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The Influence of Equine Conformation on Performance

By

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INTRODUCTION

As a nationally ranked 4-H horse judging contestant in high school, I was introduced to many rules about how horses should look in order to be considered ‘good’ horses (horses that would be chosen to be bred to produce even better horses for athletic performance). When judging horses in this way, you are considering their ‘conformation,’ or the degree of physical correctness regarding how the skeletal and muscular frameworks are connected. The general idea is that you can estimate a horse’s athletic potential by evaluating its body, since it is the functioning of those body systems that determine the quality of the movements that are required in athletic disciplines.

I believed every tenet of equine conformation judging that I was taught because they were explained using common sense. For example, straight legs are important for performance because they won’t interfere with each other during motion. A few years ago, I began to hear about younger students performing small experiments testing some of these tenets, mostly regarding shoulder conformation, with mixed results. This intrigued me because I had previously thought that all of the rules were in place because they had tested to be true. Although the scientific research was amateur, the fact that it wasn’t supporting what I had considered common knowledge was still alarming. More recently I read that someone had modeled the ‘ideal’ (imaginary) horse standard that every horse is compared against when judging conformation. They asserted that the ‘ideal’ horse, with all the exact proper placement of bones and angles between bones, would never exist because, according to the laws of physics, it *would not be able to move*.

When beginning to brainstorm my own project, I suspiciously could not find either of these articles again, but I wanted to investigate for myself if those amateur researchers may have been on to something. Of the many basic tenets of 'ideal' horse conformation, how many exist simply because they have been passed down through generations of horsemen? How much scientific research has actually been done to show that the conformational features that horsemen consider most important are actually tied to athletic performance as they were believed? As it turns out, not much scientific research has even attempted to test the accepted 'truths' of horse conformation.

I began my project with a literature review of studies and reviews that I could find that attempted to link equine conformation to equine performance in athletic disciplines (such as horse racing, jumping, etc.) I found major differences between the studies. Each studied different aspects of equine conformation using various methods. Additionally, each quantified equine athletic performance differently. Sometimes these variations were due to the age of the study; techniques and instruments were developed over time and became more popular over the years. Other times researchers had slightly different questions that they wanted to answer through the study, which forced their measuring techniques to be completely different.

The researchers also faced some difficulties. For one, the availability of test subjects was narrow, while the population they were trying to generalize about was very wide. Only so many performance horses are available for research. Plus, it is important to keep most variables similar among the test subjects when performing research, which is difficult with such large and complex test subjects. For another challenge faced by the researchers, the factors they were trying to study are very subjective. For example, the definition of a 'narrow' neck can vary among observers. In regards to performance, athleticism can be defined as success in the athletic competitions or physiological superiority. The studies all basically concluded that there were few significant connections between the conformational conditions and athletic performance, but that there were so many other factors to take into consideration that it was difficult to be confident in the results.

After reviewing the research that had already been done, I began to design my own research study. What had most frustrated me while reading the other studies was that they had used so many 'measurements' that were not numerical in nature. Many used rating scales or judgments to quantify conformation, which were too subjective, in my opinion. In order to avoid subjectivity, I chose conformational factors that were considered most important and could be quantified easily. I used a variety of horses from the Alfred University equestrian program to gather data that I could apply to many horses, rather than just those belonging to a specific discipline. Because the horses were all part of the same program, I knew they all received similar care and exercise during the course of my study.

When judging horses, I was taught to first look at the slope of the horse's shoulder, as that was very important in determining a long stride length. A 45˚ angle between the scapula and a line drawn parallel to the ground was the golden rule of shoulder slope. In my research, I also found that shoulder angle is a different but similarly important measurement. In order to ensure a healthy and long stride length, the angle between the scapula and the humerus (the two bones that form the full shoulder of the horse) is supposed to be as close to 90˚ as possible, without exceeding, according to conformation experts. I decided to test whether or not either shoulder slope or shoulder angle are actually significantly correlated to stride length. I also knew that it could be argued that leg length plays a major role in stride length, so I needed to measure that as well. If I could find evidence to support a strong relationship between shoulder conformation and stride length, people could feel more confident using shoulder conformation observations to predict a horse's athletic performance in regards to stride length.

For this part of the test, I used protractors to measure angles and measuring tapes to measure lengths between the above defined anatomical locations on each horse. I had a volunteer lead the horses across a freshly raked arena so that I could measure the distance between hoofprints in the dirt in order to measure the stride length with a measuring tape.

I was interested in using stride length because I thought it must be closely related to athletic ability, especially in disciplines that require speed, such as horse racing. Logically, an animal with a longer stride would require a lower stride frequency in order to cover more ground, meaning they would expend less energy to perform an activity than an animal with shorter strides would expend. In order to strengthen this argument, I decided to test it in my study as well. As I learned during my literature review, there are many ways to measure physiological athleticism and energy expenditure. However, there were much fewer techniques that were available to me in my research. Blood tests and tests that measured oxygen intake generally require the horse to be exercised on a treadmill. Instead I chose to use heart rates and respiration rates after a standardized exercise to estimate how much energy each horse was expending during exercise and how physiologically athletic each horse was.

Using simple measurement techniques helped to emphasize the point of my project, which was to form a connection between scientific research techniques and reliable conclusions that common horsemen can use to make informed decisions when choosing horses for athletic disciplines. I did not find any significant correlations supporting the idea that shoulder conformation was related to stride length, but I did have some results that suggested that longer strides would cause the horse to be more physiologically capable of performing exercise. Like the researchers that I studied in my literature review, as well as scientists in many different areas of science, my research had somewhat disappointing results; however, I was happy to be able to learn more about the scientific process and the challenges that come with following it through an entire project.

LITERATURE REVIEW

Introduction

As early as 354 BC, horses (*Equus caballus*) have been evaluated based on their conformation, which is the degree of physical correctness regarding their skeletal and muscular frameworks (Van Weeren and Crevier-Denoix 2006). Conformation can enhance or limit the animal's movement, and because equine conformation is heavily correlated with equine performance, horse breeders carefully select for certain physical characteristics when choosing breeding stock (Mawdsley *et al.* 1996). Although horsemen have many accepted 'truths' about the best conformation for their own disciplines, researchers still seek to quantitatively determine the most important conformation traits that determine how well a horse will perform athletically. Problems arise because athletic potential is difficult to standardize and because athletic performance depends on many factors besides conformation (Weller *et al.* 2006). As a result, physiological capacity, the relative ease at which physical tasks are performed, is often used as a measure of athleticism in order to estimate performance potential.

The characteristics that horsemen favor in their horses vary depending on the discipline, or type of performance, for which the horse will be participating or competing. For example, distance racehorses generally have long legs, powerful muscles, and light bodies, while dressage horses can be of a slightly heavier build while still maintaining gracefulness (Love *et al.* 2006). With that understanding, there are also many features that are preferred in all performance horses, which are generally considered 'correct' conformation. These include having balanced body proportions, straight limbs, and proper angles between important structural bones.

The aim of this paper is to analyze the disconnect between common equestrian knowledge and scientific research in regards to equine conformation's effect on equine performance capability. First, the findings from the limited scientific research that has investigated equine conformation will be reviewed, in comparison with the common, yet scientifically unproven, understandings in the equine field. This will be followed by a discussion of the complexity regarding scientific research into equine conformation's effect on performance, as conformation and athleticism are both multidimensional qualities that are difficult to quantify.

Common Conformation Needs for Performance

Physiological traits, such as the functionality of the cardiovascular system, have an obvious link to physical performance capabilities (Weller *et al.* 2006), but regardless of discipline or training, the overall conformation of the horse affects its performance to some degree. The proportions and angles of the bones have the capacity to limit the horse's range of motion, negatively impacting its performance. Some traits, such as height, neck size, and back length can be linked to age, while others, such as head shape, neck shape, and neck size are linked to sex (Mawdsley *et al.* 1996). These factors will be discussed in the following section, in order of anatomical location, from the ground up.

Foot and Limb Conformation

Foot and limb conformation is known to play a role in performance, so it is closely monitored at studbook admissions (Ducro *et al.* 2009). Much of the research in the field primarily records the occurrence of different conformation traits in populations of performance horses and then compares any variation in conformation to performance records. Having a high proportion of a trait in a population of performance horses doesn't necessarily mean that that trait is specifically being bred for, but it does mean that it isn't an unfavorable trait for that type of performance horse. Ideally, the hooves should point parallel to each other when viewed from the front of the horse; deviations from this ideal are termed 'toed out' or 'toed in.' 'Toed out' describes a condition in which the hooves point away from each other, while 'toed in' describes the opposite condition, in which the hooves point towards each other. Mawdsley *et al.* (1996) suggests that being 'toed out' in the front is less of a problem than being 'toed in,' as most racehorses studied had 'toed out' conformation, so it isn't a trait that is selected against when breeding for good performance. The researchers hypothesized that being slightly 'toed out' may be favorable because it allows the hind legs to extend farther without interfering with the front hooves, which allows for longer strides and greater collection (Mawdsley *et al.* 1996). However, it should be noted that this finding is challenged by Love *et al.* (2006), who showed that horses that are 'toed out' or 'toed in' have significantly poorer race records, so there is not a consensus in the field.

