Original Article

A longitudinal study of kinematic stride characteristics in maximal sprint running

KLAUS MATTES[1] , NELE HABERMANN[1] ✉ , NINA SCHAFFERT[1] & THOMAS MÜHLBACH[2]

[1] *Department of Human Movement Science, University of Hamburg, Hamburg, Germany*

[2] *Athletic Association Hamburg, Hamburg, Germany*

ABSTRACT

Mattes, K., Habermann, N., Schaffert, N. & Mühlbach, T. (2014). A longitudinal study of kinematic stride characteristics in maximal sprint running. *J. Hum. Sport Exerc., 9*(3), pp.686-699. Purpose of the present study was to measure the kinematic stride characteristics of track-and-field-sprinters and jumpers in maximal sprint-running during different training periods (TP) of a double-periodisation (DP). 26 participants (7 females, age: 22.7 ± 5.7yrs, body mass: 60.1 ± 6.7kg, body height: 172.1 ± 4.4cm; 19 males, age: 20.9 ± 3.3yrs, body mass: 73.7 ± 6.5kg, body height: 182.3 ± 7.5cm) participated in flying 30-meter-sprints. Kinematic stride parameters (stride-velocity, stride-length, stride-frequency, contact-time, flight-time and stride-rhythm) were measured for every single stride with Optojump (Microgate S.r.L., Italy). The training data were collected via protocol. A variance analysis with repeated measures was calculated for 3 respectively 6 TPs as well as multiple regression functions for the stride-velocity. The longitudinal results showed significant values for the 6 TPs, however cyclic increase of maximal sprint-velocity (on average 0.42 ± 0.08m/s) with a DP that corresponded with the recorded training data. 3 TPs differed significantly in average stride-velocity, stride-length, stride-frequency and contact-time of the maximal sprint, but not in flight-time and stride-rhythm. Our findings suggest that kinematic stride characteristics depend on TP. A systematic training control to increase the sprint-speed must take into account these changes of the kinematic parameter during the training year. **Key words**: KINEMATIC ANALYSIS, TRACK-AND-FIELD, SPRINTERS AND JUMPERS, DOUBLE-PERIODISATION, FLYING 30-METER-SPRINT.

✉ **Corresponding author.** University of Hamburg, Department of Human Movement Science, Mollerstr. 2; 20148 Hamburg, Germany
E-mail: nelehabermann@gmx.de
Submitted for publication January 2014
Accepted for publication July 2014
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.14198/jhse.2014.93.02

INTRODUCTION

Sprint running can be divided into three main parts: an acceleration phase, a maximum speed phase and a deceleration phase (Delecluse, 1997; Gajer, Thepaut- Mathieu & Lehenaff, 1999; Mero, Komi & Gregor, 1992).

From a biomechanical point of view, maximum sprint velocity is defined by stride frequency and stride length. These two factors need to be understood in a negative relation towards each other: an increase in one factor will result in an improvement in sprint velocity, as long as the other factor does not undergo a proportionally similar or larger decrease (Hunter, Marshall & McNair, 2004). This will result in three different ways in order to increase the maximal sprint velocity: a change in stride length while the stride frequency remains the same and vice versa, or the simultaneous change of both parameters. For the change of these kinematic parameters of the sprint stride, 'facilitated' or 'hindered' running are recommended. The effects of these training exercises on kinematic parameter of sprint stride have been researched numerous times before (Delecluse, Ponnet & Diels, 1998). 'Facilitated' running entails downhill and supra maximal training with the use of a towing device (Vitasalo & Bosco, 1982), 'hindered' running, on the other hand, entails running with a weight-sled, a parachute or weight belt (Alcaraz, Palao & Elvira, 2009; Lockie, Murphy & Spinks, 2003; Cronin & Hansen, 2006; Young, Benton, Duthie & Pryor, 2001).

The contact phase represents one of the most important biomechanical parameters in the sprint stride structure (Mero & Komi, 1986; Bruggemann & Glad, 1990; Tidow & Wiemann, 1994; Mero & Komi, 1994; Bosco, Vittori & Matteucci, 1995; Viitasalo et al. 1982; Wank, Frick & Schmidtbleicher, 1998). During maximum sprint velocity (10-12 m/s) contact time of 100 m were measured from Bosco and Vittori (1986) as well as from Coh, Milanovic and Dolenec (1999). Faster sprinters apply greater ground force in shorter contact time than slower sprinters, for instance in a comparison of decathletes and sprinters (Kunz & Kaufmann, 1981). If the horizontal velocity of the athlete is greater, the time available to make contact with the ground is shorter (Hunter et al., 2004). At a given maximal sprint velocity, the contact phase of the sprint stride depends on the stride frequency, stride length and the sprint performance (Coh, Colja, Dolonec & Stuhec 1998; Ae, Ito & Suzuki, 1992).

