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KINETIC AND KINEMATIC ANALYSIS OF HURDLE CLEARANCE OF AN AFRICAN AND A WORLD CHAMPION ATHLETE: A COMPARATIVE STUDY

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ABSTRACT

The modelling of athletic movement is an important method in motor-skill learning. A world champion and a world record-holder, C.J, with a time of 12.91s, was chosen as a model-athlete in 110m hurdles in this study. He was compared with R.G, a Tunisian athlete and African champion based on his personal best of 13.90s. The biomechanical characteristics of the latter were analysed and compared with that of C.J's using the kinematic and kinetic parameters of the 110m hurdle clearance of the two athletes to determine the difference in their hurdling technique. R.G's hurdling sequences over the fourth and fifth hurdle were recorded using four cameras [Sony DCR-PC108^E]. His kinematic model was digitised using SkillSpector® software. The results showed a difference in the centre of mass displacement at hurdle clearance and velocity-parameters in both the take-off and the landing phases. When comparing R.G to C.J, the latter had a smaller vertical displacement and a longer horizontal displacement, in addition to, a greater horizontal velocity along with a better reaction force and a higher peak-power. To improve R.G's performance, greater horizontal velocity and lower contact time at the take-off phase through a higher rate of force development are needed.

***Keywords*:** 110m Hurdles; Motion analysis; Displacement; Velocity; Reaction force.

INTRODUCTION

Through advanced biomechanical tools, such as the motion analysis, hurdlers' technical execution and performance has been greatly optimised (Coh *et al.*, 2000; Li & Fu, 2000; Salo & Scarborough, 2006; Shibayama *et al.*, 2008, 2011, 2012; Graubner & Nixdorf, 2011; Park *et al.,* 2011; Sidhu & Singh, 2015). Nevertheless, from a technical point of view, high hurdles are the most demanding in track and field events (Coh *et al.,* 2004), where clearance of the hurdle is one of the key techniques (La Fortune, 1988; McDonald & Dapena, 1991; McLean, 1994; Salo & Scarborough, 2006; Coh & Iskra, 2012; Sidhu & Singh, 2015). In addition, biomechanical data help athletes improve their own performance by providing a detailed overview to coaches and researchers about the strengths and weaknesses of each athlete (Salo *et al.*, 1999). Hurdle clearance's kinematic analyses showed that horizontal velocity is one of the most crucial factors, thus losing it should be minimised (Coh *et al.*, 2004). Furthermore, for an efficient hurdle clearance, the optimal ratio between the take-off of the trial leg and the landing of the lead leg should be 60:40 ratio in flight distance (La Fortune, 1988; McLean, 1994; Salo & Grimshaw, 1998). In this context, numerous investigations showed that the correct position for these two situations is a prerequisite for an optimal flight path of the centre of mass (COM) where the vertical displacement of the COM would be lower and the flight time would be shorter (Dapena, 1991; Coh *et al.*, 2004; Bubanj *et al.*, 2008).

The Biomechanical models of motion present and describe at the same time the sports motion aiming at further defining the differentiation in biomechanical characteristics with relation to changes of body position (Adashevskiy *et al.*, 2014). In this context, several authors focused on case study research conducted on elite athletes (La Fortune, 1988; Li, 1990a, 1990b; Rash *et al.*, 1990; McLean, 1994; Chow, 1998; Coh, 2003; Coh *et al.*, 2004; Lee, 2004, 2009; Lee *et al.*, 2008; Li *et al.*, 2011; López, 2011). All these studies aimed to define the main criteria of an optimal hurdle clearance technique (horizontal velocity, height of COM at take-off, velocity of the trail-leg, flight time, height of COM at landing, and contact time). For instance, López (2011) compared Jackson Quiñónez (Spanish record holder, Osaka 2007) with Dayron Robles (World record holder, Ostrava 2008 and Olympic champion, Beijing 2008). The author showed that Dayron Robles was faster than Quiñónez in that he had a shorter contact time, a greater reactive strength and a capacity to reach the first hurdle in seven strides. In addition, he suggested that Robles could improve his performance by reducing the flight time with the hurdle clearance. Li *et al.* (2011) conducted a comparative study between two Chinese elite-level athletes, Yin Jing (World Champion, 2009) and He Xiang (Olympic Champion, 2004; World Champion, 2007, 2008; Asian Champion, 2002, 2006, 2010). They showed that Yin Jing had an optimal clearance technique and a better stability, but it would be necessary to reduce the braking time in the landing phase to improve his performance.