Some conformational features are impacted by lifestyle or behavioral patterns, so breeding for a specific trait would not be sufficient to develop the desired conformational feature in the horse. Similarly, breeding for one ideal trait can cause another conformational trait to be unfavorable. 'Uneven feet,' a conformation fault in which the front feet are different sizes and/or shapes, is an example of how both a behavioral pattern and breeding for a specific ideal trait can cause an undesirable conformational feature to develop. The occurrence of uneven feet is associated with lameness, and Ducro *et al.* (2009) found a negative correlation between competition performance and uneven feet. As investigated by Ducro *et al.* (2009), uneven feet can be caused by excessive lateral motion, which is related to tall horses with short necks, often seen in young horses with high growth rates (Ducro *et al.* 2009). Although height is a not generally considered an unfavorable trait, precautions need to be taken to avoid breeding a horse that is predisposed to corresponding unfavorable features such as uneven feet.

Since the hoof is such a compact structure, many hoof traits are correlated to each other to some extent. The pastern bones are between the bones of the hoof and the upper portion of the leg, and they are known to be angled parallel to the scapula in horses that have ideal conformation. Having upright pasterns is dangerous, as it predisposes the superficial digital flexor tendon to tendonitis; although if the pasterns are too sloped, horses are also known to be likely to develop tendonitis (Weller et al. 2006). Higher heels, narrow hooves, and upright pasterns are associated with each other, as they are factors which contribute to developing uneven feet (Ducro *et al.* 2009). 'Uneven feet' is an example of a conformation flaw that can be caused by other poor conformation features as well as by wear on the hooves caused by behaviors.

Likewise, foot conformation is also related to limb conformation. For example, upright pasterns are correlated with a horse being 'calf-kneed' (Ducro *et al.* 2009), a major fault in which the knees are behind the plane of the feet. Being calf-kneed is highly influenced by genetics and is correlated with poor race performance. The knee and tarsus should be directly in line with the rest of the leg, as viewed from the front or back of the horse, respectively. This allows the forces on the body to be evenly distributed across the leg during movement. If the knee isn't in line, tendonitis is more likely to occur, and if the tarsal joint, known as the hock, isn't in line, a pelvic fracture or digital tendon sheath effusion is more likely to occur (Weller et al. 2006). Another major fault that is strongly influenced by genetics is being 'tied below the knee,' when the circumference of the leg is smaller below the knee than above the fetlock (Love *et al.* 2006). When viewing the hock from the side, the angle of the joint shouldn't be too acute or too wide. The condition in which the hock angle is too acute is termed sickle-hocked. This absorbs more concussion during the impact phase of motion than a wider angle, but it can lead to plantar desmitis in some disciplines (Van Weeren and Crevier-Denoix 2006).There are many joints and bones located closely together in the limbs of the horse. If one joint is poorly angled, it can affect the position and functioning of most of the other joints and bones in the limb.

Joint angles are often considered important to performance, mostly in that if they are incorrect, they can severely limit correct movement. Studies have tried to determine whether joint angles or leg lengths determine stride length, but they either had mixed results or concluded that neither were good predictors for stride length (Van Weeren and Crevier-Denoix 2006). Although conformation can be an important predictor of performance, many other factors contribute to performance quality, such as physiological factors, genetics, character, and training (Love *et al.* 2006, Van Weeren and Crevier-Denoix 2006).

Shoulder and Hips

The shoulders and hips connect the limbs to the rest of the body, an obviously important role. Not much scientific research has gone into studying proper shoulder and hip conformation, but many horsemen regard the shoulders and hips as some of the most important conformation points to consider. Weller *et al.* (2006) found that the lateral coxal angle, the hip angle between the ilium and femur, is associated with performance and risk of injury. It is ideal to have a large hip angle in order to allow for more gluteal muscles to power the propulsion of the hindlimb. It also allows the muscles to be in alignment with the hip bones to affect them more directly, which reduces the stress to the muscles and the risk for pelvic fracture (Weller *et al.* 2006). The common understanding by professional horsemen across many disciplines agrees with these findings, that larger shoulder and hip angles are best for strength and also for stride length. Connections between angles and stride length have not been thoroughly researched.

Back

The area between the withers and the point of hip is simply referred to as the horse's back. It is always important to find a balance when discussing proper conformation, but especially so in regards to the back. In most disciplines, a short back is a desired trait because it creates strength in the back; however, it must be proportional to the size of the horse, as a short back paired with long limbs may cause the front and hind legs to interfere with each other, lowering performance capabilities (Van Weeren and Crevier-Denoix 2006). Van Weeren and Crevier-Denoix (2006) also found a positive significant correlation of thorax width to performance, as measured by racing time over a kilometer, in Standardbreds, most likely because a wider chest cavity should allow for larger lung capacity. Therefore, the conformation and size of the back and thorax is important because it affects both the mechanical and physiological functions of the horse.

Neck and Head

The rest of the horse, the head and neck, are important when choosing attractive animals for breeding; however, traits of the head and neck are rarely considered to be important to predict future athletic performance in any discipline. Many desirable traits of the head are only desirable due to an aesthetic preference and can be linked to the sex of the animal, with mares typically exhibiting more delicate features than stallions (Mawdsley *et al.* 1996). However, some conformation traits of the head are associated with better performance as well. For example, larger mandibular width allows for greater respiratory capacity. Since respiratory capacity is expected to increase athletic capacity, mandibular width is also expected to impact athletic capacity (Van Weeren and Crevier-Denoix 2006).

Desired neck length depends on the breed standards and discipline of riding, but the neck length should generally be proportional to the body length. Longer, slimmer necks are generally known to be more flexible than shorter, thicker necks (Ducro *et al.* 2009). Likewise, the flexibility of the poll, the top of the neck composed of the first few cervical vertebrae, becomes more flexible as the distance between the wing of the first cervical vertebrae and the mandible increases (Van Weeren and Crevier-Denoix 2006). This flexibility in the poll allows the performance horse to achieve an improved head carriage.

Performance Needs of Sporting Disciplines

Since disciplines require different athletic capabilities from the performance horses (McMiken 1983), 'ideal' conformation varies between disciplines. It is also important to note that 'safe' conformation varies between disciplines; that is to say that conformation qualities can protect against lameness in different ways for different disciplines (Love *et al.* 2006). Unfortunately, conformation needs of specific western disciplines have not been researched to any extent. Interest in western disciplines is rising in the global horse community, but the vast interest is in other, more lucrative disciplines. The available research reflects this interest, as well as the availability of test subjects from disciplines such as racing. This section will discuss the specific desirable conformation traits of the most commonly researched performance disciplines in the equine industry: horse racing, jumping, and dressage.

Racing

There is variability within the field of horse racing, as some horses are selected for their jump-racing ability, others for their flat-racing ability. There is also a difference between the horses chosen for sprint races or races over longer distances. One such difference is in the length of the croup, the topline from the top of the hip to the dock of the tail. Mawdsley *et al.* (1996) found that sprinting horses have shorter croups, which lets them have shorter, more frequent strides. On the other hand, long distance horses have longer croups for longer, more powerful strides (Mawdsley *et al.* 1996). Light distal limbs are important to allow the horses to run as fast as possible without carrying extra weight; however, this has the potential to predispose the athletes to injury (Weller et al. 2006). Here again we see that balance is key to conformation; the goal in breeding a successful racehorse is to produce a horse with light but strong limbs.

In the equine racing industry, conformation is an important factor for buyers because it is believed to affect the horse's future performance and soundness. Yet, Love *et al.* (2006) found no difference in the proportion of conformationally ideal, or 'correct,' horses that had been raced compared to horses that were not raced. Research commonly seeks to find the worst conformation faults, the ones that are significantly correlated with lowest performance. Conformation faults that lead to low performance are difficult to identify because outside factors that lead to low performance need to also be taken into consideration. The effect of bloodlines is more significantly correlated with race performance than are the effects of specific conformation faults (Love *et al.* 2006).

Although racehorses are typically tall animals, lightness and 'correctness' are key to speed and durability. It may be assumed that taller animals are generally weightier, with a larger girth area. A large girth is not ideal, however, as it is associated with large body mass, which increases the energy cost to the horse and the force on the limbs (Weller *et al.* 2006). In a sport that puts so much stress on the legs of the horse, leg conformation correctness is most highly valued in order to prevent injury. As in all disciplines, common knowledge dictates that legs should generally be straight through the knee. When the carpus is behind the hoof and the top of the radius when viewed from the side, it is considered a fault called 'back at the knee.' According to Love *et al.* (2006), being 'back at the knee' is associated with low race performance, but this not significant when the effect of the sire, the horse's paternal parent, is included in the statistical analysis. Horses that severely toe out or toe in are known to have a weakly significant negative correlation with race performance, even when the effect of sire and type of race are taken into consideration. Another fault, 'base narrow,' when the hooves are closer together than the knees or than where the legs join the body when viewed from the front, is significantly correlated with a lower frequency of racing (Love *et al.* 2006). Straightness of the lower limb is also important; when the fetlock joint is angled outward, it causes too much stress to the joint and increases risk of injury (Weller *et al.* 2006). Risk of injury is heavily considered when considering the conformation of a race horse, or of any horse destined for a high impact sporting career, because injuries are likely to be severe and career-inhibiting.

Jumping

Like racing, jumping is also a sport that requires speed and strength, but it also requires more flexibility and coordination than racing. Weller *et al.* (2006) suggests that in order to be a successfully competitive jumping horse, the animal must have a sloping shoulder and long humerus to allow for a greater stride length to increase speed while decreasing energy consumption. A connection between slope of shoulder has not been found by other studies to increase stride length significantly, although a sloped shoulder is understood by most horsemen to improve stride length. The understanding in the field is that the pasterns and hip joint should echo the shoulder conformation in order to maintain consistency and coordination. In research, long front pasterns and a long, flat pelvis are known to increase jumping ability (Van Weeren and Crevier-Denoix 2006).

