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The use of various strength-power tests as predictors of sprint running performance

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Backround. The present study assessed the relationship between various strength-power tests and maximal running velocity parameters.

Methods. Nine trained males were tested on four separate occasions. On the first occasion the maximum running velocity (MRV), stride rate (SR) and stride length (SL) were measured over 35 m. On the second occasion maximal vertical jumps [squat jump (SJ), standing broad jump (SJ), counter movement jump (CMJ) and drop jumps (DJ) from heights of 30, 50 and 80 cm] were performed on a force platform: On the third occasion the maximal bilateral isometric force (MBIF) of leg extensors and the force time characteristics (f-t 10-30%, f-t 1060% and f-t 10-90%) were determined using a leg extension machine connected to a force plate. On the final fourth occasion peak anaerobic power was measured via repeated 6 s maximum cycle sprints. Pearson product-moment correlation coefficients were calculated for all the aforementioned parameters.

Results. The correlation coefficients showed that MRV correlated significantly with f-t 10-60% and DJ30 ($r = 0.73$ and $r = 0.73$, $p<0.05$ respectively). In addition, SR and SL showed significant, and critical for SR, relationship with f-t 10-60% ($r = -0.82$, $p<0.01$ and $r = 0.75$, $p<0.05$ respectively).

Conclusions. The present findings suggest that the ability to produce force quickly, as measured by the time to achieve 60% of maximum voluntary contraction is related to sprinting performance, with the coefficient of determination accounting for 53% of the variance in the data. These data also showed that sprinting ability is linked with drop jumping performance, especially the drop jump from a height of 30 cm. It is suggested that the above tests may prove useful in preparing and testing the sprinting ability and sprint specific strength levels.

KEY WORDS: maximal velocity, drop jumps, force-time characteristics, maximum voluntary contraction.

Introduction

Sprint running, a popular topic in the world of sports, has been extensively analysed in terms of kinematic, kinetic and physiological aspects. Running speed is the result of combinations between stride length and stride rate. However, these two parameters are only the measurable products of other more complex physiological and neuromuscular mechanisms. Previous studies have shown the critical role of stride rate which is connected with fibre distribution and neuromuscular function of the leg muscles whereas stride length is affected by anthropometric characteristics and the amount of forces generated during movement[1-3]. Strength and power tests, such as maximal isometric strength measurements and upward or forward jumps have also been shown to be closely related with stride rate and maximum running velocity[2]. However, there are more recent studies suggesting that stride length is more important than stride rate in determining sprinting performance and one of the best predictor for sprinting speed in male and female sprinters[4,5]. Therefore, there is a need to re-examine the relationship between a number of strength-power tests and sprint running parameters in order to gain fresh information regarding the role of the latter. In addition, further education of coaches and athletes with regard to which tests are the best for assessing sprinting ability as well as the way of interpreting data obtained during these tests.

Furthermore, the use of short all-out cycle sprints as a way to evaluate the capacity of leg muscles to utilize the peak anaerobic power and therefore to predict sprint running performance has been debated widely since the conventional cycle power tests[6] are not corrected for the changes in the kinetic energy of the flywheel, thus peak power is measured over 5 s intervals[7]. It has been reported[8] that corrected compared to uncorrected peak power values are significantly higher (110-370 W; 25.8%)

during the first seconds of a 30 s Anaerobic Wingate Test. Considering the fact that peak power output occurs within the first 3 seconds, any lack of measurement accuracy in this time period could be crucial for the measurement of power production and consequently the establishment of a relationship between peak power and sprint running performance. Therefore, the present study is also going to investigate the relationship between peak anaerobic power measured every 1 s during all-out 6 s cycle sprints and sprint running performance.

Materials and methods

Subjects

Nine trained males with mean age 25.5 ± 3 years, body mass 78.1 ± 8.4 kg and height 1.79 ± 0.5 meters volunteered to participate in the present study after being informed of the nature and risks of the experiments and signing subject consent forms. All participants were ex national/regional level sprinters and currently sport science students who undertake regular strength/power training. They were tested on four separate occasions approximately the same time interspersed by 48 hours recovery.

