Introduction

As a sport with a relatively young history, climbing has gained public popularity in the 1970s. During the early stages of the sport it was not widely accepted by society as a sport and merely something “weirdos” or social outcasts who lived in their cars would do. There were no rules or regulations when it came to gear, security or how to judge the performance or difficulty of a climb. A movement that took place in the famous Yosemite Valley in Yosemite national park during the 70s helped the sport gain some public support. Following these first pioneers who were climbing almost anything they could find in regular shoes and with static ropes that allowed for no stretching, an increasing number of people started to view climbing as a way to explore freedom and as an actual sport. As the public interest was growing larger first companies and associations started to form that gave the sport a more graspable frame. Grading systems were developed to judge the difficulty of a climb and make performance comparable across regions and countries. As a result of the sport becoming more competitive climbers were looking for ways to increase their performance.

One way was the introduction of training regimens that helped strengthen the specific active and passive structures of the body required to climb hard. Another way was the development and improvement of the gear used by climbers. In the meantime various disciplines had developed that were once gathered under the name climbing. While today there is bouldering, sport climbing, trad climbing, rock climbing, speed climbing, crack climbing and various other sub disciplines that all rely on different styles of rock, heights or gear involved, one thing they all have in common is a shoe that to the untrained eye always looks quite similar.

To a climber the shoe presents a whole world of possibilities and has become necessary to accomplish difficult climbs as it becomes a second layer of skin during climbing. An experienced climber chooses the shoe based on the requirements of a certain climb. There are different types of rock, different inclinations of the route and the size of the footholds to be considered. While a steep or even overhanging climb with sharp rock and small holds might require a very stiff shoe with an aggressive downturned nose and a hard rubber, a route on a positively inclined wall (slab) with very round features that present almost no sharp edges will require a soft outsole with an almost flat form. What aspects of performance are to be considered in the different disciplines and what product and material properties of a shoe can be changed, together with the results of current research will be discussed in the following chapters.
Understanding Climbing
Disciplines and Requirements

As stated in the introduction there are many different disciplines of climbing and even more styles across these. Covering all of them with their individual aspects and differences would not contribute much in the analysis of the shoes worn. Because of this there will be a focus on the two most prominent disciplines of climbing that also show the largest differences in structure of the routes, fields of fitness that are needed to excel and thus require an educated choice of shoes.

Bouldering

Bouldering is a style of climbing that takes place in small heights until 4 – 6m and is done without any form of security gear like a harness, except for mats on the floor to cushion a fall. As the routes aren’t as long the density of hard and powerful moves is a lot higher in bouldering than in any other form of climbing. The inclination of the wall is often overhanging or even parallel to the ground. Climbers looking to excel in bouldering often need to have a lot of explosive strength to be able to do long moves that can even include jumps, a lot of finger strength in order to hold on to tiny holds that can get as small as a credit card is thin and most importantly core tension.

When the body is parallel to the ground, the lever arm of the attacking forces is also increasing and leads to very high rotational moments. Most of the time when a fall is happening in such a situation it is because the climber can’t produce enough core tension or because the feet slip due to unprecise placement or a lack of traction (Noé, Quaine, & Martin, 2001; F. Quaine & Martin, 1999).

Lead Climbing

Lead climbing can also be considered the classical style of climbing. The routes in lead climbing are usually around 30m long but can go up to 80m in extreme cases. The climber is wearing a harness and is secured to a rope. Along the route there are bolts with regular spacing and the climber clips the rope into so called quickdraws (two carabiners connected by a piece of fabric; one end is clipped into the bolt in the wall, while the other end hangs
freely until the rope is secured to it) to prevent large falls. While such routes also often include overhanging parts, it is also common to have them combined with slab sections. In these the wall has positive inclination and with increasing difficulty of the route the holds for the feet become smaller until there is almost nothing left to stand on. When the holds get smaller and rounder the role of friction drastically increases. Up to a certain point it is mainly a question of foot muscles and technique to be able to stand on a hold. Past that point a climber can merely rely on the traction between his shoes and the wall in order to successfully finish a climb.

Looking at the two different disciplines there are certain situations that repeatedly appear in different routes. Overhanging or slabby sections often appear isolated in a bouldering route, while when looking at the longer climbs in lead climbing combinations of the two get more common. Depending on the different sections in a route a climber might want to choose a more aggressive and harder shoe to be able to stand on small and sharp edges and keep the feet from slipping on overhanging terrain or choose the complete opposite. Standing on slabs with very round edges is also called smearing and requires a very soft shoe with a flatter sole to maximize the contact area between the feet and the wall.

Performance influencing factors
As climbing is becoming increasingly popular as a leisure activity and competitive sport there is a need for a valid and reliable performance assessment. In order to quantify the performance level, it is important to know the factors contributing to performance in the different disciplines of climbing and how to measure them. What factors contribute the most to performance in climbing? In order to answer this question Magiera et al. (2013) performed a canonical analysis of 45 parameters and divided them into three groups to find out each variable’s “pure” contribution to rock climbing performance. They could show that the influences of the physiological & anthropometric (38%), coordination & technique (33%) and mental & tactic characteristics (25%) were similar, yet different.

