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An Indirect Measurements of Kinematic and Kinetic Parameters of Sprinters

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Abstract: This study examined the velocity, acceleration, ground reaction, stopping, and take-off forces, during running in a hundred meter event. An electronic telemetry system was designed and constructed for kinematic investigations, while videography was used to analyze each stride kinetic characteristics. During the constant speed, the ground reaction force and also stopping and take-off force, mean energy and power consumption in each stride were also estimated. The performance criterion measure was time to each 10m. We have used Micosoft Excel for tracing the variation of velocity and acceleration of each subject. Three male sprinters (top national team) volunteered as subjects for the study. The sprinter's record was 10.8 second in 100 meter run. The study demonstrates how the velocity increases widely at the beginning, then remains constant for sometime then decreases, when the runner reaches the end of the run. On the contrary, the acceleration is, maximum, just at the take-off, then decreases to zero when the sprinter reaches to his maximum velocity, then decelerates arriving to the end of run. The results on force measurements showed that the sprinter with larger strides presents larger ground reaction, stopping, and take-off forces which agree well with what the other researchers have obtained.

Key Words: Acceleration, Velocity, Average and Maximum forces, CG flight Angle, Sprinters

Introduction

Electronic devices are widely used in sports training and applied research, to measure running, walking, jumping and skiing velocities. Ten transmitters with adequate power (0.5 watt at 100 MHZ), were designed and distributed every 10 meter distance intervals. Each of these transmitters is controlled by a lens and a photocell with an adequate amplifier. The transmitters are normally off, but whenever a sprinter reaches in the view of the lens ,the transmitter turns on, sending an electric signal. Ten signals present ten distance intervals. The transmitters are in the same condition and are sensitive to body of the sprinters, that means, whenever, the whole body, takes place in the field of the lens, the photocell, as transducer, let the transmitter, transmit a signal.
The photocells are also widely directly used in sports training and applied research to measure time and velocities in most sport skills. By combining several photocells, researchers can build light curtains for time and space determination of a moving object. The measurements of release velocity and angle for flying objects such as javelins and balls have been reported by using photoelectric, computerized on-line system (Viitasalo and Korjus, 1987 and 1988).
Another photocell computerized on-line system, the Photocell Contact Mat (PCM) was also developed for applied research as well as for coaching purposes to measure ground contact time and flight time as well as step and stride frequency as a function of running time or running distance (Viitasalo, 1995). Another, such a system was alsoused to measure contact and flight times in running (Viitasalo, Luhtanen, Mononen, Norvapalo, Paavolainen and Salonen, 1997).
The purpose of our study was to evaluate the validity and accuracy of our system in determining the variation of velocity and the acceleration of the top sprinters and also finding out their behavior in a 100m running to make a comparison. In addition, stride characteristics such as ground reaction, stopping, and take-off forces have also been evaluated.

Materials and Methods

(a): Kinematic Study

Generalities: The analysis of men's 100 meters was carried out on the basis of recording obtained from 10 video cameras (60 fields/sec) (Ae,M, *et al.*, 1992).
All cameras were synchronized with the flash of the starter's gun. They used these cameras located at 10m intervals straight along the stadium. The elapsed time of the sprinter could be achieved then the variation of velocity could easily be traced.
Other method reported byn (Viitasalo *et al.*, 1997), was based on two separate photocell bars and a micro computer. The width of the current version was selected at about 1.12m, based on the width of on athletic running lane. Both of the two photocell bars consisted of 19 receiving photocells and two transmitting units sending fan-shaped infrared light to the receiving photocells. The combined horizontal resolution of the two infrared fans perpendicular to the running direction was less than 50mm. The distance that the current version could cover was up to 120m. The on-off signal information from the photocells was recorded by a micro computer, using an A/D converter card, with a sampling frequency of 2KHZ.

Proposed Method : The proposed system consists of 10 FM transmitters and a receiver with a main board having a crystal based oscillator with 10 timers.

