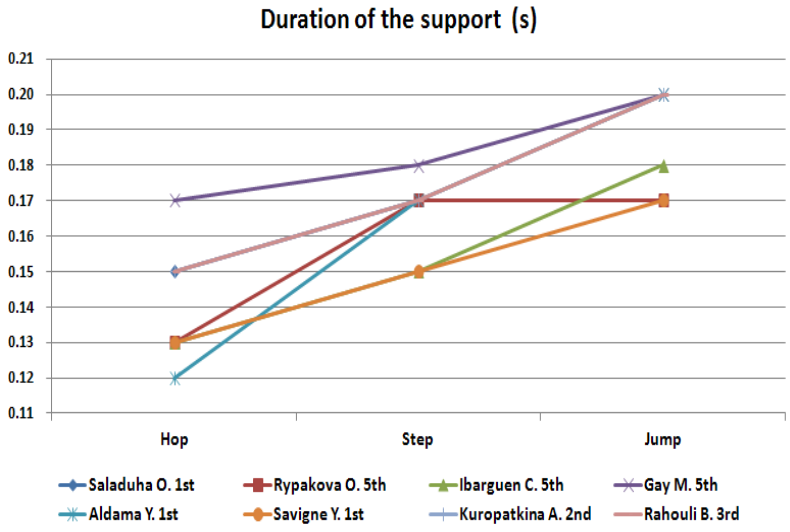

Jump distances (% & m)
Saladuha O. 1st
5.73
4.15
5.16
Rypakova O. 5th
5.38
4.23
5.53
Ibarguen C. 5th
5.48
4.19
5.22
Gay M. 5th
5.55
4.33
5.04
Aldama Y. 1st
5.62
4.49
4.51
Savigne Y. 1st
5.18
3.82
5.59
Kuropatkina A. 2nd
5.03
4.18
5.02
Rahouli B. 3rd
4.95
4.23
5.08
0%
20%
40%
60%
80%
100%
Hop
Step
Jump


Landing Distance (m)
Saladuha O. 1st
0.4
Rypakova O. 5th
0.48
Ibarguen C. 5th
0.43
Gay M. 5th
0.58
Aldama Y. 1st
0.52
Savigne Y. 1st
0.47
Kuropatkina A. 2nd
0.48
Rahouli B. 3rd
0.47


Horizontal velocity (m/s)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
2L
1L
Hop
Step
Jump
Saladuha O. 1st
Rypakova O. 5th
Ibarguen C. 5th
Gay M. 5th
Aldama Y. 1st
Savigne Y. 1st
Kuropatkina A. 2nd
Rahouli B. 3rd


Vertical velocity at take-off (m/s)
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
Hop
Step
Jump
Saladuha O. 1st
Rypakova O. 5th
Ibarguen C. 5th
Gay M. 5th
Aldama Y. 1st
Savigne Y. 1st
Kuropatkina A. 2nd
Rahouli B. 3rd


Angle of take-off (°)
23.5
21
18.5
16
13.5
11
8.5
6
Hop
Step
Jump
Saladuha O. 1st
Rypakova O. 5th
Ibarguen C. 5th
Gay M. 5th
Aldama Y. 1st
Savigne Y. 1st
Kuropatkina A. 2nd
Rahouli B. 3rd


Duration of the support (s)
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
Hop
Step
Jump
Saladuha O. 1st
Rypakova O. 5th
Ibarguen C. 5th
Gay M. 5th
Aldama Y. 1st
Savigne Y. 1st
Kuropatkina A. 2nd
Rahouli B. 3rd

The triple jump event for female qualifiers began at 11:41 AM. on August 30th, 2011. The temperature was 27° Celsius with a humidity of 70%. There were two groups of athletes, with 17 athletes in group A and 17 athletes in group B.

Athletes with a qualification distance of over 14.45 m and the top 12 ranked athletes advanced to the next round. The 34 athletes had an average distance of 13.95 ± 0.39 m. Only 3 of the athletes had a distance greater than this. The cut off line for advancement was 14.35 ± 0.14 m, which was only 0.40 m longer than the average distance. Yargeris SAVIGNE (CUB) was ranked first, Mabel GAY (CUB) was ranked second, and Caterine IBARGUEN (COL) was ranked third. These three athletes had an average distance of 17.23 ± 0.07 m, which was 0.61 m longer than the qualification distance and 0.21 m longer than the average distance of other qualifying athletes.

The finals of the women's triple jump event began at 7:17 AM. on September 1st, 2011. The temperature was 29° Celsius with a humidity of 53%.

The average distance for the female triple jump finalists at the 2011 Daegu World Championships was 14.58 ± 0.31 m, while the top ranked Olha SALADUHA (UKR) jumped 0.36 m further than the average of the top eight ranked athletes.

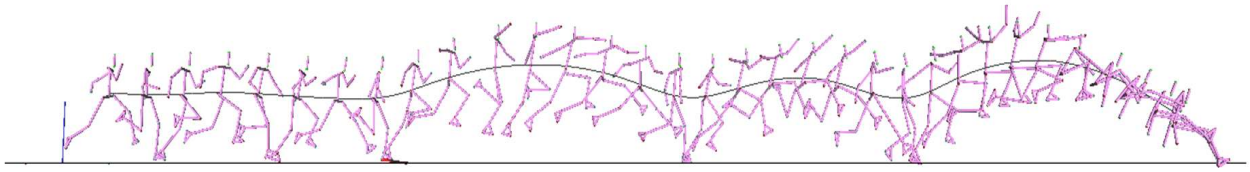
The hop, step and jump phases with the stride length relative distance were classified into the hop-dominated technique, the balanced technique and the jump-dominated technique. The number two ranked Olga RYPAKOVA (KAZ), sixth ranked Yargeris SAVIGNE (CUB), and seventh ranked Anna KUROPATKINA (RUS) used the jump-dominated technique, while eighth ranked Baya RAHOULI (ALG) used the balanced technique. Number one ranked Olha SALADUHA (UKR) and the remaining athletes used the hop-dominated technique.

The horizontal velocity at take-off for all of the phases for the top eight ranked athletes at the 2011 Daegu World Championships averaged: L (9.09 ± 0.34 m/s), 1L (9.09 ± 0.26 m/s), Hop (8.14 ± 0.37 m/s), Step (7.38 ± 0.58 m/s), and Jump (6.24 ± 0.55 m/s). The vertical velocity at take-off averaged: Hop (1.98 ± 0.20 m/s), Step (1.59 ± 0.29 m/s), and Jump (2.21 ± 0.17 m/s).

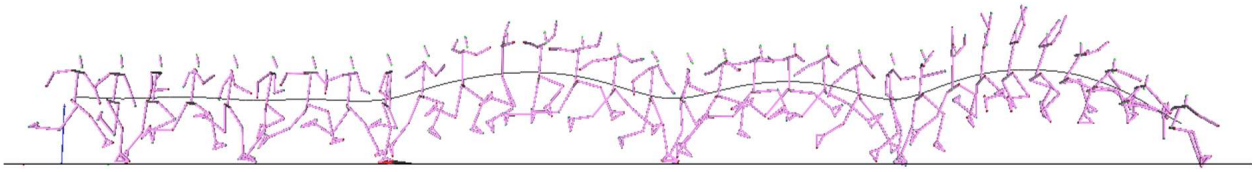
The average take-off angle for the top eight ranked females at the 2011 Daegu World Championships was: Hop (13.69 ± 1.30°), Step (12.33 ± 3.01°), and Jump (19.75 ± 2.50°) for each of the phases. The support phase duration was: Hop (0.14 ± 0.02 s), Step (0.17 ± 0.01 s), and Jump (0.19 ± 0.02 s).

3. Stick figures of the top 8 athletes

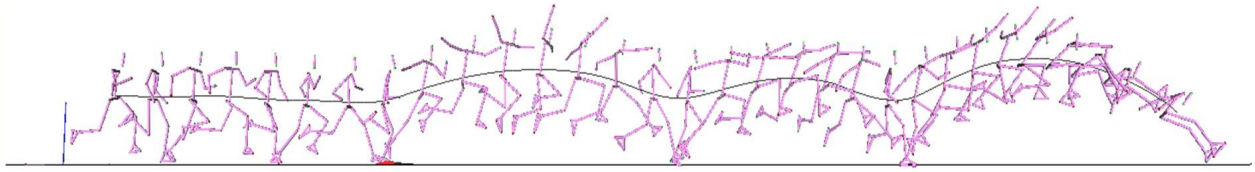
Rank 1 : Saladuha, O.; 1st Attempt; 14.94 m



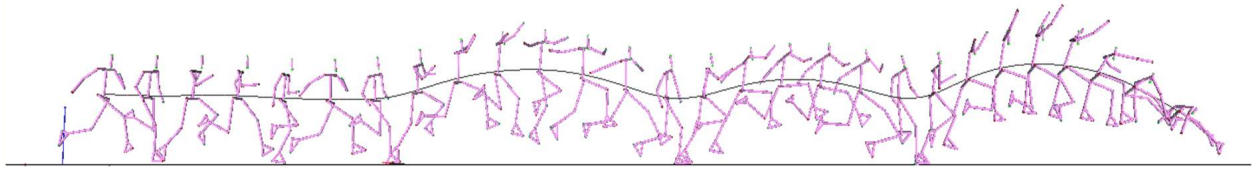
Rank 2 : Rypakova, O.; 5th Attempt; 14.89 m



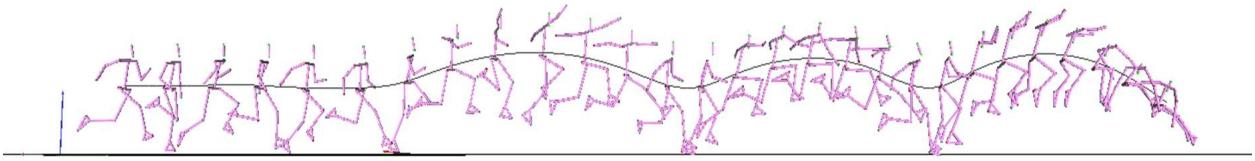
Rank 3 : Ibarguen, C.; 5th Attempt; 14.84 m



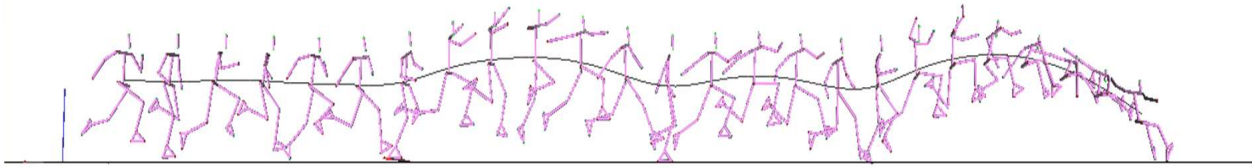
Rank 4 : Gay, M.; 5th Attempt; 14.67 m



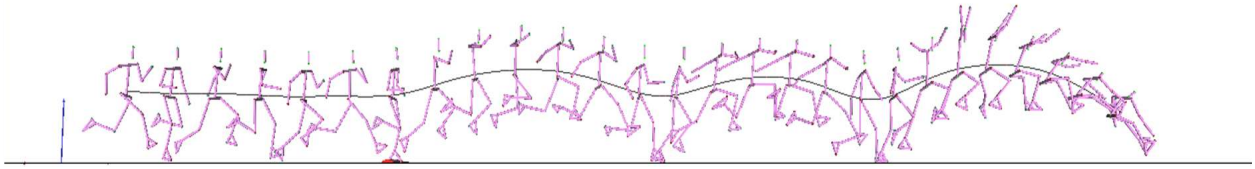
Rank 5 : Aldama, Y.; 1st Attempt; 14.50 m



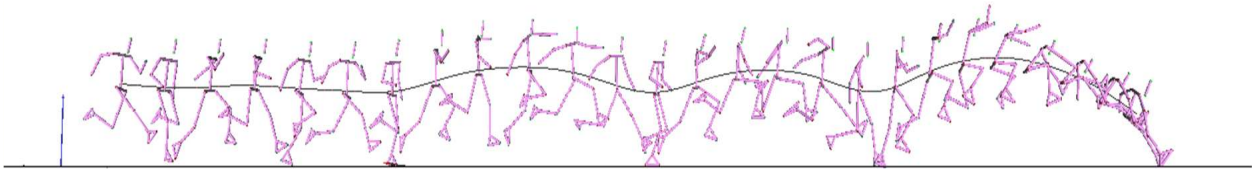
Rank 6 : Savigne, Y.; 1st Attempt; 14.43 m



Rank 7 : Kuropatkina, A.; 2nd Attempt; 14.23 m



Rank 8 : Rahouli, B.; 3rd Attempt; 14.12 m



13th IAAF World Championships in Athletics, Daegu Final Report Men's Shot Put Finals

- Director :

Cheong-Hwan Oh(Chungnam National University, Korea) · Eui-Su Shin(Chungnam National University, Korea) Su-Nam Choi(Chungnam National University, Korea) · Ik-Su Jeong(Chungnam National University, Korea) Jae-Hee Bae(Chungnam National University, Korea) · Jeong-Tae Lee(Korea Research Institute of Standards and Science, Korea) · Seung-Bum Park(Busan Economic Promotion Agency, Korea)

11. Biomechanical Analysis of Men's Shot Put Finals

13th IAAF World Championships in Athletics, Daegu on September 2nd, 2011 at 18:56

The preliminary round for men's shot put began at 09:56 on September 1st, 2011. The weather was sunny, and the temperature was 27° C with a humidity of 74%. 27 athletes from all over the world, were divided into two groups. Group A consisted of 14 athletes and group B consisted of 13 athletes.

Only 12 athletes could move on to the finals. To qualify, competitors either had to throw the qualification distance of 20.60 m or place within the top 12. The average throw distance of the 27 athletes during the preliminary round was 19.92 ± 0.92 m, and only 7 threw further than the qualification distance.

David STORL (GER) took 1st place in the preliminary round, Dylan ARMSTRONG (CAN) took 2nd and Reese HOFFA (USA) took 3rd. The average throw distance of the three was 21.17 ± 0.29 m. This was 1.25 m longer than that of the other 24. The average throw distance, speed, angle of projection and height of the three are as shown in <Figure 1>.

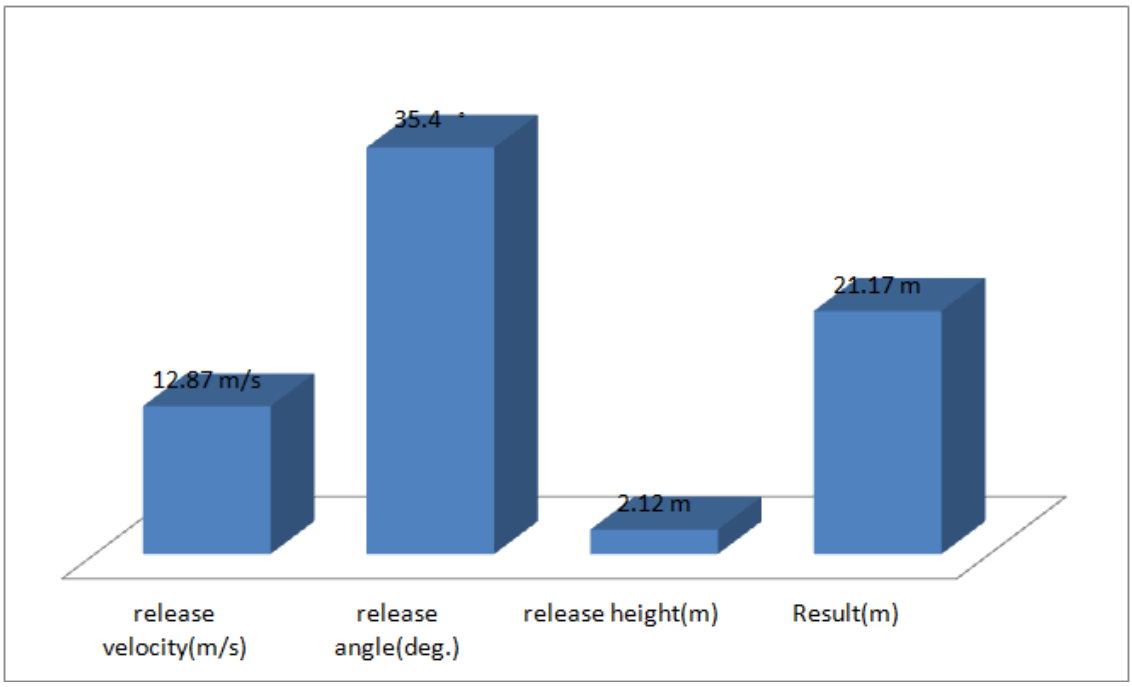


Figure 1. Selected kinematic data from the men's shot put qualifications

The final round for the men's shot put began at 18:56 on September 2nd, 2011. The weather was a little cloudy, and the temperature was 27°C with a humidity of 64%. The average throw distance was 21.13 ± 0.50 m. This was 0.11 m shorter than that of the 2009 Berlin World Championships, which was 21.24 ± 0.53 m. In terms of technique styles used by the top 8 athletes, the 1st and the 3rd place finishers used the glide technique, while the 5 other top

finishers used the rotational technique. Similar to 2009 Berlin World Championships, more athletes in Daegu used the rotational technique than the glide technique. In Berlin, 3 athletes used the glide technique and 5 athletes used the rotational technique. Nevertheless, athletes using the glide technique took 2 medals (gold and bronze) out of 3 at the 2011 Daegu World Championships, and athletes using the glide technique also took the silver and bronze at the Berlin Championships. In other words, many athletes used the rotational technique but the glide technique has proven to be a good way to achieve a long distance.

The gold medalist, David STORL (GER), set a personal record of 21.78 m outperforming his season's best of 21.05 m by 0.73 m (3.4%). The 2nd to 8th place finishers threw an average of -3.6% shorter their season's best.

Table 1. Official competition results from the men's shot put finals in relation to season's best (SB) before the World Championships (WCh) and the technique style used

Rank	Athleta	Result WCh (m)	SB before WCh (m)		Style
1	David STORL (GER)	21.78	21.05	3.40%	glide
2	Dylan AMSTRONG (CAN)	21.64	22.12	-2.20%	rotational
3	Andrei MIKHNEVIKI (BLR)	21.4	22.1	-3.20%	glide
4	Christian CANTWELL (USA)	21.36	21.87	-2.40%	rotational
5	Reese HOFFA (USA)	20.99	21.87	-4.10%	rotational
6	Marco FORTES (POR)	20.83	20.89	-0.30%	rotational
7	Ryan WHITING (USA)	20.75	21.76	-4.70%	rotational
8	Adam NELSON (USA)	20.29	22.09	-8.20%	rotational

The average throw speed at the men's shot put quarterfinals at the 2011 Daegu World Championships was 13.24 ± 0.38 m/s. It was 0.58 m/s slower than that of the Berlin Championships which was 13.82 ± 0.24 m/s. The average angle of projection was 34.68 ± 2.90°. This was 1.32° lower than that of the Berlin Championships which was 36.00 ± 2.77°.

The average throw height was 2.10 ± 2.91 m, which was lower than at the Berlin Championships, which was 2.23 ± 0.15 m. The average angular velocity at the shoulder was 922.38 ± 61.07°/s, This, was faster than the speed at the Berlin Championships, which was 859.37 ± 126.35°/s. But the average angular velocity at the hip in Daegu was 479.50 ±

101.81°/s, which was slower than the Berlin Championships (502.50 ± 110.58 °/s).

In terms of the throw height in relation to the types of technique, the average throw height of athletes using the glide technique was 2.24 m, which was 0.19 m higher than that of the ones using the rotational technique. In terms of the average shoulder and hip angular velocity, the athletes using the rotational technique speeds of 953.2°/s and 520.8°/s respectively, which was faster then the speeds of the athletes using the glide technique, who recorded speeds of 830.0°/s and, 355.5°/s respectively. Athletes using the rotational technique recorded shorter times during delivery compared to the athletes using the glide technique.

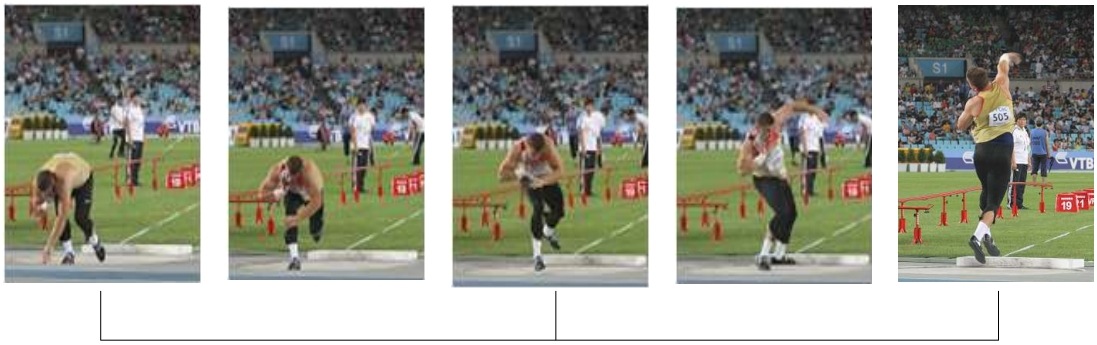
Male fourth and fifth place finishers at the Berlin Championships, Reese Hoffa (1.80 m, USA) and Adam Nelson (1.83 m, USA) are of relatively shorter height and used the rotational technique. They had the lowest throw heights among the top 8 athletes. Their projection angles were also fairly small: 32.9° and 34.4° respectively.

But their throw speed was relatively high: 14.0 m/s and 14.1 m/s respectively. Adam Nelson's (USA) shoulder angular speed was the highest among the top 8 athletes. Reese Hoffa (1.80 m, USA) who placed 5th in the Daegu Championships had a small projection angle of 31.16° and a low throw height of 2.02 m. However, his angular velocity at the shoulder was 997°/s, which was the highest among those who participated in the Championships. His throw speed of 13.51 m/s was also high. These results demonstrate that high angular velocity in the upper body from the rotational technique can increase throwing speed. Thus, relatively shorter shot putters can use this technique to achieve long distances instead of attempting to increase throw height or projection angle.

Table 2. Selected kinematic data of men's shot put of finals

Rank	Athlete	Analysed attempt	Result WCh (m)	Release velocity (m/s)	Release angle (deg)	Release height (m)	Angular velocity shoulder (°/s)*	Angular velocity pelvis (°/s)*	Duration time of delivery phase (sec)**
1	David STORL (GER)	6	21.78	13.96	37.20	2.27	830	399	0.28
2	Dylan ARMSTRONG (CAN)	4	21.64	13.03	37.47	2.11	965	640	0.15
3	Andrei MIKHNEVIKI (BLR)	3	21.40	13.37	35.70	2.20	830	312	0.23
4	Christian CANTWELL (USA)	5	21.36	12.94	35.96	2.06	952	545	0.17
5	Reese HOFFA (USA)	2	20.99	13.51	31.16	2.02	997	484	0.17
6	Marco FORTES (POL)	4	20.83	13.26	31.87	2.09	930	522	0.18
7	Ryan WHITING (USA)	4	20.75	12.75	37.31	1.91	949	413	0.15
8	Adam NELSON (USA)	1	20.29	13.14	30.79	2.10	926	521	0.15
mean			21.13	13.25	34.68	2.10	922	479	0.18

* Average between power position (touch down brace leg) and delivery position (release shot)
** Delivery phase between rear foot touchdown and front foot touchdown



* Glide phase between initiation and rear foot touchdown
** Delivery phase between rear foot touchdown and front foot touchdown

Figure 2. Glide technique style (Young, 2009)

* Rotational phase between initiation and rear foot touchdown
** Delivery phase between rear foot touchdown and front foot touchdown

Figure 3. Rotational technique style (Young, 2009)

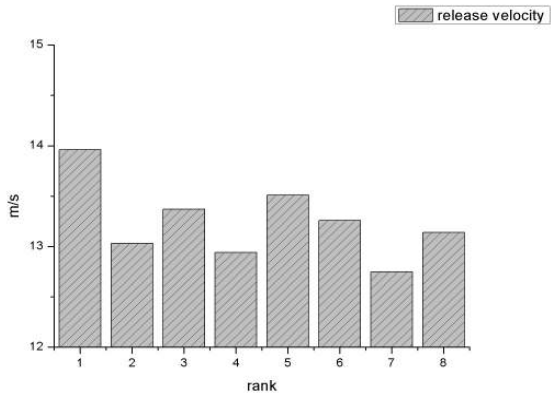


Figure 4. Release velocity

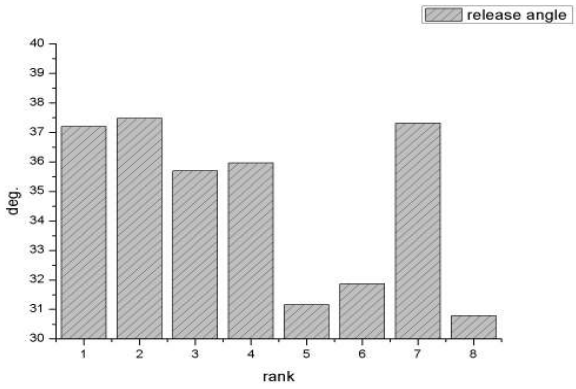


Figure 5. Release angle

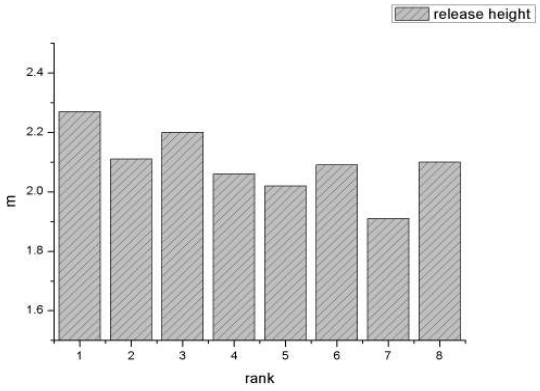


Figure 6. Release height

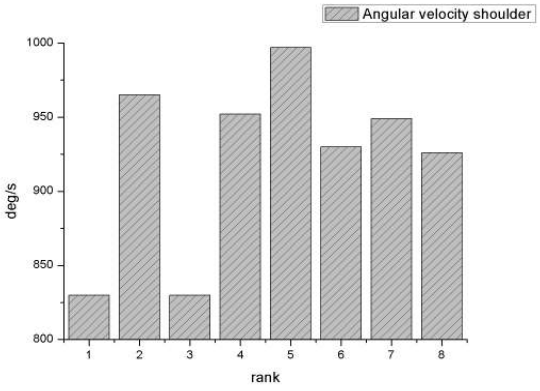


Figure 7. Angular velocity shoulder

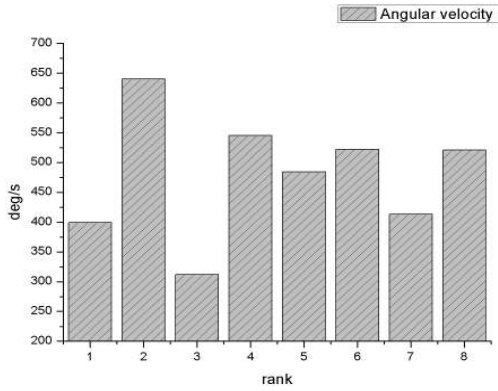
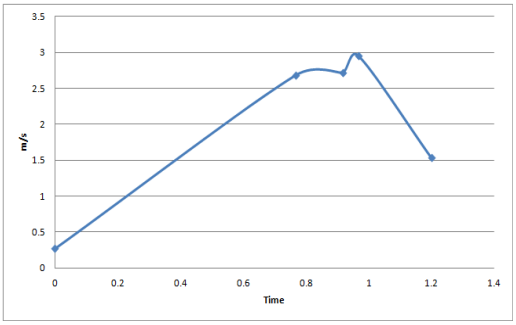
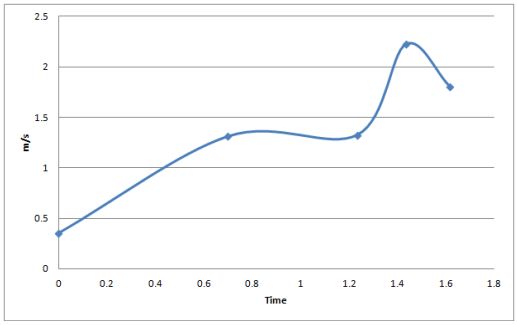


Figure 8. Angular velocity pelvis

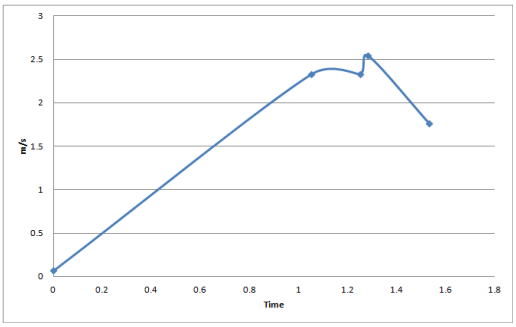
1st David STORL(GER)



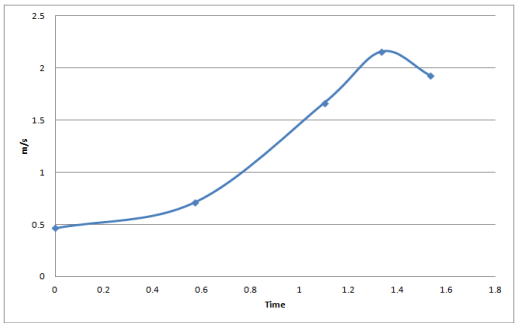
2nd Dylan RMSTRONG(CAN)



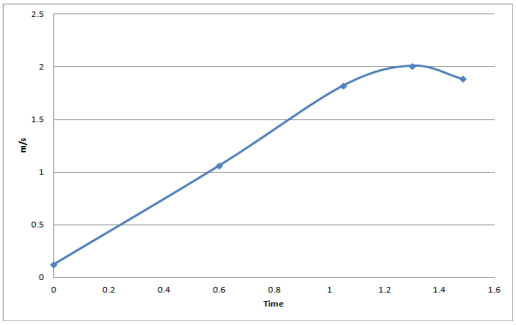
3rd Andrei MIKHNEVIKI (BLR)



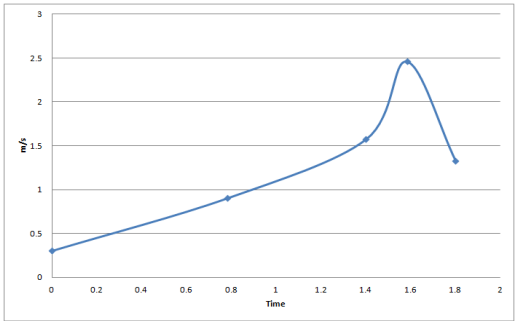
4th Christian CANTWELL (USA)



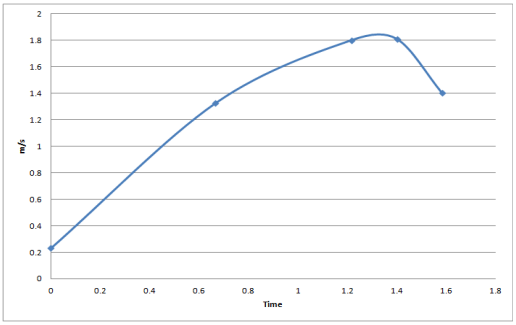
5th Reese HOFFA (USA)