In contrast, the contact time of the sprint stride is not currently utilised efficiently in training, because data about contact time and its change is not available in daily training. Sprint time can be measured fairly accurately and easily by a light barrier. The measurement of the contact time with diagnostic equipment (bottom contact sensor, light barriers, force plate or high speed cameras etc.) is time consuming. Testing sprints only with mean velocities or rather total length and without the other kinematic stride parameters limits the diagnostic considerably, because the same sprint speed can result from different relationships between stride length and stride frequency as well as flight and contact times. It is assumed that kinematic parameters of a flying 30-meter sprint depend on the athlete's condition and technique, on the current training load as well as on the training periodisation.

In track and field sprint and jump disciplines, usually a double-periodisation (DP) with two main competitions in winter and summer seasons were used (Joch, 1992; Killing, et al., 2008). A high sprint or jump performance cannot be kept for the whole training year, because the necessary high training intensity results in an overtraining. A training year starts with a general preparation phase (gPrep) over 6-8 weeks with high training volume followed by a specific preparation phase (sPrep) over 10-12 weeks with a main focus on training intensity and specificity. During the four week competition phase (CP), training volume and intensity decreases in order to achieve a peak condition for the competitions. The cycle passes through two times in the training year. A transition phase to undergo physical and psychological regeneration disconnect this cycle.

The aim of this study was to measure the kinematic parameters of the sprint stride in different TP of the DP, to show the modifications of the maximal sprint velocity based on its kinematic parameters. Due to the cyclical characteristics of the DP, it was assumed, that an increase in maximal sprint velocity is produced by a decrease in contact time from the gPrep, over the sPrep to the CP. The specific kinematic stride length and stride frequency data should be individually distinctly distinguishable in the two cycles.

MATERIAL AND METHODS

Data collection was part of routine measurements within the sport science support. Ethical approval for this study was granted by the review committee of the German Athletic Association (DLV).

Participants

The participants were track and field athletes (sprinters and jumpers) from four different training groups in Berlin with B- and C-squad athletes of the German Track and Field Association (DLV) competing at a national to international performance level. Seven female and 19 male athletes participated in maximum flying 30-meter sprints in three or six TPs (table1).

Table 1. *Overview of the sample of testing in maximum flying 30-meter sprints*

Gender	Training period (TP)	Number of participants	Age [yrs]	Body mass [kg]	*Body height [cm]*
Female	Tests in 6 TP; 1.gPrepP until 2.CP	3	22.7 ± 6.4	57.0 ± 7.2	*171.3 ± 5.9*
Male		7	21.9 ± 2.0	75.0 ± 6.3	*182.1 ± 7.9*
Female	Tests in 3 TP; gPrepP, sgPrepP and CP	7	22.7 ± 5.7	60.1 ± 6.7	*172.1 ± 4.4*
Male		*19*	*20.9 ± 3.3*	*73.7 ± 6.5*	*182.3 ± 7.5*

Experimental Design

The athletes were tested in maximal sprint running with flying start over a 30 meter distance three or six times in the TP from October 2007 until August 2008. Table 2 shows the arrangement of the TP.

Table 2. *Arrangement of the training period from October 2007 until August 2008*

Training period	1.gPrepP	1.sPrepP	1.CP	2.gPrepP	2.sPrepP	*2.CP*
Month	Oct.-Nov.	Nov.-Jan.	Feb.	March	April-June	*June-Aug.*
Calendar week	*40-46*	*47-4*	*5-8*	*9-14*	*15-25*	*26-35*

After performing the individual warm-up, flying 30-meter sprints followed with maximal velocity. The athletes could choose an individual start-up, which did not exceed 20m. The athletes performed two runs and the sprint with the higher sprint speed was evaluated. The sprint trials were conducted on a synthetic track in an indoor athletic stadium. Participants wore their own athletic training clothes and spiked sprint shoes.

Kinematic Data

The kinematic stride parameters were measured with Optojump (Migrogate S.r.L., Italy). Optojump is an optical measurement system with infrared light barriers. One single part of the measurement system is one meter and has 32 separate light barriers, which were mounted in a structure of length about 3.0cm (figure1).

For the tests, the measurement system was connected in series over the 30m distance. The light barriers from Optojump measure the contact and flight time with a sample rate of 1/1000s as well as the stride length with a measuring error of 3.0cm. The data were sampled on a computer. With the test data it is possible to display and calculate the kinematic parameters of the sprint stride directly (table 3).

