Development of Kinematic Analysis Methods and its Application for Technique Training of Elite Sports in Hong Kong

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CONTENT

I. ABSTRACT

The purpose of this study is to create biomechanical profiles of specific sports techniques performed by Hong Kong elite athletes. The formation of these profiles are based on the kinematic information generated from two dimensional and/or three dimensional video filming.

This biomechanical profiles consist of data in time, displacement, velocity and acceleration of the body parts, and the corresponding sports equipment, such as squash racket and ball. This biomechanical analysis aids in improving athletes' performances in three ways:

1. Enabling them to compare their own biomechanical features with those of their world top counterparts. Thus technical differences can be objectively revealed.
2. Evaluating their technique improvement upon comparing the biomechanical features of a series of trials performed by the athletes themselves.
3. Building up of models optimal motion technique upon analysing the techniques on biomechanical perspectives.

The research team successfully selected some specific and essential techniques from various sports events in Hong Kong. For the technique analysis, high speed video filming was done, and then the video materials were processed by the Peak motion analysis system. The biomechanical profiles were used to compare the previous trials and the profiles of same techniques performed by top world class athletes. In addition, , the video materials were notated, and then statistically compared with the world's top athletes for the game strategy analysis. The accomplishment was technically successful, and the implication and application were very appreciated by the athletes and coaches concerned. Further investigation of other sports techniques using similar approach can obtained more comprehensive results analysis.

II. INTRODUCTION

Correct execution of body movement leads to a successful sports performance. Only sports biomechanics that can provide valuable kinematic information of sports movements. In countries, such as United States, Australia and Germany, where sports and sports science are well developed, the study of sports biomechanics has already been proved as a major scientific tool for the innovation of techniques and thus achievement in performance.

Biomechanical service for the elite sports has just started in Hong Kong. Coaches and athletes were the first the parties to benefit from it, and a lot has been and yet to be achieved. All in all, biomechanical motion analysis has been proved to be very helpful in boosting athletes' performance.

Biomechanical profiles generated from motion analysis system are used by coaches in determination of optimum techniques for the of individual athletes. With these profile, coaches can integrate the important mechanics aspects and individual characteristics, thus giving best possible suggestion on techniques and training routines in skills and specific sport related-fitness. Through analysis of motion, a correct and safe motion pattern can be generated. The possibilities of sport injuries can thus be greatly reduced. Together with Cybex muscle training data, recommendation on the design of individualised strength training program can be made.

Strategy and tactics employed in game sports are usually examined by means of notational analysis. The notations of player, action, position of the action, and/or outcomes of rallies can be made in real-time analysis to provide immediate feedback or in post-event analysis to provide more accurate and comprehensive information (Hughes, 1995). The increasing sophistication and reducing cost of video system have greatly enhanced post-event analysis: the sequential skill performances are recorded on film or video, analyzed post event, and then summarized statistically. During the video analysis, the player's motion is broken down, the frequency and/or timing of a particular shot, and the success or failure of that shot is determined. Based on this information, the strength and weakness of a player and of his/her opponent can be effectively evaluated (Clark, 1979).

Throughout the process of the study, continuous interactions with coaching personnel were being undergone. This was to ensure relevant information be generated, applied and perceived by coaches, athletes and person concerned.

III. ACHIEVEMENT IN METHODOLOGY AND TECHNOLOGY

For technique analysis, the Peak Motion Measurement System was the main tool for data acquisition from the video tapes. However, the software allows only stationary camera position so that the shooting range is confined. To overcome this problem, by using computer language PASCAL to develop computer program to correct the 2-D data, shooting was performed with panning and tilting. Also this program combine the 2-D data when shooting was performed with two separate cameras, provided that calibration marks were correctly set on the side of the motion plane. With this break through, even large motion range events, such high jump, triple jump and 100m sprint, makes possible.

With the utilisation of synchronisation signal generator for 3-D video filming, the application for studying high jump, badminton smash and squash stroke, etc. has been enhanced. It is the first time, that 3-D video filming and kinematics analysis were conducted for the player's performance in the international competition.

For game strategy analysis of squash, this study profiled and compared strategy and tactics employed by Hong Kong elite players and world's top players through collection of information out of the recorded video material according to a specially designed classification program. This classification program includes working procedure, protocol and criteria for various types and effectiveness categories of shots, as well as court positions.

IV. APPLICATION OF BIOMECHANICAL ANALYSIS IN TECHNIQUE TRAINING OF ELITE SPORTS IN HONG KONG

Sub-project 1 : Biomechanical Study on High Jumping Technique and Training Program of Chang Yu Ho, the Elite High Jump Athlete of Hong Kong

Introduction

Chang Yu Ho is one of the elite high jump athletes of the 'Hong Kong Track and Field elite development scheme". In recent years, Chang had a progressive improvement in his high jumping performance and has represented Hong Kong in numerous international competitions. He made a new Hong Kong men high jump records of 2.13 m and 2.15 m in two international high jump competitions held in Philippine and Canada in May and August of 1994 respectively.

Chang has a great potential to be a high jump athlete. In order to further improve his high jump techniques, Xu Zhao Sheng , Chang's coach, has cooperated with the sports biomechanists of the Hong Kong Sports Institute (HKSI) to set up a long-term training programs for Chang since 1992. The aim of this program is to apply the biomechanical principles into his training programs. In 1994, Professor Lu Yu Lin, Guangzhou Institute of Physical Education, and Jiang Chong Shang, Shandong high jump head coach, were invited to prescribe and arrange training programs for Chang which progressed his performance to a new peak.

The purpose of this project is to profile the high jump technique of Hong Kong elite high jump athlete through biomechanical methods and to develop the training programs which lead to performance improvement.

Method

3-dimensional filming method was employed in which two cameras were placed separately at the starting position of approach and the take-off position (Figure 1). The camera were horizontally panned to capture the motion of the last three strides of approach, take-off and bar clearance. The recorded movements were digitalized and analyzed by the Peak Performance System. The anatomical landmarks and joint centers for digitization were the right and left sides of: toes, heels, ankles, knees, hips, waists, shoulders, elbows, wrists, ears, and middle neck. The filming frequency was 50 Hz and the shuttle speed was 1/500s. The date, venues and results etc. were presented in Table1.

Several international top high jump athletes': (1) Zhu Jian Hua (China), (2) Conway (USA), and (3) the top eight high jump athletes of the 1988 Olympics Games were selected for performance analysis. After their results and techniques were analyzed, comparisons were made with that of Chang's.

Figure 1 : Arrangement and Placement of the Two Cameras.

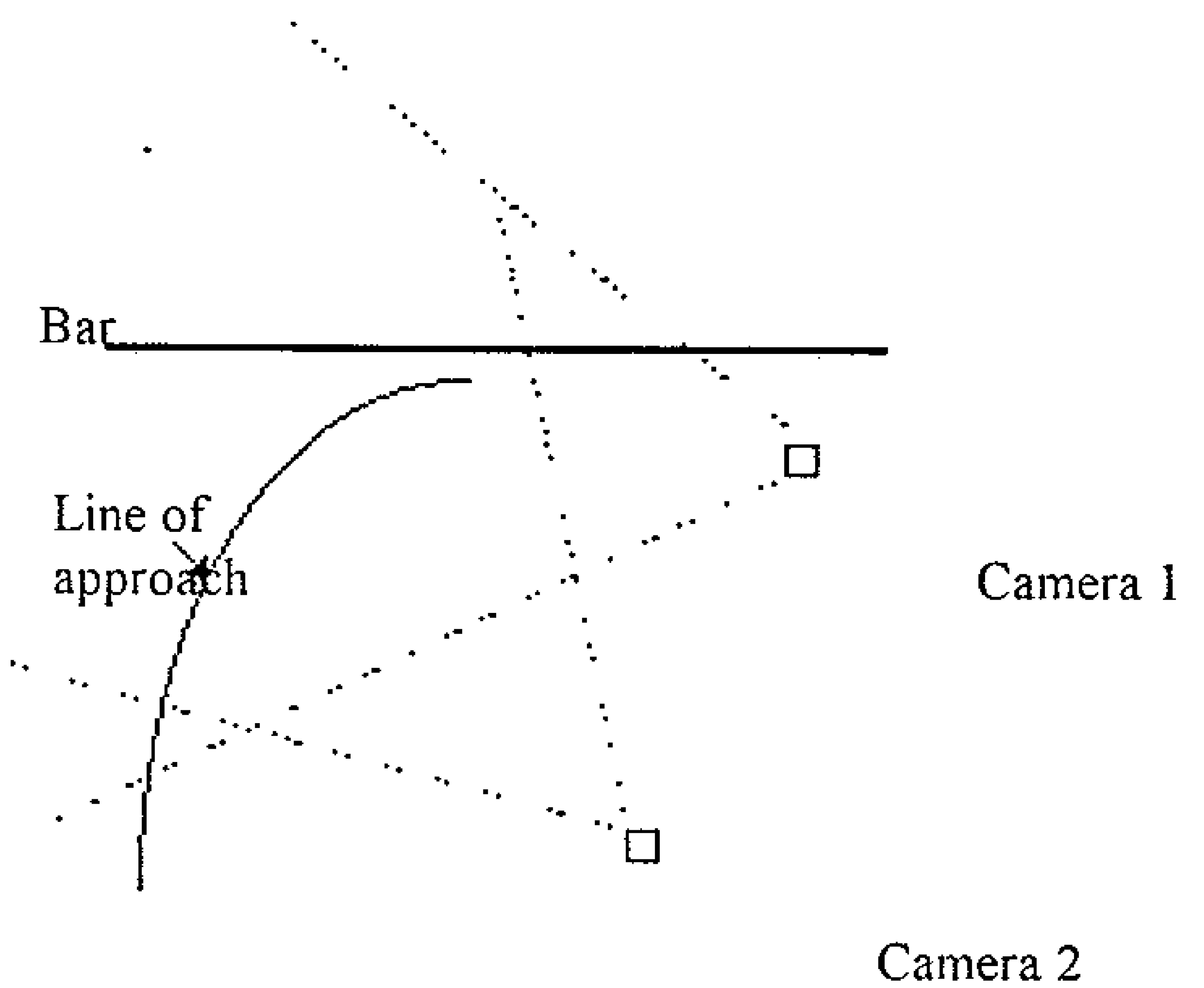


Table 1 : The results of Chang Yu Ho at different occasions.

Trial	Time	Venue	Nature of competition	Height (m)	Results
1	11/92	Hong Kong	Training session	2.00	√
		Sports Institute		2.10	x
2	4/3/93	Hong Kong	Training session	2.00	√
		Sports Institute		2.05	x
3	14/9/93	Tai Po	International invitation	2.00	√
		Sports Ground	competition	2.05	X
4	15/5/94	Wai Chai	International invitation	2.05	√
		Sports Ground	competition	2.10	X

Results and Discussion

For clear analysis and explanation, the whole sequence of high jump was divided into three procedural stages: (1) approach, (2) take-off, and (3) bar clearance. In the stage of approach, only the last two strides were selected for analysis.

1. Approach

From Table 2, it was revealed that Chang's techniques of approach were unstable and occasionally adjusted to strive for improvement. For the second last stride of approach, Chang's performance was relatively good and similar to the international high jump athletes. On the other hand, problems existed at the last stride of approach. For example, in the fourth trial (Table 2), Chang's last stride length was 1.61 m which led to a declination of the velocity of approach which would reduce the energy created from the take-off phase and increase the touchdown angle of the take-off leg which would hinder the lowering of the mass centre.

Table 2 : The kinematic data of last two strides at approach.

Name	Trial	Height (m)	Result	Second last stride			Last stride		
				Stride length (m)	Stride frequency (Hz)	Velocity (m/s)	Stride length (m)	Stride frequency (Hz)	Velocity (m/s)
Chang Yu Ho	1	2.00	√	2.02	3.85	7.77	2.05	/	/
		2.10	X	2.28	3.57	8.14	2.05	/	/
	2	2.00	√	2.28	3.42	7.80	1.96	3.65	7.15
		2.05	X	2.21	3.28	7.25	1.92	3.70	7.11
	3	2.00	√	2.24	3.40	7.61	1.95	3.55	6.93
		2.05	X	2.19	3.32	7.28	1.94	3.65	7.08
	4	2.05	√	1.96	3.84	7.54	1.63	4.54	7.41
		2.10	X	2.14	3.57	7.64	1.61	4.54	7.32
	Average			2.17	3.53	7.63	1.89	3.94	7.17
	Standard deviation			0.11	0.19	0.27	0.16	0.43	0.16
Zhu	5th National Games	2.38	√	2.31	3.62	8.37	2.09	3.92	8.19
Conway	24th Olympic Games	2.34	√	2.37	3.33	7.89	1.89	4.88	9.22

Table 3 : The angles of approach (horizontal plane) and the height of the mass centre at touchdown of take-off leg during take-off phase.

Name	Date	Place	Results (m)	α_1 (deg)	α_2 (deg)	α_3 (deg)	α_4 (deg)	$\Delta\alpha$ (deg)	H_{1-1} (cm)
Chang Yu Ho	11/92	Hong Kong Sports Institute	2.00 √	49	39	37	37	12	90
			2.10 X	49	42	41	39	10	92
	5/94	Wai Chai Sports Ground	2.05 √	43	36	36	38	5	90
			2.10 X	43	34	36	34	9	92
	Average			46	38	37.5	37	9	92
	Standard deviation			3	3.03	2.06	1.87	2.56	1
*Olympics	1988	Seoul		52	43	/	37	15	90
Conway	1988	Seoul	2.34	50	41	/	34	16	79

* The average results of the top eight high jump athletes of the 1988 Olympics Games.

α_1 : Angle of approach of second last stride.

α_2 : Angle of approach of last stride.

α_3 : Angle of take-off.

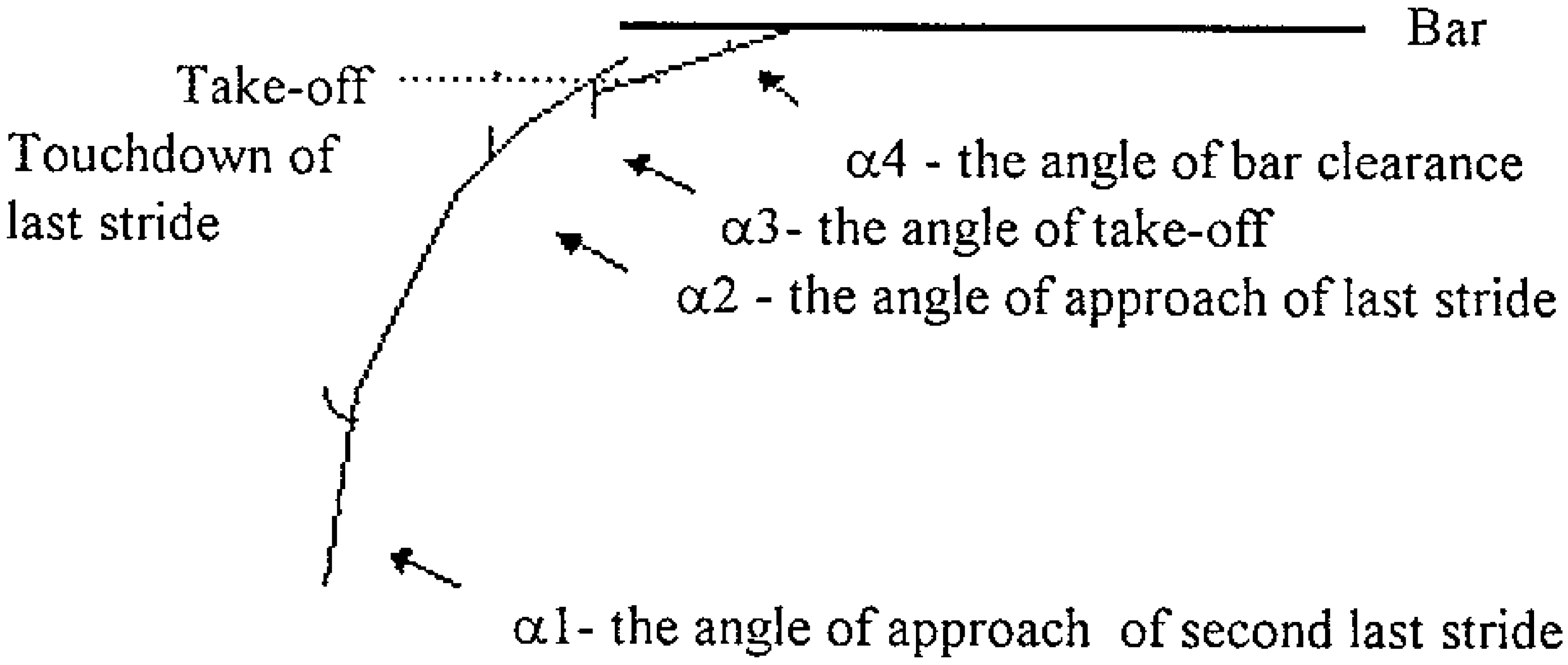
α_4 : Angle of Bar Clearance.

H_{1-1} : Height of the mass centre at touchdown of take-off leg during take-off phase.

$\Delta\alpha$: Difference of the angle of approach ($\Delta\alpha = \alpha_1 - \alpha_4$).

From Table 3, also refer to figure 2, it was revealed that the difference of the angle of approach ($\Delta\alpha$) of the last two strides was relatively small: the largest one was 12° whereas the smallest one was 5° and the average of the four trials was 9°. From the results of the international high jump athletes, the difference of the angle of approach of the last two strides ($\Delta\alpha$) of the top eight Olympics high jump athletes was 15°, whereas Conway, was 16°. Compared with the results of the international high jump athletes, the curvature of Chang's approach pathway of the last two strides was comparatively small (the approach was too straight). Therefore, the inclination of the body toward the centre of the pathway was not enough and the value of mass centre (H1-1) become large.

Figure 2. Movement of the mass centre during approach (top view).



In four trials of high jump, Chang's average height of the mass centre (H_{1-1}) was 92cm. This result was higher than that of the top eight Olympics high jump athletes 2cm although the average height of the Olympic athletes were higher than Chang 5cm or above. Compared with Conway, a significant difference of 13cm in mass centre (H1-1) was observed and body height of them was similar.

From Table 3, the information of the Olympics high jump athletes indicated that there was a tendency of decreasing the angle of approach. However, Chang indicated little or no change and even a tendency of increase in the angle of approach (from α_2 to α_4).

The direction of take-off and the angle of bar clearance ($\alpha 4$) of Chang was basically similar to that of the Olympics high jump athletes. It was suggested that the factors for the small curvature of approach pathway of Chang were attributed to: (1) problem existed in Chang's approach techniques, and (2) the slow speed of approach. As a result, it was recommended that the training program of Chang should aim at increasing his speed of approach. Especially the last stride of approach, the stride length should be maintained at medium level in the range of 1.80m to 2.00m. Also, a high stride frequency (4.5Hz) and a relatively high approaching speed (above 8m/s) should be used. In addition, the curvature of approach pathway of the last two steps (α_1 and α_2) should also be increased in order to improve the technique of the overall performance in take-off.

Table 4. Biomechanical profile data at take-off.

