Gait Analysis

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Ever since the 1880s, when Edweard Muybridge set up a series of cameras to capture the character of footfalls of a racehorse, we've been fascinated by how horses move. No doubt you've seen that early sequence of photos, which demonstrated that the artists who produced hunting prints and racing scenes were wrong: horses didn't trot or gallop in great leaps like a rabbit, with all four feet off the ground, but instead performed a complex pattern of footfalls which propelled them forward too fast for the human eye to catch every detail.

Muybridge's work not only changed the face of equestrian art (the transition is particularly obvious in the work of the great impressionist Degas, who incorporated realistic galloping poses in his paintings of European racecourses after the photos were published), it launched an entire field of study which continues to fascinate us today. For horses don't just walk, trot, and canter. They pace, they fox-trot, they tolt, they rack, they perform paso largos and running walks and a vast array of other gaits. They take ordinary gaits and transform them, with training, into elegant maneuvers like piaffe, passage, and pirouettes. They move differently when carrying a rider than when they're performing on their own. They move differently, too, when they're sound than when they're sore or diseased. And how their various joints and limbs behave as they move—and the forces they exert, and receive—provide us with an endless series of questions to answer, and avenues to explore, in the study of equine locomotion.

Hilary M. Clayton, BVMS, PhD, has made the gait analysis of sport horses her life's work. After 15 years at the University of Saskatchewan, she relocated in 1997 to Michigan State University in Lansing, Michigan. There, under the auspices of the McPhail Endowed Dressage Chair (a permanent position created by MSU alumnus and dressage enthusiast Mary Anne McPhail and her husband Walter), she established the McPhail Gait Analysis lab, with the objective of creating a center for the scientific study of the sport of dressage, with a special emphasis on soundness problems.

At MSU, Clayton is continuing to explore the many ways in which horses move, using a number of sophisticated techniques including high-speed video analysis, force plates which measure the impact of the equine foot on the ground, and computer analysis. Her work combines veterinary science with the nuts and bolts of biomechanics, and, indeed, the staff and graduate students who populate Clayton's lab are as likely to come from a background in mechanical engineering as from vet school. With an amazing number of projects on the go at any given time, her lab must be not only one of the busiest in North America, but also one of the most productive.

Cramped Quarters, New Spaces

It has been easy to set up the experiments Clayton needed to do in her new position. When she arrived, MSU's large animal hospital had little room for runways down which horses could canter, piaffe, or fox-trot. So her practical lab ended up, for the first two years, in a storage building across the parking lot, which also housed the hospital's feed supply and a number of stalls containing horses involved in a study of chronic obstructive pulmonary disease (COPD, or heaves). Clayton and her lab crew learned to ignore the frequent coughing sounds in the background of their gait analysis videos (though they found that they had to reassure clients who had brought horses to study that there was nothing contagious going on in the shed!), and made do by longeing horses in the parking lot. But with a computer lab hidden in the bowels of the large animal hospital building, and office space two floors above that, working conditions were far from ideal.

Fortunately, the McPhails have again come to the rescue, committing a further half a million dollars towards the construction of a brand new Equine Performance Center on the MSU campus. Fundraising efforts have matched that amount and are well on the way to covering the building's approximate cost of $2.5 million—ground was broken on the new facility in July of 1999. Due to be completed by January of 2000, Clayton's new lab will incorporate a permanent force plate installation, an indoor arena, a hard-surfaced longeing area, a large meeting room looking out onto the arena, plus a treatment area for lameness or neurological problems, several box stalls, lab space, and offices.

Clayton's mandate is not only to study the mechanics of sport horse movement, but also to make her research relevant and helpful to the riding public, especially those involved in the sport of dressage. To that end, she envisions the new Equine Performance Center as a place where equine biomechanics comes to the people.

"We hope to have courses here explaining form and function—the kind of thing where people can come for three or four days of intensive, hands-on stuff. Once we get this all up and running, we're aiming to get some really top trainers coming to do clinics—and we can do some of our research on the clinicians and participants. That's definitely in the plans, to have both riding clinics and instructional programs for horse people, trainers, and veterinarians. And what we're going to try to do is make sure our major donors get something back in return beyond their names on a plaque. If we have a big clinic, the donors will all get first opportunity to be part of it."

One of the other major functions of the new Center, according to Clayton, is an emphasis on preventative maintenance for equine athletes, or, as she describes it, "a focus on sport horse wellness."