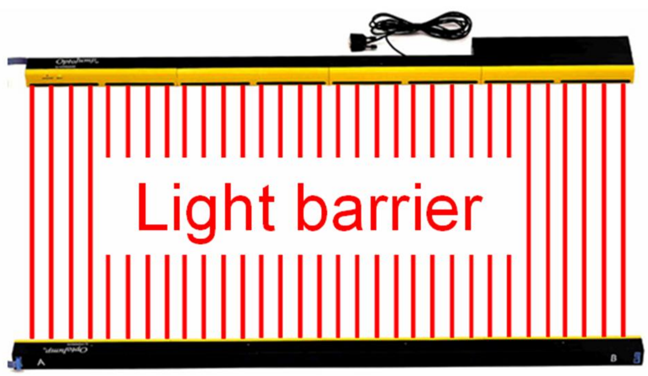

Figure 1. *One meter Optojump with light barriers*

Table 3. *Overview of the kinematic parameters of the sprint stride*

kinematic parameter	symbol [unit]	Definition	*observation error*
Stride velocity	v_s [m/s]	$\frac{s_L}{t_C + t_F}$	*± 3%*
Stride length	s_l [cm]		*± 3cm*
Stride frequency	f_s [Hz]	$\frac{t_C + t_F}{1}$	*± 0,2Hz*
Contact time	t_c [s]		*± 1ms*
Flight time	t_f [s]		*± 1ms*
Stride rhythm	t_f/t_c	$\frac{flighttime}{contacttime}$	*± 2%*

Training Data
For the analysis of the training data, a registration sheet was developed, which lists the training categories and intensity in the different training weeks (table 2). In running training, five different intensities were distinguished to develop the aerobic and anaerobic capacity (I1-I5). The strength training is subdivided into endurance strength training, muscle hypertrophy methods, neuronal activation methods, speed strength training, plyometrics and specific strength training (including sprint associated exercise like 'hindered' running etc.).

The return of the training data was different between the training groups. Almost all (19 of 17) male athletes returned the training data. The return of the training data from the female athletes was less effective, so that the female training data was not statistical evaluated. The frequency of the different running and strength training categories were counted in the training periods and weeks (table 7).

Statistical Analysis
The data was statistically described (mean, standard deviation) and calculated by a variance analysis of the general linear model with repeated measures as factor within groups TP (gPrepP, sPrepP and CP) and between group macro-cycle. Pairwise comparisons resulted from the Scheffé-Test. Normal distribution and homogeneity of variance were analysed using Kolmogorov-Smirnov- and Levene-Test. The effect size was measured with partial eta-squared (ηp2). Partial eta squared is often higher than eta squared. The following assessment of the effect size was used: 0.20 refers to a minimal effect; 0.50 to a medium effect; everything equal to or greater than 0.80 refers to a large effect (Cohen, 1982, 1992). To appraise the maximal sprint velocity from the kinematic data, multiple regression analysis was used. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 15.0, SPSS Inc., Chicago, IL, USA).

RESULTS

Comparison of kinematic stride characteristics of sprints in six TP
From October 2007 to June 2008 a systematic increase of the maximal sprint velocity (vS) in addition of the TP (1.gPrep, 1.sPrep, 1.CP, 2.gPrep, 2.sPrep, 2.CP) were found with visible DP. The sprint velocity differed highly significantly between the TP ($F=6.4$; $p=0.001$) with a medium effect size ($\eta_P^2=0.56$). The increase of the maximal sprint velocity was periodic from the gPrep throughout the sPrep to the CP. At the two CPs (winter or summer season) the athletes demonstrably performed at peak maximal sprint velocity. The increase of the maximal sprint velocity from the 1.gPrep to the 2.CP was on average 0.42 ± 0.08m/s (fig. 2).