Name	Trial	Results	D_1 (m)	Time of take-off (s)	H_{1-1} (m)	H_{1-2} (m)	ΔH_1 (m)	Take-off efficiency Index	Horizontal velocity at take-off (ms^{-1})	Vertical velocity at take-off (ms^{-1})
Chang Yu Ho	1	2.00 √	1.15	0.16	0.90	1.26	0.36	2.25	4.9	4.0
		2.10 X	1.12	0.14	0.92	1.28	0.36	2.57	4.8	4.0
	2	2.00 √	0.80	0.12	0.91	1.23	0.32	2.67	3.45	3.97
		2.05 X	0.93	0.12	0.87	1.25	0.38	3.17	3.42	4.07
	3	2.00 √	0.79	0.12	0.90	1.27	0.37	3.08	3.15	3.74
		2.05 X	0.79	0.12	0.91	1.24	0.33	2.75	3.30	3.77
	4	2.05 √	1.14	0.14	0.90	1.25	0.35	2.50	3.35	4.00
		2.10X	1.18	0.14	0.92	1.29	0.37	2.64	3.72	3.97
	Average		0.99	0.13	0.90	1.26	0.355	2.70	3.80	3.94
	Standard deviation		0.166	0.014	0.015	0.019	0.019	0.28	0.61	0.11
Zhu		2.38 √	1.00	0.17	0.92	1.38	0.46	2.70	4.30	4.66
Conway	Olympics	2.34 X	1.05	0.175	0.79	1.30	0.55	3.14	3.60	5.00

D_1: Horizontal distance between the bar and the position of take-off.

H_{1-1}: Height of the Mass centre at the moment when the take-off leg touchdown during take-off.

H_{1-2} : Height of the Mass centre at take-off.

ΔH_1 : Distance of Take-off = $H_{1-2} - H_{1-1}$.

Take-off efficiency index = ΔH_1 /Time of take-off.

2. Take-off

Data regarding the biomechanical characteristics of take-off are presented in Table 4. From these data, the following problems could be found:-

(a) The take-off time of Chang was obviously less than that of Zhu Jian Hua and Conway. The factors for the short take-off time were attributed to the elevated mass centre (H_{1-1}) at the moment that the take-off leg touchdown.

(b) Knee straightening was not enough during take-off (i.e. decreased angle of knee joint). This led to the shortened distance of take-off (ΔH = 37cm). However, Zhu is 46cm and Conway is 51cm.

(c) Comparing with Conway, the take-off efficiency index of Chang was relatively small. Chang was about 2.70 which was close to Zhu and Conway was 3.14. The take-off efficiency index can reflect the high jump athletes' speed and explosive power during take-off. It was suggested that the training program of Chang should aim at improving his explosive power of the take-off leg and increasing the upward swinging speed of his swinging leg and arms.

(d) The vertical velocity of Chang at the moment of take-off was 3.94 ms^{-1}. This result was significantly lower than that of Zhu Jian Hua and Conway. This vertical velocity was one of the most important elements that contributed to the success of high jump. It determined the height of high jump athlete's mass centre during flight phase. There are many factors influencing the height of mass centre of an athlete. But the technique of approach and take-off are the major factors.

3. Bar Clearance

Table 5 presents the height elements in each jump performed by Chang, Chu and Conway. The data show that Chang's maximum height of the mass centre (H_2) and the flight height of the mass centre (ΔH_2) increased constantly in different trial test indicating that his take-off technique was improving. However, there was a significant difference when compared with other international athletes. In order to raise the result to the level of 2.15 m to 2.20 m, Chang's flight height of the mass centre (ΔH_2) should reach approximately 1 m. In fact, Chang equipped with the ability to reach that standard. The determining factors were mainly attributed to his ability to improve his techniques of approach and take-off.

Table 5 : Height elements of each high jump.

Name	Trial	HB (m)	H_2 (m)	ΔH_2 (m)	H_3 (m)
Chang Yu Ho	1	2.00 √	2.06	0.76	0.06
		2.10 X	2.06	0.74	- 0.04
	2	2.00 √	2.09	0.86	0.09
		2.05 X	2.10	0.83	0.05
	3	2.00 √	2.06	0.79	0.06
		2.05 X	2.06	0.82	0.01
	4	2.05 √	2.12	0.87	0.07
		2.10 X	2.14	0.85	0.04
	Average		2.09	0.81	0.05
	Standard deviation		0.03	0.04	0.02
Zhu Jian Hua		2.38 √	2.41	1.03	0.03
Conway		2.34 √	2.56	1.26	0.22

HB : Height of the bar.
H_2 : Maximum Height of the Mass centre.
ΔH_2 : Flight Height of the Mass centre = $H_2 - H_{1\text{-}2}$.
H_3 : Distance between the Maximum Height of the mass centre and the bar.

From the results of all the successful bar clearance, the distance between the maximum height of mass centre and the bar (H_3) were above 6cm, reflecting some problems existed during the phase of bar clearance. It was observed that, when the mass centre reached the highest point, the "arc" of the trunk hyperextended movement did not perform well. The head raised so fast that there was a coupling movement of the hip (i.e. the hip moved downward). At this particular moment, the hip, which has still not cleared the bar, easily touched the bar. As a result, the training program of Chang should aim at improving the bar clearance technique, attention should particularly be paid to maintain the backward swinging motion of the head and both arms during bar clearance. It was not until the hip has completely cleared the bar, the head could be raised, the hip bent, and the knee straightened.

Training Programme

According to the results of the biomechanical analysis data and the physical quality index, coaches determined that the core of training should be on technical skill training - to strengthen the quality of specific skills and intensify the training on specific skill. It aimed at augmenting Chang's techniques and specific quality at a relatively short period of time.

In technical skill training, the following four components should be emphasized: (a) approach, (b) the transition from approach to take-off., (c) take-off, and (d) bar clearance. Particularly attention should be focused on (1) improving the skill at the second last stride during approach with a reasonable curved path of running., (2) the co-ordination of driving up and swing up movements during take-off, and (3) a reasonable speed, range, and direction during bar clearance.

In physical quality training, the core of training should switch from general physical quality to specific physical quality. Focus should be on intensification of specific physical quality training. Combining the rapid support, rapid amortization and extent ability of the take-off leg with the rapid swinging characteristic of the swinging leg, specific speed and power training could be implemented, thus enhancing Chang's specific skill development.

According to the results of technique analysis and the 1994 competition, coaches were aiming at constructing a one year and phase-oriented training plan and guideline in order to guarantee that the planned training activities could be successfully implemented. (see table 6)

Table 6 : Data of quality & skill index and results improvements of Chang

Stage	Period	Training Venue	Quality index						Skill index			Competition	
			30m run (s)	60m run (s)	Standing long jump (m)	Standing 3-step jump (m)	20m curved run (s)	Approach touch jump (m)	Short distance approach jump (m)	Standard approach jump (m)	Training intensity (m)	Competition	Result (m)
1	Feb - Mar	Guang Zhou	3.66	6.76	3.15	9.46	1.93	3.35	1.95	2.00	2.00	Hong Kong Invitation Athletics Meet	2.00
2	April - June	Hong Kong	3.65	6.70	3.20	9.50	1.92	3.40	1.95	2.05	2.03	Hong Kong Track & Field Open	2.10
3	July - Aug	Shang Dong	3.60	6.70	3.26	9.50	1.90	3.45	1.96	2.08	2.05	Philippine International Athletics Meet	2.13
Prior to Asian game	Sept	Hong Kong							2.00	2.12	2.10	Canada International Invitation Athletics Meet	2.15

After more than half year's planned scientific training, Chang's skill and training index indicated significant improvements. His high jumping performance increased by more than 10cm, hence, he has broken the Hong Kong male high jumping record twice.

Conclusions

Chang is a speed-oriented high jump athlete and possesses a superior quality of becoming one of a talented high jump athletes in Asia. However, technical problems still existed at the phases of approach, take-off, and bar clearance. The overall problems are summarized as follows:

1. The curvature of the approach pathway at the last two strides of approach is relatively small. The stride length of the last stride is also small.
2. The mass centre at the initial phase of take-off is relatively high. But the mass centre is too low at the later phase of take-off. This leads to the shortened of vertical distance of take-off and decrease of take-off time. Moreover, the following two factors hinder the take-off efficiency: (1) the extension of the take-off leg during take-off is inadequate and (2) the upward velocity of the swinging leg and both arms are relatively low.
3. During bar clearance, Chang's head is raised so soon that a faster downward movement of the hip before the bar is cleared. This will affect the performance of bar clearance.

We hoped that, if Chang can make improvements in the three above-mentioned areas, his level of performance will be enhanced.

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Sub-project 2 : Biomechanical Study on Technique Characteristics and Training Program of Men's 100m Elite Sprinters of Hong Kong

Introduction

The purpose of this project is to profile the 100m sprint technique of Hong Kong sprinting athlete and improve the training programs through biomechanical methods and the effective cooperation of researcher and coach.

In recent years, the level of Hong Kong men 100m sprint continues to rise. Especially, the 19 year old boy Ku Wai Ming, who is a scholarship athlete in Hong Kong Sports Institute, is our typical example. In 1992, Ku represented Hong Kong to take part in the 25th Olympic Games and the Asian Youth Athletic Meet. In 1993, Ku took part in the East Asian Games and the 2nd Asian Junior Athletic Championships. Ku brings great honour to Hong Kong. At present, he keeps the Hong Kong 100m record with the result 10.50s. To further raise the level of men 100m sprint in Hong Kong, biomechanists and coach, Wong Chung Him, have set up a long term research plan since 1993. This plan is to provide Hong Kong 100m sprinters a periodic biomechanical clinic on their techniques. This clinic is a course to correct the sprinter's techniques and to obtain a better result. This paper is based on material from several biomechanical analysis to expose the technique characteristics of Hong Kong 100m sprinters. Then the kinematic parameters of the Hong Kong sprinters will be compared with the world class athlete and the China top athletes - Zheng Chen and Li Tao. They were the champion and runner-up of the 6th National Games. We will try to point out the Hong Kong sprinters' merits and find out the techniques differences with those China and world top athletes. From the above analysis, the training direction can be set up for the Hong Kong sprinters.

Method

Two video cameras with a distance 10m apart were pointed perpendicular to the motion plane. The filming distance of each camera covered about 10m. By panning the video cameras, the movement of the sprinters at the distance 20m and 60m from start line were filmed. After that, the filmed materials were analysed with Peak Performance System. The data were smoothed through a low pass filter with a cutting frequency 6. The human model including toe, heel, ankle, knee, hip, shoulder, elbow, arm, ear and neck totally 19 points for digitalization was designed. Then the kinematic parameters including time, displacement, velocity, angle and angular velocity were given. The video cameras were JVC GY-X1 with video speed 50 frames per second and shutter speed 1/500s. The time, place and type of events for our analysis are shown on table 1:

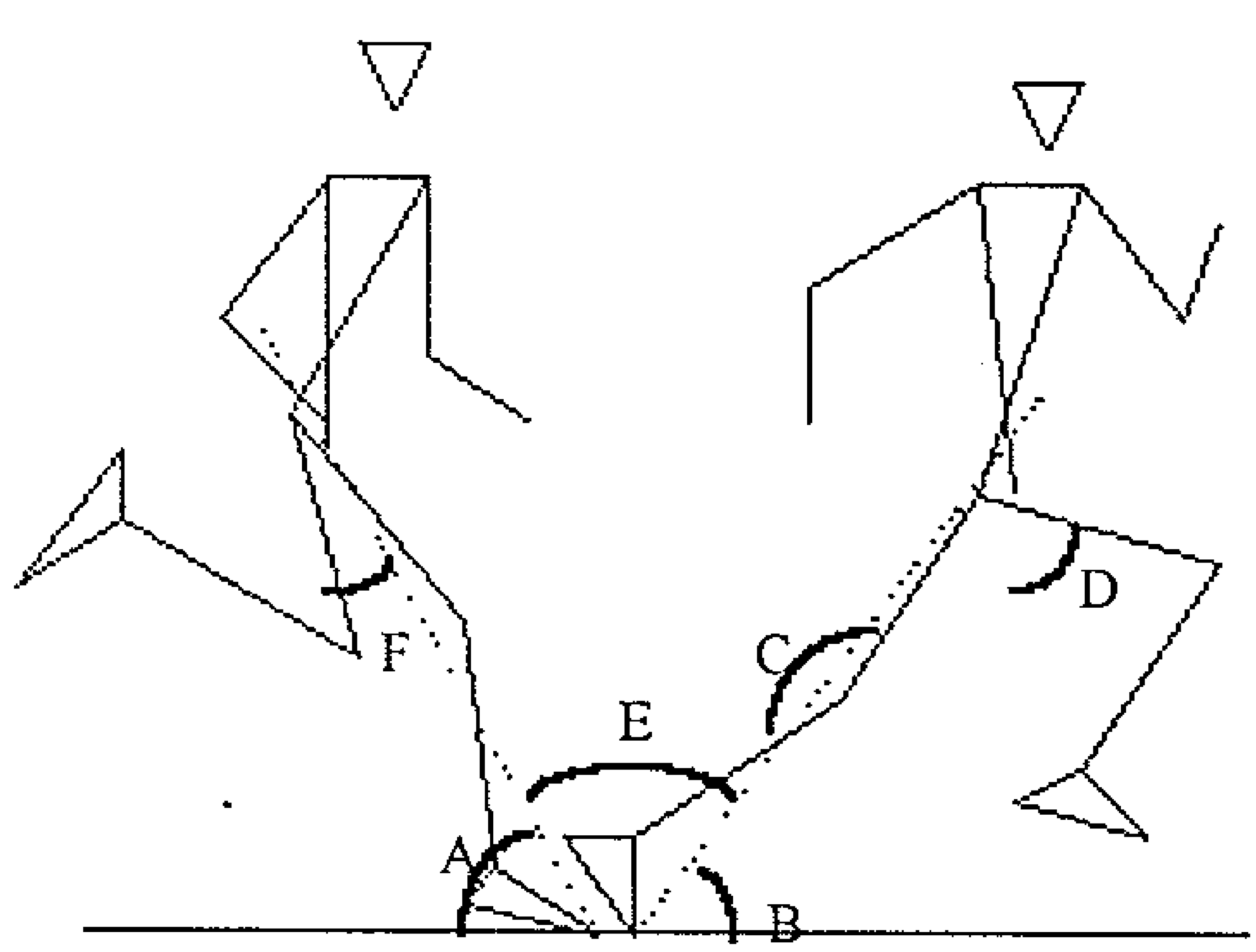
Table 1. The results of the Hong Kong sprinters at different events.

Time	Place	Sprinter	Results (s)	Type
5/08/92	Hong Kong Sport Institute	Ku Wai Ming		Training
24/12/92	Wai Chai Sports Ground	Ku Wai Ming	10.70	Open Competition
		Lai Tung Sing	10.90	
		Lo Kam Wing	11.07	
15/05/94	Wai Chai Sports Ground	Ku Wai Ming	10.63	Open Competition

Referring to Figure 1, some terms assosiated with biomechanical characteristics of running technique and used in this paper are defined as follows:

1. Supporting time : the time period between a leg touching the ground and take off.
2. Flight time : the period between a leg take-off from the ground and touch down of another leg.
3. Stride time : supporting time + flight time.
4. Touch down angle (∠A) : at the instant of touch down, the angle between the horizontal line and the line joining the hip joint and toe.
5. Takeoff angle (∠B) : at the instant of takeoff, the angle between the horizontal line and the line joining the hip joint and toe.
6. Supporting angle (∠E) : 180° - (∠A + ∠B)
7. Knee extension angle (∠C) : at the instant of take off, the angle between thigh and shank of supporting leg.
8. Knee lift angle (∠D) : at the instant of take off, the angle between the vertical line and the line joining the hip joint and knee joint of swinging leg.
9. Pawing angle (∠F) : at the instant of the front paw touch down, the angle between the vertical line and the line joining the hip joint and toe.

Figure 1: Definition of angles.



Results and Analysis

Table 2 gives time parameter of some analysed 100m-run performed by Ku and other elite Hong Kong 100m sprinters. From Table 2 we find that the supporting time of Ku Wai Ming in acceleration phase, between 30m and 50m is obviously short. That means the stride time will also be reduced. However, we discover that the flight time of Ku between 40m and 50m is comparatively long. The supporting time to flight time ratio is 1:1.75. The Chinese scientists Xu Yao Qiu and Yao Tian Bai have their professional view in their publications about the above problem. They believe that "the supporting time to flight time ratio should be about 1:1.2 for "bend driving style athlete". For "full driving style" athlete, the ratio should be about 1:1.46. The supporting time and flight time of "bend driving style" athlete are comparatively close. The co-ordination of legs during support and flight period is easy. These will enhance a higher stride frequency and velocity. The difference of supporting time and flight time of "full driving style" is comparatively large. This will lead to a poor coordination of legs during supporting and flight phases. Only emphasis on the full driving action and the velocity is low.[1]" According to this theory, the ratio of supporting time to flight time in Ku is not reasonable. This may due to the existing problem in driving up technique. The ratio of supporting time and flight time in Lai Tung Sing and Lo Kam Wing in 50m to 60m section are comparatively reasonable.

Table 2. Time parameters.

Analysis	Name	Section (m)	Supporting Time (s)	Flight Time (s)	Stride Time (s)	Ratio of Supporting Time and Flight Time
First	Ku W. M.	26-34	0.100	0.125	0.225	1:1.25
		36-44	0.100	0.140	0.240	1:1.4
Second	Ku W. M.	50-60	0.088	0.128	0.216	1:1.45
	Lai T. S.		0.090	0.127	0.217	1:1.41
	Lo K. W.		0.090	0.127	0.217	1:1.41
Third	Ku W. M.	30-40	0.095	0.12	0.215	1:1.25
		40-50	0.080	0.14	0.22	1:1.75

Table 3 compares the stride frequency, stride length and velocities of 100m-run performed by Ku and some China and world's top sprinters. From table 3, we found that i) the stride lengths of Hong Kong athletes are not worse than the China athletes and Ben Johnson from Canada. However the differences in stride frequency is greater. ii) In Hong Kong athletes, the maximum velocity appear at 50 to 60m section. This is similar to the Chinese and international top track and field athlete. iii) the acceleration power of Hong Kong elite athlete comparatively weak. The parameter of acceleration power can reflect this. The Chinese athletes Zheng Chen and Li Tao at the section of 30 to 40m have respectively attained 98% and 100% of their peak velocities. Ben Johnson at 30-40m is 96.6% and Carl Lewis who has a poor acceleration power has a value of 92%. Ku at 30-40m is 88% and at 40-50 is 91%.

Table 3. Stride frequency, stride length and velocities.

Name	Section (m)	Result (s)	Stride Frequency (Stride/s)	Stride Length (m)	Average Velocity (m/s)	*Acceleration Power
Ku Wai Ming	26-34		4.44	2.02	8.96	80%
	36-44		4.08	2.36	9.63	86%
Ku Wai Ming	50-60	10.70	4.56	2.46	11.22	100%
Lai Tung Sing	50-60	10.70	4.65	2.33	10.83	100%
Lo Kam Wing	50-60	11.07	4.57	2.26	10.31	100%
Ku Wai Ming	30-40	10.63	4.65	2.14	9.95	88%
	40-50		4.55	2.24	10.19	91%
Zheng Chen (China)	30-40	10.35	4.61	2.39	11.00	98%
	40-50		4.60	2.41	11.10	99%
	50-60		4.78	2.33	11.20	100%
Li Tao (China)	30-40	10.36	4.80	2.27	10.90	100%
	40-50		4.80	2.28	10.90	100%
	50-60		5.01	2.18	10.90	100%
Ben Johnson (Canada)	30-40	9.83	5.01	2.24	11.2	96.5%
	40-50		4.92	2.34	11.5	99%
	50-60		4.87	2.36	11.5	99%
Carl Lewis (U.S.A.)	30-40	9.91	4.66	2.32	10.8	92%
	40-50		4.72	2.43	11.5	98%
	50-60		4.64	2.50	11.6	99%

*Acceleration power = Average velocity / Max. velocity x 100%.

The stride frequency, stride length, and maximum velocity of the Hong Kong elite athletes, the first eight athletes of 6th National Games in China and the 24th Olympic Games (first 8) are shown on Table 4.

