Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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# On performance factors in sprint running

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**Abstract**:

**Purpose:** The aim of this thesis was to examine the performance factors in sprint running and look at ways to improve performance. There were 3 main factors, acceleration, propulsion, and locomotor form. **Method:** The studies used in this article were found through Pubmed, Scopus and SportsDiscuss. The participants in the studies were between 18 and 40 years old, and they had to be athletes. The studies also had to be about sprint running. **Results:** From these 8 studies, factors like GRF, propulsion and braking impulses, coordination and metabolic power were found as factors that could be improved to better performance. **Conclusion:** This thesis found factors that could be used by athletes to improve performance, and coordinate what they need to look at for the highest possible performance increase.

**Abstrakt**:

**Bakgrunn:** Målet for dette studiet var å studere faktorer for å forbedre resultater i sprint løping, og se på måter for å forbedre resultatene. 3 hovedfaktorer: akselerasjon, propulsjon og teknikk var fokus for dette studiet. **Metode:** Studiene som ble brukt i denne artikkelen ble hentet fra Pubmed, Scopus og sportsdiscuss. Deltakerne var i alderen 18 til 40 år, og de var atleter. Studiene måtte også være om sprint løping. **Resultater:** Fra de 8 studiene som ble brukt, var det faktorer som GRF, propulsjon og bremse impulser, koordinasjon og metabolsk kraft som gikk frem som faktorer som kunne bedre prestasjon. **konklusjon:** Dette studiet fant faktorer som kan bli brukt av idrettsutøvere for å forbedre prestasjon, samt hvilke forbedringspunkter de burde trene med.

**Key words**: Sprint, Running, Performance, Acceleration, Propulsion, Locomotor form

## 1. Introduction

“Although the mechanical principles of sprint running are similar to those of running in general, a major difference is in the acceleration at the start” (1).Sprinting is a rapid burst of high-intensity movement that is utilized for a variety of purposes, such as crossing a street or catching transportation. Competitive sprint running typically takes place on a track and field surface, with popular distances ranging from 60 to 400 meters. This well-known sport and activity entails moving as quickly as possible from point A to point B, primarily using one's legs. To achieve maximum power, velocity, and acceleration over short distances, sprinters must adhere to a specialized training plan that emphasizes the development of a robust lower body, efficient technique, and exceptional coordination.

Sprint running is an element that underlies performance in many sports, which shows from the scientific literature how much devotion that lies in sprint (2). Most sports enthusiasts understand how sprinting works in most competitions. It can be the difference between scoring a goal or preventing the opposing team from taking an advantage. In football, for example, players such as Erling Haaland utilize sprinting to reach the ball first and secure a goal for their team. Their acceleration, top speed, and individual techniques are easily observable. Likewise, athletes like Usain Bolt are recognized for their exceptional top speed and great technique. Interestingly, many athletes, regardless of their discipline, aim to improve their speed and excel in their respective fields. This thesis will examine three key factors that distinguish exceptional sprinters from good ones: acceleration, propulsion, and technique, the latter also known as locomotor form.

One of the easiest ways to improve performance in a sprint is by looking at the acceleration from the start. “An increase in sprint velocity can only be achieved by upsetting the balance between braking and propulsive impulses so that the runner gets a surplus of propulsion impulses" (1). To achieve greater sprint velocity, the braking force should be minimized while maximizing propulsive forces. While it may not be possible to eliminate braking forces, reducing them alone can still lead to improved sprint performance. Additionally, it's important to keep in mind that only the propulsion during ground contact determines final speed, and it's the forces that the runner exerts on the ground, known as ground reaction forces (GRF), that leads to propulsion. While only horizontal propulsion leads to velocity in the “forwards” or to the end goal, you still need some propulsion in the vertical direction as well. Because with “none to low horizontal GRF, the runner would not be able to keep upright, let alone sprint” (1) . This study looks at GRF exerted by the runner, and the correlation between GFR and acceleration. (1)(3)

The locomotor form, or the technique of the sprint is also a factor to consider when looking at performance. The locomotor form is mainly done by moving limbs relative to the center of mass (COM). The cost of moving limbs relative to the COM is called internal work (IW), and while the IW can never be removed, it might give better results to reduce the IW by improving the technique (1). To improve technique, factors like ground contact that are related to propulsion, such as less leg extension at toe-off, larger stride angels, alignment force and leg axis, and low activation of the lower limb muscles, are the factors that appear to have the strongest linking up with RE (running economy). These factors are usually more related to longer distance running, but an improved technique can also affect the IW and less energy exposure during a sprint. (4).  As mentioned before, this thesis will look into the three main factors explained above to see if they improve sprint performance.

