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Maximal strength in the deep back squat correlates with sprinting performance over short distances

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Abstract

Sprinting is characterized by a transition from propulsion via knee extending musculature during initial acceleration towards ischiocrural musculature thereafter. This may lead to a decrease of correlation of the maximal strength in the back squat and sprinting performance with increasing distance. The aim of this investigation was to show the correlation between maximal dynamic force of the extensor chain of the lower limbs and short distance sprinting performance. Therefore, sprinting performance (0-5, 0-10, 0-15, 0-20, 0-25, 0-30m) and one repetition maximum (1RM) of 51 physical education students were determined. Pearson correlation coefficients were calculated and show significant ($p < 0.01$) correlations for the relationships with the absolute 1RM ($r = -0.661$ to -0.792) and the relative 1RM ($r = -0.648$ to -0.739). However, a decrease in correlation over distance was not found. The results show that the maximal strength of lower extremities' extensors is a basic requirement in short distance sprinting and should be considered in training.

Key words: Strength, Team Sport, Training, Performance

Introduction

A high level of performance in the sprint is not only important for sprinters in track and field, but also for athletes in jumping and throwing events as well as in team sports as for example soccer, football, hockey and many more (Brechue, Mayhew & Piper, 2010; Chelly et al., 2010; Comfort, Bullock & Pearson, 2012; Di Salvo et al., 2010). If one considers that the initiation of movements depends on the production of force(s) by (a) muscle(s), one could assume that the stronger athlete will also be the faster. Studies on the relationship of maximal force production and rate of force development further confirm the dependence of speed-strength on maximal force production (Cronin, McNair & Marshall, 2000; Peterson, Alvar & Rhea, 2006; Schmidtbleicher, 1992; Schmidtbleicher & Haralambie, 1981). However, there is also an influence of the resistance to be moved on the strength of that relationship with a stronger dependence on maximal force the

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higher the load (Komi, 1979; Schmidtbleicher, 1992; Zatsiorsky, 2003; Zatsiorsky & Kraemer, 2006). At the same time, if resistance or movement duration – and therefore the time to apply force - is small, the level of performance in rate of force development gains importance Zatsiorsky, 2003; Zatsiorsky & Kraemer, 2006).

In team sports as for example soccer, hockey, basketball and football, sprints over distances of 5-20m (Abdelkrim et al., 2010; Brechue et al., 2010; Chelly et al., 2010; Comfort et al., 2012; Di Salvo et al., 2010) and / or short durations of 1.8 – 2.1s (Abdelkrim, El Fazaa & El Ati, 2007; Spencer et al., 2004) are common and may be characterized as short. Therefore, Cronin and Hansen (2005) emphasize the importance of the ability to produce a fast acceleration for these athletes.

Although many authors have reported on a possible relationship between maximal force production and the level of performance in sprints (Bissas & Havenentidis, 2008; Blazevich & Jenkins, 1998; Bret, Rahmani, Dufour, Messonnier & Lacour, 2002; Dowson, Nevill, Lakomy, Nevill & Hazeldine, 1998; Hori et al., 2008; Keiner, Sander, Wirth & Schmidtbleicher, 2014; Kukolj, Ropret, Ugarkovic & Jaric, 1999; McBride et al., 2009; Requena et al., 2009; Wisløff, Castagna, Helgerud, Jones & Hoff, 2004; Young, McLean & Ardagna, 1995) results have been heterogeneous: Some publications have described a relationship (Chelly et al., 2010; Cronin & Hansen, 2005; McBride et al., 2009; Wisløff et al., 2004), but their data cannot always be compared well. For example, Wisløff et al. (2004) and Chelly et al. (2010) have reported significant to highly significant correlation coefficients between 1RM in squats and sprints of 5 to 30m of length, but the half squat (90° angle at the knee joint as turning point) had been used. This variation of the squat typically allows for higher loads (Hartmann et al., 2012). However, it has been shown that mechanical stress on leg extensors is less compared to the deep squat, which is why the level of core muscle strength dominates 1RM performance (Bryanton, Kennedy, Carey & Chiu, 2012; Hartmann, Wirth & Klusemann, 2013; Hartmann et al., 2016). Cronin and Hansen (2005) using the deep squat and sprints of 10 and 30m could not observe a statistically significant relationship between maximal force production and sprinting performance in rugby players. However, 3-repetition maximum had been used for the strength test. It has been reported that even in strength training experienced subjects any estimate of number of repetitions to intensity or the other way around is vague (Faigenbaum et al., 1998; Hoeger, Barette, Hale, & Hopkins, 1987; Hoeger, Hopkins, Barette, & Hale, 1990). However, McBride et al. (2009) have reported significant relations for 1RM in squats to 70° knee angle and sprint times over 10 and 30 yards in football players.

