# BIOMECHANICAL COMPARISON BETWEEN SPRINT START, SLED-PULLING AND SELECTED SQUAT TYPE EXERCISES

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# ABSTRACT

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The purpose of the present study was to compare kinetics, kinematics and muscle activity between sprint start, sled-pulling and selected squat type exercises and also to examine how different exercises and variables correlate with the performance time of the block start (10 m). Nine male athletes (4 sprinters, 3 decathlonists, 1 long jumper and 1 triple jumper; mean ± SD; age = 24.9 ± 3.9 yr; height = 180.4 ± 5.9 cm; weight = 80.3 ± 7.5 kg; 100 m record = 11.35 ± 0.29 s) performed measurements and different force-time, electromyographic (EMG) and kinematic variables were compared to sprint start. Most of the comparison was done to the block phase (the phase of force production towards starting blocks) of the block start. In nearly all exercises, the activity of the gluteus maximus (GM) was significantly ($p \leq 0.05$) higher than during the block phase. The opposite was true for the activation of the biceps femoris (BF). Ground reaction forces (GRF) were highest during the 1-RM (one repetition maximum) ½-squat (SMAX). The GRFs were also significantly ($p \leq 0.05$) larger during the countermovement jumps (CMJ) with different loads and during the ½-squat with 70 % of 1-RM (S70) as compared to the block phase. The angular velocity of the knee was significantly ($p \leq 0.05$) higher during CMJs than during the block phase. The highest correlation existed between the performance time in the block start (10 m) and the takeoff velocity during CMJ ($r=-0.950$, $p \leq 0.05$). According to the results of the present study, it can be suggested that to overload the force production (peak and average force) of the block phase, CMJs and ½-squats could be used in training. If the aim is to activate the GM intensively, almost all of the exercises analyzed in the present study seems to be suitable. The results also indicate that CMJs could be used as supra-velocity exercise for the knee joint in the training of the block start. In addition, the correlation analyses indicate the importance of a good performance in CMJs for a good performance in the block start.

Keywords: Sprint start, sled-pulling, CMJ, squat, biomechanics, comparison

# CONTENTS

ABSTRACT

# 1 INTRODUCTION

Sprint training usually includes i.a. speed, speed-endurance and strength training. Strength training of sprinters comprises of hypertrophy, maximum- and speed-strength training. By hypertrophy training (60–80% 1RM) sprinters are trying to increase the cross-sectional area of muscles (especially the cross-sectional area of fast muscle fibers) and thereby increasing maximum strength. By maximum strength training (90–100% 1RM) athletes are trying to improve the function of their nervous system (e.g. rapid/increased recruitment of motor units, increased firing rate of motor units and improved synchronization of motor units). (Komi 1986; Schmidtbleicher 1991, 384; Delecluse 1997.) In maximum strength training the goal is also to activate the largest fast twitch motor units (Delecluse et al. 1995), although it might be also possible with rapid ballistic muscle actions (Sale 1991, 256).

In speed-strength training, loads are lighter than in maximum strength training (and usually lighter than in hypertrophy training) and thereby movement speeds are faster and closer to the movement speeds of sprint running. Examples of speed-strength training include ballistic exercises (e.g. squat jump), plyometric exercises (jumps) and sprint specific exercises (e.g. sled pulling). It is thought that strength training effects are movement and velocity specific so that adequate employment of plyometric and sprint specific exercises is important in sprint training. (Delecluse 1997.)

Despite the common use of speed-strength / strength exercises in training of sprinters, there is a lack of knowledge of biomechanical characteristics of these exercises (e.g. force production, angular velocities, EMG activity) as compared to sprinting (Lockie et al. 2003, Maulder et al. 2008 and Mero & Komi 1994). The purpose of the present study was to compare kinetics, kinematics and muscle activity between the sprint start, sled pulling and selected squat type exercises and thus to acquire more information about the relations between these exercises. Ultimately, this new information could probably be utilized in sprint start training and possibly in general sprint training.

# 2 TRANSFER OF STRENGTH AND POWER TRAINING TO SPORTS PERFORMANCE

The ability to produce relatively high forces (strength) and to produce a high work rate (power) is important for various sports. As such, resistance training has become an integral part of many training programs. A key issue is the efficiency of training. Therefore, transfer of training to performance is paramount. Transfer may be conceptually expressed as: gain in performance / gain in trained exercise. (Young 2006.)

Essential to the concept of transfer is the well-accepted training principle of specificity. Specificity means that adaptations are specific to the nature of the training stress. Extremity of this principle would be that all training would mimic competition demands. (Young 2006.) Such an approach might induce a good transfer to performance in short term, but it also might have some negative influences: overtraining, muscle imbalances, increased risk of injuries and boredom in long term (Young 2006).

Positive transfer could be achieved by increased excitatory neural drive to agonist and synergist muscles that contribute to skillful performance and/or by inhibition of muscles that can decrease performance. The coordination of muscles involved in a sports movement has been termed intermuscular coordination and is considered important for sprint performance. (Young 2006.) Also improvement of intramuscular coordination can contribute to the performance enhancement. Improved intramuscular coordination refers to increased motor-unit recruitment, firing rates, synchronization and reflex potentiation and decreased inhibition from eccentric loads during stretch-shortening cycle. (Komi 1986; Schmidtbleicher 1991, 384.) A poor transfer might be explained by a violation of the specificity principle. It is suggested that training should be specific in terms of movement pattern, contraction velocity, contraction type and contraction force. (Young 2006.)

However, if only the principle of specific training would be followed, it can be hypothesized that neuromuscular system would adapt to that kind of training and after a while no further adaptation would most likely occur. In this kind of a scenario, it could be advisable to add some exercises wherein force production and/or velocity of the movement would be higher than in a certain sport performance. This kind of a training could lead to improvements in force production and/or velocity of the movement (positive changes on the force-velocity curve) and to improvement in a certain sport performance (Malisoux et al. 2006; Cormie et al. 2010).

Also general strength training might be beneficial for athletes, because of its potential to enhance the force-generating capabilities of muscle, reduce the risk of sports injuries, and improve core stability. However, direct transfers to improve sports performance might be limited by such training in experienced athletes. It appears that to maximize transfer to specific sport skills, training should be as specific as possible, especially with regard to movement pattern and contraction velocity. This type of training can be expected to enhance intermuscular coordination. Resisted sports movements might be suitable strategy to achieve this specificity (Table 1). (Young 2006.)

TABLE 1. Strategies for developing power in a sprinter based on neuromuscular factors (modified from Young 2006).

| Strength training Method | Example of neuromuscular factor | Influence on sprinting performance |
|---|---|---|
| Hypertrophy | Increased muscle cross-sectional area | Increased muscle cross-sectional area |
| Exercises with loads that maximizes power outputs | Increased motor-unit recruitment, firing rates, synchronization, reflex potentiation | Enhanced intramuscular coordination of involved muscles |
| Resisted sprints, unilateral/horizontal plyometrics | Increased activation of agonists and synergists<br>Decreased activation of antagonists | Enhanced intermuscular coordination |

*Velocity and movement pattern specificity.* In general, smaller (slow twitch) muscle units are recruited first, followed by larger (fast twitch) muscle units (size principle). In some cases this size principle does not necessarily hold. For example, the largest fast twitch motor units may be preferentially recruited over the smaller slow twitch units when rapid ballistic muscle actions are performed. It is possible that neural adaptations to high velocity training consists of an accentuation of the preferential activation of fast twitch motor units and/or an acquired ability to increase the maximum motor unit firing rates in ballistic actions. The high firing rate increases the rate of force development and the peak force of dynamic actions done at high velocity. (Sale 1991, 256–258.)

It has often been observed in strength-training studies that the magnitude of measured increase in strength depends on how similar the strength test is to the actual training exercise. This specificity of movement pattern in strength training probably reflects the role of learning and coordination. Improved coordination shows in the most efficient activation of all of the involved muscles, and the most efficient activation of motor units within each muscle. Fast muscles (relatively high proportion of fast twitch motor units) may be preferentially activated over slow muscles in the execution of high velocity movements. The gastrocnemius has shown to be preferentially activated over the soleus during stationary cycling at higher pedaling speeds and in hopping. In moderate force concentric and eccentric actions, the soleus is preferentially activated during the concentric phase, while the gastrocnemius is preferentially activated in eccentric phase. The latter pattern is accentuated at higher lengthening velocities. Similar observations have been made when the activity of slow and fast twitch fibers in concentric and eccentric actions have been studied (slow twitch fibers were preferentially activated in concentric phase and fast twitch fibers were preferentially activated in eccentric phase). (Sale 1991, 258–259.)

# 3 INFLUENCE OF VELOCITY SPECIFICITY OF TRAINING ON SPRINT PERFORMANCE

## 3.1 Resisted, normal and supramaximal sprint training

It is generally accepted that strength training can improve sprint performance and muscle strength seems to be an important factor in sprinting, especially in the acceleration period (Kristensen et al. 2006). It has been suggested that to achieve an effective transfer between strength training and sprint running, there is a need for specificity in the strength exercises that mimics sprinting (Delecluse et al. 1995).

Kristensen et al. (2006) studied the training effects of normal, resisted and supra-maximal sprinting in athletes who did not have previous experience with specific sprint training. During resisted sprinting the running velocity was 8.5 % lower and during supramaximal sprinting 3.3 % higher when compared to normal sprinting. Every training group trained 6 weeks, 3 trainings / week (5 x 20 m / training).

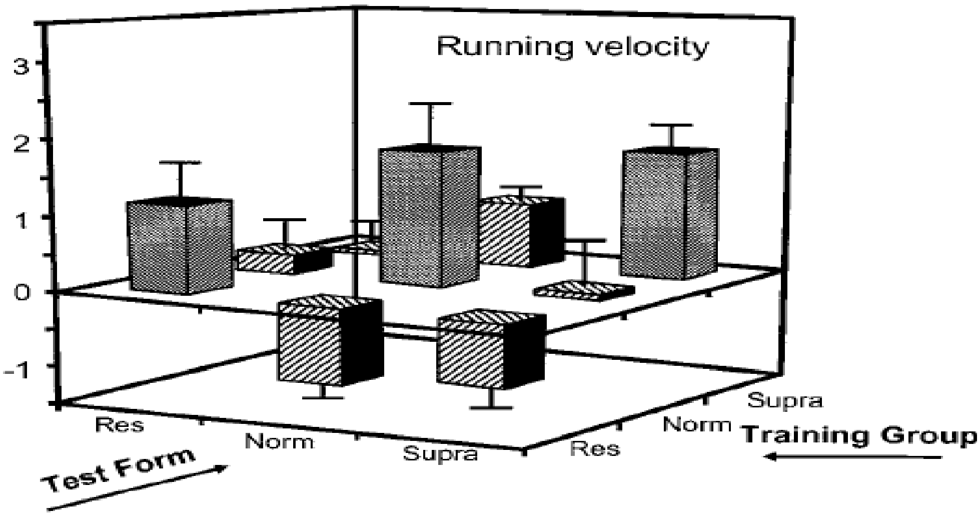

FIGURE 1. Pre-post difference (%) in running velocity is shown in Y-axis (modified from Kristensen et al. 2006).

As it can be seen from Figure 1, every training group had training specific adaptations: supramaximal training increased most supramaximal running velocity, normal training normal running velocity and resisted sprinting resisted running velocity.

Zafeiridis et al. (2005) studied the effects of resisted sled-pulling (5 kg) and unresisted sprint-training on acceleration and maximum speed performance in recreational athletes (Table 2). Subjects trained 3 times / week for 8 weeks.

TABLE 2. Relative changes (%) in sprint times in different running sections and in few biomechanical variables after resisted sprint training (sled-pulling) and unresisted sprint training. (Modified from Zafeiridis et al. 2005.)

| Variable | Resisted | Unresisted |
|---|---|---|
| 0-10 m (s) | -4.1 | n.s. |
| 0-20 m (s) | -2.0 | n.s. |
| Stride rate (acceleration phase) | 7.0 | n.s. |
| Trunk angle (acceleration phase) | -9.7 | n.s. |
| 20-40 m (s) | n.s. | -3.4 |
| 40-50 m (s) | n.s. | -3.3 |
| 20-50 m (s) | n.s. | -3.7 |
| Stride length (maximum running phase) | n.s. | 5.3 |
| 0-50 m (s) | n.s. | -1.9 |

n.s.= not statistically significant

The authors concluded that sled-pulling (5 kg) improves acceleration and unresisted running maximum speed. Therefore, the results of their study supported the view that each phase of sprint running demands different training methods. The main reason for improved acceleration was increased stride frequency which was a possible result of decreased trunk angle. Improved maximum speed was a consequence of increased stride length.

## 3.2 High velocity vs. low velocity training

Blazevich and Jenkins (2002) investigated the effects of high and low velocity resistance training on strength and sprint times in elite junior sprinters (mean 100 m record 10.89 s). The intervention period lasted 7 weeks and concurrent ”normal” training was done by subjects (e.g. sprint training). The high-velocity group used weights of 30–50 % of 1RM and the low-velocity group weights of 70–90 % of 1RM in each exercise. The concentric phases of the movements were performed as quickly as possible in both groups. The exercises used in the training were ½-squat, hip extension, leg extension, hip flexion and leg flexion.

In both groups, there were statistically significant improvements in 20 m acceleration time, squat strength and torque produced during hip extension at 60 °/s and near-significant ($p<0.20$) improvements in ”flying” 20 m time and torque produced during hip extension and flexion at 270 °/s (Table 3). There was also near-significant interaction effect (time x group) on hip flexion torque at 480 °/s, indicating that the high-velocity group improved more than the low-velocity group.

TABLE 3. Relative changes (%) in 20 m acceleration time, 20 m running time with flying start and squat (modified from Blazevich and Jenkins 2002).

| Variable | High-velocity group | Low-velocity group | *P* |
|---|---|---|---|
| 20 m acceleration | -4.3 | -2.9 | <0.05 |
| 20 m flying | -1.9 | -2.4 | <0.20 |
| Squat | 12.4 | 11.8 | <0.05 |

Probably because of a low number of subjects (the high-velocity group 5 and the low-velocity group 4 subjects), there were only few statistically significant changes. The results of their study suggest that a movement speed in resistance training does not have significant effect on sprint performance when resistance training is combined with sprint training in high level athletes.