Other studies aimed at creating individual models of hurdling techniques, for example the kinematic model of Liu Xiang (Xu *et al.*, 2005) and the kinematic model of Colin Jackson (Coh, 2003; Coh *et al.*, 2004). At the same time, they analysed the technical inefficiency for each model. They concluded that hurdle clearance is an inevitable tool to minimise the velocity loss during the take-off phase and mainly in the landing phase at the touchdown moment. Bubanj *et al.* (2008) compared the differences in hurdle clearance techniques and speed between elite and non-elite athletes using the Colin Jackson model. The main findings of this study showed a significant difference in speed, but there was no great technical difference between the clearances. It is worth noting that the Colin Jackson model is considered as a relevant role model athlete of hurdle clearance for medium sized athletes [between 1.70m and 1.84m] (Park *et al.*, 2011), where Coh (2003) and Coh *et al.* (2004) identified 36 determining factors of hurdle clearance performance.

PURPOSE OF THE STUDY

The aim of this study was to compare the hurdle clearance kinematic data (take-off, flight and landing phases) between C.J (world champion and world record holder Stuttgart, 1993) and R.G (African champion 2011, Arab champion 2012 and Tunisian record-holder 2012) to detect the kinematic parameters that differentiate between these two performance levels (international *vs*. African level, respectively), in the hurdle clearance techniques. In addition, C.J's and R.G's data simulations of COM trajectory over the hurdle (Adashevskiy *et al.*, 2014) and peak force and power estimations during the take-off and the landing phase (Smith, 1983) will be determined and analysed.

METHODOLOGY

Participants

R.G, a national level athlete, holder of the 2012 Tunisian record, along with the African Championship 2011 and the Arab Championship 2012 with a time of 13.90s (age 23 years; height 1.87m; mass 80kg) participated in this study. His kinematic data in hurdle clearance were compared with the international athlete, C.J, the world champion and the world record holder in Stuttgart, 1993 with a time of 12.91s, along with 10 European records and 8 Commonwealth records (age 35 years; height 1.82m; mass 75kg). Being informed in advance of the experimental design, procedures, methods, benefits and possible risks involved in the study, the participants had to read and sign an informed consent before participating. Out of respect for research ethics, the experimental protocol was performed in accordance with the latest version of the Declaration of Helsinki for human experimentation and was approved by the local Ethical Committee.

Experimental design and procedures

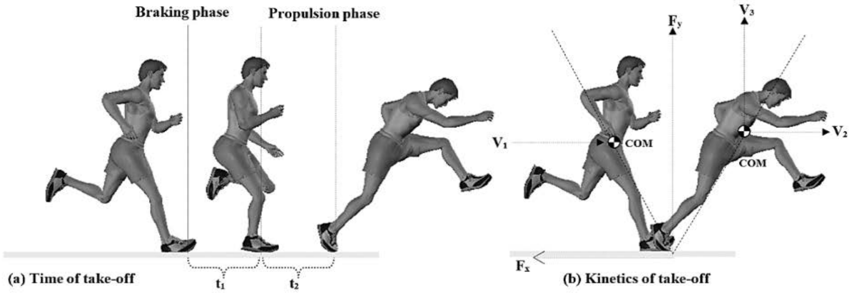
The research design is a kinematic and kinetic comparison between an African and an international athlete at the fourth and fifth hurdle clearance in 110m hurdling, using a posterior data of C.J, international athlete reported by Coh (2003) and Coh *et al.* (2004). The assessment protocol used by the latter two studies consisted of a kinematic analysis with two synchronised cameras [SONY-DSR-300 PK; sample rate 50Hz] placed at an angle of 120°. The model of Dempster (1955) was used for the calculation of the body's COM and the kinematic programme ARIEL [Ariel Dynamics Inc., USA] for the digitisation. In order to collect kinematic data on R.G's clearance, twenty retro-reflective body markers were attached to his body for digitisation. The hurdling sequences at the fourth and fifth hurdle were recorded using four cameras [Sony DCR-PC108^{E} Mini DV; sample rate 50Hz]. Body markers, using the Dempster (1955) model, were digitised using the video-based data analysis system SkillSpector® 1.3.2 [Odense SØ – Denmark] (Mkaouer *et al.*, 2013). Similarly, the body segments' COM were computed using the Dempster (1955) model. The environmental conditions recorded during the experiment were a temperature of 25°C and a wind velocity on an outdoor athletic track of w=0.10m.s^{-1}.

