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Kinematic Analysis of Sprinting Pickup Acceleration versus Maximum Sprinting Speed

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ABSTRACT

Pickup acceleration and maximum sprinting speed are two essential phases of the 100-m sprint with variant sprinting speed, step length, frequency and technique. The aim of the study was to describe and compare the kinematic parameters of both sprint variants. Hypothetically it was assumed to find differences in sprinting speed, step length, flight and contact times as well as between the body angles of different key positions. From 8 female and 8 male (*N=16)* track and field junior athletes a double stride of both sprint variants was filmed (200 Hz) from a sagittal position and the 10-m-sprint time was measured using triple light barriers. Kinematic data for sprinting speed and angles of knee, hip and ankle were compared with an analysis of variance with repeated measures. The sprinting speed was 7.7 m/s and 8.0 m/s (female) and 8.4 m/s and 9.2 m/s (male) with significantly higher values of step length, flight time and shorter ground contact time during maximum sprinting speed. Because of the longer flight time, it is possible to place the foot closer to the body but with a more extended knee on the ground. These characteristics can be used as orientation for technique training.

Key Words: *Step frequency, Step length, Ground contact time, Sprint technique, Knee angle*

INTRODUCTION

The 100-m sprint may be subdivided into three phases on the basis of running speed according to Brüggemann and Glad (4), Ae, Ito and Suzuki (1), Mero, Komi and Gregor (17), Shen (25), Bergamini (2) as well as Maćkała, Fostiak & Kowalski (13): block start with acceleration, maximum speed, and deceleration. A more detailed analysis of the sprinting speed revealed distinct sub-phases of the entire acceleration phase: the initial acceleration (0-20 m) and the extended or pickup acceleration (20-40 m) (2, 5, 11, 12, 15) or three phases (13, 20, 21). Maćkała et al. (13) distinguish the acceleration phase between initial or starting acceleration (0–12 m), main acceleration (12–35 m) and a third transition sub-phase (35–60 m).

No consensus exists for the exact duration of each phase because the time period mainly depends on the athletes' performance ability and speed (12, 13, 15, 20, 21). Top-level sprinters reach their maximum speed between 50 and 70 m or later. An extended acceleration between 25 and 60 m is found only among the world's best sprinters (13). Differences between adult and adolescent sprinters exist, besides the greater values of sprinting speed achieved by adults and so the magnitude and the length of the acceleration phase are lower in adolescents (30-40 m) (12). Furthermore, pickup acceleration is more important than the start acceleration and a longer distance of positive acceleration reduces the 100-m final time (12).

Sprinting speed depends on step length and step frequency (8, 10, 14, 19, 27), who showed different relations in the several phases of the 100-m sprint. Nagahara, Matsubayashi, Matsuo and Zushi (20), Nagahara, Naito, Morin and Zushi (21) as well as Maćkała et al. (13) investigated the entire acceleration phase of maximum sprinting. Both studies found an increase in step length and flight time but a decrease in the support time. This is in accordance with the result that the adolescents' step frequency is maximized after 10-20 m during the race and maintained during the constant speed phase. The maximum contribution of step length for running speed occurs in the 50-80 m segment (5). Furthermore the step length influences the velocity curve of the 100-m-sprint more than step frequency and seems to be a more important performance-determining factor in average- or high- level performers (15). World class sprinters achieve their maximum sprinting speed with greater step length and, on the contrary, other athletes increase their sprinting speed via step frequency (3). A short contact phase is important for maximum sprinting speed (6).