Cronin et al. (2001) investigated the effect of 6 weeks heavy load training (80 % 1RM; 2 times / week) and power training (60 % 1RM; 2 times / week) on netball chest pass throwing velocity. Both training methods were combined with sport specific training (explosive netball passing). As subjects, they had female netball players (n=21) with no previous weight training history. Subjects were randomly assigned to three groups: strength, power or control. Both training groups were instructed to move their respective loads as rapidly as possible. The strength-trained group improved peak velocity of netball chest pass by 12.4 % and the power-trained group by 8.8 % and there was no significant difference between groups.

The authors noticed that there was a great difference between the velocities performed during the training and those attained during netball chest pass. Average training velocity during bench press throw was 0.308 m/s for strength group and 0.398 m/s for power group. Mean netball chest pass velocity was 11.38 m/s, 28–37 times greater than training velocities. They concluded that most weight training could be classified as low velocity training in relation to high velocity sports movements such as the netball throw. They thought that explanations other than velocity-specificity are necessary to explain the improvement in throwing velocity following strength and power training found in their study. Possibly the intention to move an isoinertial load as rapidly as possible coupled with performance of the sport specific movement immediately after a weights set, allows improved adaptation and increased control of muscle to occur. (Cronin et al. 2001.) However, if sport specific movement influenced (possibly a lot) on passing velocity, then the principle of velocity-specificity would hold true.

Harris et al. (2008b) examined the effects of machine squat jump training at heavy load (80 % 1RM) vs. at a load maximizing power output (20–43.5 % 1RM) on concentric strength and power output and sprint ability. As subjects they had 15 elite-level rugby players (age: 21.8 years; height: 180.7 cm; mass: 96.2 kg). Both groups (heavy and power load) trained approximately 2 times / week for 7 weeks. The heavy load group (H- group) performed 5 x 5 x 80 % 1RM / training session and the power load group (P-group) performed 6 x 10–12 x 20.0–43.5 %. Both groups were instructed to perform all training as explosively as possible. In addition both groups performed sprint drills, other lower-body exercises at various loads and upper-body training. Machine squat jump training constituted about 20 % of total lower-body training. The machine hack squat apparatus is shown in Figure 2 and results in Table 4.

TABLE 4. Percent changes in sprint times and strength for H- and P-groups after intervention (modified from Harris et al. 2008b).

| Variable | Heavy load group | Power load group |
|---|---|---|
| 10 m time | -2.9 | -1.3 |
| 30 m time | -1.9 | -1.2 |
| Squat | 15.0 | 10.5 |

The authors concluded that a lack of difference in improvement of sprint times between the H- and P-groups could be explained by that both groups did their squat jumps as explosively as possible. They also thought that biomechanical specificity of training exercises to the functional tasks would seem to be important.

FIGURE 2. Customized machine hack squat apparatus (Harris et al. 2008a).

Also Delecluse et al. (1995) have investigated the effects of heavy resistance training and high velocity training on sprint performance. Subjects were physical education students who had not taken part in an earlier strength training program. They were divided in four groups: the high-velocity group (HV, n=21), high-resistance group (HR, n=22), run control group (RUN, n=12) and passive control group (PAS, n=11). The HV and HR groups followed specific strength training program twice a week and both group participated together in a sprint running workout once a week. The training of the

HV group included, for example, different kind of vertical and horizontal jumping/ bounding (plyometrics) and the training of the HR group comprised of lower- and upper-body training executed at the highest possible speed. Loads were in the range of 10 RM to 3 RM. The RUN group participated in a sprint running workout together with the HV and HR group. The PAS group did not train. The HV training was expected to be the most efficient training method to improve maximum running velocity because it can be organized according to the principles of movement specificity and velocity specificity (Table 5).

The authors concluded that velocity specificity and movement specificity of the training exercises is of paramount importance for realizing a significant improvement in sprint performance within 9 week. It is clear that sprint specific approach is necessary to improve maximum running velocity within a short period.

TABLE 5. Relative changes (%) in high-velocity group and high-resistance group (Modified from Delecluse et al. 1995).

| Variable | HV group | HR group |
|---|---|---|
| 0-10 m average acceleration | 7.1 | 1.1 |
| Max velocity | 1.4 | n.s. |
| 100 m time | -1.7 | n.s. |

## 3.3 Plyometric training vs. sprint training

Plyometric exercises include vertical jumps and bounds (body moves in horizontal and vertical planes) and these movements involve stretch-shortening cycle. Plyometrics develops the ability of muscles to produce power (force at high speeds). (Rimmer & Sleivert 2000.)

The aim of the study of Rimmer and Sleivert (2000) was to determine the effects of a sprint-specific plyometrics program on sprint performance. Their subjects were either rugby (n=22) or touch rugby (n=4) players and they were randomly allocated to the plyometrics, sprint or control group. The intervention took 8 weeks and the training groups trained twice a week. The plyometrics group performed different kind of vertical jumps and bounds (body moves in horizontal and vertical planes), and the sprint group performed maximal effort sprint training (distances 25–55 m).

Improvement in 40 m time was 1.8 % after plyometrics training and 1.1 % after sprint training. The plyometrics group improved especially over the first 10 m. The authors thought that improvement in the acceleration phase could be a result of velocity specificity of plyometric exercise used in their study.

## 3.4 Summary of the effects of velocity specific training

According to some above mentioned studies, it would seem that adaptations to training are velocity specific and according to some they are not. In many of those studies, where adaptations were velocity specific, subjects did not do any additional training. On the other hand, in many of those studies where authors did not find differences in adaptations between training velocities, additional training (e.g. sprint training) was done. An exception was the study of Delecluse et al. (1995), where additional sprint training was done, but there was still velocity specific adaptation. Other things that may have influenced on adaptations is the level of subjects (untrained or athletes) and contrast between “high-velocity” and “low-velocity” training (80 % 1RM vs. 60 % 1RM [Cronin et al. 2001] or heavy load vs. plyometrics [Delecluce et al. 1995]).

# 4 BIOMECHANICS OF SPRINT START

## 4.1 Contact and flight times

Contact times of sprint running are longest during the block phase and tend to decrease after it. The decrease will continue till the maximum (constant) velocity is achieved. For the flight times, the opposite is true: they are short at the beginning and tend to increase till the maximum (constant) velocity is achieved. Contact and flight times of sprint start from various studies are presented in Table 6.

TABLE 6. Contact and flight times (ms) of sprint start.

| | Contact time | Contact time | Contact time | Contact time | Contact time |
|---|---|---|---|---|---|
| Block phase | 310-370 | 342 | 365 | | |
| 1st step | | 193 | 168 | 200 | 177 |
| 2nd step | | | 139 | 173 | 159 |
| 3rd step | | | | 159 | 136 |
| 4th step | | | | 135 | 131 |
| 5th step | | | | | 120 |
| 6th step | | | | | 123 |
| 7th step | | | | | 120 |
| 8th step | | | | | 112 |
| 9th step | | | | | 103 |
| 10th step | | | | | 110 |
| | Flight time | Flight time | Flight time | Flight time | Flight time |
| 1st step | | | 82 | 45 | 51 |
| 2nd step | | | 101 | 58 | 82 |
| 3rd step | | | | 74 | 82 |
| 4th step | | | | 81 | 99 |
| 5th step | | | | | 89 |
| 6th step | | | | | 98 |
| 7th step | | | | | 101 |
| 8th step | | | | | 112 |
| 9th step | | | | | 105 |
| 10th step | | | | | 116 |
| Subject(s) | Skilled sprinters | Men (100 m: 10.79 s) | Woman (100 m hurdles:13.19 s) | Man (100 m: 10.80 s) | Man (100 m: 10.14 s) |
| Reference | Harland & Steele (1997) | Mero (1988) | Coh (2007) | Salo et al. (2005) | Coh (2006) |

## 4.2 Force production

An example of force production during the sprint start is presented in Figure 3. The Y-axis indicates force (N) and the X-axis indicates time (s). The upper part of the figure presents vertical force and the lower part horizontal force (anterior-posterior force). The body weight (BW) of this particular subject was about 780 N and it is shown in the upper part of the figure. The ”cursor 1” is placed at the beginning of the force production towards the starting blocks and the ”cursor 2” is placed at the end of block phase force production. The ”cursor 3” points out the beginning and the ”cursor 4” the end of the force production of the first step after block clearance. The first peak force achieved in the block phase is a sum of force production through both legs toward the blocks and the second peak is produced only through the front leg. At the beginning of the first steps after block clearance there is a short negative force production in horizontal direction (lower part of the Figure 3). During this negative horizontal force production, velocity decreases and during the positive horizontal force production,

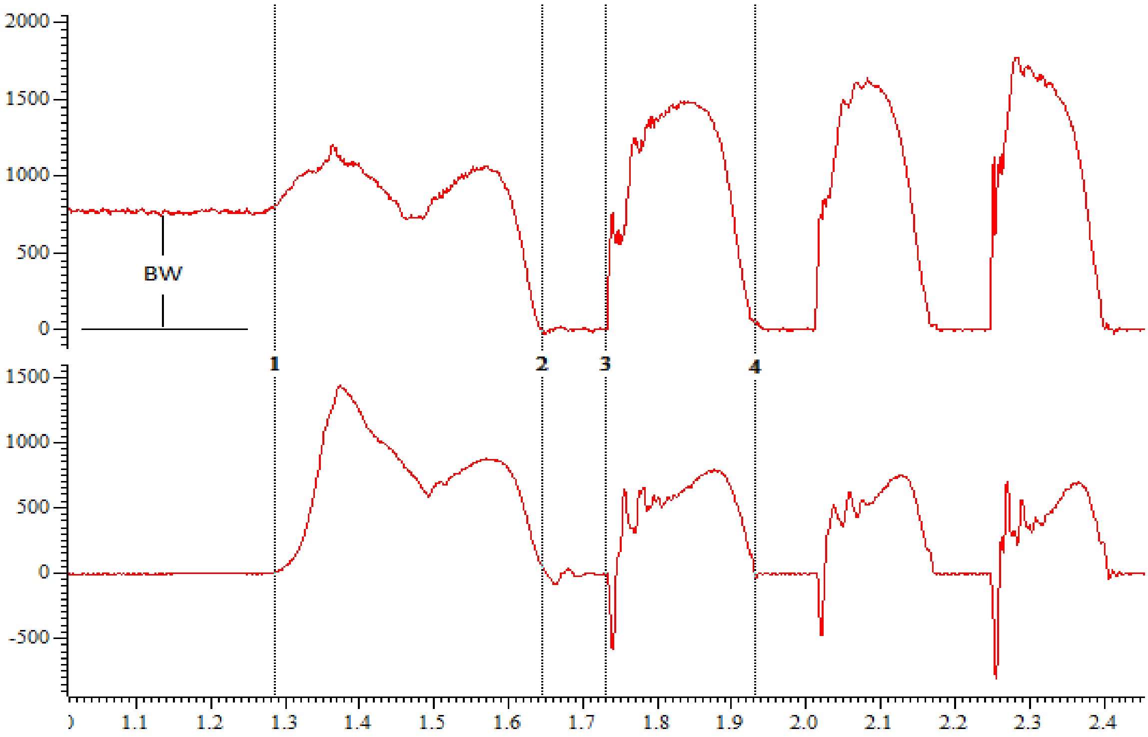

FIGURE 3. Force production during the block phase and three steps after block clearance. See text for further information. (Unpublished observation, Okkonen 2009.)

velocity increases. During the sprint start peak vertical force tends to increase step by step and net horizontal impulse (negative horizontal impulse + positive horizontal impulse) tends to decrease step by step.

### 4.2.1 Peak forces

The peak forces from the block start in Mero's (1988) and Salo's et al. (2005) studies are presented in Table 7. The vertical peak forces (VPF) were larger than horizontal peak forces (HPF), and VPF also tend to increase during the first steps.

TABLE 7. Horizontal (HPF), vertical (VPF) and resultant peak forces (RPF) during the block start.

| Phase of the block start | HPF (N) | VPF (N) | RPF (N) | Subject(s) | Reference |
|---|---|---|---|---|---|
| Block phase | 1220 | 1490 | 1920* | Men (10.79 s) | Mero 1988 |
| 1st step | 790 | 1460 | 1660* | | |
| 1st step | 850 | 1450# | 1680* | Man (10.80 s) | Salo et al. 2005 |
| 2nd step | 710 | 1300# | 1480* | | |
| 3rd step | 705 | 1450# | 1610* | | |
| 4th step | 750 | 1600# | 1770* | | |

***** Computed from the HPF and VPF; # Estimated from a figure

### 4.2.2 Impulses

Impulse is the integral of force with respect to time. In simple words, impulse = average force x time (of a force production). Impulse is an important variable because a change in velocity depends on impulse. For example, during a ground contact in sprint running velocity is decreased during a braking phase of a contact (negative horizontal force production → negative horizontal impulse) and increased during a propulsion phase of a contact (positive horizontal impulse). The different phases of horizontal force production are shown in Figure 5. Darkened area under the horizontal line is the area of negative (braking) force production so the darkened area is the negative horizontal impulse. Lined area in turn represents positive (propulsion) force production so the lined area represents positive horizontal impulse.

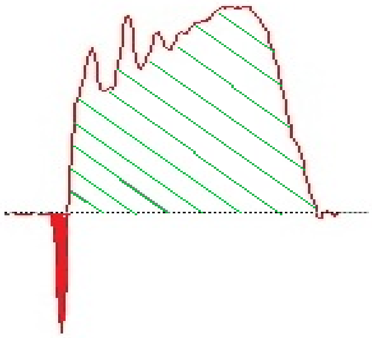

FIGURE 5. An example of horizontal force production during the second step after leaving the blocks. See text for further information. (Unpublished observation, Okkonen 2009.)

TABLE 8. Horizontal (Hor IMP), vertical (Ver IMP) and resultant impulses (Res IMP) during the block start.

| Phase of the block start | Hor IMP (Ns) | Ver IMP (Ns) | Res IMP (Ns) | Subject(s) | Reference |
|---|---|---|---|---|---|
| Block phase | 223 | 173 | 282 | Men (10.79 s) | Mero 1988 |
| 1st step | 87* | 74 | 114 | | |
| Block phase | | | 276 | Men (10.27 s) | Slawinski et al. 2010 |
| | | | 215 | Men (11.31 s) | |
| 1st step | | | 105 | Men (10.27 s) | |
| | | | 79 | Men (11.31 s) | |
| 2nd step | | | 75 | Men (10.27 s) | |
| | | | 56 | Men (11.31 s) | |
| 1st step | 94* | | | Man (10.80 s) | Salo et al. 2005 |
| 2nd step | 65*# | | | | |
| 3rd step | 60*# | | | | |
| 4th step | 50*# | | | | |

* Horizontal net impulse (negative impulse + positive impulse); # Estimated from a figure

As it can be seen above (Figure 5 and Table 8), propulsion horizontal impulses are large compared to braking horizontal impulses during the block phase and few steps after the block phase. On the other hand, propulsion impulses decrease step by step until constant velocity is achieved and the opposite is true for braking impulses.