Transmitters: In order to have time interval for each 10 meter distance interval, 10 FM transmitters have been designed and constructed , the frequency being changeable with the range of 90-110 MHZ. These transmitters are located at every 10 meters and normally at off, their conduction is conditioned with a photocell which is at the focus of a lens . The photocells are incorporated in appropriate switching amplifiers which toggle whenever the subject is in front of the lens and go to conduction, permitting the transmitters to send, for a very short time, an electric signal which will be received and handled by the main board.

Main Board: This main board consists of a receiver which receives the signals coming from the transmitters and ten timers. This board has also an output to be linked with the computer, in order to use its internal timer ,in case of possessing a Laptop computer. The receiver output signal is shaped by an appropriate shaping circuit, then is sent to a BCD counter, the binary output of which is converted to decimal by an appropriate IC. The outputs of the latter are used to stop the timers at the time when the subject is in front of a lens.

A crystal based pulse oscillator (1 MHZ) oscillates all the time and is ready to be applied to the counters. These counters begin to count by the starter gun. The sound of the starter gun is detected by a capacitive Microphone and an appropriate amplifier and shaper in order to make the counters counting. Whenever a subject passes by a transmitter, it turns on and sends a signal which the receiver receives and applies it to the corresponding counter to stop it. Therefore in a 100-meter distance we have 10 signals for stopping 10 counters. The first counter shows the time corresponding to the first 10 m, the second timer shows the time of 20 m, and so on. We have used Microsoft Excel and Harvard Graphics to trace the distance versus time curves. Then after fitting we have extracted the first and second derivatives in order to achieve the variations of the velocity and acceleration for each sprinter.

In case of possessing a Laptop, we can use the special output dedicated to computer, to connect to Laptop. With a simple program we can reach the internal timer of the computer. In this case the signals coming from the receiver, after being shaped in standard form are serially sent to the Laptop. The time intervals recorded by computer can be processed in the same way as mentioned above.

(b) Kinetic Study

Generalities: The greatest musculoskeletal stresses in the lower extremity occur during the support phase of running, and analysis of ground reaction forces can provide insight into the factors that affect these stresses. The ability to qualify individual force contributions from muscle and other soft tissues would greatly enhance the ability to identify relationships between movement force and injury. However, because of the invasive nature of direct measures of muscle force, it is seldom undertaken.

An alternative method for estimating internal forces is to use musculoskeletal models to predict forces, but these methods may include errors due to the assumptions that have to be made. Forces in the Achilles tendon have been estimated to range from 5 to 10 times BW (body weight) with ankle bone-on-bone forces ranging from 8.7 to 14 BW (Burdett 1982; Scott and Winter 1990). A model predicting internal forces gave ranges of 4.7 to6.9 BW for plantar fascia force (Scott and Winter 1990). As with individual muscle forces, little information is available identifying direct bone or joint loading patterns in the lower extremity during running.

Proposed Method: In order to study the ground reaction force a force platform is normally used, A. Mero and P.V.Komi,1994). An EMG (Electromyography) activity can also be telemetered from five leg muscles, during each stride, (A. Mero, and P.V. Komi 1994).

The kinematic study for each sprinter showed the distance where he was running at constant speed. The sprinters were requested to run again and at this time, using a video camera MP9000 Panasonic with 25Hz, which was located at an adequate distance perpendicular to the track of run, we measured the time of contact for each foot (T_{TD}) and the time of flight of each stride (T_F). In order to measure the stride length we have fastened a paper with adequate length and width on the Tartan. The foot prints on the paper, helped us to measure the stride length with a precision better than 1 cm. In order to estimate the different forces the formulae proposed by(Shahbazi *et al.*, 1998, 2000 and 2002) have been used.

