

**Sprint characteristics and proportion of the horizontal performance of the  
lower extremities of a one man push start in bobsledding through field  
testing**

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## Abstract

Bobsleigh requires a fast force and speed to be able to reach a satisfying performance. This occurs mainly at the push-start of the track together with the entire bobsled team. Authors clarified that the push-start defines 1/3 of the ending time of the run. However, there is not much literature of how the condition level of the lower limbs should be for a bobsled runner when pushing the sled. The purpose of this study was to clarify and compare suitable sprint characteristics in male and female bobsled athletes and to ascertain how high the proportion of the horizontal power in resisted sprinting with light (3 kg) and heavy (21 kg) weight could be in a one-man bobsled push. Fourteen Swiss National bobsled athletes ( $n = 9$  men; age =  $24.1 \pm 2.6$  years; mass =  $99.7 \pm 7.8$  kg; height =  $184.4 \pm 4.6$  cm; and  $n = 5$  women; age =  $24.5 \pm 4.5$  years; mass =  $74.9 \pm 2.9$  kg; height =  $174.0 \pm 3.7$  cm) participated in this study. Athletes ran four trials on a 30 m track with a tensile rope attached around their hips and towed four different external loads (3, 9, 15 and 21 kg). The step patterns were measured in three different sprint distances (0-10, 10-20 and 20-30 m). Whereas, in the horizontal performance test the athletes' power was measured and correlated with a one-man roll bob push test (heavy sled; 45 kg women, 50 kg men) performed on a 30 m track (plus 10 m fly-zone). The sprinting kinematics and maximum forces, correlations, significances, explained variances and the test for differences were statistically calculated with the statistical program SPSS depending on the question. Results showed that when external loads are added to a sprint, the step patterns are affected, in particularly when their weight increases. Stride length, stride frequency and velocity decrease while ground contact time increases and the percentage average difference get's larger compared to the unloaded sprint as the external loads get greater. However, they reverse as the athlete increases the own velocity. The horizontal performance with heavy load (21 kg) has a significantly relationship of 88 % with the one-man roll bob push (heavy sled), whereas the lighter weight (3 kg) not. Females reached their peak performance with 12 % of external load according to their body mass, whereas by males was set at 21 %. The difference between female and male athletes already begins in the constitution in their muscles. Women can produce less force than men and consequently get tired more easily and have a greater counterweight to the load due to their lighter body mass. Towing a resistant external weight could be a very practical training for bobsled athletes, in which they can improve their acceleration and fast velocity so that they can start efficiently at their push-start.

## **1 Introduction**

Bobsleigh is a winter sport invented by the Swiss at the end of the 1860s. This sport requires making runs as fast as possible down a narrow ice track with a gravity-powered sled. The race consists of the push-off phase and in the sled phase. However, the actual bobsleigh sport discipline began at the end of the 19<sup>th</sup> century, when the Swiss had the idea to build a steering wheel onto a sled, specifically to a toboggan. In 1897 the first clubs were located in St Moritz, Switzerland, and in the following seventeen years competitions were becoming more popular in Europe (Federation IBSF, 2017a). Nowadays, there are sixteen bobsleighbing and skeleton ice tracks with many teams spread around the world. Through the years, this sport has become more popular and 4-man race teams were introduced at the Winter Olympic Games in 1924 in Chamonix, France and 2-man race teams in 1932 at the Lake Placid Games, USA. Only as late as 2002 at the Olympic Games in Salt Lake City, USA was the first time, a woman's bobsleighbing competition took place with 2-woman teams (Federation IBSF, 2017a). Bobsleigh is one of the fastest winter sports, with medals decided based on differences of as little as one-thousand of a second.

The rulebook is regulated and controlled by the International Bobsleigh and Skeleton Federation (IBSF), originally *Fédération internationale de bobsleigh et de tobogganing* (FIBT), which was founded in 1923 (Federation IBSF, 2017a). Referring to the IBSF rules, the bobsleighbing competitions usually begin in November and run until March (Federation IBSF, 2018a). The entire competition ice track length of the new artificial tracks ranges from 1200 m to 1650 m of which the push-start track is 65 m long, but the competition clock starts when the nose of the bobsled crosses the 15 m start line. In these 15 m, each track must have a 2 % downhill slope followed by 50 m of a fly-in zone with a maximum 12 % downhill slope (Federation IBSF, 2018b). The 2 % downhill slope serves to stipulate the acceleration to the bobsled and to the athletes during the first running phase.

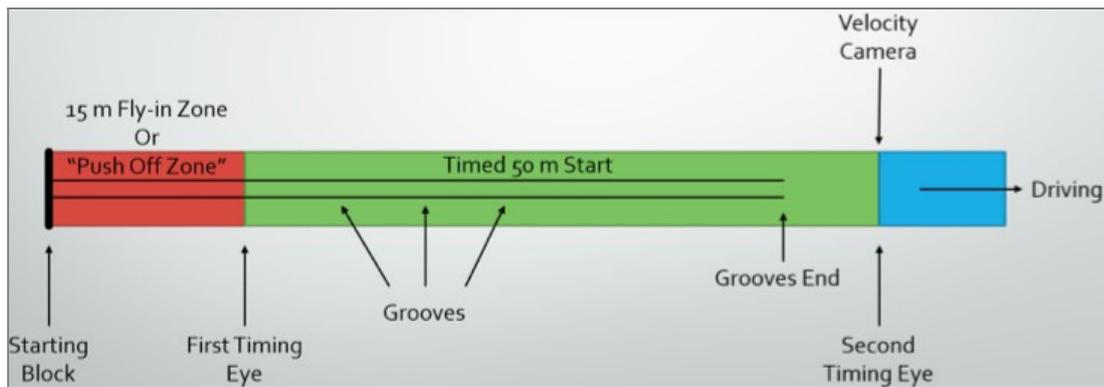


Figure 1. Start track representation, retrieved from(Harrison, 2017).

A major influence of a bobsled team competition result is the interaction between the start performance, driving skills and the equipment quality and preparation. The bobsled requires a team of two or four athletes (Federation IBSF, 2017b). It is divided into two functions: the push athletes and the pilot, (who also has a role in the pushing performance). The push-start phase is of major significance and responsibility of the bobsled team, because this phase is the main task for three out of four of the athletes in the 4-man race. Consequently, the speed and strength abilities of the athletes give rise to a bobsled team selection. This is one of the key factors that contribute to the finishing time of each bobsledding team. In fact, the bobsledding team's goal is to push their bobsled with maximum effort to create a momentum from the starting block (wooden board) of the track and slide to the bottom as fast as possible. The bob start is divided into four phases: the introductory phase, the pushing/reversing phase, the acceleration/thrust phase and the achievement of maximum speed. Physics is needed to maximize the philosophy of this sport. A bobsled athlete must always bring his or her maximum power in the starting phase. In this fast sport, the start phase is determined by performance. It consists of speed, explosiveness, strength and power. The explosive power of the lower extremities has a high value in the management structure. At the beginning of a race, the athletes need to push off and build momentum through the use of acceleration high force, long contacts and high frequency. Specifically, a high stride frequency is significantly more important than the power per stride when athletes are on the sled, this is because if the athletes would decrease the frequency, than they would slow down the sled. Moreover, the acceleration of the team should be at its highest at the end of the starting track. The athletes have to produce enough fast power to be able to reach the required amount of speed and acceleration. Unless there is no action by another force onto the sled, it will not accelerate or increase its velocity, therefore will influence the final velocity. In fact to allow a consistent

acceleration, a massive accelerative force production until a point where the gradient no longer changes, followed by the quick removal of external forces would aid an optimal strategy for the bobsled team. Also the mass of the object is highly significant to its acceleration and velocity (Woolley, 2019). The coordination between the team at the start, the biomechanical factors of each individual athlete and the construction of the bobsled influence the performance as well. According to the results of the study of Szepessy Steinmann (2016), the athlete with a greater body mass (BM) could have a positive effect on the first 15 m of the track, whereas athletes with a lower BM could have an advantage at 65 m. The last athlete that will jump into the sled is the one that can produce fast power the longest. Also the sprinting performance follows a specific strength-speed spectrum (see figure 2). Women tend to use maximal strength longer than the men, which delays their other strength-speed spectrums and consequently have less time (or in case of the pilot, not at all) compared to the 2-man and 4-man bobsled teams to produce (over) speed power. This means that pilots can produce until maximal power and the brakeman is “responsible” for the (over) speed power of the team. It’s very important that the athletes know when they have reached their maximum velocity and power pressure to know exactly when they should jump into the bobsled, because if the bobsled goes faster than the athletes, they will consequently slow down the sled. The strength-speed spectrum is influenced by the gradient steepness.

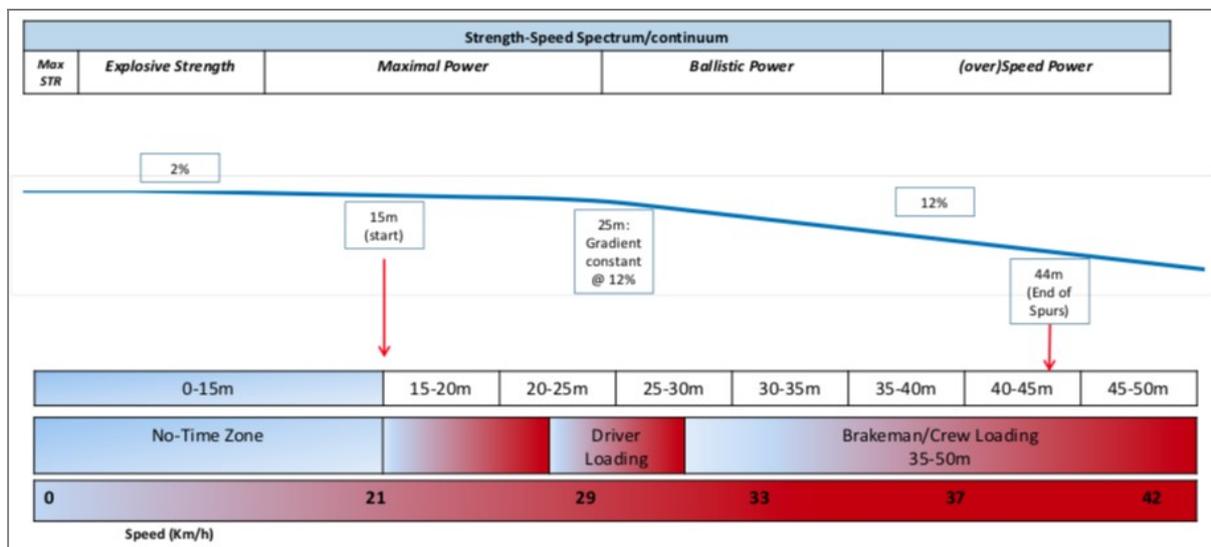


Figure 2. Pushing phase (Woolley, 2019).