In earlier classifications of functional phases, the sprint step is divided into a flight and stance phase and emphasized the knee extensors for generating propulsion (17, 18). On the basis of EMG-investigations, Wiemann and Tidow (28) established the 'swing-pull technique' that underlines the function of the ischiocrural muscles as an important contributor of the sprinting speed. The sprint step consists of a swing and support phase with a back-swing and a forward-swing phase as well as a front and rear (frontside and backside) support phase. The most important phase for the production of sprinting speed is the support phase followed by their preparation during the backswing phase before take on. In both phases (pre-support and support phase) the hip extents by hamstring activation while the gluteus maximus and the knee extensors (vastus medialis) activate only during the pre-support and the first half of the support phase. During the back-swing of the pre-support leg a powerful hip extension moves the thigh downwards to produce a high back-swing velocity of the leg before take on. The function of the knee extensors during the support phase are the stabilization of the knee joint angle by an eccentric action at the beginning and the acceleration of the body in an upward direction by a concentric action at the end of the support phase. After breaking contact with the ground, the activity of the hamstrings during the full speed sprint indicates that the knee flexion of the swinging leg is actively through the contraction of the hip extensors (28).

Compared to the phase of maximum sprinting speed studies about pickup acceleration are rare, cover primary male athletes, the relation of speed, step length and step frequency (7, 13, 20, 21) but seldom other kinematic parameters like body angle at key sprint positions. Although in pickup acceleration the same characteristics determine the performance as during maximum sprinting speed, it is still unclear which parameters are more or less distinct in comparison of both sprint variants.

The aim of the study was to describe and compare the kinematic parameters of the sprint step during maximum sprinting speed and pickup acceleration on the basis of a kinematic analysis using the phase structure from Wiemann and Tidow (28). It was expected that (1) the sprinter realize a higher running/sprinting speed because of a greater step length and shorter ground contact time during maximum sprinting speed compared to pickup acceleration and (2) the greater step length results from a more extended knee joint during pre-support and is associated with a more extended knee at foot contact followed by a higher flexion of the knee joint at the beginning of the contact phase.

MATERIAL AND METHODS

Participants

A priori sample size calculation (G*power 3.1., ANOVA: repeated measures within factors; f= .90; α= .05; power= .90, number of measurements= 2) calculated a total number of 16 participants.

Participants (*N=16*) were between 15 and 23 years old and have been running in track and field for a mean of 6.5 years at the time of testing. Table 1 shows the details for age and anthropometrics. At testing time all participants were healthy and preparing for the upcoming summer season 2015.

Table 1
Characterization of participants, N=16.

Gender	Number	Age [years]	Body height [cm]	Body mass [kg]	Leg length* [cm]	Training experience [years]
Female	8	19.0 ± 3.0	164.0 ± 6.0	57.0 ± 4.0	77.4 ± 3.2	7.3 ± 3.5
Male	8	17.0 ± 0.9	185.0 ± 4.7	71.0 ± 9.6	89.0 ± 5.8	6.0 ± 3.0
Total	16	17.6 ± 2.3	174.8 ± 12.1	63.8 ± 10.2	83.1 ± 7.4	6.8 ± 3.2

** measuring leg length from greater trochanter to ankle (lateral malleolus)*

The test procedures were in accordance with the Helsinki Declaration of 1975. Data collection was part of measurements in routine sport science support in agreement with the track and field association of Hamburg (Hamburger Leichtathletik Verband, HHLV).

Test procedure

After the general warm-up phase, visible markers were fixed on the athletes (tab. 2), followed by the specific sprint warm-up. Subsequently, athletes completed a 30-meter fly sprint test as well as a sprint from the start block after total recovery. All sprints were performed on tartan ground in the track and field gym of Hamburg. Double steps were filmed with high-speed-camera (Photonfocus) from a sagittal position taking 200 pictures/s and a resolution of 1760x448 pixels with a pixel size of appr. 5x5 mm.

Table 2
Marker model with anatomic reference points.

Anatomic reference point	
Upper body	lower costal arch
Trochanter	trochanter major
Knee	central on knee joint space
Ankle	central on ankle, knuckle
Toe	metatarsophalangeal joint of the fifth toe
Medial side of toe	metatarsophalangeal joint of first toe opposite side

The testing setup is shown in figure 1. Referring to the starting point, the area of recording covered the distance over 15-25 m (pickup acceleration) and 35-45 m (maximum sprinting speed). For the calibration, two hurdles were placed within the area of recording whose corners were marked with reflecting tape. The hurdles were placed exactly 8 m apart from each other and had a standing height of 1.05 m. In addition, sprint time within the 10 m section was measured with a triple light barrier (Wilhelm Köster, Ditzingen, Germany).