It is also preferred for the jumping animal to be tall with light, clean limbs. If the front legs are too calf-kneed, rather than straight, the horse will not be athletic enough (Ducro *et al.* 2009). There is no consensus on whether a short neck (Ducro *et al.* 2009) or a long neck (Van Weeren and Crevier-Denoix 2006) is favorable in jumping horses. These correlations to performance are not strong enough to be definite predictors of performance in the sport, but they are based in logic and can be important considerations for horsemen in the field.

Dressage

Dressage requires similar flexibility as jumping and similar strength as racing, but it does not require the speed required by either discipline. As such, highly ranked dressage horses are generally tall with clean limbs and long necks (Ducro *et al.* 2009). As described by Van Weeren and Crevier-Denoix (2006), they have a long femur, humerus, and front pastern to allow for large movements. It is most important to have correct angles in the knee and stifle, which should be straight, as well as the elbow and hock to allow for graceful movement of the limbs. It is also beneficial to have a femur and pelvis that slopes forward (Van Weeren and Crevier-Denoix 2006). A sloping shoulder is preferred because it is believed to be correlated to a larger stride length at the walk, by both general horsemen and Weller *et al.* (2006); however, as was stated previously, no other researchers have found a significant correlation there. The pelvis is flat, and the stifle angle is straight in the ideal dressage athlete. Although a long back can be weaker, dressage horses can have a slightly longer back than other horses because it adds to their suppleness in their motions. The wing of the atlas vertebrate, the first cervical vertebrae, should be far from the mandible, as that increases the flexibility of the neck and allows the horse to bend that joint to collect into a proper frame (Van Weeren and Crevier-Denoix 2006). As with other disciplines, the ‘perfect’ horse, the horse with each of the above characteristics in perfect proportions, does not exist; however, industry professionals look for the most functional combination of these traits when selecting their next equine athlete.

History of Conformation Research

Historians estimate that civilizations first began to domesticate horses approximately 5000 years ago; however, the first person to write about horse conformation was Xenophon, who lived from 430 to 354 BC in Greece. The idea that equine conformation is related to athletic performance can be traced back to Xenophon’s publication, *De re equestri*. As cited by Van Weeren and Crevier-Denoix (2006), the understanding at the time was that a short lumbar area strengthens the back, and that the hindquarters need to be strong, since athletic propulsion seems to come from muscular hindquarters Symmetrical hooves were also favored for functionality, as were pasterns, the parts of the leg just above the hooves, that weren’t too sloped or too steep (Van Weeren and Crevier-Denoix 2006). It is interesting that all of these observations are still accepted tenets of equine conformation knowledge.

Scientific research on the subject of equine performance was difficult until Eadweard Muybridge and Etienne Marey began to use photography to study equine gaits in the late 1800s.

Van Weeren and Crevier-Denoix (2006) acknowledge researchers in 1984 for being the first to use photography to scientifically relate conformation to jumping performance. These researchers used skin markers to measure the shoulder and hip angles while photographing the horses jumping. The researchers concluded that proper angles are correlated with good jumping performance. More importantly, the basic technique of using skin markers and photography to measure conformation subjectively became, and still is, popular for this type of research (Van Weeren and Crevier-Denoix 2006).

Some researchers choose to use experienced veterinarians or horsemen to evaluate equine conformation on a descriptive rating scale (Mawdsley *et al.* 1996). These live observations allow for a more holistic evaluation of the horse's conformation; however, this leaves more to subjective evaluations, as standards can be slightly different between evaluators, even if they are defined in words (Love *et al.* 2006). To eliminate this subjectivity, studies can adopt a linear method using measurements of conformational characteristics, provided that the measurements are taken correctly. Even though these techniques are being used in research, there is no standard for assessing conformational traits of horses. The American Holstein Cattle Association developed a standard system for assessing conformation traits linearly, but this hasn't been successful in the horse industry, although some researchers have tried. Some traits simply can't be scored objectively with linear measurements, so they rely on a rating scale, which is inherently subjective to some degree (Mawdsley *et al.* 1996). Photography can be incorporated into this as well to speed the process for many horses (Love *et al.* 2006). No method is without its faults, and none has been developed yet that allows us to quantitatively and definitively conclude any specific relationships between conformation and performance or injury (Mawdsley *et al.* 1996; Love *et al.* 2006; Van Weeren and Crevier-Denoix 2006). However, the growth of technology is expected to further improve the way we measure conformation traits in order to relate them to performance (Van Weeren and Crevier-Denoix 2006).

Quantifying Performance

Although some horses are obviously more athletic than others, actually quantifying the performance potential of each horse accurately and in a way that allows comparisons to be made is very difficult. Love *et al.* (2006) used competition performance records to quantify successful performance of racehorses. For equine sports with numerical results, such as racing, competition performance records can be used; however, they must be used cautiously, taking into account factors such as environment, training styles, and management choices. However, comparing performance records only works to compare horses competing in the same discipline, as each discipline uses different measurements in its competitions. This also only allows for horses that have competition records to be evaluated, which is only a proportion of the horses that are actually developed for competition. As a result, only performance data of racehorses and Warmblood performance horses have been described through research, and even that data is limited and unstandardized (Bitschnau *et al.* 2010).

Instead of measuring equine performance in competition, some studies prefer to quantify performance by measuring physiological responses to exercise in order to evaluate athletic capacity (Evans 2007; Bitschnau *et al.* 2010; Vervuert 2011). Exercise tests can be used in a clinical setting because they can be standardized within a laboratory to diagnose conditions that may limit athletic performance (Evans 2007).

Physiological Parameters

While some sports require more energy than others, most equine athletic performance relies on production and conservation of energy during exercise (McMiken 1983, Evans 2007). Energy expenditure depends on the volume of work, such as distance travelled, and on the intensity of work, such as maximum velocity or oxygen consumption (Fortier *et al.* 2015). Energy consumption during exercise is important for many equine professionals to understand because a balanced diet needs to provide enough calories to offset the energy expenditure during performance (Fortier *et al.* 2015).

Horses have many physiological characteristics that allow them to be athletic, including their aerobic capacity, muscular glycogen and mitochondrial concentrations, thermoregulation, and powerful gaits (Vervuert 2011). Common parameters of exercise capacity used in research are oxygen consumption, blood lactate concentration, and heart rate (Bitschnau *et al.* 2010, Evans 2007). Each of these will be discussed in further detail as they apply to performance measurements in this section.

Oxygen Consumption

Oxygen consumption can be used to estimate energy expenditure. A common measure of oxygen consumption is $VO_{2\ max}$, which is the maximum amount of oxygen an individual uses during exercise. A performance horse with a lower $VO_{2\ max}$ has a limited aerobic capacity (Evans 2007). Oxygen consumption is a combined function of both the circulatory and the respiratory systems (McMiken 1983). Oxygen consumption is the best way to estimate energy expenditure because exercising horses require more energy for their body systems and more oxygen to their muscles (Vervuert 2011).

Although some portable devices have been developed to measure VO_2 during exercise (Art *et al.* 2006), it is generally only measured in a research setting since it requires complex equipment, such as a mask for the horse's head (Bitschnau *et al.* 2010, Evans 2007). A portable device adapted for horses from a device meant for measuring gas exchange in humans yielded reproducible results, but this is not yet commercially available (Art *et al.* 2006).VO_2 can be calculated by multiplying the cardiac output by the difference in the oxygen concentrations between the blood in the arteries and the blood in the veins, and its units are usually mL of oxygen/min/kg of body weight). Oxygen uptake can be measured per distance travelled by the horse using the units mL O2/kg/m. Higher values of these show a lower energy efficiency when the horse is exercising (Evans 2007).

Respiratory Function

Perhaps a more obvious way to evaluate aerobic ability is to consider the respiratory function of the equine athlete, or how effective the lungs are at inhaling enough oxygen to support exercise. As investigated by Curtis *et al.* (2006), horses utilize locomotory-respiratory coupling to reduce the amount of energy required by the lungs to facilitate air flow. The chest cavity expands to allow for inspiration when the legs extend, and it contracts to allow for expiration when the legs pull in. As a result, during exercise, the respiratory rate and stride frequency are correlated (Curtis *et al.* 2006). The idea of locomotory-respiratory coupling suggests that respiratory rate would increase to inhale more oxygen for the muscles to use during exercise requiring faster speeds.

There are multiple instruments used to measure different aspects of respiratory function. Spirometers can be used to record the pulmonary ventilation, and often can determine the severity of known respiratory problems. Spirometers record air flow, tidal volume, and respiratory cycle phases during and after exercise (Evans 2007). CO_2 analyzers measure $\%CO_2$ expired during exercise, and both spirometers and CO_2 analyzers can be used to identify big respiratory cycle (BRC) frequency. A BRC is a breath type, in which the inspiration and expiration periods are approximately twice as long as those of normal breaths, that occurs normally during exercise to improve air flow (Curtis *et al.* 2006). The type of instrument that each study uses depends on which specific aspect of respiratory function the researchers are attempting to investigate.