According to Woolley (2019) to enhance the pushing phase, the rate of force development of each athlete should be considered so that athletes and coaches can monitor and eventually

improve their ballistic training and explosiveness, respectively. Other variables, such as amount and vector of force, and frequency application can manipulate the pushing performance as well. He also claims that the influence of net force production must be considered when recruiting and training athletes in order to achieve a successful performance. The symbiosis of power and speed in combination with a high body weight would be optimal for this sport. The realization of a good run time might be that the team should come as near as possible to the maximum weight together with the bobsled, so that the bobsled will accelerate easier down the track. If the athletes' body weight can be as close as possible to the accorded maximum weight, they would have a percentage weight advantage on the push-start of the bob. The IBSF rulebook (Federation IBSF, 2018a) allows that the bobsled of the 2-woman team, without crew, a minimum weight of 170 kg same as for the 2-man team without crew, whereas the bobsled for the 4-man team without crew has a minimum weight of 210 kg. The maximum weight, with crew, of a 2-woman team is 330 kg and for men 390 kg; whereas for the 4-bobteam is 630 kg. This would mean that in the 2-woman team, the maximum that one athlete could weigh is 80 kg, and the pusher has to push 85 kg of the sled, which is 106 % of her own body weight. For the 2-man team, each athlete can weigh a maximum of 110 kg (for 4-man team 105 kg), where the pusher has to push 85 kg (4-man team 52.5 kg), of which 77 % (4-man team 50 %) of its body weight. One likely effect of these rules is to allow the bobsled to reach a speed of 150 km/h on the ice track. It's important to consider that the mass of the object is highly significant to its acceleration and velocity.

## World Leading Standards

International Competition data: [Track record data](#)

| Location/Track  | womens      | 2man        | Diff.       | %           |
|-----------------|-------------|-------------|-------------|-------------|
| Altenberg       | 5.54        | 5.11        | 0.43        | 8.41        |
| Calgary         | 5.45        | 5.01        | 0.44        | 8.78        |
| Igls            | 5.38        | 4.96        | 0.42        | 8.47        |
| Königssee       | 5.11        | 4.77        | 0.34        | 7.13        |
| La Plagne       | 6.36        | 5.73        | 0.63        | 10.99       |
| Lake Placid     | 5.34        | 5.00        | 0.34        | 6.80        |
| Park City       | 5.10        | 4.77        | 0.33        | 6.92        |
| PyeongChang     | 5.21        | 4.85        | 0.36        | 7.42        |
| Sochi           | 5.12        | 4.77        | 0.35        | 7.34        |
| Whistler        | 5.06        | 4.70        | 0.36        | 7.66        |
| Winterberg      | 5.43        | 5.05        | 0.38        | 7.52        |
| <b>Averages</b> | <b>5.37</b> | <b>4.97</b> | <b>0.40</b> | <b>7.95</b> |

| Location/Track  | 2man        | 4man        | Diff.       | %           |
|-----------------|-------------|-------------|-------------|-------------|
| Altenberg       | 5.11        | 5.04        | 0.07        | 1.39        |
| Calgary         | 5.01        | 4.95        | 0.06        | 1.21        |
| Igls            | 4.96        | 4.93        | 0.03        | 0.61        |
| Königssee       | 4.77        | 4.73        | 0.04        | 0.85        |
| La Plagne       | 5.73        | 5.73        | 0.00        | 0.00        |
| Lake Placid     | 5.00        | 4.90        | 0.10        | 2.04        |
| Park City       | 4.77        | 4.72        | 0.05        | 1.06        |
| PyeongChang     | 4.85        | 4.80        | 0.05        | 1.04        |
| Sochi           | 4.77        | 4.72        | 0.05        | 1.06        |
| Whistler        | 4.70        | 4.70        | 0.00        | 0.00        |
| Winterberg      | 5.05        | 4.98        | 0.07        | 1.41        |
| <b>Averages</b> | <b>4.97</b> | <b>4.93</b> | <b>0.05</b> | <b>0.97</b> |

\*St Moritz data omitted as it varies by season

Figure 3. World leading standards of track record data (Woolley, 2019).

According to Hübner (2009), 1/3 of the push-start and 2/3 of the driving skills define the performance of a competition or heat. This explains the importance as to why the athletes have to push as fast and as powerful as possible on the starting track in the push-start phase to still be able to win the competition. Moreover, approximately 1/10 of a second lead at the start equals about 3/10 of a second advantage at the finish line (Federation IBSF, 2017b). In this sport every thousandth of a second counts (the four runs are timed to 0.01 seconds, and the fastest total time determines the winner). A slow start could damage the ranking of the team. In season 2013, Lüthy (2013) analyzed that who desires to win, can last 0.05 seconds (2-man) or 0.06 seconds (4-man) on the fastest pusher in the field (Szepessy Steinmann, 2016). For example, the Federation confirmed that during the 2014-2015 World Cup in Lake Placid, the 4-man bobsled race winner was 0.04 seconds faster than the third place team and the percentage difference between bronze and gold was just over three-hundredths of one percent (Harrison, 2017). Bobsled races are comprised of two heats (in the World Championships and in the Olympic Games there are 4 heats, 2 heats each are held on separate weekends) (Federation IBSF, 2017b), therefore the importance of winning thousandths of seconds in the start phase is central, due to the fact that one-thousandth of a second in the start phase can be multiplied by 2.5 to understand the final performance time (Harrison, 2017). The competition is managed by time and this means that the end velocity is fairly relevant to the bobsled teams. Indeed, the split time (the first 30 m) is fundamental for the outcome performance, because the 5-15 m time is directly proportional to the 30 m time and the following is also directly proportional to the 50 m time. The difference of time in the first 30 m between bobsled teams competitors is relevant for the final race time, because the time will accumulate during the run.

While frequency speed, strength and power are major elements for the sport of bobsledding, especially at the start, also reaction speed plays indeed an important role. Indeed, at the start it is important to listen to the pilot's voice (start command), a simple reaction ability, and to bring the common strength into the deportation process. This cyclic movement must be performed against a high resistance to affect a continuous longer lasting (good acceleration capability) process and consequently be well coordinated. All these forms of speed are dependent on the central nervous system and genetic factors, for example on both psychological-cognitive and physical performance. It is based on very many different anatomical-physiological prerequisites, which the athlete brings along and is of course

trainable. Along with velocity capacity, strength also plays a major role in this fast power discipline. In fact the bobsled athlete still needs a good maximum speed within the start track. In order to have an authentic starting time, the most important skill for a bob athlete is to have an elevated fast power, which will allow a faster push start and a higher running velocity. Thereby, sprint velocity is the product of step length (SL), step frequency (SF) and ground contact time (GCT). In fact, the fastest runners tend to have a short GCT (less than 100 milliseconds) (Brüggeman & Susanka, 1987; Mero, Komi, & Gregor, 1992). This has to do with the running economy, because there is less time for the braking force to slow down while moving forward with the body proved that sprint running speed depends on SF and the SL, while the values of SF and SL depend on the characteristics of athlete's support and flight movements. It is known that the beginning of a resisted sprint is characterized by long GCT and short SL, however, as the athlete accelerates, these running elements reverse themselves, meaning that the GCT decreases and the SL becomes longer. By adding external weight, this step pattern reaction get's stronger (Lockie, Murphy & Spinks, 2003), which supports Hoffmann (2014) statement, that the more ground reaction force output there is, creates a more powerful horizontal running performance and so the bobsled is easier to push down the starting track.

Bobsleighbing is a sport where engineering "mechanics meets biology" and is characterized by accuracy. Nowadays, resisted sprinting is known as a conditioning technique for improving the sprinting performance, which maximizes the transfer of the training effects. Even though there have been studies with field-athletes where the effect of sled towing (a resisted sprinting form) on sprinting performance was analyzed, until now, there have not been studies of step analysis for traction resistance sprints in bobsleigh athletes, respectively the difference between men and women. Moreover, Lockie et al. (2003) confirm that field-sport athletes with an increased resistance (12 % and 32 % of BM) over 15 m tend to reduce the stride length and the flight time, whereas the GCT becomes lengthier. The study stated that stride length can be reduced from 10 % to 24 % and there is a significant difference of stride frequency between unloaded and resisted sprint, whereas GCT can increase from 10 % to 22 % on the first two contacts with external load. Moreover, Kawamori, Newton and Nosaka (2014) analyzed that GCT and the propulsive phase duration are significantly longer with 30 % of BM in the second ground contact of a 5 m sprint. It is noteworthy that Hoffmann (2014) claimed that athletes with a longer GCT push heavier sleds faster (Harrison, 2017) and by

reducing stride length allows the athlete to maintain its stride frequency (Lockie et al., 2003). That is to say, a sprinting characteristic can assume different dynamics when sprinting with resisted load, for example Lockie et al. (2003) claimed that sled towing may improve stride length and stride frequency during free sprinting, due to the propulsive force generated by the leg muscles when pushing off from the ground and by a higher hip extension power.

In combination with sprint kinematics and velocity, bobsled athletes' need strength and fast power. In order to achieve high acceleration values, a high level of explosive power in the corresponding muscle groups is essential. Mechanical performance as a physical quantity for the assessment of explosive force may be an appropriate parameter. Explosive force is decisive when it comes to mobilizing the force quickly and producing a great effect in a short time. Maximum development of the explosive power of the lower extremities has a great influence on the result of the competition and is therefore the goal of the training in this sport discipline (Hübner, 2009). Cross, Brughelli, Samozino, Brown and Morin (2017) have suggested that training with greater force at low velocity may improve the performance in acceleration-based sports. By increasing resistive loads the velocity will be reduced, however there could be an increase in force production. In fact, maximum force production can be produced at zero velocity. External loading can influence maximizing power produced by the athlete. As displayed in figure 4, such a sled-training method could lead to develop the horizontal power. This could be a good system to analyze and establish the athlete's performance (force-velocity in relationship to power-velocity), respectively. To receive a maximum velocity during the push-start with the bobsled, the athlete can obtain high power and force by accumulating horizontal impulse. Consequently, according to Newton's law of motion, the force will change into velocity and with the velocity will generate a force, because the change in velocity depends on the mass of the object. However, the acceleration will slow down when more external load is applied during the movement.

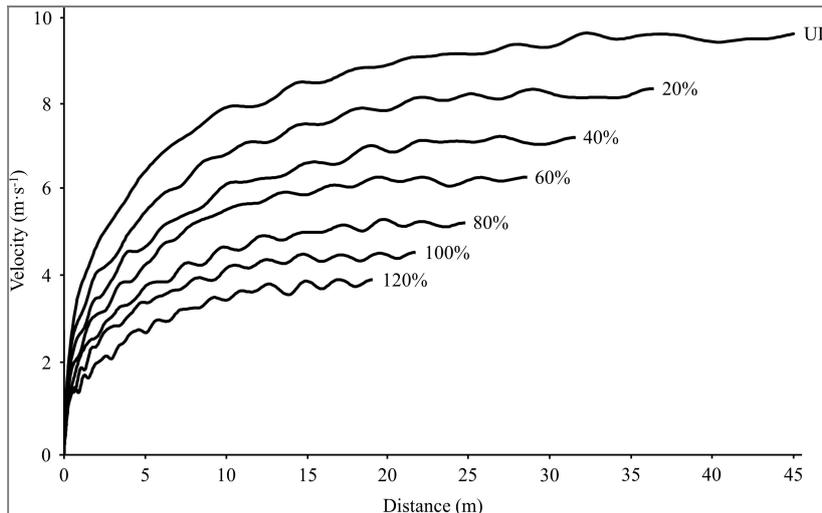


Figure 4. Graphical representation of the clipped raw velocity–distance radar data. Seven sled trials are pictured, clipped before deceleration occurred. From the trial with the highest maximal horizontal velocity ( $v_{hmax}$ ). Unloaded sprint (UL), the loading ranges from 10 % to 120 % of body mass with each trial (Cross et al., 2017).