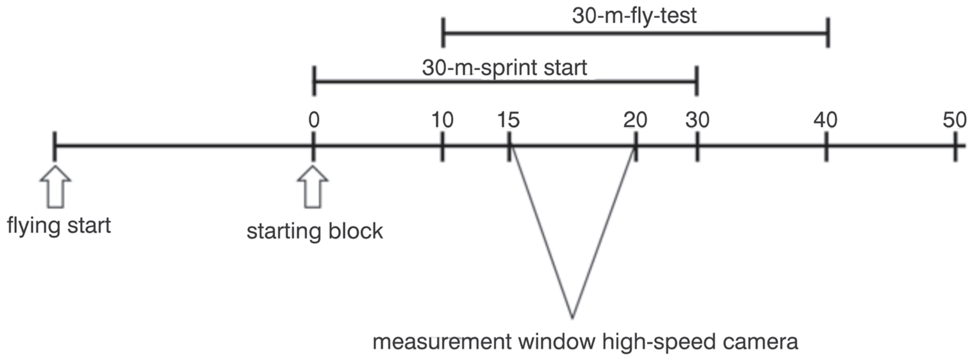

Figure 1. *Testing setup*

Data analysis

Kinematic analysis (raw data tracking) was realized using Peak Motus (10.1). Raw data were smoothened with a Butterworth filter (cutoff frequency 10 Hz) and angle data were rounded to 1° before event detection. In addition to the parameters for characterizing the sprinting speed (table 3), four body angles were measured for six different key positions of the sprint step as well as the horizontal distance between the toe marker and the hip marker during foot contact (fig. 2).

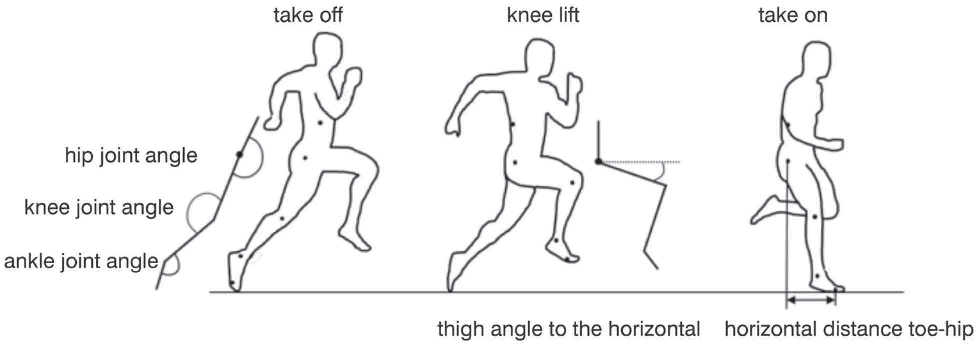

Figure 2. *Definition of body angles and the horizontal distance between marker points from toe to hip.*

The key positions were takeoff (picture 1 and 7), minimal angle of the knee during heel to the buttocks (picture 2), maximal knee lift at the end of the knee lift swing (picture 3), maximal knee angle at swing down (picture 4), take on (picture 5) and minimal angle of the knee during support phase (picture 6, fig. 3). The measurement accuracy was ±5 ms for time and ±1.5° for angle.