## 2. Method

For the literature search in this thesis, Sportdiscus, Scopus and Pubmed were used. Keywords such as propulsion, mechanical, acceleration, energy, running, technique, sprint, and performance were used and paired with and/or, to get the articles for this thesis. And by searching between similar articles the search gave 51 results. Further, there was used inclusion and exclusion criteria (listed below) to narrow the search down even further. The last results from our literature search gave us 15 articles where 8 were main articles, and the rest was supporting literature to this study.

### 2.1 Inclusion and exclusion criteria

The table shows a variety of exclusion and inclusion criteria that was used to narrow the literature search.

| Inclusion Criteria | Exclusion criteria |
|---|---|
| Athletes | Younger than 18 years or older than 40 years. |
| Articles published in the year 2000 and after. | Articles that aren't written in English. |
| Running or sprinting. | Large scale studies ( n = 500 ) |
| | |

**3.Results**

8 studies were included with sprinters from various sports. All studies examined athletes, and focused on either acceleration, propulsion, or locomotion form. Table 2 gives a summary of each study and below the table it comes more specific of some of the findings that we think are important prior to the thesis.

3.1 Article table

| **Name of article** | **Method** | **Results** | **Validity** |
|---|---|---|---|
| Purkiss and Robertson (2003) | Compared two methods for calculating IW. They used 8 athletes and compared the IBC of normal running with the IBC of inefficient running. | The power and work methods detected inefficient runs. | The work approach was deemed invalid compared to the power approach. It was predicted that the power method would detect much more inefficient runs than it did. This was predicted because of energy-based equations who were proved invalid. |
| Zamparo et al. (2019) | 20 different athletes performing shuttle runs with 180 degree turns at 3 different paces and 4 different lengths (5-10-15-20 meters). | Braking power twice as high as positive power at maximum speed. Constant speed phase and elastic energy saving mechanisms who plays roles in improving efficiency. | A more thorough examination of this study could be needed to be able to assess the validity in more details. This study gives valuable insights to the efficiency roles in shuttle running. |

| | | | |
|---|---|---|---|
| Yu et al. (2016) | 20 male sprinters that were maximal sprinting 12m and 40m away from the center in a synthetic gymnasium. They used a 3-dimensional motion analysis system to collect the kinematic data | The results showed during mid acceleration, it showed shorter braking and longer propulsive durations and lower peak at the horizontal braking forces in counter to the phase of maximal velocity. | A paired t-test was used for both samples that showed P value<0.05, which means it is significant |
| Samozino et al. (2022) (5) | 231 athletes from various sports were used in a biomechanical model that they developed. During running acceleration (<30m) to express the time to cover a given distance as a mathematical function of maximal power output and force velocity profile. | The results show that sprint performance depends on both factors, where the individuals depend on both maximal power output and sprint distance. the lower the sprint distance, the more velocity will gain and vice versa. | By using regression analysis and RMSError that shows a difference between modeled and observed values that contributes to variables in sprint performance. |

| | | | |
|---|---|---|---|
| Donaldson et al.<br><br>(2023)<br><br>(6) | 21 sprinters were tested by obtaining angular kinematics and coordination was determined using vector coding methods with step 1 and steps 2-4 separated for analysis | The study identified coordination patterns for endurance runners during the different phases of the run. These were associated with differences like speed, power and force production. | The study has taken steps to ensure and provide insights into coordination and the performance of the runners. It would need a more thorough examination of the methods and results of the study to be able to assess the complete validity |
| Folland et al. (2017) | 97 endurance runners on a Treadmill test with three-dimensional full body kinematics that measured five categories of kinematics. | The results show numerous variables that correlates with RE and performance were 39% of LEc while another 31% from fire other valuables combined explained the performance | Since there has been regression analysis in the study and the values shows $p<0.05$, we can say that the data are valid. |
| Nagahara et al. (2018) | After a warmup, the participants ran 60m at maximum effort, wearing spiked shoes. Fifty-four platforms (1000hz) all connected to a single computer (TF-90100, TF-3055, TF-32120, Tec Gihan, Uji, Japan) trough 52m, approximately 1.5m behind the starting line to the | As running speed increased, propulsive and net anterior-posterior impulses and mean forces decreased, while breaking impulses and mean forces increased. Greater propulsive, smaller breaking and smaller vertical impulses, contributed to greater acceleration at 55%-95% and 75%-95% of maximal speed. greater propulsion, smaller breaking and smaller vertical mean forces contributed to | the significance value was set at $p < 0.5$, and all values was calculated using JMP 12 statistical software |