Table 4. Stride frequency, stride length and maximum velocity of the Hong Kong athletes, China top athletes and world class athletes.

Event/Athletes	Result(s)	Peak Velocity (m/s)	Stride Frequency (stride/s)	Stride Length (m)
The 24th Olympic Games (Average value first 8 athletes)	9.99	11.44	4.71	2.42
The 6th National Games in China (Average value first 8 athletes)	10.58	10.84	4.90	2.21
Ku Wai Ming	10.70	11.22	4.56	2.46
Lai Tung Sing	10.90	10.83	4.65	2.33
Lo Kam Wing	11.07	10.31	4.57	2.26

Data in Table 5 reflect technique characteristic of Hong Kong 100m sprinters:

1. According to the research findings from Chinese scientists Xu Yao Qiu and Yao Tian Bai[2], the "bend driving style" athlete should have the following values in their kinematic parameters a) knee angle at the finish of driving up is about 155° and take-off angle (∠B)is about 53°. b) For the "full driving style" athlete, the knee angle at the finish of driving up and take-off angles should be about 165° and 60° respectively. The knee extension angle of Hong Kong elite athlete is about 157.5°± 1.4°. The value is in between the "bend driving style" and "full driving style". Since the height of Hong Kong athletes are comparatively short, developing "bend driving" technique can improve their stride frequency and can make use of the flexibility of "Titan" track.
2. The average takeoff angle is 59.5° ±3.78° which belongs to full driving style. This is the main reason for a long flight time. Also, the horizontal velocity will be reduced. Therefore, the takeoff angle should be reasonably made smaller.
3. The average angular velocities of supporting angle and pawing angle are 650 ± 50.35°/s and 590 ± 39.8°/s respectively. Especially, Ku Wai Ming, his average angular velocities of supporting angle and pawing angle are 725°/s and 630°/s. This indicates Hong Kong elite athlete has better rapid pawing and rolling techniques.

Table 5. Angular parameters of Hong Kong elite athletes.

Trial	Name	Section (m)	Touch down Angle (deg)	Take-off Angle (deg)	Support-ing Angle (deg)	Rate of Support-ing angle (deg/s)	Knee Exten-sion Angle (deg)	Knee Lift Angle (deg)	Rate of Pawing Angle (deg/s)
First	Ku W. M.	26-34	/	/	/	/	156.5	70.45	544.8
		36-44	/	/	/	/	/	/	589.8
Second	Ku W. M.	50-60	54.1	57.3	68.6	663	158.5	70.90	632.9
	Lai T. S.		56.7	61.3	62.0	602	159.3	74.4	610.4
	Lo K. W.		60.7	53.5	65.8	586	157.4	71.3	/
Third	Ku W. M.	30-40	55.2	61	63.7	672	158	78	530
		40-50	57.5	64.5	58	725	155	77	630
Average			56.8	59.5	63.6	650	157.5	73.7	590
Standard deviation			2.26	3.78	3.57	50.35	1.40	3.0	39.8

Improvement of Training Programme

The stride frequency and stride length of Ku are two main determining factors that Ku must pay attention to. Therefore, these two factors are emphasised in the day-to-day training programme.

The most effective method to improve the stride frequency and stride length is "running the mark". That is, running on the track and stepping the interval of the marks which are set on the ground. Taking the profile of the world top athletes as models, Ku has trained to run at the frequency of 4.8-5.0 strides/s in his 20 stride sprints. If he could finish the run in 4 seconds, a stride frequency of 5.0 strides/s was reached. The instant feedback of Ku helps to make adjustments for the next run by setting the mark intervals slightly shorter than his maximum stride.

The "running the marks" have also been used to improve the stride length of Ku. The mark intervals are set slightly longer than his stride length as measured in the biomechanical study. In this exercise, Ku must use the pawing-driving pattern instead of "pushing across". Advice were then given by the coaches to Ku after each training. So that, Ku can make adjustment in the next training session. The leg muscle strength is very demanding if the pawing-driving technique is employed. A special strength training programme was designed. The athlete is trained with pawing-driving technique and full knee extension at take-off under additional heavy loading.

Conclusions

After analysis, the technique characteristics of Hong Kong 100m sprinter were found to be:

1. Stride length is comparative long and stride frequency is comparatively low.
2. Pawing technique and the rapid rolling technique after touchdown are doing well.
3. Large driving knee angle, fully use of driving up action, long flight time, and their technique is in between the "bend driving style" and "full driving style".
4. Comparatively large maximum velocity and poor acceleration power.

Suggestions

According to the analysis and investigation abobe, some suggestions can be made as follows:

1. The stride length should relatively keep unchanged and try to increase the stride frequency. Since "Titan" track has good flexibility, this will prevent the energy loss when action applied by the athletes. However, when the action force is too large, the flexibility of the track will be lowered. Therefore, the athlete should try to employ the " bend driving technique". That is, at the instant of driving up, the knee extension angle of touchdown leg should be relatively small about 150°. So that, they make use of the flexibility of the track and the take-off angle can be reduced. The flight time can also be reduced and the horizontal force can be increased. This will increase the stride frequency and hence the velocity.
2. Starting technique and acceleration run ability should be improved.

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Sub-project 3 : Comparison of Backhand Straight Drive Technique Between Hong Kong Elite and World's Top Squash

Introduction

The backhand and forehand drive form the majority of shots played in high level squash competition (Wollstein and Neal, 1993). The backhand stroke of squash consists of four consecutive actions: step-to-stance, backward swing, forward swing, and follow through. Successful production of these skills rely on the techniques employed by the players to perform, especially, the actions of backward and forward swing. Behm (1987) analyzed general backhand stroke from the viewpoint of kinesiology. Wollstein and Neal (1993) quantitatively studied the angle of racket shaft to vertical and racket height at start of downswing in a international competition through video material recorded. Woo and Chapman (1991) proved the proximal to distal pattern of segment recruitment in playing the backhand stroke from a shot in a lab condition. Studies on the kinematics profile of world class squash players in playing these skills in a competitive situation have not been reported in the international publications. The biomechanical descriptions of backhand stroke are mostly presented in squash books which are written by coaches or players and are usually based on their observations or practical experiences. There is a lack of biomechanically quantitative descriptions of the techniques displayed in the real-world, competitive environment. Furthermore, the challenge for coach and teaching is to determine the common model of these techniques from the elite level athletes (Wollstein and Neal, 1994). A skilled athlete exhibits less variation among repetitions of a movement pattern than a less-skilled athlete (Kreighbaum and Barthls, 1990), especially for the world class squash players, it should be assumed that there must be underlying fundamental, common characteristic in stroke techniques that enable these athlete to perform at the highest level. It is important for coaches to understand these relative consistent technique components and to introduce them into practice sessions.

Squash is one of the most rapidly developed sports in Hong Kong and is has been defined as one of the target sports by the Hong Kong Sports Development Board. The purpose of this paper is to compare the kinematic data of Hong Kong squash players with the world top squash players and provide information to the coach for the technique improvement of the Hong Kong players.

Method

Two gen-locked 3-CCD video cameras of 50 Hz (exposure time 1/500 s) were used to film the 93' & 94' Cathay Pacific Unisys Squash Open and 7th Perrier Asian Junior Squash Championships 1995. One camera was positioned in the back of the court and another in the side of the court (Figure. 1). Two representative backhand straight drives of the world top players, Brett Martin & Jahangir Khan, and Hong Kong top player, Faheem Khan, were selected by the coach and analyzed. Also, two representative backhand straight drives of Hong Kong junior squash players, Jackie Lee and Wong Wai Hang, were selected and analyzed. All the backhand straight drives were recognized as hitting from sufficient running preparation and being in the left-back area of the court. The video materials were processed by Peak three-dimensional performance system.

Figure 1. The positions of cameras and the orientation of axes.

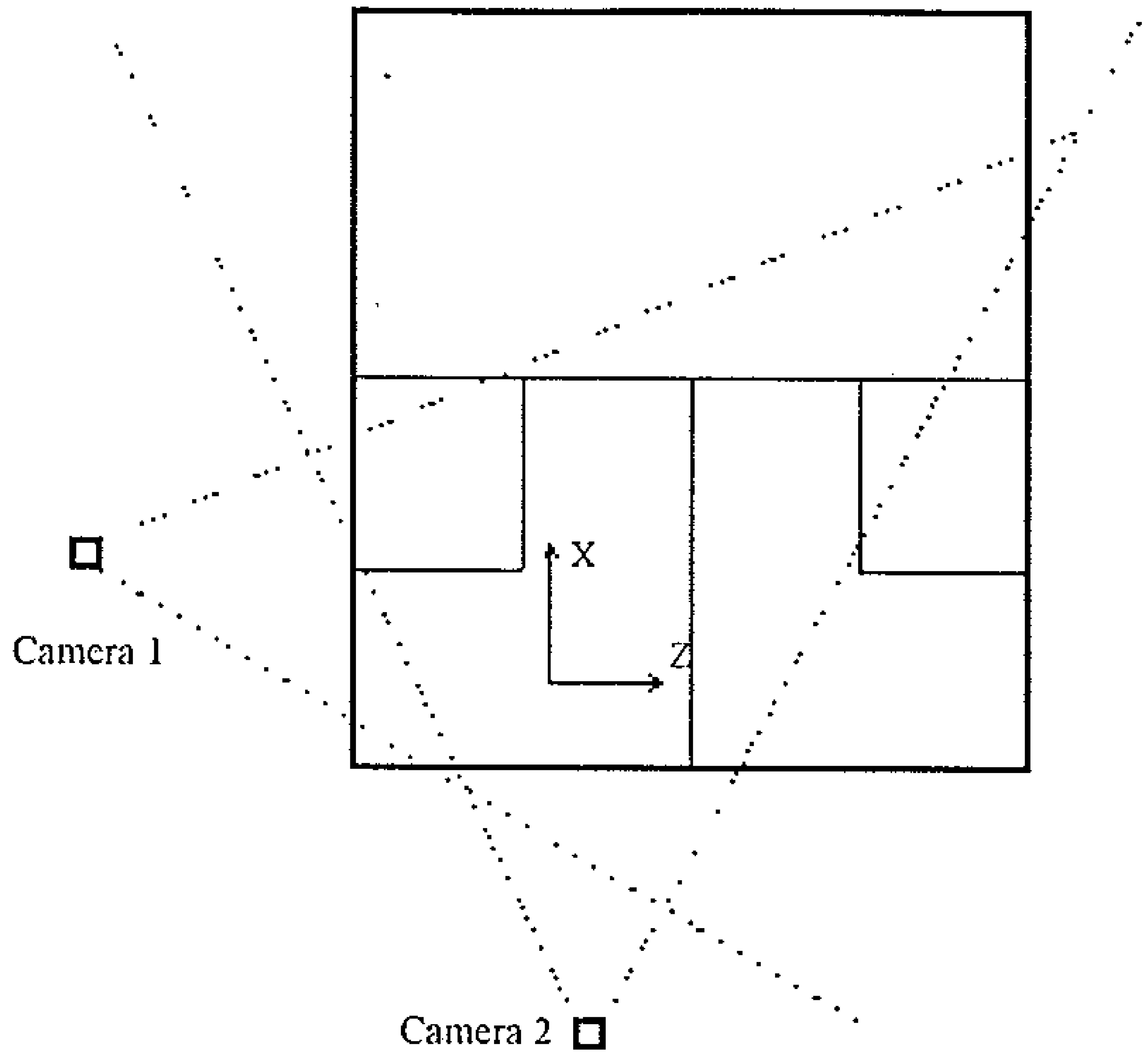


Figure 2. Stick figure showing the angles.

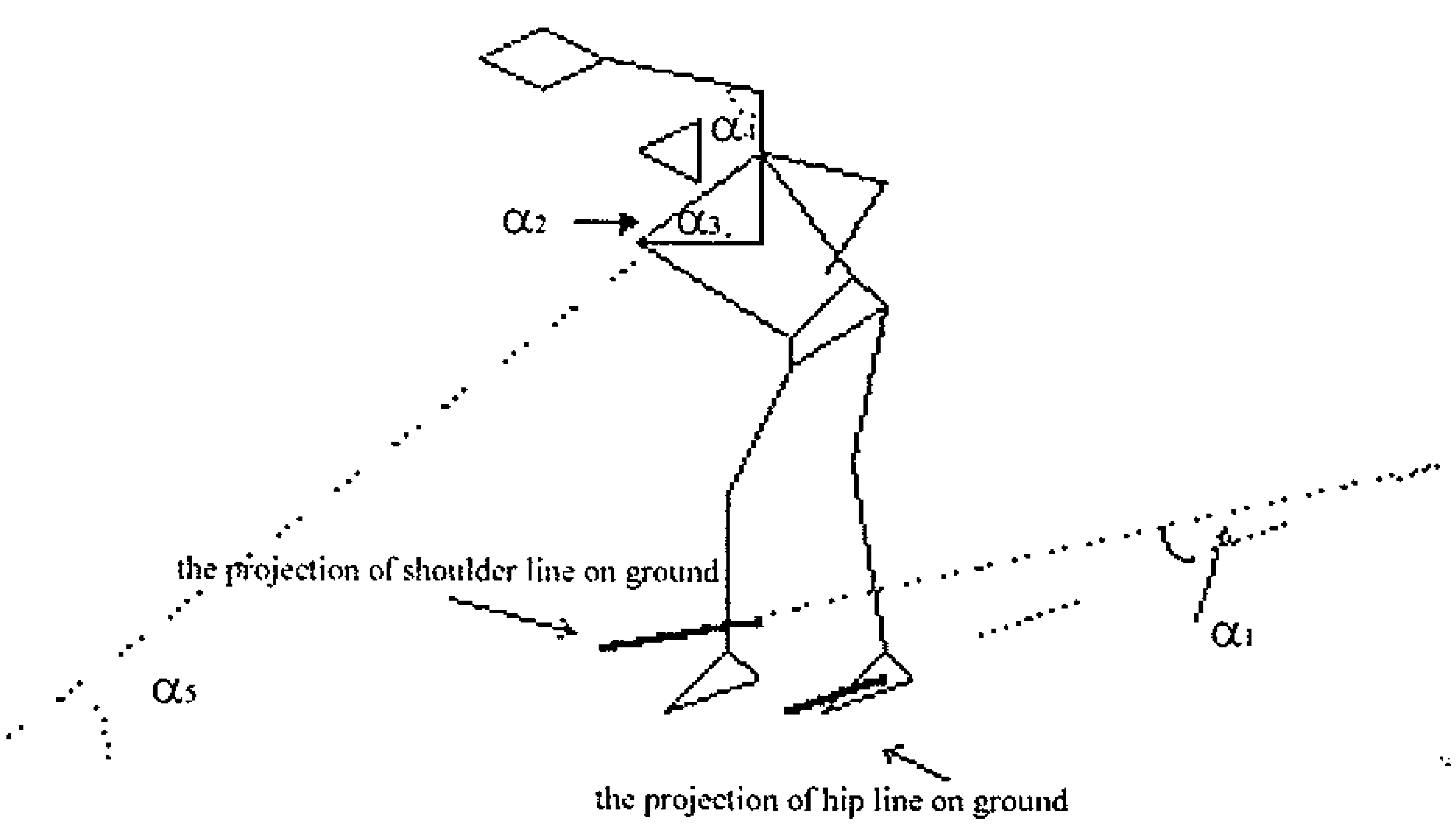


Table 1. The rotational angles at the moment of maximum backswing and racket-ball impact.

Name	Trial	Maximum Backswing					Racket-ball Impact					
		α_1(deg)	α_2(deg)	α_3(deg)	α_4(deg)	α_5(deg)	α_1'(deg)	α_2'(deg)	α_3'(deg)	α_4'(deg)	α_5'(deg)	$\Delta\alpha_1$(deg)
Jahangir Khan	1st	54.2	77.5	102.5	113.6	33.6	0.85	105.5	158.9	125.6	15.6	53.4
	2nd	40.0	68.1	69.9	119.8	33.0	-6.10	98.0	166.8	126.4	6.0	46.1
	Mean	47.1	72.8	86.2	116.7	33.3	-2.60	102.9	165.1	126.0	10.4	50.0
Brett Martin	1st	52.0	91.7	60.8	129.3	34.2	-3.3	107.6	167.2	139.2	19.7	48.7
	2nd	53.8	88.5	80.5	133.6	37.5	-5.3	116.4	164.3	136.8	22.3	35.9
	Mean	52.9	90.1	70.7	131.5	35.9	-4.3	112.0	165.8	138.0	21.0	42.3
Faheem Khan	1st	51.0	59.7	87.4	109.6	29.8	-8.14	92.0	154.3	151.8	15.9	59.1
	2nd	40.2	70.9	89.5	117.4	32.2	-5.8	93.2	157.6	164.5	7.1	46.0
	Mean	45.6	65.3	88.5	113.5	31.0	-7.0	92.6	156.0	158.1	11.5	52.6
Jackie Lee	1st	50.0	64.4	72.7	129.9	28.0	12.7	123.9	170.1	127.1	26.4	37.3
	2nd	61.5	57.4	95.1	119.8	25.5	-6.8	113.4	166.7	132.5	11.9	68.3
	Mean	55.8	60.9	83.9	124.9	26.8	3.0	118.7	168.4	129.8	19.2	52.8
W.H. Wong	1st	31.6	99.1	79.3	102.2	32.2	2.9	91.2	154.7	148.1	3.1	28.7
	2nd	32.9	82.6	83.0	119.0	33.4	8.7	114.0	168.9	124.8	19.5	24.2
	Mean	32.3	90.9	81.2	110.6	32.8	5.8	102.6	161.8	136.5	11.3	26.5

α_1: The angle between the projections of shoulder line and hip line on the X-Z plane at maximum backswing. (Please refer to figure 2)

α_2: The angle between the shoulder-line and the upper arm at maximum backswing.

α_3: The elbow angle at maximum backswing.

α_4: Wrist cocking angle. i.e. The angle between the racket shaft and the forearm at maximum backswing.

α_5: The inclined angle between the shoulder-line and ground at maximum backswing.

α_1': The angle between the projections of shoulder line and hip line on the X-Z plane at racket-ball impact.

α_2': The angle between the shoulder-line and the upper arm at racket-ball impact.

α_3': The elbow angle at racket-ball impact.

α_4': The angle between the racket shaft and the forearm at racket-ball impact.

α_5': The inclined angle between the shoulder-line and ground at racket-ball impact.

$\Delta\alpha_1$: The forward swing angle of trunk. i.e. α_1- α_1'.

Results and Discussion

Angles representing the internal and external orientation of the body and racket at the moment of maximum backswing and racket-ball impact were presented in Table 1. From these data comparisons of techniques between Hong Kong elite to the world's top players can be made as follows:

1) At maximum backswing:

   The trunk rotational angles (α_1) of Jahangir Khan, Brett Martin and Faheem Khan and Jackie Lee were relatively large ranging from 45° to 55°. This can form a good preparation posture and provide a better condition for the muscle contraction in forward swing. The trunk rotational angles of W.H. Wong was relatively small, only about 32°.

   The angle between the shoulder-line and the upper arm (α_2) of Jahangir Khan, Faheem Khan and Jackie Lee were fairly good. However, the angles of Brett Martin and W.H. Wong relatively large.

   The elbow angles (α_3) of Hong Kong players were large and bending of elbow was not enough.

   The wrist cocking angles (α_4) of Jahangir Khan, Faheem Khan and W.H. Wong were fairly good. The wrist cocking angles of Brett Martin and Jackie Lee were large.

   The inclination of shoulder line (α_5) of Jahangir Khan and Brett Martin are large. But the angle was relatively small in Hong Kong players.