6th Marco FORTES (POR)



7th Ryan WHITING (USA)



8th Adam NELSON (USA)

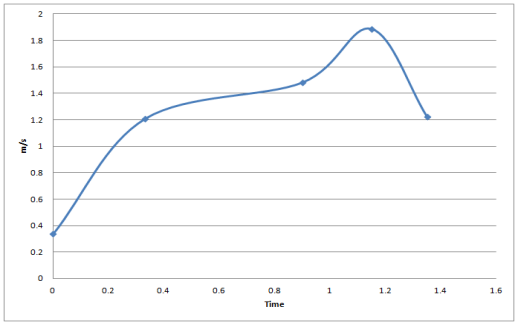
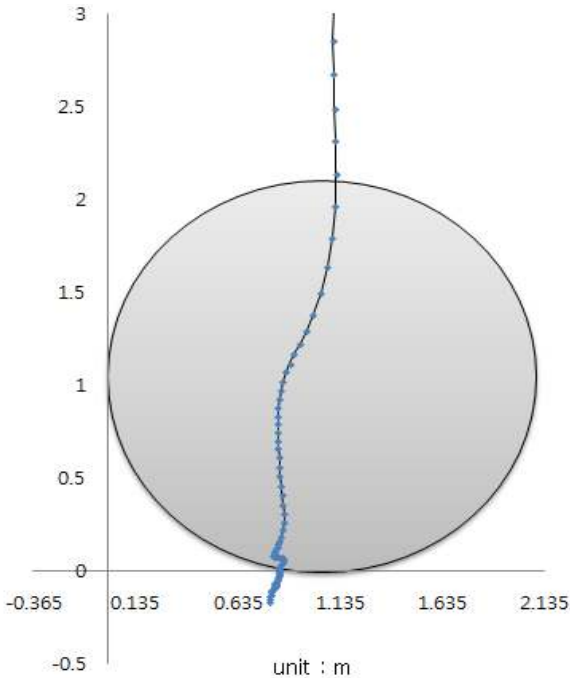
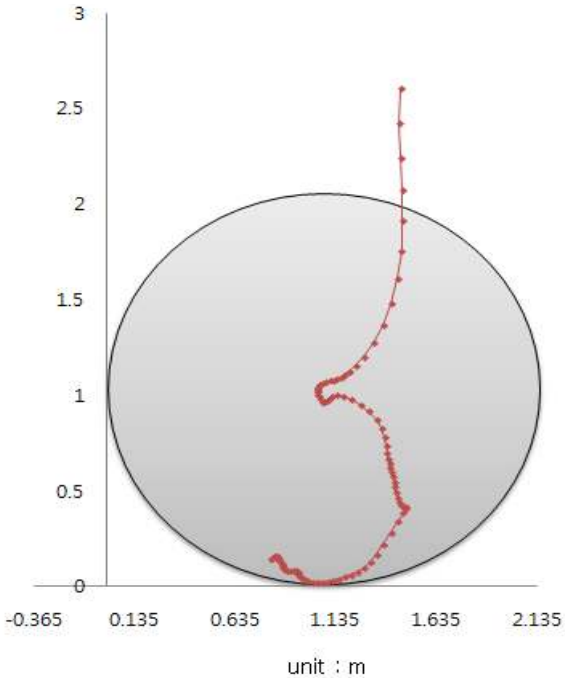


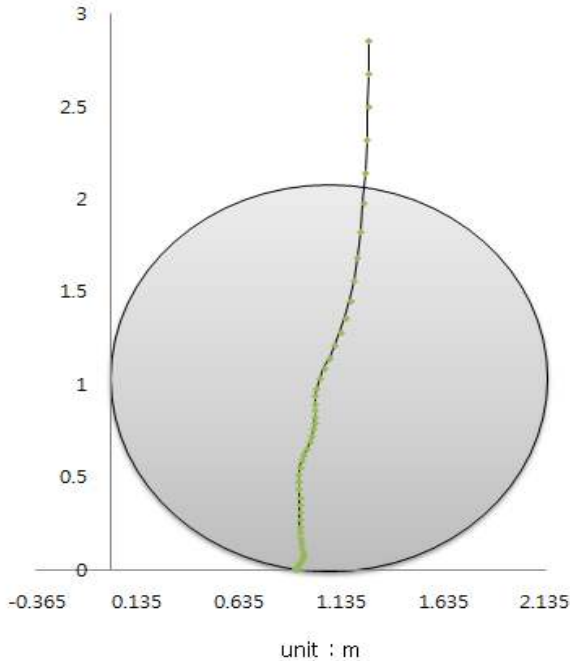
Figure 9. Center of mass velocity



1st David STORL (GER)



2nd Dylan AMSTRONG (CAN)



3rd Andrei MIKHNEVIKI (BLR)

Figure 10. Trajectory of the shot

1st David STORL (GER)

Figure 11. Duration time of delivery phase (0.28 s)

2nd Dylan AMSTRONG (CAN)

Figure 12. Duration time of delivery phase (0.17 s)

3rd Andrei MIKHNEVIKI (BLR)

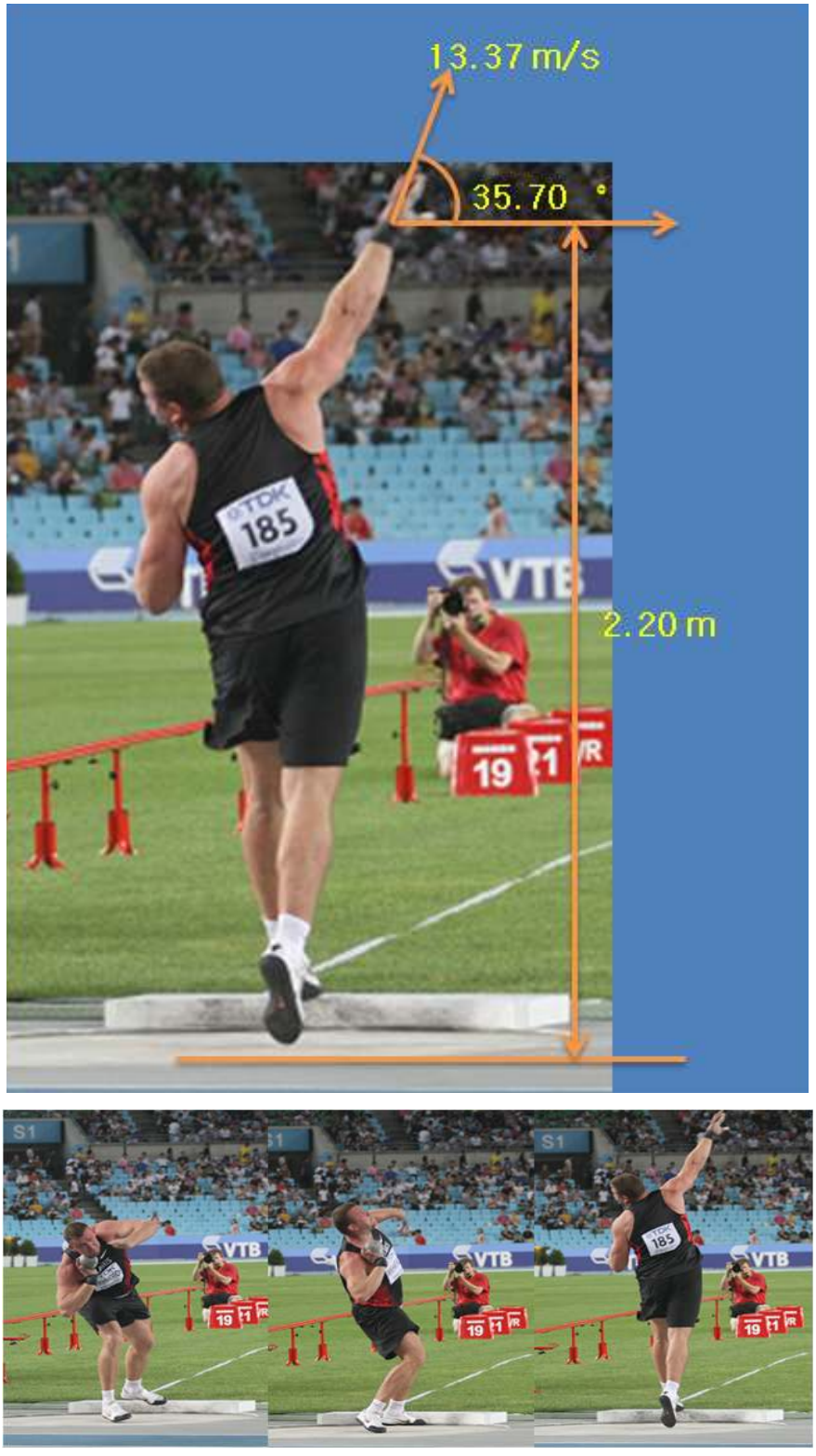


Figure 13. Duration time of delivery phase (0.23 s)

13th IAAF World Championships in Athletics, Daegu Final Report Women's Shot Put Finals

• Head Researcher :

Cheong-Hwan Oh(Chungnam National University, Korea) · Eui-Su Shin(Chungnam National University, Korea) · Su-Nam Choi(Chungnam National University, Korea) · Ik-Su Jeong(Chungnam National University, Korea) · Jae-Hee Bae(Chungnam National University, Korea) · Jeong-Tae Lee(Korea Research Institute of Standards and Science) · Seung-Bum Park(Busan Economic Promotion Agency)

12. Shot Put Women - Final

Table 1. Official competition results of the women's shot put finals in relation to season's best (SB) before the World Championships (WCh) and used technique style used

Rank	Athleta	Result WCh (m)	SB before WCh (m)		Style
1	Adams, V. (NZL)	21.24	20.78	2.21%	glide
2	Ostapchuk, N. (BLR)	20.05	20.94	-4.3%	glide
3	Camarena-Williams, J. (USA)	20.02	20.18	-0.8%	changing
4	Gong, L. (CHN)	19.97	18.73	6.6%	glide
5	Kolodko, Y. (RUS)	19.78	19.33	2.3%	glide
6	Li, L. (CHN)	19.71	19.72	-0.06%	glide
7	Avdeeva, A. (RUS)	19.54	19.17	1.93%	glide
8	Kleinert, N. (GER)	19.26	19.22	0.20%	glide

The average throw distance of the women's shot put at the 2011 Daegu Championships was 19.94 m, which was 0.92 m longer than the 19.02 m qualifying distance for the finals. The 19.94 m average distance in Daegu was higher than both the average distance at the 2009 Berlin Championships (19.54 m) and that of the 2007 Osaka Championships (19.42 m). In the finals, 5 athletes outperformed their season's best distances. Adams, V. (NZL) won the Championships with this season's best distance, which also set a new IAAF record for women's shot put at the 2011 Daegu Championships in Athletics (Table 1).

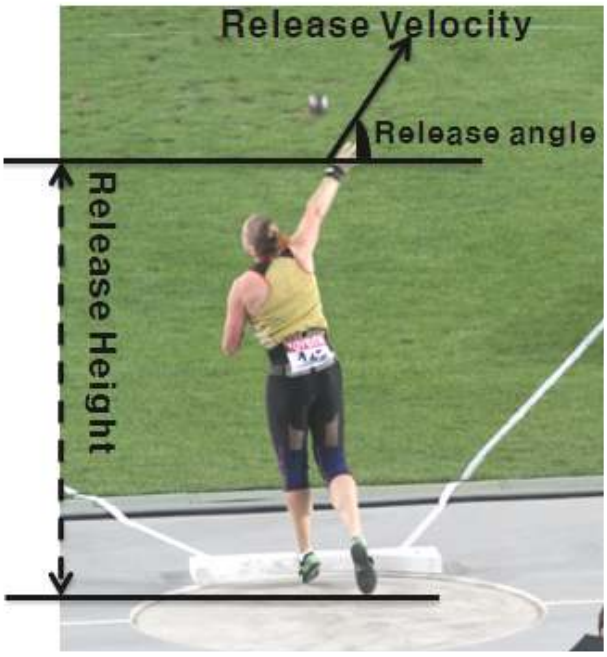


Figure 1. Definition of factory

Table 2. Selected kinematic data of women's shot put of finals

Rank	Athlete	Analysed attempt	Result WCh (m)	Release velocity (m/s)	Release angle (deg)	Release height (m)	Angular velocity shoulder (°/s)	Angular velocity pelvis (°/s)*
1	Adams, V. (NZL)	6	21.24	13.75	33.49	2.21	888	621
2	Ostapchuk, N. (BLR)	5	20.05	13.14	39.18	2.09	863	442
3	Camarena-Williams, J. (USA)	4	20.02	13.26	33.95	1.95	988	587
4	Gong, L. (CHN)	5	19.97	13.06	35.17	1.90	883	445
5	Kolodko, Y. (RUS)	3	19.78	13.04	37.77	2.07	792	569
6	Li, L. (CHN)	2	19.71	12.91	35.68	2.03	812	505
7	Avdeeva, A. (RUS)	5	19.54	13.20	35.13	1.94	838	261
8	Kleinert, N. (GER)	1	19.26	12.70	34.45	1.93	789	555
mean			19.94	13.13	35.60	2.01	876	523

At the women's shot put tournament, the average throw speed was 13.13 ± 0.30 m/s; the average angle of projection was 35.60 ± 1.94°; and the average throw height was 2.01 ± 0.10 m. The average angular velocity at the shoulder and pelvis from power zone until release were 876 ± 65.53°/s, 523 ± 115.57°/s respectively. The average throw speed was slower than that of the Berlin Championships, which was 13.27 ± 0.21 m/s. Combined analyses from both events revealed that men need a minimum of 13.5 m/s to throw 21 m while women need 13.0 m/s to throw 19 m. The scores from the men's shot put finals at the Berlin Championships did not show any correlation between throw speed and distance, but there was a strong correlation between these two variables at the Berlin women's shot put finals. This correlation was $r=0.9$, $p>.01$. At the 2011 Daegu Championships in Athletics, the scores from the women's shot put finals showed a high correlation between throw speed distance. This correlation was $r=0.88$, $p>.05$ (Figure 3). As far as individual records were concerned, Adams (NZL) who scored 21.24 m had a speed of 13.75 m/s, while Ostapchuk (BLR) and Camarena-Williams (USA) who also scored over 20 m had speeds of over 13 m/s. Others who also recorded distances of 19 m or more had speeds of 13.0 m/s or higher. Kleinert (GER), who won the silver at the Berlin Championships by scoring 20.20 m with a throw speed of 13.5m/s, threw 19.26 m with 12.70 m/s at the 2011 Daegu Championships in Athletics. The results demonstrated an obvious correlation between throw speed and distance.

Through analysis at the 2009 Berlin World Championships in Athletics and the 2011 Daegu World Championships in Athletics, it was proven that faster throw speed has a positive influence on the increase in throwing distance.

The optimal projection angle in shot put is considered to be 37°. The average projection angle at the Daegu Championships was 35.60°, and the average throwing distance was 19.94 m. At the Berlin Championships the average projection angle was 36.9°, and the average throwing distance was 19.54 m. Adams (NZL) threw 21.24 m using the glide technique and had a projection angle of 33.49°. Camarena-Williams (USA) threw 20.02 m using the rotational technique and had projection angle of 33.95°. In contrast Ostapchuk (BLR) threw 20.05 m using the glide technique and had a high projection angle of 39.18°. These results show that the optimal projection angle did not have a large impact on throw distance, while throw technique and physical characteristics could also influence the distance.

Out of the elements directly influencing the score, there was a big difference in throw height depending on the athlete's height and length of upper limbs. In Daegu, the tallest female shot putter Adams (NZL) had a release height of 2.21 m. Ostapchuk (BLR), who is comparatively short, used the glide technique and released at a height of 2.09 m. Camarena-Williams (USA), who is the same height as Ostapchuk (BLR), used the rotational technique for a release height of 1.95 m. As far as throw height was concerned, there was no significant difference between the top athletes and the others, as shown in <Table 2>.

However, Adams' (USA) score was noteworthy. Among the athletes who made it to the finals, she was the only one who used the rotational technique and had a low throw height and small projection angle. In particular, her angular velocity at the shoulder, as well as throw speed, were high numbers compared to other competitors. It appears that Adams' (USA) strategy was to utilize high angular velocity at the shoulder using the rotational technique to increase her throw speed rather than attempting to increase throw height and projection angle. Her results support the theory that the rotational technique is a better fit for competitors who have a shorter height.

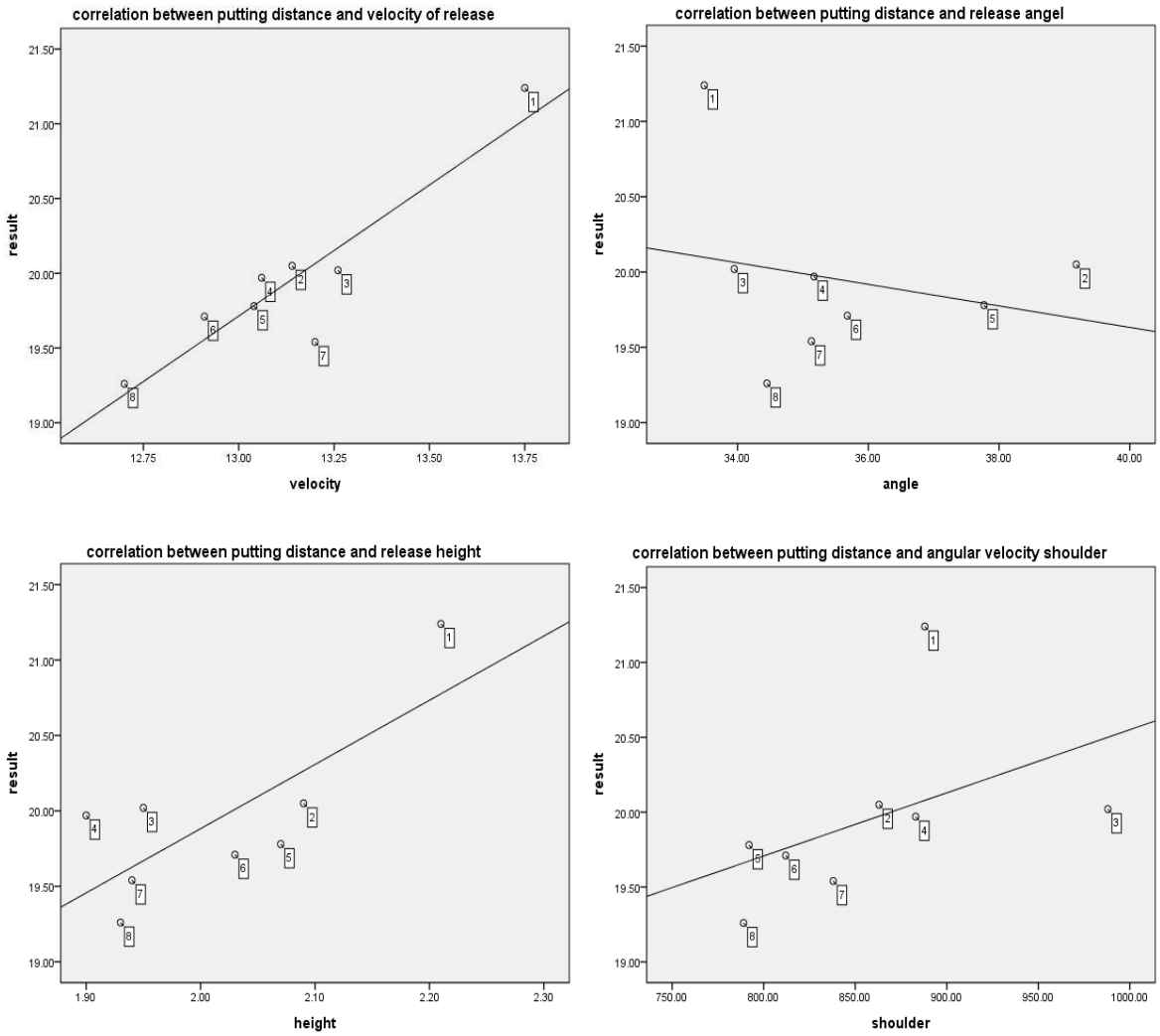
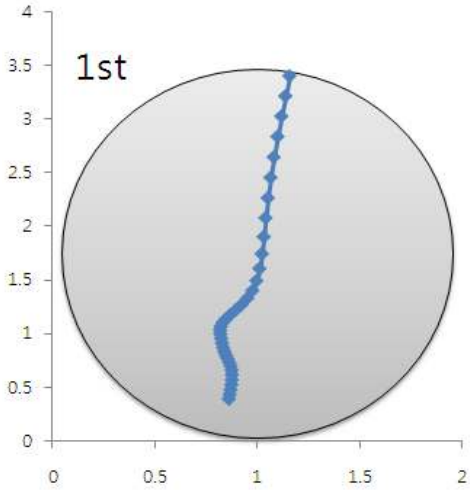
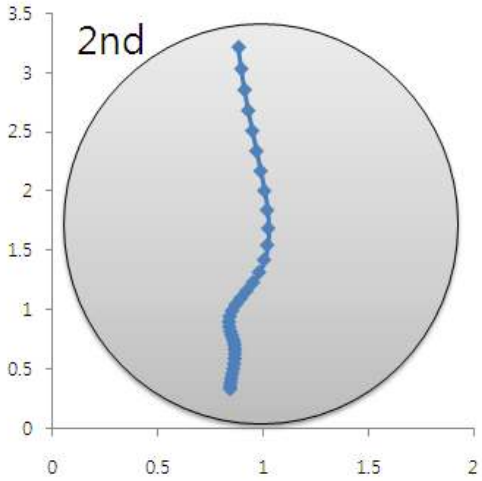


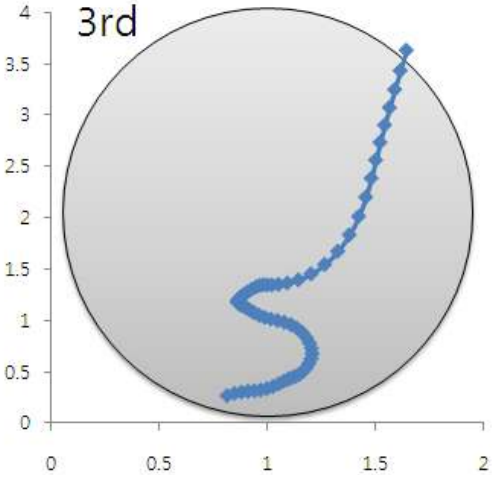
Figure 2. Correlation between throwing distance and kinematic data



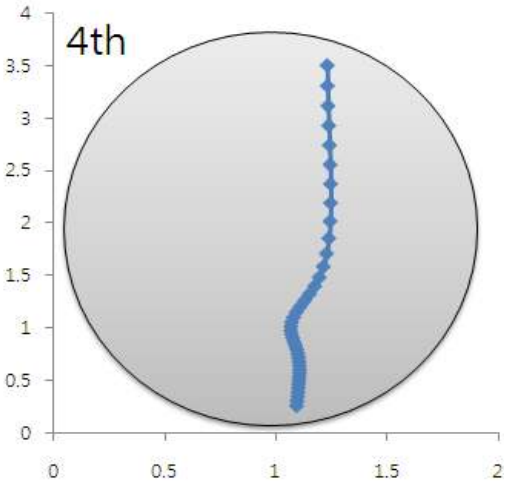
1st Valerie ADAMS (NZL)



2nd Nadzeya OSTPCHUK (BLR)



3rd J. CAMARENA-WILLIAMS (USA)

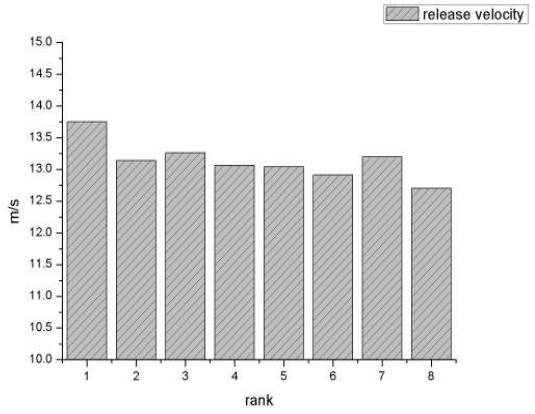


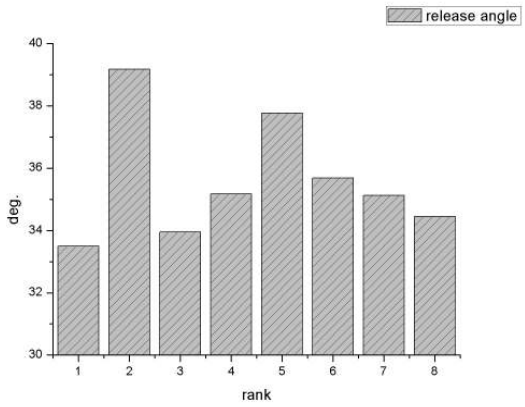
4th Lijiao GONG (CHN)

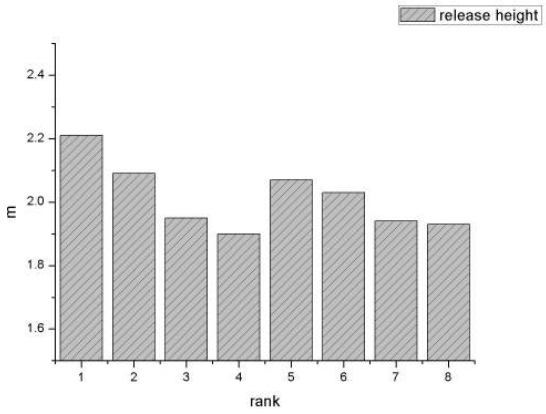
Figure 3. Trajectory of the shot putters

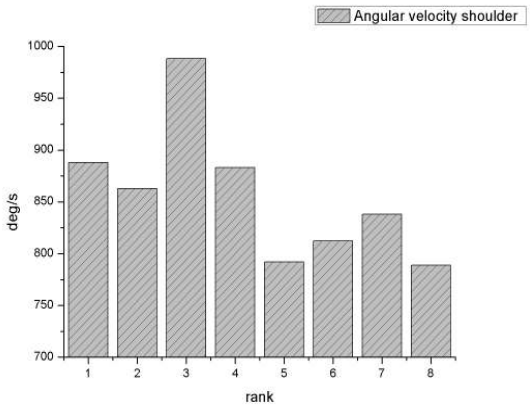
Biomechanical Analysis of the Women's Shot put- Finals

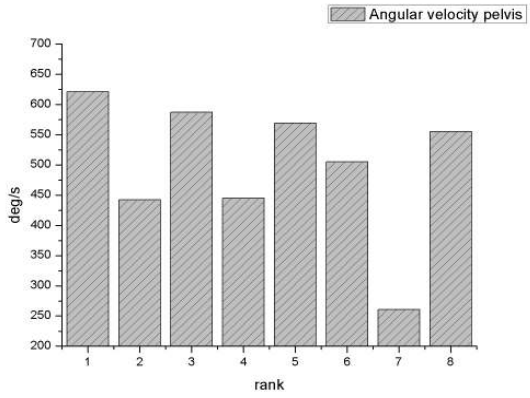
13th IAAF World Championships in Athletics - Daegu on August 29th 2011 at 20:36











ADAMS, V.(NZL)

2011 IAAF World Championships, Daegu KSSB Project Final Report (Javelin Throw - Men's - Finals)

- Director :

  Woen-Sik Chae(Kyungpook National University, Korea) · Young-Tae Lim(Kunkuk University, Korea)

- Researcher :

  Chang-Jin Yoon(Kyungpook National University, Korea) · Haeng-Seob Lee(Kyungpook National University, Korea) · Jong-Woo Kim(Kyungpook National University, Korea) · Dong-Soo Kim(Kyungpook National University, Korea) · Jung-Ho Park(Kyungpook National University, Korea) · Gun-Su Kim(Kyungpook National University, Korea) · Chang-Eun Kim(Kyungpook National University, Korea) · Sung-Jung Kim(Kunkuk University, Korea)

13. Biomechanical Analysis of the Javelin Throw - Men's Finals

At the 2011 IAAF World Championships, Daegu, men's javelin throw event, M. de Zordo from Germany won the gold medal with a distance of 86.27 m. It was an unexpected win since A. Thorkildsen from Norway was favored to win, but M. de Zordo's first attempt set the record for the season's best throw (Figure 1).

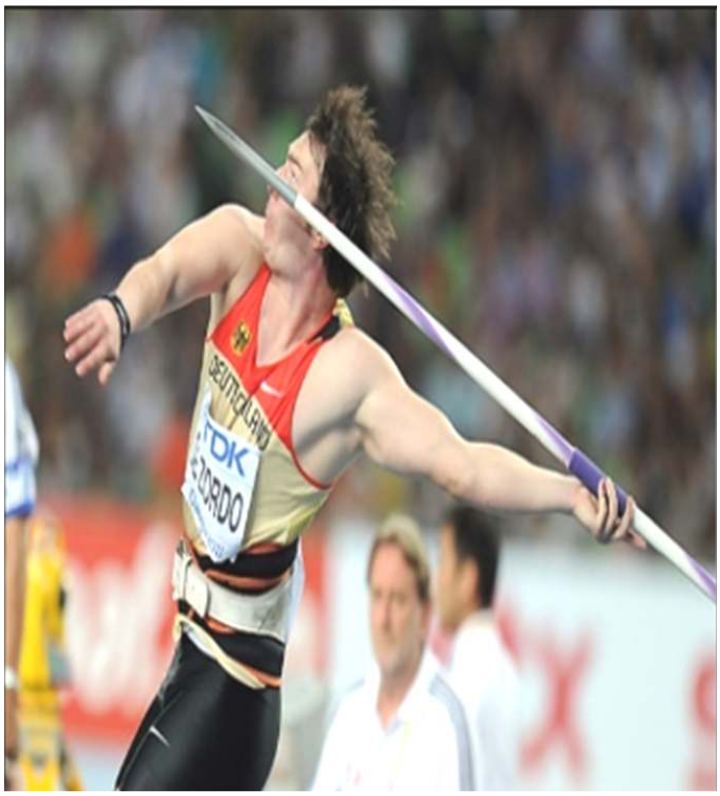


Figure 1. M. de Zordo (GER)

Before starting the analyses, three high speed digital cameras (Casio EX-F1 Exilim, JPN, 300 frames/ sec, shutter speed 1/1000 second) were installed 45° above the athlete to capture each movement more precisely (Figure 2). The DLT (direct linear transformation) algorithm was used to calculate 3-D coordinate values. Four critical events and three phases were used for analysis (Figure 3). Temporal parameters, velocity variables, release conditions, inclination angle of body segments, and distance variables were determined for each trial.