The least athletic horses can generally be identified easily by evaluating respiratory function. Horses with poor respiratory function, often caused by disease, have a higher respiratory rate after exercise, which can decrease performance ability. They also have higher tidal volumes and lower ratios of expiration time to inspiration time (Evans 2007). Additionally, horses with shorter strides, and therefore higher stride frequency, will perform less BRCs, have reduced air flow during exercise compared to horses with longer strides, and have lower performance as a result (Curtis *et al.* 2006). Identifying the least athletic horses is perhaps the first step in quantifying the athletic capacities of all performance horses.

Blood Lactate Concentration

The concentration of lactate in the horse's blood both at rest and after exercise are commonly recorded measures when considering equine exercise physiology in a veterinary or research setting. Like VO_2, lactate concentration can be a measure of aerobic metabolism of athletes (Fortier *et al.* 2015). Blood samples can be taken during treadmill exercise and measured immediately using a hand-held device (Bitschnau *et al.* 2010). Technology to analyze blood chemistry is not readily accessible to non-scientific amateur or professional horsemen, so its applications are limited to a research setting.

Maximum amounts of energy can be generated by breaking glycogen down through the full process of cellular respiration, which includes anaerobic glycolysis and the aerobic processes of the Citric Acid Cycle and the Electron Transport Chain. When the horse is inhaling adequate amounts of oxygen to support its activity, muscle cells will produce energy aerobically by allowing pyruvate to enter the Citric Acid Cycle.

Oxygen requirements rise during periods of high exertion, and if the horse is not adequately inhaling enough oxygen to support its activity, the muscle cells cannot access enough oxygen to perform the Citric Acid Cycle quickly enough to produce enough energy to support the necessary muscle activity. Anaerobic pathways provide energy at the beginning of exercise (during the first 60 seconds) and during short bouts of maximal exercise, such as sprinting (Vervuert 2011). In order to produce the required energy without oxygen available, pyruvate will be anaerobically converted to lactate instead of entering the aerobic Citric Acid Cycle. Lactate concentrations in the blood will increase when the horse is less capable of gathering enough oxygen to support its activity, either because the activity is too strenuous or because the horse is less fit (McMiken 1983).

Although this technology is most accessible to researchers and veterinarians, it can be used to measure aerobic athleticism. Horses that are better able to respond to the stress of exercise (i.e. better athletes) will have lower blood lactate concentrations because their bodies are better able to reduce lactate accumulation.

Heart Rate Recovery

Heart rate is a relatively simple measurement to record with commercially available monitors and is a popular method for evaluating horses' responses to different training protocols. Measuring heart rate can provide an alternative to measuring the much more difficult VO_2. For example, Evans (2007) found that the velocity at which the horse's heart rate is highest, VHR_{max}, is highly correlated with the velocity at which the horse's oxygen uptake is the highest, when the horse has reached $VO_{2\ max}$. Heart rate measures physical stress, but these measurements need to be analyzed before making causal conclusions, as some factors may obfuscate real results. For example, the horse's heart rate may rise simply due to fear of the experimental procedure. Heart rate can also be affected by the breed, conformation, and health of the horse (Bitschnau *et al.* 2010). Heart rate recovery, or how quickly heart rate returns to normal after strenuous exercise, is a more important parameter of equine fitness because it measures the body's ability to adapt to exercise, so more well-trained and athletic horses have faster HRR values than less athletic horses (Bitschnau *et al.* 2010). Because heart rate is such an accessible measurement, it can be applied by scientists and horsemen alike to measure athleticism.

Benefits of Treadmill v. Field Work

Horses are often exercised on treadmills while researchers record physiological parameters because it allows for standardized conditions between animals (Bitschnau *et al.* 2010). Specially developed treadmills allow the horses to be trotted and galloped at specific speeds to measure breathing, oxygen consumption, heart rate, and blood chemistry, such as lactate levels (Evans 2007). VO_2, especially, had never been successfully measured in the field until 2006 (Art *et al.* 2006), but it is still preferred to measure VO_2 using a treadmill because the field equipment isn't commercially available yet. One of the limitations of treadmill work is that the procedure is often foreign to the animals. High heart rates could be caused in part by fear of the treadmill, surroundings, or procedure, rather than by the exercise itself. This can be ameliorated by acclimating each horse to the procedure until it is no longer afraid of the equipment, but this could take a long period of time.

Although treadmills allow for standardization of procedures and measurements, the results may not be as relevant to actual equine exercise recommendations (Bitschnau *et al.* 2010). Beginning in the 2000s, researchers have been developing novel methods to assess performance under field conditions (Art *et al.* 2006, Evans 2007, Fortier *et al.* 2015). Equipment that measures heart rate and incorporates GPS allows the velocity of the horse to be calculated at its maximum heart rate (VHR_{max}). This specific parameter is correlated with performance of racehorses (Evans 2007). Relatively few field studies, which often use previously untested procedures, have been reported. The field studies that have been reported validate the accuracy of other field studies, but some report different physiological data than are commonly reported in treadmill tests (Fortier *et al.* 2015).

Applications & Limitations

Physical conformation traits such as angles of joints and length of bones are interesting and relevant to performance; however, conformation traits related to physiological performance, such as thorax width and mandibular width for respiratory capacity, may be even better standards for predicting performance. As this review has stressed throughout, no single conformation trait is a good predictor for performance due to the other factors that influence performance. Studies often rely on race or event performance records to evaluate performance, when these can be affected by too many random and unmeasurable events. This research technique also doesn't allow for a thorough longitudinal study, as it doesn't take into account management and veterinary records (Love *et al.* 2006; Weller *et al.* 2006; Ducro *et al.* 2009).

Measuring techniques incorporate various levels of human error. The inter-rater reliability of measuring anatomical landmarks can be weak, depending on the researchers and structures they are attempting to measure. Proximal body parts are harder to measure than distal ones simply because of the fact that they are closer to bulkier parts of the body (Weller et al. 2006). The fact that some measurement techniques are less repeatable than others makes some research results more questionable than others.

Even a combination of favorable traits to create a perfect horse by research standards isn't guaranteed to produce the best performance horse (Van Weeren and Crevier-Denoix 2006). This is partly because some advantageous conformational traits can predispose horses to injuries if they are taken towards an extreme. For example, having light limbs helps the horse move faster, but it also may make the structure of the limb less strong and more prone to injuries (Weller *et al.* 2006).

The sport horse industry suffers when horses are produced that do not become successful athletes. A greater proportion of successful equine athletes can be produced by implementing the knowledge gathered by research studies about the factors that contribute to success and the heritability of those factors. The financial and ethical burdens on the industry will be reduced as the proportion of successful equine athletes is increased. The more that breeding programs know about how subtle conformation variations can affect functionality (Mawdsley *et al.* 1996), the better horses they will produce, even within the already selective standards for performance that exist (Weller *et al.* 2006). By pinpointing these important conformation considerations, they could attempt to eliminate lesser-known factors that limit performance, such as uneven feet (Ducro *et al.* 2009). These changes could be facilitated by breeding organizations, such as studbooks, which could begin to outline more specific and scientifically backed standards to improve the quality of their breeds (Van Weeren and Crevier-Denoix 2006).

Understanding the influence of conformation is not only important for selecting good performers, it is also important for identifying risk factors (Ducro *et al.* 2009). Purchasing a horse, especially one intended for high performance, is a big investment that can easily go wrong in a variety of ways. Having more scientifically-backed clues as to which horses will be most successful would allow people to make smarter investments. Although it is difficult to assess conformation quantitatively and objectively enough to definitively relate it to risk of injury (Love *et al.* 2006), limb injuries are the top cause of early retirement of equine performance horses (Ducro *et al.* 2009). It is strongly believed that conformation affects risk of injury of performance horses because of its effect on weight bearing and way of going. This idea can be difficult to prove because only the horses with the best conformation are chosen to perform, so they are the only ones who are studied under performance conditions. Of the horses that are trained for racing, 6.2% never race because of unsoundness or inability (Weller *et al.* 2006). Because being involved in the sport horse industry is a risky investment, being able to use conformation measurements to predict likely future injuries would allow industry professionals to invest on the more sound horses in order to experience a greater return on investment.

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RESEARCH

Abstract

This study seeks to objectively determine to what degree shoulder angle, shoulder slope, and leg length affect the stride length of the horse. Stride length is important if it is assumed that an increased stride length decreases the amount of energy the horse requires during exercise. This study also tests this assumption using quantitative measures such as post-exercise heart rate, post-exercise respiration rate, heart rate recovery time, and respiratory rate recovery time. Data was collected from a variety of 29 horses with similar daily workload. Conformation parameters (leg length, shoulder angle, and shoulder slope) were collected for each horse. Average stride length at the walk and at the trot were determined for each horse. Each horse was also tested for average energy consumption by measuring post-exercise values and post-exercise recovery time for both heart and respiration rates. Of the three conformation parameters, leg length was the only significant predictor of Stride Length at the walk ($r=0.738$, $F=32.26$, $p<0.001$) and Stride Length at the trot ($r=0.515$, $F=9.75$, $p<0.001$). Stride Length at the walk significantly predicted Post-Exercise Heart Rate ($r=-0.396$, $F=5.01$, $p=0.034$). Equine leg length is a positively correlated predictor for stride length. Neither shoulder angle nor shoulder slope is a significant predictor for stride length. A large stride may allow for improved exercise fitness, as measured in this study by Post-Exercise Heart Rate.