However, so far, in bobsledding, only the relationship between vertical jumping power (Hübner, 2009) and bobsleigh acceleration time has been shown (Kawamori et al., 2014; Lockie et al., 2003). Authors Mero et al. (1992) have shown that a good vertical force performance is required for the accumulation of speed during the acceleration of an athlete due to their large BM as well (Harrison, 2017). Indeed, Hübner (2009) found high correlation significance between maximum and explosive strength and also between isometric maximum force and all forms of roll bob start. A one-man's push-start can be explained on of 50 % average (avg) by absolute maximal voluntary contraction parameters and on 80 % avg by absolute explosive power with 100 % additional load of BM Szepessy Steinmann (2016). In this case, there is a relationship between the horizontal and the vertical force load during the initial phase of the bobsled push-start. On the other hand, Kawamori et al. (2014) and Lockie et al. (2003) claimed that horizontal resisted sprinting could increase the horizontal performance in the lower limbs during ground contact force. This factor can benefit the relationship between force production and acceleration. In fact, resisted sprinting may be a great training method to improve acceleration. Therefore, by repeating it over time, more horizontal power would be performed and as well a better sprint performance. Kawamori et al. (2014) asserted that with high hip power and with help of propulsive forces applied onto the ground, the athlete could still be successful in pushing the bobsled, although the athlete does not have a high running velocity. Indeed, according to Kawamori et al. (2014), with 30 % of BM added (30 % BM), net horizontal (propulsive impulse minus the absolute value of

braking impulse) and propulsive impulse can increase significantly due to a force application and a long duration applied onto the ground. Park, Lee, Kim, Yoo and Kim (2015) added that athletes during the first steps of the push start with the support of the handlebars of the sled can attain a certain power and velocity thanks to an optimal foot placement (directly under or just behind their own center of mass) and restricted range of motion at the hip and knee joints (Harrison, 2017), which may allow a more aggressive ground reaction force. This could explain the reason why a horizontal resisted sprint performance could have a significant influence on pushing a bobsled. However, it has been argued that training with heavy resistant weights could cause modification on sprint mechanics, weakening the sprint performance. On the other hand, Kawamori, Nosaka and Newton (2013) experimented in an 8-week training with heavy versus light sled towing, with a result of a same effective improvement performance in a 10 m sprint (Kawamori et al., 2014). These experiments could assimilate well with bobsled training due to the requirement of fast power in bobsled athletes. There are new traction resistance training devices that record the horizontal power during sprinting. We should emphasize that the bobsled athlete needs to bring power onto the sled allowing for a greater acceleration outcome during the push-start phase.

No analysis of the sprint characteristics above 30 m in bobsled athletes has been performed so far. In the first part of the work, the ground contact time, stride length and stride frequency and their variations were measured with increasing pull resistance during the sprint for male and female bobsleigh athletes. It could be interesting for this study to see the evolution effect of the sprinting characteristics of male and female bobsled athletes with light to heavy load and also how the sprint characteristics for these athletes change over 30 m sprinting area since so far only the first two steps of the traction resistance sprint and speed over a longer running distance (20-45m) have been biomechanically investigated. It would be also interesting to clarify if the proportion of the bob push-start running time changes when sprinting against a light resistance versus a heavier resistance during the entire push start.

Moreover, since the traction resistance system used can also be practiced to measure the horizontal sprint power, the second part of the work examines the proportion of horizontal sprint power with traction resistance in the acceleration time with the roll bob. By evaluating and monitoring training direction using tests, would also allow to identify the areas that show greatest significance to the athletes' overall performance and guide them individually towards

objectives concerning gaps. This study could help coaches to prepare a specific and off-season preparation for the athletes, such as working on increasing acceleration and create alternate acceleration technique training, with strength and power. The athletes will be prepared with high acceleration and powered speed, ready to jump into the bob season.

### **1.1 Aim and questions**

The aim of this study is to find the proportion of the horizontal force application of the lower extremities of a single push start in bobsledding through field-testing. This aim is followed by two main questions:

- 1) How does velocity, stride length, stride frequency and ground contact time change with increasing horizontal force towing in male and female elite bobsled athletes?
  
- 2) How high is the distribution of the horizontal performance in the start-up time of the roll bob? Is there a difference between a light (3 kg) and a heavy (21 kg) resistance load?

## 2 Methods

### 2.1 Subjects

Fourteen Swiss bobsleigh athletes (5 females and 9 males) were recruited from the Swiss national Bobsled Team. Nine Swiss national bobsled male athletes (age =  $24.1 \pm 2.6$  years; mass =  $99.7 \pm 7.8$  kg; height =  $184.4 \pm 4.6$  cm) and five Swiss national bobsled female athletes (age =  $24.5 \pm 4.5$  years; mass =  $74.9 \pm 2.9$  kg; height =  $174.0 \pm 3.7$  cm) participated in this study. Two male and two female athletes of the study group were top military sport athletes which participated on May 30<sup>th</sup> 2018 and the ten other bobsleigh athletes participated on June 17<sup>th</sup> in the Gym “Halle Ende der Welt” in Magglingen, Bern in Switzerland. All participants signed a consent form and have had performed maximum effort sprints on a regular basis.

### 2.2 Research design

This study pursued to determine the sprint characteristics under the influence of external force and the distribution of the horizontal sprint performance in the push-start of a bobsled in female and male bobsled athletes. In order to measure the performances required for this study the participants had to sprint a distance of 30 m in unloaded and loaded trials. All of the 30 m unloaded and loaded sprint testing was completed on the same running lane of an indoor track, as the step analysis device was installed there. On the first testing day, the athletes (top military sport athletes;  $n = 4$ ) only performed the tests required for this study (see figure 5). Whereas, the ten other athletes performed the test within the framework of the official Swiss Sliding association performance test (see figure 6). Indeed the 30 m loaded sprint test was added. Also the 30 m sprinting test was measured within the 60 m sprint of the official association performance test. The unloaded and loaded 30 m sprint were measured in velocity time and subdivided into three different sections (0-10, 10-20, 20-30 m). The resisted sprints implemented five loading protocols (unloaded, 3, 9, 15 and 21 kg). The five-frog jumps test (regulated by the framework of Swiss Sliding association) was not considered in this study. All of the athletes filled out the athlete’s information form and were informed about the timetable of the performance test. All of the participants were requested to warm-up independently before the test and to wear their typical footwear for maximal sprinting.

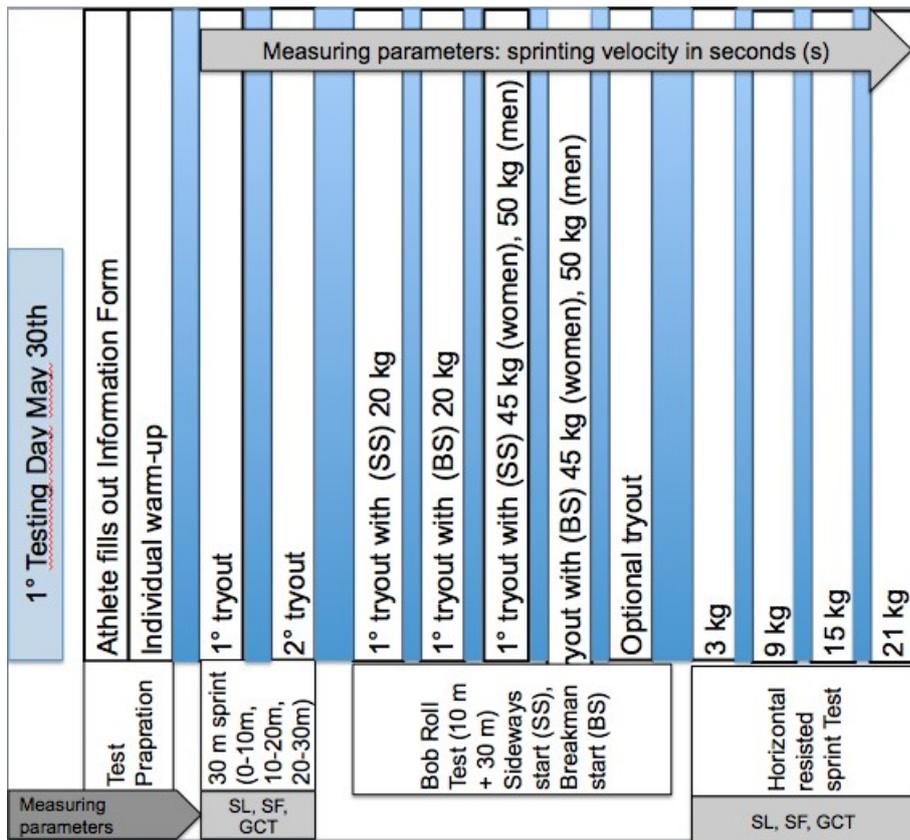


Figure 5. Timetable of test day one. Measuring parameters: SL (= stride length), SF (= stride frequency), GCT (= ground contact time). Blue bars (= pause of minimum 6 minutes to full recovery).

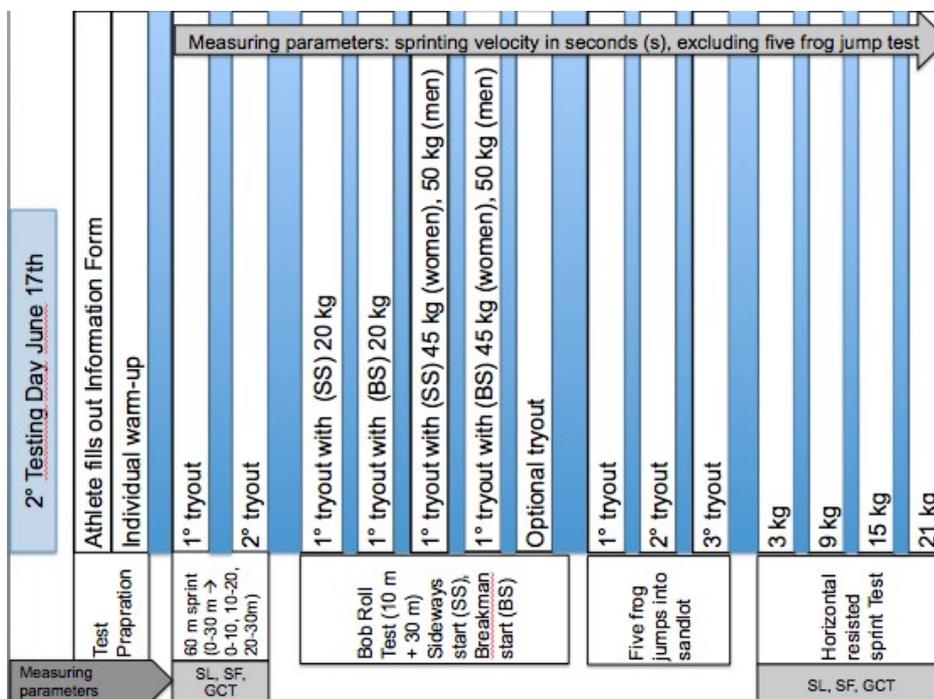


Figure 6. Timetable of test day two. Measuring parameters: SL (= stride length), SF (= stride frequency), GCT (= ground contact time). Blue bars (= pause of minimum 6 minutes to full recovery).

The three measuring sections of the 30 m loaded and unloaded sprint tests were measured for a better understanding of step analysis patterns, in which was calculated the athletes sprinting time, sprinting velocity, SL, SF and GCT. The sprints with weight added (four trials), were performed with the according weights:

Table 1

*30 m sprints (divided in three phases 0-10, 10-20 and 20-30 m) with external load*

| 0-10 m   | 10-20 m  | 20-30 m  |
|----------|----------|----------|
| 1x 3 kg  | 1x 3 kg  | 1x 3 kg  |
| 1x 9 kg  | 1x 9 kg  | 1x 9 kg  |
| 1x 15 kg | 1x 15 kg | 1x 15 kg |
| 1x 21 kg | 1x 21 kg | 1x 21 kg |

In the 30 m resisted sprint, each athlete ran one time for each external load unit, yet in the 30 m unloaded sprint, the athletes had 2 tryouts and the best one was considered. In each sprint trial, participants were verbally encouraged to ensure a full maximal-effort sprint devoid of any purposeful deceleration.