These formulae are as followings;

$$F_R=Mg+(MV_Y)/\Delta t \qquad (1)$$

Where F_R is the ground reaction force, M is the mass of sprinter, V_Y is the sprinter's vertical velocity component and Δt is the time of contact of the foot with ground.

$$F_B= Mg+(MV_Y)/\Delta t_B \qquad (2)$$

Where F_B is the braking force and Δt_B is the braking time which was considered as 43% of touchdown time, measured by camera.

$$F_P=Mg+(MV^2_Y)/(2h) \qquad (3)$$

Where F_P is the propulsive force and h is the displacement of CG (centre of Gravity) of the sprinters and can be calculated by;

$$h=(1/2)V_Y\Delta t_P \qquad (4)$$

Results and Discussion

a.Kinematics: Table 1. gives the elapsed times at 10m intervals and corresponding velocities and accelerations. The sprinter A reached his maximum speed, 10.79 m/s in the 40-50m section or during 4.9-5.81 sec., therefore he could maintain this maximum speed about 10m. Sprinter B reached his maximum speed,10.54 m/s in the 38-50m section or during 5.1-5.89 sec., therefore he could maintain this maximum speed about 12m. The sprinter C reached his maximum speed, 9.82 m/s in the 60-70m section or during 7.5-8.5 sec., therefore he could maintain his maximum speed about 10m. Ae, Ito and Suzuki, (1992) reported in the III World Championships in Athletics, in Tokyo, that a great number of finalists (33) reached their maximum speed in the 60-70m section, while few (5) reached their maximum speed in the 70-80m section a feature which can rarely be seen in top-class competition. A noticeable number of finalists (19) also reached in 40-50m section. Therefore two top Iranian sprinters (A and C) reached their maximum speeds in the 40-50m section as noticeable numbers III world championships in athletics Tokyo, 1991. finalists did, but their records are not comparable with the international sprinters, this may come from the lack of enough energy and correct technique of running and / or the stride rate.

Table 1: Elaps Time and Corresponding Velocities and Accelerations. Error Allowance ± 0.02 Sec

Sprinters	Parameters	10m	20m	30m	38*m	40m	45*m	50m	60m	66.3*m	70m	80m	90m	100m
A	Time	1.85	2.85	3.70	-	4.90	5.200	5.81	6.55	-	7.66	8.60	9.66	10.80
	Velocity	8.36	9.71	10.39	-	10.72	10.790	10.72	10.66	-	10.30	9.83	9.25	8.45
	Acceleration	1.80	0.98	0.53	-	0.12	-0.002	-0.09	-0.23	-	-0.40	-0.52	-0.62	- 0.71
B	Time	1.99	3.06	4.08	5.10	5.15	-	5.89	6.89	-	7.90	9.12	9.81	11.02
	Velocity	8.08	9.68	10.31	10.540	10.53	-	10.52	10.40	-	10.16	9.83	9.63	9.24
	Acceleration	2.13	0.92	0.12	-0.002	-0.05	-	-0.08	-0.18	-	-0.25	-0.29	- 0.30	-0.31
C	Time	2.10	3.30	4.40	-	5.40	-	6.50	7.50	8.100	8.50	9.60	10.60	11.60
	Velocity	7.63	8.74	9.27	-	9.55	-	9.74	9.81	9.820	9.82	9.75	9.63	9.45
	Acceleration	1.33	0.63	0.36	-	0.22	-	0.11	0.03	-0.002	-0.02	-0.09	-0.14	- 0.20

NB. The values with (*) indicate the time at which the velocity is maximum and the acceleration is practically zero (the Zone With Uniform Velocity)

Table 2: Stride Length, Stride Rate, Touch-Down, Flight, Braking and Propulsive Phases, CG Angle of Flight and Vertical Velocity Component

Subjects	Total S.L. (m)	Effective S.L.(m)	S.R. (Hz)	Flight Phase (ms)	Total T-D (ms)	Braking Phase (ms)	Propulsive Phase(ms)	CG Angle of Flight (Deg.) Θ	Vertical Velocity Component Vyo (ms^{-1})
A	2.35	1.34	4.6	127	99	42.57	56.43	3.45	0.65
B	2.18	1.24	4.84	115	112	53.94	63.8	3.1	0.57
C	1.95	1.11	5.04	107	115	49.45	60.95	2.95	0.51