Experimental procedures

First series of testing – Running test

A 35 m sprint running test was used to measure maximum running velocity (MRV), stride rate (SR) and stride length (SL). Three sprints from standing position were performed by each participant in an indoor corridor 60 m long which was covered with a synthetic track (tartan) of the same length and width of 2.5 m. A Kodak EktaPro 1000 Hi-Spec Motion Analyser System (250Hz) was used to record the runs during the constant-speed phase (35 m) with its optical axis placed perpendicular the plane of movement. A running stride - *starts with the occurrence of one event by one foot until the same event is repeated by the opposite foot* – was analysed from each participant's three runs in order to calculate the above kinematic parameters for the best run which was selected according to researcher's and participant's subjective criteria. The digitised displacement-time data were smoothed by a second-order quintic spline curve-fitting programme.

Second series of testing - Vertical jumps and Standing Broad jump

The participants performed maximal vertical jumps on a Kistler force plate (928B model - dimensions 60x40 cm) from the following starting positions:

Squatting Jump (SJ): From a squatting position (knee angle: 90o approx.) in which no preliminary counter movement was performed.

Countermovement jump (CMJ): From an upright standing position with a preliminary counter movement.

Drop jump (DJ): From an upright standing position on wooden boxes of three different heights: 30, 50 and 80 cm (DJ30, DJ50, DJ80).

The participants stepped off the box and landed on the force plate. Upon landing a maximum vertical jump was performed immediately. During all jumping conditions the participants kept their hands on the hips. Each participant performed three maximum jumps for each jumping condition in order to select the best of three. The flight time values obtained from the force-time curves were used to calculate the height (h) of rise of the centre of gravity (CG) for all jump conditions. On the same day each subject performed also three standing broad jumps (SJB). The participants assumed a position behind a line drawn on a tartan surface and jumped horizontally as far as possible landing on both feet. The nearest point of the feet landing to the starting line was marked with a chalk.

Third series of testing - Maximal Isometric Test

The Maximal Bilateral Isometric Force (MBIF) and the force production characteristics of the leg extensor muscles were measured using a Universal leg extension machine connected to the Kistler force plate. The hip and knee joint angles during the leg extension test were kept at 110^{o} and 107^{o}[9]. Posture stabilisation was accomplished using a femoral strap and by gripping the sides of the leg extension bench. The angles were set using templates together with the adjustment of the length of chain. The trials were also filmed using a Kodak EktaPro 1000 Hi-Spec Motion Analyser System (50 Hz). The kinematic analysis confirmed the maintenance of these angles during maximum voluntary contractions.

Each participant after responding to an auditory signal performed three maximum voluntary contractions of their knee extensor muscles with the duration of each contraction at 2.5 s. A different auditory signal was used then to indicate the termination of the test. The force data from all tests was processed in order to select the best trial for each participant. MBIF was calculated using trigonometry as the resultant force produced by the maximal values obtained by the two components (Fy and Fx). In addition, further analysis on the forcetime curve was conducted to calculate different force-time (f-t) characteristics.

As a result of the latter the times needed to reach a relative level of the maximum force from the level of 10% were calculated. Thereby, the 30%, 60% and 90% levels on the relative scale were calculated.

Fourth series of testing - Maximal Cycle Sprint

This test was conducted to determine the peak anaerobic power output for each subject during a 6 s maximal cycle sprint. A modified Monark 814 cycle ergometer was used for this test. Pedal revolutions were measured with a voltage generator attached to the flywheel. During the test, the power output was recorded for each second of the test, in a microcomputer, by a computer programme developed by Lacomy[8]. Analytically, participants were instructed to attain an initial pedal frequency of 80 rpm with no resistance and the load (0.075 kg. kg^{-1} of body weight) was applied progressively within 3 s. Then the participants accelerated to a maximum pedal frequency and attempted to maintain this power output for 6 s. It must be pointed that the participants were seated on the cycle ergometer by means of a belt system, in order to maintain them in the seated position. The establishment of the highest peak anaerobic power was determined via repeated trials and the habituation process for cycle sprints[10].

A Pearson product - moment correlation coefficient was employed to correlate the examined variables. Probability values from level 0.01 to level 0.05 were taken to indicate statistical significance.

Results

The Mean ± SD values for MRV, SR and SL were 9.03 ± 0.58 $m.s^{-1}$, 4.34 ± 0.58 Hz and 2.09 ± 0.21 m respectively. In terms of Jumping Performance average values for SJ, CMJ, DJ30, DJ50, DJ80 and SBJ were 34.4 ± 5.5 cm, 36.2 ± 5.4 cm, 36.9 ± 5.7 cm, 35.8 ± 6.0 cm, 36.0 ± 5.7 cm and 2.49 ± 0.16 m accordingly. Data from the Maximal Isometric Test and particularly for MBIF, f-t 10-30 % (ms) f-t 10-60 % (ms) f-t 10-90 % (ms) were 3285 ± 843 N, 25.4 ± 6 ms, 64.8 ± 29 ms and 303.2 ± 122.7 ms respectively. Finally, the mean value for peak anaerobic power obtained during a series of 6 s cycle sprints was 1209 ± 205 W.