They compared the numbers of their analysis to a thought model postulated by Hörst (2003), in which he presented the performance determining characteristics of different sports. Both authors concluded that the structure of performance in climbing is complex and multifaceted.

The coordination & technique characteristic is arguably the one most influenced by the climbing shoes as they enable the climber to use advanced techniques and by contributing 33% to the performance during climbing its impact on the outcome of a climb can be huge. Obviously wearing better or newer shoes can’t enhance climbers’ abilities, but it can help them be able to use their full potential. On the other hand, wearing the wrong or an ill-fitting shoe can be a large handicap. Slipping from footholds and falling are direct consequences of
the choice of the wrong shoe. It could also be argued that there is an influence on the mental side of climbing, as “trusting your feet” is a common saying among climbers. This probably doesn’t affect the performance as much as slipping from a hold due to an unsuitable or old shoe but should still be considered.

Importance of load distribution

First biomechanical analyses of rock climbing were conducted in the late 1990s. In their paper from 1997 Quaine et al. describe the role of the upper and lower limbs as following:

“In rock climbing, the functional role of the upper limbs is to stabilize posture through contact forces, while the lower limbs support the body weight through vertical forces.”

In a preceding study from 1996 Quaine et al. looked at different weight redistribution strategies when one hand was voluntarily released in a vertical position on a climbing wall and a horizontal position on the ground. In a vertical position the goal of load distribution in a tripodal state seemed to be an equal distribution. The authors concluded that this was the case as it allows the climber to release any other limb in following movement without risking a fall. In a horizontal position the subjects could not follow the same strategy but had to rely on a diagonal redistribution of the forces in order to maintain their position.

In order to quantify how the feet contribute to the bearing of the body weight during climbing Noé et al. (2001) additionally analysed the moments acting on the different supports. They looked at the distribution in a quadrupedal state and after voluntarily releasing one foot while hanging from two differently inclined walls (0° and 10°). They found that on the vertical wall there was a more contralateral shift of the forces in order to maintain an equilibrium of moments. In the overhanging position moments around the sagittal axis were decreased and the strategy after releasing a hold was to equally distribute the forces. According to the authors this was done to reinforce safety in case one of the remaining supports slipped unexpectedly.

When looking at climbing shoes these results suggest that on a vertical wall the resistance against slipping due to rotational moments around the sagittal axis and the bearing of the body weight are the main objectives. In a situation when a climber is present on an inclined
wall it seems to be more important to be able to reliably increase the load on a foot hold after releasing a limb. This is done in order to reinforce safety in case of a slip or to prepare for a following movement.

Lever arm management

In climbing it is a regular practice to wear tight shoes. This is usually achieved by choosing shoes that are a few sizes smaller than comfortable fitting street shoes. It has been shown that this effect is correlated to and increasing with the climbing ability (McHenry, Arnold, Wang, & Abboud, 2015). It was also shown that people choose their climbing shoes up to 6.5 sizes smaller than their street shoes, with most of them being in the 2.5-5 size range (figure 3).
Climbing shoes: How can they influence performance, how are they built and are they worth it?
There are two main mechanisms that increase performance when wearing such small shoes. One of them is directly connected to the tight fit of the shoe all around. When the shoe is so small that it forces the foot into a certain position it is less likely to experience movement of the foot within the shoe. When this happens all other properties like rubber friction or hardness of the outsole loose importance as the shoe is not loaded in the intended direction anymore and most likely looses traction.

The other mechanism is connected to lever arm management. When a smaller sized shoe is chosen not only the tightness of the fit increases but also the length of the shoe. In their paper McHenry et al. (2015) expressed length of the shoe relative to the foot length. With an increasing climbing ability, the frequency of lower values increased with some of them being as low as 90%. As the moment that needs to be produced depends on the loading force and the square of the lever arm, every centimetre saved can make all the difference.
Another way to decrease the lever arm is to use an aggressively formed shoe. These are characterised by having a downturned tip of the shoe. On the one hand this decreases the lever arm of the applied forces, on the other hand it also provides a semi-rigid and straight platform to stand on once the shoe is loaded.

**Principle of a climbing shoe**

After discovering the different ways a climbing shoe can influence the performance of a climber this chapter will look at the structure of climbing shoes, what different kinds there are and how they are built.

**Structure of a climbing shoe**

As any other sport shoe, a climbing shoe consists of an upper, a midsole and an outsole. There usually is no insole as it doesn’t influence the behaviour of the shoe. The inside of the shoe usually is made from leather, synthetic leather or another kind of soft fabric. The main function here is to provide a rigid base layer that the rest of the shoe can be built around. The midsole of a climbing shoe is made from a rubber or even plastic. The material chosen for the midsole influences the overall stiffness of the shoe. Most aggressive shoes have a hard insole made from a plastic that gives the shoe it’s form and provides a long-lasting structure. Soft shoes on the other hand are sometimes built without any kind of midsole to make the sole as thin as possible and provide a lot of sensitivity and flexibility to the foot.