Table 3: CG Vertical Displacement, Average Braking and Propulsive Accelerations, Average and Maximum Reaction, Braking and Propulsive Forces

Subjects	CG Vertical Displacements (m)		CG Vertical Average Accelerations (ms ^{1})		Total Reaction Force (Ave.) F_R, (N) (Max.)		Braking Force, F_B, (N) (Ave.)	(Max.)	Propulsive Force, F_P, (N) (Ave.)	(Max.)
A	-0.18	+0.20	-15.26	+11.53	1242	1735	1894.4	3040	1614	2478
B	-0.16	+0.18	-10.58	+ 8.90	1086	1453	1481.4	2242	1363	2007
C	-0.17	+0.19	-10.30	+ 7.80	1083	1415	1522.5	2297	1333	1916

Sprinter B reached his maximum speed in 70-80 section but his maximum speed was very pour. It seems that he can, by spending more energy and correcting his stride length and frequency, get a better record. We could not measure the stride length and frequency in order to offer a better diagnostic analysis to the sprinters, because our main aim was to design a telemetry system for measuring time parameters with a simple method at very low price, comparing with other systems presented by other researchers. Fig. 1, 2 and 3 show the variation of velocities and accelerations versus time curves of sprinters. Fig.4and 5 show the velocities and the accelerations respectively of the sprinters for comparison.

As can be seen, in fig.5 sprinter C ran, a longer distance with positive acceleration but as a whole he has applied less acceleration relative to other sprinters.

(b): Kinetics: On Table 2. stride length, stride rate, touchdown, flight, braking and propulsive phases, CG angle of flight and vertical velocity component are presented. As can be seen, braking and propulsive phases are 43 and 57 percent of the touchdown phase respectively. On Table 3, CG vertical displacement, average braking and propulsive accelerations, average and maximum reaction propulsive and braking forces are presented. The reaction force depends mainly on the speed of the sprinter and on his mass, while the braking and the propulsive forces depend on the vertical displacement of the CG, and as a whole on the height of the sprinters. The braking force is always greater than the propulsive force and is responsible of ankle, knee and hip injuries.

Air resistance plays a smaller role in the work done during running than in other sports where speed is higher, such as cycling or speed skating. Nevertheless (Pugh, 1971) found the extra oxygen consumed while running against a wind increased relative to the square of wind velocity. While he predicted the overall energy cost of overcoming air resistance in track running to be approximately 8% at a distance speed of 6 $m.s^{-1}$ and 16% at sprint speeds (10 $m.s^{-1}$), (Davies ,1980) predicted somewhat lower values (7.8% at 10 $m.s^{-1}$, 4% at 6 $m.s^{-1}$, and 2% at marathon speeds). Running behind other competitors provides shielding from air resistance and reduces drag and matabolic costs (Kyle,1979). Running in a pack has been predicted to reduce air resistance by 40-80%, depending on how close one runner follows another, lowering oxigen costs by 3-6%(Pugh ,1971and Kyle, 1979).

Conclusion

The proposed telemetry system is inexpensive and very simple to use comparing with other systems used by other researchers and reliable for kinematic study of sprinters. For kinetic study of sprinters, the kinematic results were used and helped us to determine theare a where the sprinters reached their maximum speed. At their maximum speed, we could determine ground, braking, and propulsive forces as well as the other mechanical parameters such as flight angle, vertical velocity component. In addition, the kinetic results can be combined with body kinematics and anthropometric models to give average joint forces and torques.