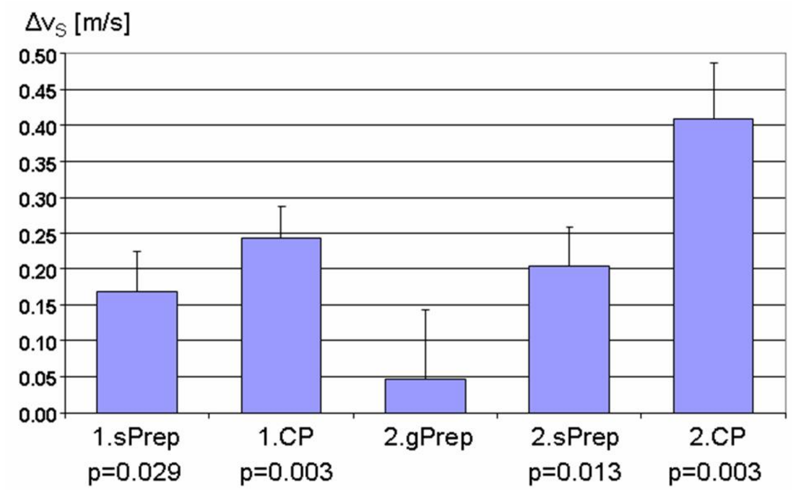

Figure 2. *Comparison of the sprint velocity differences (Δv_S) in maximal flying 30-meter sprints in the TP (1.sPrep, 1.CP, 2.gPrep, 2.sPrep, 2.CP) with the reference period (1.gPrep), mean differences and standard error, p = statistical significance, N=10*

Stride length (s_S), stride frequency (f_S), contact time (t_c), flight time (t_F) and stride rhythm (t_F/t_c) changed periodically like the maximal sprint velocity, however, the differences between the TP were not significant. From the 1.gPrep to the 2.CP the mean average of the stride length increased about 4.4 ± 3.7cm and of the stride frequency about 0.1 ± 0.05Hz. The mean average of the contact time decreased about -3 ± 1ms as well as the mean average of the flight time -2 ± 3ms Only the contact time showed a minimal effect size ($\eta_P 2$ = 0.32) with a trend level of significance (p=0.07). The mean value and the standard deviation, distinguished by gender, were shown in table 4.

Table 4. *Arithmetic mean and standard deviation of the kinematics stride characteristics, stride velocity, Stride length (s_S), stride frequency (f_S), contact time (t_c), flight time (t_F) and stride rhythm (t_F/t_c) of the flying 30-m sprint in different TP*

Gender	TP	v_S [m/s]	s_l [cm]	f_S [Hz]	t_C [ms]	t_F [ms]	t_F/t_C [s]
Male	1.gPrep	9.63 ± 0.19	218.4 ± 15.9	4.43 ± 0.27	106 ± 5	121 ± 11	*1.14 ± 0.10*
N=7	1.sPrep	9.83 ± 0.33	218.9 ± 14.1	4.50 ± 0.23	103 ± 7	120 ± 9	*1.16 ± 0.11*
	1.CP	9.87 ± 0.29	220.3 ± 12.7	4.49 ± 0.24	102 ± 8	121 ± 7	*1.19 ± 0.11*
	2. gPrep	9.75 ± 0.43	219.9 ± 12.9	4.44 ± 0.26	106 ± 10	120 ± 8	*1.15 ± 0.11*
	2. sPrep	9.86 ± 0.27	220.9 ± 12.0	4.48 ± 0.20	105 ± 8	119 ± 8	*1.15 ± 0.12*
	2. CP	10.14 ± 0.30	224.4 ± 15.9	4.54 ± 0.26	103 ± 7	118 ± 9	*1.15 ± 0.10*
Female	1.gPrep	8.41 ± 0.43	207.0 ± 10.1	4.07 ± 0. 06	116 ± 2	130 ± 3	*1.12 ± 0.03*
N=3	1.sPrep	8.60 ± 0.57	208.7 ± 16.0	4.13 ± 0.10	115 ± 3	128 ± 5	*1.12 ± 0.06*
	1.CP	8.72 ± 0.54	209.3 ± 12.1	4.17 ± 0.21	111 ± 4	130 ± 8	*1.17 ± 0.03*
	2. gPrep	8.45 ± 0.67	206.3 ± 14.0	4.09 ± 0.11	114 ± 8	131 ± 4	*1.15 ± 0.10*
	2. sPrep	8.59 ± 0.53	206.7 ± 12.5	4.16 ± 0.02	113 ± 4	128 ± 4	*1.14 ± 0.07*
	2. CP	*8.72 ± 0.56*	*211.0 ± 15.7*	*4.14 ± 0.09*	*113 ± 3*	*129 ± 2*	*1.14 ± 0.00*

The mean sprinting average of the male athletes was about 18cm longer in stride lengths at about 0.23Hz stride frequency and about 10ms shorter in flight time and approx. 1.23m/s faster compared to the female athletes.