According to the Swiss Sliding rulebook for the velocity sprint, the athlete had to have their foot on the ground between the -1 m mark and the sprint starting line. Furthermore, in this study, the external loads were based on an absolute value (kg).

## 2.3 Equipment

All of the athletes had their personal equipment and spike shoes (maximum 0.6 cm needles, according to the Gym “Halle Ende der Welt” rules). The velocity time of each athlete was collected and saved in a traditional Excel file (Excel, Microsoft Corporation, Redmond, WA, USA) as the athletes performed the tests. The step analysis and horizontal performance was registered respectively software in the software of each measuring device.

**2.3.1 Unloaded 30 meters sprint.** The sprinting parameters over the 30 m sprint were calculated with running velocity, GCT, SL and SF during the running sections 0-10, 10-20 and 20-30 m. The sprint was tested on the sprinting track in the “Halle Ende der Welt” Gym in Magglingen. The sprint was calculated in seconds and measured by the timekeeper (KASAS3, Swiss Timing, ST Sportservice GmbH, Leipzig, Germany) placed at a height of 0.5 m at the starting line and every 10 m from the starting line was a timekeeping photocell measuring the athletes’ velocity time. The GCT, SL and SF of each athlete were measured

with the Optojump (Optojump Microgate, Bolzano, Italy). This is an optical measurement system consisting of a transmitting and a receiving bar. Through the Optojump software the athletes' names and data were registered, allowing the live performance to be seen on a graphical representation.

**2.3.2 Loaded 30 meters sprint.** The loaded 30 m sprint tests took place using identical parameters to the unloaded 30 m sprint test (see 2.3.1). However, the sprinting characteristics were influenced by an external load (3, 9, 15 and 21 kg) in each sprint (see table 1) and the athlete had to tow the weight by wearing a belt, which was attached to a tensile rope. The external load was programmed with the Quantum 1080 Sprint apparatus (1080 Motion™, Lindigö, Sweden). This device is a portable resistance training and testing device for sprints, skating, swimming and change of direction movements. It has a support speed rope that is attached to a belt, which the athletes wore during sprinting. The Quantum 1080 Sprint has a very smooth and controllable resistance and measures the force, power and speed. All the variable resistance can be programmed. This device has a line length of 90 m and a diameter of 1.7 mm.

**2.3.3 Horizontal performance.** The same Quantum 1080 Sprint apparatus (1080 Motion™, Lindigö, Sweden) for the loaded 30 m sprint test was used to measure the athletes' horizontal resisted sprint performance. For this test the mean power absolute and relative were calculated in Watt (W) respectively in Watt divided by the athlete's body weight (W/kg) for each external load.

Table 2

*Horizontal power measuring system*

| Measuring system          | Measuring parameter<br>0-10 m | Measuring parameter<br>10-20 m | Measuring parameter<br>20-30 m |
|---------------------------|-------------------------------|--------------------------------|--------------------------------|
| HP Pavg absolute of W:    | 3, 9, 15, 21 kg               | 3, 9, 15, 21 kg                | 3, 9, 15, 21 kg                |
| HP Pavg relative of W/kg: | 3, 9, 15, 21 kg               | 3, 9, 15, 21 kg                | 3, 9, 15, 21 kg                |

*Annotation.* Horizontal resisted sprint performance (HP). Mean power (Pavg) absolute and relative measured in Watt (W). Relative power performance measured in Watt (W/kg). External load used for this test (3, 9, 15, 21 kg).

**2.3.4 Roll bob push test.** In the bob push the running velocity of the 30 m sprint was calculated. In the bobsled push start a roll bobsled made by Aero, Glarus of Switzerland was

used. The starting line was a starting block (wooden board), to simulate a regular bobsled start on ice. The sprinting length was long 30 m sprint (with a 10 m fly-zone) and the sprinting time of the athlete with the roll bobsled was calculated with dual-beamed photocells P1-R from Swiss Timing, ST Sport service GmbH, Leipzig, Germany. The photocells were positioned 0.25 m from the ground in order that it could measure the first wheels of the roll bobsled at the start and finish line. The photocell reader measured the sprinting time of the athlete. The external weights were placed in the front and in the back of the roll bobsled. For the calculation of the correlation the roll bob start-up push time with the heavy bob was used.

## 2.4 Measuring parameters

Table 3 displays the measuring system used for calculating the sprinting variables. The data used for this study was described by the sprinting variables and horizontal performance.

Table 3

*Measuring conditions for overall sprints, horizontal performance and bob push*

| Conditions   | Sprinting variables | Measuring system                 |
|--|---------------------|----------------------------------|
| <i>Mean ± SD</i> of sprint and resisted sprint<br>(0-10, 10-20, 20-30 m) | Sprinting velocity  | Seconds (s)                      |
|  | Ground contact time | One thousand second (ms)         |
|  | Stride frequency    | Hertz (Hz)                       |
|  | Stride length       | Meters (m)                       |
| <i>Mean ± SD</i> of HP sprint<br>(3, 9, 15, 21 kg)                       | Mean Power absolute | Watt (W)                         |
|  | Mean Power relative | Watt divided by body mass (W/kg) |
| Mean of roll bob push<br>(10 m fly-zone within 30 m)                     | Roll bob push time  | Seconds (s)                      |

*Annotation.* All the measurements of the test were calculated by their mean and standard deviation (SD). Horizontal power (HP). The conditions represent the type of tests made for this study.

## 2.5 Statistical analysis

In this study descriptive statistics were used to calculate the means and the standard deviations (SD's) of the sprint characteristics and horizontal resisted sprint performances. All of the measurements were registered in an Excel File (Excel, Microsoft Corporation, Redmond, WA, USA) and in the software of the OptoJump and of the Quantum 1080. All the

data was calculated in the traditional statistical software package (IBM SPSS Statistics 22, SPSS Inc, Chicago, IL, USA). To answer question one, a mean value comparison of the sprint characteristics with the lower load was calculated. Since the data are normally distributed, a paired T-test was used. For question two a linear correlation between two variables was calculated. Namely, the horizontal mean power relative and the pushing time with the heavy roll bob. The significance of the results was evaluated with a 95 % significance level.

## 3 Results

### 3.1 Sprint characteristics

As shown in table 4 and table 5, male and female velocity, the athletes' velocity increased during their 30 m sprint, yet the sprinting kinetics adopted the opposite effect. SL, SF decreased significantly ( $p < 0.05$ ) to highly significant ( $p < 0.01$ ) and GCT significant to highly significant increased as the external weight increased with a longer running distance.

Table 4

*Velocity, SL, SF and GCT over three different (0-10, 10-20 and 20-30 m) sprint distances (women; n =5)*

|                               | Unloaded<br>(mean $\pm$ SD) | Load 1 (3 kg)<br>(mean $\pm$ SD) | Load 2 (9 kg)<br>(mean $\pm$ SD) | Load 3 (15 kg)<br>(mean $\pm$ SD) | Load 4 (21 kg)<br>(mean $\pm$ SD) |
|-------------------------------|-----------------------------|----------------------------------|----------------------------------|-----------------------------------|-----------------------------------|
| Velocity 0-10 m (m/s)         | 6.09 $\pm$ (0.07)           | 5.50 $\pm$ (0.25)**              | 4.89 $\pm$ (0.31)**              | 4.51 $\pm$ (0.24)**               | 3.28 $\pm$ (0.32)**               |
| Velocity 10-20 m (m/s)        | 7.90 $\pm$ (0.14)           | 6.94 $\pm$ (0.14)**              | 5.98 $\pm$ (0.23)**              | 5.21 $\pm$ (0.26)**               | 3.70 $\pm$ (0.44)**               |
| Velocity 20-30 m (m/s)        | 8.54 $\pm$ (0.16)           | 7.43 $\pm$ (0.16)**              | 6.13 $\pm$ (0.21)**              | 5.30 $\pm$ (0.33)**               | 3.47 $\pm$ (0.47)**               |
| Stride length 0-10 m (cm)     | 149.2 $\pm$ (5.1)           | 136.4 $\pm$ (1.9)*               | 126.8 $\pm$ (6.3)*               | 122.8 $\pm$ (5.9)**               | 97.2 $\pm$ (6.3)**                |
| Stride length 10-20 m (cm)    | 186.0 $\pm$ (5.1)           | 169.2 $\pm$ (4.1)**              | 151.0 $\pm$ (5.6)**              | 139.9 $\pm$ (5.9)**               | 107.2 $\pm$ (9.2)**               |
| Stride length 20-30 m (cm)    | 198.6 $\pm$ (4.0)           | 182.4 $\pm$ (2.4)**              | 159.8 $\pm$ (6.2)**              | 143.8 $\pm$ (4.5)**               | 104.5 $\pm$ (10.2)**              |
| Stride frequency 0-10 m (Hz)  | 4.1 $\pm$ (0.0)             | 4.0 $\pm$ (0.1)                  | 3.8 $\pm$ (0.3)*                 | 3.7 $\pm$ (0.1)**                 | 3.4 $\pm$ (0.2)**                 |
| Stride frequency 10-20 m (Hz) | 4.3 $\pm$ (0.1)             | 4.1 $\pm$ (0.1)*                 | 3.9 $\pm$ (0.1)**                | 3.7 $\pm$ (0.1)**                 | 3.5 $\pm$ (0.2)**                 |
| Stride frequency 20-30 m (Hz) | 4.3 $\pm$ (0.1)             | 4.1 $\pm$ (0.1)**                | 3.8 $\pm$ (0.1)**                | 3.7 $\pm$ (0.1)**                 | 3.3 $\pm$ (0.2)**                 |
| Contact time 0-10 m (ms)      | 144.5 $\pm$ (16.8)          | 150.5 $\pm$ (21.1)*              | 165.4 $\pm$ (24.6)*              | 177.0 $\pm$ (23.0)**              | 208.6 $\pm$ (28.7)**              |
| Contact time 10-20 m (ms)     | 116.0 $\pm$ (14.2)          | 124.8 $\pm$ (12.4)*              | 137.5 $\pm$ (17.5)**             | 153.0 $\pm$ (22.8)**              | 188.4 $\pm$ (28.6)**              |
| Contact time 20-30 m (ms)     | 109.3 $\pm$ (18.3)          | 120.4 $\pm$ (18.8)*              | 142.6 $\pm$ (17.3)**             | 158.2 $\pm$ (20.8)**              | 205.6 $\pm$ (22.8)**              |