## 4.3 Joint angles and angular velocities

In Mero's (1988) study knee angles of the front and rear legs in the set position were 96° and 126°, respectively. Same values for hip were 39° and 77°. According to Harland and Steele (1997), knee angles of front and rear legs are ”usually” between 89–111 ° and 118–136°, respectively and that there are not significant differences in the knee angles between good and average sprinters. In turn, there seems to be differences in the hip angles of different level sprinters (good: 41° [front leg] and 80° [rear leg]; average: 52° [front leg] and 89° [rear leg]). The peak extension velocity values for hip, knee and ankle joints from various studies are shown in Table 9. For a comparison, there are also values from maximum running phase (at 45-m and 60-m mark).

TABLE 9. The peak extension velocity values (°/s) for hip, knee and ankle joints at various phases of sprint running.

| Phase | PAV (°/s) | | | Number and level of subjects | Reference |
|---|---|---|---|---|---|
| | Hip | Knee | Ankle | | |
| Block start | | | | | |
| Front leg | 460 | 660 | 640 | 8; Elite | Slawinski et al.(2010) |
| Rear leg | 200* | 100* | 380* | | |
| 16-m mark | 740* | 400* | 1100* | 4; Sub elite | Hunter et al. (2004) |
| 45-m mark (max) | 800* | 570* | 1400* | 4; Elite to regional | Bezodis et al. (2008) |
| 60-m mark (max) | 774 | -50 | 664 | 1; Top elite | Ito et al. (2008) |
| 60-m mark (max) | 693 | -68 | 743 | 1; Top elite | Ito et al. (2008) |

* = estimated from figure; max = maximum running phase

As it can be seen from the values above, peak extension values of hip and ankle seems to be lower and peak extension values of knee extension higher during block phase when compared to acceleration phase (at the 16-m mark). The values of the study of Hunter et al. (2004) (at 16-m mark; acceleration) and the values of the study of Bezodis et al. (2008) (at 45-m mark; maximum speed) were quite similar. But the values of two maximum speed studies (Bezodis et al.2008 and Ito et al. 2008) were significantly different, except the values of hip extension velocity. In the former the knee extended in propulsion phase while in the latter the knee actually bent in propulsion phase. However, it is good to remember that the actual change in joint angle is not as obvious as you could assume according the peak angular velocities, because the change in joint angle is the product of the average angular velocity and time.

## 4.4 Muscle activity

Mero and Komi (1990) and Coh et al. (2007) studied the EMG activity in sprint start. The results from these two studies were quite similar, although there were also some differences between the results. In addition, great interindividual variation in the pattern of muscle activation was noticed in the study of Mero and Komi (1990) which emphasizes the complexity of the sprint start.

The gluteus maximus muscles (GM) of the front and rear legs were active at the beginning of the block phase and GM of the front leg reached another activation peak at the end of the block phase. GM was also active at the end of the contralateral contact, probably because of eccentric action. Moreover, the activation was high during the entire 1st and 2nd contact phases.

The biceps femoris muscles (BF) were active during the block phase, although the timing of the peak activation varied among studies (at the beginning / in the middle). Like GM also, BF was active at the end of the contralateral contact. During the 1st and 2nd contact phase the activation was highest in the second half of the contact phase.

The vastus lateralis (VL) of the front leg was active throughout the block phase and VL of the rear leg was active at the beginning of the block phase. During the 1st step the VL was active throughout the contact phase. The rectus femoris (RF) of the front increased its activation through block phase. The RF of the rear leg was active at the beginning of the block phase and after rear leg left the block the RF acted as a hip flexor. RF was also activated during the swing/flight phase (hip flexion). During the contact phase the timing of the peak activation varied among studies (at the beginning / at the end).

The peak activation of the gastrocnemius muscles (GA) were achieved in the final phase of the push off from the blocks. The timing of the peak activation during the contact phase varied among studies (at the beginning / at the middle).

GM, VM, VL, BF (Coh et al. 2007; Mero & Komi 1990) and GA (Mero & Komi 1990) were activated before the first and second ground contact. Adequate pre-activation is important because it ensures that muscles are properly rigid to overcome ground reaction forces (Coh et al. 2007). When muscles are properly rigid at the beginning of the ground contact, the associated cross-bridges are responsible for the short-range elastic stiffness, which diminishes the lengthening of the muscle during the initial ground contact. At the same time, stretch reflex activity enhances the actual muscle force which enhances the storing of elastic energy in the elastic parts of the associated muscles and tendons. This permits a powerful push off of the body during the subsequent concentric phase. (Schmidtbleicher 1992, 383; Komi 1991, 169; Kyröläinen 2004, 150.)

# 5 BIOMECHANICAL COMPARISON BETWEEN SPRINT START AND SELECTED STRENGTH EXERCISES

There has been only a few studies comparing biomechanics of sprinting and strength exercises: sprint start vs. sled-pulling (Maulder et al. 2008 and Lockie et al. 2003) and maximum speed sprinting vs. forward bounding exercises (Mero & Komi 1994). Moreover, it seems that there has not been any studies executing a biomechanical comparison between sprint start and squat type exercises.

## 5.1 Sprint start vs. sled-pulling

Maulder et al. (2008) compared the kinematics of sprint start and sled-pulling. As subjects they had 10 male sprinters (100 m: 10.87 s). Each subject performed 4 x 10 m sprints from the starting blocks in three experimental conditions: unresisted sprinting and sled-pulling with approximately 10 % and 20 % of body mass (BM).

TABLE 10. The values for various kinematic variables in different resistance conditions. Relative change (%) from unresisted condition is represented in parenthesis. (Modified from Maulder et al. 2008.)

| Variable | Unresisted | 10 % BM | 20 % BM |
|---|---|---|---|
| Start velocity (m/s) | 3.4 | 3.1 (8) | 2.9 (15) |
| Block takeoff angle (°) | 42 | 40 (5) | 38 (10) |
| Force production time in blocks (ms) | 310 | 330 (6) | 340 (10) |
| 1st step CT (ms) | 200 | 210 (5) | 220 (10) |
| 2nd step CT (ms) | 180 | 180 (0) | 200 (11) |
| 3rd step CT (ms) | 160 | 170 (6) | 180 (13) |
| Step frequency (Hz) | 4.26 | 4.13 (3) | 4.07 (5) |

Block takeoff angle = the angle (relative to horizontal) between the most front part of the front foot and the center of gravity at the moment of takeoff; CT = contact time

The 10 m time deteriorated from unresisted sprinting by 8 % and 14 % in sled-pulling with 10 % BM and 20 % BM, respectively. The start velocity (the horizontal velocity at the moment of takeoff from the starting blocks) decreased in similar way: 8 % and 15 %, respectively. Values for various kinematic variables in different resistance conditions are shown in Table 10.

Lockie et al. (2003) also studied the effects of sled-pulling on sprint kinematics. Their subjects (n = 20; i.a. rugby and soccer players; body mass: 82.6 kg) performed 15 m sprints in three experimental conditions: unresisted and sled pulling with 12.6 % and 32.2 % of body mass (BM). These loads were selected because the aim was to achieve a 10 and 20 % decrease in running speed.

The velocity (hip velocity at takeoff into the second stride) decreased 9 % and 24 %, respectively. The contact times of the first and second steps increased statistically significantly in both resisted conditions compared to unresisted condition, and there was also change in trunk lean (Table 11). Sled-pulling also increased the range of motion (ROM) of the shoulders and flexion of the hips during the first and second stride. (Lockie et al. 2003.)

TABLE 11. Contact times of first two steps and trunk lean in relation to vertical line (at the touchdown of the first stride). Relative change (%) from unresisted condition is represented in parenthesis. (Modified from Lockie et al. 2003)

| Variable | Unresisted | 13 % BM | 32 % BM |
|---|---|---|---|
| 1st step CT (ms) | 210 | 230 (10) | 250 (19) |
| 2nd step CT (ms) | 180 | 200 (11) | 220 (22) |
| Trunk lean (°) | 39 | 42 (8) | 45 (15) |
| Stride frequency (Hz) | 1.8 | 1.7 (6) | 1.7 (6) |

The authors suggested that increase in ground contact time seems to be a result of the athlete requiring more time to produce greater muscular power, in order to overcome the higher resistance, and would consequently be appropriate for the development of hip extension power. Increased ROM of shoulder, flexion of hip and trunk lean are also thought to be positive differences. A vigorous arm action is thought to assist the forward drive during the sprint start, one of the main muscle groups that increase gait speed is thought to be hip flexors and greater trunk lean might allow greater application of horizontal force to the ground. The authors concluded that sled-pulling may be very useful in order to overload an athlete's sprint technique and develop the specific recruitment of fast-twitch muscle fibers, particularly compared with traditional weight training.

## 5.2 Sprint start and selected squat type exercises

As mentioned earlier, biomechanical comparisons between the sprint start and squat type exercises have not been performed. Therefore, the following Tables (12, 13 and 14) include information from several different studies, and the results are not fully comparable because of some methodological reasons (i.a. different subjects). However, it can be thought that values from different studies describe quite well the exercises and a comparison, at least in some level, can be executed. Unfortunately, in many studies only the peak values are presented, although the average values could possibly tell something more about exercises.

### 5.2.1 Peak velocities and force production times

The peak and average concentric velocities, concentric force production times and contact times from selected squat type exercises and sprint start are shown in Table 12. As expected the peak concentric velocity increases when the weight in the bar decreases in squat type movements and the opposite is true for the concentric force production time. For example, the peak concentric velocity during the block start (Mero 1988) is 7.7 times as great as during the 1RM squat (Escamilla et al. 2001) and, on the other hand, concentric force production time is 7.8 times as long as in the 1RM squat than in the block start. The peak concentric velocity in the countermovement jump (CMJ) (Cormie et al. 2009) is rather similar to the block start velocity (Mero 1988): 3.64 vs. 3.46 m/s, respectively. Also the concentric force production time in the concentric squat jump with weight of 7 % of 1RM (Kellis et al. 2005) is rather similar to the block start force production time (Mero 1988): 377 vs. 342 ms, respectively.

### 5.2.2 Peak forces

The peak concentric forces from the selected squat type exercises and sprint start are presented in Table 13. When the weight in the bar decreases, decreases also the relative peak force (peak force / body weight). According to the data presented in Table 13, the relative peak concentric force in the squat jump with the load of 55 % 1RM is similar to the corresponding force in the block start. Interestingly, when the relative peak force per leg is examined, the force is greater in the first step after block clearance than in the isometric squat (knee angle 90°).

### 5.2.3 Peak angular velocities of hip, knee and ankle

As expected, the peak extension angular velocities of hip, knee and ankle are lowest during the 1RM squat and increases as extra load decreases (Table 14). In the study of Kellis et al. (2005) the peak angular velocities of hip, knee and ankle were significantly higher at the lightest load (7 % 1RM = 10 kg) than with other loads in the concentric squat jump. Furthermore, peak angular velocity decreased significantly in the two heaviest loads (62 and 70 % 1RM = 90 and 100 kg). The peak angular velocity of the hip extension at the lightest load was approximately 680°/s (Kellis et al. 2005) and it is quite similar than the corresponding angular velocities during acceleration (16-m mark, Hunter el al. 2004), and during maximum speed running (45-m mark, Bezodis et al. 2008; and 60-m mark, Ito et al. 2008). According to the data presented in Table 14, the peak angular velocities of the hip extension at the loads from 14 % to 54 % 1RM corresponds quite well the peak extension velocity of the hip of the front leg during the block start. The peak angular velocity of the knee extension at the load of 7 % 1RM (Kellis et al. 2005) exceeds the peak knee extension values achieved at the different phases of sprinting. The values at the loads of 14–54 % 1RM are rather similar to the value of the front leg in the block start. The value of the peak angular velocity of the ankle extension at the load of 7 % 1RM is the closest to the values at the block start and maximal running (Slawinski et al. 2010 and Ito et al. 2008) (Table 14).

TABLE 12. Peak and average concentric velocities, concentric force production times and contact times from the selected squat type exercises and sprint start. *Italicized values* are estimated from figures.

| Exercise/phase of exercise | PCV (m/s) | ACV (m/s) | FPT (ms) | Subject(s) | Reference |
|---|---|---|---|---|---|
| Powerlifting squat (1RM) | 0.45 | | 2680 | 39 competitive powerlifters | Escamilla et al. 2001 |
| Powerlifting squat (1RM) | *0.7* | | 2500 | 25 competitive powerlifters | Hales et al. 2009 |
| Concentric SJ 70 % 1RM (knee 80°) | 0.78 | 0.54 | 1119 | 8 students (1RM 140kg) | Kellis et al. 2005 |
| Concentric SJ 62 % 1RM (knee 80°) | *0.9* | | 991 | | |
| Concentric SJ 54 % 1RM (knee 80°) | *1* | | 914 | | |
| Concentric SJ 47 % 1RM (knee 80°) | *1.1* | | 894 | | |
| Concentric SJ 40 % 1RM (knee 80°) | *1.3* | | 773 | | |
| Concentric SJ 32 % 1RM (knee 80°) | *1.5* | | 783 | | |
| Concentric SJ 28 % 1RM (knee 80°) | *1.6* | | 624 | | |
| Concentric SJ 21 % 1RM (knee 80°) | *2* | | 613 | | |
| Concentric SJ 14 % 1RM (knee 80°) | *2.1* | | 500 | | |
| Concentric SJ 7 % 1RM (knee 80°) | 2.5 | 2.39 | 377 | | |
| SJ 74% 1RM | 1.62 | | | 18 untrained males (1RM 113 kg) | Cormie et al. 2008 |
| SJ 55% 1RM | 1.86 | | | | |
| SJ 37% 1RM | 2.15 | | | | |
| SJ 18% 1RM | 2.56 | | | | |
| SJ 0% 1RM | 3.09 | | | | |
| CMJ | 3.64 | | | 12 male power ahtletes | Cormie et al. 2009 |
| CMJ | 3.02 | | | 14 untrained males | Cormie et al. 2009 |
| Block start | 2.84 | | 365 | 1 female sprinter | Coh et al. 2007 |
| 1st step | 4.03 | | 168 | | |
| 2nd step | 4.78 | | 139 | | |
| Block start | 3.46 | | 342 | 8 male sprinters | Mero 1988 |
| 1st step | 4.65 | | 193 | | |
| Blocks | 3.46-3.94 | | | Skilled sprinters | Harland & Steele 1997 |
| 1st step | 4.65-5.16 | | | | |
| Block start | 4.18 | | | 1 male sprinter | Coh et al. 2006 |
| 1st step | 4.52 | | 177 | | |
| 2nd step | 6.05 | | 159 | | |