Comparison of kinematic stride characteristics of sprints in three TP

From the gPrep to the CP identifiable average results were:

-a significant increase in stride velocity of 0.28±0.03m/s ($F=33.3$, $p=0.00$, $\eta p2=0.6$), in stride length of 3.2±1.0cm ($F=5.9$, $p=0.00$, $\eta p2=0.21$) and in stride frequency of 0.08±0.02Hz ($F=8.1$, $p=0.00$, $\eta p2=0.27$) that means 0.76 strides more in 10s and

-a significant decrease in the contact time of -3±1ms ($F=7.6$, $p=0.00$, $\eta_P^2=0.26$) (figure 3 and table 4)

The flight time and stride rhythm did not on average show significant differences from the gPrep to the CP results.

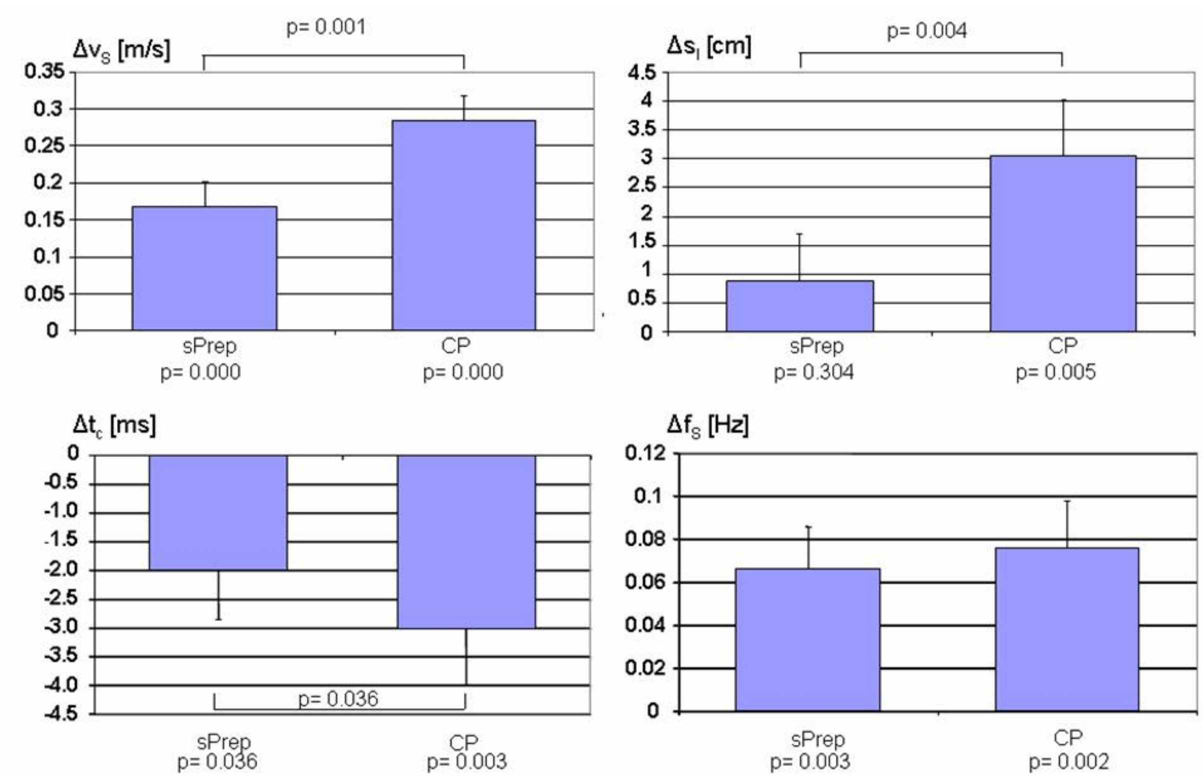

Figure 3. *Comparison of the kinematics stride characteristics: stride velocity (v_S), Stride length (s_l), stride frequency (f_S), and contact time (t_c), of the TP with the reference period (gPrep), mean differences (Δ) and standard errors, p = statistical significance, N=36*

Multiple regression analysis of the stride characteristics of the sprint

An estimate of the stride velocity was made by multiple regression analysis from the stride characteristics: stride length (s_l), contact time (t_C) and flight time (t_F) by the first formula. In all three TPs, the multiple regression function reached a very high coefficient of determination (R2) with consistently 0.99 (table 5).

$$v_S = K + B_{tC} \cdot t_C + B_{tF} \cdot t_F + B_{sl} \cdot s_l \quad (1)$$

Table 5. Multiple regression analysis to prognosticate the stride velocity from the kinematics stride characteristics stride length (s_l), contact time (t_c) and flight time (t_F), R^2 – coefficient of determination, age groups of female (*N*=10) and male athletes, (*N*=26)