Introduction

Many domesticated animals, including horses (*Equus caballus*), are evaluated based on their conformation, which is the degree of physical correctness regarding skeletal and muscular frameworks. Conformation can enhance or limit the animal's movement. Because equine conformation is heavily correlated with equine performance, horse breeders carefully select for certain physical characteristics when choosing breeding stock (Mawdsley *et al.* 1996). In any discipline, slope of the shoulder, shoulder angle, and stride length are known to be important in determining soundness and smoothness of gait (Clayton and Van Weeren 2013).

Most breeding standards are subjective and vary among breeders. Even research into the relationship between equine conformation and performance often relies on some degree of subjective evaluations or categorical ratings, rather than quantitative measures. The American Holstein Cattle Association developed, and continues to update and utilize, an objective assessment system in the 1970s to evaluate conformation qualities of cattle on a rating scale from ideal to least desirable (Holstein Association USA, Inc 2016). This still relies on some measure of objectivity for certain qualities. Few equine conformation studies have attempted or been successful at using completely objective measures to evaluate horses. For example, Mawdsley *et al.* (1996) and Love *et al.* (2006) used objective rating scales for some conformation parameters. Ducro *et al.* (2009) used mostly objective measurements to assess horse conformation and performance, although the validity of the performance parameters, racing records, is questionable.

According to traditional knowledge in the horse industry, a sloping shoulder is generally preferred to a steeper shoulder slope because it allows for a smoother gait. The slope of the shoulder is measured using the horizon and the line created by the horse's scapula. The scapula is measured from the withers (a point on the topline at the base of the neck) to the point of the shoulder. Conformation angles can be measured by using standardized photographs of the standing horses to measure shoulder angle (Mawdsley *et al.* 1996). Conformation angles can also be measured directly on the horse with a goniometer, which is an instrument containing two arms that rotate around a fixed point to measure the angle between two lines. It is generally accepted that a 45˚ shoulder slope allows horses to display longer strides and better quality movements (Melbye 2017).

Shoulder angle is a different measurement than the slope of the shoulder, although many people incorrectly use the terms interchangeably. Shoulder angle uses the same line along the scapula, but instead of the horizon, it uses the humerus to form the angle. The humerus is measured using the line from the point of shoulder to the point of elbow (Weller *et al.* 2006). It is an undesirable trait in performance horses for this angle to be less than 90 degrees because horsemen believe that a narrow shoulder angle inhibits shoulder motion and therefore limits the horse's stride (Melbye 2017). Scarce scientific research has even attempted to confirm this common belief, and the results of the few existing studies do not concur. Weller *et al.* (2006) found that a narrow shoulder angle was associated with a decrease in racing performance, but was not successful in attributing the poor racing scores with a decreased stride length or exercise capacity. The only existing studies that attempted to directly associate shoulder angle with stride length were performed and reported in Germany in 1935 by Franke and 1944 by Wehner. According to a review by Van Weeren and Crevier-Denoix (2006), both studies concluded that shoulder angles were not reliable predictors for stride length. There is a need for current research into a possible association between shoulder angle and stride length in an attempt to explain the industry understanding that a large shoulder angle is essential for good performance.

Limb length is often considered an important aspect of equine athleticism. Clayton and Van Weeren (2013) found that longer limb length is correlated with longer stride length. Horses can cover further distances at lower stride frequencies when they have longer limbs (Clayton and Van Weeren 2013). Limb length can be measured using measuring tapes, as long as there are clear points to take measurements from that are easily observed and standard across all horses (Mawdsley *et al.* 1996).

Shoulder angle, slope, and limb length are important conformation points because, within the industry, they are generally considered to affect length of stride. Stride length is defined as the distance between the fall of a certain hoof to its next footfall. Stride length is often measured with a series of high speed cameras and sensors while the horse runs on a treadmill, but in the absence of this technology, stride length can be measured by tracking footfalls in an even dirt path (Art *et al.* 2006). The average stride length is around 6 feet at the walk and between 9 and 17 feet at the trot, but this is dependent on the size of the horse (Ball 2000). In most disciplines, it is generally preferred that a horse have a lengthy stride, which can cover ground more effectively and more smoothly than a short and choppy stride. Stride frequency decreases as stride length increases (Clayton and Van Weeren 2013). Energy expenditure in all animals depends on the energy consumption of the body systems involved in movement. The more strides the horse needs to take to cover a certain distance, the more energy its muscles, respiratory system, and cardiovascular system will require (Vervuert 2011).

Although horsemen have many accepted ‘truths’ about the best conformation for their own disciplines, researchers still seek to quantitatively determine the most important conformation traits that determine the performance potential of horses, their ability to perform well in the desired discipline (Van Weeren and Crevier-Denoix 2006). Problems arise because performance potential in each discipline is difficult to standardize and because athletic performance depends on many factors besides conformation (Weller *et al.* 2006). As a result, physiological capacity is often used as a measure of athleticism in order to estimate performance potential (Bitschnau et al. 2010; Evans 2007; Fortier 2015).

Energy consumption and performance capability of the horse can be measured using heart rate, lactic acid concentration, or oxygen use. Oxygen consumption is considered to be the best measure of energy metabolism (Vervuert 2011), but measuring it involves a bulky apparatus that requires the horse to be on a treadmill (Bitschnau *et al.* 2010). Pagan and Hintz (1986) developed an apparatus to measure oxygen consumption of horses on a track, rather than on a treadmill. However, these methods are still not commercially available. As a substitute, respiratory frequency can be used to estimate aerobic efficiency. The average lung capacity of the horse is 55 liters. The resting respiratory frequency of the horse is 8-16 beats per minute and up to 120 breaths per minute during extreme exercise (Pilliner and Davies 2004). Lactic acid concentration is also generally reliable, but it requires blood testing. Heart rate is the most accessible measure of performance capacity to use in the field (Bitschnau *et al.* 2010). Heart rate, on the other hand, can be measured using a monitor that is attached to the horse using electrodes and sends recordings to a computer system. Heart rate should be lower directly after exercise and recover faster in more fit individuals (Bitschnau *et al.* 2010). Resting heart rate for the horse is 26-42 beats per minute and can reach 240 beats per minute during intense exercise (Betros *et al.* 2002).

This study seeks to objectively determine to what degree shoulder angle, shoulder slope, and leg length affect the stride length of the horse. This is important with the assumption that an increased stride length decreases the amount of energy the horse requires during exercise. This assumption is also tested during this study, using quantitative measures such as post-exercise heart rate, post-exercise respiration rate, heart rate recovery time, and respiratory rate recovery time. Healthy horses with similar training intensity backgrounds will be compared, although horses trained in various disciplines were selected in order to make any possible comparisons.

Stride length is expected to be most strongly influenced by length of leg. Stride length should be correlated with better energy efficiency, represented in this study by heart rate recovery and respiratory rate. In this case, stride length would be an important quality for performance horse breeders to select for, especially for horses intended for speed and endurance events. Shoulder angle and shoulder slope should also serve as strong limiting factors for stride length. Determining which conformational feature affects or limits stride length the most would allow breeders to quantitatively determine which horses are best to breed for more athletic offspring.

Methods

Study Site & Subjects

The study was performed at the Bromeley-Daggett Equestrian Center at Alfred University during the autumn and winter of 2017 using a variety of horses belonging to the Equestrian Center. Fourteen horses with a Western training background (six trained in reining, and eight trained in horsemanship), and fifteen horses with a Hunt Seat training background (approximately eight trained in jumping and seven trained for flat work) were studied. Efforts were made to choose 29 horses with similar daily exercise programs, although the horses had a random variety of ages and breeds (Table 1).

Table 1. A complete list of the horses used in the study, sorted by discipline and age.

Discipline	Age	Breed	Sex	Horse
Flat	12	Quarter Horse/Paint	Gelding	Scotch
	13	Quarter Horse	Gelding	Jig
	19	Appendix Quarter Horse	Gelding	Archer
	19	Hanovarian	Gelding	Desi
	20	Paint	Mare	Foxy
	20	Quarter Horse	Mare	Evie
	25	Warmblood/Welsh Pony	Gelding	Zim
Horsemanship	8	Paint	Gelding	Strider
	10	Quarter Horse	Gelding	Kody
	11	Quarter Horse	Gelding	Cash
	11	Quarter Horse	Mare	Dixie
	11	Quarter Horse	Mare	Sissy
	15	Quarter Horse	Gelding	Spencer
	16	Quarter Horse/Paint	Gelding	Henry
	21	Quarter Horse	Gelding	Willie
Jumping	16	Appendix Quarter Horse	Mare	Ginger
	16	Hanovarian	Gelding	Wilbur
	17	Hanovarian	Mare	Breeze
	17	Holsteiner/Thoroughbred	Mare	Jasmine
	17	Thoroughbred	Mare	Clare
	17	Thoroughbred/Pinto	Mare	Meg
	19	Trakhener	Gelding	Merlot
	20	Thoroughbred	Gelding	Sully
Reining	11	Quarter Horse	Gelding	Sunny
	12	Quarter Horse	Mare	Sugar
	14	Quarter Horse	Gelding	Kiddo
	15	Quarter Horse	Gelding	Frank
	17	Quarter Horse	Gelding	Paulie
	18	Quarter Horse	Gelding	Rey

Data Collection:

Conformation points were collected for each horse. Leg length was measured using a measuring tape from the right front point of elbow straight to the ground, when standing on a level surface. Left front legs were expected to be basically the same length as the right legs in functioning athletes, so they were not measured. The right front leg was later used to measure stride length, so this assumption should not have impacted the results in any way. Height at the withers was not considered an appropriate measure of leg length because height at the withers is impacted by body size, not just the length of the leg. Shoulder angle was measured using a goniometer and digital protractor. The average of both measurements was used as the shoulder angle value. Shoulder slope was measured in the same way as shoulder angle, using both a 360˚ goniometer from Prestige Medical and a digital protractor, from True Power. Additionally, a level from True Power was used to ensure that a line parallel to the ground was being used to form the angle. Two measuring tools were used to ensure accuracy, since human error could easily occur by using the goniometer, and technological error had the potential to occur by using the digital protractor. The two measurement techniques tended to result in very similar angle readings, each confirming the accuracy of the other.