Table 1 presents the correlation coefficients for all conducted correlations. According to the coefficients presented below, MRV significantly correlated with SR (r = 0.78; p<0.05), DJ30 (r =0 .74; p<0.05), (Figure 1) and f-t 10-60% (r = -0.73; p<0.05), (Figure 2).

TABLE I. *Correlation coefficient matrix between MRV (and its components SR, SL) and various tests*

	MRV	SR	SL
SR	0.78*	-	-0.89**
SL	-0.44	-0.89**	-
SJ	0.09	-0.39	0.59
CMJ	0.38	-0.11	0.37
DJ30	0.74*	0.34	0.007
DJ50	0.60	0.19	0.09
DJ80	0.55	0.06	0.20
SBJ	0.36	-0.11	0.36
MBIF	0.06	-0.08	0.08
F-t 10-30%	-0.62	-0.42	0.21
F-t 10-60%	-0.73*	-0.82**	0.75*
F-t 10-90%	-0.11	-.039	0.46
Peak anaerobic power	0.14	-0.21	0.31

Significance levels (r ≥ 0.797;**p< 0.01), (r ≥ 0.666; *p< 0.05)

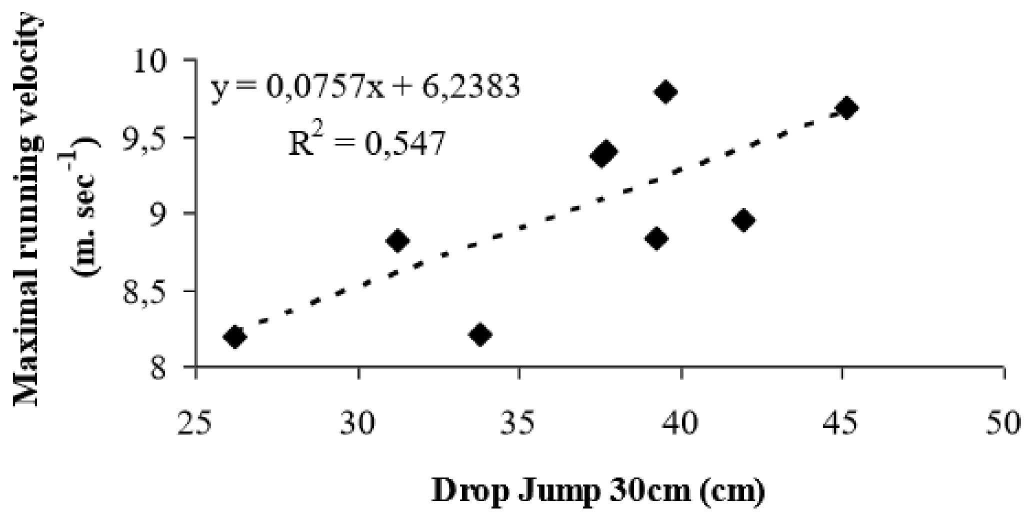

Figure 1 - Relationship between maximal running velocity and drop jump performance (30cm) (r=0.74 p<0.05)