Maximum ground reaction force (F_{max}) was analysed in accordance with the data acquisition of R.G and the reported data of C.J (Coh, 2003; Coh *et al.*, 2004) using rigid body inverse dynamics via Smith (1983) equations (Equation 1 and 2; Figure 1 a and b).

$$F_x = m \cdot \left(\frac{v_2 - v_1}{t_1 + t_2} \right) \quad (1)$$

$$F_y = m \cdot \frac{v_3}{t_2} \quad (2)$$

F_x=Horizontal force; F_y=Vertical force; t_1=Breaking time; t_2=Propulsion time; V_1=Initial horizontal velocity "beginning of the breaking phase"; V_2=Final horizontal velocity "end of the propulsion phase"; V_3=Final vertical velocity "end of the propulsion phase"



COM=Centre of mass; F_x=Horizontal force; $F_{y=}$Vertical force; $t_{1=}$Breaking time; $t_{2=}$Propulsion time; V_1=Initial horizontal velocity "beginning of the breaking phase"; V_2=Final horizontal velocity "end of the propulsion phase"; $V_{3=}$Final vertical velocity "end of the propulsion phase"

Figure 1. **CALCULATING METHOD RELATED TO SMITH (1983)**

Delta-percentage (Δ) between C.J and R.G "$\Delta_{(\%)} = [(S_1-S_2)/S_1] \times 100$" was calculated in order to evaluate the percentage variation of kinetic and kinematic parameters.

RESULTS

Comparing an African athlete (R.G) with an international one (C.J) showed dissimilarity in COM displacement at hurdle clearance (Figure 2). Likewise, a large difference (Δ>10%) between the two athletes in the velocity parameters in both phases (take-off and landing) was recorded (Figure 3). Table 1 shows the results of kinematic analysis and delta variation between R.G and C.J. Figure 4 presents a simulated trajectory of R.G and C.J over the hurdle. Finally, the maximum ground reaction force (GRF) estimated and the peak-power reveals a large difference (Δ>10%) between R.G and C.J at the take-off and the landing in favour of C.J (Table 2).

DISCUSSION

The aim of this study was to compare hurdle clearance kinetic and kinematic data with support phases before and after the hurdle between R.G, an athlete participating at African level, and C.J, an athlete participating at international level. The comparison between them shows several dissimilarities in the hurdle clearance parameters. In fact, C.J’s stride length over the hurdle is longer than that reported for R.G (3.67m *vs.* 3.02m, respectively; Δ=17.7%), the take-off distance is 2.09m *vs.* 1.76m (Δ=15.78%) representing 56.9% *vs.* 58.4%, and the landing distance is 1.58m *vs.* 1.26m (Δ=20.25%), which represents 43.1% *vs.* 41.5% of the total hurdle stride, respectively (Figure 2). The short stride distance of R.G may be due to an irregularity of the stride rhythm, a high take-off angle, a loss of horizontal velocity and an excessive height of the vertical COM displacement. Numerous studies have shown that the optimal ratio between the take-off point and the landing is 60%:40% (La Fortune, 1988; McLean, 1994; Salo & Grimshaw, 1998).