PCV = peak concentric velocity; ACV = average concentric velocity; FPT = force production time; 1RM = 1 repetition maximum; SJ = squat jump; CMJ = countermovement jump

TABLE 13. Peak concentric forces from the selected squat type exercises and sprint start.

| Exercise/ phase of exercise | Peak concentric force (N) | Peak concentric force / BW | Peak concentric force (N) / leg | Peak concentric force (N) / leg / BW | Subject(s) | Reference |
|---|---|---|---|---|---|---|
| Isometric squat (knee 90°) | | 3.26 | | 1.63 | 8 students (1RM 140kg) | Kellis et al. 2005 |
| Concentric SJ 70 % 1RM (knee 80°) | | 3.21 | | 1.61 | | |
| Concentric SJ 7 % 1RM (knee 80°) | | 2.30 | | 1.15 | | |
| SJ 74 % 1RM | 2292 | 2.89 | 1146 | 1.45 | 18 untrained males (1RM 113 kg) | Cormie et al. 2008 |
| SJ 55% 1RM | 2106 | 2.66 | 1053 | 1.33 | | |
| SJ 37% 1RM | 1935 | 2.44 | 968 | 1.22 | | |
| SJ 18% 1RM | 1745 | 2.20 | 873 | 1.10 | | |
| SJ 0% 1RM | 1688 | 2.13 | 844 | 1.06 | | |
| CMJ | 1993 | 2.38 | 997 | 1.19 | 12 male power ahtletes | Cormie et al. 2009 |
| CMJ | 1664 | 2.14 | 832 | 1.07 | 14 untrained males | Cormie et al. 2009 |
| Block start (front leg) | 1023* | 1.86 | 1023* | 1.86 | 1 female sprinter | Coh et al. 2007 |
| Block start (rear leg) | 628* | 1.14 | 628* | 1.14 | | |
| Block start (net vertical force) | 1426* | 1.97 | | | 8 male sprinters (100 m: 10.79 s) | Mero 1988 |
| Block start | 1920*# | 2.67 | | | | |
| 1st step | 1660*# | 2.31 | 1660*# | 2.31 | | |
| 1st step | 1680*# | 2.16 | 1680*# | 2.16 | 1 male sprinter (100 m: 10.80 s) | Salo et al. 2005 |
| 2nd step | 1480*# | 1.90 | 1480*# | 1.90 | | |
| 3rd step | 1610*# | 2.07 | 1610*# | 2.07 | | |
| 4th step | 1770*# | 2.27 | 1770*# | 2.27 | | |

1RM = 1 repetition maximum; SJ = squat jump; CMJ = countermovement jump; * = resultant force; # = computed from peak horizontal and vertical force

TABLE 14. Peak extension angular velocities (PAV) of hip, knee and ankle from the selected squat type exercises and sprint start. *Italicized values* are estimated from figures.

| Exercise/ | PAV (°/s) | | | Subject(s) | Reference |
|---|---|---|---|---|---|
| phase of exercise | Hip | Knee | Ankle | | |
| Powerlifting squat (1RM) | 109 | 120 | 37 | 39 competitive powerlifters | Escamilla et al. 2001 |
| Powerlifting squat (1RM) | | 170 | | 29 different level powerlifters | Miletello et al. 2009 |
| Concentric SJ 70 % 1RM (knee 80°) | *350* | *280* | *300* | 8 students (1RM 140kg) | Kellis et al. 2005 |
| Concentric SJ 62 % 1RM (knee 80°) | *350* | *400* | *400* | | |
| Concentric SJ 54 % 1RM (knee 80°) | *450* | *570* | *450* | | |
| Concentric SJ 47 % 1RM (knee 80°) | *400* | *450* | *570* | | |
| Concentric SJ 40 % 1RM (knee 80°) | *400* | *570* | *570* | | |
| Concentric SJ 32 % 1RM (knee 80°) | *450* | *550* | *500* | | |
| Concentric SJ 28 % 1RM (knee 80°) | *450* | *550* | *400* | | |
| Concentric SJ 21 % 1RM (knee 80°) | *450* | *650* | *570* | | |
| Concentric SJ 14 % 1RM (knee 80°) | *450* | *570* | *570* | | |
| Concentric SJ 7 % 1RM (knee 80°) | *680* | *800* | *680* | | |
| Block start (front leg) | 460 | 660 | 640 | 8 elite sprinters | Slawinski et al. 2010 |
| Block start (rear leg) | *200* | *100* | *380* | | |
| Acceleration 16-m mark | *740* | *400* | *1100* | 4 male sprinters | Hunter et al. 2004 |
| Max speed 45-m mark | *800* | *570* | *1400* | 4 male sprinters | Bezodis et al. 2008 |
| Max speed 60-m mark | 774 | -50 | 664 | 1 top elite sprinter | Ito et al. 2008 |
| Max speed 60-m mark | 693 | -68 | 743 | 1 top elite sprinter | Ito et al. 2008 |

1RM = 1 repetition maximum; SJ = squat jump

## 5.3 Associations between sprint start and speed-strength / strength exercises

Correlations between different exercises and a certain sport event are interesting and important to know because they can tell, for example, which exercises and/or qualities are essential in a certain sport event. Thus, it is not surprising that there have been quite a lot of studies examining correlations between sprint start and speed-strength / strength exercises (e.g. Young et al. 1995; Cronin & Hansen 2005; Smirniotou et al. 2008). Different kind of vertical and horizontal jumps (e.g. countermovement jump (CMJ), squat jump (SJ), drop jump (DJ), unilateral horizontal drop jump) are examples of speed-strength exercises. These kind of speed-strength exercises have correlated quite well with sprint start (10 m; correlation coefficients between -0.55 and -0.66) (Cronin & Hansen 2005; Smirniotou et al. 2008; Jonsson Holm et al. 2008). Young et al. (1995) found even higher correlations when different variables during speed-strength exercise (static jump squat from knee angle of 120° [19 kg]) were examined. A correlation coefficient between relative peak force (PF/BW [body weight]) during exercise and sprint start was -0.86 and corresponding value for relative PF in 100 ms was -0.73. Correlations between sprint start and strength exercises seem to be more equivocal. In the study of Harris et al. (2008), 1-RM squat (knee angle 110°) correlated rather poorly with sprint start (10 m; r=0.2) and, on the other hand, in the study of Young et al. (1995) PF in isometric squat (knee angle 120°) correlated well (r=-0.72).

# 6 PURPOSE OF THE STUDY

The purpose of the study was to compare kinetics, kinematics and muscle activity between the sprint start, sled pulling and selected squat type exercises and also to examine how different exercises and variables correlate with the performance time of the block start (10 m). Thus, the purpose was to acquire more information about the relations between these exercises. Ultimately, this new information could probably be utilized in sprint start training and possibly in general sprint training.

## 6.1 Research problems

1) Which of the exercise(s) analyzed in the present study is/are movement and/or velocity specific with regard to the block start?
2) In which exercise(s) the ground reaction forces (GRF) are larger than in the block start?
3) In which exercise(s) the electromyographic (EMG) values of the gluteus maximus (GM), biceps femoris (BF) and/or vastus lateralis (VL) are higher than in the block start?
4) In which exercise(s) the angular velocities of the hip, knee and/or ankle are higher than in the block start?
5) How different exercise(s) / variable(s) correlate with regard to performance time of the block start (10 m)?

# 7 METHODS

## 7.1 Subjects

Subjects included 9 male athletes (4 sprinters, 3 decathlonists, 1 long jumper and 1 triple jumper; mean ± SD; age = 24.9 ± 3.9 yr; height = 180.4 ± 5.9 cm; weight = 80.3 ± 7.5 kg; 100 m record = 11.35 ± 0.29 s). All subjects were familiar with the exercises done in the present study. Subjects provided informed consent and health inquiry before the study. Approval for the study was obtained from the ethics committee of the Central Finland Health Care District.

## 7.2 Procedures

Subjects attended only one session. At the beginning of the session each subject filled out informed consent and health inquiry. Then weight and height of the subject were measured and the locations of the EMG electrodes were defined and shaved (if necessary). After defining EMG electrode locations (SENIAM), subject did his own warm up (which usually lasted about 30–40 min). After warm up, electrode locations were slightly treated with abrasive paper and alcohol to reduce the impedance (< 10 kOhm). Electrodes (Blue sensor N, Ambu A/S, Denmark, Ballerup) were placed only on the other leg (the front leg in the starting blocks). The EMG activity was measured from the gluteus maximus (GM), biceps femoris (BF), vastus lateralis (VL) and gastrocnemius medialis (Ga). After electrode placements, subject tested starting blocks (Nordic) and after attaching the markers (for 2D movement analysis) subject was ready to start the measurements. The marker locations were head of the second metatarsal, calcaneous, lateral malleolus, lateral epicondyle of the femur, greater trochanter and middle portion of the neck. In CMJ10, CMJ20 and S70, the marker of the neck was replaced by the marker in the head of the weightlifting bar.

The measurements included following exercises: block start (10 m) (Blocks), sled pulling with about 10 % and 20 % of body mass (10 m) (Sled10 and Sled20), testing of

½-squat 1-RM in smith machine (SMax; Figure 6), countermovement jump (CMJ), CMJ with a load of about 10 % and 20 % of 1-RM in ½-squat (CMJ10 and CMJ20) and ½-squat with a load of about 70 % of 1-RM in ½-squat (S70). One subject did not do either S70 or SMAX. The deepness in ½-squat exercises (knee angle 90°) was controlled by rubber band and visual control. All exercises, except 1-RM ½-squat, were performed twice. If the subject performed 2-RM squat, 1-RM was calculated (Ahtiainen & Häkkinen 2010, 147). The exercises were performed in the above mentioned order and recovery times between repetitions and exercises were about 2–5 minutes to minimize fatigue accumulation. An exception was 1-RM ½-squat testing which included own warm up (½-squatting with increasing weights) and the recovery after ½-squat testing was at least 10–15 minutes before performing next exercise (CMJ).

FIGURE 6. Smith machine which was used in ½-squat 1-RM testing.

In all exercises ground reaction forces (GRF) were measured by strain gauge sensor force plates (Raute PLC, Finland, Lahti; sampling rate 1000 Hz) and EMG activity was measured by wireless EMG system (Telemyo DTS, Noraxon U.S.A. Inc., U.S.A., Arizona; sampling rate 1500 Hz, gain 1000-fold, band-pass filter 10–500 Hz). All exercises, except ½-squat 1-RM, were also recorded by high-speed digital video cameras (Fastec Imaging, Fastec InLine, Fastec Imaging Corporation, U.S.A, San

Diego; frequency 250 frames per second, shutter speed 1/500, resolution 640 x 480). High speed cameras were calibrated before every subject with the calibration frame. The data from force plates and EMG system passed through analog-to-digital converter (ADC) to computer and was recorded and analyzed with Signal-program (Signal 4.04, Cambridge Electronic Design Ltd.). High-speed digital video camera data was recorded on another computer with FIMS -software (FIMS 3.0.4, Fastec Imaging inc., San Diego, CA, USA) and analyzed with Vicon Motus -software (Vicon Motus 9.2, Vicon Motion Systems Inc.). Before analyzing with Vicon Motus, data was converted with MiDAS Player 2.2.0.8. Measurements were started by manual triggering (Figure 7).

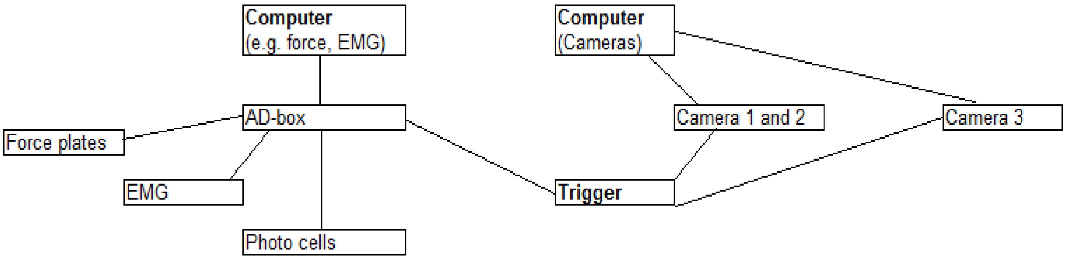

FIGURE 7. Measurement design.

Blocks, Sled10 and Sled20 were performed on the strain gauge force plates which were embedded in the ground. The force plates covered the distance of 10 meters and were surfaced with normal synthetic running track (Figure 8). Blocks was performed from starting blocks and Sled10 and Sled20 from “3-point starting position” (Figure 9). Sled-pullings were performed with custom made sled (mass 4.9 kg; Figure 10). The sled was attached to the waist of the subject with rope (17.4 m long) and powerlifting belt. The placement of the starting blocks on the force plates is presented in Figure 8. The force plates measured GRFs during the block phase (the phase when force is produced toward the starting blocks) and at least 6 following steps. GRFs were measured separately from both legs. Photo cells were used in timing.

FIGURE 8. Position of the starting blocks on the force plates.

FIGURE 9. Three-point starting position.

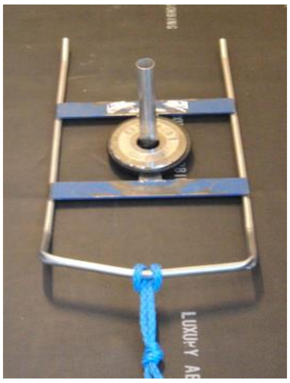

FIGURE 10. Custom made sled.