Gender	TP	R^2	standard error	K	Bs_l	Bt_F	Bt_C
Male	gPrep	0.996	0.02760	9.704	0.043	-41.954	-41.612
	sPrep	0.992	0.03510	9.782	0.044	-42.493	-42.896
	CP	0.994	0.03343	9.823	0.045	-44.179	-43.294
Female	gPrep	0.999	0.01103	8.125	0.040	-30.912	-34.254
	sPrep	0.998	0.02137	8.359	0.041	-33.901	-34.635
	CP	0.999	0.02290	8.600	0.042	-38.184	-34.334

In training, usually only stride length and stride frequency were considered, but not the contact time and flight time. Using the following formula, the stride velocity from both data were calculated (table 6).

$$v_S = K + B_{fS} \cdot f_S + B_{sl} \cdot s_l \qquad (2)$$

Table 6. *Multiple regression analysis (ß-data) to prognosticate the stride velocity from the kinematics stride characteristics stride length (s_l) and stride frequency (f_s), R^2 – coefficient of determination, age groups of female (N=10) and male athletes, (N=26)*

Gender	TP	R^2	standard error	K	Bs_l	Bf_S
Male	gPrep	0.992	0.02216	-9.103	0.042	*2.166*
	sPrep	0.994	0.0312	-9.687	0.044	*2.205*
	CP	0.994	0.0312	-9.268	0.043	*2.142*
Female	gPrep	0.998	0.02216	-8.179	0.042	*1.965*
	sPrep	0.998	0.02193	-8.196	0.042	*1.955*
	CP	*0.999*	*0.01615*	*-8.248*	*0.041*	*2.010*

Training protocols of the athletes with tests over six TP

The training data showed an increase in training intensity especially from the gPrep throughout the sPrep to the CP. The training intensity increased from the gPrep throughout the sPrep to the CP during running training from GA, NI, I3, I2 to I1 and during strength training (from strength endurance to specific strength). Endurance runs were performed in all TPs, but were reduced considerably during the CP. In CP, running training was only used to compensate the competition exposure. The peak of training intensity was during the CP. The training intensity of the 2.gPrep was higher than in 1.gPrep (table 7)

The main focus during the gPrep in running training was the basic endurance (GA, NI) and in strength training the speed strength endurance methods with low training intensity. At calendar week 43 the running training began with mean intensity (I.3 between 75-89% of the maximal speed) and at calendar week 45 with a higher training intensity (I.2 between 90-94% of the maximal speed). Strength endurance and hypertrophy methods dominated in the strength training. Some athletes practiced specific strength training (resistance sprints).

Table 7. *Training protocols of the male athletes, which were testing in three TP, N = 17*

Competitions and training categories		Training period and division after calendar weeks																									
		1.gPrep							1.sPrep					1.CP								2.gPrep					
		40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13
sprint competitions								1	1	1	1	1	4	3	5	9	9	6	3		1	3	1		1	1	1
running training	SSE I 1 (95-100% vmax)										2	6	4	7	10	11	5	8	3	5	3				2	2	3
	SSE I 2 (90-94% vmax)						1	5	7	8	10	9	8	7	7	4	6	5	2	5	3		2			2	3
	SSE I 3 (75-89% vmax)				3	3	4	9	11	10	10	7	9	5	2	3		4								2	3
	SSE I 4, (50-70% vmax)	4	8	15	16	16	15	10	8	10	6	6	3	4	5	4	4	3	3	2	2	4	9	10	10	8	8
	aeE I 5 (<50 % vmax)	6	9	13	13	12	12	8	8	7	10	10	5	6	6	2	3	3	6	4	4	9	12	12	11	11	11
strength training	specific strength		3	3	3	3	3				3	4	3	5	5	5			3	3	3					2	3
	speed and reactive strength							2	2	3	6	6	3	5	10	8	8	3	3	3	3	3		5	5	5	5
	maximum strength and NAM									3	6	10	14	13	11	12	13	9	1	3	3			3	3	3	3
	hypertrophy	3	4	6	6	10	10	10	10	10	7	2	1		1	1	1	1	1			2	5	6	8	6	6
	strength endurance methods		3	8	9	9	9	9	9	9	9	5	3	3	3	3	3	3	3	3	3	5	7	7	7	5	5
	other methods			3	3	3	3	1	1																		

The training intensity increased during the sPrep: during running training, the proportion of low training intensity decreased, and the proportion of mean and submaximal training intensity increased. Furthermore, during the middle of the sPrep, maximal intensity training was included in the training process. During strength training, hypertrophy training changed to maximal strength training as well as to neuronal activation methods. Several athletes carried out speed strength and reactive strength training. Beginning at calendar week 49, several athletes practised specific strength training (resistance sprints). Few athletes participated at preliminary competitions during the sPrep.