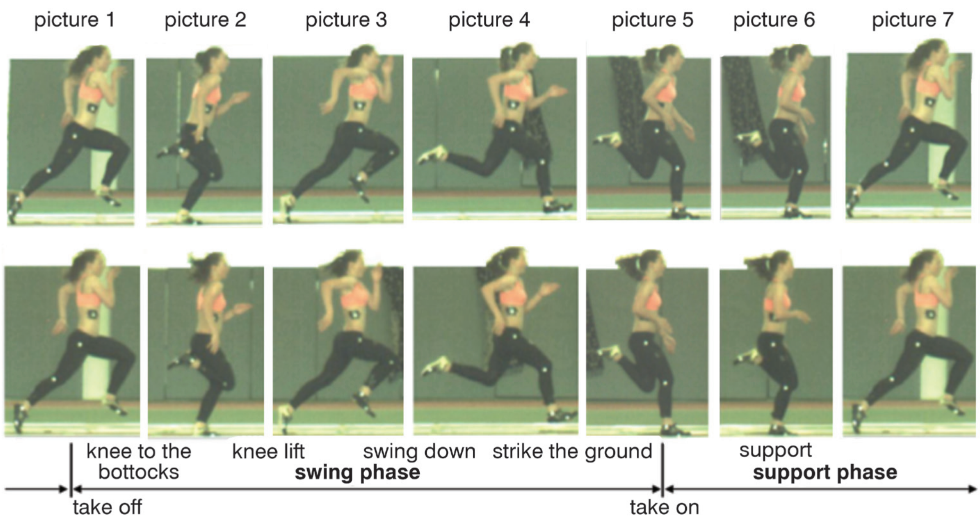

Figure 3. *Exemplary picture series of a female athlete, comparison of pickup acceleration (above) and maximum sprinting speed (below).*

Mean values and standard deviation were calculated for the parameters. An analysis of variance with repeated measures (general linear model) and within-subject factor sprint variant and between-subject factor gender was performed to examine differences between mean values of the sprint variants and gender. All parameters fulfilled the requirements for the variance analysis (normal distribution and homogeneity of variance). The level of significance was set at as $p \leq 0.05$. Statistical calculations were performed using IBM SPSS 20.0 (Chicago, IL, USA).

RESULTS

Significant differences between pickup acceleration versus maximum sprinting speed were found for

- sprinting speed, step length (left and right), double step length and flight time (left and right) with higher values for sprinting with maximum speed
- contact time (left and right) with smaller values for sprinting with maximum speed (tab. 3).

Body angles showed significant differences in comparison of the two sprint variants (tab. 4). Higher values were found for the knee angle of the front leg during swing down (picture 4), the foot contact (picture 5) as well as when flexing the knee joint during the ground contact of the supporting leg (picture 5 to 6) when sprinting with maximum speed. The knee angles of the swinging leg differed significantly during the foot contact of the opposite side as well as by tendency ($p=0.07$) in minimum during heel to the buttocks with smaller values during maximum sprinting speed (tab. 5).

Significant higher sprinting speed, step length (left and right) and double step length were found for men compared to women (tab. 3). Furthermore, the women's foot contact was closer to the body (horizontal distance between marker points of hip and toe). The position of takeoff was characterized by a greater knee extension for the women than for men (tab. 4).

Table 3

Mean ± standard deviation in comparison of pickup acceleration (pickup) and maximum sprinting speed (sprint), p-value of the main effect sprint variant (pickup vs. sprint) and p-value of the between subject gender (female vs. male), N=16

Gender	Test	Speed [m/s]	Step length [m]			Step frequency [step/s]			Contact time [ms]		Flight time [ms]	
			Left	Right	Double stride	Left	Right	Double stride	Left	Right	Left	Right
Female (n=8)	**Pickup**	7.7 ± 0.4	1.87 ± 0.08	1.91 ± 0.13	3.78 ± 0.19	4.26 ± 0.31	4.19 ± 0.28	2.11 ± 0.12	115 ± 11	116 ± 10	121 ± 12	123 ± 10
	Sprint	8.0 ± 0.3	1.94 ± 0.09	1.97 ± 0.11	3.91 ± 0.19	4.22± 0.23	4.20 ± 0.25	2.10 ± 0.11	108 ± 9	109 ± 11	129 ± 12	130 ± 10
Male (n=8)	**Pickup**	8.4 ± 0.3	2.01 ± 0.16	2.04 ± 0.13	4.04 ± 0.26	4.34± 0.38	4.37 ± 0.31	2.17 ± 0.14	113 ± 10	110 ± 12	119 ± 16	120 ± 13
	Sprint	9.2 ± 0.3	2.14± 0.14	2.19 ± 0.09	4.33 ± 0.22	4.36 ± 0.29	4.38 ± 0.28	2.18 ± 0.13	108 ± 9	106 ± 7	123 ± 11	124 ± 12
Total (*N=16*)	**Pickup**	8.1 ± 0.5	1.94 ± 0.14	1.97 ± 0.14	3.91 ± 0.26	4.30 ± 0.34	4.28 ± 0.30	2.14 ± 0.13	114 ± 10	113 ± 11	120 ± 14	122 ± 11
	Sprint	8.6 ± 0.7	2.04 ± 0.15	2.08 ± 0.15	4.12 ± 0.29	4.29 ± 0.26	4.29 ± 0.27	2.14 ± 0.12	108 ± 9	107 ± 9	126 ± 12	127 ± 11
Pickup vs. Sprint (p-value)		0.00	0.00	0.00	0.00	0.81	0.87	0.98	0.01	0.02	0.05	0.05
Female vs. Male (p-value)		0.00	0.01	0.00	0.00	0.47	0.22	0.28	0.74	0.33	0.52	0.38