## 7.3 Analyses

The best trial in each exercise for each subject was analyzed (if the measurements were successful). Force and EMG data was analyzed manually with Signal -software (Signal 4.04). In *Blocks, Sled10 and Sled20*, clear increase in the horizontal force (anterior-posterior) was used as the mark for the beginning of the performance and signal from photo cells at 10-m mark ended the performance. In most analyses, only “block phase” (phase of force production toward starting blocks [or corresponding phase in Sled10 and Sled20]), 2nd and 6th step were used. An exception was step frequency which was presented as a mean value of first six steps. Resultant peak forces (RPF) were calculated at the moment of vertical peak forces (VPF). Almost all force-time variables were defined from the propulsion phase of ground contact, with the exception of FPT in which the braking phase was also included. Resultant impulses (Res IMP) and angle of force productions (angle of FP) were calculated from vertical (net) impulses (Ver IMP) and horizontal impulses (Hor IMP). The takeoff velocity in the block phase was computed from Res IMP. In the kinematic analyses, in addition to the block phase, also the 6th step was analyzed (flight and contact phase). The flight phase was defined to begin when the hip of the swinging leg started to extend.

In the *CMJs and ½-squats*, the beginning of concentric phase was computed from force-time signal and concentric phases of CMJs and squats were used in analyses. The takeoff velocity in the CMJs was computed from net concentric impulse. In the kinematic analyses the beginning of the concentric phase was defined from the kinematic analyses data.

The EMG values were normalized individually to the EMG values of the CMJ20 when Blocks was compared to Sled10, Sled20, CMJs and ½-squats. When only Blocks, Sled10 and Sled20 were compared, the EMG values were normalized to the block phase of Sled20. These phases of exercises were selected, because the EMG measurements were most successful in them. Because of some problems in measurements, EMG values of the gastrocnemius medialis were not analyzed in the present study (small n-value). Also statistical differences were not calculated for all phases of exercises in movement analysis, because of low n-value (measurement problems). These phases of exercises were the flight phase of the 6th step in Blocks, Sled10, and Sled20 and the contact phase of the 6th step in Blocks.

## 7.4 Statistical analyses

Standard statistical methods were used for the calculation of means and standard deviations (SD). General linear model (GLM) and repeated measures (PASW Statistics 18 -software) were used to compute statistically significant differences between the exercises. Spearman's rho was used to calculate correlation coefficients between performance time in block start (10m) and other variables. An alpha level of $p \leq 0.05$ was chosen as the criterion for significance.

# 8 RESULTS

Average ½-squat 1-RM was 185.5 kg (range: 167–227 kg) and average 1-RM / body mass was 2.32 (range: 1.91–3.01). Average load used in CMJ10, CMJ20 and S70 were 11.0 % (20.3 kg), 20.6 % (38.1 kg) and 70.2 % (130.3 kg) of SMAX, respectively. Average load used in Sled10 and Sled20 were 9.9 % (7.9 kg) and 20.1 % (16.1 kg) of body mass, respectively.

## 8.1 Force-time variables

### 8.1.1 Block start vs. sled-pulling, CMJs and ½-squats

Performance times (10 m), force production times (FPT) and resultant impulses (IMP) were significantly greater and step frequency (over six first steps) significantly smaller in Sled10 and Sled20 than in Blocks. FPTs in concentric phase during CMJ and CMJ10 were significantly shorter, and FPTs in squats were significantly longer than in Blocks (Figure 11). Resultant peak forces (RPF) and resultant average forces (RAF; Figure 12) were significantly greater in CMJs and squats when compared to Blocks (Table 15).

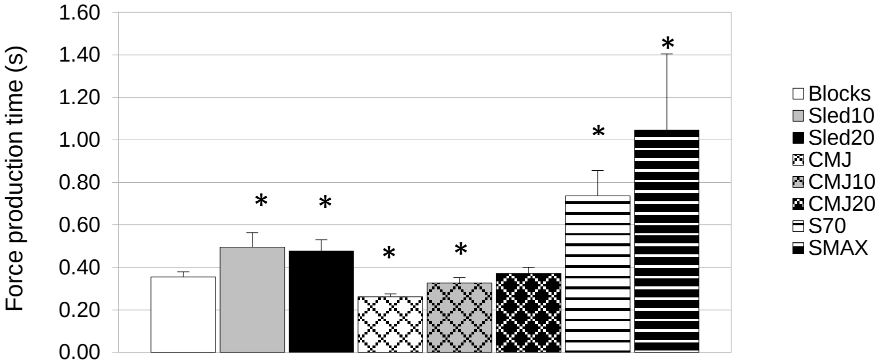

FIGURE 11. Force production times (FPT) (means and standard deviations (SD)) during the "block phase" in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20), ½-squat with 70 % of ½-squat 1-RM (S70) and ½-squat 1-RM (SMAX). * Significantly ($p \leq 0.05$) different from Blocks.

TABLE 15. Force-time variables (means and SDs) during the "block phase" in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20), ½-squat with 70 % of ½-squat 1-RM (S70) and ½-squat 1-RM (SMAX). Step frequency value presents a mean value of first six steps.

| Exercise | Variable | | | | | | |
|---|---|---|---|---|---|---|---|
| | Performance time (10 m) (s) | Step frequency (Hz) | FPT (s) | RPF (N) | RAF (N) | Res IMP (Ns) | Takeoff velocity (m/s) |
| Blocks | 1.980<br>0.060 | 4.30<br>0.27 | 0.355<br>0.024 | 1722<br>202 | 1172<br>63 | 266<br>22 | 3.28<br>0.12 |
| Sled10 | 2.272*<br>0.118 | 4.18*<br>0.27 | 0.494*<br>0.068 | 1747<br>186 | 1086*<br>90 | 299*<br>27 | |
| Sled20 | 2.422*<br>0.092 | 4.00*<br>0.29 | 0.476*<br>0.053 | 1780<br>238 | 1128<br>97 | 311*<br>26 | |
| CMJ | | | 0.261*<br>0.013 | 2273*<br>244 | 1742*<br>118 | 247*<br>21 | 3.06*<br>0.21 |
| CMJ10 | | | 0.326*<br>0.026 | 2231*<br>131 | 1809*<br>93 | 264<br>20 | 2.60*<br>0.17 |
| CMJ20 | | | 0.372<br>0.028 | 2292*<br>116 | 1919*<br>110 | 276<br>18 | 2.31*<br>0.14 |
| S70 | | | 0.737*<br>0.118 | 2990*<br>307 | 2298*<br>183 | | |
| SMAX | | | 1.046*<br>0.359 | 3152*<br>343 | 2655*<br>204 | | |

FPT = force production time; RPF = resultant peak force; RAF = resultant average force; Res IMP = resultant impulse; * Significantly ($p \leq 0.05$) different from Blocks

### 8.1.2 Comparison of force-time variables between block phase, 2nd and 6th steps

Force-time variables during the different phases of Blocks, Sled10 and Sled20 are presented in Table 16 and vertical and horizontal forces from the same phases are presented in Table 17. FPT and Res IMP during the second step were greater and the angle of force production (angle of FP) smaller in Sled20 when compared to Blocks. During the 6th step, FPTs were longer and RPFs, RAFs (Figure 13) and angle of FPs (Figure 14) were smaller in Sled10 and Sled20 than in Blocks.

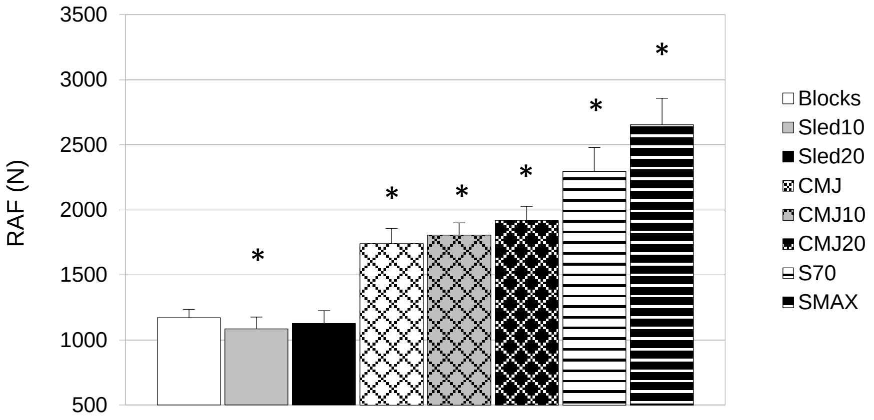

FIGURE 12. Resultant average forces (RAF) (means and SDs) during the “block phase” in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20), ½-squat with 70 % of ½-squat 1-RM (S70) and ½-squat 1-RM (SMAX). * Significantly (p≤0.05) different from Blocks.

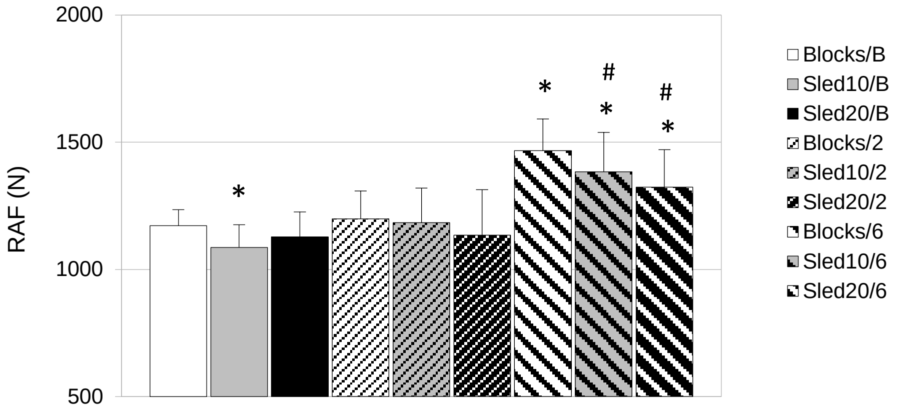

FIGURE 13. Resultant average forces (RAF) during the “block phase” (B), second (2) and sixth step (6) in block start (Blocks), and sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20). * Significantly (p≤0.05) different from Blocks/B. # Significantly (p≤0.05) different from Blocks/2 or Blocks/6.

There were no large differences in vertical and horizontal forces during the block phase and actually, horizontal AFs in Sled10 and Sled20 were significantly smaller than in Blocks. However, during the 6th step horizontal AFs were higher and vertical AFs and PFs were lower, especially in Sled20 (Table 17).

TABLE 16. Force-time variables (means and SDs) during the "block phase" (B), second (2) and sixth step (6) in block start (Blocks), and sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20).

| Exercise/ phase of exercise | Variable | | | | | |
|---|---|---|---|---|---|---|
| | FPT (s) | RPF-Both (N) | RPF-Front (N) | RAF-Both (N) | Res IMP (Ns) | Angle of FP (°) |
| Blocks/B | 0.355 | 1722 | 1379 | 1172 | 266 | 10 |
| | 0.024 | 202 | 150 | 63 | 22 | 3 |
| Sled10/B | 0.494* | 1747 | 1438 | 1086* | 299* | 9 |
| | 0.068 | 186 | 138 | 90 | 27 | 2 |
| Sled20/B | 0.476* | 1780 | 1445 | 1128 | 311* | 9 |
| | 0.053 | 238 | 157 | 97 | 26 | 2 |
| Blocks/2 | 0.175* | 1705 | 1705* | 1198 | 90* | 33* |
| | 0.020 | 191 | 191 | 110 | 10 | 6 |
| Sled10/2 | 0.179* | 1717 | 1717* | 1183 | 91* | 29* |
| | 0.023 | 248 | 248 | 136 | 13 | 5 |
| Sled20/2 | 0.203*# | 1720 | 1720* | 1134 | 101*# | 26*# |
| | 0.018 | 250 | 250 | 178 | 12 | 7 |
| Blocks/6 | 0.135* | 2139* | 2139* | 1467* | 88* | 62* |
| | 0.014 | 175 | 175 | 124 | 13 | 4 |
| Sled10/6 | 0.150*# | 1969*# | 1969*# | 1384*# | 87* | 54*# |
| | 0.016 | 292 | 292 | 154 | 15 | 5 |
| Sled20/6 | 0.166*# | 1887# | 1887*# | 1322*# | 91* | 50*# |
| | 0.016 | 257 | 257 | 147 | 14 | 6 |

FPT = force production time; RPF-Both = resultant peak force produced through both legs; RPF-Front = resultant peak force produced through front leg; Res IMP = resultant impulse; Angle of FP = angle of force production; * Significantly ($p \leq 0.05$) different from Blocks/B; # Significantly ($p \leq 0.05$) different from Blocks/2 or Blocks/6

### 8.1.3 Associations between performance time in block start (10 m) and force-time variables

The highest correlation existed between takeoff velocity in CMJ and block start (10 m) ($r=-0.950$, $p \leq 0.05$; Figure 15). Also, for example, takeoff velocity in CMJ10; PF in squats; AF in CMJs; and relative 1-RM in SMAX (load/BM; Figure 16) correlated significantly with perfor-mance time in the block start (10 m) (Table 18).

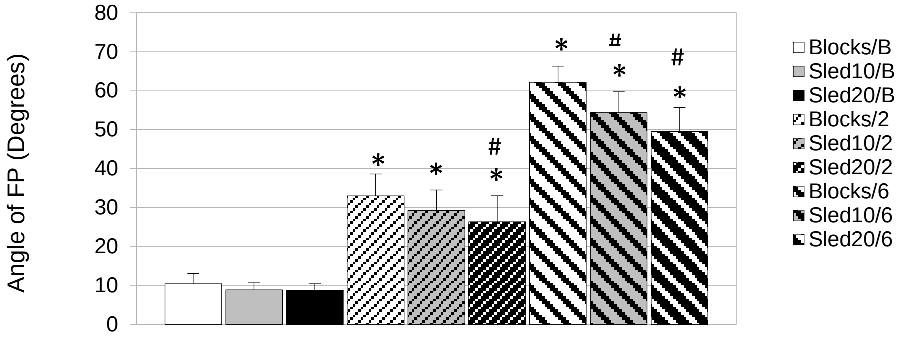

FIGURE 14. Angle of force production (angle of FP) (means and SDs) during the “block phase” (B), second (2) and sixth step (6) in block start (Blocks), and sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20). * Significantly (p≤0.05) different from Blocks/B. # Significantly (p≤0.05) different from Blocks/2 or Blocks/6.