During the CP (winter season), the highest training intensity was performed. In running training, runs with wide maximal intensity and submaximal training intensity dominate the training process. In strength training, maximal strength training and neuronal activation dominated the training process, as well as a proportion of orientated speed strength and reactive strength training. Specific strength training was performed in two parts. Competitions were utilised to reach the peak of intensity.

During the 2.gPrep, the total of higher training intensity were compared with the 1.gPrep, because some athletes performed sprints with maximal intensity as well as strength training in order to increase maximal strength, neuronal activation and speed strength as well as reactive strength.

DISCUSSION

The study analysed the variations in kinematic stride characteristics with maximal sprint velocity over the TP in a training year. A systematic increase of the maximal sprint velocity as a function of the TP with a visible DP was found. The increase in maximal sprint velocity was cyclic from gPrep over sPrep to CP. The peak of the maximal sprint velocity was measured during the 2.CP in the summer season. Because of the low number of tested participants, the results of the kinematic stride characteristics: stride length, stride frequencies, contact time and flight times did not show the same development statistically over the six TP. With this parameter, the realisation of the maximal sprint velocity was specified. A larger sample number and more test data over the three TP would statistically increase the significance of increase in sprint velocity as well as in stride length and stride frequency by a decrease in contact time.

Male athletes were short- distance and long-distance sprinters from three different age groups (Age: 20.9 - 33y, from youth to senior athletes). The flying 30-meter sprints times ranged from 2.81 to 3.07s. In comparison to the results, the structured training plan for sprint in Development Training, requires a sprint performance over that distance of 2.88s together with a sprint performance of 10.9s over 100m and 21.95s over 200m (Joch et al., 1992, p.44). Several athletes did undercut these times at the competition peak time with 10.79s and 10.72s over the 100m as well as 21.84s and 21.79s over 200m.

Female athletes were 400m-sprinters, long- distance sprinters, long and high-jumpers. Their age differed considerably (22.7 ± 5.7y). The flying 30-meter sprint times ranged from 3.30 to 3.77s. In comparison to the results, the structured training plan for sprint in Development Training, requires a sprint performance over that distance of 3.26s together with a sprint performance of 60.6s over 400m hurdles, 11.95s over 100m and 24.6s over 200m as well as 56s over 400m (Joch et al. 1992, p.44). The following times in the competition were slightly below the times in the structured training plan (57.99s over 400m hurdles, 24.1s over 200m and 54.75s over 400m and 6.56m in the long jump).

The cyclical development of the maximal sprint velocity was reconstructed with the training protocols. From gPrep over sPrep to CP the training intensity as well as the specificity increased. The highest training intensity was performed during 1.CP (winter season) and not during sPrep. It must be considered that no training data from 2.CP exists. In addition, the training intensity during 2.gPrep was greater than during 1.gPrep.

The average development of the maximal sprint velocity varied considerably in individual cases. The increase of the maximal sprint velocity developed individually from less than 0.2m/s to more than 0.8m/s. Different factors were responsible for that. On the one hand, the training composition takes place at different times during the training year. For example, individual peak level of competitions differ (regional competitions versus national or international competitions). Accordingly, individual sprint performance was planned differently. On the other hand, the individual use of training facilities as well as an improvement in the sprint technique, affected the increase in sprint performance. According to the main training focus different adaptations occurred. Strength training and sprint associated exercises play a key role in this process. The most specific way to affect stride characteristics is by 'facilitated' or 'hindered' running (Delecluse, Ponnet & Diels, 1998). Some studies analysed the momentary effects of facilitated and hindered running. The experimental group in the study of Viitasalo et al. (1982) showed significantly higher stride frequencies and higher running velocities following facilitated sprint training. Hindered sprinting is supposed to result in greater stride length. Alcaraz, Palao, Elvira and Linthorne (2008) tested and compared the kinematics at maximal sprint velocity to the kinematics of sprinting with the use of three types of resisted sprint training devices (sled, parachute and weight belt). Results showed that the three types of resisted sprint training devices put a substantial overload on the athlete, as indicated by reductions in stride length and running velocity. Additionally, other authors differentiated the training effect by the way that after training with weight sleds the stride length (Lockie et al., 2003) and after training with weighted vests the stride rate (Cronin & Hansen, 2006; Young et al., 2001) increased. Different strength training methods (hypertrophy, IK-Training, speed-strength Training) are proposed to improve the power output of the sprint specific muscles. As heavy resistance training results in a conversion from fibre type IIx into fibre type IIa, the aim of the coach is to search for an optimal balance between sprint-specific and non-specific training components (Delecluse, 1997). The application of the different training methods with their specific effect is reflected in the measured kinematic parameter but with individual characteristics.