To measure stride length at the walk, the right front hoof prints were tracked as the horse was walked by a handler in a straight line at a normal pace on a freshly raked stretch of the arena, and a measuring tape was used to measure the length between two footfalls of that hoof. Stride length at the trot was measured in the same way, with the same horse handler. The handler held the lead rope loosely and encouraged the horse to walk or trot in a straight line as needed, but the handler did not impact speed of the horse to ensure a natural gait and stride length. An average stride length was calculated after testing each horse three times at both the walk and the trot.

Each horse was tested for energy consumption, using three repetitions of the following procedure per horse and then calculating the average. Each horse was longed (exercised on a long line in a circle around a handler, without a rider or tack) at a working canter for three minutes. Heart rate and respiration were recorded at multiple specific time points (before exercise and directly after the three minutes of longe line work.) Using a commercial Polar Equine Healthcheck heart rate monitor, heart rate was also recorded by one observer every 30 seconds after the exercise as well, until it returned to baseline, which was generally less than 15 minutes. Respiration rate was visibly measured every 30 seconds directly after exercise until it returned to baseline. Respiration rates were measured by a different observer so that they could be measured simultaneously with the heart rates. The time it took for each parameter to return to resting was also recorded.

Data Analysis

The Kruskal-Wallis tests was used to compare medians between groups to determine if there were any significant differences between the four disciplines or between the two sexes. All other comparisons between parameters were performed used a Pearson Correlation and linear regression. Slope of shoulder, shoulder angle, and limb length were individually compared to stride length. A principal component analysis was considered in order to determine to what extent each is related to stride length, in relation to each other, but was not applicable because of the results of the regression test. Respiratory rate and heart rate recovery results were compared in order to potentially validate that they are both indicators of the same factor, aerobic performance capability. Next, stride length averages were compared to respiratory rate and heart rate recovery averages to determine to what degree stride length affects aerobic performance capability. All data analyses were performed using Minitab Statistical Software (Minitab 17 Statistical Software 2010).

Results

Difference Among Groups

Relatively few parameters were significantly different between the four discipline groups, except for age (H=9.39, p=0.025), leg length (H=13.91, p=0.003), stride length at the trot (H=12.39, p=0.006), and respiration recovery time (H=9.49, p=0.023). Western horses were significantly younger, with horsemanship horses averaging 12.9 years and reining horses averaging 14.5 years. Hunt Seat horses were significantly older, with flat horses averaging 18.3 years and jumping horses averaging 17.4. Reining horses had significantly shorter legs, an average of 0.888 meters, while Jumping horses had significantly longer legs, an average of 0.973 meters. The flat and horsemanship horses had average leg lengths very similar to the overall total, averaging 0.940m and 0.934 m, respectively. At the trot, stride length was significantly shorter for Western horses. Reining horses averaged 1.85m trotting stride lengths, and Horsemanship horses averaged 1.95m trotting stride lengths. Hunt Seat horses had longer trotting stride lengths than Western horses, an average of 2.11m for flat horses and 2.21 m for jumping horses. None of the exercise parameters were significantly different between groups except respiration recovery time, which was significantly shorter in Flat (101.4s) and Horsemanship (90.0s) horses than in Jumping (216.3s) and Reining (175.0s) horses. All of the above values are detailed in Table 2, which lists the overall average values for each parameter as well as averages by discipline. There were also no significant differences due to sex on any of the variables tested.

Table 2. A summary of the average values of each parameter measured in this study, including averages by discipline. Averages were rounded to the nearest whole number for heart and respiration rates. Astericks (*) denote parameters that were significantly different between the discipline groups, according to the Kruskal-Wallis test. Standard deviations are also included.

	Overall	Flat	Horsemanship	Jumping	Reining
Age (years)*	15.8 ±3.9	18.3 ±4.1	12.9 ±3.9	17.4 ±1.3	14.5 ±2.5
Shoulder Angle (˚)	83.8 ±5.1	83.6 ±3.3	81.3 ±6.6	85.8 ±2.4	82.3 ±5.5
Shoulder Slope (˚)	58.7 ±3.7	59.4 ±2.7	57.8 ±3.1	59.4 ±3.5	58.0 ±5.1
Leg Length (m)*	0.938 ±0.04	0.940 ±0.03	0.934 ±0.03	0.973 ±0.04	0.888 ±0.02
Stride Length – Walk (m)	1.64 ±0.2	1.68 ±0.09	1.57 ±0.1	1.74 ±0.2	1.54 ±0.1
Stride Length – Trot (m)*	2.04 ±0.2	2.11 ±0.2	1.95 ±0.2	2.21 ±0.1	1.85 ±0.2
Resting Heart Rate (bpm)	40 ±4.5	39 ±4.5	40 ±3.6	42 ±4.9	39 ±3.5
Post-Exercise Heart Rate (bpm)	79 ±16.1	78 ±15	82 ±17.4	75 ±12.8	81 ±18.0
Heart recovery time (s)	444.7 ±138.8	425.7 ±100.1	482.5 ±153.4	412.5 ±140	461.7 ±141.1
Resting Respiration Rate (bpm)	15 ±3.8	15 ±3.9	15 ±3.2	17 ±4.0	12 ±2.0
Post-Exercise Respiration Rate (bpm)	25 ±9.0	22 ±5.08	21 ±6.8	31 ±11.7	25 ±6.0
Respiration Recovery Time (bpm)*	144.3 ±114.1	101.4 ±32.3	90.0 ±105.8	216.3 ±152.6	175.0 ±42.3

Stride Length Predictors

Neither shoulder angle (Figure 1) nor shoulder slope (Figure 2) significantly predicted stride length at either the walk or the trot. Leg length, however, was a significant predictor of stride length at the walk (r=0.738, F=32.26, p<0.001, Figure 3) and stride length at the trot (r=0.515, F=9.75, p<0.001, Figure 3). As expected, neither shoulder angle nor shoulder slope were significantly correlated with leg length. Stride length at the walk and stride length at the trot are significantly positively correlated (r=0.573, F=13.17, p=0.001), and shoulder angle and shoulder slope are also significantly positively correlated with each other (r=0.438, F=6.39, p=0.018). Age significantly predicts stride length at the trot (r=0.399, F=5.10, p=0.032), but not significantly at the walk. Sex had no significant impact on stride length.

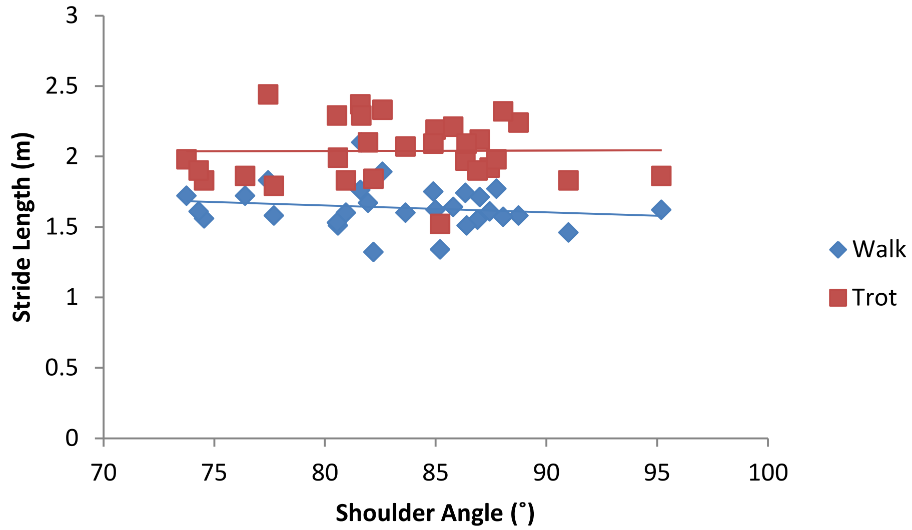

Figure 1. Horse shoulder angle is not significantly correlated with stride length at either the walk (r^2=0.026) (blue diamonds) or the trot (r^2=9x10^{-5}) (red squares).

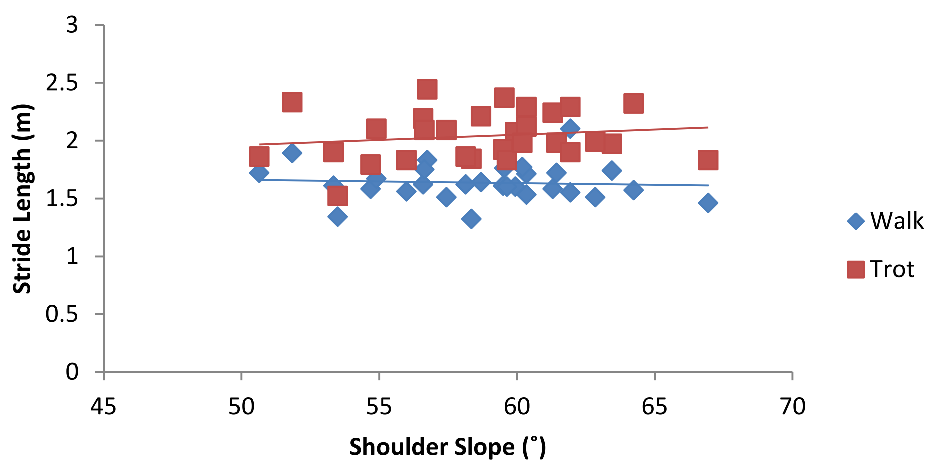

Figure 2. Horse shoulder slope is not significantly correlated with stride length at either the walk (r^2=0.0045) (blue diamonds) or the trot (r^2=0.025) (red squares).