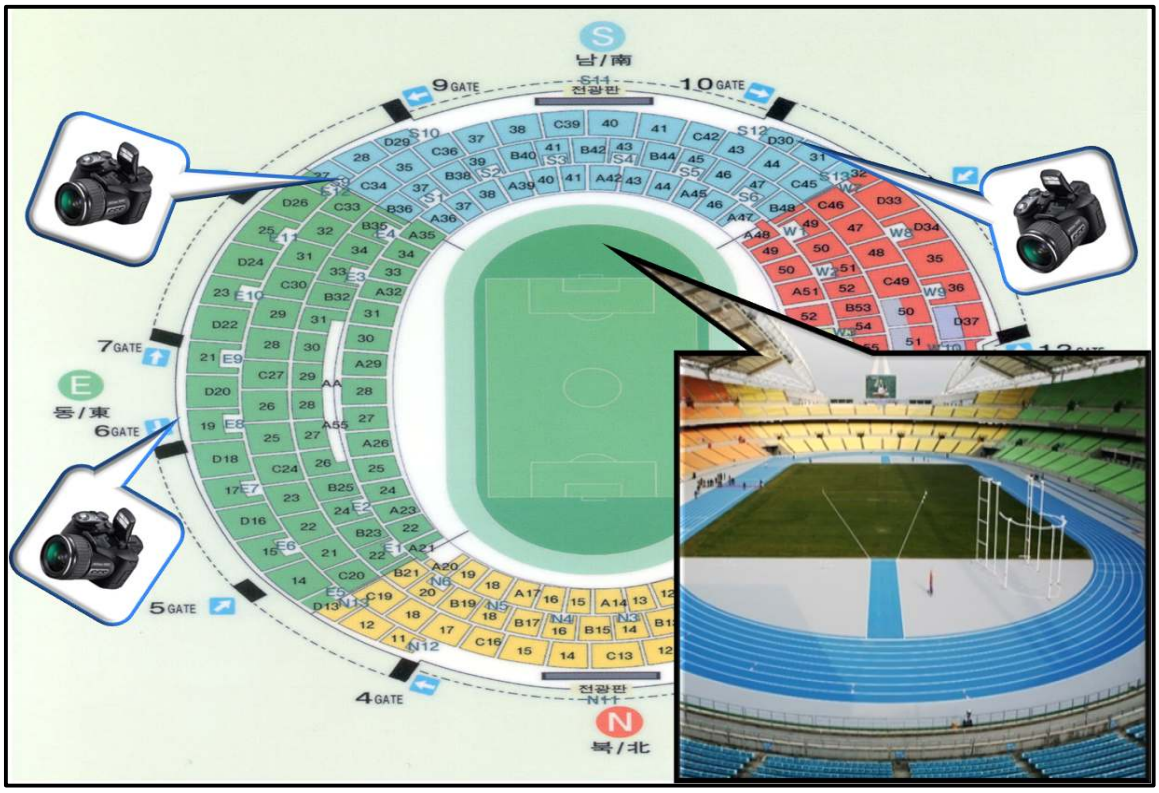
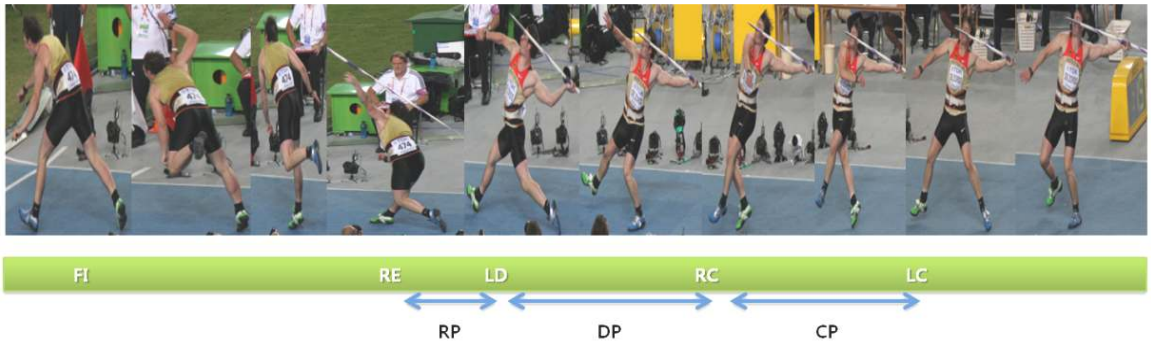


Figure 2. Camera locations



Events
· LC : Left Foot of Cross step · RC : Right Foot Contact · LD : Left Foot in Delivery · RE : Release
Phases
· CP : Crossover Stride Phase · DP : Delivery Phase · RP : Release Phase

Figure 3. Events & Phases

The men's final competition results were as follows: average release angle 34.6 ± 2.2°, average attitude angle 37.4 ± 3.5°, and average attack angle 3.2 ± 2.4°. At the release, the average inclination angle of the body segments were as follows: trunk angle 54.2 ± 7.6°, upperarm angle 48.3 ± 9.1°, and forearm angle 51.1 ± 8.7°. Moreover, the average release velocity and the average release height results were 27.90 ± 1.04 m/s, 1.99 ± 0.07 m respectively. The average release angle at the 2009 Berlin World Championships ('09 WC) was slightly lower (on average 2.1°), compared with the average release angle at these championships ('11 WC). It is common knowledge that in the javelin throw, the optimal release angle is 34-36°. However, positive outcomes are still possible with angles that are lower than 34° or higher than 40°. This is possible because the optimal angle can change based on a slight difference in the throwing method and/or a change in flight trajectory.

The release angles for gold medalist M. de Zordo, silver medalist A. Thorkildsen, and bronze medalist G. Martinez were 37.3°, 35.9° and 36.7° respectively. Surprisingly, there was a similarity between the gold medalist for these championships ('11 WC) and the gold medalist for the Berlin World Championships ('09 WC), as both athletes' release angles were around 37.6°. A. Thorkildsen who was the gold medalist for the 2009 Berlin World Championships ('09 WC), under performed this year when he scored 4 m less than his winning performance in Berlin of 89.59 m, hence, earning a silver medal. When comparing the two competitions, his release angle in 2011 also decreased by 1.7°. However his attack angle, which is the difference between the release angle and attitude angle, increased by 3°. Therefore, it can be concluded that the reason he was not able to win this championship was his low release angle and high attack angle. When comparing the finalists' release angles with those of other athletes, it can be seen that the finalists had higher release angles. Hence, as the throwing distance and the throwing angle are positively correlated, it is important for athletes to find the appropriate release angle in order to achieve the longest throwing distance.

Table 1. Kinematic data of men's javelin throw finals

Rank	Athlete	Analysed attempt	Result (m)	Release velocity (m/s)	Release height (m)	CM Velocity at release (m/s)	Angle at release (deg)			Inclination angle (deg)			Distance (m)			Duration (ms)		
							Attitude	Release	Attack	Trunk	Upper arm	Fore arm	Impulse stride	Delivery stride	Foul line	Impulse stride	Delivery stride	Release
1	**Matthias de Zordo (GER)**	**1**	**86.27**	**29.90**	**2.01**	**0.86**	**40.3**	**37.3**	**3.0**	**44.4**	**45.2**	**46.0**	**1.96**	**1.71**	**1.40**	**366**	**253**	**140**
2	**Andreas Thorkildsen (NOR)**	**4**	**84.78**	**28.62**	**1.93**	**0.96**	**39.2**	**35.9**	**3.3**	**50.7**	**40.1**	**57.6**	**2.39**	**1.89**	**1.84**	**400**	**170**	**107**
3	**Guillermo Martinez (CUB)**	**1**	**84.30**	**28.33**	**2.07**	**0.95**	**35.7**	**36.7**	**1.8**	**53.4**	**32.9**	**44.5**	**2.51**	**1.99**	**1.45**	**443**	**243**	**124**
4	Vitezslav Vesely (CZE)	3	84.11	26.79	1.92	0.81	39.9	34.6	5.3	67.3	54.3	40.4	1.92	1.83	0.85	320	180	120
5	Fatih Avan (TUR)	2	83.34	27.44	1.97	0.91	35.2	31.5	3.7	54.1	54.7	58.5	2.06	1.66	1.07	323	197	163
6	Roman Avramenko (UKR)	1	82.51	27.93	1.91	0.73	41.5	34.2	7.3	63.3	45.0	42.5	2.53	1.58	0.65	374	183	137
7	Jarrod BANNISTER (AUS)	1	82.25	27.11	2.05	0.75	31.2	31.5	0.3	52.6	53.9	55.7	2.39	1.61	0.37	427	193	143
8	Mark FRANK (GER)	2	81.81	27.04	2.08	0.69	35.8	35.2	0.6	48.1	60.5	63.4	2.13	1.87	1.88	374	213	143
mean			83.67	27.90	1.99	0.83	37.4	34.6	3.2	54.2	48.3	51.1	2.24	1.77	1.19	378	204	135
	Sang-Jin, Jung (KOR)	1	72.03	27.60	1.76	0.70	42.0	42.3	0.3	43.9	52.0	54.4	1.96	1.6	2.61	410	180	130

In the javelin throw, the most important factor is the release velocity. Gold medalist M. de Zordo had a release velocity of 29.90 m/s, the highest velocity of all athletes. He achieved a slightly higher velocity than A. Thorkildsen, who was the 2009 Berlin Competition gold medalist. At the 2009 Berlin Competition, A. Thorkilden recorded a distance of 89.59 m, with a release velocity of 29.30 m/s. The biggest difference between both athletes is in their attack angles. The attack angle is the difference between the release angle and the attitude angle. A. Thorkildsen's attack angle was 0.3°. However, the gold medalist M. de Zordo had an attack angle that was 10 times higher, 3.0°. Perhaps, if M. de Zordo had had a smaller attack angle, it is possible he could have achieved a greater distance. From analyses of both the 2009 Berlin World Championships and the 2011 Daegu World Championships demonstrate that faster release velocity, a release angle close to 37° while taking outside influences into account, and minimizing the attack angle are the best ways to achieve the maximum throwing distance, especially if all three are synchronized.

The research team analyzed the duration of the finalists' three phases (CP, DP, and RP). The average times for CP, DP, and RP were 0.378 ± 0.044 sec, 0.204 ± 0.030 sec, 0.135 ± 0.017 sec, consecutively. When analyzing each section individually, the distance it took for CP averaged 2.24 ± 0.25 m, for DP it was 1.77 ± 0.15 m, and the distance to the foul line was 1.19 ± 0.55 m. At the 2009 Berlin Competition, all the medalists had one thing in common, which was that the CP took longer and had a longer length than the DP.

The reasons why the CP was longer is because it maximizes the use of the lower body while it is in movement. Also, the athlete's throwing direction and the back slope are in opposite directions, therefore biomechanically it has a huge influence in increasing strength and distance. Thus, when strength (F) and time (t) are combined it increases the crossover stride.

In the delivery stride, it is important for an athlete to put his/her feet forward, then step forward and also to secure enough space in the base side so there are no disturbances when the athlete maximizes his/her strength. The athlete's hip and shoulders should be facing opposite the throwing direction and should rotate, hence increasing the strength which will lead to a longer distance. Therefore, when looking at the differences between medalists and other finalists, medalists had an average CP of 2.29 m while the other finalists had a slightly lower average of 2.21 m. In DP, the medalists achieved a distance of 1.86 m while the other finalists had a distance of 1.71 m. In particular, the bronze medalist G. Martinez had a stride distance of 2.51 m in CP and a distance of 1.99 m in DP. However, even with a long crossover stride and long delivery stride, his angle of attitude and angle of release were too low, preventing him from throwing further.

At the point of release, the CM velocity of the body of the medalists was an average of

0.92±0.06 m/s, while the other finalists were at 0.78 ± 0.09 m/s. From the results, it can be concluded that these medalists had a faster velocity than other finalists.

Figure 4. Sang-Jin Jung (KOR)

The Korean athlete Sang-Jin Jung's throwing results were as follows: release velocity of 27.60 m/s, angle of release 42.3°, and release height 1.76 m. In addition, the inclination angle of the body segments at release were as follows: trunk angle 43.9°, upper arm angle 52.0°, and forearm angle 54.4°. The speed of CP was 4.78 m/s and the DP was 8.89 m/s. The attack angle was 0.3°, which means the release should have been very effective. However, his attitude angle and release angle were slightly too high. This can happen when the upper body is more bent or curved at release than that of other athletes. In order for the Korean athlete to increase his distance he needs to increase his velocity of release. What this means is that at the time of release he should increase the CM velocity of his body while simultaneously increasing the release velocity by increasing the rotation speed of his hip and also maximizing the rotation speed of his upper arm. Moreover, he should align his body angle in the throwing direction while leaning forward slightly. Compared to other athletes, his final steps were considerably short of the foul line. In this competition, he had a difference of 1.42 m, which ultimately meant that he lost 1.42 m in the overall distance. Additionally, compared to other athletes, he had a shorter movement distance in the crossover stride. However, as he took longer than other athletes, it can be concluded that he was not effectively transiting the CM velocity of his body to the javelin, which negatively influenced his throws. When cross stepping up to the moment of release, the appropriate step distance and a continuous rhythmical take off movement is necessary.

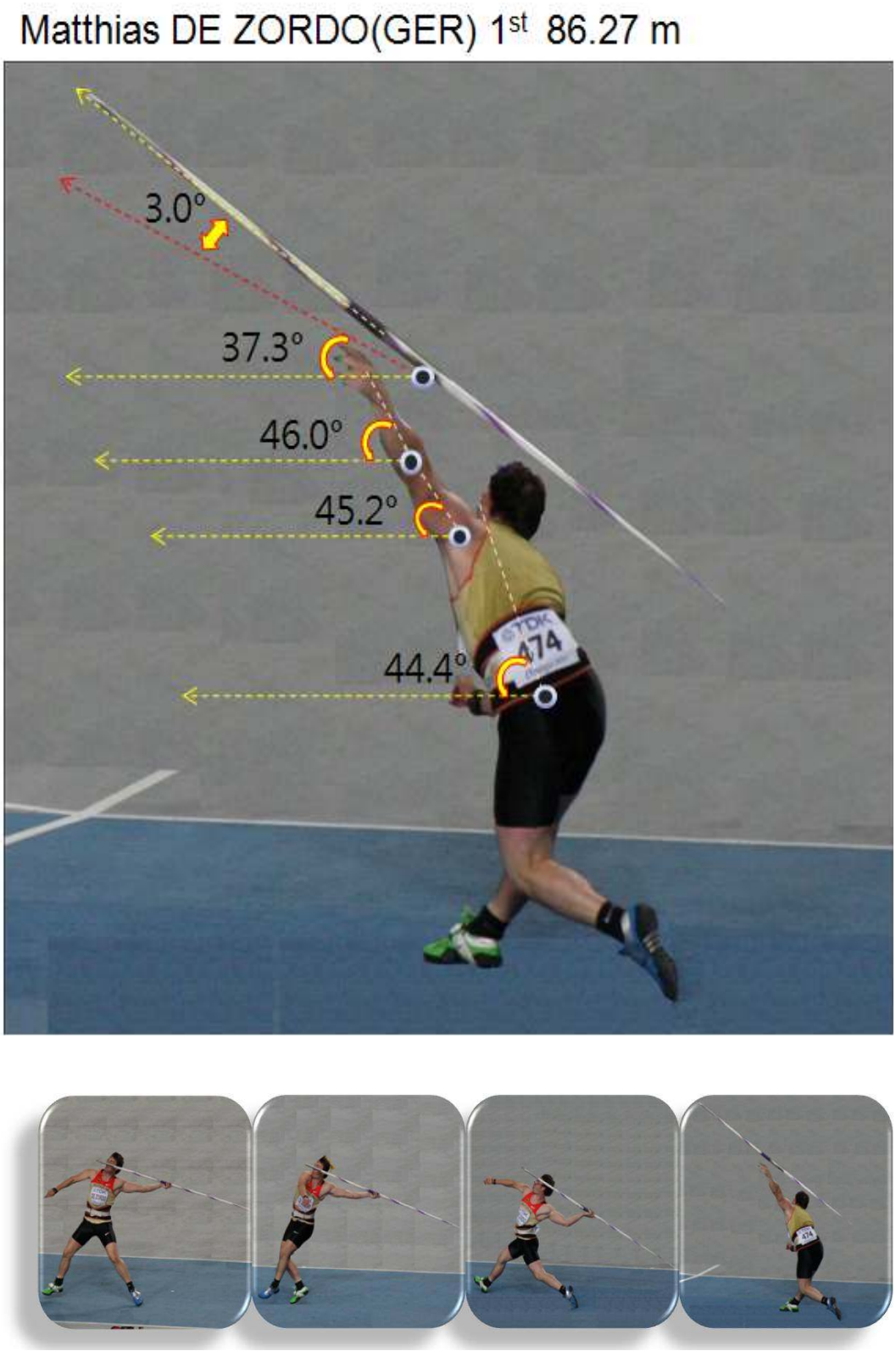


Figure 5. M. DE ZORDO (GER)

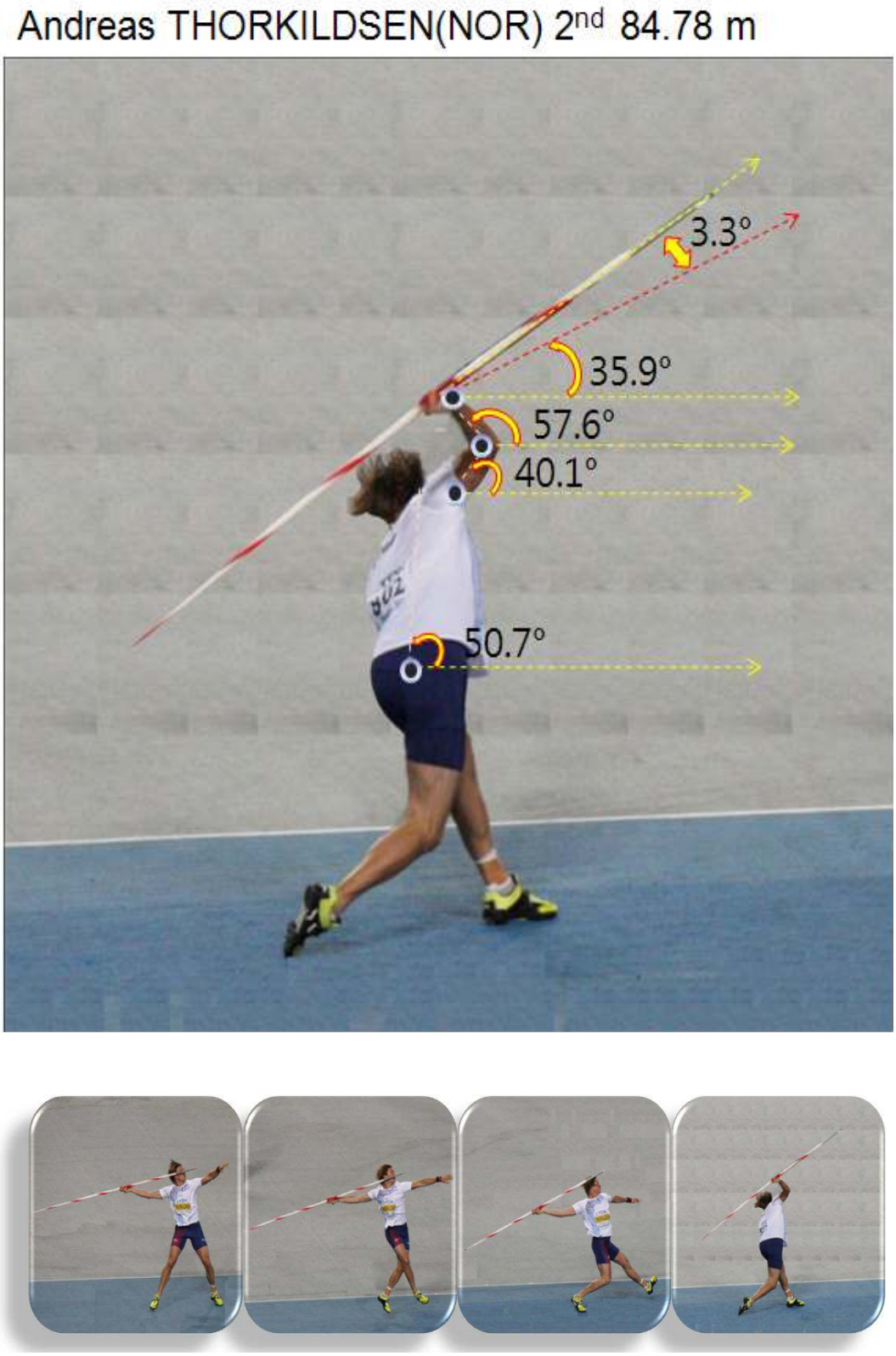


Figure 6. A. THORKILDSEN (NOR)

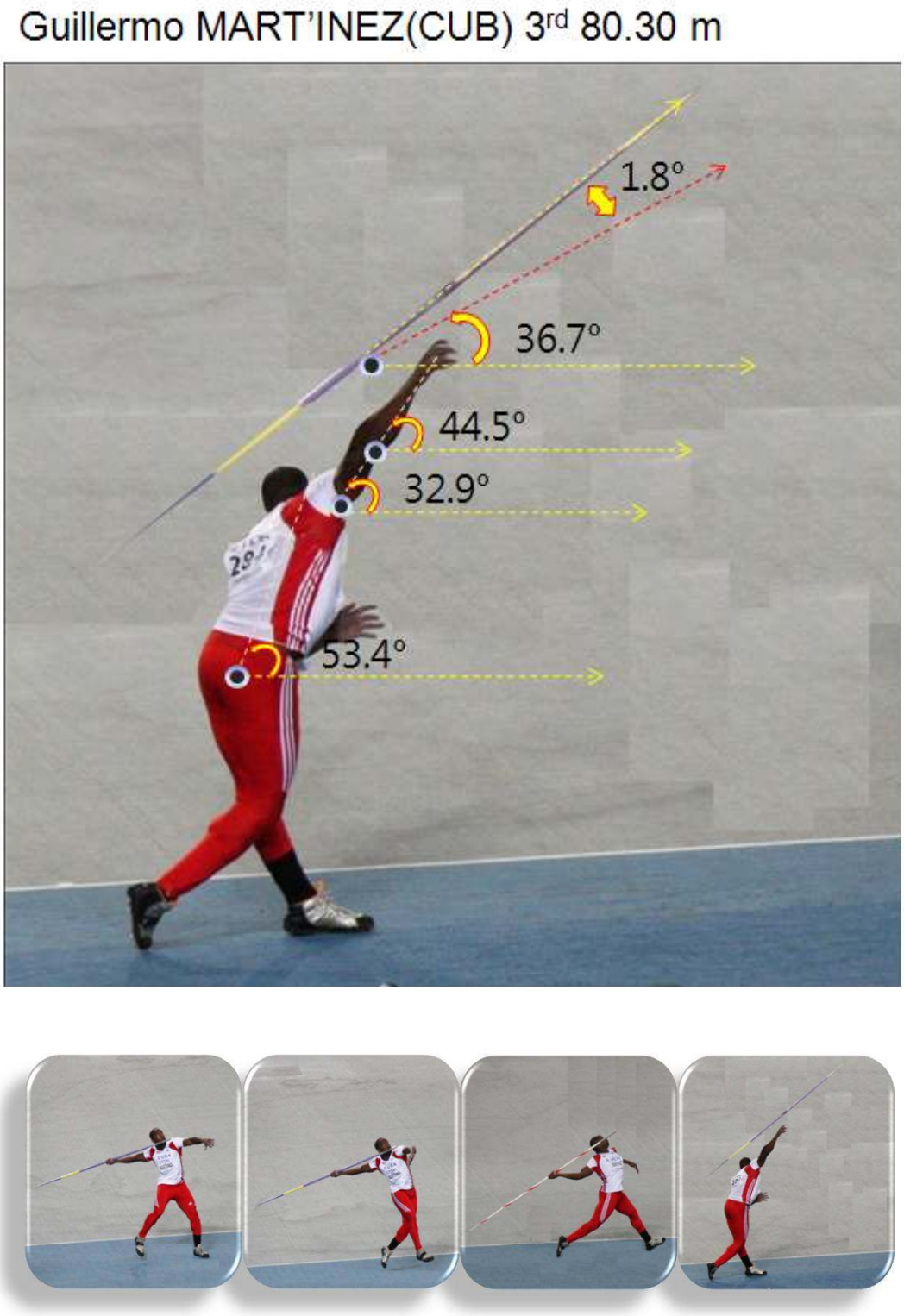


Figure 7. G. MART'INEZ (CUB)

2011 IAAF World Championships, Daegu KSSB Project Final Report (Javelin Throw - Women's Finals)

- Director :

  Woen-Sik Chae(Kyungpook National University, Korea) · Young-Tae Lim(Kunkuk University, Korea)

- Researcher :

  Chang-Jin Yoon(Kyungpook National University, Korea) · Haeng-Seob Lee(Kyungpook National University, Korea) · Jong-Woo Kim(Kyungpook National University, Korea) · Dong-Soo Kim(Kyungpook National University, Korea) · Jung-Ho Park(Kyungpook National University, Korea) · Gun-Su Kim(Kyungpook National University, Korea) · Chang-Eun Kim(Kyungpook National University, Korea) · Sung-Jung Kim(Kunkuk University, Korea)

14. Biomechanical Analysis of the Javelin Throw - Women's Finals

The 2011 IAAF World Championships, Daegu, women's javelin throw came to a surprising end as the competitors kept overtaking the previous records. Russian javelin thrower, M. Abakumova (RUS), was finally able to win the gold medal after a long, agonizing streak of coming in second (Figure 1).

Figure 1. M. Abakumova (RUS)

Before starting the analyses, control objects (4 m x 9 m x 4 m) had to be set up in order to find a control point. The control point took the movement of javelin throwers into account. Three high speed digital cameras (Casio EX-F1 Exilim, JPN, 300 frames/ sec, shutter speed 1/1000 second) were installed 45° above the athlete to capture each movement more precisely (Figure 2). The DLT(direct linear transformation) algorithm was used to calculate 3-D coordinate values. Four critical events and three phases were used for analysis. Temporal parameters, velocity variables, release conditions, the inclination angle of body segments, and distance variables were determined for each trial (Figure 3).

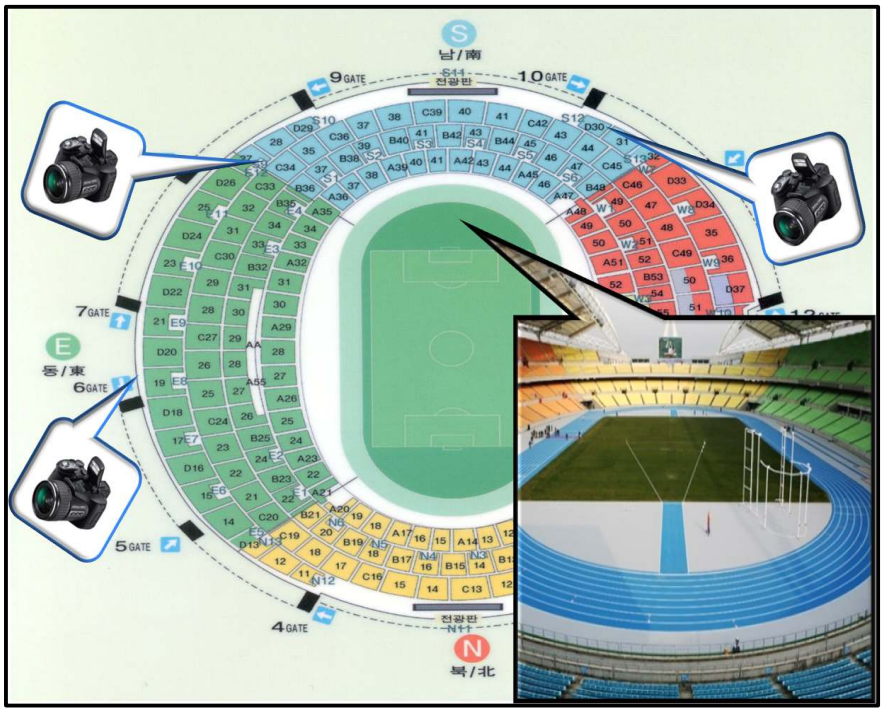


Figure 2. Camera locations

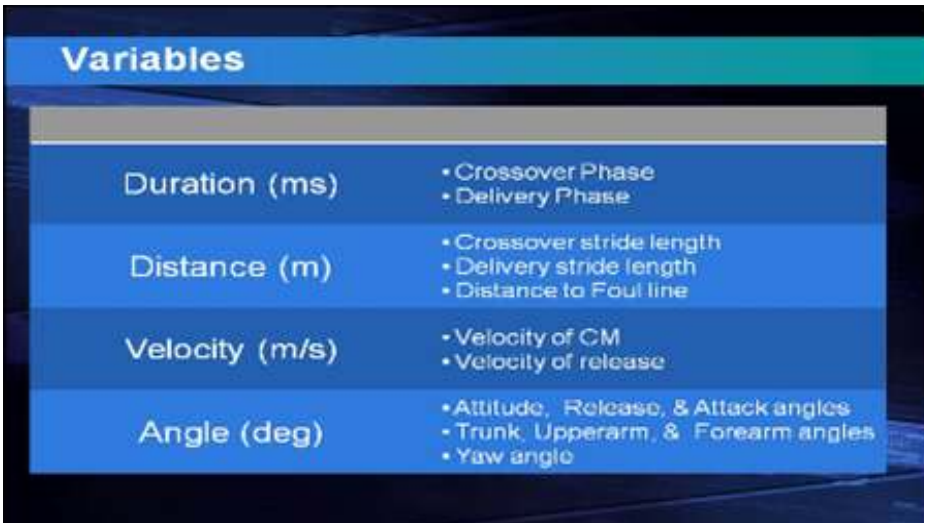


Figure 3. Variables

The women's final event analytical results were as follows: average angle of release 38.0 ± 2.0°, angle of attitude 40.4 ± 4.3°, and angle of attack 3.7 ± 1.1°. At the release, the average inclination angle of the body segments were as follows: angle of the trunk 60.8 ± 8.3°, angle of the upper arm 47.3 ± 10.1°, and angle of the forearm 62.6 ± 10.6°. Moreover, the release velocity and the release height results averaged 25.60 ± 1.16 m/s and 1.86 ± 0.05 m, respectively. Additionally, three phases, the crossover phase (CP), delivery phase (DP), and release phase (RP), had an average durations of 0.350±0.066 sec, 0.198±0.039 sec, and

0.138 ± 0.013 sec. The CP and DP had average distances of 1.88 ± 0.31 m and 1.53 ± 0.21 m accordingly, while after release, the distance difference between the landing foot and the foul line averaged 1.72 ± 0.63 m.

Gold medalist M. Abakumova achieved the season's best throw when she beat her 2009 season's best throw from the qualifying rounds of the Berlin Competition by 3.07 m. The defending champion, and second place finisher, B. Spotakova (CZE), who had not been performing well recently, also improved from her previous Berlin Competition score by 5.16 m, making it her personal best throw for the whole season. However, she was not able to beat her all-time personal best throw and World Record of 72.28 m. South African third place finisher S. Viljoen (RSA) did not qualify for the finals at the Berlin Competition. However, she was able to achieve her season's best throw and set the record for furthest throw by an African. Every athlete, excluding the top three winners, underperformed by an average of 2.52 m compared to their season's best throws. In particular, C. Obergfoll (GER) underperformed with a fourth place finish 3.14 m behind the bronze medalist. She also fell short of her throw at the Berlin Competition by 5.57 m. During the qualifying records C. Obergfoll's first and only throw was her best throw of the season. And during both the qualifying and final rounds she consistently threw further than third place finisher S. Viljoen (RSA). However, Viljoen shot ahead of Obergfoll with her second to last throw of 68.38 m, and Obergfoll took fourth place with a throw of 65.24 m.