DISCUSSION

The sprinting speed was 7.7 m/s and 8.0 m/s for the women and 8.4 m/s and 9.2 m/s for the men with higher values during maximum sprinting speed as expected. The required difference in speed was given for both samples. The increase in sprinting speed occurred as hypothesized because of an extended step length and reduced ground contact time at comparable step frequency. The mean double stride length during maximum sprinting speed was 21 cm greater than during pickup acceleration whereas for male athletes the mean double step length increased by 29 cm and for females by 13 cm from pickup acceleration to maximum sprinting speed. Moreover, the increase in step length at comparable step frequency indicates that the athletes realized the pickup acceleration in a good way.

Step frequency showed no significant differences between maximum sprinting speed and pickup acceleration. This is in accordance with the result of the adolescents' step frequency, which is maximized after 10-20 m of the race and maintained during the constant speed phase (5). An increase in step length at comparable step frequency during the acceleration phase was also reported from Rabita, Dorel, Slawinski, Sàez de Villarreal, Couturier, Samozino and Morin (23) as well as from Debaere, Jonkers and Delecluse (9). Thereby, the correlation between step length and step frequency must be considered. However, improving one of the characteristics often does not lead to an improvement of the other and might even worsen it and vice versa. Although a negative relationship between step length and step frequency exists, which determines sprinting speed (10, 14, 19, 27), the athletes realized increases in speed over the step length while maintaining the same step frequency in line with Corn and Knudson (8).

The mean contact times during maximum sprinting speed were approximately 6 ms shorter in mean whereas flight times were approximately 5 to 6 ms longer. The time for the double step (approx. 235 ms) remained the same. These findings are in accordance with Maćkała (15) and Nagahara et al. (20, 21), who also found an increase in sprinting speed during the entire acceleration phase of maximum sprinting with an increase of in step length and flight time and a decrease of the support time. The reduction in contact time by increase the flight time in combination with an increased step length explains higher sprinting speed compared with pickup acceleration.

This change in producing of sprinting speed was closely related with characteristic movement patterns, which is reflected in the picture series (fig. 3). Both sprint variants differed in landing position between the knee angle of the swing and support leg (picture 5,) but not in takeoff position (picture 1 and 7). Because of the longer flight time it is possible to place the foot on the ground comparably close to the body during maximum sprinting speed although the knee angle is more extended during downswing (picture 4). Young (29) already emphasized the importance of a longer flight time for achieving an effective landing position. The more extended knee angle of the front leg during downswing supported a greater step length and facilitates at the same time the compensation of the pressure during landing at the beginning of the ground contact phase. The resulting flexion angles of approx. 150-151° were comparable of both sprint variants.

The following knee extension of approx. 23° for both sprint variants thus yielded to a comparable takeoff position with knee angles of approx. 164° at the end of the ground contact phase (picture 1 and 7). The measured knee angles of markedly smaller than 170° accorded well with already presented data (10). A full knee extension at takeoff is not necessary for pickup acceleration as well as for maximum sprinting speed. This is in accordance with a negative correlation between knee extension at foot strike and sprint performance (22) and the minor priority of the knee extension in producing sprinting speed (26). Mann (16) showed a flexor to extensor dominance at the knee during the ground phase followed by an extensor to flexor dominance during the air phase.