\* Significant ( $p < 0.05$ ) different from lower loaded condition

\*\* Highly significant ( $p < 0.01$ ) different from lower loaded condition

Table 5

*Velocity, SL, SF and GCT over three different (0-10, 10-20 and 20-30 m) sprint distances (men; n =9)*

|                               | Unloaded<br>(mean ± SD) | Load 1 (3kg)<br>(mean ± SD) | Load 2 (9kg)<br>(mean ± SD) | Load 3 (15kg)<br>(mean ± SD) | Load 4 (21kg)<br>(mean ± SD) |
|-------------------------------|-------------------------|-----------------------------|-----------------------------|------------------------------|------------------------------|
| Velocity 0-10 m (m/s)         | 6.73 ± (0.25)           | 6.09 ± (0.43)**             | 5.72 ± (0.41)**             | 5.40 ± (0.49)**              | 4.55 ± (0.42)**              |
| Velocity 10-20 m (m/s)        | 8.62 ± (0.24)           | 7.85 ± (0.29)**             | 7.10 ± (0.34)**             | 6.59 ± (0.43)**              | 5.38 ± (0.29)**              |
| Velocity 20-30 m (m/s)        | 9.35 ± (0.36)           | 8.55 ± (0.36)**             | 7.55 ± (0.37)**             | 6.92 ± (0.55)**              | 5.54 ± (0.37)**              |
| Stride length 0-10 m (cm)     | 158.5 ± (5.9)           | 149.8 ± (5.4)**             | 142.2 ± (6.4)**             | 135.3 ± (5.4)**              | 118.8 ± (5.2)**              |
| Stride length 10-20 m (cm)    | 196.5 ± (6.8)           | 184.5 ± (5.1)**             | 171.2 ± (6.1)**             | 162.5 ± (6.5)**              | 137.9 ± (3.6)**              |
| Stride length 20-30 m (cm)    | 212.7 ± (7.0)           | 201.1 ± (6.8)**             | 184.1 ± (5.8)**             | 171.9 ± (8.6)**              | 144.7 ± (6.4)**              |
| Stride frequency 0-10 m (Hz)  | 4.3 ± (0.2)             | 4.0 ± (0.2)**               | 4.0 ± (0.3)**               | 4.0 ± (0.4)**                | 3.8 ± (0.3)**                |
| Stride frequency 10-20 m (Hz) | 4.4 ± (0.1)             | 4.3 ± (0.1)**               | 4.2 ± (0.2)**               | 4.0 ± (0.3)**                | 3.9 ± (0.2)**                |
| Stride frequency 20-30 m (Hz) | 4.4 ± (0.1)             | 4.3 ± (0.1)**               | 4.1 ± (0.2)**               | 4.0 ± (0.3)**                | 3.8 ± (0.2)**                |
| Contact time 0-10 m (ms)      | 141.8 ± (10.4)          | 150.5 ± (16.2)*             | 162.2 ± (23.5)**            | 168.5 ± (27.4)**             | 183.4 ± (28.5)**             |
| Contact time 10-20 m (ms)     | 119.1 ± (7.4)           | 122.7 ± (9.0)               | 130.8 ± (10.7)**            | 136.7 ± (16.1)**             | 155.9 ± (16.6)**             |
| Contact time 20-30 m (ms)     | 110.9 ± (6.0)           | 119.0 ± (11.5)**            | 128.5 ± (10.9)**            | 138.0 ± (13.5)**             | 161.4 ± (16.9)**             |

\* Significant ( $p < 0.05$ ) different from lower loaded condition.

\*\* Highly significant ( $p < 0.01$ ) different from lower loaded condition.

As can be seen in tables 4 and 5, the sprint characteristics change as the additional load increases. The following graphs (figure 7, 8, 9 and 10) show the course of the different parameters of the sprint characteristic velocity, SL, SF, GCT) as a function of the percentage of body weight.

Figure 7 displays a highly significant drop in velocity with all of the additional loads to the athlete's BM in both groups compared to their UL sprints. As can be seen from this figure, the female athletes had in general a higher percentage average of external weight than the male athletes. Consequently, they had a greater velocity variation between the three different running sections than the males, however in the first 10 m the women's velocity dropped the same as the men. Figure 7 also illustrates that the velocity also slightly reaches a plateau, in fact in both groups, the velocity gradient between the second load (females = 12 %; males = 9 %) and third load (females = 20 %; males = 15 %) slightly stabilizes and then from the third to the fourth load (females = 28 %; males = 21 %) drops steadily in all curves. Overall there was a highly significant ( $p < 0.01$ ) decrease in speed on all running sections with the increment of additional loads.

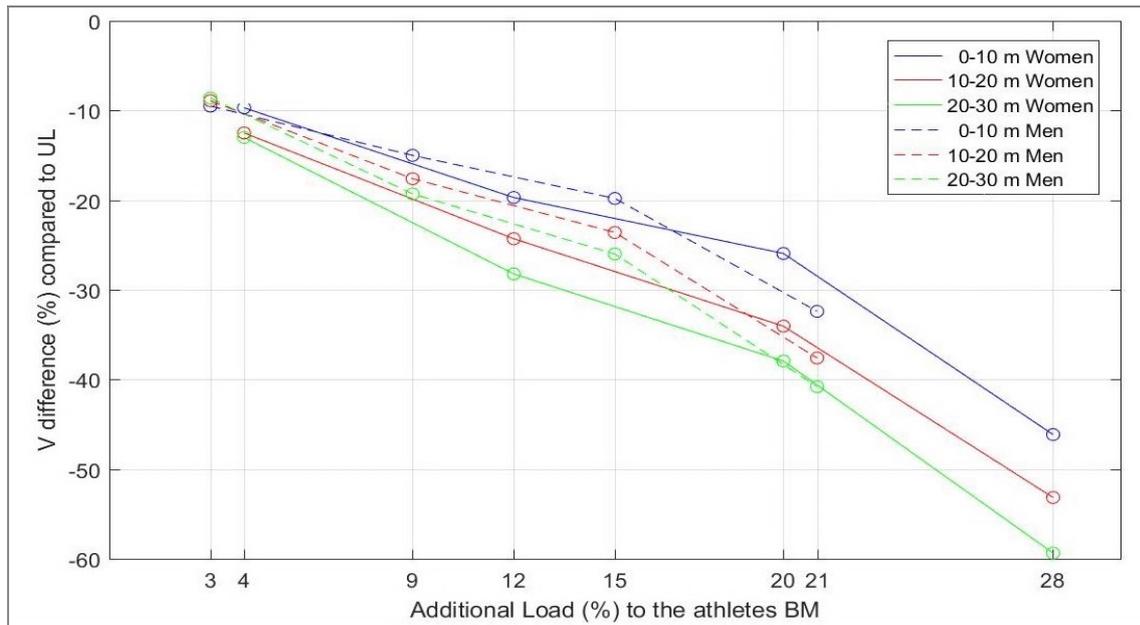


Figure 7. Representation of percentage (%) difference in velocity (V) to unloaded (UL) sprint, with added external load (%) to females' and males' body mass (BM) during a 30 m sprint.

Figure 8 displays a significant to a highly significant decrease of the women's and men's SL for each load added. Figure 8 illustrates that as the running distance increased with each additional weight, the SL significantly declined more in percentage. In the overall sprinting sections with additional loads of 4 % (females) and with 3 % (males) in ratio to the athletes BM the athletes SL dropped similarly in percentage, yet in section 20-30 m the SL decreased less than in sections 0-10 and 10-20 m. In fact, the SL during the first 10 m decreased less in length than in the last 10 m with the same weight. Especially with the female athletes during the first sprinting section, their SL did not shorten in percentage as much as in the last two sprinting sections. From figure 8 it may be seen that there is a slight fluctuation in the 0-10 m section of the women's SL with the 12 % and the 20 % additional weight to their BM. Whereby the men have a steady decrease in SL with all additional loads. In both groups, the SL with 28 % of additional weight to the female's BM and 21 % to the male's BM hit a trough over all sprinting distances.

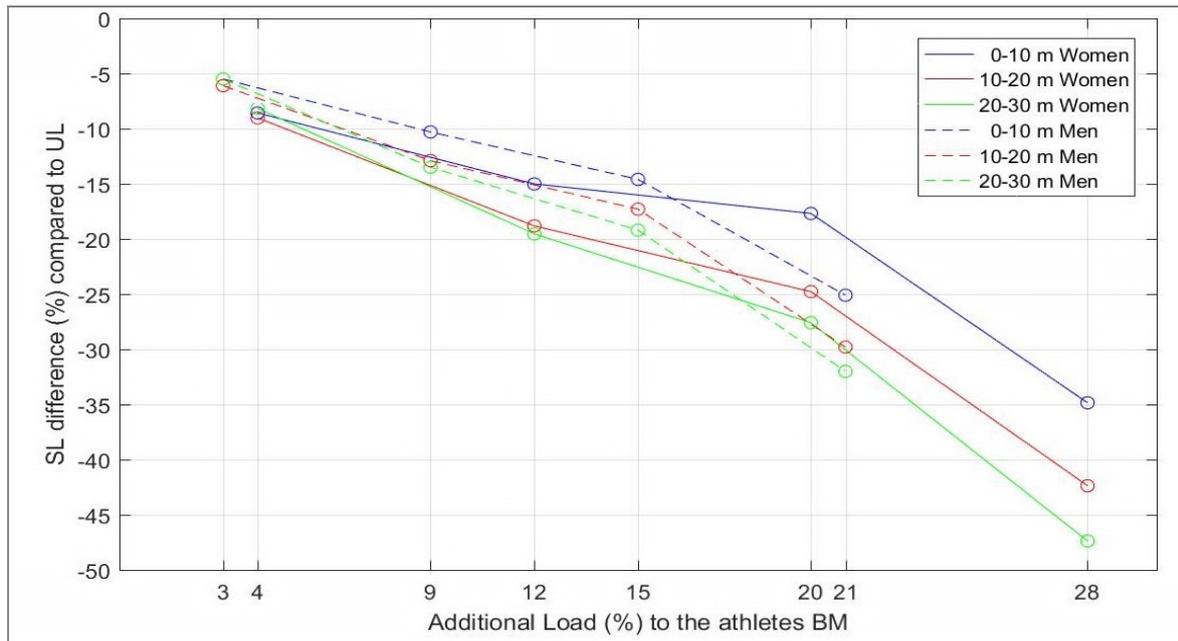


Figure 8. Representation of percentage (%) difference in step length (SL) to unloaded (UL) sprint, with added external load (%) to females' and males' body mass (BM) during a 30 m sprint.

According to figure 9, the male athletes' SF in section 0-10 m dropped highly significant comparing to the UL and this decrease stabilized with loads 3 % through 15 % of additional weight to the BM. After that, it dropped highly significant with 21 % almost as much as in section 10-20 m. Whereby the female's SF dropped steadily, statistically significant to highly significant as the loads increased, most noticeably in the 10-20 m section. The women's SF dramatically dropped with the additional loads of 28 % in the 0-10 m and the 20-30 m sections. The athletes' SF with 20 % females BM and 15 % males BM dropped significantly in section 20-30 m as much as in the 10-20 m section.

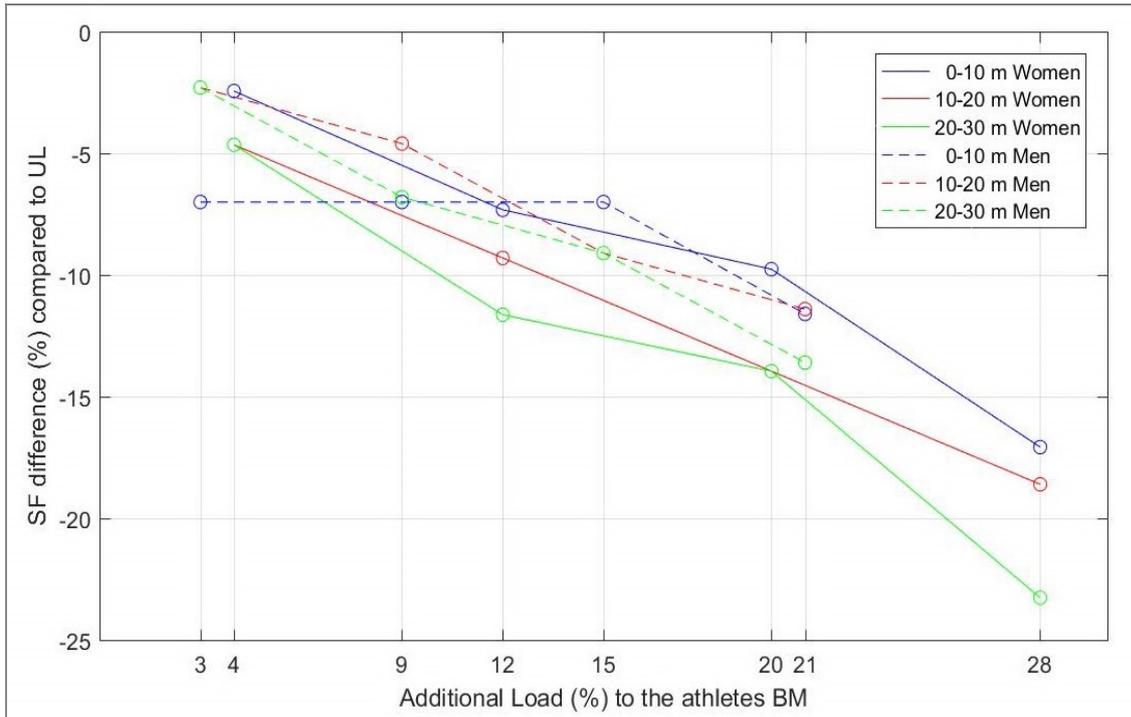


Figure 9. Representation of percentage (%) difference in step frequency (SF) to unloaded (UL) sprint, with added external load (%) to female and male body mass (BM) during a 30 m sprint.