Figure 4. The Medalists

Table 1. Kinematic data of women's javelin throw finals

Rank	Athlete	Analysed attempt	Result (m)	Release velocity (m/s)	Release height (m)	CM Velocity at release (m/s)	Angle at release (deg)			Inclination angle (deg)			Distance (m)			Duration (ms)		
							Attitude	Release	Attack	Trunk	Upper arm	Fore arm	Impulse stride	Delivery stride	Foul line	Impulse stride	Delivery stride	Release
1	Maria ABAKUMOVA (RUS)	**5**	**71.99**	**25.11**	**1.85**	**0.85**	**43.8**	**39.4**	**4.4**	**61.2**	**43.7**	**47.6**	**1.87**	**1.74**	**2.36**	**313**	**194**	**140**
2	Barbora SPOTAKOVA (CZE)	**5**	**71.58**	**26.27**	**1.96**	**0.87**	**42.2**	**38.2**	**4.0**	**52.8**	**47.5**	**67.8**	**1.61**	**1.60**	**2.54**	**313**	**190**	**147**
3	Sunette VILJOEN (RSA)	**5**	**68.38**	**24.42**	**1.84**	**0.80**	**43.0**	**39.3**	**3.7**	**46.7**	**62.8**	**68.6**	**1.59**	**1.41**	**1.66**	**310**	**167**	**113**
4	Christina OBERGFOLL (GER)	4	65.24	26.48	1.88	0.80	35.2	33.2	2.0	65.1	29.6	62.7	2.10	1.66	1.20	370	173	143
5	Kathrina MOLITOR (GER)	6	64.32	26.09	1.78	0.63	41.3	38.8	2.5	58.8	47.1	51.8	1.91	1.51	0.57	433	203	154
6	Kimberley MICKLE (AUS)	5	61.96	25.10	1.83	0.66	43.9	38.9	5.0	62.5	40.6	80.6	1.81	1.74	1.91	350	203	130
7	Martina RATEJ (SLO)	5	61.65	27.49	1.87	0.69	32.3	37.3	5.0	73.5	56.8	65.9	2.51	1.51	1.64	450	164	133
8	Jarmila KLIMESOVA (CZE)	1	59.27	24.96	1.86	0.67	41.7	38.6	3.1	66.0	50.5	56.0	1.66	1.10	1.85	257	287	143
mean			65.55	25.60	1.86	0.75	40.4	38.0	3.7	60.8	47.3	62.6	1.88	1.53	1.72	350	198	138
	Kyung-Ae Kim (KOR)	3	54.96	21.20	1.62	0.63	44.7	43.2	1.5	43.9	60.3	67.3	1.46	1.60	1.62	312	258	147

Looking at the kinematic variables of the top three finalists for the women's javelin throw at the 2011 IAAF World Championships, Daegu, reveals that gold medalist M. Abakumova's release velocity was lower than her velocity at the Berlin Competition by 0.01 m/s. Nonetheless, she was still able to throw the javelin 5.93 m further. Even though the travel distance of the javelin is highly correlated to the release velocity, she was able to achieve a higher distance with lower velocity. This is because the angle of release and release height (103.4 %/height) led to a positive outcome.

Out of all of the medalists, M. Abakumova had the highest vertical body angle at release. When release occurs closest to a vertical body angle, the javelin can travel more smoothly. Moreover, she had the fastest delivery velocity, called the power stride. A power stride is possible when the delivery stride secures a wide base, efficiently sending power from the ground to the javelin. Most of all, even though her angle of release decreased by 3.2° compared to the Berlin Competition, with the right combination of javelin balance and movement direction, she was able to effectively release the javelin, enabling her to secure the gold medal.

The number one ranked thrower in the world, B. Spotakova missed the gold medal by just 0.41 m. In terms of kinematic analysis, it can be concluded that she had a more favorable position by achieving a release velocity of 26.17 m/s and an angle of attack of 4.0°. However, the distance between her landing foot and the foul line was 2.54 m, 1.06 m more than the other athletes. Furthermore, compared to the gold medalist, her CP and DP phase speeds were 2.56 m/s and 0.19 m/s lower respectively. In order for her to win the gold medal, she would need to improve her step distance, maintaining a continuous rhythmical run-up, and taking her steps into account from cross step until the moment of release. Additionally, she would need to work on her release position so that the distance between the foul line and her landing foot decreases.

S. Viljoen, who won bronze, achieved the lowest score for release velocity compared to the other competitors, which has the most direct influence on distance in the javelin throw. She had a body angle of 46.7° which was too low for the throw to be at top efficiency. Moreover, her CM velocity was the slowest out of the three medalists: this had a negative effect on the release velocity. This type of outcome shows that if the CM velocity of the body is too slow, it will cause a negative effect on the horizontal flight distance.

Comparing the kinematic parameters of the female medalists to those of male athletes at the 2011 IAAF World Championships, Daegu, reveals that the women had a higher average angle of release and angle of attitude. Gold medalist M. Abakumova, silver medalist B. Spotakova, and bronze medalist S. Viljoen achieved angles of 39.4°, 38.2°, and 39.3°, respectively. It can be seen that all the medalists had an angle of release close to 40°.

In the 2009 Berlin Competition, the best throw was 68.92 m, set by M. Abakumova in the qualification round. In the finals, B. Spotakova won the silver medal. Both athletes exceeded the male athletes with angles of release of 38.7°, and 38.8°. This can be interpreted to show that even a slight difference in the weight of the javelin or in the release velocity can change the outcome. This study, demonstrated that a medalist's average angle of release was 39.0 ± 0.7°, while the other athletes got 37.4 ± 2.4°. Both top male and female athletes attained higher angles of release compared to other finalists.

Figure 3. Kyung-Ae Kim (KOR)

The Korean athlete's results were as follows: release velocity of 21.20 m/s, angle of release of 47.2°, and release height of 1.68 m. Moreover, the inclination angle of the body segments were as follows: angle of the trunk 43.9°, angle of the upper arm 60.3°, and angle of the forearm 67.3°. Each phase movement speed for crossover was 5.12 m/s and the delivery was 5.65 m/s. A small difference in the release velocity, even as small as 1 m/s, can make a difference of 2.25 m to 3.68 m. In order to improve the Korean athlete's javelin performance, the athlete should improve her CM velocity when throwing the javelin. Increasing the hip joint and trunk rotation velocity can also increase release velocity.

In addition, at release, the upper body should not be transversely stiff, but slightly rotating so that the delivery motion can be smoother. However, if movement distance and duration are too short, then the momentum of the center of mass will decline. Conversely if release duration is too long, then initial velocity of the javelin will significantly decrease, just like in the case of the Korean athlete. However, if the release duration is too long, then the velocity of the javelin will decline. For that reason, the Korean athlete will need to change her landing style by controlling the landing distance from her foot to the foul line and her velocity. It is highly recommended that she decrease the time it takes for her to land on her foot and the time it takes for the javelin to leave her hand.

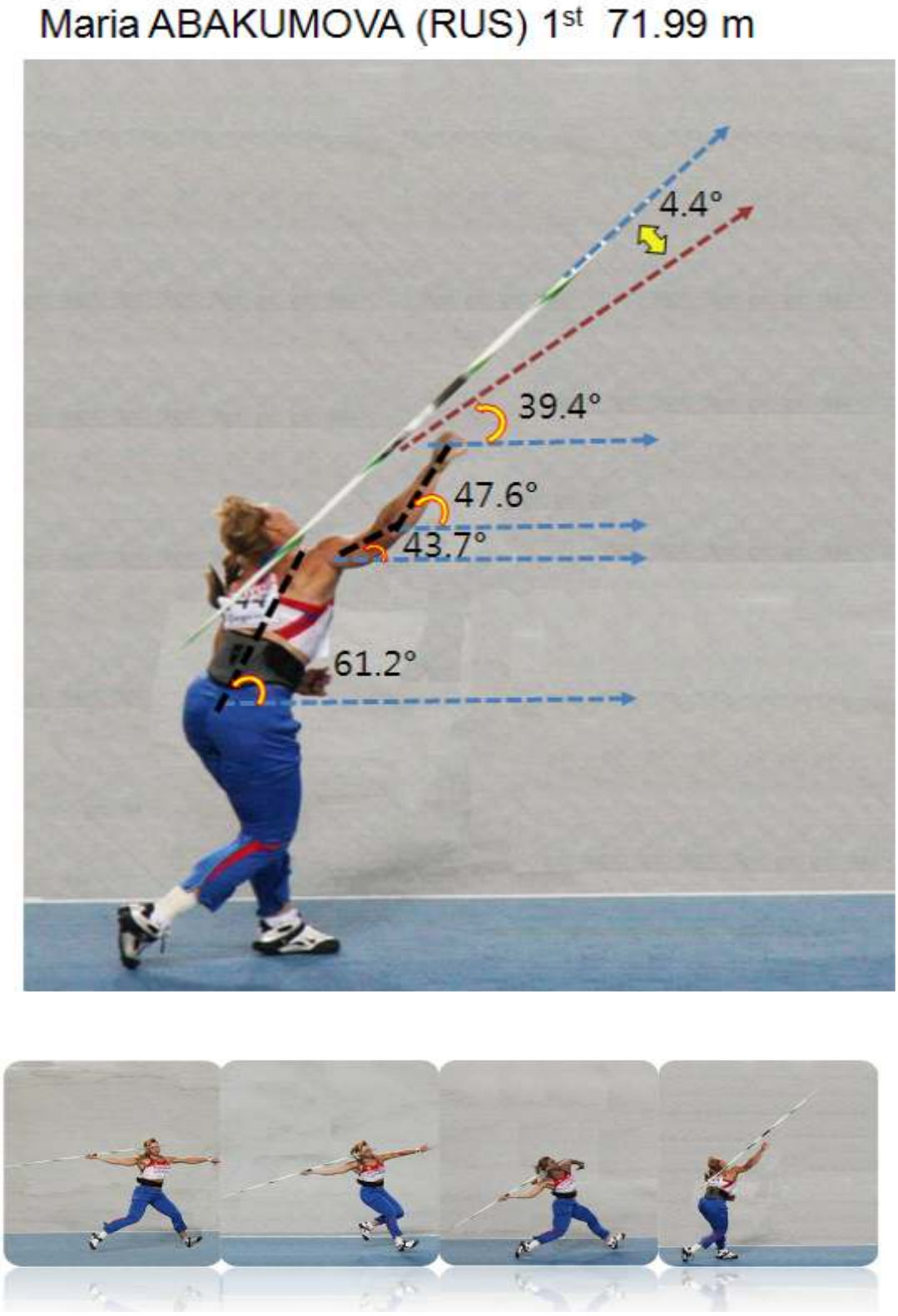


Figure 4. M. ABAKUMOVA (RUS)

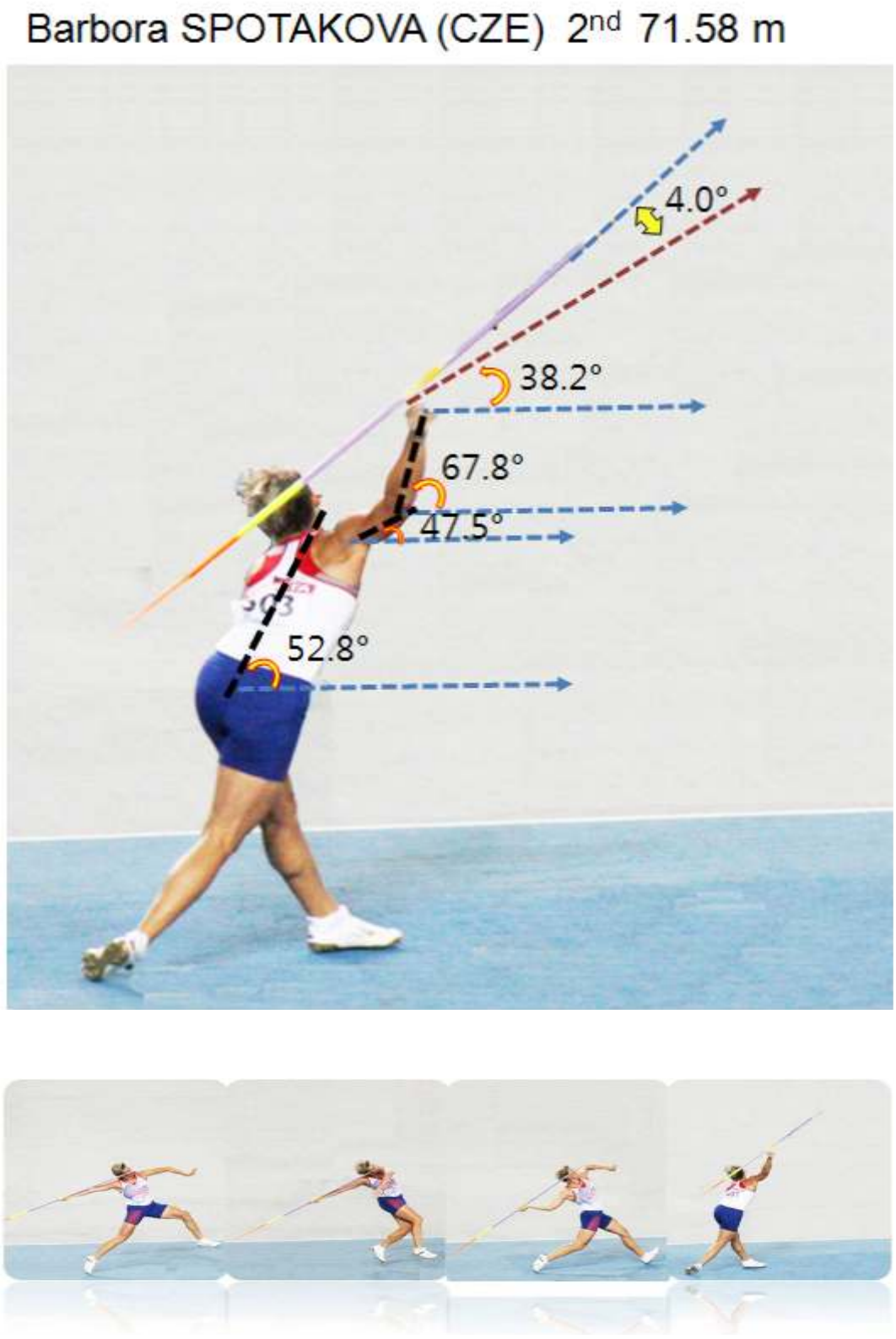


Figure 5. B. SPOTAKOVA (CZE)

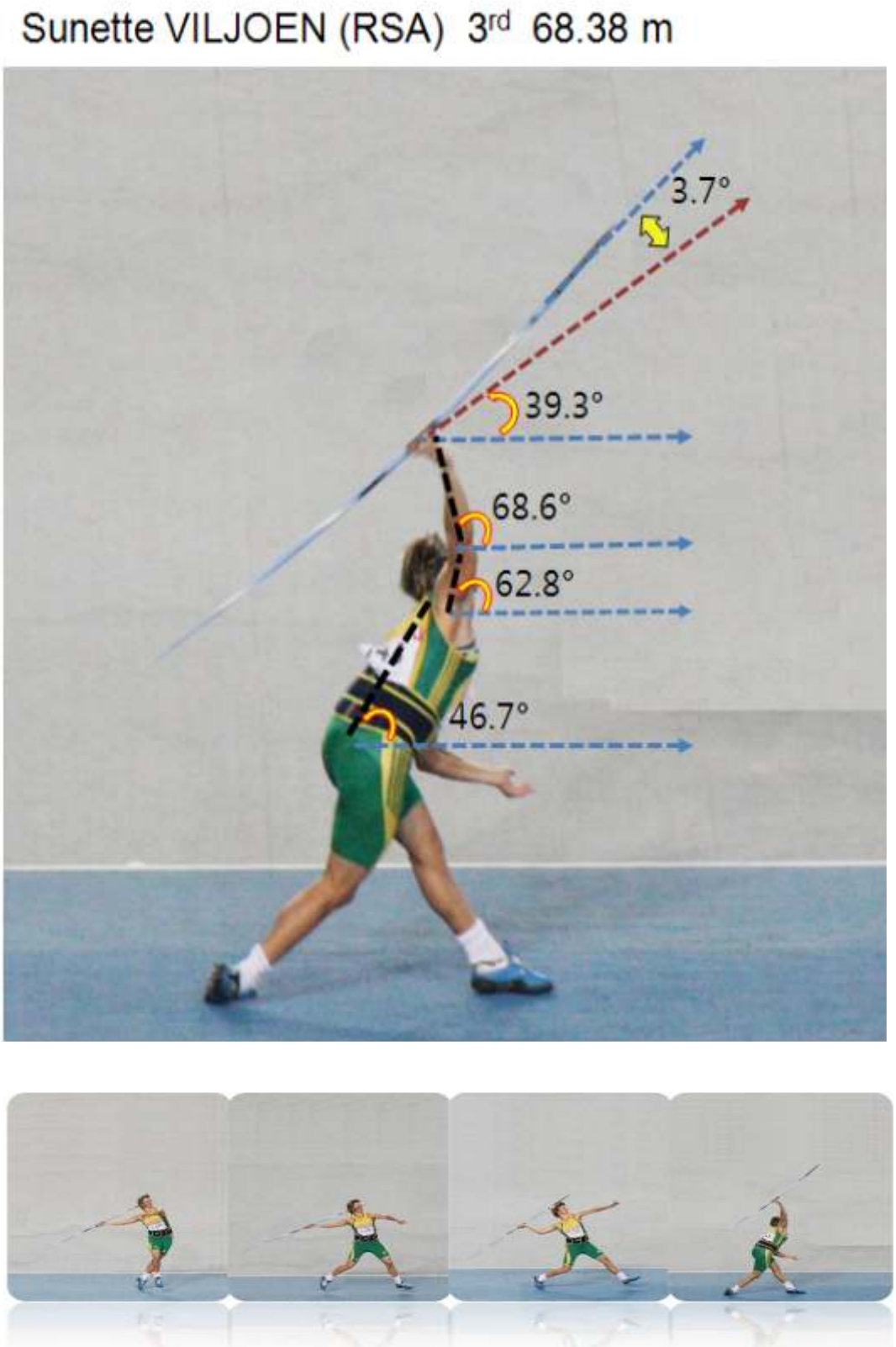


Figure 6. S. VILJOEN (RSA)

[27 August - 3 September 2011]

Scientific Research Project Biomechanical Analyses

at the IAAF World Championships Daegu 2011

Daily Report

Korean Society of Sport Biomechanics

Contents

Scientific Research Project Biomechanical Analyses
at the IAAF World Championships Daegu 2011

August 30, 2011

- High Jump Men - Qualification
- Pole Vault Women - Final
- Women's Pole Vault
- Triple Jump Women - Qualification (Mabel Gay)

September 1, 2011

- High Jump Men - Final
- Shot Put men - Qualification (Group A & Group B)
- Triple Jump Women - Final

September 2, 2011

- 100 M Hurdle Women - Round 1
- 200 M Men - Semi Final
- 200 M Women - Final
- Javelin Throw Women - Final
- Long Jump Men - Final
- Shot Pun Men - Final
- Triple Jump Men - Final

September, 2011

- 200 M Women - Final
- 200 M Men - Final
- High Jump Women - Final
- Javelin Throw Men - Final

Scientific Research Project Biomechanical Analyses

at the IAAF World Championships Daegu 2011

- August 27, 2011 -

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

100 M Men - Round 1 : Heat 6

(August 27, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Men's 100 meter

(Round 1 : Heat 6)

Rank	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
1	Usain BOLT (JAM)	Lap time (sec)	2.20	3.83	5.30	6.80	8.29	9.03	10.10
	Total Steps: 40	Avg. Speed (m/s)	5.92	10.39	11.59	11.36	11.41	11.38	9.84
		Avg. Step L (m)	2.24			2.83		2.71	
		Avg. Step Freq.	3.96			4.02		3.86	

Rank	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
2	Dwain CHAMBERS (GBR)	Lap time (sec)	2.28	3.93	5.43	6.96	8.49	9.24	10.28
	Total Steps: 44	Avg. Speed (m/s)	5.71	10.30	11.33	11.06	11.16	11.28	10.10
		Avg. Step L (m)	2.04			2.43		2.71	
		Avg. Step Freq.	4.24			4.58		3.90	

Rank	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
3	Angel David RODRIGUEZ (ESP)	Lap time (sec)	2.24	3.93	5.45	7.02	8.56	9.32	10.37
	Total Steps: 47	Avg. Speed (m/s)	5.79	10.08	11.21	10.81	11.06	11.09	10.03
		Avg. Step L (m)	1.96			2.27		2.38	
		Avg. Step Freq.	4.41			4.82		4.41	

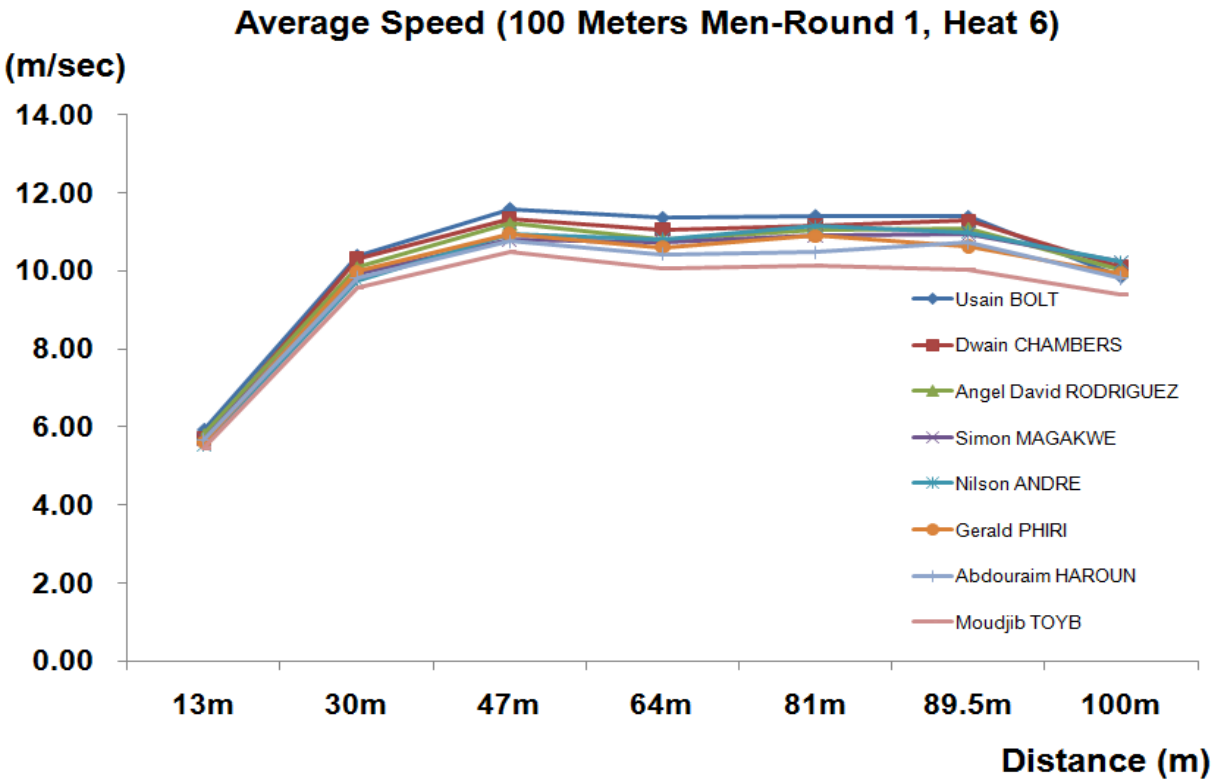
Rank	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
4	Simon MAGAKWE (RSA)	Lap time (sec)	2.29	4.01	5.58	7.17	8.73	9.50	10.53
	Total Steps: 50	Avg. Speed (m/s)	5.67	9.90	10.81	10.74	10.90	10.94	10.23
		Avg. Step L (m)	1.74			2.13		2.71	
		Avg. Step Freq.	4.84			5.09		3.88	

Rank	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
5	Nilson ANDRE (BRA)	Lap time (sec)	2.34	4.09	5.64	7.21	8.74	9.51	10.54
	Total Steps: 53	Avg. Speed (m/s)	5.55	9.75	10.94	10.81	11.14	10.99	10.23
		Avg. Step L (m)	1.68			2.13		2.11	
		Avg. Step Freq.	4.96			5.16		5.00	

Rank	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
6	Gerald PHIRI (ZAM)	Lap time (sec)	2.32	4.03	5.58	7.18	8.74	9.54	10.60
	Total Steps: 47	Avg. Speed (m/s)	5.60	9.98	10.94	10.60	10.90	10.63	9.94
		Avg. Step L (m)	1.88			2.27		2.71	
		Avg. Step Freq.	4.48			4.74		3.77	

Rank	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
7	Abdouraim HAROUN (CHA)	Lap time (sec)	2.29	4.02	5.60	7.23	8.86	9.65	10.72
	Total Steps: 46	Avg. Speed (m/s)	5.67	9.83	10.76	10.43	10.47	10.71	9.81
		Avg. Step L (m)	1.96			2.43		2.38	
		Avg. Step Freq.	4.28			4.30		4.29	

Rank	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
8	Moudjib TOYB (COM)	Lap time (sec)	2.39	4.17	5.79	7.48	9.16	10.00	11.12
	Total Steps: 48	Avg. Speed (m/s)	5.45	9.55	10.49	10.06	10.12	10.04	9.40
		Avg. Step L (m)	1.88			2.27		2.38	
		Avg. Step Freq.	4.32			4.45		4.07	



Scientific Research Project
Biomechanical Analyses
at the
IAAF World Championships Daegu 2011

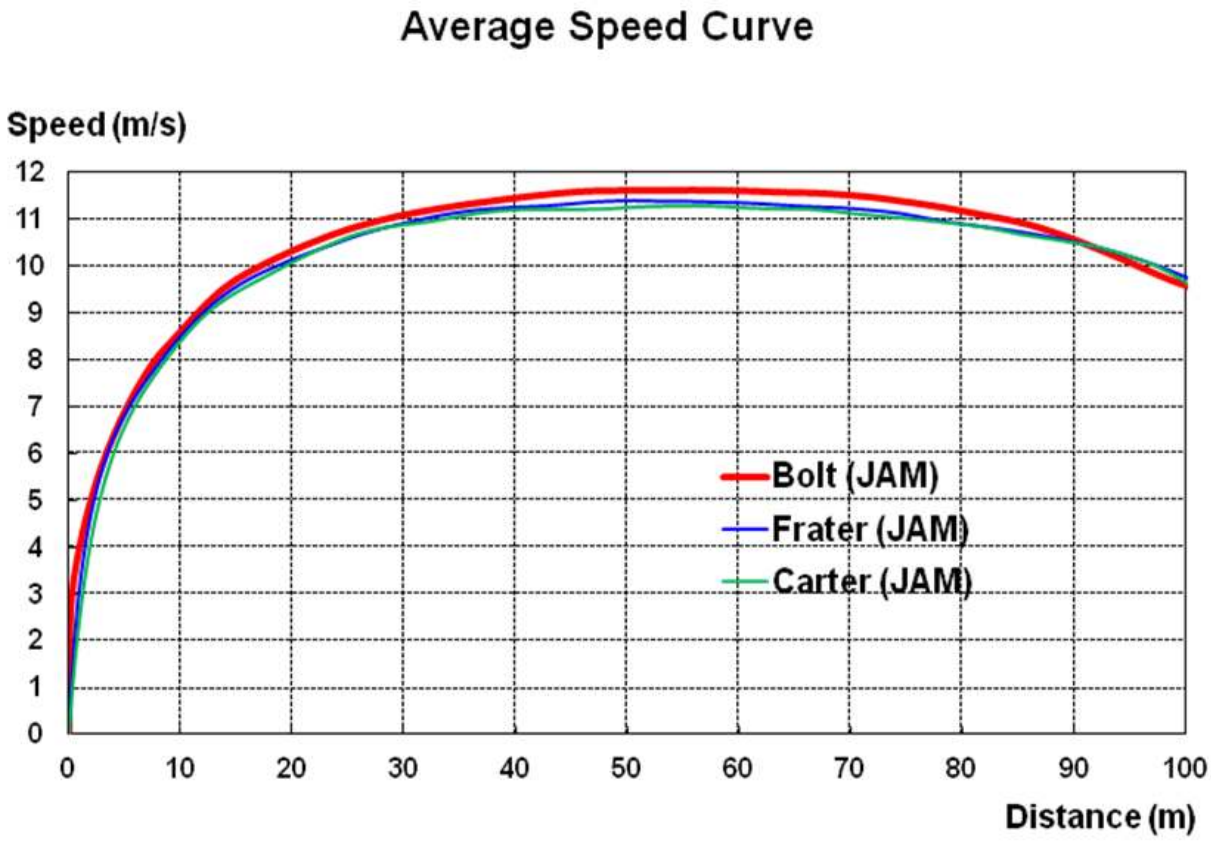
100 M Men - Round 1
Long Jump Women - Qualification Group B
Pole Vault - Men Qualification Groups A & B
(August 27, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Men's 100 meter

(Round 1)