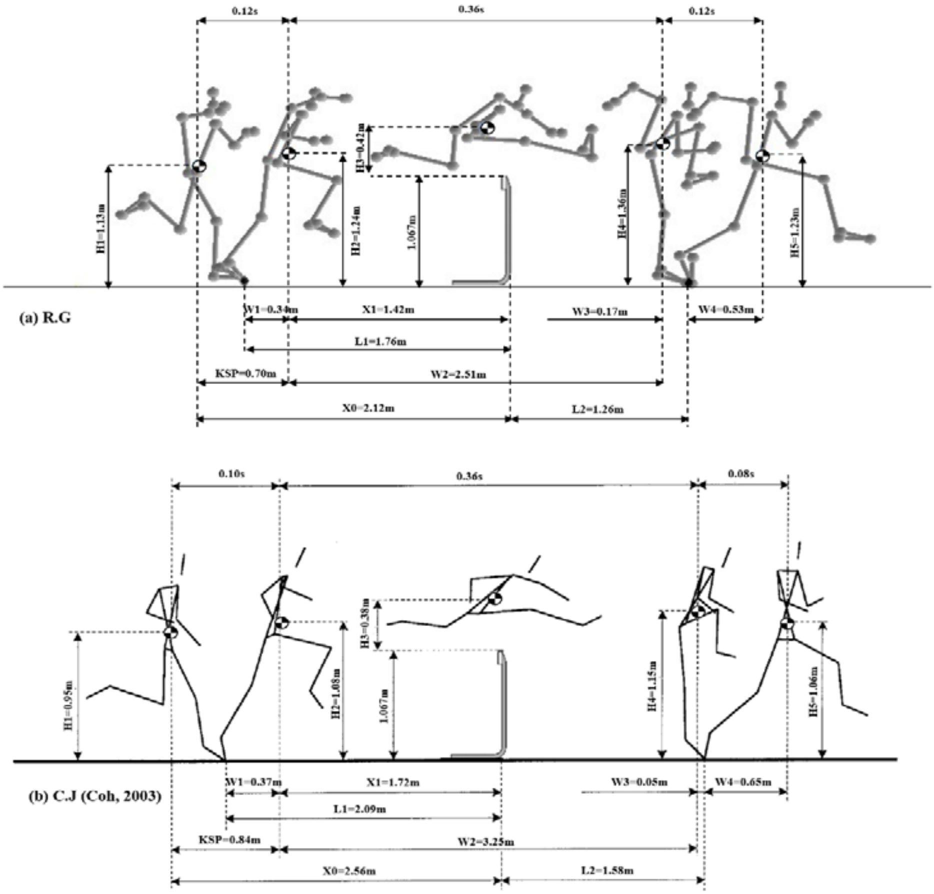


Figure 2. **DISPLACEMENT PARAMETERS OF CLEARING 4th HURDLE** (Coh, 2003)

During the take-off, we found a slight difference (Δ<5%) between C.J and R.G at the braking phase, the angle between the lead foot and the track surface which is lower for C.J than that of R.G (64° *vs.* 68.77°, respectively) . Nevertheless, in the propulsion phase, values are quasi-similar (72.93° *vs.* 73.04° respectively). In addition, a change in COM elevation is recorded from the braking phase to the propulsion phase (0.13m for C.J and 0.11m for R.G). The COM placement relative to C.J at the propulsion phase is 1.08m *vs.* 1.24m for R.G (Δ=14.8%). Li and Fu (2000) indicated that during the take-off, the average height of the COM in the propulsion phase was 1.12±0.02m, which was higher than the hurdles. In fact, R.G has a high placement of COM, which can be explained by the short stride before the take-off in addition to the loss of velocity.