2) At racket-ball impact

   At the instant of racket-ball impact, Jahangir Khan, Brett Martin and Faheem Khan kept their shoulder lines swing over their hip lines. Their forward swing angles of trunk ($\Delta\alpha_1$) were about 50°. This could extend their reaction distance to apply the force. As the result, the velocity of racket would be increased. Most of the forward swing of shoulder line played by the Hong Kong junior squash players did not exceed their hip lines since the forward swing was not enough. The forward swing angles ($\Delta\alpha_1$) of W. H. Wong were below 30° in both trials. Although the forward swing angles of Jackie Lee were large, the differences between his two individual result were great (37.3° and 68.3°). This indicates the instability of his technique.

   At impact, the extent of elbow (α_3) was not enough in W. H. Wong and Faheem Khan. The wrists of Jahangir Khan and Jackie Lee were in a "partly cocked" position. Brett Martin was normally cocked at 45°. Faheem was in a "uncocked" position. W.H. Wong was in a "partly cocked" position in his first trial and "uncocked " in his second trial. These would affect the racket head velocity.

Table 2 presented data of timing, average angular velocity of trunk during forward swing and average velocity of racket head directly prior to impact. From these data some technique comparisons can be made as follows:

- The average angular velocities of trunk (AVs) rotation of Jahangir Khan and Brett Martin were less than Faheem Khan. However, the momentarily the racket head velocity just before impact was rather large. This showed that their co-ordination between the trunk rotation and extent of joints on the arm was good.
- The forward swing time (T_f) of Faheem Khan was the shortest and the average angular velocity of trunk rotation was the greatest. But the racket head velocity was not the greatest at the moment of racket-ball impact. This reflected the waist muscle of Faheem was relatively strong. But his co-ordination between the trunk

rotation and extent of joints on the arm was disordered in some extent. The forward swing time, average angular velocity and racket head velocity of the two Hong Kong junior players were not good. This shows that their waist muscle was weak and their co-ordination between the trunk rotation and extent of arm was disordered.

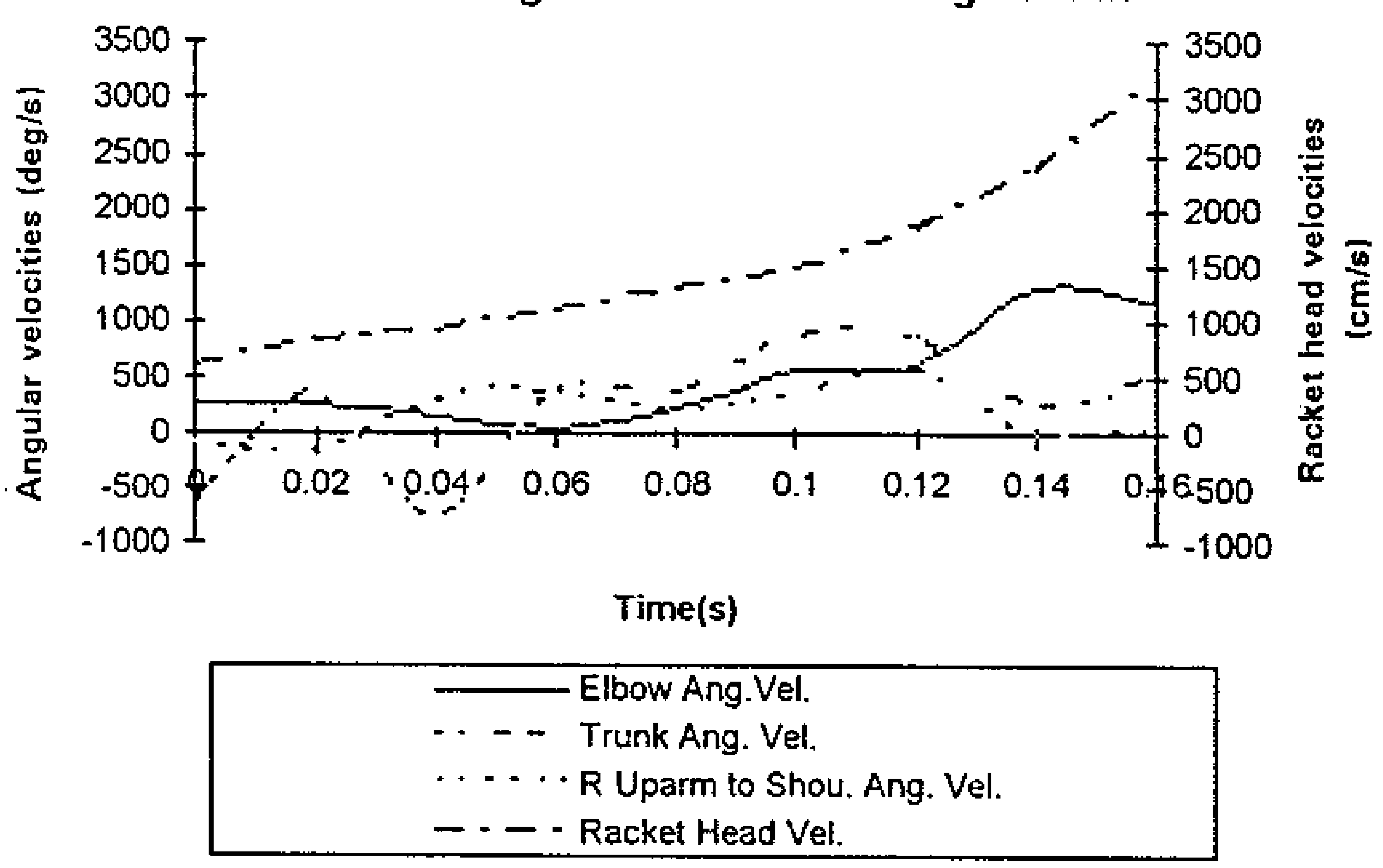
- From Figure 3, we discovered that, at the initial phase of the forward swing, the muscle groups of trunk and shoulder of Jahangir Khan first worked. At the middle phase, the muscle groups for the extent of elbow started function. But the rotation of trunk was the major power source. However, at the final phase, the muscle group for extent of elbow was the major power source. The muscle groups for trunk rotation and extent of elbow of Jahangir Khan were in a balance condition and their contribution to the racket head velocity was quite the same.

Table 2. Mean value of tim spent for forward swing, angular velocity of trunk forward rotation and velocity of racket directly prior to impact.

Name	T_f(s)			A Vs (deg/s)			V_p (m/s)		
	1st	2nd	Mean	1st	2nd	Mean	1st	2nd	Mean
Jahangir Khan	0.16	0.18	0.17	333.8	256.1	295.0	33.9	32.9	33.4
Brett Martin	0.14	0.16	0.15	347.9	224.4	286.1	34.4	33.9	34.2
Faheem Khan	0.14	0.16	0.15	422.1	287.5	354.8	32.1	32.1	32.1
Jackie Lee	0.22	0.18	0.20	169.5	356.7	263.1	26.1	25.8	26.0
W.H. Wong	0.22	0.22	0.22	130.5	110.0	120.3	23.3	25.0	24.2

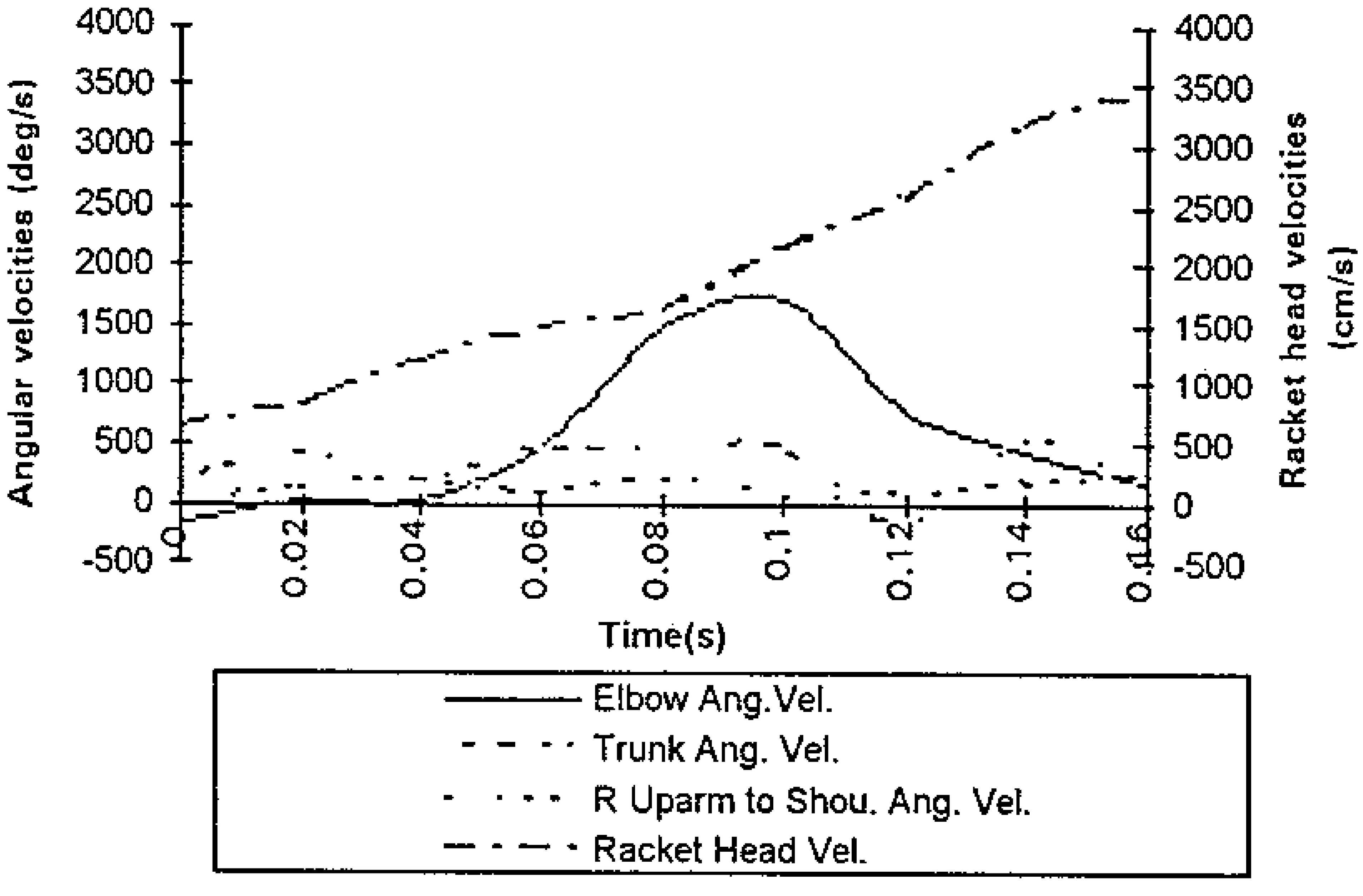
T_f: The forward swing time between max. backswing and racket-ball impact.
A Vs: The average angular velocity of trunk rotation during forward swing.
V_p: The racket head velocity at racket-ball impact.

Fig. 3 Angular velocities of joints and racket head velocities against time of Jahangir Khan



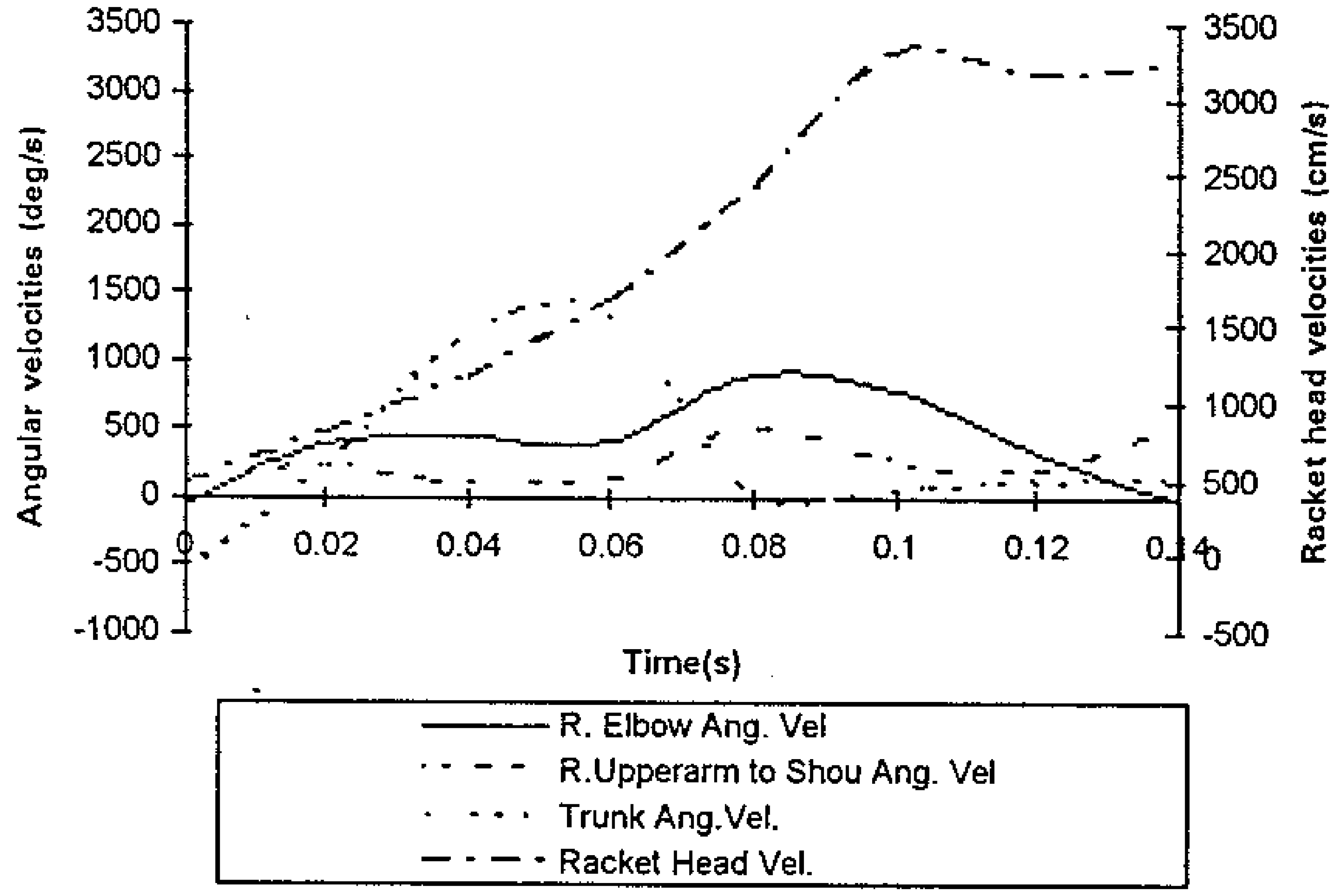
With reference to Figure 4, at first, the muscle group of trunk rotation of Brett Martin functioned. During the middle and final phase of forward swing, the muscle group for extent of elbow worked mainly. The curve of elbow angular velocity can reflect his muscle group of the extent of elbow was very strong. The sequence of contribution to the racket head velocity was 1. extent of elbow, 2. trunk rotation and 3. extent of shoulder.

Fig. 4 Angular Velocities of joints and racket head velocities against time of Brett Martin



The sequence of forward swing movement of body segments of Faheem Khan are shown in Figure 5. At the beginning, the muscle groups for the rotation of trunk functioned first. Then.the muscle groups for extent of elbow and shoulder worked. At impart, the shoulder muscle group mainly worked. From the curve of racket head velocity we can find that there is a decrease in racket head velocity at impact. This may due to the early extent of elbow. However, the overall performance in the co-ordination of different muscle groups was fairly good. For example, the functional sequence of muscle groups were as follows: 1. trunk rotation, 2. extent of elbow and 3. extent of shoulder.

Fig. 5 Angular velocities of joints and racket head velocities against time of Faheem Khan



From table 2, the forward swing time of Hong Kong players were obviously long and their racket head velocities were obviously slow. From fig. 6 and fig. 7, the major unit worked at ball impact was the muscle for the extent of elbow and they did not make use of the trunk rotation at the beginning of forward swing. Also, the extent of elbow was too early. This will reduce the velocity of racket head at racket ball impact. Moreover, this violated the sequence of the action of the big muscle groups promote the function of small muscle groups. This indicates the co-ordination of trunk rotation and the joints for extent of arm was disordered.

Fig. 6 Angular velocities of joints and racket head velocities against time of Jackie Lee