After takeoff the swinging leg differed by tendency in the minimum knee angle during the heel to the buttocks (picture 2). The marked heel to the buttocks with a small knee angle of the swinging leg remains an open question: whether the heel to the buttocks was achieved with relaxed muscles (loose knee) as requested or through an active knee flexion (24, 28). It is critical for the athlete to minimize the moment of inertia of the thigh because of an early bend in the knee joint (24). During maximum sprinting speed the knee flexion of the swinging leg after breaking ground contact is actively through the contraction of the hamstrings (28).

It must be seen critically that the knee lift at the end of the knee lift swing showed no significant differences between both sprint variants (picture 3). Wiemann and Tidow (1995) emphasized the importance of a high knee at the end of the knee lift. The knee lift directly affects the conditions of the involved muscles as well as the reaction forces of the supporting leg. A high lifted knee stretches the hamstrings and gluteal muscles for the following hip extension at downswing during the pre-support-phase. This leads, furthermore, to a sudden stop of the upper leg at maximum knee lift to the momentum transfer on the entire body and supports the takeoff extension because the time of maximum knee lift coincides with the takeoff of the opposite side. In this respect, it would be aimed achieving greater knee lift at the end of the knee lift swing particularly at maximum sprinting speed.

The higher sprinting speed and step length for men at a step frequency comparable with the women was expectable. However, no shorter ground contact time for men though higher sprinting speed were found. The ground contact times differed in mean between 0 and 6 ms. A possible explanation for the non-significant differences between the ground contact times could be the low time resolution of 200 pictures/s (5 ms between two pictures) of the video.

The greater horizontal distance between the foot and the body at foot contact can be explained by the greater leg length for the men. Furthermore, differences were found for the ground contact phase which became evident for the women with a greater knee angle at takeoff as a result of the greater knee extension during the ground contact phase.

The athletes of this study were partly squad athletes of the Hamburger D-squad but for the most part member of a training group whose sprinting times were below squad-level. Thus, it is not possible to transfer the results to higher sprinting speed of world class athletes. A further limitation was the measurement of a double step with one high-speed camera from a sagittal position. Only a 2D kinematic analysis occurred using a reduced marker model focused on the lower extremities. The position of the upper part of the body was not measured.

CONCLUSION

The results confirm an increase in step length at comparable step frequency with a reduction of the ground contact time and longer flight time during the maximum sprinting speed in comparison to the pickup acceleration phase. As a consequence, the step rhythm changes (relation ground contact to flight time) and the conditions for the sprint technique are different. Because of the extended flight time it is possible to place the foot comparably close to the body but with a more extended knee on the ground. During the frontside support phase, the knee of the support leg can be more flexed and still reaches a comparable minimal knee angle as during pickup acceleration. Because subsequently a comparable extension in the knee joint occurs, an identical knee angle at takeoff position for both sprint variants is realized. An increased vertical momentum is a necessary prerequisite to extending the flight time.

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REFERENCES

1. Ae M, Ito A, Suzuki M. The Scientific Research Project at the III World Championships in Athletics: Preliminary Reports: The Men's 100 meters. New Stud Athl 7(1): 47-52, 1992.