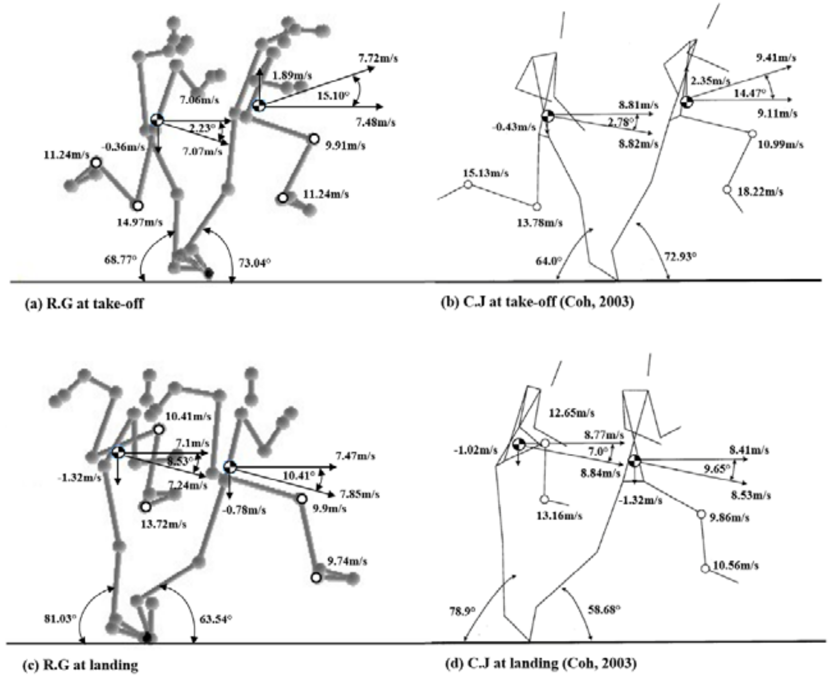


Figure 3. **VELOCITY PARAMETERS OF CLEARING 4th HURDLE**

Over the hurdle, C.J's COM elevation is lower than that of R.G (0.37m *vs.* 0.42m, respectively; Δ=13.5%). The flight parabola is more fluent for C.J compared to R.G (Figure 4). This can be explained by the smaller vertical part of the movement (Kampmiller *et al.*, 1999). The COM's different trajectory between C.J and R.G is mainly due to the high position adopted by R.G in front of the hurdle, which seemed to affect the trajectory clearance (Figure 2).

The resultant velocity shows a high difference (Δ>10%) between C.J and R.G. The recorded values were 8.82m$\cdot$s^{-1} *vs.* 7.07m$\cdot$s^{-1} at the braking phase (Δ=19.8%) and 9.41m$\cdot$s^{-1} *vs.* 7.72 m$\cdot$s^{-1} at the propulsion phase (Δ=18%) for C.J and R.G, respectively. The observed low level of R.G's acceleration in front of the hurdle seems to be mainly due to the insufficient transformation capacity from cyclic to acyclic propulsion and to the longer registered contact time (0.12s *vs.* 0.08s). However, with regard to C.J, he reveals a very good synchronisation between these parameters and a high capacity of changing from running into hurdling with a short contact time 0.1s (Coh *et al.*, 2004). Moreover, the results of the present study shows dissimilarities between R.G and C.J in the swing leg velocity during the take-off and the propulsion phase (Figure 3). In fact, the knee swing velocity of C.J is faster than that of R.G (10.99m$\cdot$s^{-1} *vs.* 9.91m$\cdot$s^{-1}, respectively; Δ=9.8%).

Table 1. **KINEMATIC PARAMETERS OF CLEARING 4th HURDLE**

Parameters	Unit	C.J	R.G	Diff	Δ (%)
Take-off (braking phase)					
Horizontal velocity of COM	$m\cdot s^{-1}$	8.81	7.06	1.75	19.86
Vertical velocity of COM	$m\cdot s^{-1}$	-0.43	-0.36	-0.07	16.28
Velocity resultant of COM	$m\cdot s^{-1}$	8.82	7.07	1.75	19.85
Height of COM	m	0.95	1.13	-0.18	-18.95
COM to foot distance	m	0.46	0.36	0.1	21.74
Knee swing velocity	$m\cdot s^{-1}$	13.78	14.94	-1.16	-8.42
Ankle swing velocity	$m\cdot s^{-1}$	15.13	11.24	3.89	25.71
Take-off (propulsion phase)					
Horizontal velocity of COM	$m\cdot s^{-1}$	9.11	7.48	1.63	17.89
Vertical velocity of COM	$m\cdot s^{-1}$	2.35	1.89	0.46	19.57
Velocity resultant of COM	$m\cdot s^{-1}$	9.41	7.72	1.69	18.01
Height of COM	m	1.08	1.24	-0.16	-14.81
COM to foot distance	m	0.38	0.34	0.04	10.53
Push-off angle	°	72.9	73.04	-0.14	-0.19
Knee swing velocity	$m\cdot s^{-1}$	10.99	9.91	1.08	9.83
Ankle swing velocity	$m\cdot s^{-1}$	18.22	17.41	0.81	4.45
Take-off distance	m	2.09	1.77	0.32	15.31
Contact time	s	0.1	0.12	-0.02	-20.00
Flight					
Flight time	s	0.36	0.36	0	0.00
Height of COM above hurdle	m	0.37	0.42	-0.05	-13.51
Maximal height COM	m	1.44	1.48	-0.04	-2.78
Maximal velocity over hurdle	$m\cdot s^{-1}$	9.05	7.27	1.78	19.67
Landing (braking phase)					
Horizontal velocity of COM	$m\cdot s^{-1}$	8.77	7.1	1.67	19.04
Vertical velocity of COM	$m\cdot s^{-1}$	-1.02	-1.32	0.3	-29.41
Velocity resultant of COM	$m\cdot s^{-1}$	8.84	7.24	1.6	18.10
Height of COM	m	1.15	1.36	-0.21	-18.26
COM to foot distance	m	-0.05	-0.17	0.12	-70.59
Knee swing velocity	$m\cdot s^{-1}$	12.65	10.41	2.24	17.71
Ankle swing velocity	$m\cdot s^{-1}$	13.16	13.72	-0.56	-4.26
Landing distance	m	1.58	1.26	0.32	20.25
Clearance distance	m	3.67	3.03	0.64	17.44
Landing (propulsion phase)					
Horizontal velocity of COM	$m\cdot s^{-1}$	8.41	7.47	0.94	11.18
Vertical velocity of COM	$m\cdot s^{-1}$	-1.32	-0.78	-0.54	40.91
Velocity resultant of COM	$m\cdot s^{-1}$	8.53	7.85	0.68	7.97
COM to foot distance	m	0.65	0.53	0.12	18.46
Knee swing velocity	$m\cdot s^{-1}$	-9.86	-9.9	0.04	-0.41
Ankle swing velocity	$m\cdot s^{-1}$	-10.56	-9.74	-0.82	7.77
Contact time	s	0.08	0.12	-0.04	-50.00