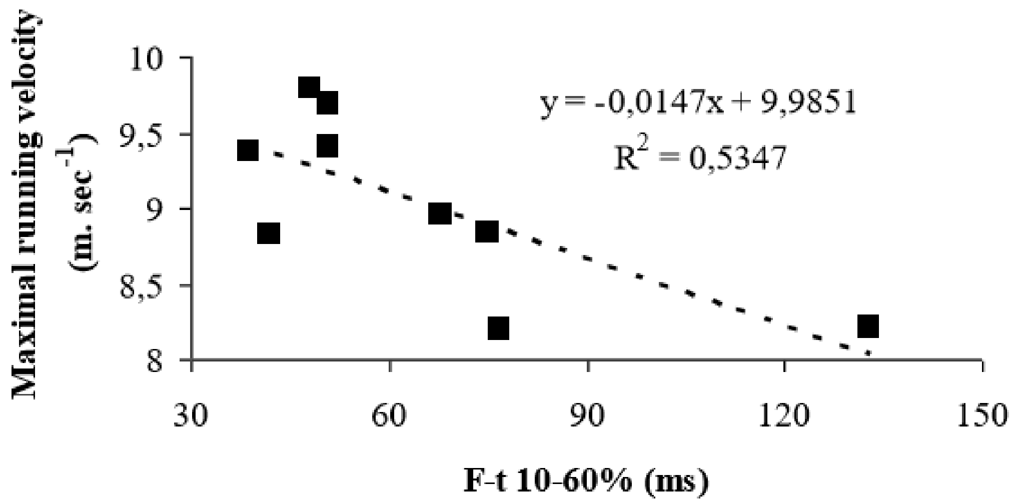

Figure 2 - Relationship between maximal running velocity and force-time parameter (10-60%) of maximal isometric force (r=0.73 p<0.05)

Moreover, SR (Figure 3) and SL apart from their inter-correlation (r = -0.89, p<0.01), were found to correlate significantly (negatively and positively) with f-t 10-60% (r = -0.82; p<0.01 and r = 0.75; p<0.05) respectively.

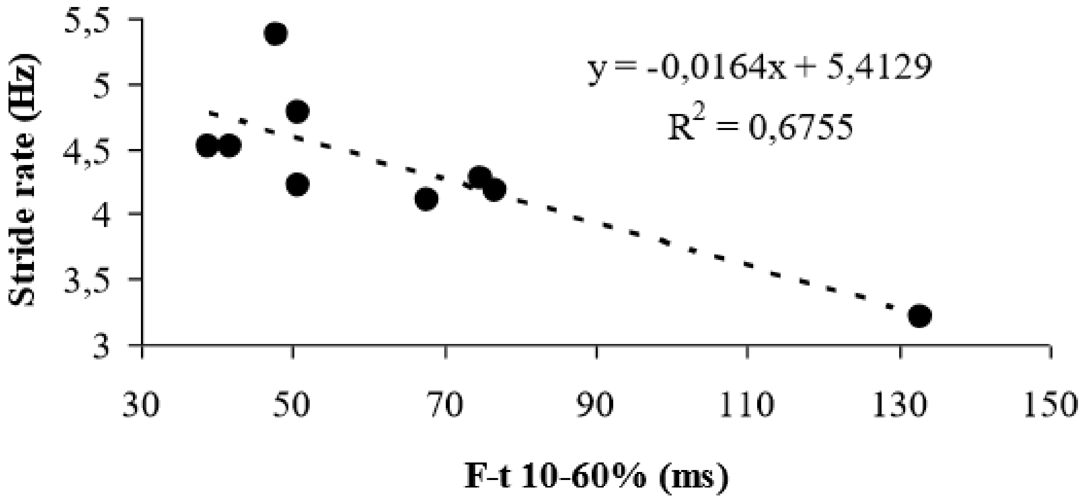

Figure 3 - Relationship between stride rate and and force-time parameter (10-60%) of maximal isometric force (r=0.82 p<0.01)

Discussion and conclusions

The relationships found in this study confirm in part previous findings[2]. Regarding the relationship between the running parameters and MBIF, the results of the present study did not reveal any significant relationship. On the other hand, the present study shows clearly a significant relationship between running parameters and the times needed to develop certain force levels during the maximal leg extension test. Significant correlations were observed between MRV, SR and f-t 10-60% while MRV almost reached significance with f-t 10-30% (r= -0.62). The reasoning for these observations can be derived from previous arguments which state that the f-t curve during maximal voluntary contractions could depend on % FT fibres and not on the size of muscle fibres which in turn is the determinant for the achievement of large peak force[11-13]. FT fibres affect force production time because of their high myosin ATPase activity and their ability to release and take up Ca^+ fast. It is therefore evident, since the rate of force production is more important in power events such as sprinting, that more attention should be paid in the force development characteristics rather the value of the maximum force when leg strength tests are employed by coaches and athletes [14]. In particular, the present findings seem to suggest that the lower and middle levels in the relative scale of the maximal isometric force production are more important in order to assess the mechanical characteristics of the FT fibres in the leg muscles than the 90% level.