2. Bergamini E. Biomechanics of sprint running: a methodological contribution. Doctoral thesis, Arts et Métiers ParisTech, Paris, 2011.
3. Bezodis I. Investigations of the step length-step frequency relationship in sprinting: applied implications for performance. In Proceedings of the 30th Annual Conference of Biomechanics in Sports: 43-49, 2012.
4. Brüggemann GP, Glad B. Time analysis of sprint events: Scientific research project at the games of the XIV-th Olimpiad-Seoul 1988.New Stud Athl 5: 27-55, 1990.
5. Chatzilazaridis I, Panoutsakopoulos V, Papaiakovou G. Stride characteristics progress in a 40-m sprinting test executed by male preadolescent, adolescent and adult athletes. Biology of Exercise. 8(2): 58-77, 2012. doi: 10.4127/jbe.2012.0060.
6. Čoh M, Dolenec A, Jošt B. Kinematic, kinetic and electromyographic characteristics of the sprinting stride of top female sprinters. In *ISBS-Conference Proceedings Archive*. 1(1): 353-356, 1999.
7. Čoh M, Milanović D, Kampmiller T. Morphologic and kinematic characteristics of elite sprinters. Coll Antropol, 25(2): 605-610, 2001.
8. Corn RJ, Knudson D. Effect of elastic-cord towing on the kinematics of the acceleration phase of sprinting. J Strength Cond Res 17(1): 72-75, 2003.
9. Debaere S, Jonkers I, Delecluse C. The contribution of step characteristics to sprint running performance in high-level male and female athletes. J Strength Cond Res 27(1): 116-124, 2013.
10. Hunter JP, Marshall RN, McNair PJ. Interaction of step length and step rate during sprint running. Med Sci Sport Exer 36(2): 261-271, 2004.
11. Jones R, Bezodis I, Thompson A. Coaching sprinting: expert coaches' perception of race phases and technical constructs. Int J Sports Sci Coach 4(3): 385-396, 2009.
12. Letzelter S. The development of velocity and acceleration in sprints. New Stud Athl 21(3): 15, 2006.
13. Maćkała K., Fostiak M, Kowalski K. Selected Determinants of Acceleration in the 100 m Sprint. J Hum Kinet 45(1): 135-148, 2015.
14. Maćkała K., Mero AA. Kinematics Analysis Of Three Best 100 M Performances Ever. J Hum Kinet 36(1): 149-160, 2013.
15. Maćkała K. Optimisation of performance through kinematic analysis of the different phases of the 100 metres. New Stud Athl 22(2): 7, 2007.
16. Mann RV. A kinetic analysis of sprinting. Med Sci Sport Exer 13(5): 325-328, 1980.
17. Mero A, Komi PV, Gregor RJ. Biomechanics of sprint running. Sports Med 13(6): 376-392, 1992.
18. Mero ANTTI, Komi PV. Electromyographic activity in sprinting at speeds ranging from sub-maximal to supra-maximal. Med Sci Sport Exer 19(3): 266-274, 1987.

19. Morin JB, Bourdin M, Edouard P, Peyrot N, Samozino P, Lacour JR. Mechanical determinants of 100-m sprint running performance. Eur J Appl Physiol 112(11): 3921-3930, 2012.
20. Nagahara R, Matsubayashi T, Matsuo A, Zushi K. Kinematics of transition during human accelerated sprinting. Open Biol 3(8): 689-699, 2014a.
21. Nagahara R, Naito H, Morin J.-B, Zushi K. Association of acceleration with spatiotemporal variables in maximal sprinting. Int J Sports Med 35(9): 755-761, 2014b.
22. Pandian KK. Interaction of Knee Kinematics During Sprint Running. PARIPEX-Indian Journal of Research 5(2): 2016.
23. Rabita G, Dorel S, Slawinski J, Sàez de Villarreal E, Couturier A, Samozino P, Morin J B. Sprint mechanics in world class athletes: a new insight into the limits of human locomotion. Scand J Med Sci 25(5): 583-594, 2015.
24. Seagrave L, Mouchbahani R, O'Donnell K. Neuro-biomechanics of maximum velocity sprinting. New Stud Athl 24(1): 19-29, 2009.
25. Shen W. The effects of stride length and frequency on the speeds of elite sprinters in 100 meter dash. ISBS-Conference Proceedings Archive Vol. 1, No. 1, 2000.
26. Vonstein W. Some reflections on maximal speed sprinting technique. New Stud Athl 11: 161-165, 1996.
27. Weyand PG, Sternlight DB, Bellizzi MJ, Wright S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. J appl phys 89(5): 1991-1999, 2000.
28. Wiemann K, Tidow G. Relative activity of hip and knee extensors in sprinting-implications for training. New Stud Athl 1(10): 29-29, 1995.
29. Young M. Maximal velocity sprint mechanics. Coaches Choice, 2007.

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