In sprints with longer distances (100m and more), it may be assumed that the relevance of maximal force production declines over time / distance, as it becomes increasingly important to be able to reproducibly produce force in the forward (= horizontal) direction (Morin, Edouard, & Samozino, 2011; Morin et al., 2012). Furthermore, ground contact times – and therefore time to transfer force to the ground – decreases (Mero, Komi & Gregor, 1992; Young, 2007), which should also lead to a decrease in relationship between maximal force production and sprinting times. To our knowledge, there have not been any studies analyzing the relationship between maximal force and sprinting times over various distances relevant for athletes in team sports completely in 5m-steps. In regard to the mentioned observations we hypothesize that the relationship of maximum strength in the squat with sprinting performance decreases with increasing sprinting length.

Methods

The aim of this investigation was to show the correlation between maximal dynamic force of the extensor chain of the lower limbs and short distance sprinting performance. Therefore, 51 physical education students participated in our investigation. The maximal force of the lower limbs was assessed using the deep back squat. Sprinting performance was measured – via double photoelectric barriers – for 30m every 5m. Therefore, the following parameters were determined: 1RM of the deep back squat, sprint times for 0-5, 0-10, 0-15, 0-20, 0-25, and 0-30m.

Subjects

56 physical education students participated in the study (40 males, 16 females). Due to the malfunction of some data, 5 participants had to be excluded. Because of this, 51 participants (35 males, 16 females) were included in the analysis. The average age was 23 ± 3.0 years, body height 176.2 ± 8.0 cm and weight 73.1 ± 9.4 kg. The exclusion criteria were acute and chronic injuries of the lower limbs and/or the spine. Each subject was informed of the experimental risks involved with the research. All subjects provided informed written consent and the research design was approved by the institutional review board of Goethe University Frankfurt (Nr. 2015-236b). The study was carried out with respect to the use of human subjects and according to the Declaration of Helsinki.

Test protocol

The measurements took place on two occasions with an interspace of one week. This served to exclude possible fatiguing effects. In the first test session, sprinting times were determined and a familiarization for the 1RM was performed. In the second test session, 1RM of the deep back squat was determined.

Sprint test

Following an individual warm up, participants performed 5 trials of 30m sprints with 5min of rest between trials. This distance was chosen because it displays a relevant motor task in many sports like soccer, football, rugby or field hockey (Brechue et al., 2010; Chelly et al., 2010; Comfort et al., 2012). Double photoelectric barriers (Refitronic, Schmitten, Germany) were used to determine the times every 5 meters. This distance was chosen to analyze several short sprint distances. According to the manufacturer the measurement error of the system is < 0.1%. The trial with the best 30m time was analyzed for every participant.

The start of each 30m sprint was performed out of a static, high start position (two point stance) with individual length. Participants were asked to position their feet behind a marker 50cm ahead of the 0m line and start on their own command. Keiner, Sander, Wirth, Hartmann and Yaghobi (2014) have reported test-retest correlations for similar tests of $r=0.94 - 0.98$ ($p<0.05$).

Squat

To determine the 1RM in the deep back squat, a free weight barbell was placed on the M. trapecius pars descendens just below the 7th cervical vertebrae. The starting position was an erect position in which every subject was allowed to choose the width of their stance individually. Subjects then flexed their hip, knee and ankle joints to achieve the required squatting depth and then returned to the starting position. The required squatting depth was defined according to the rules of the International Powerlifting Association which state the turning point being reached if "[…] the top surface of the legs at the hip joint is lower than the top of the knee" (2015). This was monitored visually by one examiner from a sagittal position. Therefore, attempts in which the subject had not reached the required depth were rated invalid.

Following an individual warm up, 1RM was determined in 5 attempts (at most) with 5 minutes of rest between trials. The test set up was based on the procedure described by Hartmann et al. (2012). Berger and Hardage (1967) have reported a test-retest reliability of $r = 0.98$. Both the absolute as well as the relative 1RM (absolute 1RM / bodyweight) were determined.

Statistics

The collected data were analyzed using SPSS (SPSS for Windows, Version 11.5, Chicago, SPSS Inc.). Testing for normal distribution using Kolmogorov-Smirnov test revealed this requirement for Pearson's product-moment correlation could be fulfilled. The level of significance for all the tests was set a priori to $p \leq 0.05$. According to Keiner et al. (2014) the relationships were classified as follows: 0 = no correlation, 0 < | r | < 0.2 = very weak correlation, 0.2 ≤ | r | < 0.4 = weak correlation, 0.4 ≤ | r | < 0.6 = moderate correlation, 0.6 ≤ | r | < 0.8 = strong correlation, 0.8 ≤ | r | < 1.0 = very strong correlation, 1 = perfect correlation.

Results

The descriptive statistics are illustrated in Table 1.