TABLE 17. Vertical peak forces (VPF), vertical average forces (VAF) and horizontal average forces (HAF) (means and SDs) during different phases in block start (Blocks), and sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20).

| Phase | Variable | Exercise | | |
|---|---|---|---|---|
| | | Blocks | Sled10 | Sled20 |
| Block phase | VPF | 1357 | 1325 | 1323 |
| | | 220 | 161 | 188 |
| 2nd step | VPF | 1590 | 1583 | 1566 |
| | | 165 | 244 | 253 |
| 6th step | VPF | 2120 | 1933* | 1832* |
| | | 176 | 283 | 257 |
| Block phase | VAF | 919 | 904 | 916 |
| | | 77 | 87 | 89 |
| Block phase | HAF | 726 | 600* | 656* |
| | | 26 | 49 | 70 |
| 2nd step | VAF | 1101 | 1081 | 1031 |
| | | 99 | 122 | 176 |
| 2nd step | HAF | 470 | 478 | 469 |
| | | 64 | 74 | 64 |
| 6th step | VAF | 1428 | 1333* | 1266* |
| | | 129 | 155 | 147 |
| 6th step | HAF | 331 | 368 | 380* |
| | | 42 | 45 | 40 |

* Significantly (p≤0.05) different from Blocks

TABLE 18. Statistically significant correlations between performance time in block start (10 m) and force-time variables.

| Variable | Exercise/ phase of the exercise | R | Significance |
|---|---|---|---|
| Performance time | Sled10 (10 m) | 0.733 | * |
| | Sled20 (10 m) | 0.617 | # |
| Force production time | Blocks B | 0.600 | # |
| Resultant peak force | Sled10 2 | 0.617 | # |
| | Sled20 B | -0.600 | # |
| | CMJ20 | -0.650 | # |
| | S70 | -0.714 | * |
| | SMAX | -0.738 | * |
| Resultant average force | Blocks B | -0.683 | * |
| | CMJ | -0.933 | * |
| | CMJ10 | -0.783 | * |
| | CMJ20 | -0.800 | * |
| | SMAX | -0.667 | # |
| Resultant impulse | Blocks 6 | 0.867 | * |
| | Sled10 6 | 0.800 | * |
| | Sled20 6 | 0.767 | * |
| Load/BM | SMAX | -0.810 | * |
| Takeoff velocity | CMJ | -0.950 | * |
| | CMJ10 | -0.900 | * |
| | CMJ20 | -0.683 | * |
| Angle of force production | Blocks 6 | 0.617 | # |
| Step frequency | Blocks (10 m) | -0.667 | * |
| | Sled10 (10 m) | -0.650 | # |
| | Sled20 (10 m) | -0.633 | # |

Blocks = block start; Sled10 = sled-pulling with a load of 10 % of body mass (BM); Sled20 = sled-pulling with a load of 20 % of BM; CMJ = countermovement jump; CMJ10 = CMJ with a load of 10 % of ½-squat 1-RM; CMJ20 = CMJ with a load of 20 % of ½-squat 1-RM; S70 = ½-squat with 70 % of ½-squat 1-RM (n = 8); SMAX = ½-squat 1-RM (n = 8); B = "block phase"; 2 = second step; 6 = sixth step; * = $p \leq 0.05$; # = $p \leq 0.10$

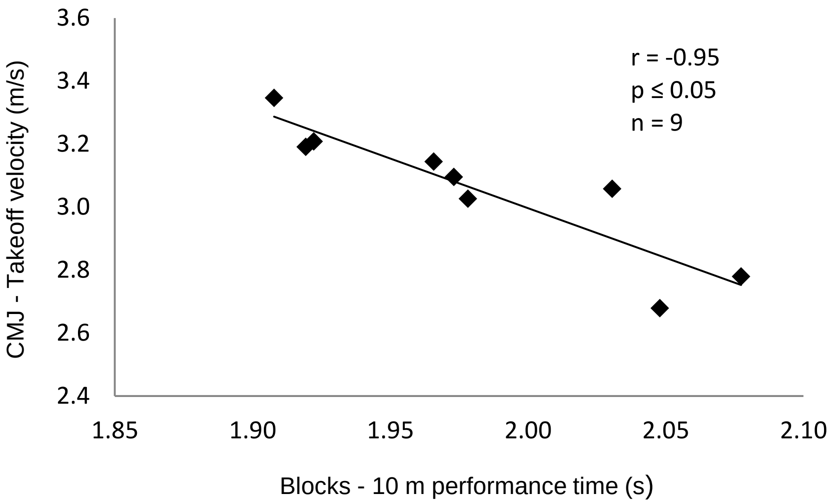

FIGURE 15. Relationship between 10 m performance time (s) in block start (Blocks) and takeoff velocity (m/s) in countermovement jump (CMJ).

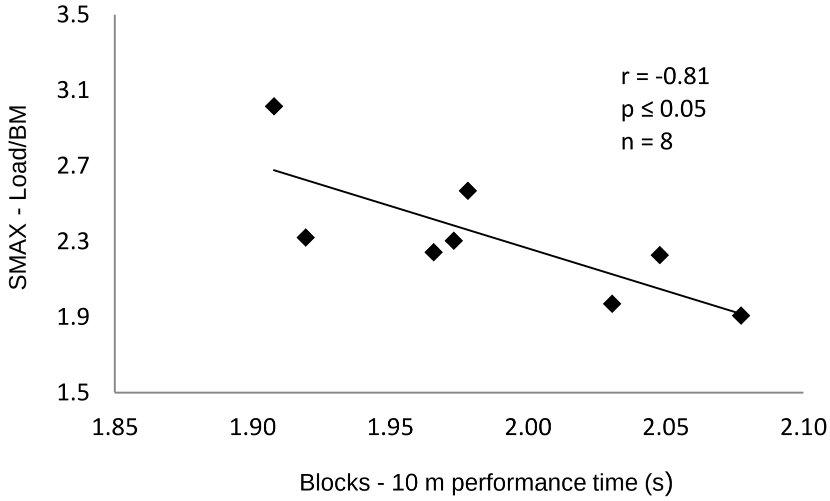

FIGURE 16. Relationship between 10 m performance time (s) in block start (Blocks) and relative load (load/body mass [BM]) used in ½-squat 1-RM (SMAX).

## 8.2 EMG variables

### 8.2.1 Block start vs. sled-pulling, CMJs and ½-squats

Table 19 presents the integrated EMG (IEMG) and averaged EMG (aEMG) values in Blocks, Sled10, Sled20, CMJs and squats. The activity of the gluteus maximus (GM) was higher in Sled10, Sled20, CMJ10, CMJ20 and squats (Figure 17). On the other hand, the activity of the biceps femoris (BF) was lower, especially in CMJs and squats (Figure 18). The IEMG value of the vastus lateralis (VL) was higher in Sled10 and squats. However, the aEMG value of VL was quite similar in all exercises.

TABLE 19. Relative integrated EMG (IEMG) and averaged EMG (aEMG) values (means and SDs) during the "block phase" in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20), ½-squat with 70 % of ½-squat 1-RM (S70) and ½-squat 1-RM (SMAX). (EMG-GM: squats [n=7], other exercises [n=8]; EMG-BF [n=8])

| Exercise | Variable | | | | | |
|---|---|---|---|---|---|---|
| | IEMG-GM (%) | aEMG-GM (%) | IEMG-BF (%) | aEMG-BF (%) | IEMG-VL (%) | aEMG-VL (%) |
| Blocks | 100 | 100 | 100 | 100 | 100 | 100 |
| | 24 | 20 | 43 | 44 | 23 | 20 |
| Sled10 | 182* | 140* | 111 | 88 | 129* | 100 |
| | 48 | 30 | 45 | 37 | 36 | 24 |
| Sled20 | 175* | 139* | 95 | 75* | 115 | 90 |
| | 35 | 30 | 40 | 33 | 32 | 20 |
| CMJ | 88 | 119 | 35* | 47* | 85 | 113 |
| | 15 | 18 | 8 | 9 | 18 | 20 |
| CMJ10 | 120 | 131* | 43* | 46* | 101 | 108 |
| | 20 | 28 | 3 | 5 | 15 | 13 |
| CMJ20 | 140* | 133* | 58* | 53* | 118 | 111 |
| | 0 | 0 | 0 | 0 | 0 | 0 |
| S70 | 260* | 126 | 95 | 45* | 210* | 102 |
| | 77 | 25 | 37 | 17 | 43 | 18 |
| SMAX | 490* | 164* | 105 | 35* | 275* | 92 |
| | 194 | 28 | 63 | 18 | 114 | 24 |

GM = gluteus maximus; BF = biceps femoris; VL = vastus lateralis; * Significantly ($p \leq 0.05$) different from Blocks

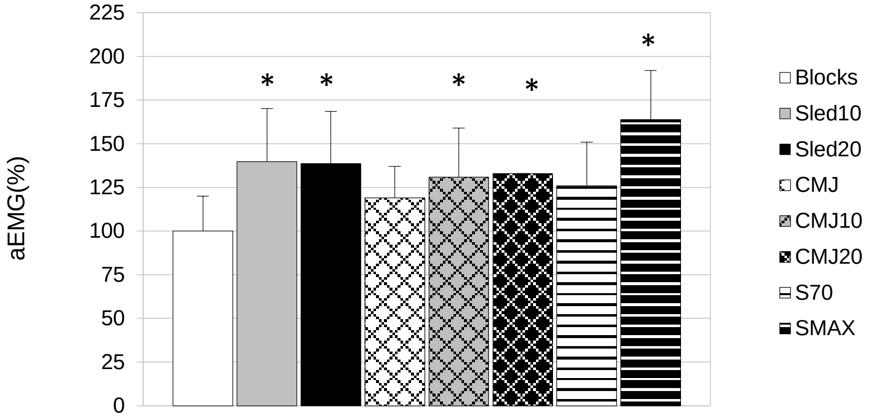

FIGURE 17. Relative averaged EMG (aEMG) value of gluteus maximus (GM) (means and SDs) during the “block phase” in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20), ½-squat with 70 % of ½-squat 1-RM (S70) and ½-squat 1-RM (SMAX). * Significantly (p≤0.05) different from Blocks.

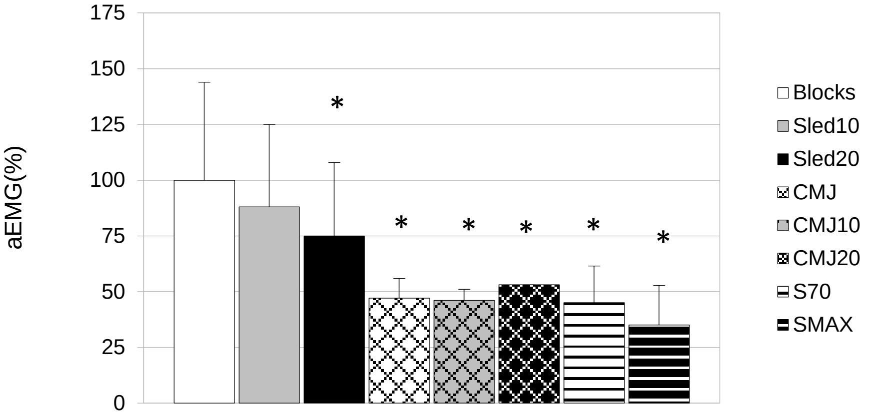

FIGURE 18. Relative aEMG value of biceps femoris (BF) (means and SDs) during the “block phase” in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20), ½-squat with 70 % of ½-squat 1-RM (S70) and ½-squat 1-RM (SMAX). * Significantly (p≤0.05) different from Blocks.

### 8.2.2 Comparison of EMG variables between block phase, 2nd and 6th steps

The EMG values of GM were quite similar during the second and sixth step in Blocks, Sled10 and Sled20. During the second step, the aEMG value of GM was greater in Blocks, Sled20 and Sled20 when compared to the block phase of the Blocks (Blocks/B). The aEMG value of BF during the second step was smaller in Sled20 and during the sixth step smaller in Sled10 and Sled20. The EMG values of VL during second and sixth step were rather similar in Blocks, Sled10 and Sled20 (Table 20).

TABLE 20. . Relative integrated EMG (IEMG) and averaged EMG (aEMG) values (means and SDs) during the “block phase” (B), and during the contact phase of the second (2) and sixth step (6) in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20). (EMG-GM and EMG-BF [n=8]).

| Exercise/ phase of exercise | Variable | | | | | |
|---|---|---|---|---|---|---|
| | IEMG-GM (%) | aEMG-GM (%) | IEMG-BF (%) | aEMG-BF (%) | IEMG-VL (%) | aEMG-VL (%) |
| Blocks/B | 100 | 100 | 100 | 100 | 100 | 100 |
| | 25 | 23 | 19 | 18 | 22 | 21 |
| Sled10/B | 185* | 143* | 113 | 89 | 127* | 99 |
| | 59 | 45 | 20 | 15 | 19 | 19 |
| Sled20/B | 172* | 136* | 94 | 74* | 112 | 88 |
| | 0 | 0 | 0 | 0 | 0 | 0 |
| Blocks/2 | 60* | 119* | 44* | 89 | 45* | 89 |
| | 20 | 36 | 14 | 29 | 14 | 27 |
| Sled10/2 | 73 | 140* | 35* | 72* | 44* | 84* |
| | 31 | 50 | 10 | 22 | 17 | 28 |
| Sled20/2 | 85# | 145* | 36* | 63*# | 56* | 94 |
| | 26 | 43 | 11 | 16 | 21 | 28 |
| Blocks/6 | 42* | 107 | 45* | 120 | 34* | 88* |
| | 16 | 39 | 9 | 22 | 11 | 32 |
| Sled10/6 | 44* | 101 | 35*# | 85# | 39*# | 89 |
| | 20 | 40 | 6 | 13 | 17 | 34 |
| Sled20/6 | 45* | 95 | 41* | 89# | 36* | 76 |
| | 14 | 29 | 13 | 29 | 20 | 39 |

GM = gluteus maximus; BF = biceps femoris; VL = vastus lateralis; * Significantly ($p \leq 0.05$) different from Blocks/B. # Significantly ($p \leq 0.05$) different from Blocks/2 or Blocks/6.

### 8.2.3 Associations between performance time in block start (10 m) and EMG variables

EMG variables did not correlate as significantly (Table 21) as force-time variables with block start (10 m). The aEMG value of BF in CMJ and Blocks B, the aEMG value of VL in Sled10/B and the IEMG value of BF in CMJ correlated significantly with block start (10 m).