| | | | |
|---|---|---|---|
| | 50.5m mark. each starting block was bolted to a separate force plate. | greater acceleration at 55%-75% of maximal speed. | |
| Prampero et al. (2023) | Mechanical and metabolic power was analyzed for Usain Bolts world record run vs medium level sprinters. | Bolts mechanical and metabolic power peaks at around 1 second with values being 35 and 140 W kg-1. These values decrease when constant speed hits at 6 seconds where Bolts velocity is at max and acceleration is at 0. The medium level sprinters have similar patterns with Bolt, but a difference in values. | The validity is consistent with the patterns and principles being similar between Bolt and the medium level sprinters. The overall values are different, because of comparing the world record vs medium level sprinters. |

## 3.2 Internal work

### 3.2.1 Running technique.

Purkiss and Robertson conducted a study in 2003 to determine the internal biomechanical cost (IBC) of running. They compared two methods for calculating the internal work of running: the absolute work method and the absolute power method. The IBC of normal running was compared with the IBC of inefficient running styles for eight runners. The results were normalized from both methods based on the athlete's body mass and running speed. Both methods were effective in finding inefficient runs. The absolute power method detected 23 of the 32 modified runs as being ineffective by seeing the higher energy costs making it 73 % accurate. The absolute work method detected 16 of the 32 modified runs where 50 % of them found a higher energy cost for the modified runs. 9 modified runs were found to be lower in energy cost compared to the normal runs. Purkiss and Robertson claims it is very unlikely that a modified run is more efficient than a normal run. This can consider to be an erroneous result (7).

The internal work calculations were computed with a great variability and a larger standard error by using the power method. They found out if one lowers an arm from a raised position and raise a leg from a lowered position, it can often detect the negative or inefficient runs. By doing it asynchronously the calculations take the work as correct. The methods can detect the runs of how inefficient they are, and the differences in doing that will be in the discussion. (7)

### 3.2.2 Locomotor form

The study that Folland et al. conducted in 2017 on aspects of RT that can relate to RE, lactate threshold velocity, and performance in endurance runners. There was significant variability that was found in the parameters within the group. Kinematic variables, pelvis vibration during ground contact and minimum horizontal velocity of the pelvis emerged as strong indicators. Through the analysis a correlation with all three outcomes appears. Larger vibration and lower velocity were linked to higher energy cost, lower lactate threshold and worse performance. Factors such as posture, stride parameters, and lower limb angels shows a correlation with the metrics on performance (8).

3.2.3 Shuttle running

A study on human locomotion by Zamparo was conducted in 2019, he stated that shuttle running can be considered as a good model for unsteady locomotion in humans. He used a motion capture system to record movements of 20 different athletes in shuttle runs with them performing at 3 different paces and 4 lengths, from 5 to 20 meters with 5 meters apart each capture. It's found that the mechanical efficiency decreases with increasing speed but will increase when the distance is longer. The aim of the study was to calculate the mechanical work and power to be able to estimate the total mechanical efficiency. They were able to find that the mechanical work was greater at shorter distances and at a high speed, and the efficiency was opposite when the speed was lower and the distance longer. The results suggest that the athletes constant speed phase and elastic energy saving plays important roles to improve the efficiency in longer runs (9).

### 3.3 Acceleration and max velocity

The study Yu et al. conducted in 2016,  analyzed various aspects of the mechanics during both phases. In the acceleration phase (AP), the average velocity achieved from the runners were 7.85 m/s, with the shorter stride lengths compared to max velocity phase (MVP). The variables in the GRF results compared breaking duration to propulsive duration.  "The precent breaking duration was significantly shorter, and the percent propulsive duration was significantly longer in the AP compared with the MVP" (10). Additionally, peak vertical GRF were lower and occurred later during AP. In terms of intersegmental dynamics, muscle torque patterns differed between the two phases. In the stance stage, it was observed significant differences in the hip and knee muscle torques, with greater hip muscle torque during the MVP. During the swing stage, the hip muscle at MVP showed better extensor peaks compared to AP, while the knee remained similar between the two phases. This shows the biomechanical differences between AP and MVP in sprinters, particularly in GRF and muscle torque patterns at various lower limb joints.