The correlations calculated for the absolute and relative force maxima with the sprinting times over 30m consistently show highly significant, strong correlations (p ≤ 0.01) with a tendency to increase with distance (see table 2).

Table 1. *Descriptive data of the sprint- and 1RM tests (BW = bodyweight)*

	N	Minimum	Maximum	Mean	Standard-Deviation
T 5m (in s)	51	0.947	1.256	1.093	0.073
T 10m (in s)	51	1.661	2.139	1.861	0.124
T 15m (in s)	51	2.258	2.955	2.546	0.179
T 20m (in s)	51	2.822	3.737	3.200	0.233
T 25m (in s)	51	3.373	4.509	3.839	0.291
T 30m (in s)	51	3.910	5.271	4.468	0.351
Squat absolute (in kg)	51	42.600	161.000	94.634	27.633
Squat relative (in kg/BW)	51	0.729	1.838	1.280	0.288

Table 2. *Correlation coefficients of the absolute and relative force maxima values with the sprinting times.*

	Squat absolute	Squat relative
T 5m	-.661**	-.648**
T 10m	-.737**	-.708**
T 15m	-.759**	-.720**
T 20m	-.774**	-.727**
T 25m	-.781**	-.732**
T 30m	-.792**	-.739**

** marks two-tailed significances of p ≤ 0.01.

Discussion

The results show consistently highly significant (p ≤ 0.01), strong correlations for both absolute (r = -0.661 to -0.792) and relative (r = -0.648 to -0.739) 1RM in the deep back squat with the sprinting times up to 30m. The correlation coefficients are substantially higher compared to those reported by McBride et al. (2009) and Comfort, Stewart, Bloom and Clarkson (2014), but below those of Wisløff et al. (2004). However, the latter two studies had used the half squat to determine maximal strength of the leg extensors and in this case Bryanton et al. (2012) have reported a predominant influence of core strength on 1RM weight. Furthermore, Comfort et al. (2014) estimated maximal force production through a regression model based on the 5RM, which – as already mentioned – is problematic due to the variability in the relation of intensity and number of repetitions (Faigenbaum et al., 1998; Hoeger et al., 1987; Hoeger et al., 1990). This could also explain the large differences in results compared to Wisløff et al. (2004).

Considering the course of the correlations with increasing running distance, a decline was expected, but could not be observed. Instead our results show an increase in correlation coefficients with the lowest values for the first section (0-5m). In regards of the technical recommendations for sprinting (Mero et al., 1992; Seagrave, 1996), a strong correlation between sprint performance and maximal dynamic force production of the leg extensors especially at the start and during the early phase of acceleration had to be expected. The early phase in acceleration is said to last approximately for 20m, which are characterized by a predominant activation of the leg extensors. The following transition phase – in which velocity still increases – should be characterized by an increased use of the ischiocrural muscles. As a gradual erection of the trunk during these phases should be aimed at (Mero et al., 1992; Mero, Luhtanen & Komi, 1983; Seagrave, 1996), a decline in relevance of 1RM of the leg extensors had been inferred. Wisløff et al. (2004) had also been able to provide empirical evidence for this assumption in soccer players using the half squat. However, our results show a different trend, which may be explained by several different mechanisms: If one considers that propulsion via hip extension of the ischiocrural muscles demands for high stiffness at the knee joint (Fletcher, 2009; Schache, Dorn, Blanch, Brown & Pandy, 2012), and that the latter has been reported with increasing running speed (Kuitunen, Komi & Kyröläinen, 2002), the requirements on leg extensors – as synergists – increase to maintain the correct sprinting technique. Therefore, a stronger dependence on the level of performance of ischiocrural muscles may be assumed in elite athletes who should have the necessary level of maximal force production in leg extensors.

Due to the pure concentric extension action at the start, the highest correlation was expected at this point, but could not be confirmed. This might have been because of the use of an upright start. According to the literature, the correlation is expected to be higher if a block start is performed, since the positioning of the upper body and the angle of the impression surfaces produce favourable starting conditions for the hip- and knee-extensors (Coh, Peharec, Bacic & Kampmiller, 2009; Guissard & Duchateau, 1990; Lemaire & Robertson, 1990). This assumption is supported by Duthie, Pyne, Ross, Livingstone and Hooper (2006), who pointed out, that the times of the first 10m for a high and low start are not comparable. However, it was decided to have the participants perform a high start (two-point stance), since block start demands for good technique to be advantageous.

Conclusions

The present study highlights the importance of dynamic maximal force production in the deep back squat on short distance sprinting performance. At the beginning of the 30m sprint, knee and hip extensors contribute directly to the propulsion force. In the later stages – when propulsion is achieved more via ischiocrural muscles – leg extensors should play an important role in the compensation of vertical ground reaction forces. Therefore, the development of a high dynamic maximal force production of the leg extensors must be considered in training.

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Conflict of Interest

The authors state that there is no conflict of interest.

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