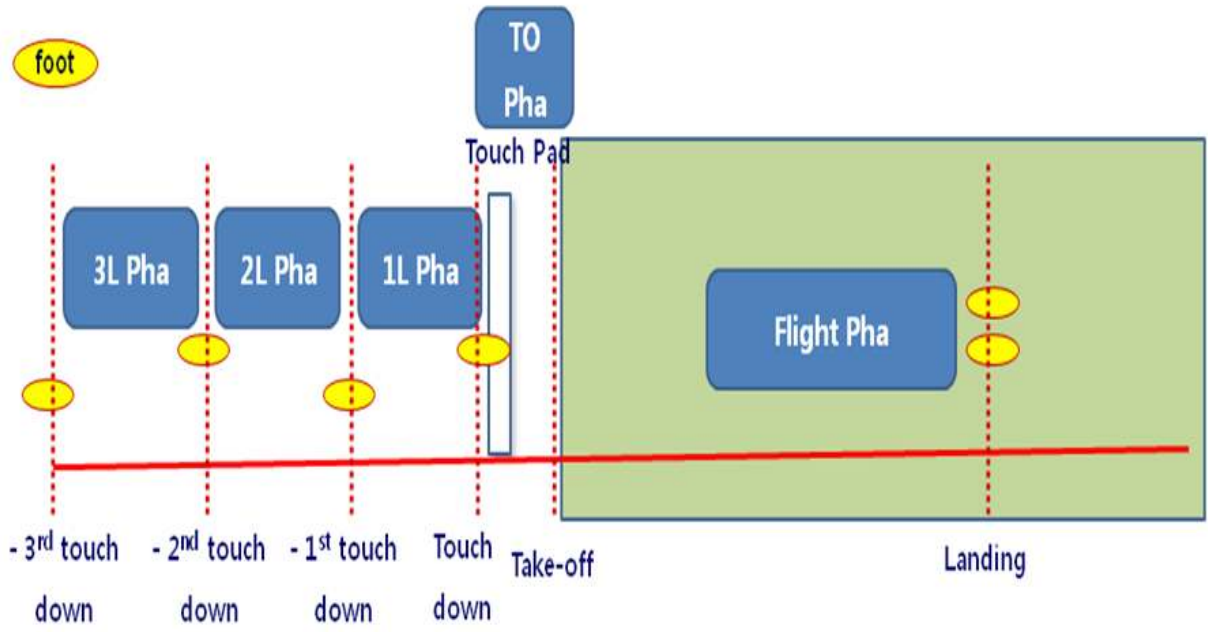
	10 m Avg. speed (m/sec)	20 m Avg. speed (m/sec)	30 m Avg. speed (m/sec)	40 m Avg. speed (m/sec)	50 m Avg. speed (m/sec)	60 m Avg. speed (m/sec)	70 m Avg. speed (m/sec)	80 m /Avg. speed (m/sec)	90 m Avg. speed (m/sec)	100 m Avg. speed (m/sec)	Max speed (m/sec)	Distance at Max Speed	Total Time (sec)
Usain Bolt (JAM)	5.30	9.63	10.78	11.31	11.59	11.64	11.59	11.38	10.94	10.12	11.64	55.27	10.10
Michael Farter (JAM)	5.17	9.48	10.59	11.15	11.35	11.40	11.32	11.11	10.74	10.31	11.42	50.61	10.26
Nester Carter (JAM)	5.33	9.57	10.69	11.12	11.25	11.29	11.21	11.00	10.66	10.17	11.31	54.55	10.26



Biomechanical Analysis of Women's Long Jump Qualification

(Group B)

		Maurren Higa MAGGI (BRA)	N. Mironchyk – IVANOVA (BLR)
Record (m)		6.86	6.80
Stride Length	3Last (m)	2.34	1.95
	2Last (m)	2.42	2.05
	1Last (m)	2.25	2.17
	Relative Length 2Last/3Last (%)	103.4	105.1
	Relative Length 1Last/2Last (%)	92.9	105.9
Velocity	Horizontal Vel. at Touch Down (m/s)	8.94	8.25
	Horizontal Vel. at Take-off (m/s)	8.24	7.91
	Loss of Horizontal Vel. During Ground Contact (m/s)	0.70	0.34
	Resultant Velocity at Take-off (m/s)	8.52	8.17



Biomechanical Analysis of Men's Pole Vault - Qualification

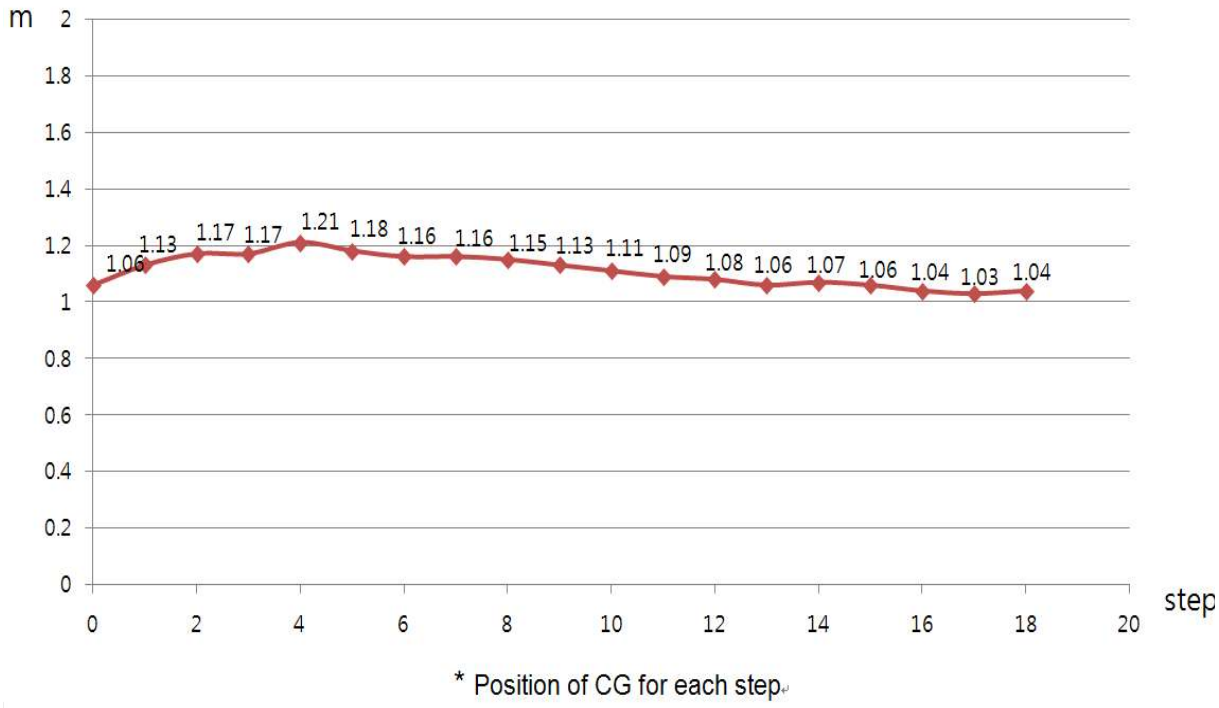
(Groups A&B)

NAME	COUNTRY	Seasonal Best (m)	Record (m)	V_A* (m/s)	AP# (m)
Romail MESNIL	FRA	5.73	5.65	9.47	4.75
Dmitry STARODUBTSEV	RUS	5.75	5.65	8.65	4.57
Fabio Gomes DA SILVA	BRA	5.80	5.65	9.88	5.68
Mateusz DIDENKOW	POL	5.75	5.65	8.47	4.57
Malte MOHR	GER	5.81	5.65	9.15	4.88
Konstandinos FILIPPIDIS	GRE	5.73	5.65	9.46	3.95
Renaud LAVILLENIE	FRA	5.90	5.65	9.01	4.80
La´zaro BORGES	CUB	5.75	5.65	9.67	4.92

* V_A : 5 m Run-up velocity before takeoff

#AP : Take-off Position at the heel from the cut in box

Pole Vaulter	Romail MENSIL (FRA)
Record	5.65 m
Run-up distance	30.15 m
Run-up time	5.12 sec
Average speed of run-up phase	5.89 m/s (Run-up distance / Run-up time)
Number of run-up steps	18 steps
Average step length	1.68 m (Run-up distance / Number of run-up steps)
Step frequency	3.52 steps/sec (Number of run-up steps / Run-up time)
AP(Take-off position from the cut in box)	4.75 m
Position of CG	*Details attached



* Position of CG for each step

Scientific Research Project Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

- August 28, 2011 -

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

Yohan Blake, JAM - 100 M men's Final

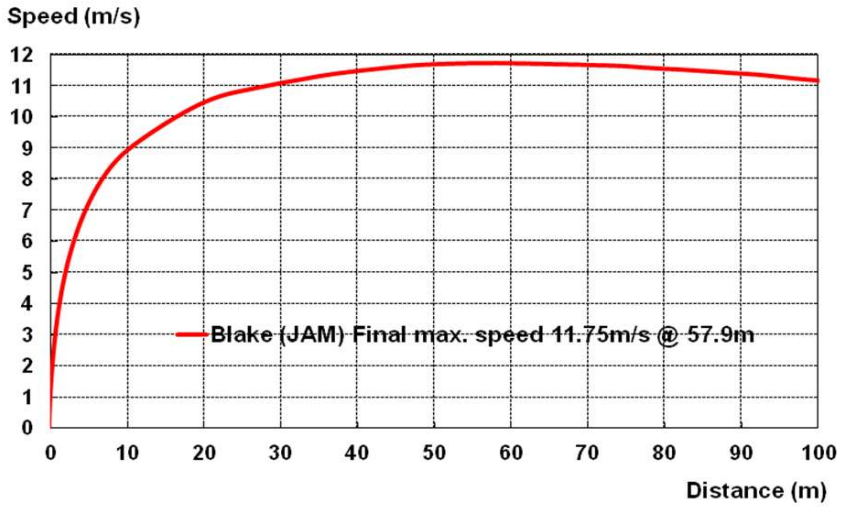
(August 28, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Men's 100 meter

	RANK / LANE	10m Avg. speed (m/sec)	20m Avg. speed (m/sec)	30m Avg. speed (m/sec)	40m Avg. speed (m/sec)	50m Avg. speed (m/sec)	60m Avg. speed (m/sec)	70m Avg. speed (m/sec)	80m /Avg. speed (m/sec)	90m Avg. speed (m/sec)	100m Avg. speed (m/sec)	Max speed (m/sec)	Distance at Max Speed	Total Time (sec)
Yohan Blake (JAM) -Final	1/6	5.35	9.76	10.84	11.32	11.62	11.74	11.71	11.63	11.49	11.29	11.75	57.9	9.92

Speed Curve (Yohan Blake, JAM- 100M men's Final)



Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

100 M Men - Final

Shot Put Women - Qualification

Long Jump Women - Final

(August 28, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Men's 100 meter

(Final)

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
1/ 6	Yohan BLAKE (JAM)	Lap time (sec)	2.21	3.84	5.33	6.78	8.24	8.98	9.92
	Total Steps: 47	Avg. Speed (m/s)	5.87	10.47	11.41	11.70	11.64	11.49	11.17
		Avg. Step L (m)	1.88			2.43		2.38	
		Avg. Step Freq.	4.69			4.88		4.65	

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
2/ 4	Walter DIX (USA)	Lap time (sec)	2.26	3.92	5.44	6.91	8.39	9.14	10.08
	Total Steps: 48	Avg. Speed (m/s)	5.74	10.24	11.23	11.54	11.51	11.33	11.13
		Avg. Step L (m)	1.81			2.27		2.38	
		Avg. Step Freq.	4.78			5.18		4.58	

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
3/ 3	Kim COLLINS SKN (SKN)	Lap time (sec)	2.19	3.82	5.33	6.83	8.34	9.11	10.09
	Total Steps: 49	Avg. Speed (m/s)	5.93	10.45	11.28	11.33	11.26	11.00	10.71
		Avg. Step L (m)	1.81			2.27		2.38	
		Avg. Step Freq.	4.88			5.03		4.49	

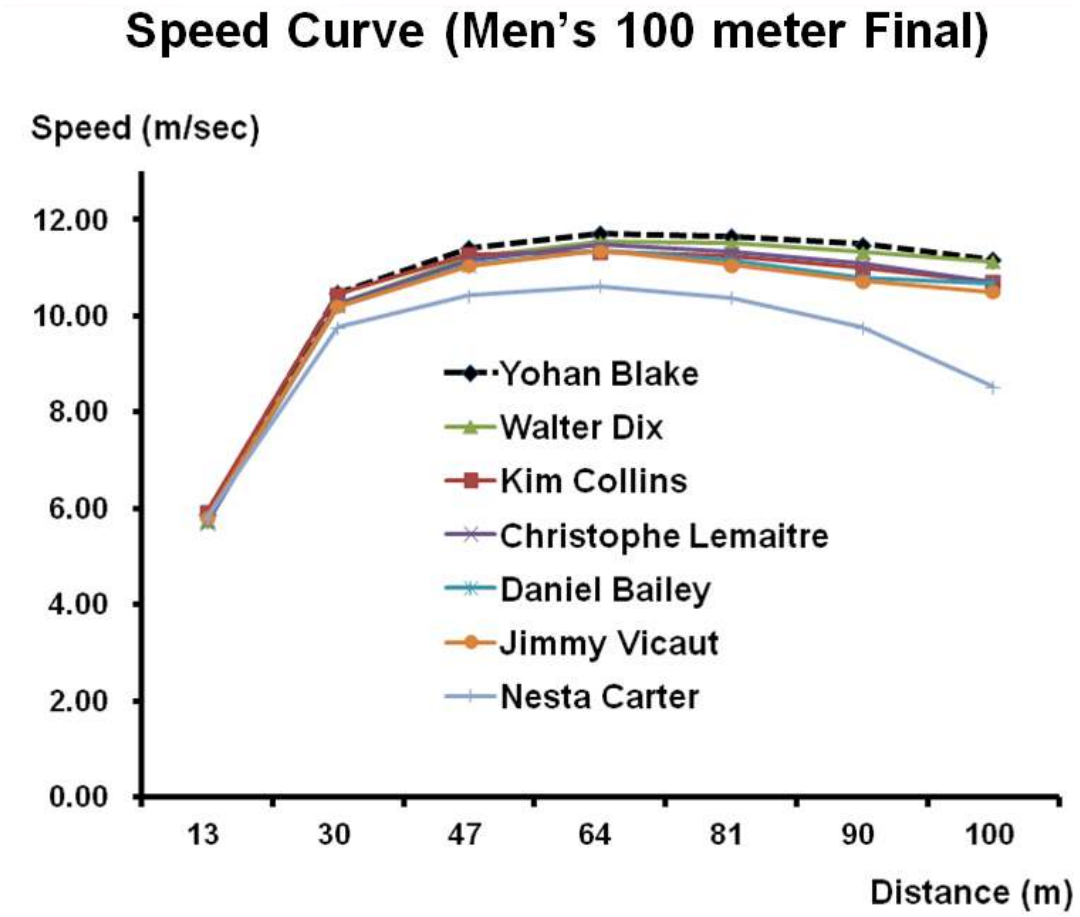
Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
4/ 8	Christophe LEMAITRE (FRA)	Lap time (sec)	2.28	3.94	5.46	6.94	8.44	9.21	10.19
	Total Steps: 41	Avg. Speed (m/s)	5.69	10.26	11.16	11.49	11.33	11.08	10.71
		Avg. Step L (m)	2.14			2.62		3.17	
		Avg. Step Freq.	4.03			4.38		3.40	

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
5/ 2	Daniel BAILEY (ANT)	Lap time (sec)	2.27	3.95	5.46	6.97	8.47	9.23	10.26
	Total Steps: 48	Avg. Speed (m/s)	5.73	10.20	11.06	11.36	11.16	10.80	10.68
		Avg. Step L (m)	1.88			2.27		2.38	
		Avg. Step Freq.	4.58			4.99		4.47	

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
6/ 1	Jimmy VICAUT (FRA)	Lap time (sec)	2.24	3.90	5.44	6.94	8.48	9.27	10.27
	Total Steps: 46	Avg. Speed (m/s)	5.81	10.20	11.04	11.36	11.06	10.72	10.50
		Avg. Step L (m)	1.96			2.27		2.71	
		Avg. Step Freq.	4.42			4.96		3.86	

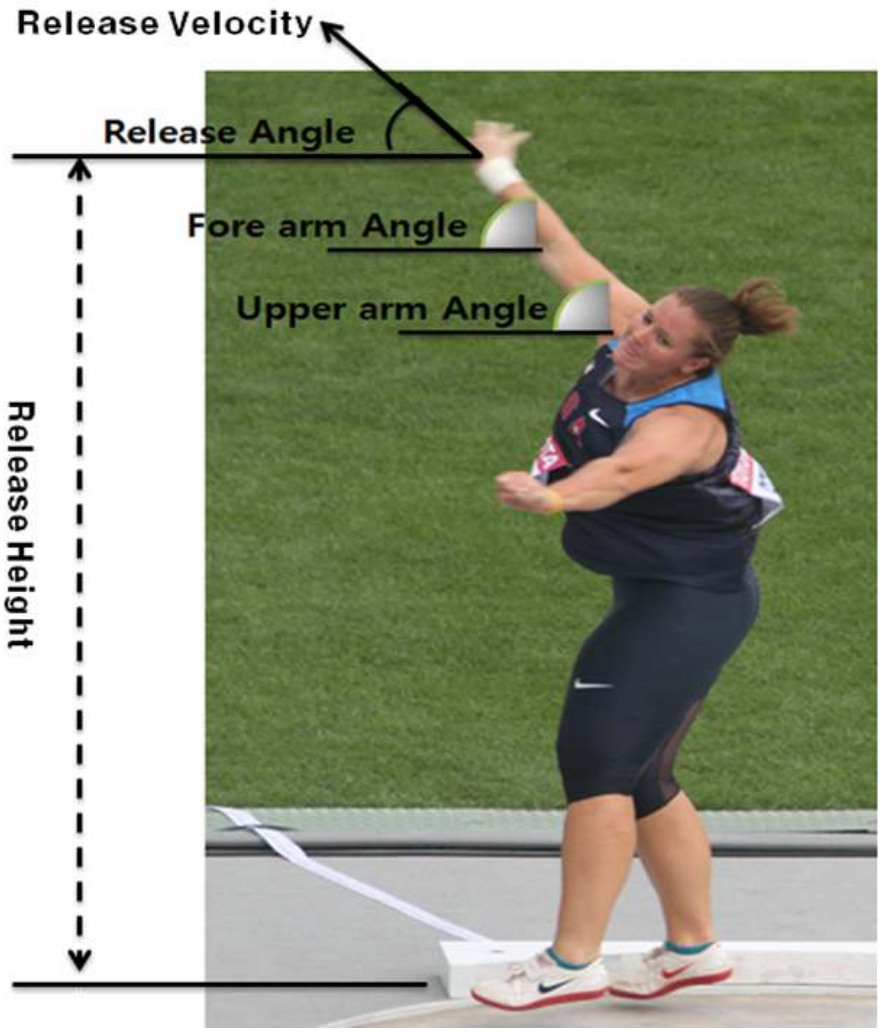
Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
7/ 7	Yohan BLAKE (JAM)	Lap time (sec)	2.24	3.98	5.61	7.21	8.85	9.72	10.95
	Total Steps: 47	Avg. Speed (m/s)	5.80	9.77	10.43	10.63	10.38	9.77	8.54
		Avg. Step L (m)	1.96			2.27		2.38	
		Avg. Step Freq.	4.28			4.67		3.76	

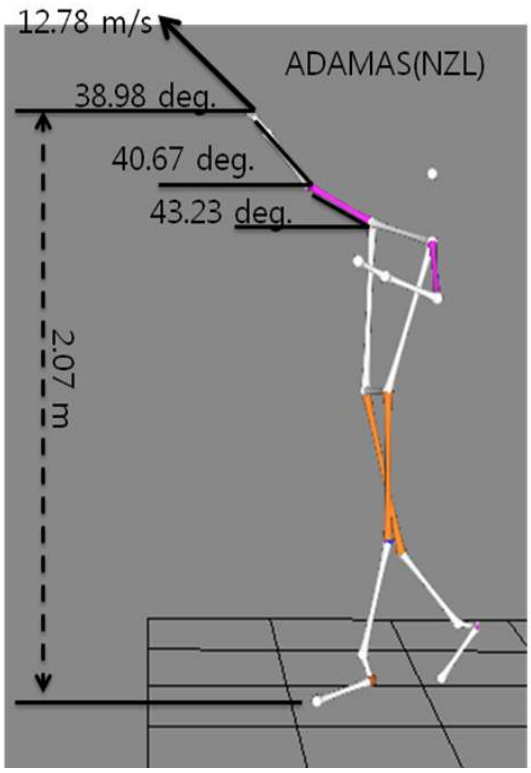
Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
8/ 5	Usain BOLT (JAM)	Lap time (sec)	DQ						
	Total Steps: 0	Avg. Speed (m/s)							
		Avg. Step L (m)							
		Avg. Step Freq.							

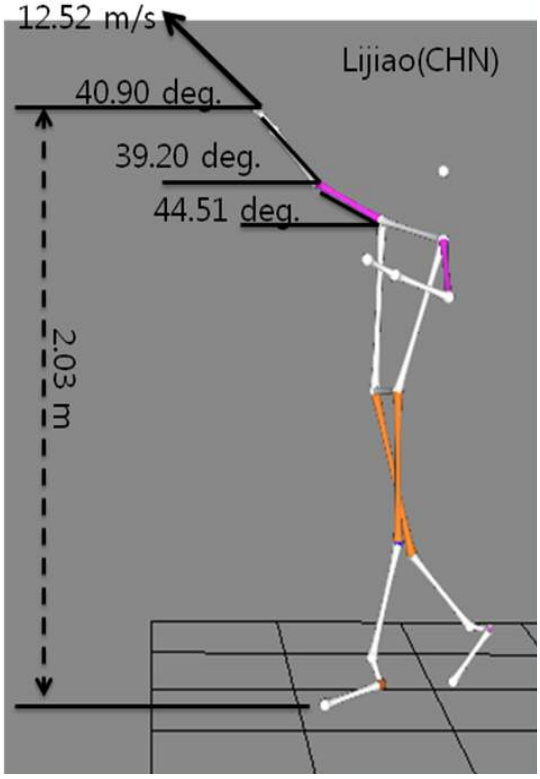


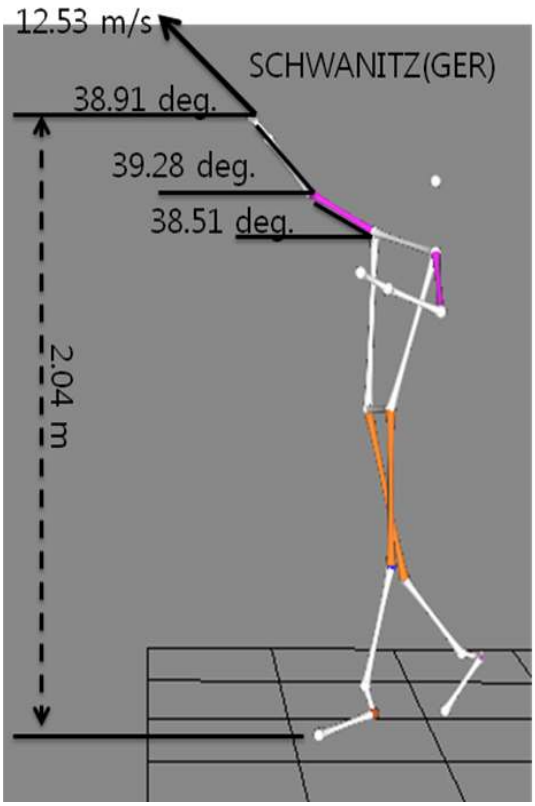
Biomechanical Analysis of Women's Shot put(Qualification)

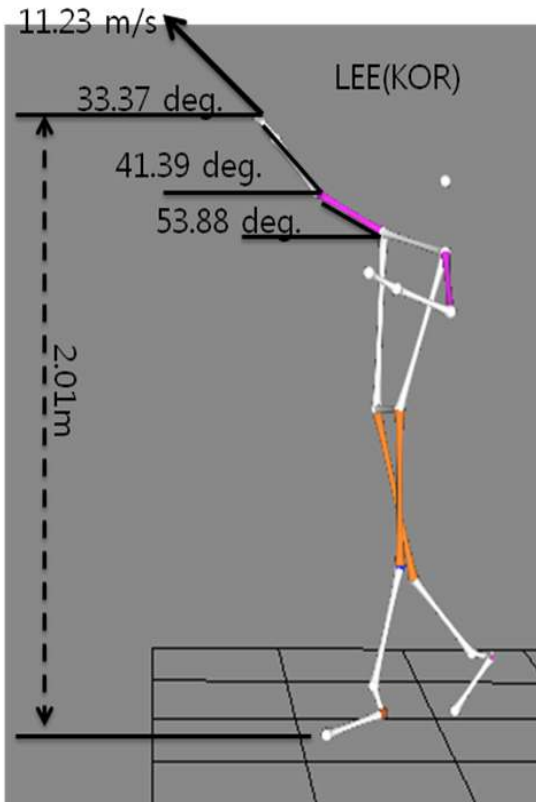
Ranking		COUNTRY	RESULT	Release Angle (deg.)	Release Velocity (m/s)	Release Height (m)	Inclination Angle at Release (deg.)		Style
							Forearm	Upperarm	
1	Valerie ADAMS	NZL	19.79 m	38.8	12.78	2.07	40.7	43.2	Glide
2	GONG Lijiao	CHN	19.21 m	40.9	12.52	2.03	39.2	44.5	Glide
3	Christina SCHWANITZ	GER	19.20 m	38.9	12.53	2.04	39.3	38.5	Glide
	LEE Mi-Young	KOR	16.18 m	33.4	11.23	2.01	41.4	53.9	Glide




12.78 m/s
ADAMAS(NZL)
38.98 deg.
40.67 deg.
43.23 deg.
2.07 m

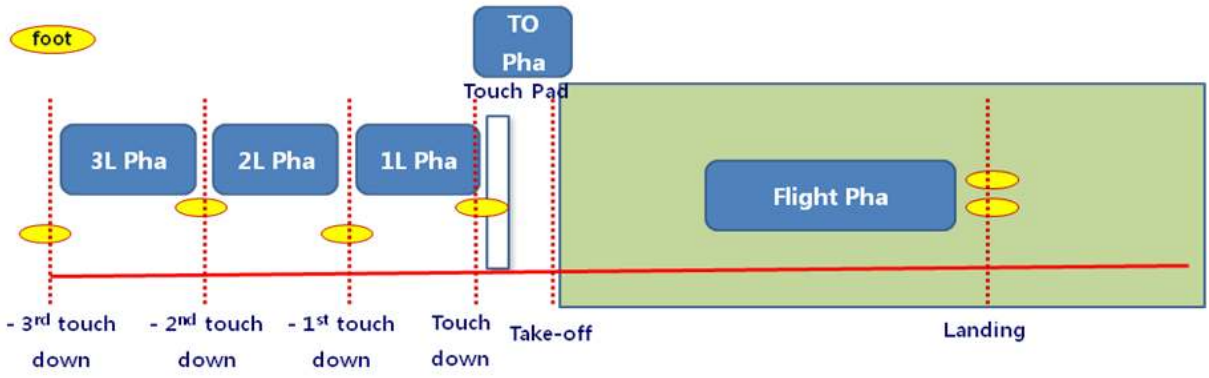

12.52 m/s
Lijiao(CHN)
40.90 deg.
39.20 deg.
44.51 deg.
2.03 m


12.53 m/s
SCHWANITZ(GER)
38.91 deg.
39.28 deg.
38.51 deg.
2.04 m


11.23 m/s
LEE(KOR)
33.37 deg.
41.39 deg.
53.88 deg.
2.01m

Biomechanical Analysis of Women's Long Jump - Final

VARIABLE (unit)		Brittney Reese (USA) 1st Place	Olga KUCHERENKO (RUS) 2nd Place	Ineta RADEVICA (LAT) 3rd Place
RESULT (m)		6.82	6.77	6.76
Stride Length	3Last (m)	1.99	2.11	2.17
	2Last (m)	2.92	2.83	2.93
	1Last (m)	1.92	2.18	2.13
	Relative Length 2Last/3Last (%)	147	134	135
	Relative Length 1Last/2Last (%)	66	77	73
Velocity	Horizontal Vel. at Touch Down (m/s)	9.03	8.64	8.57
	Horizontal Vel. at Take-off (m/s)	7.86	7.46	7.86
	Loss of Horizontal Vel. During Ground Contact (m/s)	1.17	1.18	0.71
	Vertical Velocity at Take-off (m/s)	3.02	3.04	2.87
	Resultant Velocity at Take-off (m/s)	8.42	8.07	8.37
Take-off	Take-off Angle (deg)	21.0	22.2	20.1
	Vertical Height of CoM	1.26	1.28	1.23
	Take-off Distance : Horizontal Position of CoM (m) Relative to Foot	0.44	0.45	0.36
	Duration (sec)	0.133	0.134	0.116



Scientific Research Project Biomechanical Analyses

at the IAAF World Championships Daegu 2011

- August 29, 2011 -

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

(Carmelita JETTER, USA - 100M Women's Final)

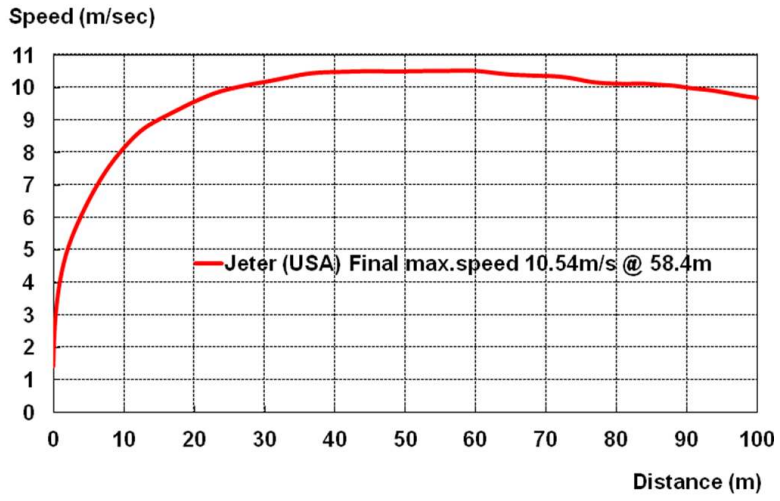
(August 29, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Men's 100 meter

	RANK / LANE	10m Avg. speed (m/sec)	20m Avg. speed (m/sec)	30m Avg. speed (m/sec)	40m Avg. speed (m/sec)	50m Avg. speed (m/sec)	60m Avg. speed (m/sec)	70m Avg. speed (m/sec)	80m /Avg. speed (m/sec)	90m Avg. speed (m/sec)	100m Avg. speed (m/sec)	Max speed (m/sec)	Distance at Max Speed	Total Time (sec)
Carmelita JETER (USA)	1/4	5.16	8.99	9.95	10.39	10.51	10.53	10.43	10.25	10.12	9.83	10.54	58.4	10.90

Speed Curve (Jeter Carmelita, USA- 100M Final)



Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

(100 M Women - Final Shot Put Women - Final)

(August 29, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Women's 100 meter

(Final)

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
1/ 4	Carmelita JETER (USA)	Lap time (sec)	2.32	4.11	5.73	7.35	8.97	9.80	10.90
	Total Steps: 50.5	Avg. Speed (m/s)	5.60	9.53	10.47	10.52	10.45	10.32	9.52
		Avg. Step L (m)	1.98						
		Avg. Step Freq.	4.63						

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
2/ 8	Veronica CAMPBELL-BROWN (JAM)	Lap time (sec)	2.39	4.17	5.81	7.42	9.03	9.85	10.97
	Total Steps: 49.6	Avg. Speed (m/s)	5.44	9.57	10.34	10.54	10.60	10.37	9.35
		Avg. Step L (m)	2.02						
		Avg. Step Freq.	4.52						

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
3/ 5	Kelly-Ann BAPTISTE(TRI)	Lap time (sec)	2.20	4.11	5.76	7.39	9.02	9.85	10.98
	Total Steps: 50	Avg. Speed (m/s)	5.92	8.87	10.32	10.43	10.41	10.24	9.32
		Avg. Step L (m)	2.00						
		Avg. Step Freq.	4.55						