## 4. Discussion

The 8 studies that were used have researched running techniques, the calculation of internal work, acceleration and GRF. The research in this study has decided to focus deeper on the three factors that we are looking into. The results include internal work, kinetic energy, maximal acceleration phase, and the work of the lower limbs that can affect performance. Further in this discussion we will talk about our findings and why these factors correlate on how to improve performance and what we should be critical about.

### 4.1 Internal work

Purkiss and Robertson wanted to determine the IBC of running. They used two different methods to analyze and detect inefficient running techniques. The absolute power and the absolute work method. Both methods were able to detect the inefficient runs. Both methods proved to be effective, but one more than the other, so the power method proved to be the most efficient to detect the inefficient runs by the athletes. To find the results, an x2 test was performed and that confirmed a significant difference between the methods. The power method was more effective and consistent in finding the results and quantifying both internal and external work compared to the work method. The combination of the negative work of lowering an arm from a raised position and the positive work of raising a leg from a lowered position can be used to detect negative or inefficient runs. This can be computed correctly if these movements are performed asynchronously. When performed simultaneously, the decrease in energy of the lowering limb is assumed to cause an increase in energy of the rising limb. However, the measuring of the total body work is underestimated considering that the energy is directly transferred between the two segments, when this assumption is incorrect. They find that inefficient runs can be detected by combining the negative work of lowering an arm from an elevated position with positive work when elevating a leg from a lowered position. If both movements were performed asynchronously, the internal work equations compute the work involved as correct. If both tasks were performed simultaneously, a decrease in the energy of the lowering limb is assumed to cause an increase in the energy of the rising limb. In this study multiple methods and calculations were introduced by different people from older times. Purkiss refers to Wells providing us with the information of the internal work calculations being correct by combining negative work with positive work and performing the task asynchronously. If both tasks were performed simultaneously, it was proved an decrease of energy in the persons lowering limb which caused the energy in the raising limb to increase (7).

Purkiss and Robertson refers to a handful of authors of different articles who provide different theories on how to calculate internal work equations. Winter uses a different approach to Wells, where he computes the different powers from the joints and then integrates them with respect to time to find out when the total work is done. Winter outlined all these principles while a researcher named Elftman outlined these equations. The equations said negative and positive values can cancel each other before they were integrated and that makes it ignore the total work. Purkiss and Robertson claimed that Elftman, another scientist, eliminated the problem by modifying the power equations. The total values of moment powers were put together to make the total mechanical work. This method is mechanically invalid compared to the power approach, but little research makes it difficult to say there is a big difference between both methods (7).

### 4.3 Shuttle running

"During locomotion the human muscles use metabolic energy to be able to produce mechanical work in an efficient way or in a less efficient way, and the mechanics and the energetics of locomotion can be considered to be two sides of the same coin (11)". This statement can align some with what Zamparo´s study was focusing on. The study of shuttle running by Zamparo has different implications for sports training. It focuses mainly on how we understand the biomechanics and energetics of shuttle training. Doing this at different speeds and distances, it can have practical implications for both athletes and coaches from all different sports and sprinters. The mechanical efficiency decreased with increasing speed but could increase when the distance was higher. This can suggest that the athletes could adjust their technique and pacing based on the demand of the task, and could be 60-meter, 100 meter or just normal shuttle runs. To improve efficiency when performing this task can be done by minimizing the brake forces and maximizing elastic energy. The findings of why humans exert braking power more than the propulsive power when running can give good insights to the muscle function of the athlete and the energy utilization when performing such dynamic tasks. This study has limitations with the small sample size of athletes but could in the future by conducting a larger scaled study become more accurate and provide even more data. Zamparo used the equations of Di Prampero and found the cost of the acceleration was estimated to be at 50 J kg^(-1) m^(-1) and at constant top speed the metabolic cost was 4 J kg^(-1)m^(-1) (9).