In order to be able to analyse the influence of training on a kinematic parameter as well as to be more precise, the training protocol must be further refined. Besides this, the application of training exercises in particular with a direct effect on the kinematic parameter such as 'facilitated' running, which entails downhill and supra maximal training with the use of a towing device or 'hindered' running, has to be considered separately. In present studies this was summarised under specific strength training.

Results for the contact time showed a wide spectrum from 94ms to 120ms, in which only three male athletes achieved a contact time below 100ms on at least three test dates. The fastest sprinter in the test achieved the highest maximal sprint velocity (10.6m/s) in the 2.CP with a longer contact time (104ms) compared to the 1.CP and 101ms contact time with 10.27m/s. This development is associated with an increase in stride length from 237cm in the 1.CP to 253cm in the 2.CP. The example shows, that during a training year the increase of the maximal sprint velocity does not necessarily show a reduction in the contact time for every athlete. To a certain extent, an individual increase in the stride length associated with longer contact times is possible. This individual case shows the reverse with an increase in the contact time from 105ms to 96ms during a macro-cycle, whereas the maximal sprint velocity showed an increase from 9.54 to 10.02m/s and the stride length a decrease of about 5cm (from 215cm to 210cm). The contact time is a sensitive parameter for the training control, which developed individually and varied considerably during a training year. With the help of the contact time it is easier to identify the actual training effect.

The contact times of the female athletes were consistently longer than 100ms. Only one female athlete has a shorter contact time (95-97ms) at a maximal sprint velocity of 9.17-9.26m/s. In comparison to the data from Coh et al. (1999), which shows contact times from 101 ± 0.05 ms at a maximal sprint velocity from 8.87 ± 0.14m/s, several athletes performed in the flying 30-meter sprints with comparable maximal sprint velocity, but did not achieve the short contact times. But it must be considered that the data from Coh et al. (1999) were averages of whole 100m-sprints. Furthermore, our female control sample was without specific short sprinters.

In the literature different attempts exist to describe the relationship between the sprint velocity and the kinematic parameters of the sprint stride where correlation and regression were found. Bosco and Vittori (1986) as well as Saziorski, Aljeschinski and Jakunin (1998) described the relationship with non-linear regressions compared to Delecluse, Ponnet and Diels (1998) who described the relationship with linear regressions. In this study a multiple linear analysis was chosen that considered a wide spectrum of performance levels (ages, training periods) separated for female and male athletes. Between the kinematic parameter and the maximal sprint velocity a functional mathematical relationship exists. This is one reason for the high quality of the calculated regression function. The coefficient of determination ($\geq$ 0.99) and the low standard error of the estimator (between 0.02 and 0.04) show the accuracy. The value of the equation showed a wide area of validity for the spectrum of the different ages and anthropometric data.

CONCLUSIONS

Kinematic parameters are important factors for the planning and control of training in sprint disciplines and talent diagnostics. In this context, the sprint velocity and the contact time are very important. The contact time provided indirect information about the ability of the athletes to perform with explosive ballistic strength under time pressure. This ability appears to be constitutional (genetically inherited; the spectrum of muscle fibre), but furthermore is affected by training. In addition to the maximal sprint velocity, the performance training effect is illustrated more clearly if the changes in the contact time and other kinematic characteristics over the DP are exactly determined. For the promotion of sprint talents, systematic capture of the kinematic parameters improved the control of the training process and not least the sprint performance.

Within the tested age groups (from youth to senior level) once bone formation and development has finished, the annual dynamics of the maximal sprint velocity as well as the basic kinematic parameters are influenced more by individual factors (training, sprint technique and other performance dispositions) and less by age (calendar age). During the training year, individual changes of the maximal sprint velocity with different combinations of kinematic parameters resulted. The sprint velocity and the basic kinematic parameters were always analysed by the TP.

The regression functions for the sprint velocity in addition to the kinematic parameters are helpful for the planning and control of the training. With these functional equations, an estimate of the kinematic parameters stride length, stride frequency, contact and/or flight time can be made for a given sprint velocity. Thereby, an adjustment of training between training cycles could be possible. For example, an increase in sprint velocity in the first macro-cycle could be achieved by a decrease of the contact time but with maintained stride length, and in the second macro-cycle, by an increase in stride length but with maintained contact time.

Our findings suggest that the kinematic parameters of the sprint stride depend on the TP. Systematic training control would be an effective means for increasing maximal sprint velocity if the changed combination of the kinematic parameters were used throughout the training year.

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