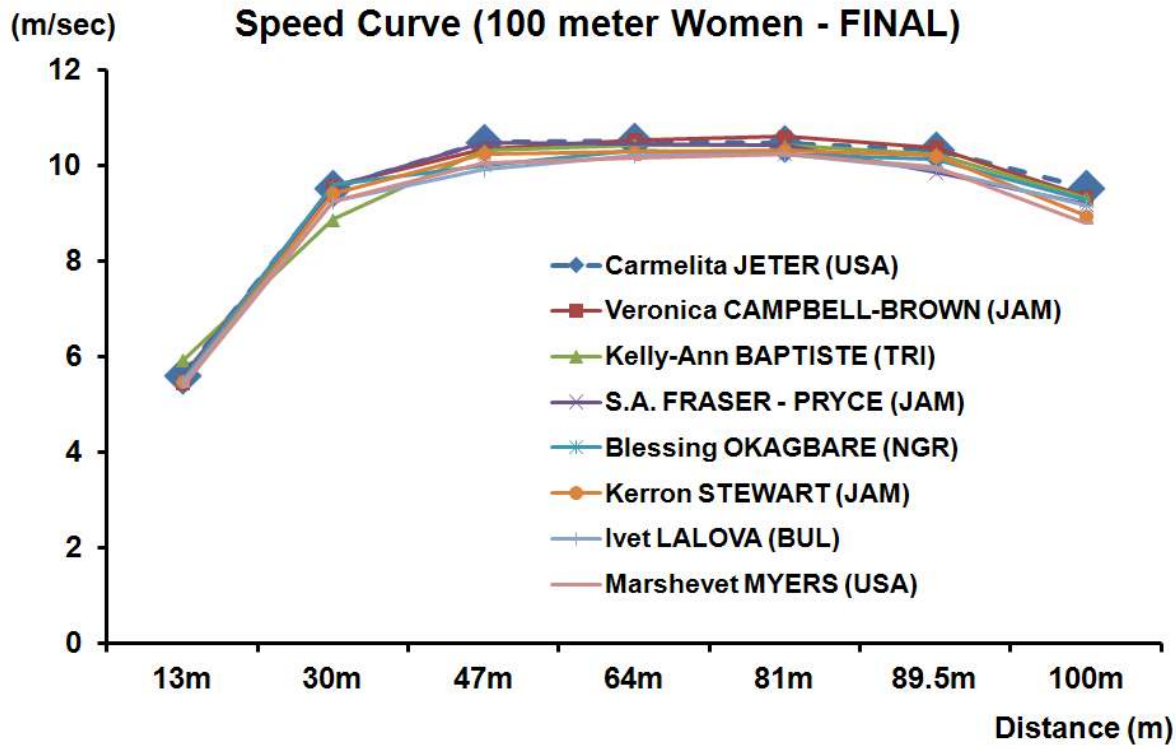
Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
4/ 3	S.A. FRASER-PRYCE(JAM)	Lap time (sec)	2.32	4.10	5.73	7.35	8.98	9.85	10.99
	Total Steps: 50	Avg. Speed (m/s)	5.60	9.53	10.47	10.45	10.43	9.85	9.18
		Avg. Step L (m)	2.00						
		Avg. Step Freq.	4.55						

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
5/ 2	Blessing OKAGBARE (NGR)	Lap time (sec)	2.36	4.14	5.84	7.49	9.15	9.99	11.12
	Total Steps: 47.4	Avg. Speed (m/s)	5.50	9.59	10.00	10.30	10.24	10.12	9.26
		Avg. Step L (m)	2.11						
		Avg. Step Freq.	4.26						

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
6/ 6	Kerron STEWART (JAM)	Lap time (sec)	2.38	4.18	5.84	7.50	9.14	9.98	11.15
	Total Steps: 47	Avg. Speed (m/s)	5.47	9.41	10.24	10.28	10.32	10.20	8.95
		Avg. Step L (m)	2.13						
		Avg. Step Freq.	4.22						

Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
7/ 1	Ivet LALOVA (BUL)	Lap time (sec)	2.38	4.22	5.94	7.60	9.27	10.12	11.27
	Total Steps: 50	Avg. Speed (m/s)	5.46	9.24	9.90	10.20	10.22	9.92	9.16
		Avg. Step L (m)	2.00						
		Avg. Step Freq.	4.44						

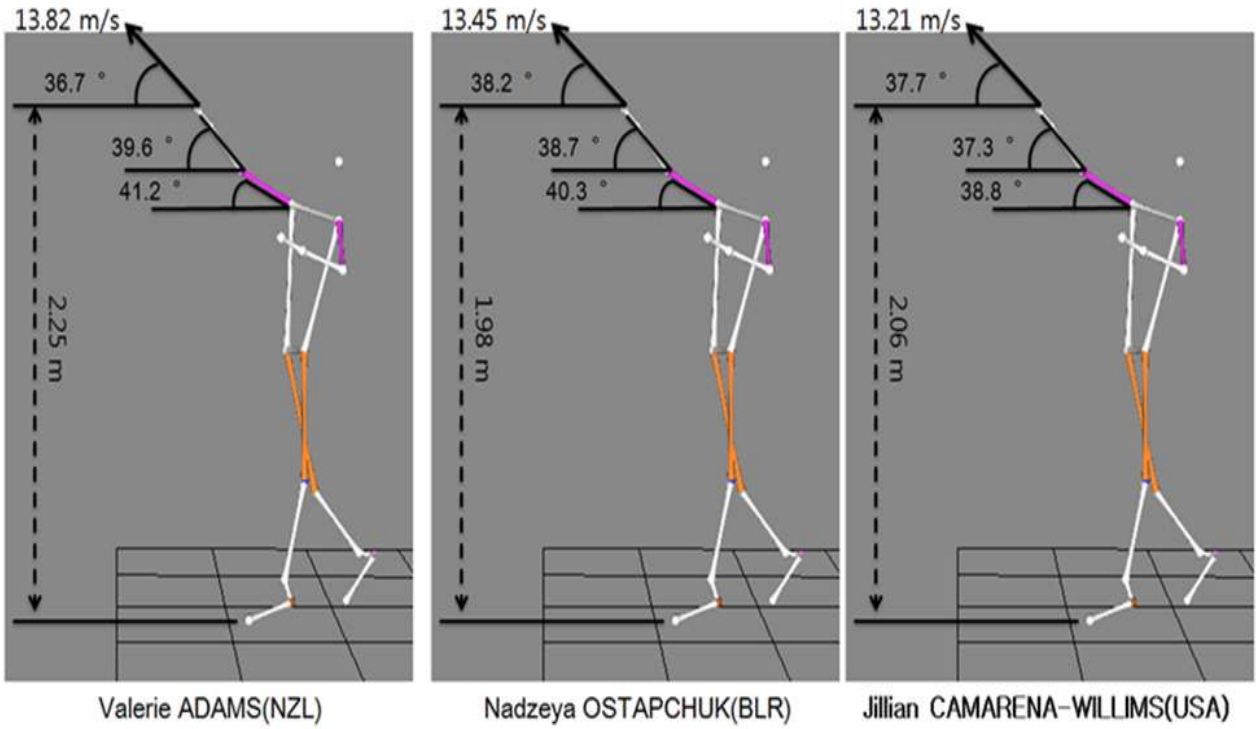
Rank / Lane	Name	Parameter	0-13 m	-30 m	-47 m	-64 m	-81 m	-89.5 m	-100 m
8/ 7	Marshevet MYERS (USA)	Lap time (sec)	2.41	4.25	5.94	7.62	9.28	10.14	11.33
	Total Steps: 47.6	Avg. Speed (m/s)	5.39	9.26	10.04	10.14	10.22	9.96	8.80
		Avg. Step L (m)	2.10						
		Avg. Step Freq.	4.20						



Biomechanical Analysis of Women's Shot put (Final)

Ranking		COUNTRY	RESULT WCH (m)	SB before WCH (m)		Release Velocity (m/s)	Release Angle (deg.)	Release Height (m)	Inclination Angle at Release (deg.)		Style
									Forearm	Upperarm	
1	Valerie ADAMS	NZL	NZL	21.24	20.78	2.21%	13.82	36.7	2.25	39.6	41.2
2	Nadzeya OSTAPCHUK	BLR	BLR	20.05	16.76	19.48%	13.45	38.2	1.98	38.7	40.3
3	Jillian CAMARENA-WILLIAMS	USA	USA	20.02	20.18	-0.8%	13.21	35.7	2.06	37.3	38.8

Valerie Adams(NZL) 1st 21.24 m



Valerie ADAMS(NZL) Nadzeya OSTAPCHUK(BLR) Jillian CAMARENA-WILLIMS(USA)

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

(Pole Vault Men - Final)

(August 29, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Men's Put Vault (Final)

BIB	NAME	COUNTRY	Place	Season Best(m)	Record (m)	V_A* (m/s)*	Approach Position#(m)	Number of STEPs
848	Pawel WOJCIECHOWSKI	POL	1	5.81	5.90	9.15	5.34	16
276	Lázaro BORGES	CUB	2	5.75	5.90	9.89	5.54	20
412	Renaud LAVILLENIE	FRA	3	5.90	5.85	9.95	5.64	18
Mean						9.66	5.51	

* V_A : 5 m Run-up velocity before takeoff
#AP : Take-off Position at the heel from the cut in box

Biomechanical Analysis of Men's Pole Vault (Final)

BIB	NAME	Variable						
		Total Approach Distance(m)	Approach Elapsed Time (Sec)	Avg. Approach Velocity (m/s)	Avg. Step length	Step Frequency (N/Sec)	Step Length (m)	Velocity (m/s)
848	Pawel WOJCIECHOWSKI	32.50	4.33	7.50	2.03	3.69	*Fig.1.	*Fig.2.
276	Lázaro BORGES	36.44	4.35	8.38	2.28	3.68	*Fig.3.	*Fig.4.
412	Renaud LAVILLENIE	35.09	4.02	8.74	2.06	4.48	*Fig.5.	*Fig.6.
Mean		34.68	4.23	8.21	2.12	3.95		

Pawel WOJCIECHOWSKI 1st 5.90m

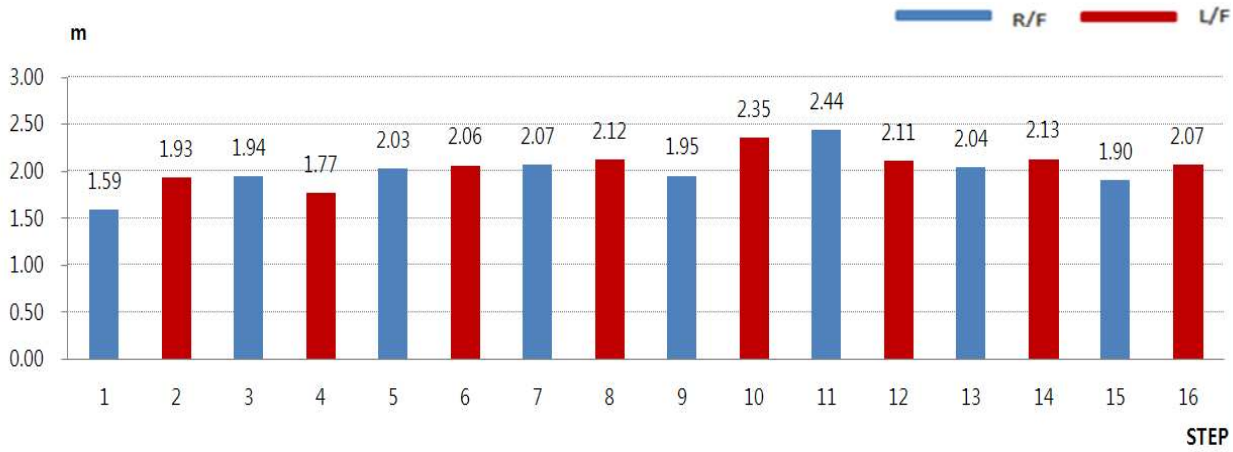


Figure 1. Step length during approach

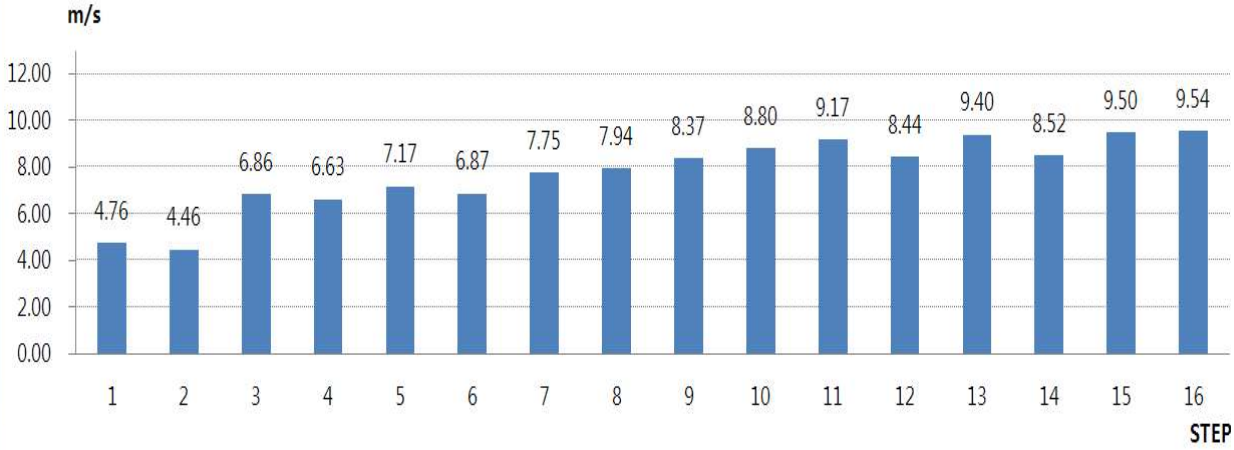


Figure 2. Velocity for each Step during approach

Lázaro BORGES 2nd 5.90m

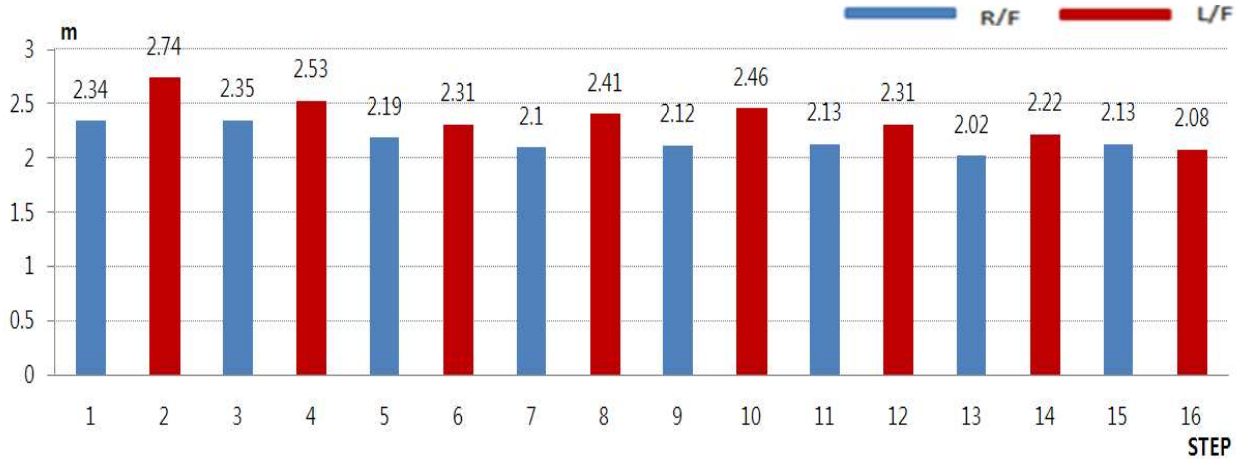


Figure 3. Step length during approach

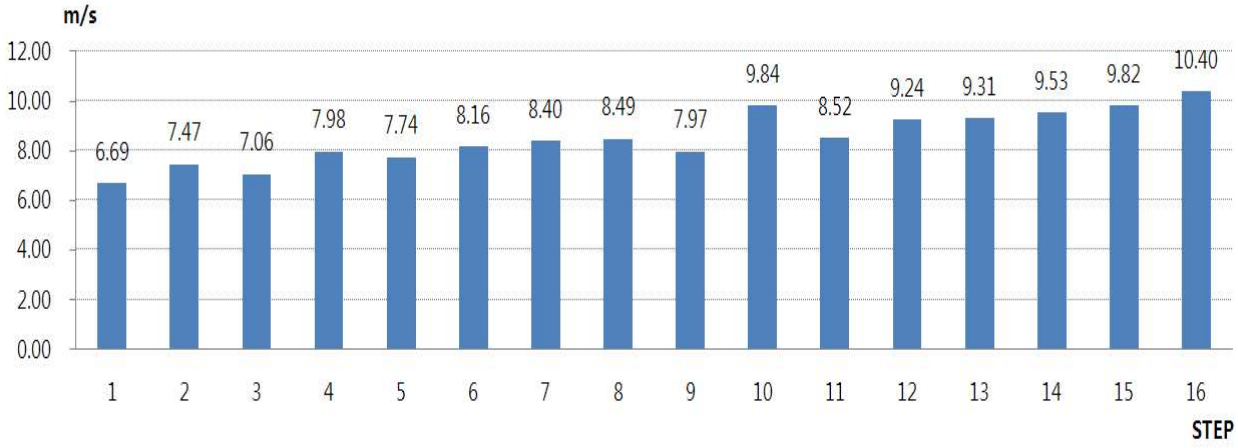


Figure 4. Velocity for each Step during approach

Renaud LAVILLENIE 3rd 5.85m

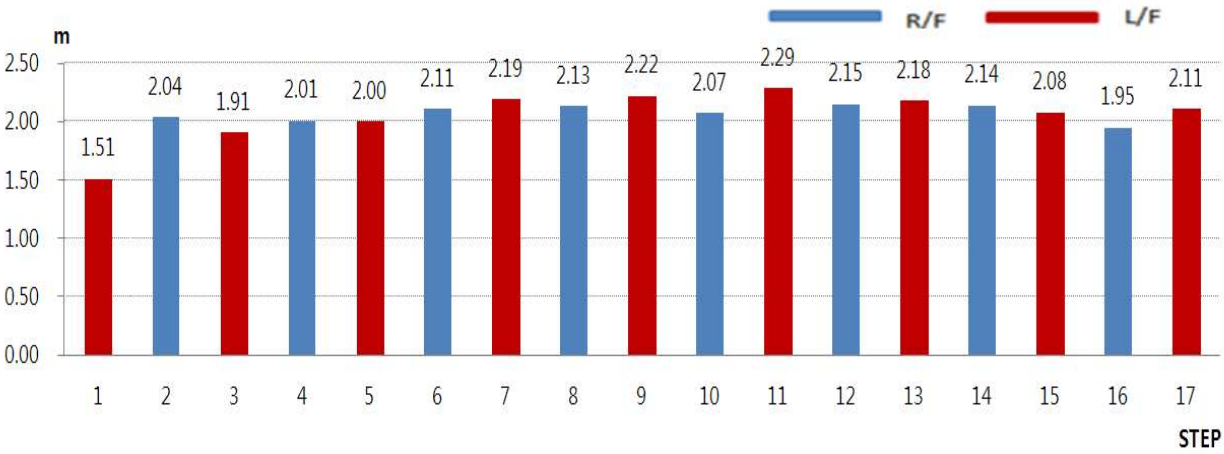


Figure 5. Step length during approach

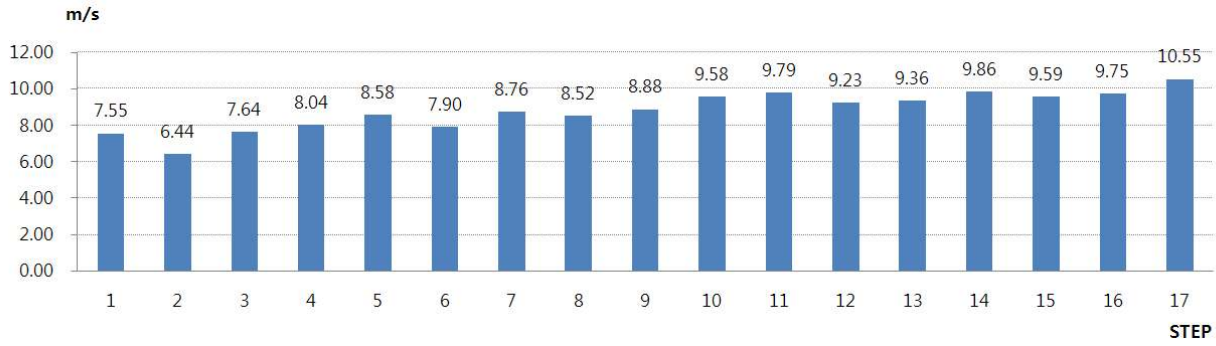


Figure 6. Velocity for each Step during approach

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

(Usain Bolt, JAM - 100M men's Semi Final)

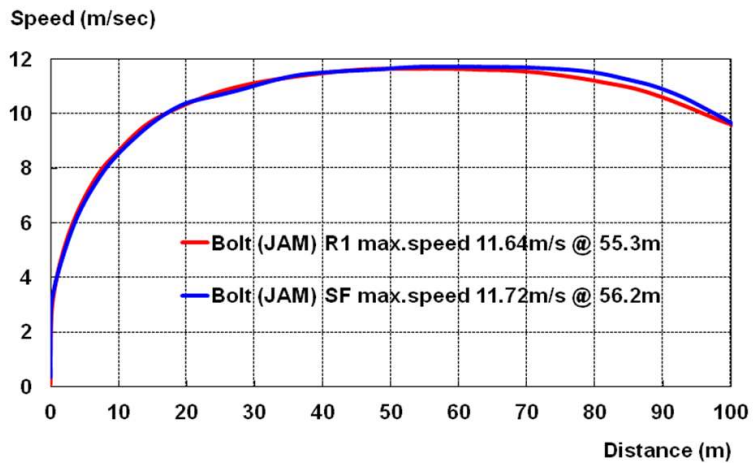
(August 29, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Usain Bolt 100 meter

	RANK / LANE	10m Avg. speed (m/sec)	20m Avg. speed (m/sec)	30m Avg. speed (m/sec)	40m Avg. speed (m/sec)	50m Avg. speed (m/sec)	60m Avg. speed (m/sec)	70m Avg. speed (m/sec)	80m /Avg. speed (m/sec)	90m Avg. speed (m/sec)	100m Avg. speed (m/sec)	Max speed (m/sec)	Distance at Max Speed	Total Time (sec)
Usain Bolt (JAM) - Round 1	1/6	5.30	9.63	10.78	11.31	11.59	11.64	11.59	11.38	10.94	10.12	11.64	55.27	10.10
Usain Bolt (JAM) - Semi Final	1/3	5.30	9.58	10.71	11.32	11.58	11.71	11.71	11.61	11.25	10.15	11.72	56.17	10.05

Speed Curve (Usain Bolt, JAM - 100M)



Scientific Research Project Biomechanical Analyses

at the IAAF World Championships Daegu 2011

- August 30, 2011 -

Scientific Research Project
Biomechanical Analyses
at the
IAAF World Championships Daegu 2011
(High Jump Men - Qualification Group A)
(August 30, 2011)

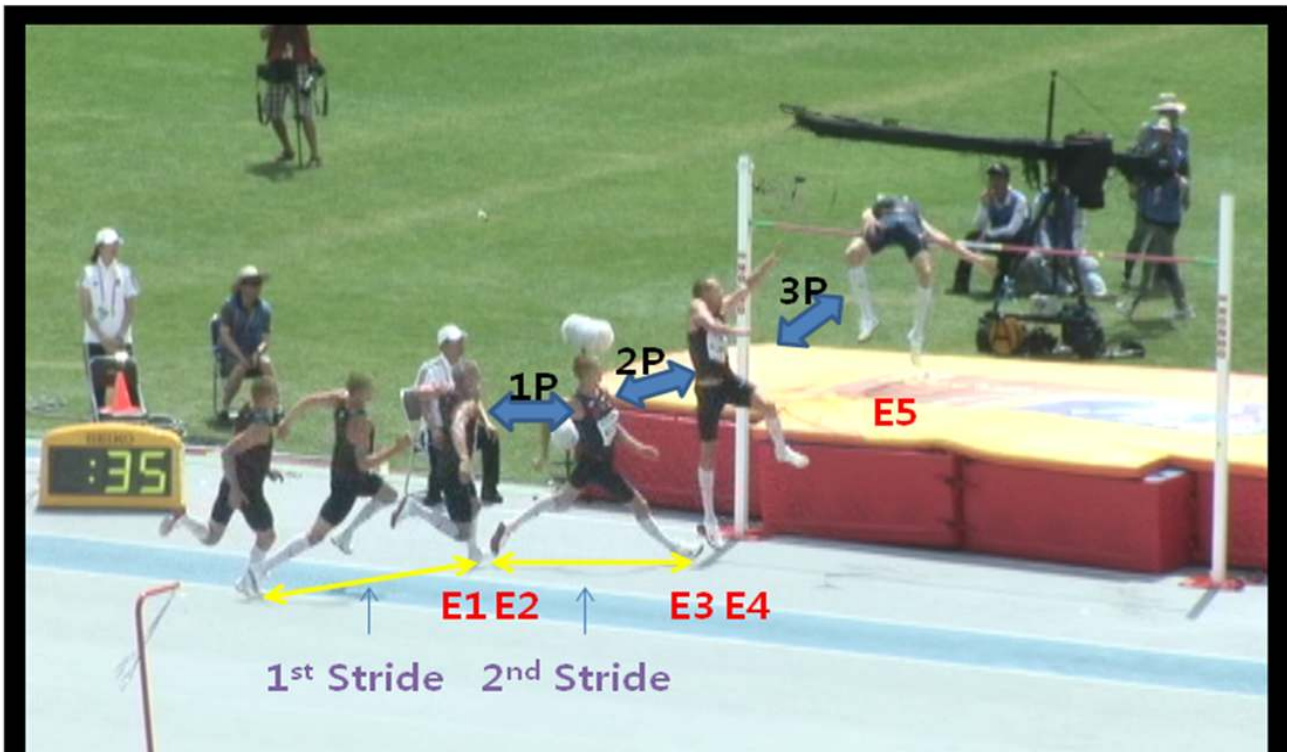
Korean Society of Sport Biomechanics

Biomechanical Analysis of the High Jump Men - Qualification

(Group A)

VARIABLE(unit)		Jesse Williams(USA)	Donald Thomas(BAH)	Dakvin Edwards(LCA)	Ye-Hwan Yun(KOR)
RESULT(m)		2.31	2.31	2.31	2.16
Time (sec.)	1Phase	0.15	0.20	0.16	0.12
	2Phase	0.17	0.17	0.19	0.14
	3phase	0.42	0.43	0.40	0.39
	1P : 2P(%)	47.3 : 52.7	53.5 : 46.5	46.1 : 53.9	46.6 : 53.4
Angle (degree)	Maximum flexion angle of the knee joint during stride	137.2	145.3	136.2	150.3
	Knee joint at 2nd touch(E3)	169.4	164.1	164.5	164.9
Relative Stride* (%)	1st stride	51.7	49.3	46.0	49.6
	2nd stride	48.3	50.7	54.0	50.4

*The ratio of stride length to result



Events & Phases

Stromotion (Jesse Williams, USA)

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

(Pole Vault Women - Final)

(August 30, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analyses of Women's Pole Vault (Final)

BIB	NAME	COUNTRY	Place	Season Best (m)	Record (m)	V_A* (m/s)*	Approach Position# (m)	Number of STEPs
175	Fabiana MURER	BRA	1	4.71	4.85	8.92	4.63	18
445	Martina STRUTZ	GER	2	4.78	4.80	8.57	4.60	16
754	Svetiana FEOFANOVA	RUS	3	4.71	4.75	8.61	4.54	18
758	Elena ISINBAEVA	RUS	6	4.76	4.65	8.41	4.13	16
Mean						8.62	4.48	

* V_A : 5 m Run-up velocity before takeoff

#AP : Take-off Position at the heel from the cut in box

Biomechanical Analyses of Women's Pole Vault (Final)

BIB	NAME	Variable						
		Total Approach Distance(m)	Approach Elapsed Time (Sec)	Avg. Approach Velocity (m/s)	Avg. Step length	Step Frequency (N/Sec)	Step Length (m)	Velocity for each step (m/s)
175	Fabiana MURER	32.79	5.24312`10	6.31	1.80	3.46	*Fig.1.	*Fig.2.
445	Martina STRUTZ	29.41	4.33	6.79	1.84	3.69	*Fig.3.	*Fig.4.
754	Svetiana FEOFANOVA	30.58	5.15	5.94	1.70	3.50	*Fig.5.	*Fig.6.
758	Elena ISINBAEVA	31.23	4.78	6.53	1.95	3.34	*Fig.7.	*Fig.8.
Mean		30.73	4.65	6.63	1.86	3.56		