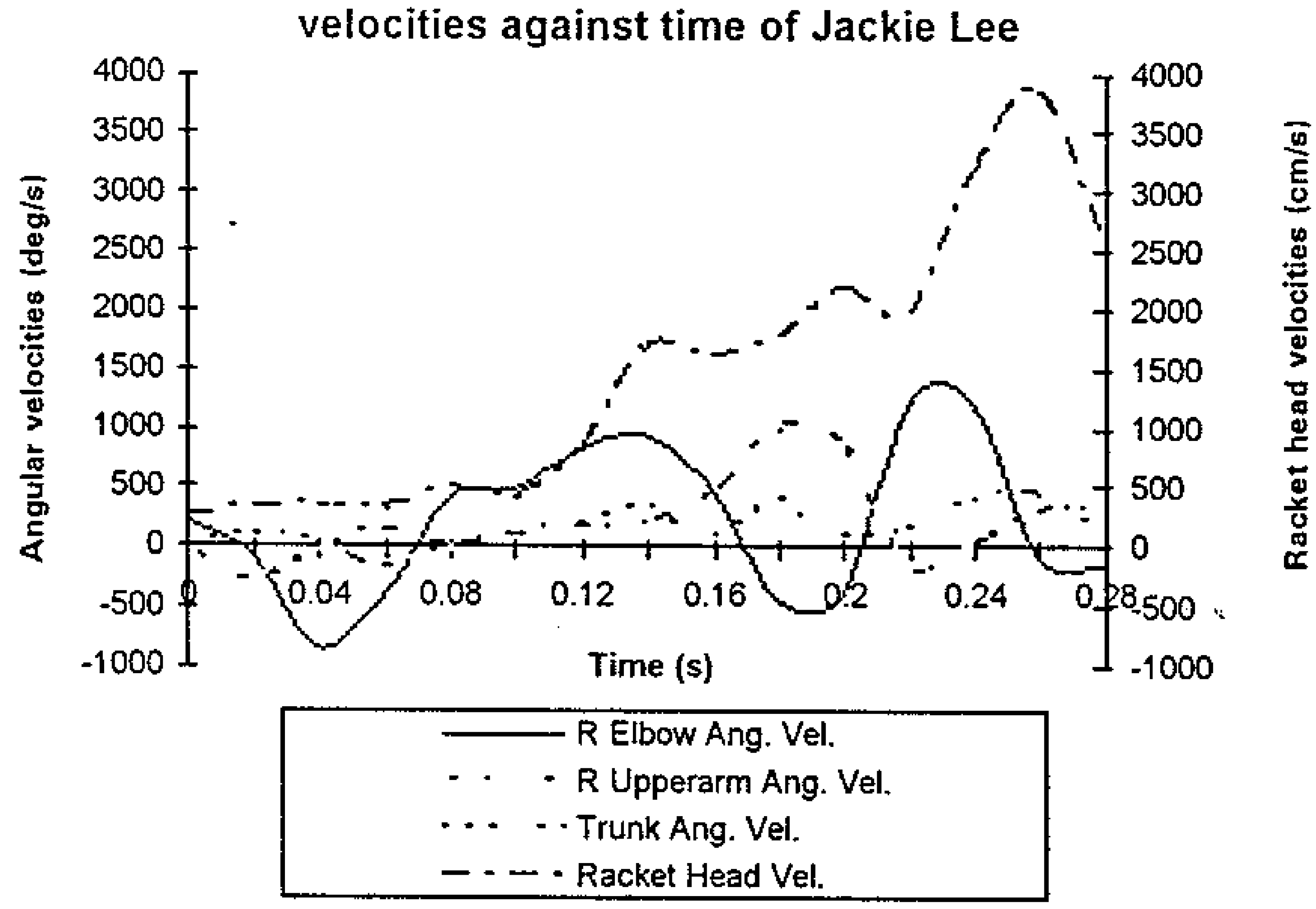
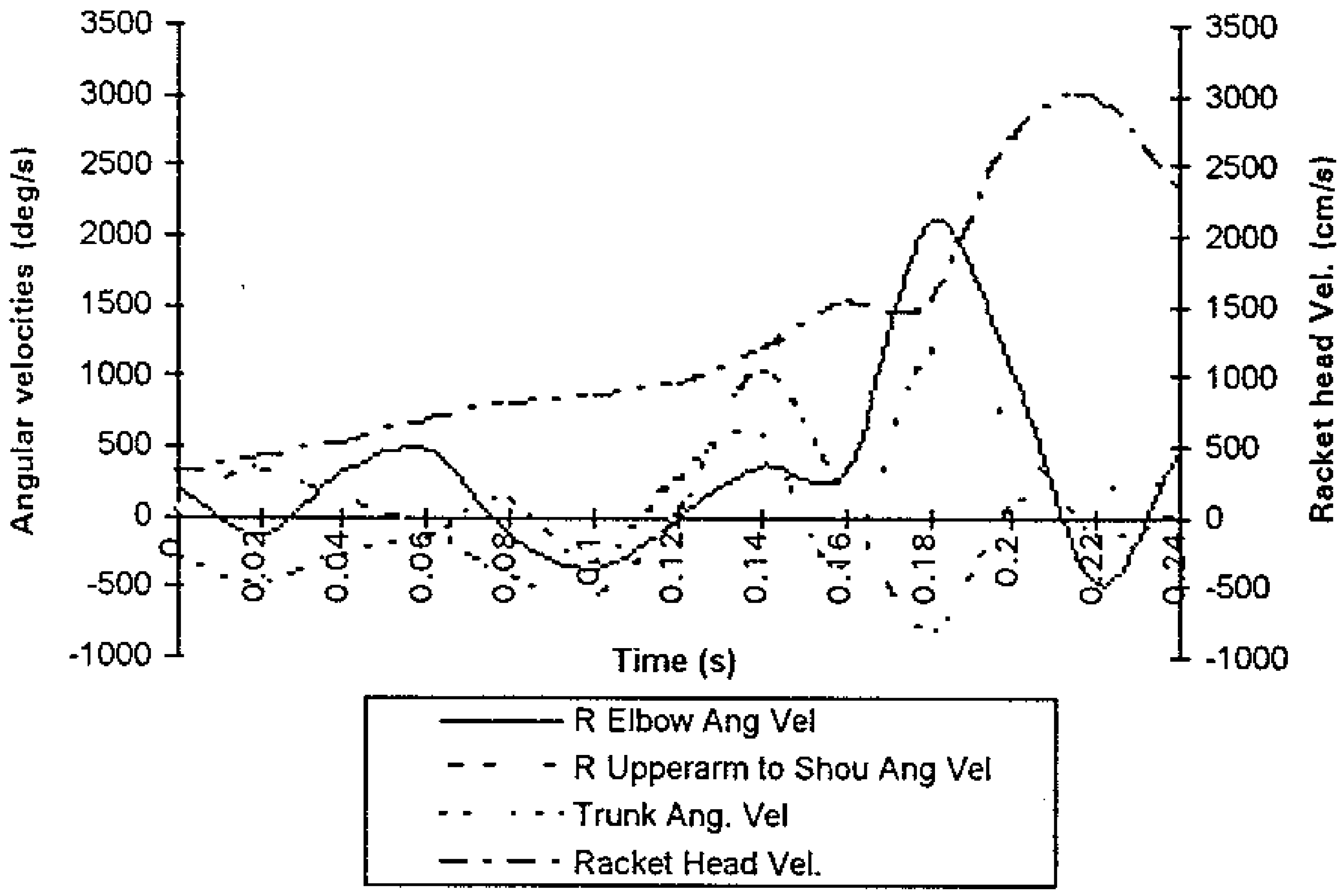


Fig. 7 Angular velocities of joints and racket head vel. against time of W.H.Wong



In this study, the position of the centre of mass of the athlethes' body, the orientation of the feet and the location of the ball were calculated and listed in Table 3. Some are presented following:

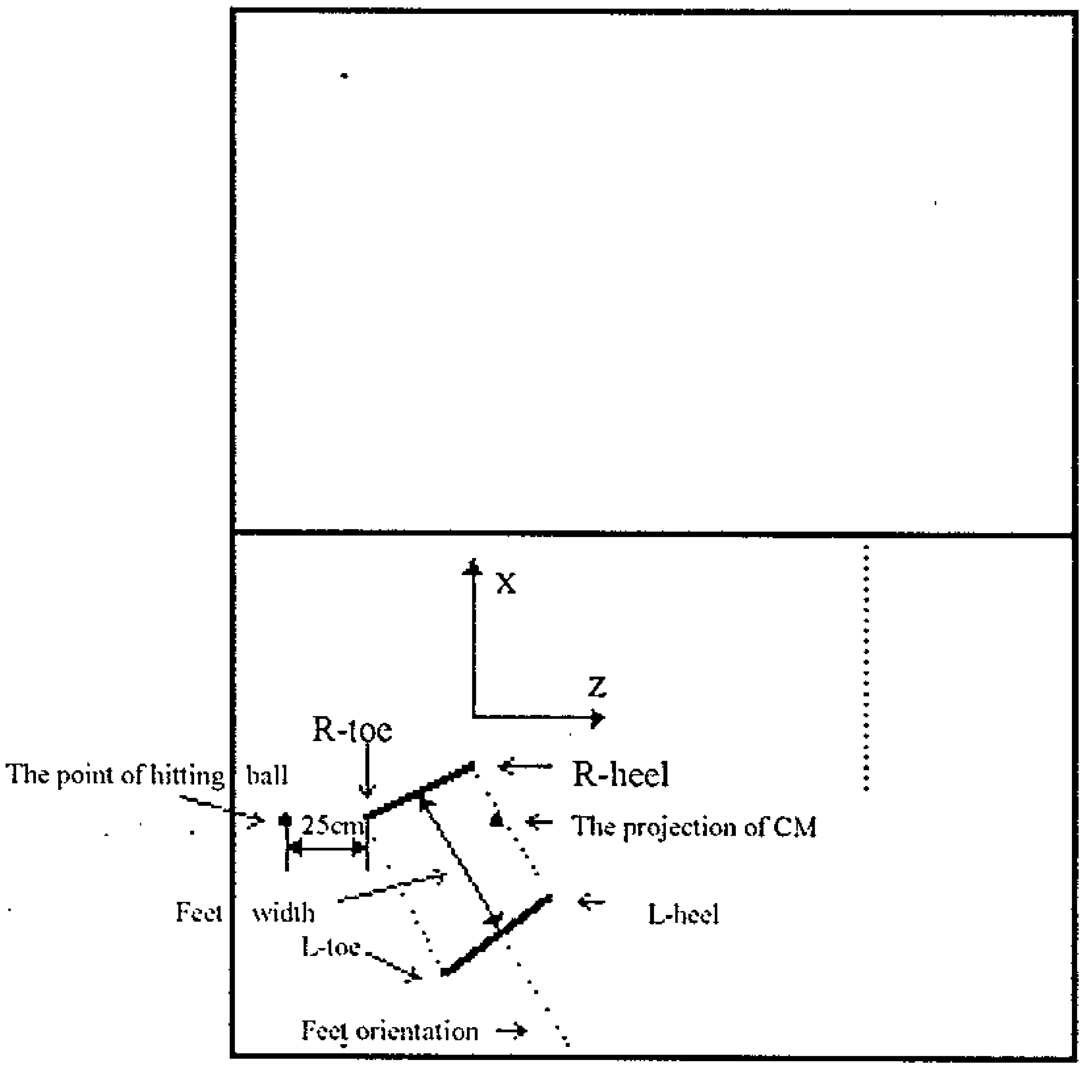
- All the players had the impact point below their right knee. Majority of them had the impact point about the midpoint between the right knee and the floor. The impact points of Brett Martin, Faheem Khan and W. H. Wong were relatively low.
- The distance separation between the projection of ball and the right toe (ΔZ) of Jahangir Khan and Brett Martin was about 20cm to 30cm. For the Hong Kong players, this distance was about 30cm to 50cm. These values are much greater than Jahangir Khan and Brett Martin.
- The body mass centre of Jahangir Khan and Brett Martin at racket-ball impact was relatively high. Especially, the impact point was low and the body mass centre was high in Brett Martin and the difference (Δh_2) was about 60cm. This is because the extent of the arm was great at the moment of racket-ball impact and the inclination of shoulder line was relatively large. High body mass centre enhanced the rapid return movement after impact. The body mass centre of Hong Kong players were relatively low.
- The distance of foot separation in Jahangir Khan and Brett Martin at racket-ball impact was very closed and about 50cm. The angle between the line passing the midpoint of the feet and the back wall was about 55° (Fig. 8) which was quite constant. However, the Hong Kong players, the position of their feet tend to be random positioning. This will affect the movement of trunk and arm during forward swing.

Table 3. The positions of mass centres, foot and ball at racket ball impact

Name	Trial	Co-ordination of ball (cm)		Knee height (cm)		Δh_1 (cm)	Height of CM (cm)	Δh_2 (cm)	Foot separation (cm)	Foot orientation (deg)
		ΔY	ΔZ	R	L					
Jahangir Khan	1	24.7	-30.0	38.4	40.2	13.7	71.3	46.6	54.4	54
	2	50.2	-25.1	51.2	50.5	1.0	86.8	36.6	52.2	52
Brett Martin	1	13.8	-23.4	45.4	42.2	31.6	80.8	67.0	54.1	59
	2	25.6	-26.0	53.6	51.9	28.0	84.2	58.6	46.4	52
Faheem Khan	1	21.4	-48.7	39.4	44.4	18.0	72.4	51.0	79.1	79
	2	21.2	-30.1	35.8	39.1	14.6	72.0	50.8	60.5	59
Jackie Lee	1	17.8	-51.3	42.5	36.0	24.7	68.1	50.3	49.0	72
	2	39.7	-45.0	43.7	41.6	4.0	86.4	46.7	36.8	67
W.H. Wong	1	19.2	-36.9	38.8	39.1	19.6	75.1	55.9	33.2	21
	2	22.2	-44.8	40.7	37.4	18.5	66.8	44.6	45.7	66

ΔY: The distance between ball and ground.
ΔZ: The distance between the projection of ball and right toe in Z direction.
Δh_1: The height between right knee and ball at impact.
Δh_2: The height between CM and ball at impact.

Fig 8. The position of ball, dimension and orientation of the two feet and the projection of CM at impact.



- Except the first trial of Jackie Lee, all of the floor projections of mass centres of the tested players were at about the midpoint of the line passing the heels (see fig. 8). At this position, the balance of body at the moment of racket-ball impact could be maintained and facilitated the rapid return to the "T" position.

Conclusions

After doing a comparison of the backhand straight drives of Hong Kong squash players and the top international squash players, we discovered that the basic technique of Hong Kong junior squash players still has room to improve. Especially, the movement co-ordination between trunk rotation and extent of arm during the forward swing, the accuracy of foot position and racket head velocity at impact should be paid more attention to them.

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Sub-project 4 : A Comparison of the Game Strategies Employed by Hong Kong National and International Squash Players in Competitive Situation by Notational Analysis

Introduction

Squash is an enjoyable and dynamic game, but advanced squash is highly demanding. The enclosed environment of the court allows fast rallies and the flight path of the ball can change abruptly after contact with the walls (Behm, 1987). Putting pressure on an opponent to create limitations in the dimensions of time and space is crucial for a winning shot. The time limitation can be achieved by "hitting the ball harder and faster, or taking the ball early by way of volleying, half volleying, or before the ball reaches the back wall", and the limitation of space dimension can be achieved by "hitting or making the ball travel and bounce closer to the side walls, particularly nearer any one of the 4 corners" (Wollstein and Neal, 1994). The successful use of strategy and tactics is of great importance.

Strategy and tactics employed in game sports are usually examined by means of notational analysis. The notations of player, action, position of the action, and/or outcomes of rallies can be made in real-time analysis to provide immediate feedback or in post-event analysis to provide more accurate and comprehensive information (Hughes, 1995). The increasing sophistication and reducing cost of video system have greatly enhanced post-event analysis: the sequential skill performances are recorded on film or video, analyzed post event, and then summarized statistically. During the video analysis, the player's motion is broken down, the frequency and/or timing of a particular shot, and the success or failure of that shot is determined. Based on this information, the strength and weakness of a player and of his/her opponent can be effectively evaluated (Clark, 1979).

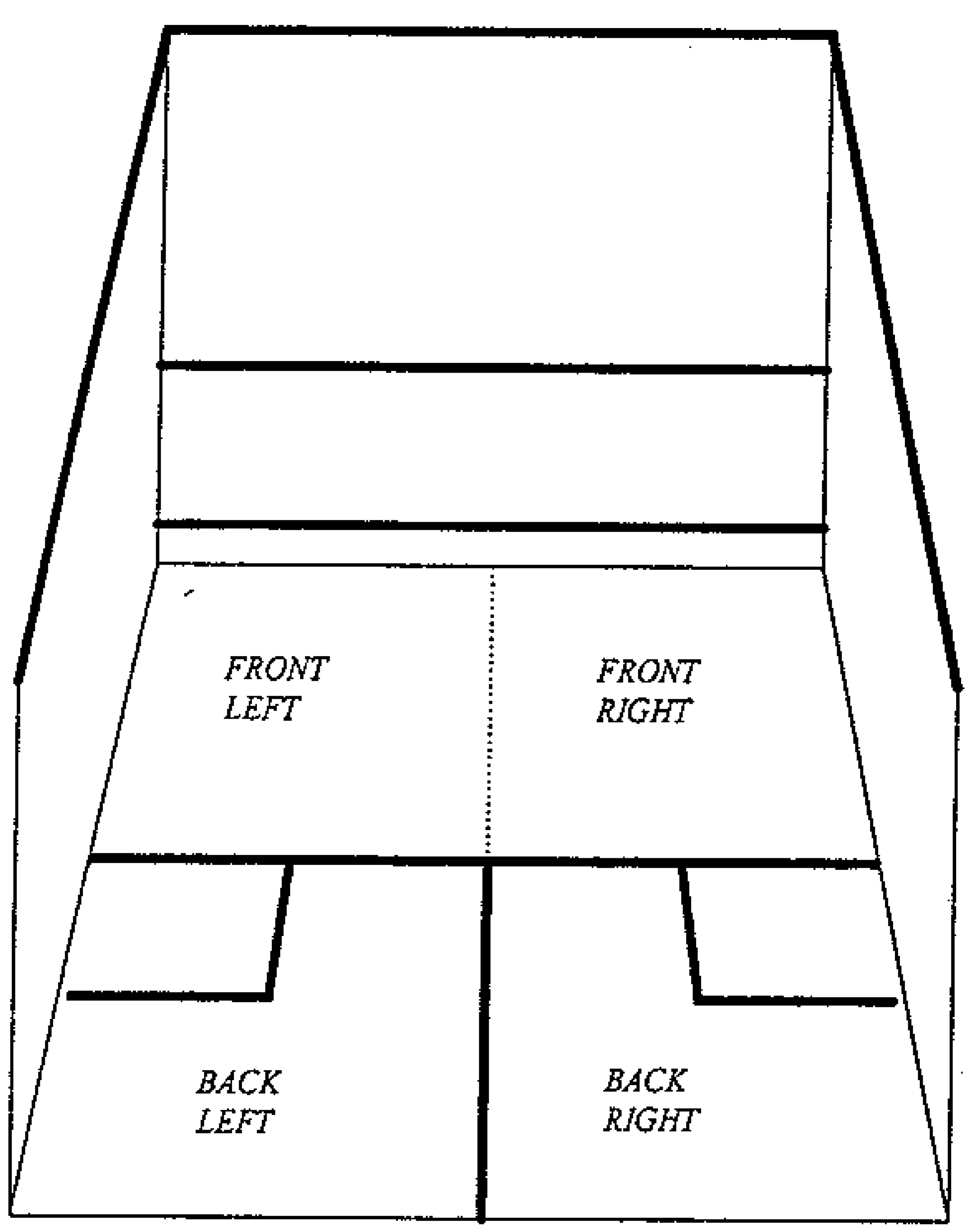
Several researches about the notational analysis of squash games have been published (Hong, et. al., 1996; Hughes, 1986, 1988, 1995; Hughes and Knight, 1995; McGarry, 1989; Wollstein and Neal, 1993). It is the notational study of games of squash which have developed databases of game strategy and which were functional and coach friendly. Although more systematic information about the strategy used in international squash has been provided, but the information about the game strategy of Hong Kong national squash players in a competitive situation have also not been investigated. The purpose of this paper is to profile the game strategy used by the Hong Kong national squash players in competitive situation and give recommendation for strategy improvement through comparing them with the world's top squash players by means of notational analysis. At the meantime, a more comprehensive database of Hong Kong squash can be established.

Method

The Perrier Hong Kong Closed Championship '94 was held in January 1994. The players participating in this competition were the top national squash players in Hong Kong. A total of 10 matches in this tournament including three in round one, the four quarter finals, the two semi-finals, and the final were filmed using 3-CDD video camera staged at the back of the court. Besides the two finalists who competed in the matches of the quarter finals and above, another 10 players from both tournaments were also involved in the analysis so as to reduce the bias of the strategy of the top two players in each tournament.

The analysis of video materials was based on the court being divided into four different areas as front left, back left, front right and back right as shown in Figure 1. The strokes that each player used, the positions of the strokes and where the ball landed were recorded. Strokes were identified according to 13 well known types as straight drive (SDr), cross court drive (XDr); boast (BO), reverse boast (RB); straight volley drive (SVDr), cross court volley drive (XVDr), straight volley drop (SVDp) cross court volley drop (XVDp), volley boast (VB); straight lob (SL), cross court lob (XL); straight drop (SDp), cross court drop (XDp). In order to depict the quality of the return shots, each return shot was classified into one of four different categories: "effective", "ineffective", "winning" and "losing" returns, showing the playing effectiveness of competitors. If the ball of a good return fell within half a racket length from the wall after rebounding or the opponent needed to play full stretch to make a good return, the shot was then classified as "effective". On the other hand, if the ball of a good return fell in an area outside this half a racket length after rebounding back from the wall or the referee decided it was a let, we classified the shot as "ineffective". A "winning" shot was one which the opponent missed, whereas a "losing" shot was an unsuccessful return on which the point was lost or the referee decided it was a stroke.

Fig. 1. The squash court is divided into four areas.



On the other hand, 10 matches of the Cathay Pacific Unisys Squash Open'93 were investigated by notational analysis with a similar design. A number of the world's top male squash players including 10 of the first 16 ISPA ranking players competed in the tournament. from. The data from these two tournaments were analysed by the percentage distribution for each player of the four categories of shots and the 13 different types of strokes used in the specific court areas involved. The 13 strokes were then grouped into five main stroke types for further comparison with t-test. Straight drive and cross court drive were grouped as drive; boast and reverse boast were grouped as boast; straight volley drive, cross court volley drive, straight volley drop, cross court volley drop and volley boast were grouped as volley; straight drop and cross court drop were grouped as drop; straight lob and cross court lob were grouped as lob.

The validity of the data collection was evaluated by comparing the results of a repeated analysis. It was found that in this match of 865 shots there were no errors in categorizing the shots into 13 types or in classifying the shots into "winning" or "losing" categories. In classifying shots into "effective" or "ineffective" shots, there was only a 1.85% error which was acceptable for this study.