The significant but in terms of direction opposite correlations between SR, SL and f-t 10-60% corroborate firstly, that stride rate is associated with muscle fibre characteristics and neuromuscular function and secondly, that the ability to produce submaximal levels of force fast is not directly linked with stride length. Flight distance, one of the three components of stride length, that contributes the most to the total length of the stride is rather affected by the amount of propulsive force and the time over that force acts than the time to reach different levels of that force[15]. However, a further examination is required in order to explore the degree of association between each of the stride length components (take-off distance, flight distance and touchdown distance) and force-time characteristics.

Significant correlations were found between MRV and drop jump performance. In particular, a significant correlation exists between MRV and DJ30 whilst for the DJ50 the correlation was close, but not reached significance (r= 0.60). These results are probably due to the fact that both types of movement use the same sequence of contraction, eccentric-concentric, known as stretch-shortening cycle which refers to the neuromuscular function of selected leg muscles that store and re-utilise elastic energy. In sprinting, as in drop jumping the pattern of force production is similar in terms of both the type of contact and the time of contact[2]. In both activities energy stored in the eccentric phase is partly recovered in the concentric phase producing a greater power output. Both the contractile and elastic properties therefore contribute to force production which is most evident in the drop jumps in the present study.

In sprinting the leg extensor muscles stretch during the braking phase and store elastic energy in the series elastic elements. This energy is partly recovered in the propulsion phase. The same function takes place during the landing and take-off phases in drop jumping. Another factor that should be taken into account in explaining the aforementioned correlations is the type of muscle fibres involved during stretch-shortening cycle movements. Fast twitch fibres and their viscoelastic properties have been shown to determine good performance in stretch-shortening cycle[14, 16]. No significant correlation was observed between MRV and DJ80 and an explanation of this may be that the very high stretching velocities and loads which developed after jumping from higher heights caused inhibitory reactions generated from the Golgi tendon organs[17].

It is therefore evident from the previous comments that drop jump performance and sprinting ability are related because of the same neuromuscular function in leg muscles probably with a high proportion of fast twitch fibres. Moreover, drop jumps could be used to test the neuromuscular performance of sprinters and of non-sprinters and also should be included in any training program that aims to develop speed. The optimal dropping height, according to the present study, is suggested to be 30 cm where attention must be taken when higher heights are used.

The non-significant correlation that was observed between CMJ and maximum running speed is somewhat surprising and needs re-examination because the CMJ has been suggested as a good movement for storage and re-utilisation of elastic energy[18].

No relationship was found between sprinting parameters and SBJ and an explanation for this result must be sought from the different muscle contributors in the two activities and the type of contraction which used. During SBJ the ankle and hip muscles are the main contributors to the total work done with the knee muscles contributing only 3.9% to the propulsion phase of the jump[19]. Moreover, SBJ seems to be similar as movement to SJ and as SJ does not take the advantage of the utilization of elastic energy[20]. Thereafter, SBJ which is generally used as a test of dynamic muscle strength is not proposed as a factor that is linked directly with maximum running velocity.

The finding, that peak anaerobic power did not correlate with sprinting variables seems strange, due to the fact that energy in all-out cycle sprints as in sprint running primarily is derived from ATP-CP. Despite the fact that maximum cycle sprints are used to evaluate the capacity of leg muscles to generate peak anaerobic power there are suggestions that power determination (within 6 s) represents also anaerobic capacity and not solely the ability of the muscle to produce as fast as possible the maximal force[7, 21]. Additionally, cycle sprinting and sprint running require the athletes to set their body segments in different positions and probably to overcome different type of loads by generating different movement frequencies. However, the cycle sprints used in this study were seated, which probably resulted in lower power output than standing cycle sprints and consequently affected the relationships with the other tests. A careful re-examination in this area will be more revealing. The use of a motorized treadmill[22] will be more efficient in order to relate the physiological and mechanical parameters of sprinting activity.

In conclusion, the findings of the present study suggest that the ability to produce force quickly, as measured by the time to achieve 60% of maximum voluntary contraction is related to sprinting performance, with the coefficient of determination accounting for 53% of the variance in the data. In addition, the interpretation of the f-t data highlighted the critical role of stride rate in sprint running. The present study also showed that sprinting ability is linked with drop jumping performance, especially the drop jump from a height of 30 cm. It is suggested that the above tests may prove useful in preparing and testing the sprinting ability and sprint specific strength levels. The strength of these correlations may be due to the influence of muscle structure and the characteristics of FT fibres. Finally it is suggested that measurements such as maximum isometric force, peak power output obtained during cycle sprints and standing broad jump should be taken with caution if the primary aim is to gauge sprint running performance.

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