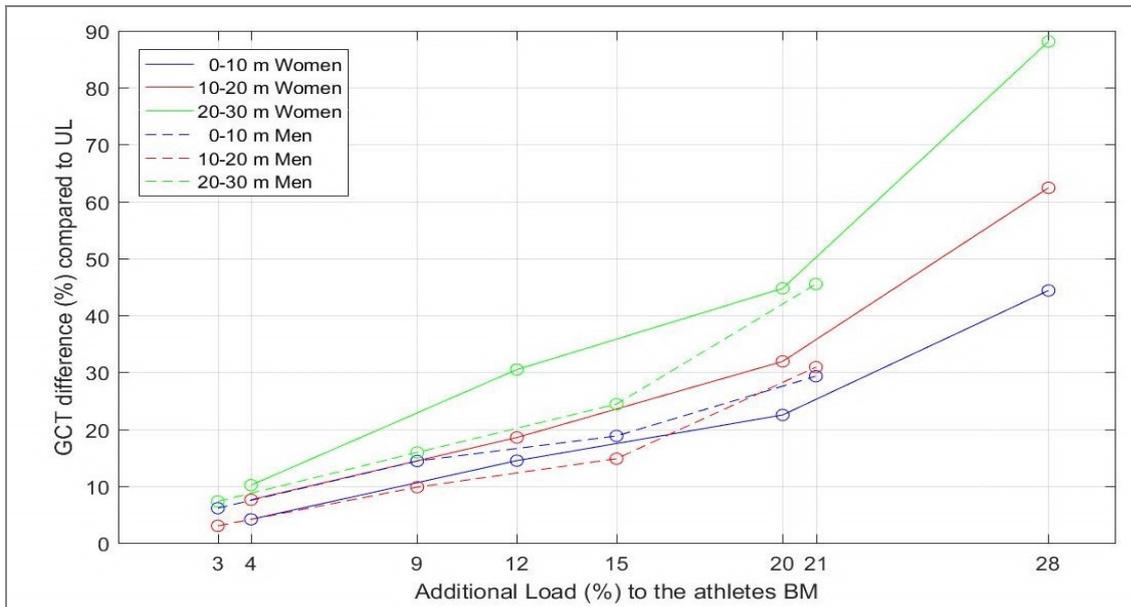


Figure 10. Representation of percentage (%) difference in ground contact time (GCT) to unloaded (UL) sprint, with added external load (%) to the female and males' body mass (BM) during a 30 m sprint.

We can see from figure 10 that as the load and the running distance increased, subsequently the GCT increased significant to highly significant as well. Female athletes' GCT increased highly significant and reached a peak with 28 % BM during section 20-30 m. Their GCT increased almost twice as much as the male athletes. The men's GCT percentage difference to

the UL sprint was greater between 0-10 m than in the 10-20 m section, whereas women's GCT in section 20-30 m was greater almost twice as much as in the first 10 m section starting already from 12 % BM. In both groups, in the overall sprinting sections, their GCT raised dramatically with load 4, which corresponds to 28 % women BM and 21 % men BM.

### 3.2 Correlation of the horizontal thrust power with the bob push time

Table 6 and 7 display the mean HP with additional loads of 3, 9, 15 and 21 kg. With the women, load 4 did not change significantly from load 3, whereas with the men it did. Indeed the women reached their HP peak at 9 kg of additional load, the men at 21 kg. This would correspond to 12 % additional body weight for the women and 21 % of additional body weight for men.

Table 6

#### *Female athletes' HP over 30 m sprint*

| Variable  | <i>n</i> | Load 1 (3 kg)<br>mean ± (SD) | Load 2 (9 kg)<br>(mean ± (SD)) | Load 3 (15 kg)<br>mean ± (SD) | Load 4 (21 kg)<br>mean ± (SD) |
|-----------|----------|------------------------------|--------------------------------|-------------------------------|-------------------------------|
| HP (W)    | 5        | 382.9 ± (16.6)               | 1006.3 ± (64.4)**              | 666.2 ± (72.8)**              | 686.0 ± (104.7)               |
| HP (W/kg) | 5        | 5.1 ± (0.3)                  | 13.4 ± (0.4)**                 | 8.9 ± (1.0)**                 | 9.2 ± (1.3)                   |

*Annotation.* Horizontal performance (HP). Mean Power (Pavg) absolute in Watt (W) and relative in Watt (W/kg). Standard deviation (SD). \*Significant ( $p < 0.05$ ) different from lower loaded condition. \*\* Highly significant ( $p < 0.01$ ) different from lower loaded condition.

Table 7

#### *Male athletes' HP over 30 m sprint*

| Variable  | <i>n</i> | Load 1 (3 kg)<br>mean ± (SD) | Load 2 (9 kg)<br>mean ± (SD) | Load 3 (15 kg)<br>mean ± (SD) | Load 4 (21 kg)<br>mean ± (SD) |
|-----------|----------|------------------------------|------------------------------|-------------------------------|-------------------------------|
| HP (W)    | 7        | 464.8 ± (29.1)               | 1224.5 ± (97.1)**            | 1084.7 ± (104.9)**            | 1341.0 ± (91.8)**             |
| HP (W/kg) | 7        | 4.7 ± (0.6)                  | 12.3 ± (1.6)**               | 10.9 ± (1.6)                  | 13.4 ± (1.0)**                |

*Annotation.* Horizontal performance (HP). Mean power absolute (W) and relative (W/kg). Standard deviation (SD).

\* Significant ( $p < 0.05$ ) different from lower loaded condition. \*\* Highly significant ( $p < 0.01$ ) different from lower loaded condition.

Table 8 and 9 display the roll-bob push start time of the entire study group. The light sled corresponded to 26.7 % females BM, whereas the heavy sled to 60 %. With the men, the light sled corresponded to 20 % and the heavy sled to 50 %. The weight difference in percentage between the two sleds corresponded to 33 % for women and 30 % for the men athletes. Subsequently, the women and men's velocity was decreased highly significant pushing the

heavier sled in comparison to pushing the light roll-bob at the push-start. The women's time dropped by 7 % and the men by 6 %.

Table 8

*Velocity time over 30 m sprint distance (n = 5; female athletes)*

|                    | <i>n</i> | Sprint velocity time<br>Mean and (SD) |
|--------------------|----------|---------------------------------------|
| Light sled (20 kg) | 5        | 4.66 ± (0.09)                         |
| Heavy sled (45 kg) | 5        | 4.98 ± (0.14)**                       |

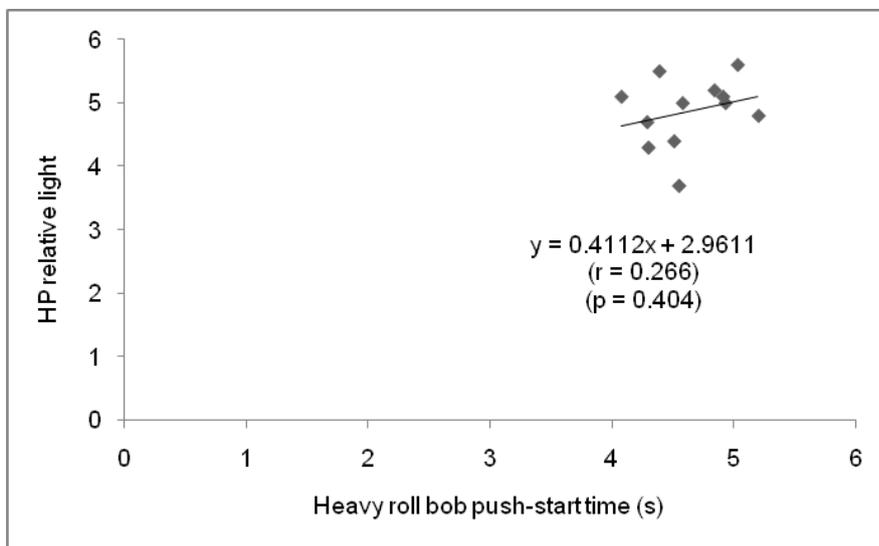
*Annotation.* Standard deviation (SD). \* Significant ( $p < 0.05$ ) different from light sled. \*\* Highly significant ( $p < 0.01$ ) different from light sled.

Table 9

*Velocity time over 30 m sprint distance (n = 9; male athletes)*

|                    | <i>n</i> | Sprint velocity time<br>Mean and (SD) |
|--------------------|----------|---------------------------------------|
| Light sled (20 kg) | 9        | 4.10 ± (0.13)                         |
| Heavy sled (50 kg) | 9        | 4.36 ± (0.16)**                       |

*Annotation.* Standard deviation (SD). \* Significant ( $p < 0.05$ ) different from light sled. \*\* Highly significant ( $p < 0.01$ ) different from light sled.



*Figure 11.* Correlation between horizontal power (HP) relative with 3 kg external weight and the heavy roll bob push-start time of female and male athletes. Significant ( $p < 0.05$ ) different between the two variables. Highly significant ( $p < 0.01$ ) between the two variables.

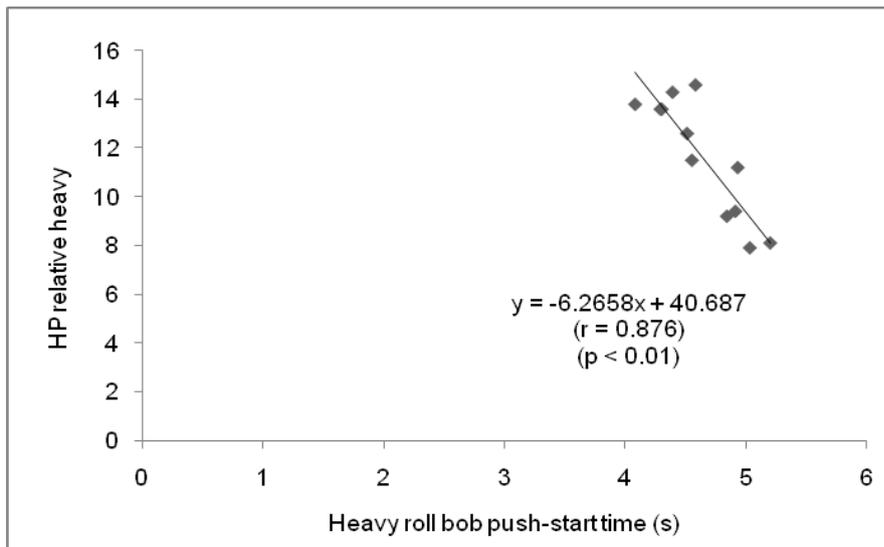


Figure 12. Correlation between horizontal power (HP) relative with 21 kg external weight and the heavy roll bob push-start time of female and male athletes. Significant ( $p < 0.05$ ) different between the two variables. Highly significant ( $p < 0.01$ ) between the two variables.