The data was analysed by calculating the percentage distribution for each player of the four categories of shots and the 13 different strokes used in the specific court areas involved. Means and standard deviations of the frequency percentages were calculated to describe the results. For some critical factors a t-test was used to determine significant difference between means.

Results and Discussion

The distribution of shots in the four court areas

The percentage distribution of shots returned from different court areas and the t-test between the national and international competitions were presented in Table 1. The data show a different pattern of the use of the court areas between the national and international players. The international players returned shots from the back left court (44.8%) more frequently than the national players (39.51%); on the other hand, the national players returned the shots from the front right court (14.54%) more than the international players (9.97%). The difference between the international and national players in the use of the front right and back left court areas were statistically significant ($p<.001$). It revealed a difference in the strategy by means of the use of the court areas. The play of the international players were more defensive in nature since they would like to pressurise the opponent's backhand - the weaker side of most players (Hughes, 1995), and waited for the right chance to launch the attack play. On the other hand, the national players preferred to attack the opponent's front right court more than the international players. They returned the shots to the front right court as much as the front left court (14.54% and 14.56% respectively) and this pattern could not be seen from the international players. Regarding the whole front and back court, Table 1 shows that the international players returned higher percentage of shots from the back court than the national players (76.10% vs 70.90%), whereas the national players returned higher percentage of shots from the whole front court than their international counterpart (29.10% vs 23.91). These results supported Hughes (1995) who compared the pattern in play between recreational players, country players and nationally ranked players and found that the recreational players played more short shots. The nationally ranked players, because of their far greater fitness, covering ability and better technique, employed the more complex tactics, using an 'all-court' game.

Table 1. Percentage distribution of shots in the four court areas

Court area	National (%) Mean	SD	International (%) Mean	SD	Comparison p (t-test)
Front Left	14.56	3.82	13.94	4.18	n.s.
Front Right	14.54	3.85	9.97	2.82	.000 **
Front	29.10		23.91		
Back Left	39.51	4.87	44.88	6.83	.007 **
Back Right	31.39	5.17	31.22	3.94	n.s.
Back	70.90		76.10		

The effectiveness of the shots

The percentage frequency of the four effectiveness categories of the shots played in the national and international competitions were listed in Table 2. The national players demonstrated more "ineffective" shots and less "effective" shots than the international players, with the statistically significant difference ($p<0.01$). Table 2 shows that for the national players, only 55.26% (SD=12.47) of shots played were classified as "effective" which were within half a racket length after rebounding from the wall or the opponent needed to play full stretch to make a good return. Meanwhile, 33.98% (SD=10.22) of the shots were classified as "ineffective" which were considerably too far from the wall after rebounding. In the nature of squash competition, "effective" shots played long and short putt pressure on the opponent, whereas the "ineffective" shots may give the opponent opportunities for attacking. Hence, in order to improve playing proficiency, there should be lots of room for improvement of the accuracy of placement of shots for the national players.

Table 2. Percentage frequency of effectiveness categories of shots in the national and international competitions

Category	National (%) Mean	SD	International (%) Mean	SD	Comparison p (t-test)
Effectiveness	55.26	12.47	70.28	12.93	.001 **
Ineffectiveness	33.98	10.22	19.86	12.00	.000 **
Winning	5.24	2.66	5.37	3.03	n.s.
Losing	5.51	2.61	4.48	1.79	n.s.

Hughes (1995) compared recreational players with country and nationally ranked players, and found that the recreational players although hit more winners they also hit more errors. Table 2 shows that the national players played equal percentage of "winning" shots to and higher percentage of "losing" shots than the international players. Although no statistically significant differences were found with these two categories of shots between the national and international players, these percentage form a striking contrast to that of the "effective" and "effective" shots. Therefore, the results of this study were in agreement with that of Hughes.

As shown in Table 3, among those 55.3% of "effective" returns from the Hong Kong national players, it was distributed nearly evenly among the four court areas. It showed that the national players were able to cover the whole court area with similar ability. However, there were far less "ineffective" returns (21.75%, SD=3.38) from the front right court than the other court areas. At the same time, there were the most "winning" returns (35.49%, SD=16.99) and the most "losing" returns (37.31%, SD=13.47) from the front right court as well. It shown that the national players preferred to launch the attack in the front right court. The front right court with the longest diagonal distance from the back left court where most of the shots were played (Table 1), thus the opponent had to travel the longest distance to reach the ball. It also revealed that the national player practised a more offensive strategy than the international players even though their shots were less "effective". The lower effectiveness of the shots were highly influenced by the level of play as well as physiological conditions of the players. Squash is a physiological demanding sport. Montpetit et al. (1977) reported the highest VO2 measured during play for each elite squash in their study averaged 75.0+5.8% VO2max (range 56.3 to 89.4%). Blankshy et al. (1973) and Montgomery et al. (1981) measured near maximal heart rates in some subjects and in some cases to maximal heart rates higher than those measured during a VO2max test in the laboratory (Mercier et al., 1987). However, the physiological differences between the national and international players were beyond the scope of this study.

Table 3. Percentage distribution and ranking of playing effectiveness in each of the four court-areas.

	Percentage (%) (mean ± SD)	*Ranking within court*
Effective Return		
Front Left	23.43±3.52	4
Front Right	24.21±3.40	3
Back Left	27.10±3.61	1
Back Right	25.26±2.96	2
Ineffective Return		
Front Left	24.87±6.71	3
Front Right	21.75±3.38	4
Back Left	26.32±4.89	2
Back Right	27.05±4.51	1
Winning Return		
Front Left	30.86±12.89	2
Front Right	35.49±16.99	1
Back Left	14.37±8.07	4
Back Right	19.28±12.00	3
Losing Return		
Front Left	28.39±13.49	2
Front Right	37.31±13.47	1
Back Left	15.57±8.87	4
Back Right	18.73±7.32	3

Hong et al. (1996) found that high level player play a more conservative, safety game from the back court where the rate of "effective" shots is significantly higher than the "ineffective" shots. However, the national players in this study (Table 4) showed no difference between the rate of "effective" shots and "ineffective" shots. Therefore, the national players were not willing or not able to play a conservatively in the back court.

Table 4. Percentage frequency and comparative relationship (CR) of playing effectiveness shots between the front and back court and between the right and left court.

Effectiveness Category	Court area				Court area			
	Front (%)	Back (%)	t_1	CR_1	Right (%)	Left (%)	t_2	CR_2
Effective	47.64	52.36	35.90^c	0.91	49.47	50.53	11.31^c	0.98
Ineffective	46.62	53.37	14.29^c	0.87	48.80	51.19	5.62^c	0.95
Winning	66.35	33.65	38.75^c	1.97	54.77	45.23	8.17^c	1.21
Losing	65.70	34.30	3.37^c	1.92.	56.04	43.96	0.13^a	1.27

N=20.
Values are means.
CR_1 is Front/Back and CR_2 is Right/Left.
t critical value for $p < .05$ is 1.960 and for $p < .01$ is 2.576.
t_1 is between the front and back court, t_2 is between the right and left court.
For Significant difference, superscript a is $p>.05$ and c is $p<.01$

Analysis of stroke types used

The percentage distribution of the five main strokes in the whole court areas for both national and international competitions are presented in Table 5. Similar patterns in the distribution were found in both competitions. The drive was the most frequently used stroke in the whole court; with the drop and volley were the next popular strokes used; and the boast and lob were used the least by both international and national players. However, the results from the t-test between the national and international competition in all these strokes used revealed that significant differences were found from the percentage of drive ($p=0.001$) as well as boast and volley ($p<0.05$). The percentage of drive used by the national players (53.80%, SD=4.28) was significantly less than the international players (60.79%, SD=7.41). At the same time, the national players used significantly more volley and boast (15.04%, SD=2.51 and 7.25%, SD=4.00 respectively) than the international players (11.79%, SD=5.09 and 4.8%, SD=2.43 respectively). The decrease in the use of drive in the whole court was trade off with the increase in use of volley and boast, and it was speculated that the reasons were the lower quality of the return shots. If the return shots were not deep enough that the player could intercept them with volley easily. It was evident that the percentage of volley in the front court competition was significantly higher in the national than in the international competition ($p<0.01$). Furthermore, there was a significant higher percentage in the use of the boast in the right court in the national competition than in the international competition ($p<0.05$). The increase in the use of boast in the right court was an evident that the national were not capable to take up the right position to return the shots with drive and were forced to use the a less safe stroke like boast. Since the opponents were able to have more time to take up a better position at the front court since the speed of boast are far slower due the more rebounces. Since the drive is the foundation stroke of the game since it is a difficult stroke to attack and helps to stabilise play (Makenzie,1986, 1992; Robinson, 1990). Khan (1992) further stated that playing the drive is not only suitable for a safe game, but also it is a strategy to increase the work output of opponents moving them from the "T" to the back corner to allow the player to occupy the "T" and prepare a better opportunity for attack. It was recommended by most of the coaches that it should be used in order to keep the ball away from the centre of the court.

Table 5. Percentage frequency of the five main strokes in the national and international competitions

Strokes	National (%)		International (%)		Comparison
	Mean	SD	Mean	SD	p (t-test)
Drive	53.80	4.28	60.79	7.41	.001 **
Boast	7.25	4.00	4.80	2.43	.024 *
Volley	15.04	2.51	11.79	5.09	.016 *
Lob	5.07	2.22	4.72	2.59.	n.s.
Drop	18.99	3.76	17.91	5.08	n.s.

Conclusion

It can be concluded that the Hong Kong national squash players

- played both significantly more shots from the front right court and less shots from the back left court than the international top players; exhibiting the use of short game instead the "all-court" game;
- played both significantly higher percentage of "ineffective" shots and lower percentage of "effective" shots than their international counterpart, indicating the necessity to develop playing ability to create pressure on the opponents;
- demonstrated relative higher percentage of "winning" shots to and higher percentage of "losing" shots than the international players, showing the lower ability to play safety game;
- returned the most "winning" shots and the most "losing" shots from the front right court, showing their preference to launch the attack in the front right court
- employed significantly lower percentage of drive and higher volley in the front court and boast in the right court, indicating the importance of improving the playing quality of the drive shots.

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Sub-project 5 : Kinematic Characteristics of Smashing Techniques of Badminton in Hong Kong Elite Players

Introduction

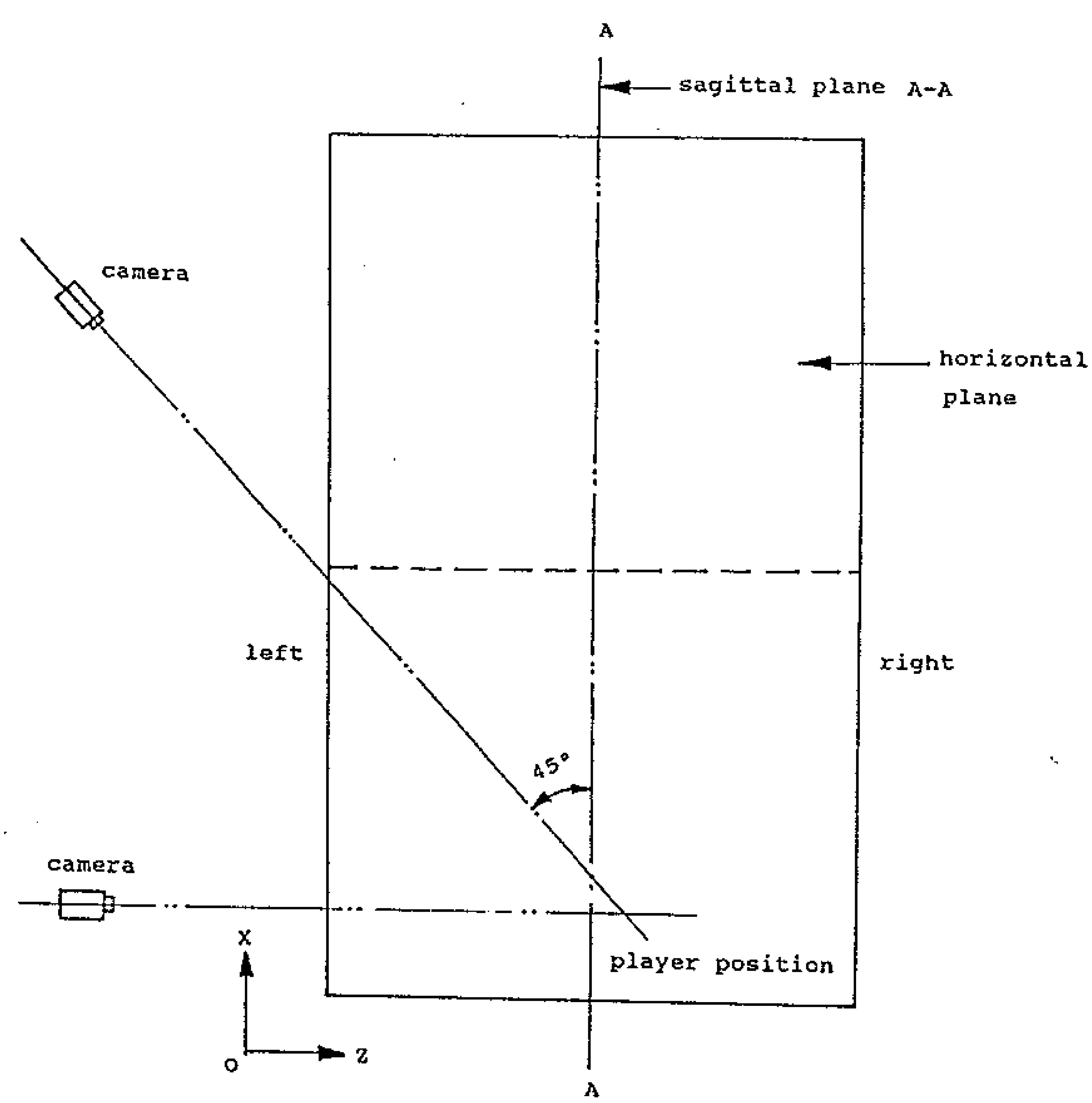
Badminton is one of the most popular sports in Hong Kong. This sport has been appointed by the Hong Kong Sports Development as one of the target sports. To further improve the playing technique of Hong Kong elite badminton players is one of the most important tasks of our biomechanics research works.

Smashing, being a crucial badminton technique, should be performed, in a biomechnial perspective, with a maximal muscular extent under an optimal segmental coordination. The purpose of this study was to identify kinematic characteristics in badminton smashing techniques of Hong Kong elite players and to give recommendation for technique improvement of Hong Kong players.

Method

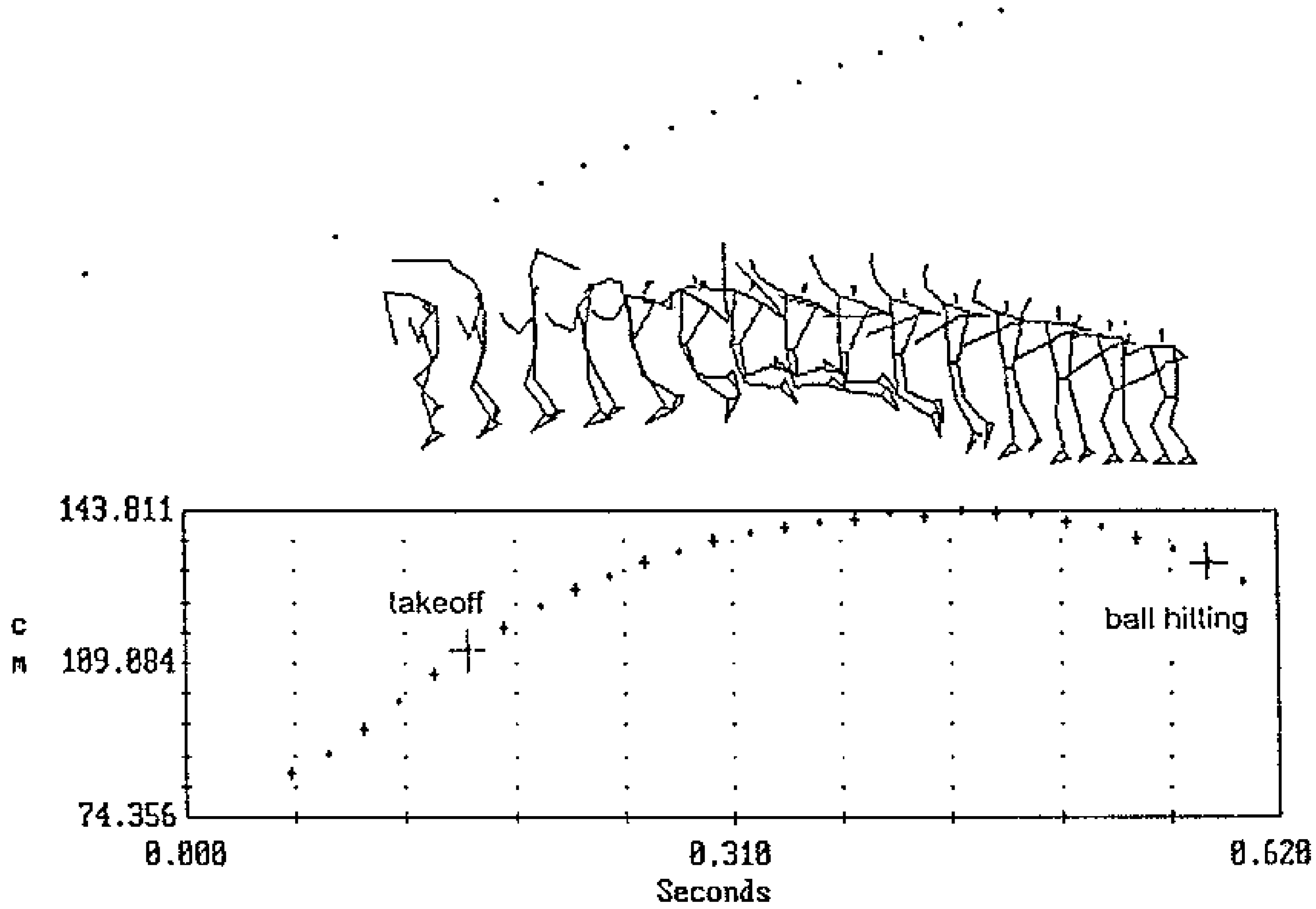
Two Gen.-locked 3-CCD video cameras of 50 Hz (exposure time 1/500 s) were used to film smashing strokes performed by 13 (6 female) Hong Kong elite badminton players. (Fig. 1).

Figure 1. A top view of camera position for 3-dimensional video shooting of badminton smash.



Each player performed smashing for 5 times. The best perceived one was used for analysis. A 3-dimensional calibration frame was also filmed after the shooting. The Horizontal and Sagittal planes were referred to for consecutive analysis. The video materials were processed by PEAK Motion Measurement Systemive to provide 3-dimensional data with a subject model. The model consisting of following identified points: shuttlecock, racket tip, ears, middle of the neck, shoulders, elbows, wrists, hands, knees, ankles, heels and toes, were displayed in a multi-stick diagram. A vertical time-history curve of mass center of the player was also attached (Fig. 2).

Figure 2. A Multi-stick motion diagram and a time-height curve of mass center during a badminton smash demonstration.



Results and Discussion

The mean value difference of racket tip velocity just prior to hitting between male ($54.47\pm6.14ms^{-1}$) and female ($51.48\pm2.05ms^{-1}$) revealed that men's players performed a faster racket swing and thus eliciting a higher shuttle speed after hitting (Table 1).

Table 1. Racket velocity before (V_{pro}) and after (V_{pre}) hitting the shuttlecock and shuttlecock velocity (S_{shu}) after being hit (m/s).