Fabiana MURER(BRA) 1st 4.85m

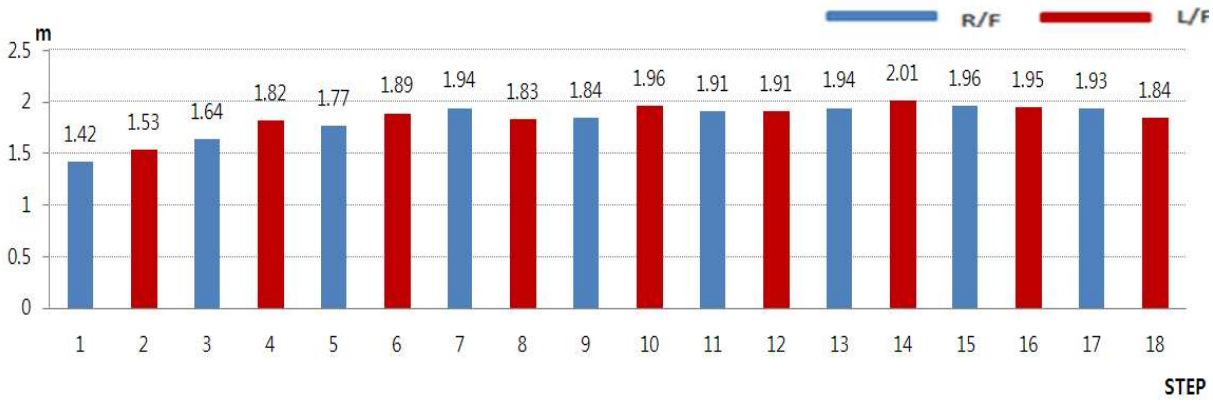


Figure 1. Step length during approach

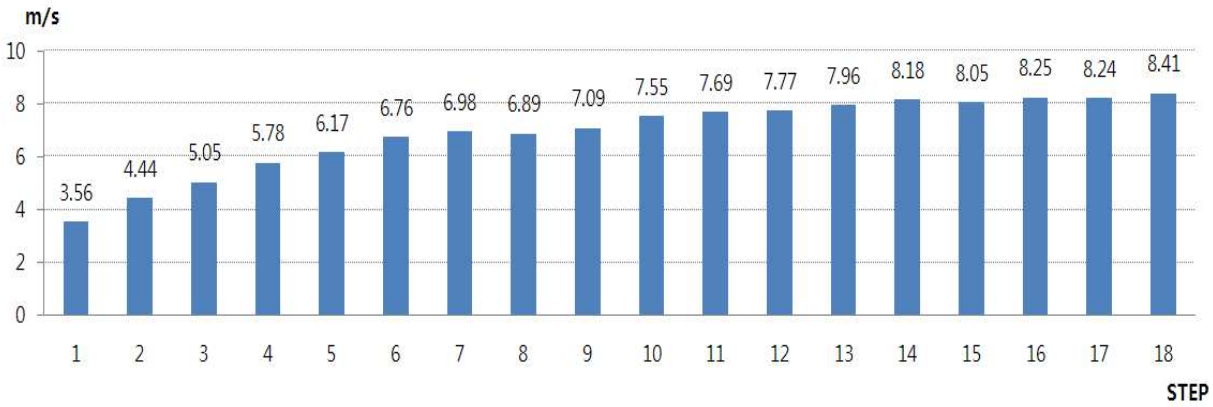


Figure 2. Velocity for each step during approach

Martina STRUTZ(GER) 2nd 4.80m

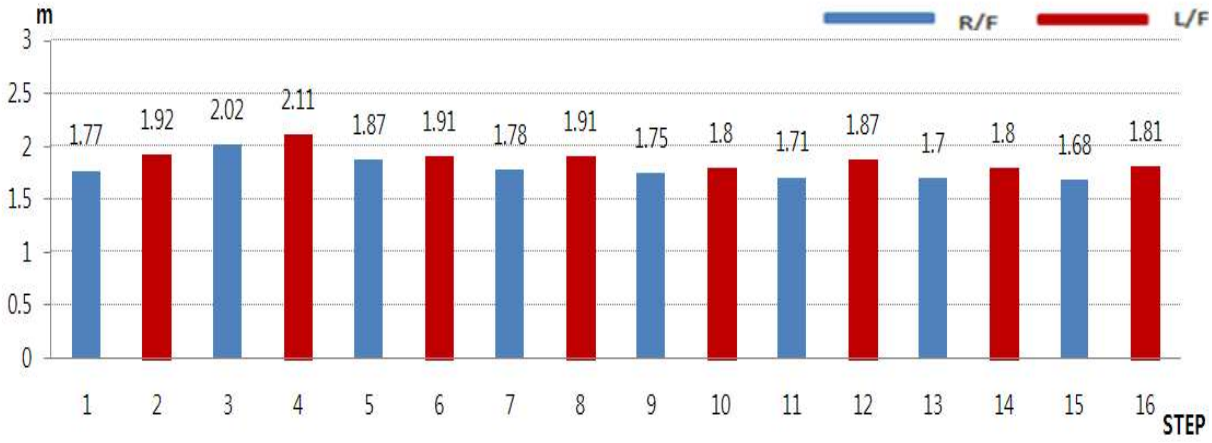


Figure 3. Step length during approach

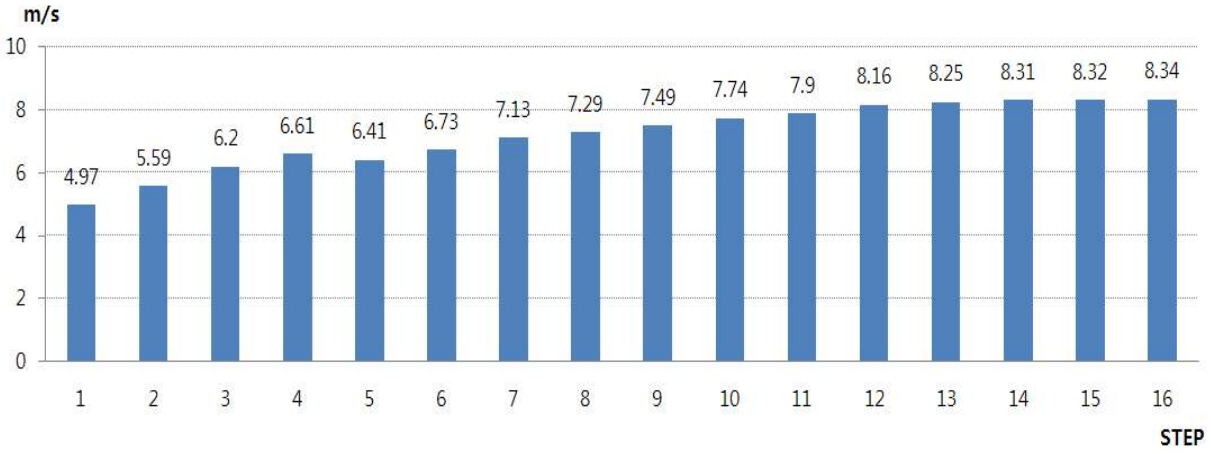


Figure 4. Velocity for each step during approach

Svetiana FEOFANOVA(RUS) 3rd 4.75m

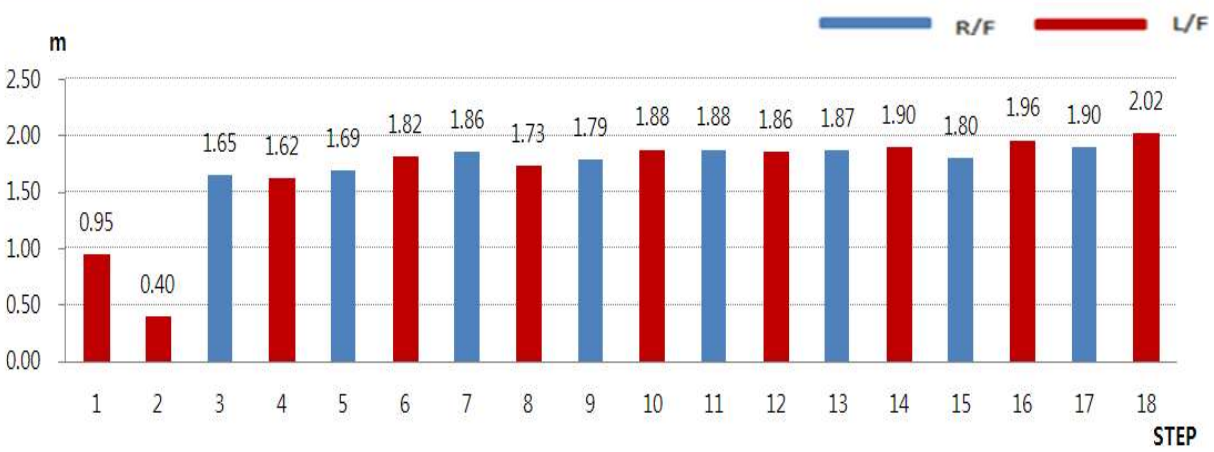


Figure 5. Step length during approach

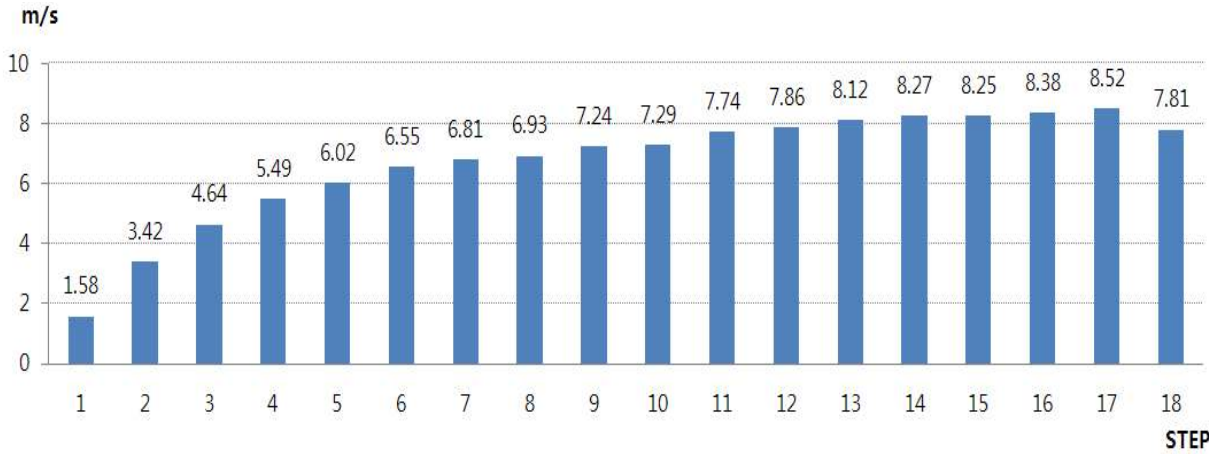


Figure 6. Velocity for each step during approach

Elena ISINBAEVA(RUS) 6th 4.65m

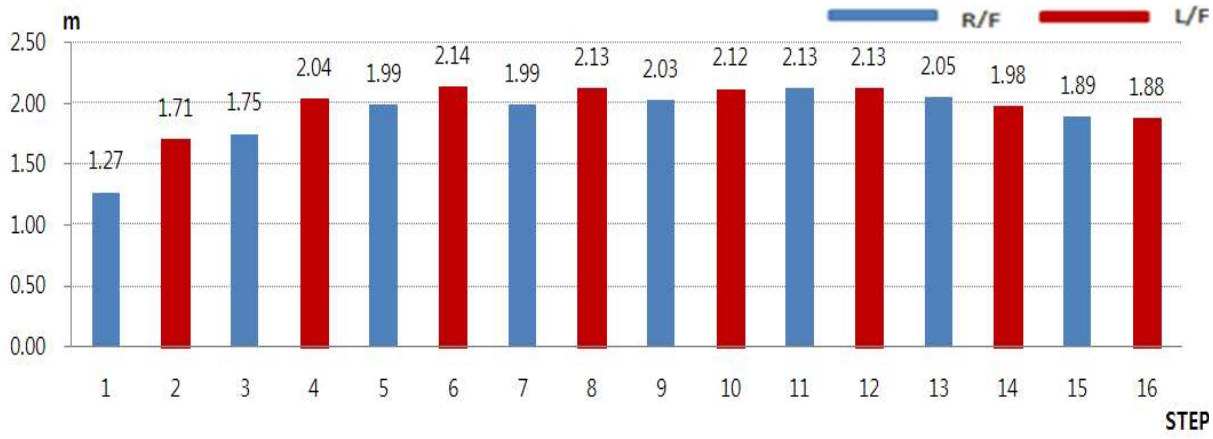


Figure 7. Step length during approach

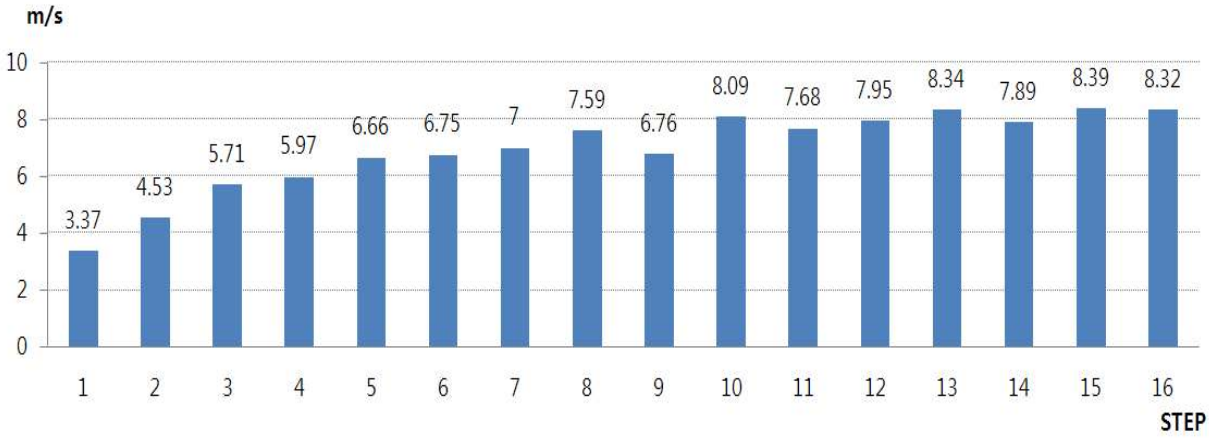


Figure 8. Velocity for each step during approach

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

(Women's Pole Vault)

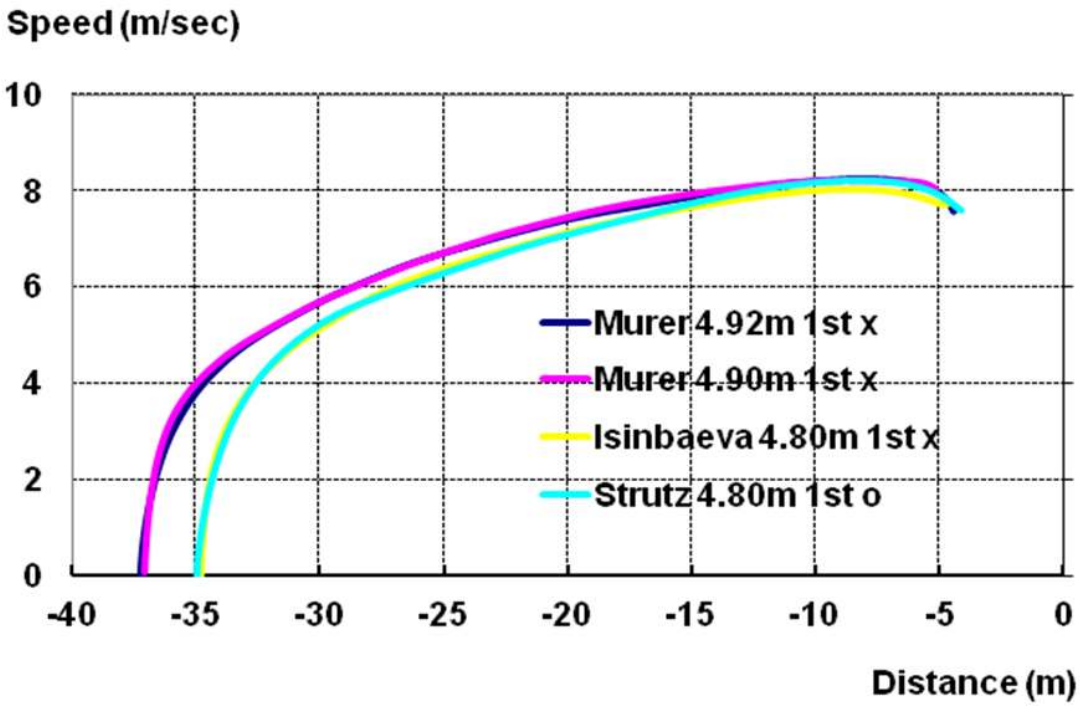
(August 30, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Women's Pole Vault (FINAL)

	Height (m)	Trial	Pass/Fail	-30m Average Speed (m/sec)	-20m Average Speed (m/sec)	-10m Average Speed (m/sec)	Maximum Speed (m/sec)	Distance (m)
Fabiana MURER (BRA)	4.90	1	Fail	5.69	7.40	8.20	8.25	-8.03
Fabiana MURER (BRA)	4.92	1	Fail	5.70	7.45	8.21	8.22	-8.78
Elena ISINBAEVA (RUS)	4.80	1	Fail	5.11	7.14	8.01	8.04	-8.62
Martina STRUTZ(GER)	4.80	1	Pass	5.20	7.07	8.15	8.20	-8.23

Speed Curve of Women's Pole Vault (FINAL)



Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

Triple Jump Women - Qualification (Mabel Gay)

(August 30, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of the Triple Jump Women

- Qualification (Mabel Gay)

Date : 30 August 2011

Name	Jump distance (m)	Stride length (m)				Relative dist. (%)		
		1L	Hop	Step	Jump	Hop	Step	Jump
Mabel GAY	14.53	2.13	5.41	4.24	4.88	37%	29%	34%

Name	Horizontal velocity (m/s)				Loss of horizontal velocity(m/s)			Vertical velocity (m/s)		
	1L	Hop	Step	Jump	Hop	Step	Jump	Hop	Step	Jump
Mabel GAY	8.86	7.79	7.34	6.07	0.95	0.38	0.85	2.09	1.65	2.5

Name	Angle of take-off (°)		
	Hop	Step	Jump
Mabel GAY	15.02	12.67	22.38

Scientific Research Project Biomechanical Analyses

at the IAAF World Championships Daegu 2011

- September 1, 2011 -

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

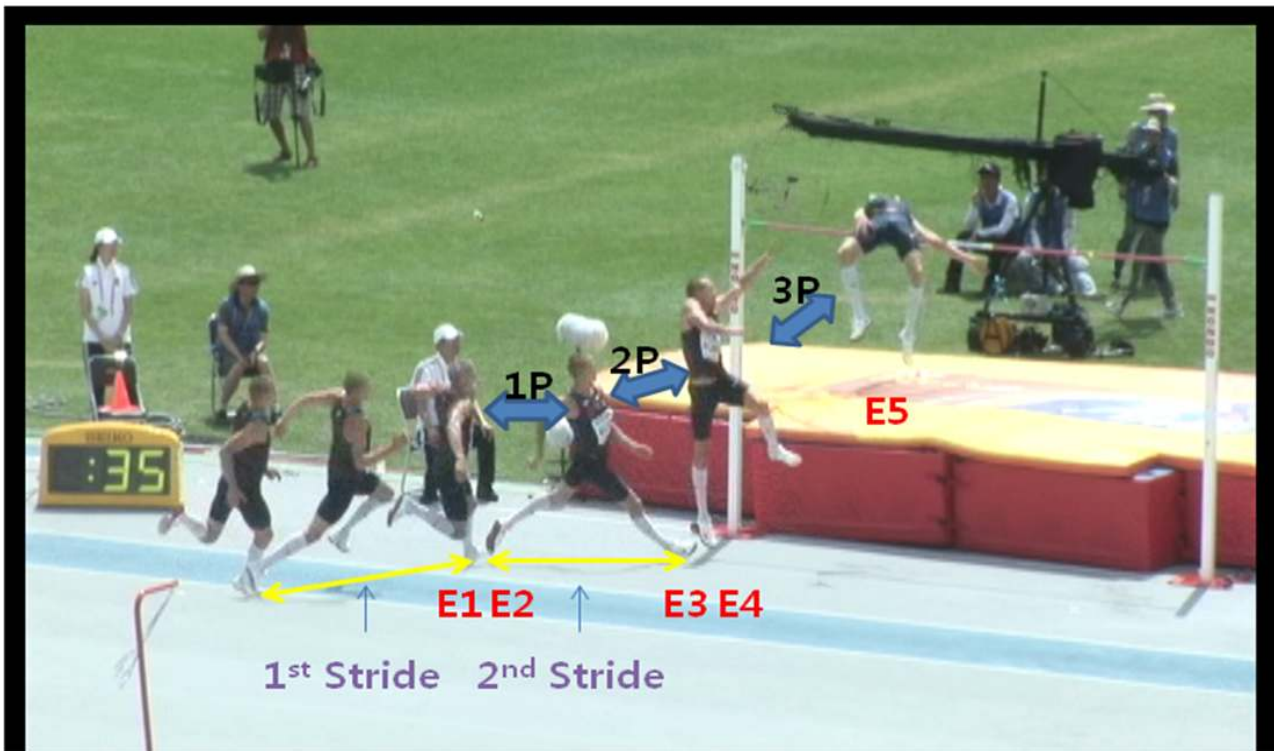
High Jump Men - Final

(September 1, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of the High Jump Men - Final

VARIABLE(unit)		Jesse Williams(USA)	Aleksey Dmitri(RUS)	Trevor Barry(BAH)
Result(m)		2.35	2.35	2.32
Analyzed attempt		1	2	1
Time	1Phase(sec.)	0.17	0.10	0.17
	2Phase(sec.)	0.16	0.15	0.20
	3phase(sec.)	0.43	0.42	0.42
	1 P : 2P(%)	51.5 : 48.5	40 : 60	45.9 : 54.1
angle	Maximum flexion angle of the knee joint during stride	138.1	149.0	123.1
	Knee joint at 2nd touch(E3)	171.1	169.3	171.8
Relative Stride* (%)	1st stride	54.6	52.3	51.2
	2nd stride	45.4	47.7	48.8



Event & Phase

Scientific Research Project
Biomechanical Analyses
at the
IAAF World Championships Daegu 2011
Shot Put Men - Qualification (Group A & Group B)
(September 1, 2011)

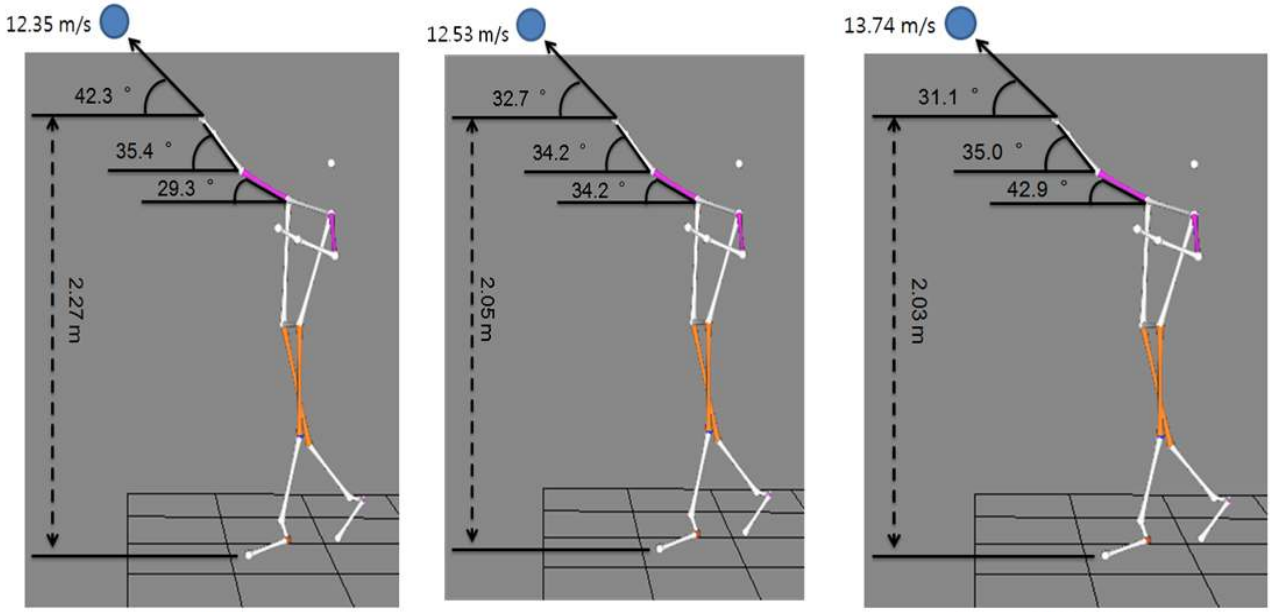
Korean Society of Sport Biomechanics

Biomechanical Analysis of Men's Shot put

Qualification (Group A & Group B)

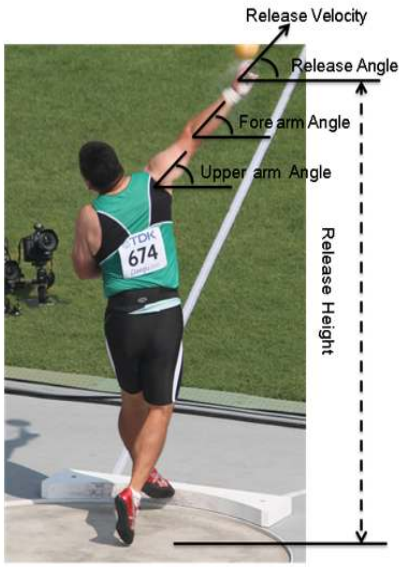
Rank	NAME	Results WCh(m)	SB before WCh(m)		Style
1.	David STORL(GER)	21.50	21.05	2.1%	glide
2.	Dylan ARMSTRONG(CAN)	21.05	22.21	-5.3%	changing
3.	Reese HOFFA(USA)	20.96	21.87	-4.3%	changing
4.	Andrei MIKHNEVIKI(BLR)	20.79	22.10	-6.3%	glide
5.	Ryan WHITING(USA)	20.77	21.76	-4.4%	changing
6.	Christian CANTWELL(USA)	20.23	21.87	-7.5%	changing
7.	Tomasz MAJEWSKI(POL)	20.73	21.60	-4.0%	glide
DQ.	In-Sung Hwang (KOR)	17.75	18.69	-5.0%	glide

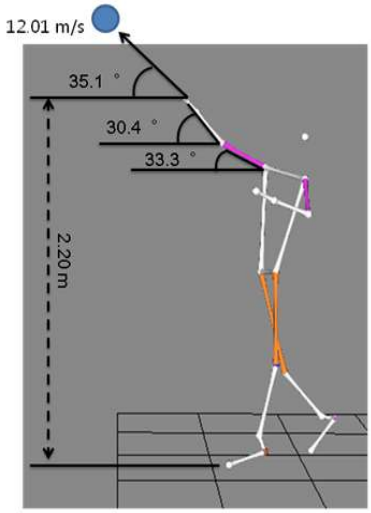
Rank	NAME	analyzed attempt	Results WCh(m)	release velocity (m/s)	release angle (deg.)	release height (m)	Inclination Angle (deg.)	
							Forearm	Upperarm
1.	David STORL(GER)	2	21.50	12.35	42.3	2.27	35.4	29.3
2.	Dylan ARMSTRONG(CAN)	2	21.05	12.53	32.7	2.05	34.2	34.2
3.	Reese HOFFA(USA)	1	20.96	13.74	31.1	2.03	35.0	42.9
DQ	In-Sung Hwang (KOR)	1	17.75	12.01	35.1	2.20	30.41	33.3



David STORL(GER) Dylan ARMSTRONG(CAN) Reese HOFFA(USA)

In-Sung Hwang Result 17.75m





In-Sung Hwang (KOR)

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

Triple Jump Women - Final

(September 1, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Triple Jump Women - Final

Rank	Name	Jump distance(m)	Stride length(m)				Relative dist.(%)		
			1L	Hop	Step	Jump	Hop	Step	Jump
1st	Olha SALADUHA (UKR)	14.94	2.14	5.72	4.19	5.03	38	28	34
2nd	Olga RYPAKOVA (KAZ)	14.89	2.71	5.4	4.17	5.32	36	28	36
3rd	Caterine IBARGUEN (COL)	14.84	2.13	5.46	4.25	5.13	37	29	34

Rank	Name	Horizontal velocity (m/s)				Loss of horizontal velocity(m/s)			Vertical velocity (m/s)			Angle of take-off(°)		
		1L	Hop	Step	Jump	Hop	Step	Jump	Hop	Step	Jump	Hop	Step	Jump
1st	Olha SALADUHA (UKR)	9.02	8.14	7.15	5.9	0.88	0.99	1.25	2.16	1.66	2.33	14.86	13.07	21.55
2nd	Olga RYPAKOVA (KAZ)	9.42	8.40	7.99	7.08	1.02	0.41	0.91	2.09	1.59	2.39	13.97	11.25	18.65
3rd	Caterine IBARGUEN (COL)	9.49	8.40	7.91	6.26	1.09	0.49	1.65	2.21	1.95	2.54	14.74	13.85	22.08

Scientific Research Project Biomechanical Analyses

at the IAAF World Championships Daegu 2011

- September 2, 2011 -

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

100 M Hurdle Women -Round 1

(September 2, 2011)

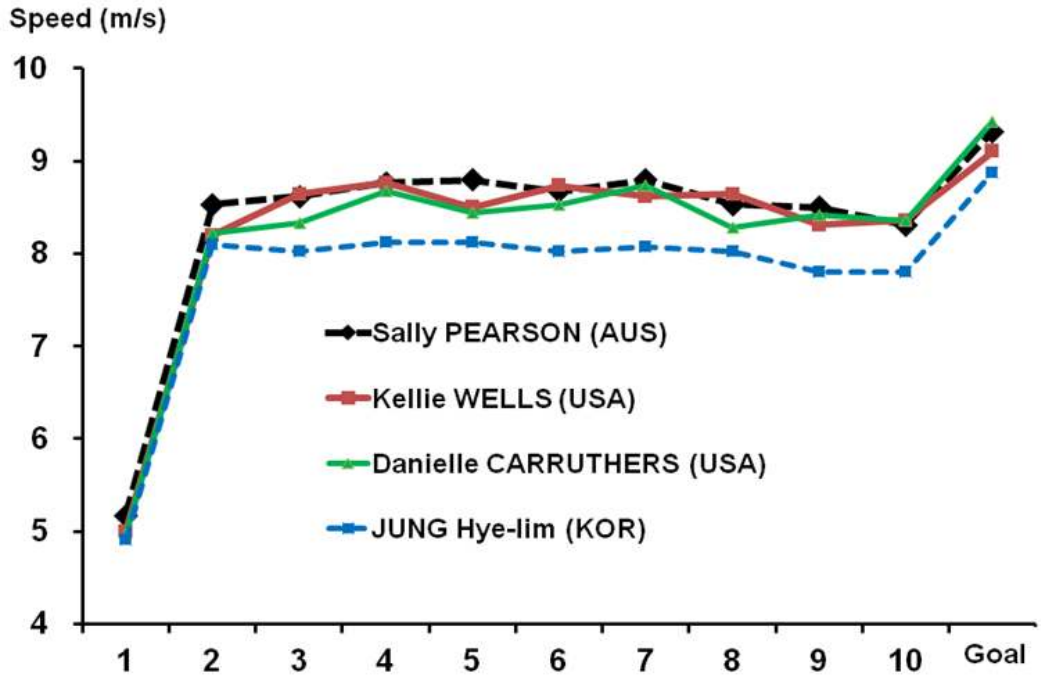
Korean Society of Sport Biomechanics

Biomechanical Analysis of Women's 100 meter Hurdle

(Round 1)

RANK	NAME	Parameter/ Hurdle	1 (0-13)	2 (-21.5)	3 (-30.0)	4 (-38.5)	5 (-47.0)	6 (-55.5)	7 (-64.0)	8 (-72.5)	9 (-81.0)	10 (-89.5)	Goal time	Avg. S (m/sec)
1	Sally PEARSON (AUS)	Spilt Time (sec)	2.52	3.51	4.50	5.47	6.44	7.42	8.38	9.38	10.38	11.40	**12.53**	
	Heat 2/5	Lap Time (sec)	2.52	1.00	0.99	0.97	0.97	0.98	0.97	1.00	1.00	1.02	1.13	
	Lane 2	Speed (m/sec)	5.17	8.53	8.61	8.76	8.79	8.67	8.79	8.53	8.50	8.31	9.32	**7.98**
2	Kellie WELLS (USA)	Spilt Time (sec)	2.60	3.64	4.62	5.59	6.59	7.57	8.55	9.54	10.56	11.58	**12.73**	
	Heat 1/5	Lap Time (sec)	2.60	1.04	0.98	0.97	1.00	0.97	0.99	0.98	1.02	1.02	1.15	
	Lane 1	Speed (m/sec)	5.17	8.53	8.61	8.76	8.79	8.67	8.79	8.53	8.50	8.31	9.32	**7.86**
3	Danielle CARRUTHERS (USA)	Spilt Time (sec)	2.61	3.65	4.67	5.65	6.65	7.65	8.62	9.65	10.66	11.68	**12.79**	
	Heat 4/5	Lap Time (sec)	2.61	1.03	1.02	0.98	1.01	1.00	0.97	1.03	1.01	1.02	1.11	
	Lane 2	Speed (m/sec)	4.97	8.23	8.33	8.67	8.44	8.53	8.73	8.28	8.42	8.36	9.43	**7.82**
28	JUNG Hye-lim (KOR)	Spilt Time (sec)	2.65	3.70	4.76	5.81	6.85	7.91	8.97	10.03	11.12	12.21	**13.39**	
	Heat 2/5	Lap Time (sec)	2.65	1.05	1.06	1.05	1.05	1.06	1.05	1.06	1.09	1.09	1.18	
	Lane 5	Speed (m/sec)	4.91	8.10	8.02	8.12	8.12	8.02	8.07	8.02	7.80	7.80	8.87	**7.47**