COM= Centre of mass Δ= Delta percentage

In the same context, the ankle swing velocity of C.J was quicker than that of R.G (18.2m•s^{-1} *vs.* 17.41m•s^{-1}, respectively; Δ=4.4%). C.J's ankle swing velocity is twice the horizontal velocity of the COM during the take-off (9.11m•s^{-1}). We can affirm that R.G, at the moment of take-off propulsion, is slower than C.J, while the latter attacks the hurdles very aggressively (Coh *et al.,* 2004; Bubanj *et al.,* 2008).

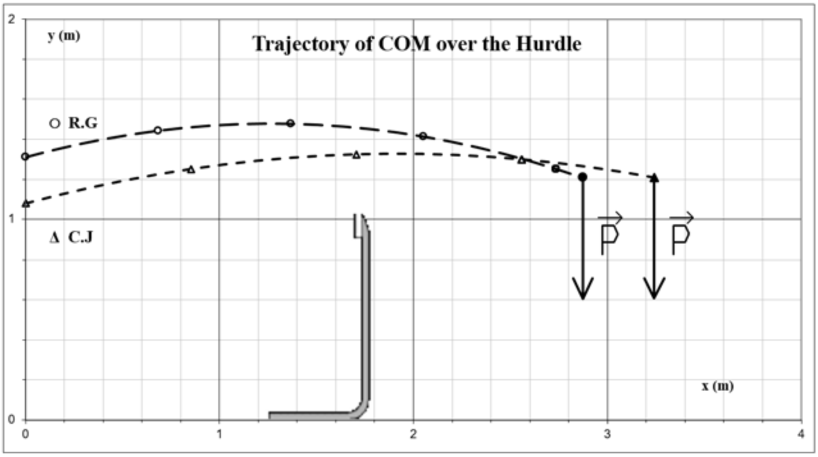


Figure 4. **TRAJECTORY SIMULATION OF CLEARING 4th HURDLE BY R.G AND C.J.**

Table 2. **KINETIC PARAMETERS OF CLEARING 4th HURDLE**

Parameters	**Unit**	**C.J**	**R.G**	**Diff**	**Δ (%)**
Take-off					
COM horizontal force	N	225.00	273.33	-48.33	-21.48
COM vertical force	N	2937.50	2640.00	297.50	10.13
COM force resultant	N	2946.10	2654.11	291.99	9.91
COM horizontal power	W	2049.75	2044.53	5.22	0.25
COM vertical power	W	6903.12	4989.60	1913.52	27.72
COM power resultant	W	7201.01	5392.23	1808.77	25.12
Landing					
COM horizontal force	N	337.50	466.67	-129.17	-38.27
COM vertical force	N	2475.00	1040.00	1435.00	57.98
COM force resultant	N	2497.91	1139.90	1358.01	54.37
COM horizontal power	W	2838.37	3640.00	801.62	28.24
COM vertical power	W	3267.00	811.20	2455.80	75.17
COM power resultant	W	4327.78	3729.29	598.48	13.83

COM= Centre of mass; Δ= Delta percentage; N=Newton; W=Watt

The flight time shows similar values (0.36s) for both athletes C.J and R.G, while the loss of velocity in the flight phase is much less important for C.J *vs.* R.G (0.36m•s^{-1} *vs.* 0.45m•s^{-1}, respectively; Δ=25%). McDonald and Dapena (1991) and Coh and Iskra (2012) indicated that the criterion for an efficient hurdling technique is manifested in the shortest time spent over the hurdles, because sprinters lose velocity in the air.