	Subject	V_{pro}	V_{pre}	V_{pro}- V_{pre}	V_{shu}
	Ngan F	54.66	43.45	11.11	55.05
	Tung CM	50.00	39.75	10.25	56.50
	Cheng YS	53.20	41.35	11.85	64.15
Female	Chung HY	49.35	40.70	8.65	58.85
	Chan ON	49.25	36.95	12.30	56.6
	Wong CF	52.50	43.40	9.10	61.30
	Mean±SD	**51.48±2.05**	**40.93±2.23**	**10.54±1.35**	**58.74±3.14**
	Chow KM	52.45	41.95	10.50	61.30
	Ng PK	41.40	18.69	22.71	60.75
	Wong WL	55.15	41.20	13.95	59.70
	Chan WK	54.90	42.00	12.90	61.25
Male	Chan KN	58.80	44.85	13.95	65.50
	Chan SK	62.70	49.00	13.70	66.45
	Ng LH	55.90	40.80	15.10	61.25
	Mean±SD	**54.47±6.14**	**39.78±9.01**	**14.70±3.50**	**62.31±2.38**

All participant's hit the shuttlecock after taking off from the ground. The time intervals of pre-hitting (T_{pre})and post-hitting (T_{pro}) airborne are (0.12±0.03S and 0.14± 0.03s) and (0.05±0.05S and 0.00±0.02s) for men and women respectively. Excessive airborne time or jumping height is unnecessary for a high birdie speed. One of the participants demonstrated a no-airborne hitting style, thus failing to transfer momentum of body parts to the birdie. As a result, the advantage of jumping and hitting was not present in such style. And it was not energy efficient to make contact in the falling phase as it gave a below-average birdie speed (Table 2).

Table 2. Time interval (sec) from take-off to contact (T_{pre}) and from contact to landing (T_{pro}).

	Subject	T_{pre}	T_{pro}
Female	Ngan F	0.08	0.04
	Tung CM	0.14	0.02
	Cheng YS	0.08	0.10
	Chung HY	0.14	0.02
	Chan ON	0.14	0.00
	Wong CF	0.12	0.12
	Mean±SD	**0.12±0.03**	**0.05±0.04**
Male	Chow KM	0.28	-0.02
	Ng PK*	0.42	0.12
	Wong WL	0.10	0.00
	Chan WK	0.16	0.04
	Chan KN	0.12	0.02
	Chan SK	0.16	-0.02
	Ng LH	0.160	0.00
	Mean±SD	**0.14±0.03**	**0.00±0.02**

* extreme cases not included in statistical analysis.
The '-' value means hitting upon landing resume, while '0' means hitting at the moment of landing.

Prior to contact, the sequence and times elapsed for joint flexion (men; women) were hip (0.09s; 0.09s), shoulder (0.08s; 0.07s) and elbow (0.04s; 0.03s). So, we found that hip flexion was the major initiator in smashing, followed by shoulder and lastly, the elbow. Trunk rotation (0.08s for both genders) was performed simultaneously with shoulder flexion (Table 3). The above pattern of movement was named as "proximal to distal"(PD) pattern. Similar PD pattern of segmental recruitment has been observed in an array of multi-segmental sporting activities, where the mechanical purpose is to generate a high endpoint velocity. Acting as the final force exertion, the wrist flexion joined force to maximize the racket tip and thus the shuttlecock velocity.

It can be concluded that to achieve a high velocity of racket and shuttlecock, one should maximize the flexion of hip, shoulder, elbow and wrist and also the trunk rotation. The sequential motion pattern of joints is hip, trunk and shoulder, elbow and finally wrist. The value of peak angular velocity of joint flexion and trunk rotation and the relative hand-to-wrist velocity correlated with shuttlecock velocity significantly. It is obvious that to strive for a powerful smashing, one should concentrate on developing powerful flexors and rotators for the segmental movements described above.

Table 3. Time interval (sec) between peak angular velocity of joints to the moment of hitting.

	Subject	Hip	Shoulder	Elbow	Trunk
Female	Ngan F	0.14	0.06	0.04	0.08
	Tung CM	0.06	0.06	0.04	0.10
	Cheng YS	0.08	0.08	0.04	0.06
	Chung HY	0.10	0.10	0.02	0.08
	Chan ON	0.10	0.06	0.02	0.08
	Wong CF	0.06	0.06	0.04	0.08
	Mean±SD	**0.09±0.03**	**0.07±0.02**	**0.03±0.01**	**0.08±0.01**
Male	Chow KM	0.10	0.08	0.04	0.08
	Ng PK	0.08	0.08	0.06	0.08
	Wong WL	0.10	0.10	0.02	0.08
	Chan WK	0.10	0.08	0.04	0.08
	Chan KN	0.08	0.08	0.04	0.08
	Chan SK	0.10	0.08	0. 02	0.08
	Ng LH	0.08	0.08	0.04	0.08
	Mean±SD	**0.14±0.03**	**0.00±0.02**	**0.00±0.02**	**0.08±0.00**

Amazingly, subjects who participated in the test held two months ago showed a significant improvement in ball smashing velocities, especially those who used to smash relatively slow. The improvement in technique might attribute to more mobilization of joint flexors and trunk rotators.

Conclusions

In order to improve badminton smashing, players were recommended to:

1. Improve joint motion coordination for a more efficient segmental PD pattern.
2. Improve shoulder joint flexibility in order to hyper-extend it for a larger range of motion.
3. Increase the strengths of trunk rotators and hip, shoulder, elbow and wrist flexors through specific weight training programs.
4. Improve the timing of takeoff, hitting and landing. A more effective hitting should happen at the vertex of the CM parabola.

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Sub-project 6 : The biomechanical analysis of Peter Haining's rowing technique on ergogmeter

Introduction

Peter Haining is the world champion in rowing (light weight). His technique is valuable to the Hong Kong rowers. So that, during his stay in Hong Kong, we video filmed the movement training on ergogmeter.

Rowing is one of the most rapidly developed sports in Hong Kong and is has been defined as one of the target sports by the Hong Kong Sports Development Board. The purpose of this paper is to find out the technical characteristics of Peter Haining rowing on ergogmeter will be analyzed and act as a reference for Hong Kong rowing athletes.

Method

Two 50 Hz video cameras (exposure time 1/250 s) were used. One was positioned at the front and the other was positioned at the right side of the ergogmeter. Peter was performed step test on the ergogmeter. This test consisted of 4 steps, 5 minutes for each step and 1 minute break between each step. In each step, three complete rowing cycles at first minute, third minute and fifth minute times were selected for analysis. The video materials were then processed by Peak Performance System.

Results and Discussion

Table 1. The kinematics parameters with respect to the vertical position of mass center (CM)

Step	Test	Y_{max} (cm)	Y_{min} (cm)	ΔY (cm)	Standard deviation	α (deg.)
1st	S_{1-1}	65.3	56.7	8.6	2.9	24.14
	S_{1-2}	64.4	56.1	8.3	2.9	26.59
	S_{1-3}	64.5	55.4	9.1	3.2	26.13
2nd	S_{2-1}	64.3	55.2	9.1	3.0	28.12
	S_{2-2}	65.6	54.4	11.1	3.5	31.36
	S_{2-3}	64.7	54.5	10.2	3.3	31.95
3rd	S_{3-1}	65.5	54.9	10.6	3.6	31.42
	S_{3-2}	65.2	54.4	10.8	3.5	30.90
	S_{3-3}	65.1	53.3	11.8	3.7	34.78
4th	S_{4-1}	64.2	53.7	10.5	3.3	31.43
	S_{4-2}	65.1	53.2	11.9	3.8	34.99
	S_{4-3}	64.7	53.3	11.4	4.0	34.00
Mean		64.9	54.2	10.6	3.5	31.68

S_{n-i}

→ i = 1,2,3
- 1, 1st min. of the step
- 2, 3rd min. of the step
- 3, 5th min. of the step

→ n=1,2,3,4, the number of step

α: The truck backward angle at the moment of the lowest CM (see Fig.3).
Y_{max}: The highest position of CM
Y_{min}: The lowest position of CM
$\Delta Y = Y_{max} - Y_{min}$

I) The average Y_{max} is 64.9 cm and the average Y_{min} is 54.2 cm. The difference between the two heights (ΔY) is 10.6 cm.

II) The average standard deviation is 3.5 cm which implies the rocking range is about 3.5 cm. This means that there is a vertical displacement 3.5 cm above or below the average vertical position of CM. The smaller the average standard deviation, the better the technique will be.

III) With the increase of the level of tiredness, the standard deviation and the ΔY increase.

VI) The average truck backward angle (α) is about 30 degree. With the increase of the level of tiredness, this angle increases obviously. This indicates that he makes use of the truck and backward waist bending to overcome the tiredness of his arms. However, this will make the CM of the system lower and cause the rocking range of the system increase.

Table 2. The stoke frequency

Test / Step	1st minute	2nd minute	3rd minute	4th minute	5th minute	Total stokes
1	29	29	29	29	28	143
2	30	30	30	30	30	150
3	32	32	32	32	32	160
4	34	34	33	30	33	164

I) Peter's stoke frequency is constant. This indicates his technique is stable.
II) During the 4th step, his stoke frequency appears to be unstable. It may due to exhaustion.

Table 3. The kinematics parameters during pulling and pushing phases

Step	Test	T_{1-1} (s)	T_{1-2} (s)	T_{2-1} (s)	T_{2-2} (s)	V_{max1} (cm/s)	V_{max2} (cm/s)	Frequency (times/s)
1st	S_{1-1}	-0.05	0.06	0.10	0.17	-125.7	125.6	0.48
	S_{1-2}	-0.12	0.06	0.08	0.18	-140.2	124.6	0.48
	S_{1-3}	-0.11	0.02	-0.02	0.26	-142.7	123.4	0.475
2nd	S_{2-1}	-0.06	0.00	-0.02	0.14	-144.6	134.0	0.50
	S_{2-2}	-0.16	0.00	0.00	0.20	-147.9	133.0	0.50
	S_{2-3}	-0.14	0.02	0.02	0.20	-152.2	128.3	0.50
3rd	S_{3-1}	-0.06	0.00	0.00	0.16	-149.6	139.5	0.53
	S_{3-2}	-0.12	0.02	0.00	0.18	-160.1	143.4	0.53
	S_{3-3}	-0.12	-0.02	0.00	0.04	-157.6	142.7	0.53
4th	S_{4-1}	-0.06	-0.02	0.00	0.16	-154.3	147.3	0.57
	S_{4-2}	-0.12	-0.02	-0.02	0.18	-158.3	150.0	0.55
	S_{4-3}	-0.06			0.32	-166.7		0.55
	mean	-0.10	0.01	0.015	0.18			

T_{1-1}: The time between seat stop and handle stop during pulling phase.
T_{1-2}: The time between seat stop and handle stop during pushing phase.
T_{2-1}: The time between seat movement start and handle movement start during pulling phase.
T_{2-2}: The time between seat movement start and handle movement start during pushing phase.
V_{max1}: The maximum speed of CM during pulling phase.
V_{max2}: The maximum speed of CM during pushing phase.

I) During the pulling phase, the seat stops prior to the handle. The average time difference between them (T_{1-1}) is 0.10 second. It is obviously that the time difference becomes longer with the increase in the level of tiredness.
II) The two parameters , T_{1-2} and T_{2-1}, can reflect the result of the coordination between the arms and legs during the translation between pushing and pulling. Except the test T_{1-1} and T_{1-2} , the other data indicate the co-odination of arms and legs is almost synchronized.
III) During the pushing phase, the handle movement begins prior to the seat movement. The average time difference between them (T_{2-2}) is 0.17 second.
VI) With the stoke frequency increase, the maximum speed of CM in pulling phase will . be increased. This situation is the same in pushing phase.

Table 4. The time of arms and legs exerting force during pulling phase.

Step	Test	T_l (s)	T_a (s)	T (s)
1st	S_{1-1}	0.30	0.54	0.84
	S_{1-2}	0.28	0.54	0.82
	S_{1-3}	0.28	0.54	0.82
2nd	S_{2-1}	0.26	0.52	0.78
	S_{2-2}	0.30	0.50	0.80
	S_{2-3}	0.30	0.52	0.82
3rd	S_{3-1}	0.30	0.48	0.78
	S_{3-2}	0.28	0.50	0.78
	S_{3-3}	0.28	0.50	0.78
4th	S_{4-1}	0.26	0.40	0.66
	S_{4-2}	0.36	0.40	0.76
	S_{4-3}	0.28	0.46	0.74
Mean		0.29	0.49	0.78

T_l: The time of legs exerting force during pulling phase (see Fig.2).
T_a: The time of arms exerting force during pulling phase (see Fig.2).

From the curves of angular velocities of knee and hip joints against time, we discover that there is a rapid extension of knee-joint just before the end of Peter's knee extension in most of the curves (Fig.1).

From the curves of seat and handle velocity against time (Fig.2), the time of rapid force exertion of legs (T_l) and arms (T_a) can be analyzed. From Table 4, we discover that, there is an increase in tiredness, T_a will become small. However, the change of T_l is not great. The total time (T) in pulling phase becomes small.