TABLE 21. Statistically significant correlations between performance time in block start (10 m) and EMG variables.

| Variable | Exercise/ phase of the exercice | R | Significance | N |
|---|---|---|---|---|
| IEMG-GM | - | - | | |
| IEMG-BF | Blocks B | -0.667 | # | 8 |
| | Blocks 6 C | 0.619 | # | 8 |
| | Blocks 6 FC | 0.643 | # | 8 |
| | CMJ | -0.667 | * | 9 |
| IEMG-VL | - | - | | |
| aEMG-GM | Sled20 6 C | 0.643 | # | 8 |
| | Sled20 6 FC | 0.619 | # | 8 |
| | SMAX | 0.643 | # | 8 |
| aEMG-BF | Blocks B | -0.738 | * | 8 |
| | Blocks 6 FC | 0.643 | # | 8 |
| | CMJ | -0.817 | * | 9 |
| | S70 | 0.619 | # | 8 |
| aEMG-VL | Blocks B | -0.617 | # | 9 |
| | Sled10 B | -0.783 | * | 9 |
| | S70 | 0.643 | # | 8 |

IEMG = integrated EMG; aEMG = averaged EMG; GM = gluteus maximus; BF = biceps femoris; VL = vastus lateralis; Blocks = block start; Sled10 = sled-pulling with a load of 10 % of body mass (BM); Sled20 = sled-pulling with a load of 20 % of BM; CMJ = counter-movement jump; S70 = ½-squat with 70 % of ½-squat 1-RM (n = 8); SMAX = ½-squat 1-RM (n = 8); B = “block phase”; 2 = second step; 6 = sixth step; F = flight phase; C = contact phase; * = $p \leq 0.05$; # = $p \leq 0.10$;

## 8.3 Kinematic variables

### 8.3.1 Block start vs. sled-pulling, CMJs and ½-squats

Table 22 shows peak angular velocities (PAV) and average angular velocities (AAV), and Table 23 shows minimum (MIN) and maximum angles (MAX) of hip, knee and ankle during different exercises or phases of exercises. The PAV and AAV of the hip (Figure 19) and knee (Figure 20) were mostly significantly lower during the block phase of Sled10 (Sled10/B) and Sled20 (Sled20/B). On the other hand, corresponding values in CMJ were higher. The PAV and AAV of the knee were also higher in CMJ10 and CMJ20. During S70 all the PAV and AAV values were lower.

Minimum (MIN) and maximum (MAX) angles (Table 23) were mostly similar in the block phase of Blocks (Blocks/B), Sled10/B and Sled20/B, although the MIN-ankle was smaller in Sled10/B and Sled20/B. The MIN-hip was larger in CMJ10, CMJ20 and S70 and, on the other hand, MIN-knee and MIN-ankle were smaller in CMJs and S70. The MIN-hip seemed to be smaller during Sled20/6 [F], but statistical differences were not computed from this phase. The MAX-hip was greater in CMJ10, CMJ20 and S70, and MAX-knee was greater in CMJs and S70.

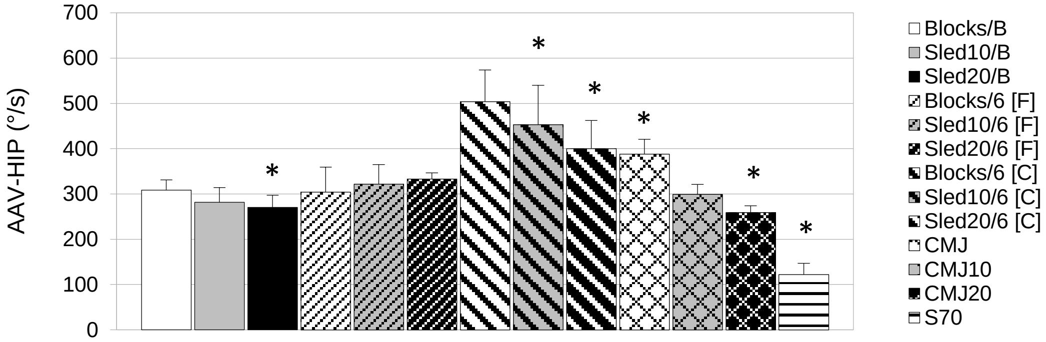

FIGURE 19. Average angular velocity of the hip joint (AAV-HIP) (means and SDs) during the “block phase” (B) and the flight [F] and contact phase [C] of the sixth (6) step in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20) and ½-squat with 70 % of ½-squat 1-RM (S70).

* Significantly ($p \leq 0.05$) different from Blocks/B. (*Note!* Statistical differences were not calculated for Blocks/6 [F], Sled10/6 [F], Sled20/6 [F], Blocks/6 [C]).

TABLE 22. Peak angular velocities (PAV) and average angular velocities (AAV) (means and SDs) of hip, knee and ankle during the “block phase” (B) and the sixth step (6) in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20) and ½-squat with 70 % of ½-squat 1-RM (S70). (*Note!* Statistical differences were not calculated for Blocks/6 [F], Sled10/6 [F], Sled20/6 [F], Blocks/6 [C]).

| Exercise/ phase of exercise | PAV (°/s) | | | AAV (°/s) | | | N |
|---|---|---|---|---|---|---|---|
| | Hip | Knee | Ankle | Hip | Knee | Ankle | |
| Blocks/B | 604 | 724 | 836 | 308 | 206 | 138 | 8 |
| | 87 | 97 | 155 | 23 | 38 | 34 | |
| Sled10/B | 532* | 544* | 930* | 282 | 154* | 148 | 8 |
| | 77 | 78 | 132 | 32 | 44 | 19 | |
| Sled20/B | 477* | 536* | 899 | 270* | 153* | 143 | 8 |
| | 60 | 50 | 138 | 27 | 37 | 20 | |
| Blocks/6 [F] | 467 | 831 | 173 | 304 | 407 | 34 | 7 |
| | 100 | 116 | 61 | 55 | 72 | 56 | |
| Sled10/6 [F] | 493 | 720 | 144 | 322 | 378 | 31 | 7 |
| | 82 | 137 | 52 | 43 | 78 | 45 | |
| Sled20/6 [F] | 526 | 594 | 122 | 333 | 314 | 15 | 6 |
| | 45 | 115 | 51 | 14 | 42 | 35 | |
| Blocks/6 [C] | 834 | 618 | 1213 | 504 | 184 | 224 | 5 |
| | 137 | 188 | 189 | 70 | 48 | 65 | |
| Sled10/6 [C] | 761* | 602 | 1083* | 453* | 221 | 250* | 8 |
| | 142 | 166 | 120 | 87 | 53 | 53 | |
| Sled20/6 [C] | 689 | 556* | 1051* | 400* | 212 | 232* | 8 |
| | 125 | 119 | 150 | 62 | 39 | 32 | |
| CMJ | 758* | 1046* | 931 | 388* | 344* | 224* | 8 |
| | 79 | 79 | 104 | 33 | 49 | 35 | |
| CMJ10 | 642 | 961* | 844 | 299 | 297* | 189* | 8 |
| | 57 | 82 | 68 | 22 | 30 | 22 | |
| CMJ20 | 587 | 907* | 847 | 259* | 259* | 165* | 8 |
| | 57 | 74 | 93 | 15 | 26 | 24 | |
| S70 | 435* | 513* | 267* | 122* | 114* | 51* | 7 |
| | 109 | 133 | 104 | 25 | 19 | 19 | |

F = flight phase; C = contact phase; * Significantly different from Blocks/B

TABLE 23. Minimum (MIN) and maximum (MAX) angles of hip, knee and ankle (means and SDs) during the “block phase” (B) and the sixth step (6) in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20) and ½-squat with 70 % of ½-squat 1-RM (S70). (*Note!* Statistical differences were not calculated for Blocks/6 [F], Sled10/6 [F], Sled20/6 [F], Blocks/6 [C]).

| Exercise / phase of exercise | Minimum angle (°) | | | Maximum angle (°) | | | N |
|---|---|---|---|---|---|---|---|
| | Hip | Knee | Ankle | Hip | Knee | Ankle | |
| Blocks/B | 53 | 95 | 73 | 158 | 165 | 126 | 8 |
| | 8 | 11 | 6 | 5 | 4 | 8 | |
| Sled10/B | 53 | 94 | 63* | 162 | 160* | 123 | 8 |
| | 6 | 7 | 6 | 9 | 5 | 10 | |
| Sled20/B | 53 | 93 | 63* | 161 | 162 | 124 | 8 |
| | 6 | 7 | 6 | 10 | 6 | 10 | |
| Blocks/6 [F] | 80 | 92 | 83 | 111 | 131 | 91 | 7 |
| | 9 | 10 | 4 | 7 | 6 | 6 | |
| Sled10/6 [F] | 78 | 91 | 80 | 108 | 125 | 86 | 7 |
| | 10 | 10 | 4 | 7 | 6 | 4 | |
| Sled20/6 [F] | 72 | 92 | 79 | 102 | 120 | 84 | 6 |
| | 10 | 9 | 5 | 11 | 7 | 5 | |
| Blocks/6 [C] | 110 | 126 | 66 | 176 | 156 | 120 | 5 |
| | 6 | 3 | 7 | 9 | 9 | 7 | |
| Sled10/6 [C] | 114* | 124* | 66* | 176* | 157* | 118* | 8 |
| | 10 | 3 | 6 | 8 | 7 | 10 | |
| Sled20/6 [C] | 106* | 121* | 64* | 172* | 158* | 119* | 8 |
| | 12 | 6 | 6 | 9 | 8 | 8 | |
| CMJ | 54 | 79* | 60* | 159 | 173* | 124 | 8 |
| | 8 | 12 | 6 | 5 | 6 | 10 | |
| CMJ10 | 73* | 77* | 60* | 171* | 174* | 125 | 8 |
| | 10 | 12 | 6 | 10 | 4 | 9 | |
| CMJ20 | 80* | 80* | 63* | 178* | 177* | 126 | 8 |
| | 7 | 11 | 6 | 5 | 5 | 8 | |
| S70 | 94* | 89* | 68* | 180* | 173* | 107* | 7 |
| | 11 | 9 | 6 | 6 | 6 | 12 | |

F = flight phase; C = contact phase; * Significantly different from Blocks/B

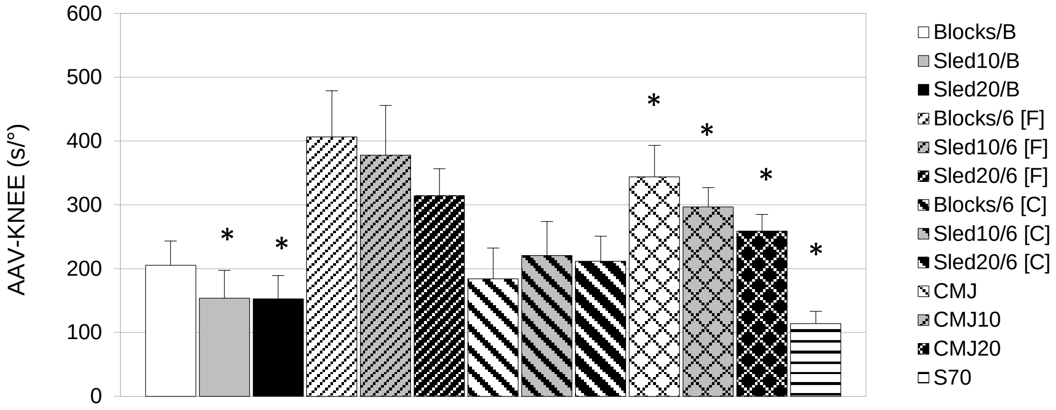

FIGURE 20. Average angular velocity of the knee joint (AAV-KNEE) (means and SDs) during the “block phase” (B) and the flight [F] and contact phase [C] of the sixth (6) step in block start (Blocks), sled-pulling with a load of 10 % and 20 % of body mass (Sled10 and Sled20), and during the concentric phase in countermovement jump (CMJ), CMJ with a load of 10 % and 20 % of ½-squat 1-RM (CMJ10 and CMJ20) and ½-squat with 70 % of ½-squat 1-RM (S70). * Significantly ($p \leq 0.05$) different from Blocks/B. (*Note!* Statistical differences were not calculated for Blocks/6 [F], Sled10/6 [F], Sled20/6 [F], Blocks/6 [C]).

### 8.3.2 Associations between performance time in block start (10 m) and kinematic variables

From kinematic variables, for example, AAV-hip during Blocks/6 and CMJ, PAV-hip during CMJ10 and CMJ20, AAV-knee during CMJ and PAV-knee during CMJs correlated significantly with block start (10 m) (Table 24).

TABLE 24. Statistically significant correlations between performance time in block start (10m) and kinematic variables.

| Variable | Exercise/ phase of the exercise | R | Significance | N |
|---|---|---|---|---|
| PAV-HIP | Sled20 6 [C] | -0.583 | # | 9 |
| | CMJ10 | -0.800 | * | 9 |
| | CMJ20 | -0.883 | * | 9 |
| PAV-KNEE | CMJ | -0.767 | * | 9 |
| | CMJ10 | -0.750 | * | 9 |
| | CMJ20 | -0.817 | * | 9 |
| PAV-ANKLE | Blocks/B | -0.786 | * | 8 |
| | Sled10/B | -0.619 | # | 8 |
| | CMJ10 | -0.600 | # | 9 |
| AAV-HIP | Blocks/6 [F] | -0.821 | * | 7 |
| | Blocks/6 [C] | -0.900 | * | 5 |
| | Sled10/6 [F] | -0.679 | # | 7 |
| | Sled10/6 [C] | -0.600 | # | 9 |
| | Sled20/6 [C] | -0.717 | * | 9 |
| | CMJ | -0.733 | * | 9 |
| | S70 | 0.619 | # | 8 |
| AAV-KNEE | CMJ | -0.733 | * | 9 |
| AAV-ANKLE | - | - | | |
| MAX-HIP | Blocks/6 [F] | 0.714 | # | 7 |
| | Sled10/B | 0.619 | # | 8 |
| | Sled10/6 [F] | 0.786 | * | 7 |
| | Sled20/6 [F] | 0.886 | * | 6 |
| MAX-KNEE | - | - | | |
| MAX-ANKLE | CMJ10 | 0.583 | # | 9 |
| | CMJ20 | 0.617 | # | 9 |
| MIN-HIP | Blocks/6 [F] | 0.714 | # | 7 |
| | Sled10/6 [F] | 0.679 | # | 7 |
| | Sled10/6 [C] | 0.800 | * | 9 |
| | Sled20/6 [C] | 0.683 | * | 9 |
| MIN-KNEE | Blocks/6 [F] | -0.679 | # | 7 |
| | CMJ | 0.650 | # | 9 |
| MIN-ANKLE | CMJ | 0.667 | * | 9 |
| | CMJ10 | 0.783 | * | 9 |
| | CMJ20 | 0.867 | * | 9 |
| | S70 | 0.667 | # | 8 |

PAV = peak angular velocity; AAV = average angular velocity; MAX = maximum angle; MIN = mimimum angle; Blocks = block start; Sled10 = sled-pulling with a load of 10 % of body mass (BM); Sled20 = sled-pulling with a load of 20 % of body mass (BM); CMJ = countermovement jump; CMJ10 = CMJ with a load of 10 % of ½-squat 1-RM; CMJ20 = CMJ with a load of 20 % of ½-squat 1-RM; S70 = ½-squat with 70 % of ½-squat 1-RM; B = “block phase”; 6 = sixth step; F = flight phase; C = contact phase; * = $p \leq 0.05$; # = $p \leq 0.10$

# 9 DISCUSSION

The primary findings of the present study were that the activity of the gluteus maximus (GM) was higher and the activity of the biceps femoris (BF) was lower in nearly all studied exercises when compared them to the block phase of the block start. Another main finding was that the performance time in the block start (10 m) correlated strongly with the CMJs. In addition, the force production (peak and average force) in the CMJs and ½-squats was higher, and in the CMJs also the angular velocity of the knee was higher. On the other hand, the angular velocities during the S70 were significantly lower.