Speed Curve of Women's 100 meter Hurdle (1 Round)



Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

200 M Men - Semi Final

(September 2, 2011)

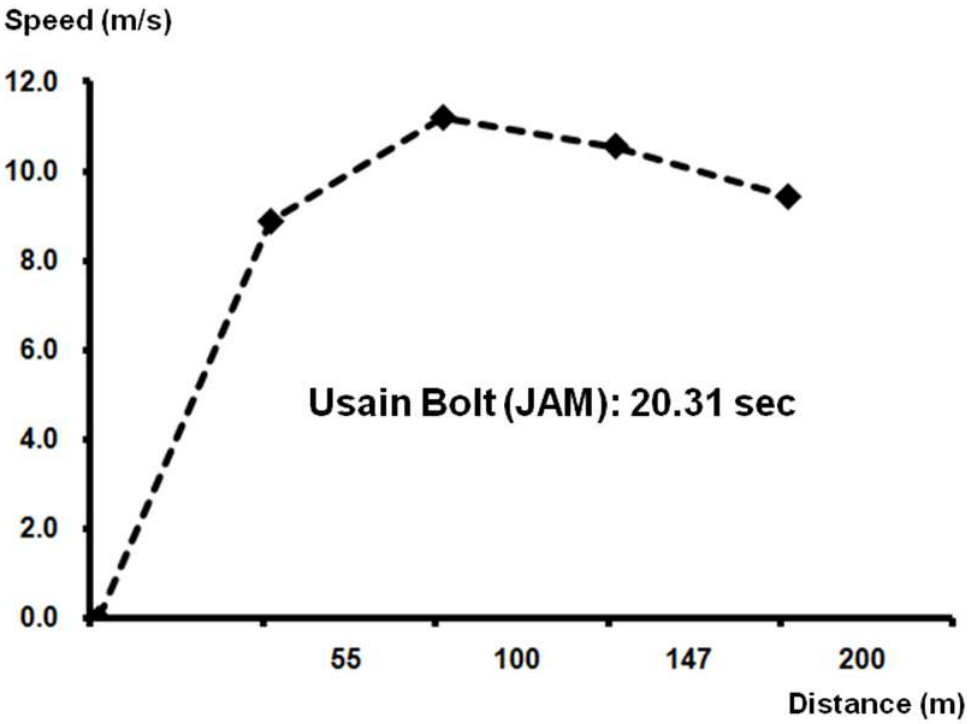
Korean Society of Sport Biomechanics

Biomechanical Analysis of Men's 200 meter

(Usain Bolt, Semi-Final)

RANK	Name	Parameter	0-55 m	-100 m	-147 m	-200 m
1	Usain Bolt (JAM)	Lap Time (sec)	6.20	10.23	14.68	**20.31**
	Heat 2	Spilt Time (sec)	6.20	4.02	4.46	5.63
	Lane 6	Avg. Speed (m/s)	8.87	11.18	10.55	9.42

Average Speed Curve (Usain Bolt, Semi-Final)



Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

200 M Women - Semi Final

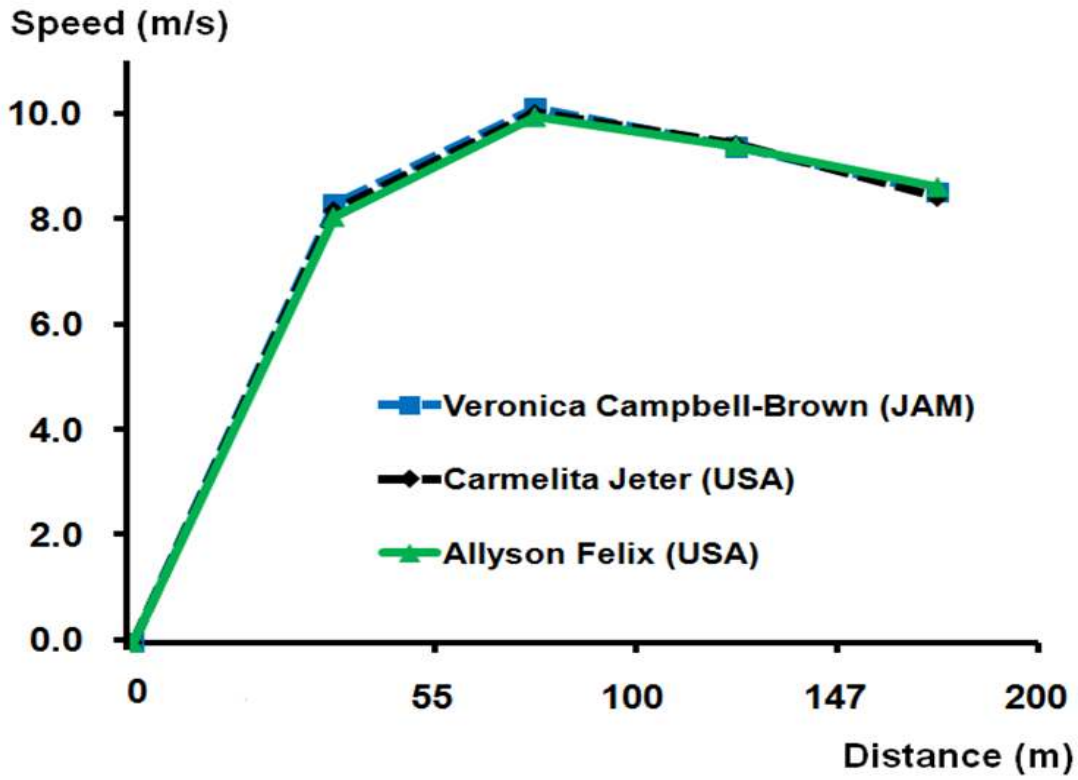
(September 2, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Women's 200 meter (Final)

RANK	Name	Parameter	55 m	100 m	147 m	200 m
1	Veronica Campbell-Brown (JAM)	Lap Time (sec)	6.60	11.03	16.02	**22.22**
	Lane 5	Spilt Time (sec)	6.60	4.43	4.99	6.20
		Avg. Speed (m/s)	8.34	10.15	9.41	8.55
2	Carmelita Jeter (USA)	Lap Time (sec)	6.69	11.15	16.11	**22.37**
	Lane 4	Spilt Time (sec)	6.69	4.47	4.95	6.26
		Avg. Speed (m/s)	8.22	10.08	9.49	8.46
3	Allyson Felix (USA)	Lap Time (sec)	6.80	11.31	16.29	**22.42**
	Lane 3	Spilt Time (sec)	6.80	4.51	4.98	6.13
		Avg. Speed (m/s)	8.08	9.98	9.43	8.65

Average Speed Curve (Women's 200 m Final)



Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

Javelin Throw Women - Final

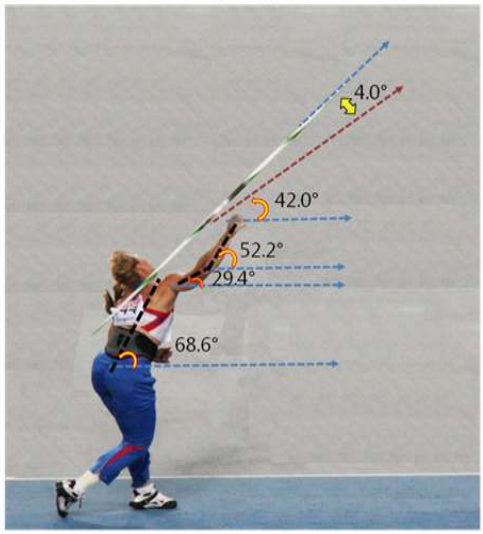
(September 2, 2011)

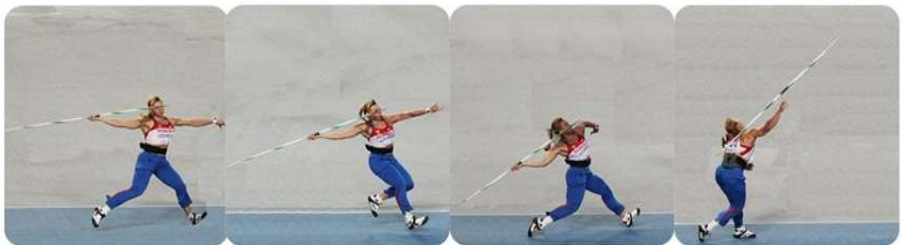
Korean Society of Sport Biomechanics

Biomechanical Analysis of Javelin Throw Women - Final

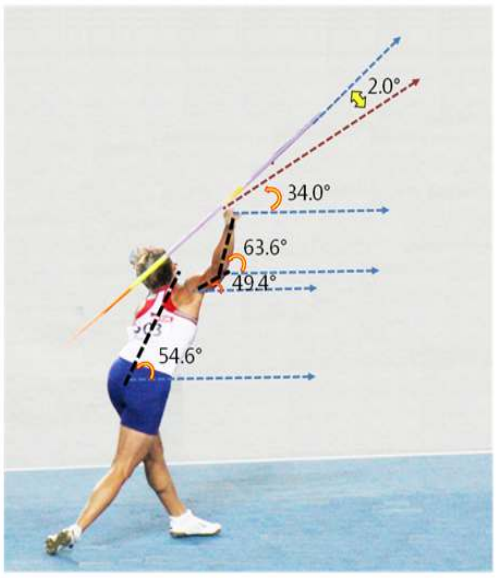
athlete		Result (m)	Release velocity (m/s)	Release height (m)	Angle at release (deg)			Inclination angle (deg)			Distance (m)			Duration (ms)		
													Foul line			
Maria ABAKUMOVA (RUS)	5	71.99	25.1	1.65	46.0	42.0	4.0	68.6	29.4	52.2	1.84	1.39	1.87	270	240	120
Barbora SPOTAKOVA (CZE)	5	71.58	22.9	1.87	32.0	34.0	2.0	54.6	49.4	63.6	1.49	1.48	3.59	300	186	147
Sunette VILJOEN (RSA)	5	68.38	24.4	1.71	44.0	32.0	12.0	51.4	51.9	78.5	1.59	1.41	0.95	327	166	84
Mean		70.65	24.1	1.70	40.7	36.0	6.0	58.2	43.6	64.8	1.60	1.40	2.10	299	197	117

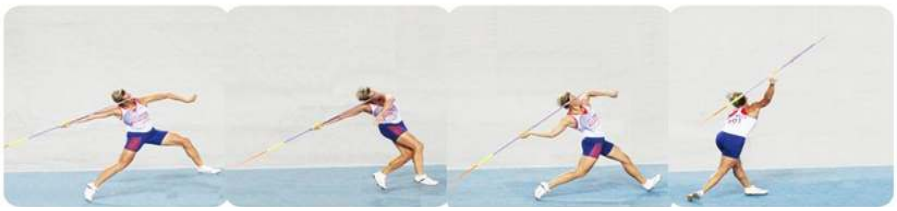
Maria ABAKUMOVA (RUS) 1st 71.99 m



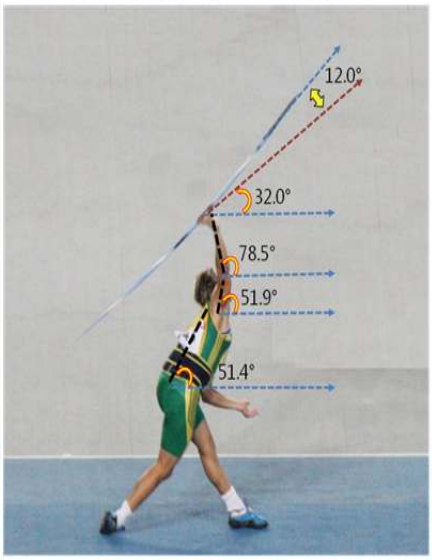


Barbora SPOTAKOVA (CZE) 2nd 71.58 m





Sunette VILJOEN (RSA) 3rd 68.38 m



Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

Long Jump Men - Final

(September 2, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Long Jump Men - Final

VARIABLE (unit)		Dwight PHILLIPS (USA) 1st Place	Mitchell WATT (AUS) 2nd Place	Ngonidzashe MAKUSHA (ZIM) 3rd Place
RESULT (m)		8.45	8.33	8.29
Stride Length	3Last (m)	2.13	2.34	2.21
	2Last (m)	2.37	2.53	2.58
	1Last (m)	1.99	2.42	2.22
	Relative Length 2Last/3Last (%)	111	108	117
	Relative Length 1Last/2Last (%)	84.0	96	86
Velocity	Horizontal Vel. at Touch Down (m/s)	10.31	10.34	10.59
	Horizontal Vel. at Take-off (m/s)	9.21	8.42	9.59
	Loss of Horizontal Vel. During Ground Contact (m/s)	1.10	1.92	1.0
	Vertical Velocity at Take-off (m/s)	3.35	3.73	3.13
	Resultant Velocity at Take-off (m/s)	9.80	9.22	10.09
Take-off	Take-off Angle (deg)	20.0	23.9	18.1
	Vertical Height of CoM (m)	1.22	1.33	1.16
	Take-off Distance (m): Horizontal Position of CoM Relative to Foot	0.55	0.5	0.36

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

Shot Put Men - Final

(September 2, 2011)

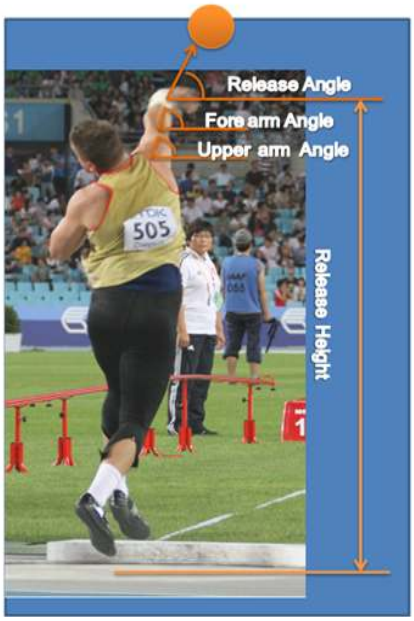
Korean Society of Sport Biomechanics

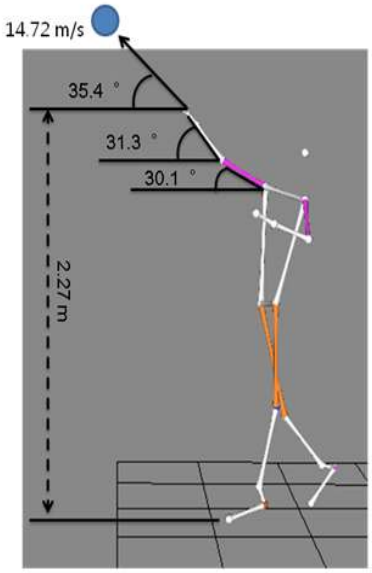
Biomechanical Analysis of M en's Shot put - Final

Rank	NAME	Results WCh (m)	SB before WCh (m)		Style
1.	David STORL(GER)	21.78	21.05	3.4	glide
2.	Dylan ARMSTRONG(CAN)	21.64	22.12	- 2.2	changing
3.	Andrei MIKHNEVIKI(BLR)	21.40	22.10	- 3.2	glide
4.	Christian CANTWELL(USA)	21.36	21.87	- 2.4	Changing
5.	Reese HOFFA(USA)	20.99	21.87	- 4.1	changing
6.	Marco FORTES(POR)	20.83	20.89	- 0.3	Changing
7.	Ryan WHITING(USA)	20.75	21.76	- 4.7	Changing
8	Adam NELSON(USA)	20.29	22.09	- 8.2	changing

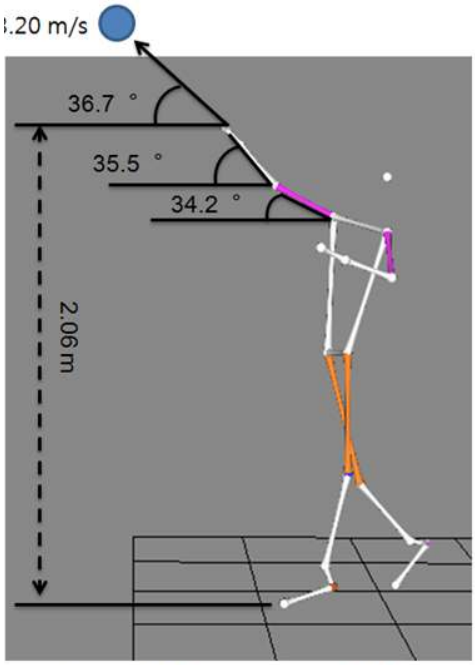
Rank	NAME	analyzed attempt	Results WCh (m)	release velocity (m/s)	release angle (deg.)	release height (m)	Inclination Angle (deg.)	
							Forearm	Upperarm
1.	David STORL(GER)	6	21.78	14.72	35.4	2.27	31.3	30.1
2.	Dylan ARMSTRONG(CAN)	4	21.64	13.20	36.7	2.06	35.5	34.2
3.	Andrei MIKHNEVIKI(BLR)	3	21.40	13.73	38.5	2.34	37.4	36.5

David STORL(GER) Result 21.78 m

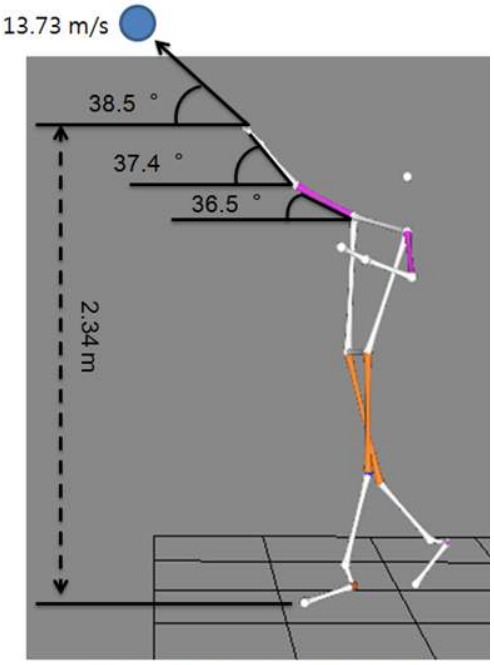




David STORL(GER)



Dylan ARMSTRONG(CAN)



Andrei MIKHNEVIKI(BLR)

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

Triple Jump Men - Final

(September 2, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Triple Jump Men

Qualification Group A

Rank	Name	Jump distance(m)	Stride length(m)				Relative dist.(%)		
			1L	Hop	Step	Jump	Hop	Step	Jump
1st	Will Claye (USA)	14.94	2.17	5.54	5.50	6.15	32	32	36

Rank	Name	Horizontal velocity (m/s)				Loss of horizontal velocity(m/s)			Vertical velocity (m/s)			Angle of take-off (°)		
		1L	Hop	Step	Jump	Hop	Step	Jump	Hop	Step	Jump	Hop	Step	Jump
1st	Will Claye (USA)	10.26	9.66	8.63	7.09	0.6	1.03	1.54	1.77	2.26	2.85	10.4	14.7	21.9

Scientific Research Project Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

- September 3, 2011 -

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

200 M Women - Final

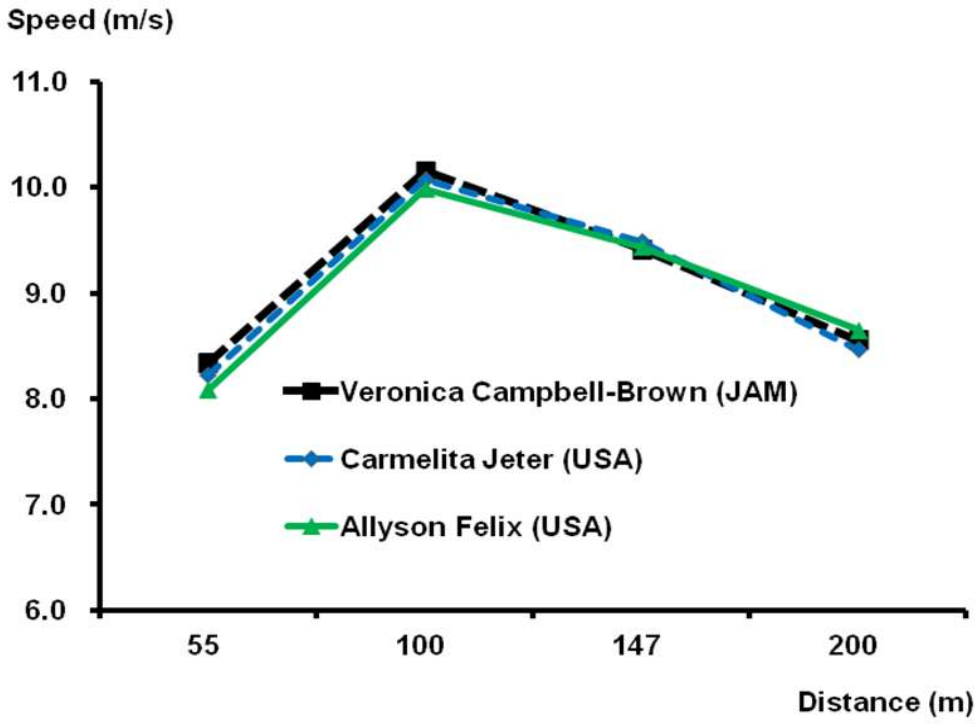
(September 3, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of Women's 200 meter (Final)

RANK	Name	Parameter	55 m	100 m	147 m	200 m
1	Veronica Campbell-Brown (JAM)	Lap Time (sec)	6.60	11.03	16.02	**22.22**
	Lane 5	Spilt Time (sec)	6.60	4.43	4.99	6.20
		Avg. Speed (m/s)	8.34	10.15	9.41	8.55
2	Carmelita Jeter (USA)	Lap Time (sec)	6.69	11.15	16.11	**22.37**
	Lane 4	Spilt Time (sec)	6.69	4.47	4.95	6.26
		Avg. Speed (m/s)	8.22	10.08	9.49	8.46
3	Allyson Felix (USA)	Lap Time (sec)	6.80	11.31	16.29	**22.42**
	Lane 3	Spilt Time (sec)	6.80	4.51	4.98	6.13
		Avg. Speed (m/s)	8.08	9.98	9.43	8.65

Average Speed Curve (Women's 200 m Final)



Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

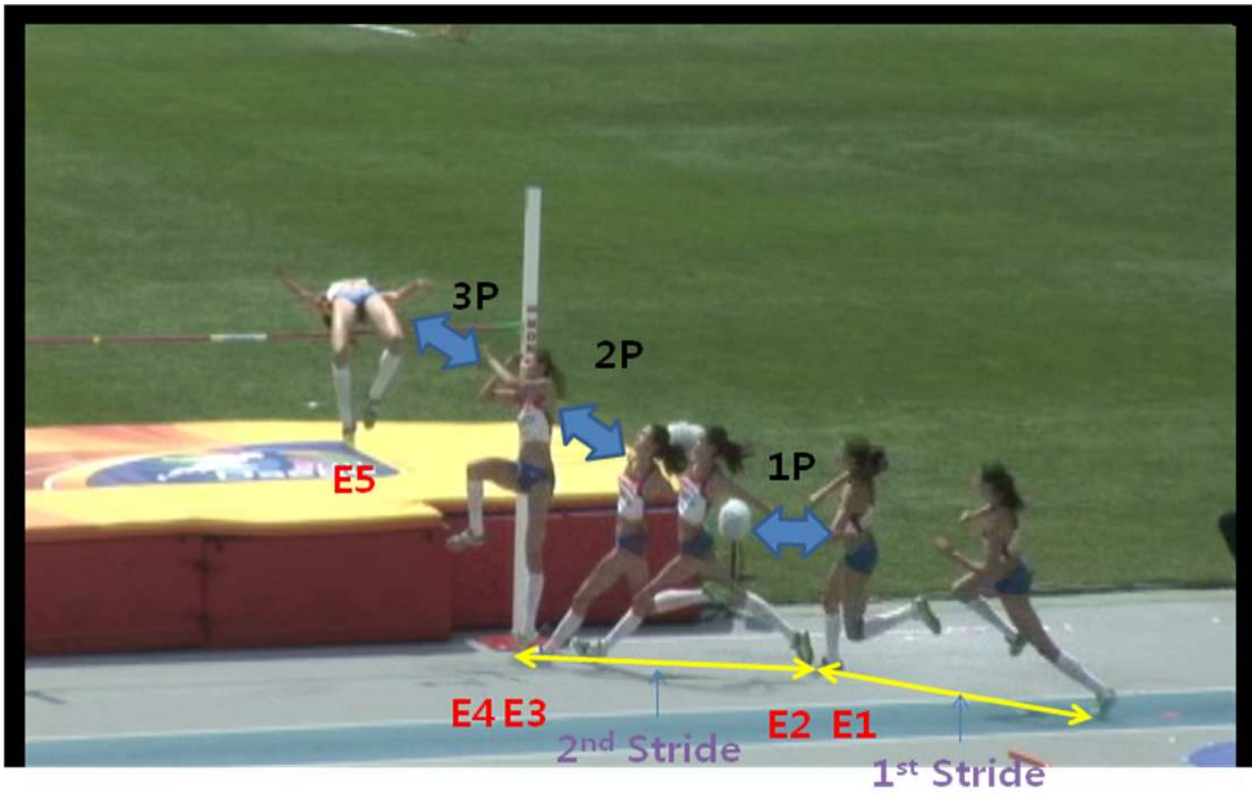
High Jump Women - Final

(September 3, 2011)

Korean Society of Sport Biomechanics

Biomechanical Analysis of the High Jump Women - Final

VARIABLE(unit)		Anna Chicherova(RUS)	Blanka Vlasic(CRO)
RESULT(m)		2.03	2.03
Time (sec.)	1Phase	0.15	0.13
	2Phase	0.18	0.17
	3phase	0.33	0.33
	1P : 2P(%)	45.5 : 54.5	43.3 : 56.7
Angle (degree)	Maximum flexion angle of the knee joint during stride	135.3	144.1
	Knee joint at 2nd touch(E3)	166.4	167.3
Relative Stride* (%)	1st stride	52.2	49.3
	2nd stride	47.8	50.7



Event & Phase

Anna Chicherova(RUS)

Scientific Research Project

Biomechanical Analyses

at the

IAAF World Championships Daegu 2011

Javelin Throw Men - Final

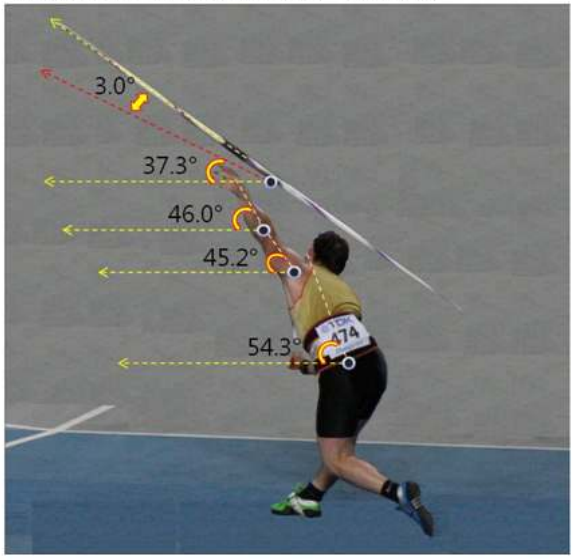
(September 3, 2011)

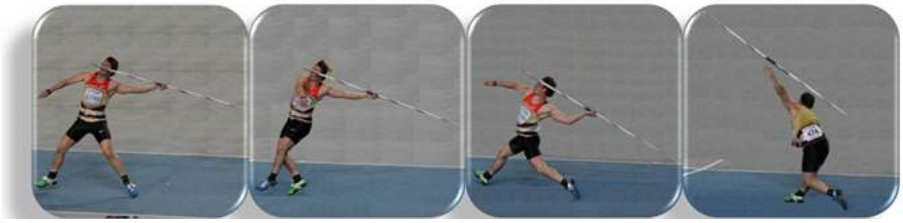
Korean Society of Sport Biomechanics

Biomechanical Analysis of Javelin Throw Men - Final

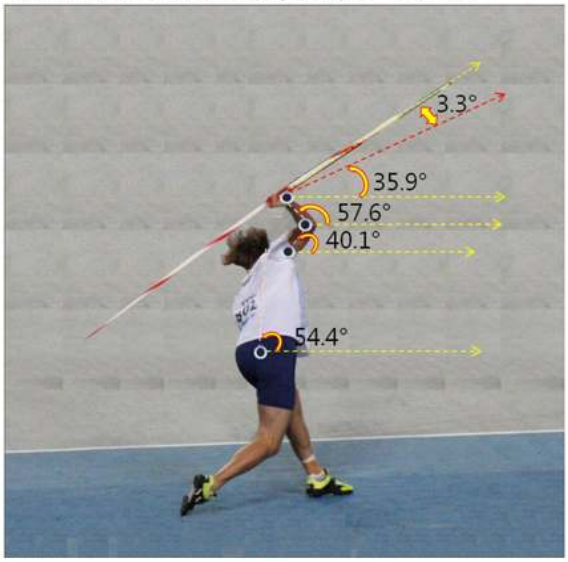
athlete		Result (m)	Release velocity (m/s)	Release height (m)	Angle at release (deg)			Inclination angle (deg)			Distance (m)			Duration (ms)		
Matthias de Zordo (GER)	1	86.27	29.3	1.91	40.3	37.3	3.0	54.3	45.2	46.0	1.96	1.71	1.63	366	253	136
Andreas Thorkildsen (NOR)	4	84.78	29.2	1.83	39.2	35.9	3.3	54.4	40.1	57.6	2.08	1.56	1.29	400	167	107
Guillermo Martinez (CUB)	1	84.30	28.5	1.87	38.2	38.7	0.5	43.9	31.3	43.1	2.03	1.47	3.48	443	237	130
Mean		85.12	29.0	1.87	39.2	37.3	2.3	50.9	38.9	48.9	2.02	1.58	2.13	403	219	124

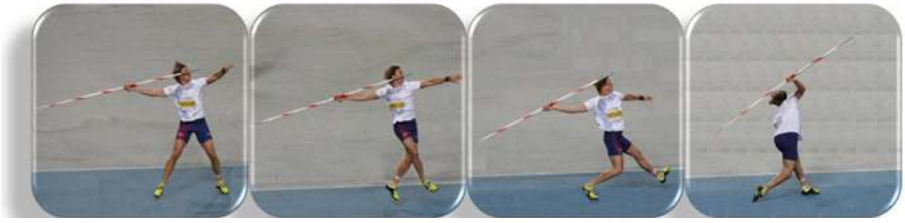
Matthias DE ZORDO(GER) 1st 86.27 m





Andreas THORKILDSEN(NOR) 2nd 84.78 m





Guillermo MART'INEZ(CUB) 3rd 84.30 m