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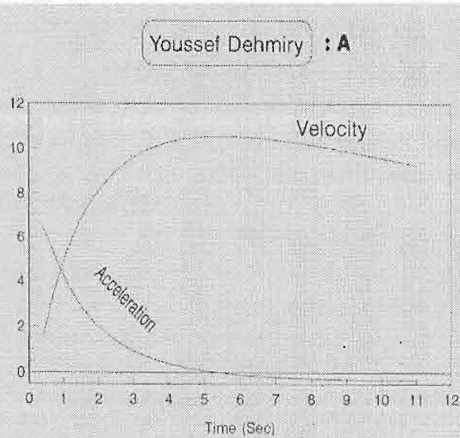
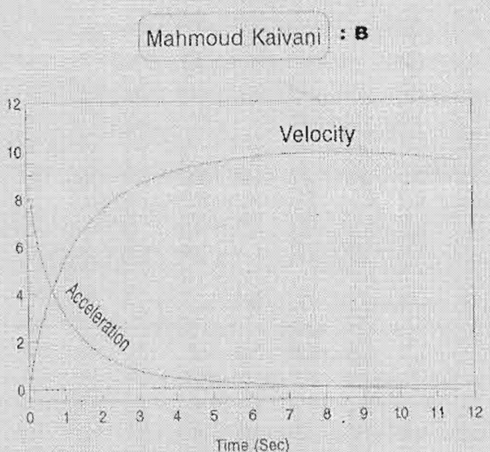


Figure 1 - Velocity and acceleration versus time of subject A.



Figuer 2 - Velocity and acceleration versus time of subject B.

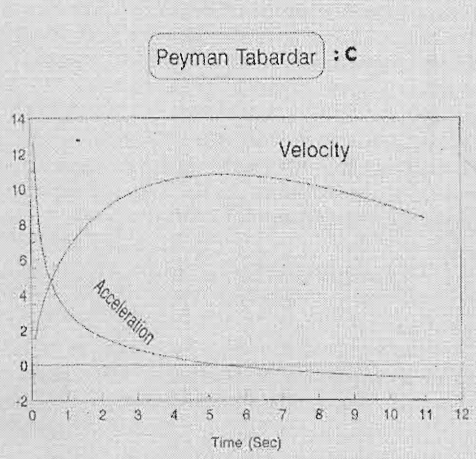


Figure 3 - Velocity and acceleration versus time of subject C.

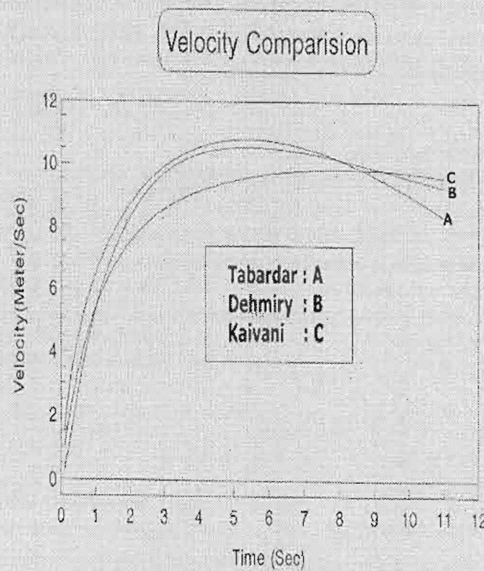


Figure 4 - The velocity comarison of three subjects

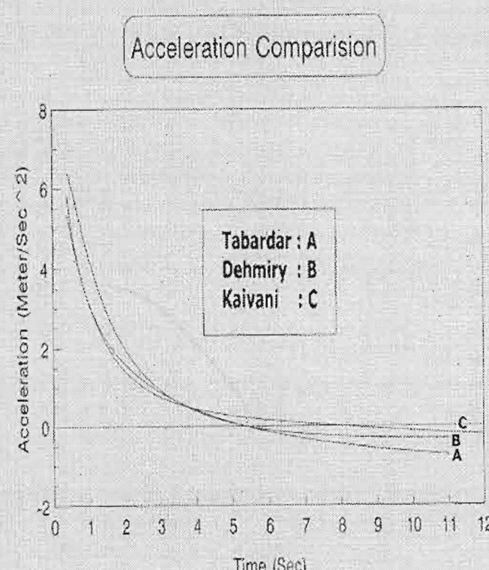


Figure 5 - The acceleration comparison of three subjects.

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