## 9.1 Sled-pulling vs. Block start

As expected the performance time of 10 m run and force pro-duction time (FPT) during the “block phase” were longer in Sled10 and Sled20. Because of the longer FPTs, also the impulses (IMP) were larger. In turn, the horizontal average force (HAF) during the block phase and step frequency over the running distance on the force plates (~8.7 m) were smaller in Sled10 and Sled20. It was surprising that the HAF was smaller in sled-pulling, but on the other hand, it probably can be explained with the absence of the starting blocks in sled-pulling.

The HAFs were larger in both sled-pullings during the 6th contact, although the difference was not significant in Sled10. However, the resultant peak forces (RPF) and resultant average forces (RAF) were smaller during the 6th contact in both sled-pullings and reason for this was the smaller vertical peak and average forces (VPF and VAF) during the 6th contact. Because of this more pronounced horizontal force production, also the angle of force production (angle of FP) was smaller (more horizontal) during the 6th step and also during the 2nd step in Sled20. The results of the present study (longer performance time, FPT, and smaller step frequency and angle of FP) support the findings of the earlier studies (Maulder et al. 2008 and Lockie et al. 2003). It can be suggested that sled-pulling is a good exercise (especially during later steps of 10 m start), if the aim is to develop horizontal force production and that heavier sled-pulling (Sled20 in the present study) might be more efficient in this aspect.

During the block phase the activation of the gluteus maximus (GM) was substantially higher in the sled-pulling. The integrated EMG (IEMG) was about 80 % and averaged EMG (aEMG) about 40 % higher in the sled-pulling. The difference in the activation of the biceps femoris (BF) and the vastus lateralis (VL) was not so obvious, although IEMG of VL was significantly higher in Sled10 and aEMG of BF was significantly lower in Sled20. Although some of the difference in the volume of the activation (IEMG) of GM can be explained with the longer FPT, also the intensity of activation (aEMG) played a big role. After all, it seems that GM is substantially more activated and BF somewhat less activated in the sled-pulling than in the block start. The higher aEMG value could be a result of an increased recruitment, firing rate and/or synchronization of motor units (Komi 1986) in GM. Moreover, it seems that EMG activation increases with strength training and the increase might be more pronounced at the beginning phases of training (4–8 weeks) (e.g. Häkkinen & Komi 1983, Häkkinen et al. 2000, Reeves et al. 2005). Thus, this increased activation of GM during the sled-pulling could in long term training lead to increased activation during the block start. It can be speculated that increased activation of GM would lead to more efficient force production of GM, which could be beneficial since GM is thought to be important muscle in sprint running (e.g. Hunter et al. 2004).

During the 2nd and 6th step, the activation of GM was not anymore so high when compared to the block start (the only significant difference was in IEMG of GM during the 2nd step of the Sled20). The most obvious difference was in the BF activation and, especially during the Sled20, aEMG of BF was significantly lower.

As expected, nearly all angular velocities were smaller during the block phase of the sled-pulling. However, the movement pattern was quite specific to the block start, because MIN and MAX angles were mostly nearly identical. Although statistical differences were not computed from the 6th step between Blocks and sled-pulling, it seems that the PAV-hip and AAV-hip during the flight phase and AAV-knee during the contact phase were slightly higher in the sled-pulling. Almost all other angular velocities were somewhat lower in the sled-pulling when compared to the block start and most of the angular velocities were slightly lower in Sled20 when compared to Sled10. The most notable difference in the range of motion during the 6th step was that the hip of the swinging leg was 10 % more flexed (smaller MIN-hip) during the flight phase in Sled20. Also Lockie et al. (2003) noticed more pronounced hip flexion during the sled-pulling and it was more obvious during a heavier sled-pulling. It can be suggested that Sled10 and Sled20 are quite velocity and movement specific when compared to Blocks and that hip flexion is more pronounced in Sled20. Moreover, Mann et al. (1986) suggested that flexion of the hip is the prime mover, when the aim is to increase the speed of gait. Therefore, more pronounced hip flexion seen in sled-pulling might be a very essential feature in this exercise.

## 9.2 CMJs vs. Block start

RPF and RAF were larger in CMJs and both increased as the load increased in CMJs. These results suggest that CMJs overload the force component of the block start. It can be speculated that a long term usage of the CMJs in training of sprint start could induce positive changes on the force-velocity curve and consequently improve the performance.

In the all CMJs, the clearest difference in the EMG activity to Blocks was in the activity of BF. Both the IEMG and aEMG values were substantially lower (42–65 %) in CMJs. On the other hand, in CMJ10 and CMJ20, the aEMG values of GM were significantly higher. This data suggests that the activation of BF is low and the activation of GM is high in CMJs as compared to the block phase of the block start. CMJs seem to activate GM in a similar way as sled-pulling does and thus they could have similar positive influence on sprint start if used in training of sprinters.

Especially the angular velocities of the knee were higher in CMJs and mean values of the angular velocities of the hip, knee and ankle in CMJs were highest in CMJ and lowest in CMJ20. In CMJ without a load, also the angular velocity of the hip was higher than during the block phase of the block start. One reason for higher angular velocities seen in CMJs (especially in CMJ without a load) could simply be that the force produced toward the ground was produced by both legs, while during the block phase of the block start, approximately the second half of the force production time is used when the force is produced only through the front leg. These results indicate that CMJs are supra-velocity exercises for the knee joint when compared to the block phase of the block start and CMJ also for the hip joint. On the other hand, according to the PAV-hip and PAV-ankle during CMJ10 and CMJ20, it can be suggested that these exercises were velocity specific with regard to the block phase of the block start. It can be speculated that the usage of CMJs in training of sprint start could induce positive changes on the force-velocity curve and thus improve the performance. Moreover, the differences in MIN and MAX angles were rather small in CMJ, so it can be suggested that CMJ is also quite movement specific exercise.

## 9.3 Half squats vs. Block start

FPT, RPF and RAF were substantially larger in the ½-squats (S70 and SMAX) and the values were larger in the SMAX than in the S70. The values of the ½-squats were also larger than the values of CMJs. It seems that S70 and SMAX significantly overload the force component of the block phase of the block start and, thus, if used in training, could enhance the force component of the force-velocity curve. However, because the angular velocities of the lower limb joints seems to be substantially lower in the squats, it can be speculated that the enhancements on the force-velocity curve occurs especially in lower angular velocities and changes in force production in higher angular velocities might be less pronounced (Naciri et al. 1989; Ewing Jr. et al. 1990). Moreover, if RPF is divided to each leg, RPF/leg in the SMAX was 1580 N. When this value is compared to RPF of the front leg during the block phase (1378 N) the difference is not very large anymore. Furthermore, when RPF/leg (1580 N) and RAF/leg (1330 N) of SMAX are compared to RPF (2139 N) and RAF (1467 N) values of the 6th step of the Blocks, it is obvious that the GRF values/leg were larger during the 6th step. One clear difference between the force production in the ½-squats and 6th contact was, for example, that MIN-knee was much smaller in the ½-squats (~90°) than during the 6th contact (126°). If the squats would have been done with larger knee angles, GRFs in the squats probably had been higher. However, this could compromise, at least a little, the EMG activity of GM which has shown to be higher in deeper squats with submaximal loads (Caterisano et al. 2002).

The IEMG values of GM and VL were remarkably higher in the squats. A lot of the difference can be explained by longer FPTs in the squats, but in the case of SMAX, also the aEMG value of GM was significantly higher. In turn, the aEMG value of BF was remarkably smaller in both S70 and SMAX. Thus, it seems that the intensity of the activation of GM was notably higher (especially in SMAX) and the intensity of the activation of BF was notably lower in the squats. It was a bit surprising that the aEMG value of GM was not higher in S70 than in CMJ10 and CMJ20, despite the higher force produced in S70. The similarity in the aEMG value of GM between these exercises could possibly be explained by higher angular velocities (Moritani et al. 2004, 7) of the hip joint and/or smaller knee (Caterisano et al. 2002) and hip angles during CMJ10 and CMJ20. However, like in the sled-pulling and CMJs, also in the squats the activation of GM was higher than in Blocks and, thus, it can be speculated that also the use of the squat exercise in training would have positive influence in long term on GM activation during the sprint start. In addition, it seems that the intensity of the activation (aEMG) was higher in SMAX than in the other exercises and, thus, SMAX could be the most efficient of these exercises to induce positive intramuscular neural adaptations (increased motor unit recruitment, firing rate and/or synchronization) in long term training. However, according to earlier studies (Cormie et al. 2010; Andersen et al. 2005; McBride et al. 2002), transfer of these EMG adaptations to faster contraction velocities seems to be less pronounced or nonexistent.

The angular velocities were 28–68 % lower in the S70 than in the block phase of the block start, and although movement analysis was not done for the SMAX, it is likely that angular velocities were even lower in the SMAX. These results indicate that the ½-squat with rather a heavy load is not very velocity specific exercise in sprint start training.

## 9.4 Associations between performance time in block start (10 m) and studied exercises

*Force-time variables*. Most of the significant correlations existed between CMJs and performance time in the block start (10 m). The takeoff velocity in CMJ correlated most strongly (r=-0.95). Also, for example, the RPF (S70 and SMAX), RAF (CMJs) and load/body mass (SMAX) correlated significantly.

These findings indicate that high force production during CMJs and squats is important in achieving a good sprint start. In CMJs this high force production was observed in high takeoff velocity and thus in high jump height. The takeoff velocity can be calculated from concentric net impulse by dividing the impulse with body mass (BM) and thus the relative force production (force/BM) is important. In earlier studies (Cronin & Hansen 2005; Smirniotou et al. 2008; Jonsson Holm et al. 2008) correlations between sprint start and speed-strength exercises (different kind of vertical and horizontal jumps) have been between -0.55 and -0.66, and thus lower than in the present study. However, in the study of Young et al. (1995) peak force in relation to bodyweight (PF/BW) and PF/BW in 100ms during a concentric jump squat with 19 kg (knee angle 120°) correlated quite strongly with sprint start (r=-0.86 and r=-0.73, respectively). In the same study, also maximum force during the isometric squat (knee 120°) correlated quite strongly with sprint start (r=-0.72, p=0.07). This correlation was very similar to that shown in the present study with RPF of SMAX (r=-0.74).

*EMG variables.* There were clearly less statistically significant ($p \leq 0.05$) correlations between the performance time in Blocks (10m) and EMG variables. The aEMG value of BF during CMJ correlated most strongly of the EMG variables. Also the aEMG value of BF during Blocks/B, the aEMG value of VL during Sled10/B and the IEMG value of BF during CMJ correlated quite strongly. It is difficult to make any final conclusions according to these correlations, but it can be speculated that high activation of BF during the block phase might be beneficial.

*Kinematic variables*. Most of the strong correlations in the kinematic variables were related to CMJs, and thus it can be speculated that many of these variables (PAV-hip, PAV-knee, AAV-hip, AAV-knee and MIN-ankle) were related to a good performance in CMJs (high velocity at takeoff → high jump height). These results confirm the observation from the force-time correlations, where good performances (high jump height) in CMJs, especially in CMJ and CMJ10, were related to a good performance in the block start (10 m). In addition, some of the strong correlations were related to Blocks. For example, high AAV-hip during the 6th step (flight and contact phase) in Blocks seems to be important for a good sprint start.

## 9.5 Limitations and strengths of the present study

From the measurement techniques used in the present study, the surface EMG is probably the most problematic. Special problems in the measurements of surface EMG during dynamic muscle contraction include, for example, moving of muscle in relation to electrode (Felici 2004, 367) and changes in the magnitude of the signal with different muscle length (decline with the increasing length) (Kamen 2004, 171). However, because ranges of motions were quite similar between exercises (especially block phase vs. other exercises) it is possible that these things did not influence much on the results. Because of technical problems with the EMG system and mistakes in the adjusting of the cameras, the EMG activity of the gastrocnemius and kinematic variables from some phases of running could not been analyzed properly. It is also possible that the results of the present study cannot be generalized to other level male or female sprinters, and thus it is possible that similar study, for example, with elite-sprinters could give different results.

The strength of the present study was that sprint start and different speed-strength / strength exercises were compared widely (force-time, EMG and kinematic variables). In earlier studies the comparison has not been so wide and, moreover, there has been a lack of studies comparing sprinting and squat type movements.

# 10 CONCLUSIONS

The exercises of the present study offer some kind of overload when compared to the block start and, on the other hand, for some variables they offer less loading. It can be suggested that when the aim is to activate GM intensively and to produce high forces, SMAX could be the best choice of the exercises analyzed in the present study. However, it is important to notice that force production through one leg to the ground seems to be higher during the 6th step than during the SMAX or all other exercises. If the aim is to overload the speed-component of the block start, CMJs seem to be the best choices. Especially CMJ without a load could be a good exercise because, in addition to the angular velocity of the knee, also the angular velocity of the hip seems to be substantially higher in CMJ than during the block phase of the block start. Also the correlation data indicates the importance of CMJs in a good block start (10 m). Therefore, training which improves the performance in CMJs could improve the performance in the block start (10 m). The ranges of motions of the lower limb joints were quite similar in the sled-pulling (Sled10 and Sled20) and CMJ when compared to the block start. Thus, these exercises seem to be movement specific when compared to the block phase and the sled-pulling also to the later phase of the block start (10 m). In the future, similar comparing studies could be done between strength / speed-strength exercises and acceleration / maximum velocity phase of sprint running. Information from these exercises could probably be utilized in sprint training.

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