According to figure 11 and 12, there is a relationship of 26 % between the HP light and the bob run time, however statistically not significant ( $p > 0.05$ ), whereas, there is a highly significant ( $p < 0.01$ ) relationship of 88 % between the HP heavy and the bob run time.

## 4 Discussion

### 4.1 Sprint characteristics

The results showed that by increasing the external weight the velocity, the SL and the SF reduce while the GCT increases. This supports Lockie et al. (2003) study, where they claimed that if the athlete increases her or his velocity than the SL and the SF will also increase and the GCT will decrease, but as soon as there is the influence of an additional weight, it will have an opposite effect on these sprinting variables. Furthermore, the athletes had to tow an external weight ranging from 3 to 21 kg, which means that for the female participants, it represented a 4 % to 28 % increase in the ratio to their body weight during the trials, and the men a 3 % to 21 % increase in ratio. This percentage difference is explained due to the difference in BM of the study groups. In fact, due to female athletes' lighter BM compared to the male athletes, they had, in general, a higher percentage of the external load to tow and this had a higher influence on the step patterns. Towards the end of the sprint track, the difference in the velocity and all other step patterns was more distinct, as the weight had a direct effect on the acceleration, which means that the percentage difference increases over the distance.

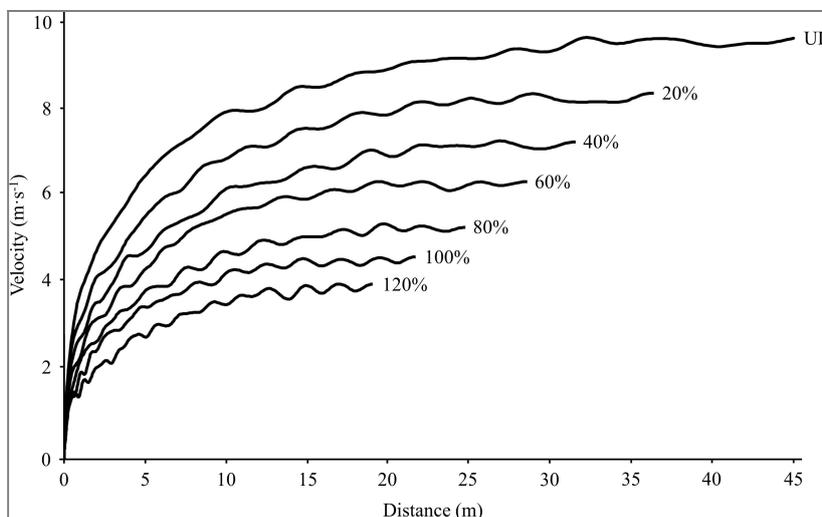


Figure 13. Graphical representation of the clipped raw velocity–distance radar data. Seven sled trials are pictured, clipped before deceleration occurred. From the trial with the highest maximal horizontal velocity ( $v_{hmax}$ ). Unloaded sprint (UL), the loading ranges from 10 % to 120 % of body mass with each trial (Cross et al., 2017).

The athletes' speed generally decreases as the external load increased. Subsequently, with the increase of the traction resistance, the average running speed in the sections is progressively reduced from 7.5 m/s at UL to 3.5 m/s in women and at 8.2 m/s UL to 5.2 m/s in men at 21 kg

additional load. As can be seen in the literature (figure 13), not only the running speed decreases but also the distance at which the maximum running speed is reached. In the mean value of the section times, this is not immediately obvious. If we compare the mean values of the individual section times, then the athletes are hardly able to accelerate with the increase of the additional load, therefore the percentage of the increase decreases, however, this also depends on the running distance. This means that the acceleration also decreases with additional loads as the running distance increases. It can even happen that the maximum running speed is reached before 30 m and the last section is no longer faster, for example by the women at 21 kg or 28 % BM, which can also be seen in the graph of the study (figure 7). However, in order to compare these results with Cross et al. (2017), a calculation between sprinting with a tensile resistance rope (1080 Sprint) and sprinting with the sled should be made (see table 10), since the results may be influenced by the friction on the ground while towing the sled.

Table 10 demonstrates the increase between the sprinting sections over the 30 m sprint. It can also be used as an instrument for comparing the percentage increase with figure 13. The external load displays also the percentage to the athletes' BM.

Table 10

*% Increase between sprinting sections over a 30 m sprint with the 1080 Sprint*

| Women                 | UL       | 3 kg (4 % BM) | 9 kg (12 % BM) | 15 kg (20 % BM) | 21 kg (28 % BM) |
|-----------------------|----------|---------------|----------------|-----------------|-----------------|
| 0-10 m                | 6.09 m/s | 5.50 m/s      | 4.89 m/s       | 4.51 m/s        | 3.28 m/s        |
| 10-20 m               | 7.90 m/s | 6.94 m/s      | 5.98 m/s       | 5.21 m/s        | 3.70 m/s        |
| 20-30 m               | 8.54 m/s | 7.43 m/s      | 6.13 m/s       | 5.3 m/s         | 3.47 m/s        |
| % increase<br>10-20 m | 30 %     | 26 %          | 22 %           | 16 %            | 13 %            |
| % increase<br>20-30 m | 8 %      | 7 %           | 3 %            | 2 %             | -6 %            |
| Men                   | UL       | 3 kg (3 % BM) | 9 kg (9 % BM)  | 15 kg (15 % BM) | 21 kg (21 % BM) |
| 0-10 m                | 6.73 m/s | 6.09 m/s      | 5.72 m/s       | 5.40 m/s        | 4.55 m/s        |
| 10-20 m               | 8.62 m/s | 7.85 m/s      | 7.10 m/s       | 6.59 m/s        | 5.38 m/s        |
| 20-30 m               | 9.35 m/s | 8.55 m/s      | 7.55 m/s       | 6.92 m/s        | 5.54 m/s        |
| % increase<br>10-20 m | 28 %     | 29 %          | 24 %           | 22 %            | 18 %            |
| % increase<br>20-30 m | 8 %      | 9 %           | 6 %            | 5 %             | 3 %             |

*Annotation.* Unloaded sprint (UL). The percentage (%) in ratio to the body mass (BM) increase is compared to the lower sprinting section.

It could be considered whether the 28 % BM could correspond to a specific load in figure 13. For example, if we compare the 28 % BM with the over 60 % additional load, the maximum running speed is reached before 30 m. Precisely, in our study, the percentage of the women's velocity increased by 13 % between 10 m and 20 m compared to the first 10 m, and then in section 20-30 m their velocity drops, which means that their acceleration does not increase anymore. Compared approximately with the literature, it shows quite the same effects. Also for the men, it shows that with 21 % BM their velocity in section 20-30 m still increases by 3 % (see table 10) that is approximately equivalent to the 60 % of external load in figure 13. However, it's noticeable that the 20 % women BM have almost the same velocity increase as the men with 21 % BM in relationship to the 60 % external load.

Furthermore, the results showed that the SL in general decreases as the additional load increases. Therefore, the velocity reduced as well. In women athletes, the SL average decreases 42 % from UL to 21 kg loaded sprint and in men athletes decrease by 29 %. Furthermore, normally the SL gets lengthier over the running distance, but the average SL demonstrates a decrease in section 20-30 m. Also, the men's SL in the UL trial increases from 158 to 212 cm while the distance gets longer, but it decreases progressively as the additional load increases. The same effect is seen in women athletes as well. Indeed, the women's SL average decreases approximately 70 cm from the UL to the 21 kg loaded sprint and approximately 55 cm in men's SL. Nevertheless, women's SL in section 20-30 m with 21 kg or 28 % BM decreases, this is due to a loss of acceleration. However, by reducing SL could make it easier for the athlete to maintain their SF.

The SF also decreases in general, but the pattern does not change with increasing running distance (see figure 9), for example, the athletes' SF during section 20-30 m remains lower than in section 10-20 m. The reason why the cadence decreases is because the GCT increases because the foot is longer on the ground. However, it is noticeable that the men's SF remains constant throughout the 3 kg and 15 kg loaded sprints in the first 10 m sprint. Meanwhile, both groups maintain the same SF during the entire sprint with 15 kg added weight rather than dropping as in the other additional loaded sprints. Thus, have in average a shorter SL with 15 kg of additional weight compared to the lower load. The literature claims that experienced athletes tend to compensate with an increased SL by maintaining their SF, and this may influence free sprinting.

In general, as the external load increases and the running distance becomes longer, the athletes' GCT increases. This could originate from overcoming the loss of speed and thereby compensating this step pattern with the accumulation of energy and force over the sprinting distance. What is noticeable, however, is that the GCT is no longer shortened from 9 kg of additional weight in section 20-30 m in women athletes and men from 15 kg. Besides, the females need to apply more force during the sprint because the women are lighter than the men athletes. However, this may be another form of a sprint, because generally the GCT would decrease as the athlete increase their velocity, but in this case, it does not. This is new and has never been shown before. A longer GCT might be necessary for increasing the athletes' force while towing the external load to be able to maintain an incremental speed thanks to the force applied onto the ground. Especially for women athletes since they are lighter than man which means that they need to apply more force. They increased their GCT from UL to the 21 kg loaded sprint with 63 % and men with 35 %, approximately half. Hoffmann (2014) claims that applying external loads may increase the potential horizontal force production in the lower body during each ground contact. This factor supports Newton's third law, in which for every force there is an equal and opposite reaction", this means that thanks to the ground contact during sprinting, the athlete can generate a better force onto the sled, which makes the sled accelerate. This study emphasizes the fact that the bobsled athlete should have a flatter step pattern comparing to a normal track sprinter, to have more GCT with the ice and apply a continual force onto the sled to make it go faster. In this case, it's important that the athlete is faster than the bobsled because the athlete could slow the bobsled down by applying a negative force (pulling instead of pushing) while the bob is accelerating. To be able to maintain or increase a certain velocity, an amount of force is required, which can be generated by the human body, specifically by the contraction of a muscle. Women generally have less muscle mass in comparison to men which means they produce less force and consequently they lose energy faster -as we have seen in the results-. Over the test sprints, the female athletes tired faster and this affected the last sprinting trials because they are more confronted with the counterweight on the external load since they had to push in percentage more weight according to their BM. However, this may have happened to the men athletes as well, but with a heavier external load. In this study, load 4 was set at 21 kg, but in further studies, heavier loads could be used to see the effects. This situation is found at the start of the women's bobsleigh competition, in other words, the percentage between a woman's weight and the weight of a bobsled is higher than that of a male athlete (106 % vs. 77 %

respectively). This study could support Lockie et al. (2003) statement, emphasizing that using an external weight while sprinting could increase the quality of the sprint characteristics of an athlete and consequently improve the acceleration and velocity. Adding an external weight during training sprinting trials affects the step patterns techniques and leads to adapted sprinting criteria for a typical bobsled athlete. Controversially, it should be noticed that bobsled athletes should not only focus on resisted sprinting, but also on over-powered speed training, where the athletes are confronted to train with a higher speed and acceleration than their usual maximum speed. These training methods are well adapted for bobsled athletes. However, we need to raise awareness of the fact that the bobsledding season starts in November and ends in March, in which the world-cup athletes have a competition every weekend. This means that this very high physical exertion and the resisted sprint training should be well balanced with regeneration.