The largest difference in the structure of a climbing shoe compared to other kinds of sport...
shoes is probably in the upper. Climbing is one of the only sports where to the upside of the foot is actually involved in movements and comes into contact with the wall/ground when doing a toe hook.

To provide good traction, stability and make this position more comfortable there is a rubber “toe patch” on top of the upper of a lot of climbing shoes.

Figure 5: Picture of a climber’s foot in a toe hook position.

Form

There are two form properties in climbing shoes that vary between models. One of them is the so called “pretension” and the other one is the asymmetry of the shape. The tension of a shoe refers to the arch of the shoe in a resting position. A highly tensed or aggressive shoe will not be able to lay flat on a table as the arch is so prominent that only the tip of the toes and the heel touch it. The more aggressive a shoe gets the better it performs on small footholds, but it also gets more uncomfortable. The pretension of a climbing shoe can be either neutral, moderate or aggressive. While most beginners’ shoes have a very low pretension to increase comfort this doesn’t necessarily mean that they perform worse on the wall. On slabs and smears a neutral shoe usually performs better as these kinds of climbs rely on friction and therefore require a larger contact area between the foot and the wall. The asymmetry of a climbing shoe is larger when the tip of the shoe is not pointing to the front but more inwards. Giving a climbing shoe this kind of shape drastically increases its’ performance on tiny footholds. When the area to stand on gets so small that not even half a toe is in contact with the wall the asymmetry of the shoe provides a natural resistance of the shoe against bending. Increasing the asymmetry of a shoe makes it very uncomfortable and is usually only done I very high-performance gear.
Material

In climbing shoes leather and rubber are the two mainly used materials. While leather builds the base of a shoe and gives it its’ form the choice of rubber influences performance and longevity of the shoe.

In climbing shoes either natural or synthetic leather can be used. Natural leather is slightly more expensive but allows the shoe to slightly stretch over time and model around the foot of the climber. This makes a shoe more comfortable in the long run but also more prone to wear. As climbing shoes are usually worn barefoot the natural resistance to smell is another welcome property of natural leather. Synthetic leather on the other hand provides a lasting form and fit of the shoe that is very resistant to deformation over the course of months.

The main difference between different rubbers in climbing shoes is the hardness. A hard rubber will provide very good resistance to wear and makes a shoe last longer. Choosing a shoe with a soft rubber will grant the climber more friction and a more sensitive feeling of the surface of the wall. The softer rubber deforms more easily and digs into the structure of the wall which increases the contact area. Because it is more easily deformed small parts of it also rip off much faster leading to increased wear of the shoe. While a medium hard rubber seems to combine the best properties of both sides it usually is just a compromise and not chosen to high performance shoes. The softer rubber also performs better on slabs and smears, while the harder rubber works better in overhanging terrain with small footholds and hooks.

There are a lot of properties that can be tweaked in a climbing shoe to make it perform better in certain situations. This also means that there is no all-round shoe that can do it all but merely the perfect shoe for a specific situation.

An example can help to highlight the importance of finding the right climbing shoe.

The hardest sport climbing route climbed to date is called “Silence” and was only climbed by the well-known climber Adam Ondra. After completing the climb, he had to introduce a new grade of difficulty to rate the climb because he felt there was nothing of a comparable difficulty established so far. In order to climb this route, he had to travel to northern Norway several times over the course of three years and was only able to complete it with two different shoes. He had to do this as the hardest key sequence of the route consists of just a small crack that is almost parallel to the ground. He needed to find a shoe for one of his feet...
that perfectly fit into the crack and allowed him to position it above his head in order to freely move his hands in this situation and continue the climb.

Conclusion

Describing the importance of climbing shoes and their influence on performance it not possible without proper tools to assess the performance of a climber. While there have been different research projects looking at the specific role of hands and feet in climbing in different situations there seems to be no publicly available research that systematically analyses the influence of form and built of a climbing shoe on its’ performance. As climbing is becoming increasingly popular and the number of climbing shoe manufacturers is also growing, the range of different climbing shoes is becoming hard to keep track of. For beginners there are certain established rules and opinions about the right choice of shoes, but it seems like those only rely on experience rather than experimental data. In the field of high-performance climbing there definitely is a need to completely understand the functional principles of climbing shoes to help the climbers perform better in competitions and push the difficulty of climbs that are possible to complete. Further research should focus on understanding the underlying principles of footwork in climbing and the shoe-wall interaction for different materials and shoe forms.

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Figures

Figure 1: http://howtoclimbharder.com/wp-content/uploads/2016/01/5041470940_39cb20faf3_o.jpg

Figure 2: From Magiera et al. (2013), adapted from Hörst (2003)

Figure 3: Authors feet.

Figure 4: From McHenry et al. (2015)

Figure 5: https://betatother.com/wp-content/uploads/2017/12/toe-hook-Climbing-Moves-1.jpg

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