Figure 1. Angular velocity of knee and hip joint against time in test S_{3-3}

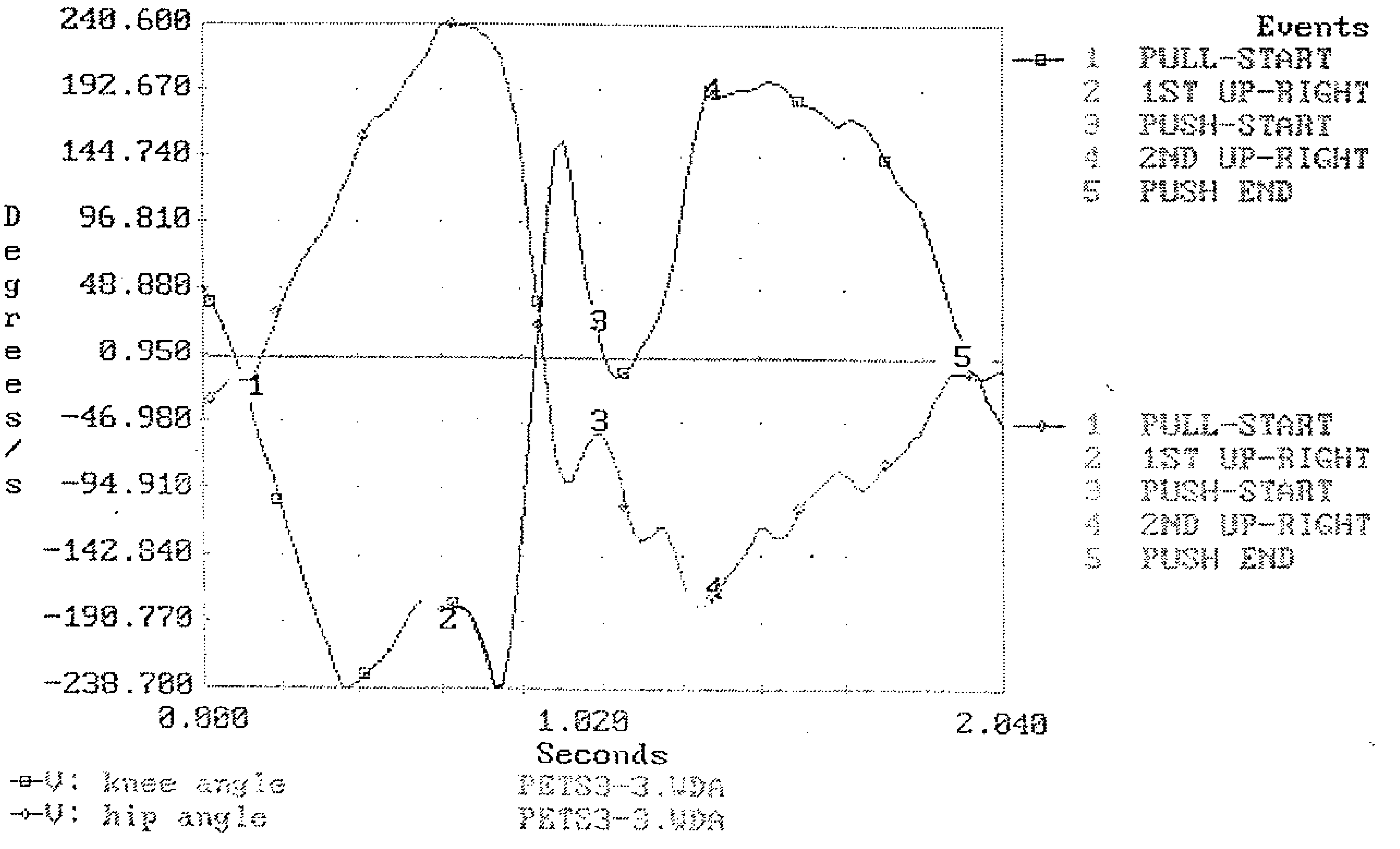


Figure 2. Horizontal velocity of handle and seat against time in test S_{1-2}

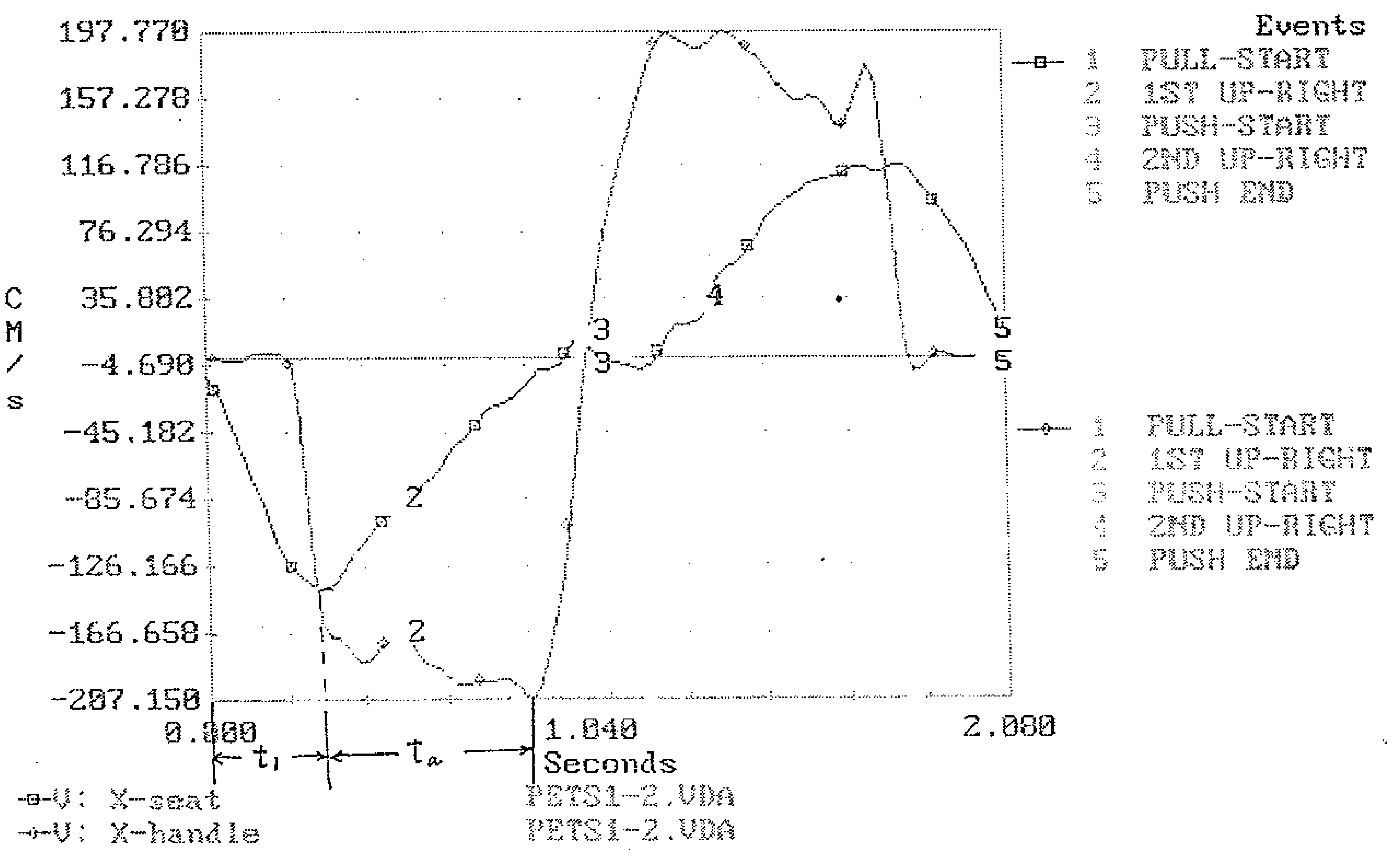
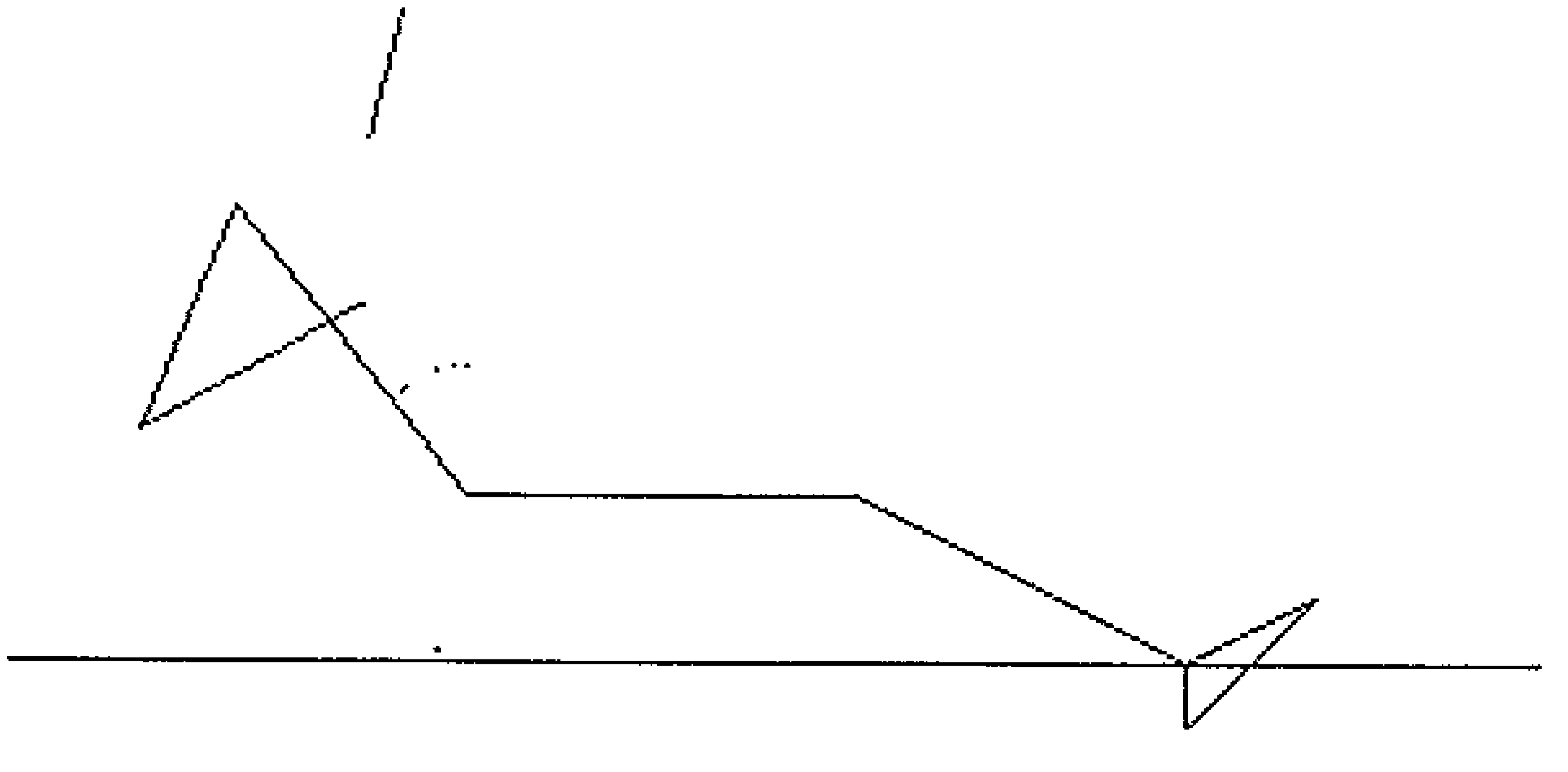


Figure 3. The truck backward angle (α) at the moment of the lowest CM



Conclusions

This is the first time for us to analyze the technique characteristics of rowing using the ergogmeter. The kinematics parameters that we selected here are based on the advice given by the coach. Moreover, the following curves are also given for the reference of Cybex training. 1) Angular velocity of knee and hip joint against time; 2) Linear velocity of seat and handle against time; 3) Vertical displacement of CM against time; 4) Angular velocity of hip joint against hip angle and 5) Angular velocity of knee joint against knee angle.

Sub-project 7 : Biomechanical Analysis of the Somersault Side Kick with Three Quarter Twist Performed by Ng Siu Ching

Introduction

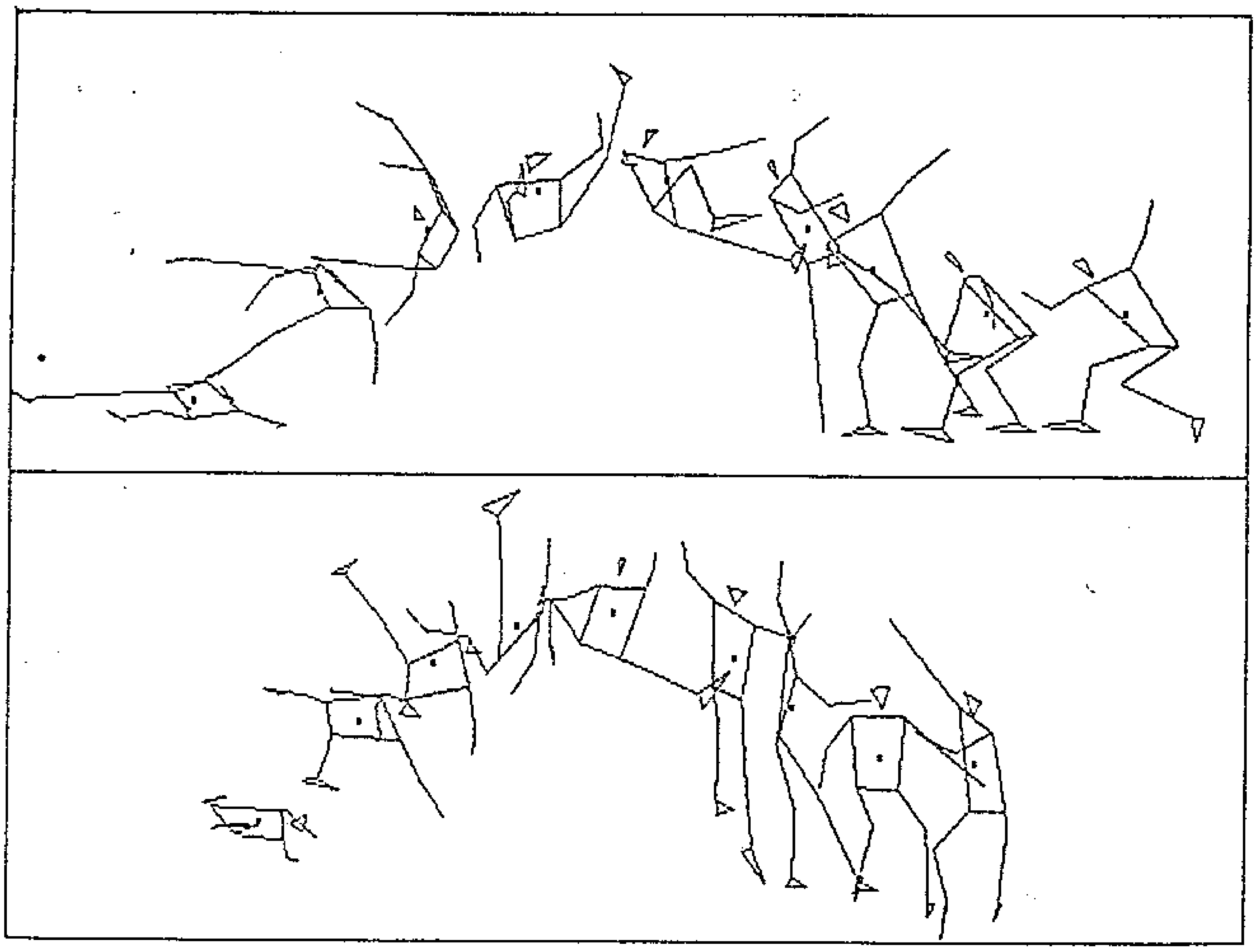
Somersault side kick with three quarter twist, a difficult and yet key movement in the Nanquan competition routine, should be performed with height, lightness, neatness and steady landing in order to impress the referees and spectators.

This study aims at helping Ng Siu Ching (Ng) improve her height and lightness in performing the somersault side kick with three quarter twist. In this pioneering study, researchers filmed and analyzed characteristics of Ng's movement patterns with biomechanical means. And then, suggestions for quality betterment was given. Wushu has a unique value system on the expression of movements. And biomechanical study in this sport is yet to be developed.

Method

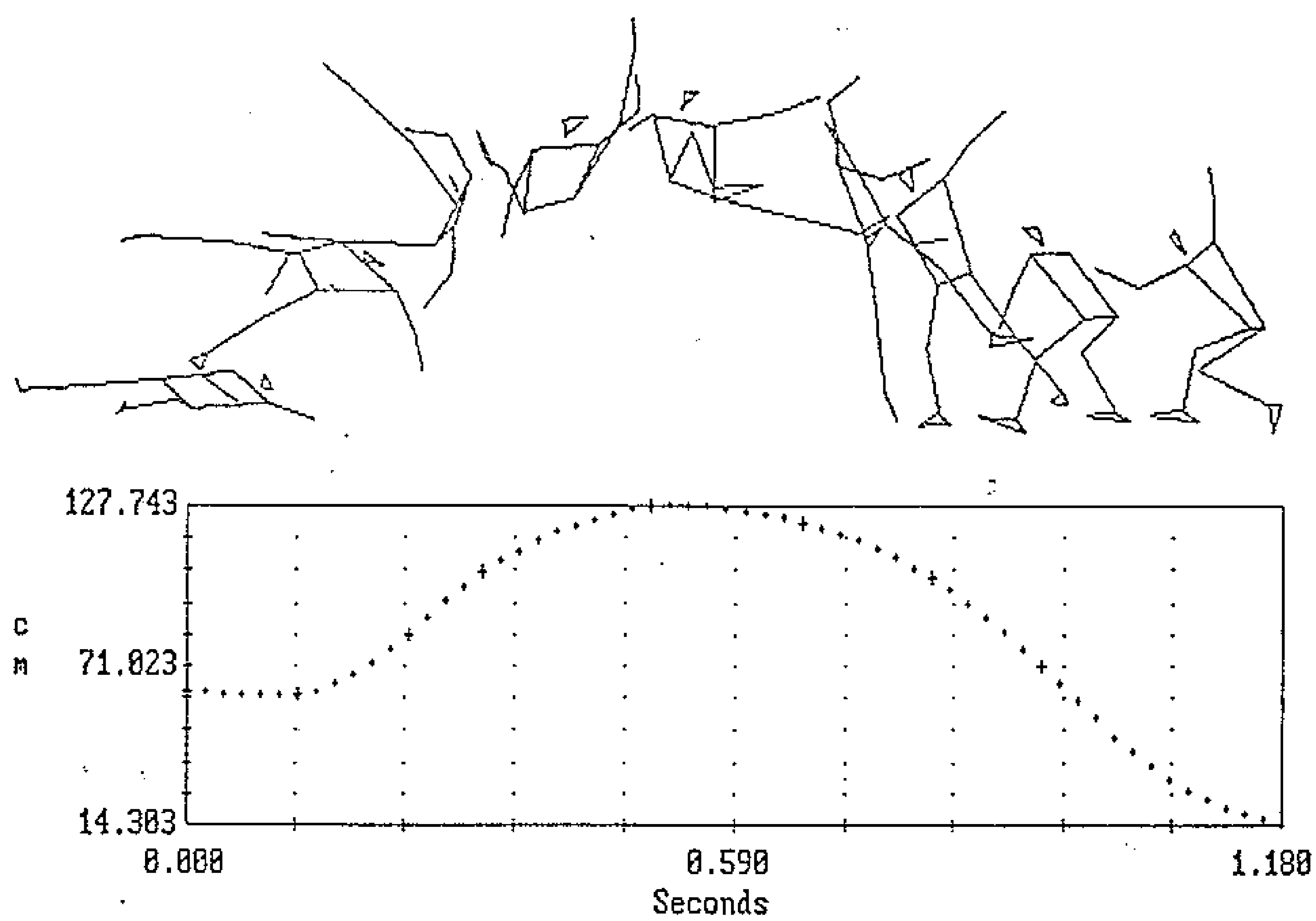
Two Gen.-locked 3-CCD video cameras of 50 Hz (exposure time 1/500 s) were positioned in front of and to the side of Ng to film her somersault side kick with ¾ twist for 3 times. The best of the 3 shots was digitized for a 3-dimensional motion analysis using Peak Motion Measurement System. Following parameters were obtained: 1) segmental center of mass (CM) displacements and velocities 2) joint angles , and 3) segmental angular velocities. The video materials were processed to give 3-dimensional data in form of a subject model which was displayed in 2 multi-stick diagrams, one in side view and the other in front view (Figure 1).

Figure 1. Multi-stick motion diagrams of Ng's somersault side kick with ¾ twist (Top: Side view; Bottom: Front view).



The curve depicted the relationship of vertical displacement of the center of gravity of Ng's body and time during the performance of this skill was given in Figure 2.

Figure 2. A time-height curve of mass center showing Ng's somersault side kick with ³/₄ twist.



Results and Discussion

Ng's somersault side kick with ³/₄ twist had a flight time, flight height and a horizontal CM displacement of 0.70sec., 1.27m and 1.29m respectively. Compared equivalent parameters (0.70sec, 1.27m and 1.46m) extracted from the same movement performed by a male world class Nanquan athlete, Ng's flight time and flight height had reached a compatible level, so her performance was unanimously believed to be very outstanding. As a major task stated before, the flight height was determined by the vertical CM velocity at take-off. And such take-off velocity was affected by the extension of the supporting leg and by arm swing.

There being a lack of previous data in this sport event, the information gathered had no target to be compared to. So these data could act as a pioneer set of reference for future studies in this exciting area. Based on our experience in studying jumping events, we found that Ng's joint angles of knee and hip were quite pertinent at take-off (Table 1).

Table 1. Kinematic Parameters of body parts in support phase.

Kinematic parameter	Ng Siu Ching
Vertical CM velocity (Takeoff)	2.25ms^{-1}
Horizontal CM velocity (Takeoff)	1.92 ms^{-1}
Knee extension angle (takeoff leg)	26.6°
Hip extension angle (takeoff leg)	38.2°
Takeoff Duration	0.08sec.
R.Shoulder angle (Takeoff)	68.2°

The overall performance could be improved by shortening the take-off period and enlarging the range of arm swing. Also, reaction force during taking off could be increased by a quicker take-off movement and arm swing.

In Wushu, "lightness" means the extent of being natural, relaxed and aesthetically pleasing. Ng's body in the air was not fully extended as her legs were so far apart and almost perpendicular to each other (Table 2).

Table 2 . Kinematic parameters of the body parts in the flight phase .

Kinematic parameter	Ng Siu Ching
Largest angle of left knee joint if the air	63.2°
Largest angle of right knee joint in the air	159.2°
Largest angle of left hip joint in the air	55.2 °
Largest angle of right hip joint in the air	41.3°
Largest angle between two legs in the air	87.9°
Horizontal displacement of CM	1.29m
Vertical displacement of CM	1.27m
Flight time	0.70sec

Also, The excessive tension at her hip and knee joints should be lessened. Without deflecting her CM trajectory by exerting excessive force for jumping height, Ng could further extend her hip and knee joints. Therefore, the lightness could be enhanced without collaborative effort for height increase. Moreover, the somersault side kick movement involves body rotation about the longitudinal axis. Slight decrease in between-leg angle and more extension at hip and knee would decrease the angular momentum with respect to the longitudinal axis of the body. The angular velocity could in turn be increased to make the airborne movement lighter.

To improve the steadiness and smoothness of landing, Ng was suggested to extend her extremities so that arms, trunk and legs could be kept at the same horizontal level prior to landing. In this way the impact force can be reduced, and injuries could also be prevented from.

Conclusions

Resulting from the findings, recommendations were listed as follows:

1. Improve power of takeoff leg and range of motions of swinging arm through physical training, so as to increase takeoff velocity.
2. Lessen the tension of lower extremities and increase extension at hip and knee, so as to be more elegant.
3. Extend all extremities and contract relevant muscles isometrically at the moment of contact, so as to enlarge body area of contact and to reduce risk of injury.

V. CONCLUSIONS

In this project, biomechanical analysis of sports techniques utilizes scientific method to analyze techniques. Such scientific analysis includes the process of video filming of athletic performance, data acquisition through digitizing on the advanced motion analysis system and data classification and identification by running the software integrated in this system. The execution of this research project mainly relies on the use of advanced motion analysis system - the Peak Motion Measurement System. This indicated that the computerized advanced motion analysis system is essential for biomechanical study on human movement.

The three dimensional video filming, which was based on synchronized operation of two video cameras, was widely used to collect information of athletic movement in "all dimension of the space". In this project, the three dimensional filming technique was used in the research of athletic performance of squash stroke, badminton smash and wushu skill. In order to guarantee the synchronization of the recording of two cameras, a "synchronization unit" was used by these investigations. The successful execution of this research project, especially its fruitful results proved that this unit was useful for 3-D data collection.

In addition, a computer program was developed by the investigators to enhance the function of the Peak motion Measurement System. This program can combine and normalize the two dimensional displacement data collected by two or more separately operated cameras together so as to study the athletic movement performed in a larger range. This program was very successfully applied to the sub-projects of 100m sprint and high jump, as well as the research works, long jump and triple jump, of the biomechanics unit in Hong Kong Sports Institute.

Game analysis based on notation methods was the first time used in Hong Kong for national squash players. With game analysis, the characteristic of strategy and tactics employed by Hong Kong national squash players in competitive situation was profiled and recommendations was given to coaches for strategy and tactics improvement through comparing them with the world's top squash players. The results proved that it is the notational study of squash games which have developed database of game strategy of Hong Kong elite squash players and which were functional and coach friendly.

It is international widely recognized that the sports science has become more and more important to enhance the athletic performance, especially when they really want to break the records or become the top level athlete. This piece of study is widely agreed to be a good start as an essential part of sports science development in Hong Kong. Moreover, a combination of motion analysis and other dynamic methods such as the force measurement and electromyography measurement, could better the outcomes. The team member of this research project would like to continue and expand the project so as to further our contribution to the development of elite sports and/or sports for the mass. We hope that the information gathered in this study could be a solid template for the biomechanical study of sport techniques in Hong Kong.