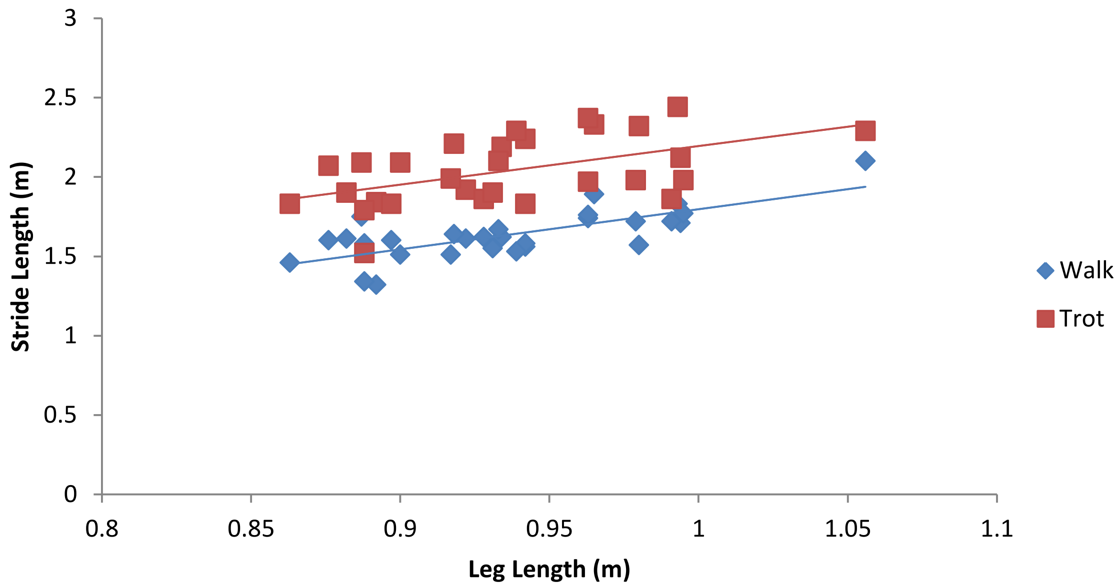

Figure 3. Horse front leg length is a significant predictor for stride length both at the walk (r^2=0.5444) (blue diamonds) and at the trot (r^2=0.2654) (red squares).

Exercise Fitness Predictors

Unlike stride length at the trot (Figure 4), stride length at the walk significantly predicted post-exercise heart rate (r=-0.396, F=5.01, p=0.034, Figure 5). No other exercise parameters were significantly correlated to stride length at the walk or stride length at the trot. Although some could argue that an increased post-exercise heart rate could simply be due to a higher resting heart rate, this data showed no significant correlation between resting heart rate and post-exercise heart rate (Figure 6).

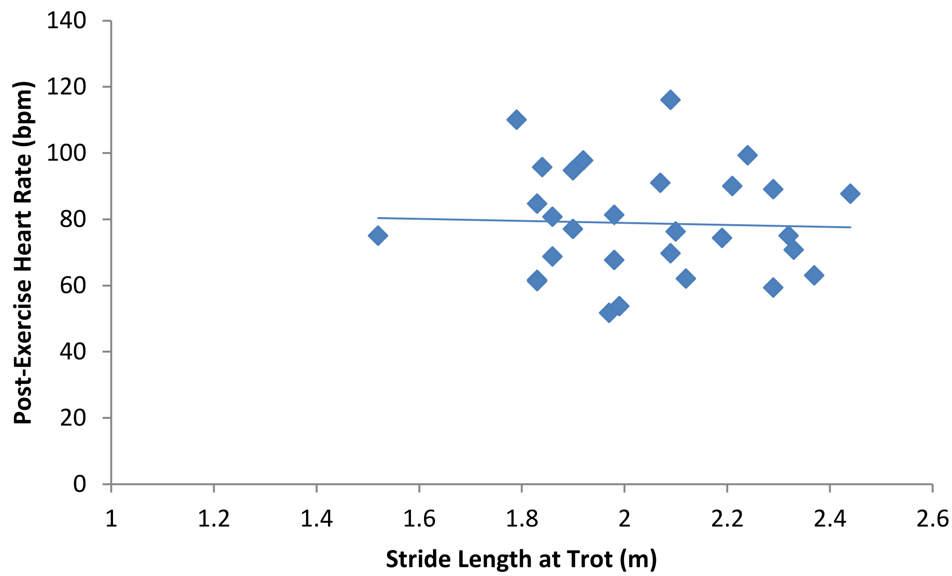

Figure 4. Stride Length at the trot (m) is not a significant predictor of post-exercise heart rate (bpm) (r^2=0.0017) .

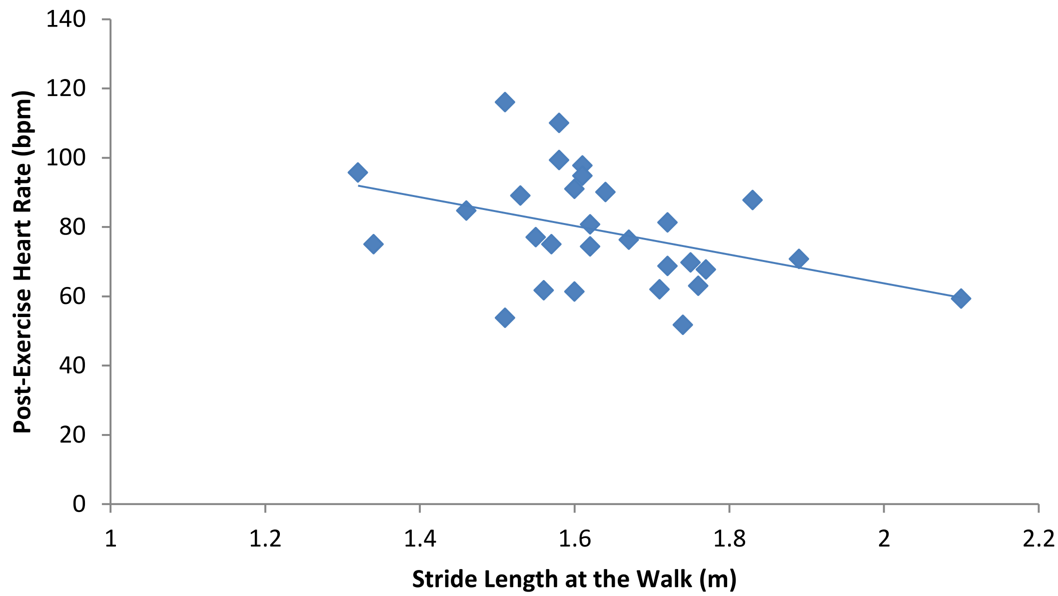

Figure 5. Stride length at the walk (m) is a significant predictor of post-exercise heart rate (bpm) (r^2=0.1565).

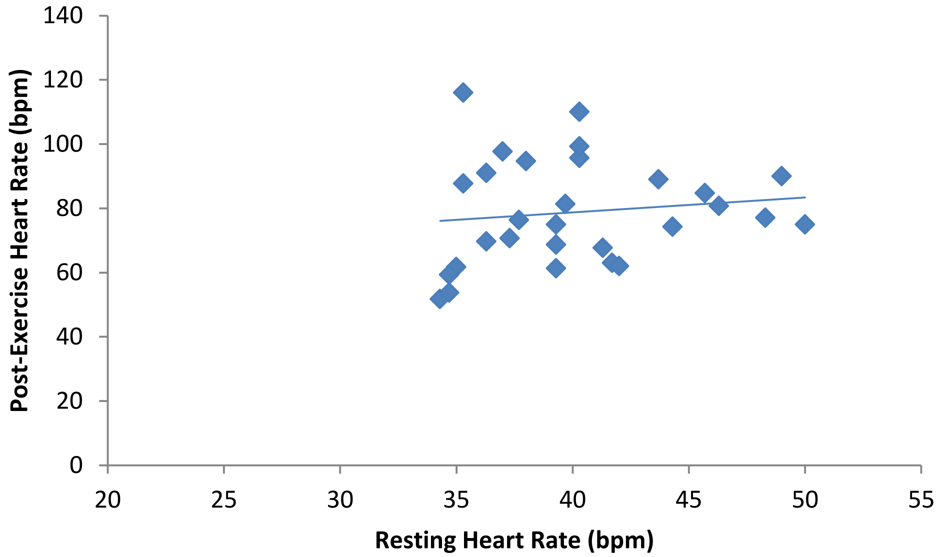

Figure 6. Resting heart rate (bpm) is not significantly correlated with post-exercise heart rate (bpm) (r^2=0.0165).