#### **4.2 Correlation of the horizontal thrust power with the bob push time**

The proportion of the horizontal performance had a highly significant relationship of 88 % between HP heavy and the roll bob-pushing test and with the HP light, there is no significant relationship. Consequently, the lighter weight may not provide an effective stimulus for maximizing horizontal power production or used as a simulation for a bobsled. However, based on other literature, a lighter weight may help the development of speediness and acceleration. This type of training may provide positive changes in the unloaded sprinting acceleration performance. The results showed by increasing the loads led to a decrease in sprint performance over 30 m. On the other hand, the heavyweight of the bob could be convenient to compare the sprint characteristics at the start with the tensile resistance at high loads. This also may explain the reason why the correlation resulted so high. Therefore, the sprint characteristic changes when is influenced by a high external load. Indeed, it could occur that with both measuring systems, such as the 1080 Sprint and the roll bob the SL remains short and the GCT long. Meanwhile, as soon as the roll bob is "rolling" the characteristics change towards sprint. Therefore, the GCT will decrease and the SL will increase. As the results revealed, the highest power produced in the mean power of the female and male group (calculated separately) was at 13.4 W/kg with 12 % females BM and 21 % in males BM. The females' GCT increased by 21.5 % and the males by 35.3 % in their peak performance. In general, the men could tow the external weight faster than the women and confirm their greatest performance with the highest load (21 kg). In both groups, the horizontal

performance dropped by load 3 and in load 4 slightly increased again. This is because during the test, technical problems occurred and it was necessary to double the tensile rope of the machine onto the athletes' waist. This may have made changes to the current conditions. However, observing the results, it seems plausible that as the athlete runs faster, more power can be applied to the movement. This last supports Cross et al. (2017) statement, where well-trained sprinters should be characterized by their ability to produce force at greater velocities rather than having the ability to produce absolute force. One possible view of the resisted sprint (influenced by external loads) is that it could be an effective way to train, because it may improve the acceleration phase and at the same time increase the horizontal power of the athlete. It may also support the fact that athletes should train in ways that they can achieve their maximum performance. According to the results of this study, it would be recommended that female athletes train their horizontal performance in resisted sprinting until 12 % BM and men between 9 % BM and 21 % BM. It is important that by training horizontal performance during resisted sprinting the awareness in the relationship between the athlete's fast force muscle fibers and the external load is not overestimated, this may lower the athlete's horizontal performance and may damage the athletes' intramuscular control (coordination capacity). Nevertheless, by calculating the horizontal performance of the athlete, especially in bobsledding could benefit the analysis of the push-start tactic of a bob team, for example when defining the start position of the athletes.

The limitation of this study is certainly the number of participants. It was difficult to recruit participants because bobsledding at its highest level in Switzerland does not have a great number of athletes, in comparison to sprinters from track and field or field-sport athletes. However, to our knowledge, since there have been no other studies such as this one made only with bobsled athletes.

It would be interesting in further studies to develop this method continually, by increasing the number of participants. Or to apply it on a bobsled ice track and to simulate strongly the effect of pushing a sled down the track with the 2 % of pendency, for example, by attaching a force measuring device onto the bob for the push-start during a competition. Also, having a study where the athletes are instructed to manipulate their step patterns, for example, to keep a high SF during the entire sprint, and consequently analyze the velocity outcome. Moreover, the second test of the study (horizontal performance) could be introduced into the official

framework of the Swiss Sliding association, since it revealed an adequate measuring system for the bobsled sport. The evidence of this study should be discussed and analyzed directly on the field with the athletes so that they can have a better understanding of where they could improve.

## 5 Conclusion

In summary, it can be said that the running speed decreases with increasing tensile resistance and the sprint characteristics change at a certain resistance. The GCT is no longer shorter and the stride length no longer lengthier. This factor may follow an accumulation principal. However, from a practical training point of view, it is important to consider whether this changed sprint characteristic is desirable during training. A longer GCT allows more time for power production and could almost be compared to fast power training. This towing method could improve athletes' acceleration and horizontal performance by influencing the sprint characteristics and also be used to monitor the percentage difference between unloaded and loaded sprints overall step patterns. Overall, the aim is to generate the greatest possible force impulse against resistance in the time available.

Horizontal performance with heavyweight had a very significant relationship of 88 % with the one-man roll-bob push test between. Contrarily, the horizontal performance with lightweight had not enough influence to assimilate to a one-man bob push-start. Therefore comparing the sprint characteristics between the roll bob start -with its very heavy weight-, with the tensile resistant sprint start could be convenient. Indeed the sprint characteristics changed at a heavy tensile resistance sprint. Supposedly, the characteristic that the SL remains short and the GCT long could occur with both measurement systems, such as 1080 Sprint and the roll bob. As soon as the roll bob is "rolling" the characteristics change towards sprint, which signifies the SL increases and the GCT decreases. Furthermore, female athletes should train with 12 % of additional load to their body weight if they want to improve their horizontal performance, while men between 9 % and 21 %.

Overall, the results of this study confirmed with the literature, for example as the external weights increase than the velocity decreases, but a high horizontal power can still be generated to make the bobsled accelerate. In general, training with external weights while sprinting could develop the fast power and force resistance asset of the athlete and help he or she to improve significantly their sprinting skills. Nonetheless, this cannot be overestimated and should be analyzed with the body weight of the athlete to prevent reducing excessively the horizontal power. This is a potential method that could be adopted in the future framework performance test of Swiss Sliding since the best athletes on a bob push-start are not always the fastest but can be the ones with the better horizontal performance as well.

## References

- Brüggeman, G. P., & Susanka, P. (1987). *Scientific Report on the II. World Championships in Athletics Rome 1987*.
- Cross, M. R., Brughelli, M., Samozino, P., Brown, S. R., & Morin, J. B. (2017). Optimal Loading for Maximizing Power During Sled-Resisted Sprinting. *International Journal of Sports Physiology and Performance*, 12(8), 1069–1077.
- Federation IBSF. (2017a). Bobsleigh History. Retrieved from <https://www.ibsf.org/en/our-sports/skeleton-history>
- Federation IBSF. (2017b). Info graphics. Retrieved from <https://www.ibsf.org/en/our-sports/bobsleigh-info-graphics>
- Federation IBSF. (2018a). International Rules Bobsleigh 2018. Retrieved from [http://www.ibsf.org/images/documents/downloads/Rules/2018\\_2019/2018\\_International\\_Rules\\_BOBSLEIGH.PDF](http://www.ibsf.org/images/documents/downloads/Rules/2018_2019/2018_International_Rules_BOBSLEIGH.PDF)
- Federation IBSF. (2018b). Track Rules 2017-2018. Retrieved from [http://www.ibsf.org/images/documents/downloads/Rules/2017\\_2018/IBSF\\_Track\\_Rules\\_Format\\_01-2018.pdf](http://www.ibsf.org/images/documents/downloads/Rules/2017_2018/IBSF_Track_Rules_Format_01-2018.pdf)
- Harrison, A. (2017). *The Bobsled Push Start: Influence on Race Outcome and Push Athlete Talent Identification and Monitoring* (Dissertation - Open Access). East Tennessee State University.
- Hoffmann Jr, J. (2014). *An investigation of the sled push exercise: Quantification of work, kinematics, and related physical characteristics* (Dissertation - Open Access). East Tennessee State University.
- Hübner, K. (2009). *Veränderung der Explosivkraft der unteren Extremitäten in Abhängigkeit vom Widerstand*. Dissertation Universität Leipzig, (Sportwissenschaftliche Fakultät) Leipzig.
- Kawamori, N., Newton, R., & Nosaka, K. (2014). Effects of weighted sled towing on ground reaction force during the acceleration phase of sprint running. *Journal of Sports Sciences*, 32(12), 1139–1145.
- Kawamori, N., Nosaka, K., & Newton, R. U. (2013). Relationships between ground reaction impulse and sprint acceleration performance in team sport athletes. *The Journal of Strength & Conditioning Research*, 27(3), 568–573.
- Lockie, R. G., Murphy, A. J., & Spinks, C. D. (2003). Effects of Resisted Sled Towing on Sprint Kinematics in Field-Sport Athletes. *The Journal of Strength & Conditioning*

- Research*, 17(4), 760–767.
- Lüthy, F. (2013). *Strength and Power Analysis to Evaluate a Key Performance Indicator (KPI) in Men's Bobsleigh*. Presented at the SGS Tagung, ISSW Universität Basel.
- Mero, A., Komi, P., & Gregor, R. (1992). Biomechanics of sprint running. *Sports Medicine*, 13(6), 376–392.
- Park, S., Lee, K., Kim, D., Yoo, J., & Kim, K. (2015). Bobsled Shoe Requirements using 3D Motion Analysis in Korea. 88 *서울올림픽기념국제스포츠과학학술대회*, 294–294.
- Szepessy Steinmann, C. (2016). *Anteil der Maximal- und Explosivkraft der unteren Extremität an der Einzelanschubzeit im Bobsport mittels Feld- und Labortests* (Masterarbeit). Eidgenössischen Hochschule für Sport Magglingen, Schweiz.
- Woolley, C. (2019). *Trainingsplanung Ski Alpin und Bob*. Presented at the Training und Monitoring im Spitzensport, Nationales Sportzentrum Magglingen.

## Attachments

Exemplary form of Swiss Sliding Performance Test:

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**SWISS**  
**sliding**

### BOB LEISTUNGSTEST SEP/OKT 2017 Beschreibung Testdisziplinen

#### Test Piloten / Anschieber und Pilotinnen / Anschieberinnen

- |                      |                   |  |                    |
|----------------------|-------------------|--|--------------------|
| <b>1. Disziplin:</b> | <b>60m Lauf:</b>  | - Ein Fuß muss innerhalb der 1m-Markierung sein.<br>- Höhe Zeitmessung: Start: 0.50m / Ziel: 1.10m<br>- Die Zeit im Ziel darf nicht mit ausgestrecktem Arm gestoppt werden.<br>- Abschnittszeiten 0-30m und 30-60m | <b>2 Versuche.</b> |
| <b>2. Disziplin:</b> | <b>Bobstart:</b>  | - Bremsenstart +20kg   | <b>1 Versuch</b>   |
| <b>3. Disziplin:</b> | <b>Bobstart:</b>  | - Seitenstart +20kg  | <b>1 Versuch</b>   |
| <b>4. Disziplin:</b> | <b>Bobstart:</b>  | - Bremsenstart +50kg (Herren) / +45kg (Damen)  | <b>1 Versuch</b>   |
| <b>5. Disziplin:</b> | <b>Bobstart:</b>  | - Seitenstart +50kg (Herren) / +45kg (Damen)   | <b>1 Versuch</b>   |
| <b>6. Disziplin</b>  | <b>Fünferhupf</b> | - Fünf aufeinanderfolgende Frosch- oder Laufsprünge<br>- Der Absprung erfolgt von einem Balken<br>- Landung im Sand  | <b>3 Versuche</b>  |

#### Bemerkungen zu den Bobstartdisziplinen für alle Tests:

- es ist kein Einschieben vorgesehen! (nur Neulinge haben einen Probeversuch)
- ein Zusatzversuch nach freier Wahl ist erlaubt
- Messdistanz: 10m Anlauf / 30m Messdistanz
- Beim Seitenstart muss die Hinterachse mindestens 50cm vor dem Startbalken sein
- Ausstoßen ist nicht erlaubt! Das heißt: Die Armwinkel müssen auf den letzten 10 Metern konstant sein. Ein Fehlverhalten wird mit einer Null bestraft! Kontrolle durch Zeitnehmer!

Ethical approval:

The present study is a retrospective study approved by the Ethics Commission of the Canton of Berne (Project ID: 2016-01970).

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