### 4.4 Acceleration and max velocity

As we can see in the results that Yu et al. found in their article, there are biomechanical differences between AP and MVP of sprint running where we are seeing mechanical factors that influence the performance and the physical attributes that requires be better. Yu et al was focusing on spatial temporal parameter and GRF Variables, but in the article, there are also highlights on the kinetic data of the lower limbs which is the most important factor for both phases. The horizontal propulsive forces were most predominant for the AP while both horizontal impulses were equal during MVP. When we look at the torque time across the sprint phases, it suggests that similar joint kinetics differ in horizontal braking rather than propulsion that can point out the relation to AP. The analysis of the vertical GRF indicates the significance of the horizontal impulses and force patterns when it comes to changes in velocity. The lower limb analysis showed a pattern of distinct muscle activation that suggests adaptation to various horizontal braking forces. There are some limitations, however the data from both phases shows critical importance related to braking and propulsion that are important biomechanical principles of sprinting. Some of this information shows valuable insight on how someone can optimize performance and improve the two phases through training. Something that can be investigated is what various types of muscle in the lower limb that affects these two phases. The article from Pandy et al. takes a deeper analysis on how the different muscle groups that relate to the lower limbs that can play a role in propulsion, stability and stride optimization, that can conclude which muscle groups are important to train considering physical strength (10,12).

### 4.5 Influence of running technique

Even if RE is not the most important factor for a sprint, it still shows a relevance to RT that is important to the sprint. A good start in a sprint can have a lot of influence on a race. It is therefore important to coordinate stride length, frequency and front mechanics to optimize the start. Coordination can be somewhat difficult to train, considering the parallel foot-arm coordination that can improve the swinging that is relevant in locomotion. Based on the data, the hip and knee exterior are the priority to optimize which Haugen et al. was looking at, even though the front and back mechanics are more reliable in the phases that includes AP and MVP. The lower limbs that relate to forces and torques involve movement patterns that correlate with joints and segments during running but are also important when we are talking about RT. Some of the factors that Moore is talking about, shows how RE can be influenced and improve the individuals RT (4,13).

### 4.6 Critical use of metabolic model

The study of di Prampero presents a model and an analysis for the world record time of Usain Bolt's 100-meter dash. He uses the concept of internal power to be able to estimate the total mechanical power. The model suggests it produced a power of 4700 W after 2 seconds and this power was maintained until 7 seconds. Ettema commented on this study and suggested that Bolt would have maintained the power of 4700 W until the end of the race since his running speed barely declined in that time. Di Prampero and the other authors acknowledge that the concept of efficiency needs to have a better clarification. It needs clarification to understand the inclusion of elastic energy and the study suggests that the efficiency cannot be higher than the isometric muscle contraction at around 25-30%, 35% at most and not 75% that was estimated with the model that di Prampero used in his article. Ettema concludes that the findings by Prampero indicate the sum of internal and external power are overestimating the power being delivered by the muscles when the whole body is doing movement. Because of this it supports that the concept could be flawed, and this especially by Aleshniky in who had criticized the concept of theoretical grounds (14,15).

## 4.7 GRF

The Nagahara 2018 study gave the obvious answer that, when propulsion impulse increased and breaking impulses decreased, it led to greater acceleration. Nagahara`s study shows a clear relation between the increased GRF and better acceleration. The study also showed a relationship in the angle on the GRF vector and acceleration. Of course, when increasing the horizontal propulsion, the GRF vector will increase, but a smaller vertical mean force also has an increase in acceleration. That would indicate that just by moving the vector in a more aggressive angle towards the horizontal plane, the GRF would go more "straight forwards"' and the acceleration would be greater as well. As Haugen comments, without any or low vertical GRF, a sprinter would not be able to keep upright, let alone sprint. However, since vertical GRF cannot be minimized, it should be optimized instead. For the most optimal acceleration, the runner should exert just the right amount of force against the gravity, so that they can stand upright (comfortably), while exerting the most propulsive force they can in the horizontal direction. That would give the GRF vector the most optimal angle, and the most value (3).

## 5. Conclusion

This thesis gives a view into the performance factors of sprint running. The results give a clear indicator on what affects performance. Acceleration comes out as the strongest factor for improving performance, and here propulsion and GRF plays a big role. As shown by the results, a lot can be improved by increasing the GRF, and decreasing the GRF vector angle by either having more propulsion or decreasing unnecessary vertical GRF. This can be done by improving the locomotive form. Better RT shows a correlation with overall performance and can improve RE. Also, the locomotor factor shows the relation between RT and energy expenditure that correlates with kinetic variable and RE for efficient running. Overall, this study gives valuable insight on the biomechanical factors in sprint running that can influence and improve a runner's sprint.

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