Although resting heart rate was not correlated with post-exercise heart rate, post-exercise heart rate was significantly correlated with heart recovery time (r=0.538, F=11.02, p=0.003, Figure 7). Likewise, post-exercise respiration rate was significantly correlated with respiration recovery time (r=0.876, F=89.37, p<0.001). Stride length at the walk and stride length at the trot were significantly positively correlated with each other (r=0.573, F=13.17, p=0.001). There were also significant correlations between corresponding heart and respiration parameters, such as between heart recovery time and respiration recovery time (r=0.482, F=8.16, p=0.008). Neither sex nor age of the horse significantly predicted any of the exercise parameters.

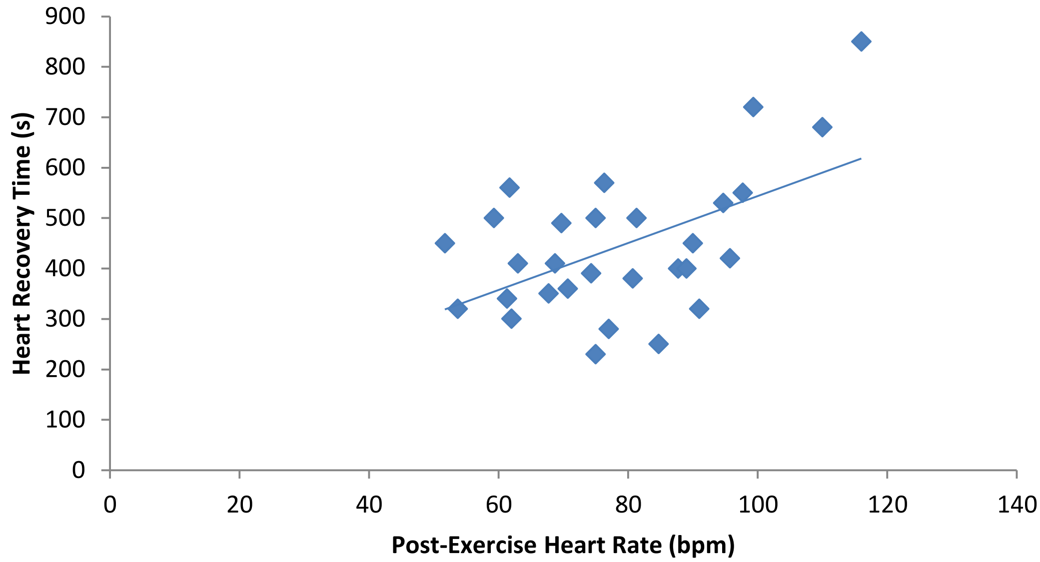

Figure 7. Post-exercise heart rate (bpm) is a significant predictor of heart recovery time (s) (r^2=0.2898).

Discussion

This study sought to investigate two common, yet scientifically untested, assumptions in the equine field by using quantitative and objective measures. The first common assumption is that both shoulder slope and shoulder angle affect the stride length of the horse (Melbye 2017). The data from this study did not support that idea. As expected, shoulder angle and shoulder slope were significantly correlated with each other. Although they are certainly not the same measure, when evaluating a horse for shoulder conformation, it may be redundant to measure both shoulder angle and shoulder slope. Even so, neither shoulder angle nor shoulder slope significantly predicted stride length at either the walk or the trot. This contradicts a nearly fundamental belief in the horse industry.

Of the three parameters, front leg length was the only significant predictor of stride length. This is not surprising in itself, as it is generally common sense that a long leg would be more capable of taking a long stride than a short leg (Clayton and Van Weeren 2013). However, shoulder conformation, which horsemen would generally expect to similarly impact stride length, actually had an insignificant impact on stride length. This is consistent with the results of the 1935 Franke and the 1944 Wehner studies, as reviewed by Van Weeren and Crevier-Denoix (2006). This is surprising especially since leg length is not generally considered nearly as much as shoulder conformation is when evaluating conformation of equine athletes in the field. It would be interesting to investigate whether back leg length is a better predictor of stride length than front leg length, since horsemen consider the hindquarters of the horse to be the main source of propulsion for movement. Back leg length was not investigated in this study because the focus was on the shoulder region of the horse.

Although age was not one of the factors expected to impact stride length, older horses tended to exhibit longer strides at the trot, but not at the walk. This discrepancy may be due to small sample size errors. Additionally, age was significantly higher in jumping horses, which was also the group with the longest legs. Since leg length is a predictor of stride length, it makes sense that the group with the longest legs would also have the longest strides. Since that group is the group with the oldest horses, it may cause a relationship to be apparent between age and leg length as well. This correlation is not necessarily applicable to horsemen.

Even though shoulder conformation was not a significant predictor of stride length, the conventional assumption that shoulder conformation determines stride length is not necessarily incorrect. Larger scale tests would need to be performed, perhaps with a wider variety of horses or a much narrowed focus. Additionally, shoulder conformation may limit stride length for each leg length. This idea would have to be tested by comparing many horses with statistically the same leg length but different shoulder slopes or angles, which would be a very difficult undertaking. Regardless of the potential influence of shoulder conformation, the results of this study only supported the idea that an increased leg length can predict an increased stride length.

Some conformation features are considered to be sex-related traits, such as head shape, with mares typically exhibiting more refined features than stallions or even geldings (Mawdsley et al. 1996). Shoulder conformation is not generally considered to be a sex-related trait, which was confirmed by this study. There were no significant differences of shoulder angle, shoulder slope, or leg length between the mares and geldings used in the study.

An increased stride length, and thus leg length, is desirable for obvious reasons in distance speed events, such as horse racing, because it theoretically allows the horse to cover more ground faster and with a lower stride frequency than horses with short strides. The second common assumption that this study sought to investigate is that a longer stride length is related to better exercise fitness, as asserted by Clayton and Van Weeren (2013). This investigation was more complex than the first because there are many physiological parameters related to exercise fitness, but few are easily accessible.

Respiratory rate and respiration recovery time were used in place of measuring oxygen consumption, which would otherwise have required an equine treadmill (Bitschnau *et al.* 2010). Heart rate and heart recovery time were also used because it is the most accurate of the common field methods to measure exercise fitness. Both heart and respiration rates were expected to be lower post-exercise and have a shorter recovery period in more fit individuals (Bitschnau *et al.* 2010).

Post-exercise heart rate and post-exercise respiration rate were significantly correlated, as were recovery heart rate and recovery respiration rate. However, during testing, respiration rates were deemed a generally unreliable measure of oxygen consumption, as they had been intended. It appeared that although rate didn't change much, volume of air expelled and inhaled did change during the recovery period. There was unfortunately no way to measure and confirm this observation during the experiment because of the lack of equipment. In the future, aerobic athletic capacity may be estimated by evaluating lung capacity through heart girth measurements, but no scientific studies have attempted that yet. Oxygen consumption may still be the best measure of energy metabolism in scientific research (Vervuert 2011), but respiratory rates are not the best measure of energy metabolism for laypeople in the equine athletic industry.

After eliminating respiratory rates as the best measure of exercise fitness, post-exercise heart rate and heart recovery time were the two parameters most expected to yield significant results as factors predicted by stride length. Because post-exercise heart rate and heart recovery time were significantly correlated with each other, it was expected that both stride length at the walk and stride length at the trot would significantly predict both parameters. Stride length at the walk and stride length at the trot are significantly correlated to each other, but only stride length at the walk significantly predicted post-exercise heart rate. Resting heart and respiration rates were measured for comparison with post-exercise heart and respiration rates. By ensuring that post-exercise rates were not significantly correlated with their resting rates, it could be asserted that any significant difference in post-exercise rates are due to other factors, such as stride length. Neither stride length at the walk nor at the trot is a significant predictor of heart recovery time. To be more confident in a direct relationship between stride length and exercise fitness, it would have been much more favorable to have seen a strong correlation between stride length and all of the reliable exercise fitness parameters.

As previously mentioned, stride length is not the only factor that affects exercise fitness. The horses were selected in order to ensure a wide variety of these other factors to reduce the effect of each other factor, such as age, training, and conditioning. This was relatively successful, since there was no significant difference in post-exercise heart rate or heart recovery time among discipline groups. Sex was not significantly correlated with any of the fitness parameters either. The horses were chosen because they were generally healthy, with similar daily exercise schedules and similar daily feed intake. The horses did not undergo any stressful procedures that they would not be exposed to during normal training, so stress should not have impacted heart rates. Heart fitness is understood to decline with age in humans as well as in horses to some extent. As a result, it might be expected that post-exercise heart rate and heart recovery time would both be higher in older horses (McKeever 2002). Because age varied among the subjects, its relationship to fitness parameters was considered; however, age was not significantly correlated with any of the fitness parameters. A review by McKeever (2002) suggests that the decline in heart fitness is more dramatic in humans potentially because they usually experience a greater decline in activity levels as they age as well, compared to horses. Although the results didn't support the hypothesis as well as expected, there was enough evidence to support the idea that an increased stride length can be a predictor for exercise fitness, although some other factors may play a role.

Larger scale tests would need to be performed to more confidently confirm these results, perhaps with an extremely wider variety of horses or a much narrowed focus. Other exercise parameters should be evaluated as well, such as blood lactate concentration and oxygen consumption, when the equipment to do so is available. For current horse owners, post-exercise heart rate measurements are still the most accessible and reliable measurements of exercise fitness.

To summarize the conclusions of this study, equine leg length is a positively correlated predictor for stride length. Neither shoulder angle nor shoulder slope is a significant predictor for stride length. A large stride is one of many factors that allow for improved exercise fitness, as measured in this study by post-exercise heart rate.

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