Analyses of the instep after the hurdle shows a similar landing angle at the moment of the touchdown between C.J. and R.G (78.9° *vs.* 81°, respectively). However, C.J's stride after the hurdle is longer (+0.30m) than that of R.G (1.58m *vs.* 1.26m, respectively; Δ=20.2%). In addition, the results show that C.J's horizontal velocity at the breaking phase is more important compared to R.G (8.84m•s^{-1} *vs.* 7.24m•s^{-1}, respectively; Δ=18.1%). Also, at the propulsion phase, C.J's horizontal velocity is greater than that of R.G's (8.41m•s^{-1} *vs.* 7.47m•s^{-1}, respectively; Δ=11.1%). These kinematic parameters also influence the contact time, where we noticed a great difference (C.J 0.08m•s^{-1} *vs.* R.G 0.12m•s^{-1}, respectively; Δ=50%). Therefore, C.J has a high level of kinetic energy transmission at this phase compared to R.G (Coh *et al.*, 2004). Coh *et al.* (2004) and Bubanj *et al.* (2008) declared that in the landing phase, the change from flying to running is necessary and it demands a high level of skill and high motor capacities, such as speed, power, strength, coordination, pace, timing and balance.

The estimation of reaction force at both phases (take-off and landing), shows a noteworthy difference (Δ>10%) in favour of C.J. The vertical component of force at the take-off is more important for C.J compared to R.G (2937.5N *vs.* 2640N, respectively; Δ=10.1%), although R.G's horizontal component of force is better than that of C.J (273.33N *vs*. 225N, respectively; Δ=21.4%). These results are lower than those presented by Coh *et al.* (2000), who demonstrated a maximal vertical- and horizontal force around 3593.75±375.16N and 1717.25±102.14N, respectively. The resultant and the vertical component of COM's power seemed to be different between the two athletes in favour of C.J when compared with R.G (7201.01W and 6903.12W *vs.* 5392.23W and 4989.6W, respectively; Δ=25.1% and Δ=27.7%). According to Li *et al.* (2011), this difference was attributed to the explosive pulse of C.J's trail leg resulting in fully extended joints (ankle, knee and hip) that allowed a rapid contraction of the muscles of the trailing leg along with a rapid recovery, which promoted an adequate transfer from a horizontal to a vertical force emphasising a high level of synchronisation between running and hurdling phases (Coh *et al.*, 2004). Likewise, at the landing phase, C.J has a more powered propulsion after the hurdle with larger values of resultant reaction force compared to R.G (2497.9N *vs.* 1139.9N, respectively; Δ=54.3%), and more than twice R.G's vertical force (2475N *vs.* 1040N, respectively; Δ=57.9%). These results are in accordance with those reported by Coh *et al.* (2000), who found a maximal vertical force around 2804.05±372.43 N estimated among elite athletes on the force plate. In addition, C.J's performance exceeds that of R.G in vertical power with Δ=75.1% (3267W *vs.* 811.2W, respectively). These differences clearly indicate that C.J has a greater reactive force and power than R.G.

CONCLUSION

The results of the present study show that the efficiency of hurdle clearance technique is higher for C.J compared to R.G. Notably, maintaining a large horizontal velocity and a low vertical displacement during hurdling seems to be among the key factors ensuring a high-level performance in sprint hurdles. By analysing R.G's performance, we established shortcomings principally related to his horizontal velocity, which can be avoided by more technical/conditioning training. Finally, to improve this latter performance, he must produce greater horizontal velocity and decrease contact time at the take-off phase by means of a high rate of force development in take-off. He must, also, decrease COM's vertical displacement above the hurdle to avoid the loss of velocity and reduce flight time.

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