"We'll be concerned with detecting problems early, before they become clinical, and then treating them and maintaining them so (the horse) can remain active in his sport for as long as possible. We're looking at providing an annual check-up: you'd bring your horse in at the end of the competitive season, and we'd give him the once-over, find out what might be getting a little creaky, and if the horse needs treatment, or a rest, or whatever, you can begin it at the end of the season instead of finding out there's a problem in April. And we'll arrange the program at different levels. Maybe you just want your horse to have the clinical exam and basic radiographs, or you could go the deluxe program, with gait analysis, scintigraphy, the works. If you've got a $100,000 Grand Prix dressage horse with five or more years of training invested, it would be well worth it (to ensure his longevity in the show ring).

"I think that's going to be a really big part of what we do."

For that reason and many others, the McPhail Equine Performance Center promises to be a unique facility. With relatively few academic institutions worldwide equipped to do a thorough job of equine gait analysis, Clayton's setup, when complete, will likely become an equine kinematics Mecca—and continue to attract the interest of researchers, engineers, and horsepeople alike.

Let's take a look at some of the current projects generating new data at the McPhail dressage laboratory.

Kinematic Data Collection

Video analysis is the mainstay of the study of equine motion. With the help of sophisticated computer software, high-speed videos of horses in motion can be analyzed, frame by frame, to identify exactly how, and why, equines move their legs in certain ways. When a horse is videotaped, reflective markers are attached to crucial moving parts, such as the joints, in order to clearly isolate various parts of the horse's body. In a darkened room the horse is videotaped moving perpendicular to the cameras along a runway (currently 60 meters long, but due to be considerably longer in the new building). The markers glow when illuminated by lamps behind the cameras, and can be automatically tracked by the lab's Ariel Performance Analysis System (APAS), computer software which records information about the horse's movement even as it occurs. Though the sight of a horse glowing like some sort of animated constellation may be a tad eerie at first, the information the markers provide about not only the sequence and rhythm of the footfalls, but also the joint angles at various times during the stance and flight phases of each limb, is useful for a number of reasons—not the least of which is plain ordinary scientific curiosity.

Patience is a key factor in gait analysis by videotape. Gait is not a symmetrical or constant thing—every step is likely to be slightly different. So it takes many repetitions to produce average calculations which are truly representative of what's going on.

Video analysis isn't limited to studies of equine movement, of course. Adding a rider can provide a number of new elements to the equation—because not only do riders move themselves, in all sorts of interesting ways, but they also affect the way the horse moves.

Although it's easy to detect even very subtle lamenesses by doing video gait analysis, it's likely that equine kinematics may *not* prove to be all that useful a diagnostic technique, because identifying the source of the lameness from the altered movement can be very difficult.

"That's one of the things we're coming around to realizing," says Clayton. "That if it's painful when a leg is bearing weight, the horse has pretty much one way of compensating. So what *we* see is similar from one lameness to another (whether the source of the problem is the fetlock or the knee, for example). I don't absolutely know that for sure yet, but it's shaping up that way. So gait analysis may not be a way to differentiate various types of lameness .... but I think it *will* be a way to pick up very subtle lamenesses, by the asymmetries between left and right leg."

Although video analysis is generally done only from the side view, graduate student Molly Nicodemus, MS, is currently working to develop a three-dimensional system of gait analysis. "Most of the movement is in one plane," Clayton explains, "but in certain situations, such as some types of hock lameness, there may be movement that goes outside that side-to-side plane." The 3-D computer model will be helpful not only in understanding lameness, but also for analyzing the peculiarities of locomotion demonstrated by gaited horses, a special interest of Nicodemus's. "Once she's developed the technology, she's going to use it on horses like Peruvian Pasos, who have a lot of exaggerated sideways movement or paddling," says Clayton. "There's hardly anything known about (the specifics of movement of) gaited horses—and one of the things about them is that when they're lame, it can be really hard to find the source of the lameness. Gaited horses tend to compensate differently for lameness than normal-gaited horses.

Most gaited horses do some variation of a four-beat gait, Clayton notes, "but some of them are regular four-beat, some are syncopated, some are lateral, and some are diagonal." A comparison of these gaits is now possible using computer software designed by Joel Lanovaz, MSc, which not only graphs the pattern of footfalls of an equine gait, but identifies the amount of time each foot spends on the ground, and where overlap occurs (instances when two, three, or all four hooves are weight-bearing).

"Molly will be looking at the effect of speed on the gaits as well—how the gait changes, for example, when a Paso Fino moves from a Paso Largo to a Classic Fino, or a Tennessee Walker moves from a flat-footed walk to a running walk."

Kinetic Data Collection

Understanding the amount and direction of the force a horse's limb undergoes when it hits the ground (not to mention the amount and direction of the force the ground exerts on the limb) is an essential part of gait analysis. Ground reaction forces are measured using a "force plate", a 2' x 4' in-ground platform which can accommodate the extreme loads exerted by equine locomotion at high speeds. When a horse steps on the force plate, sensors register the amount of pressure exerted during all phases of the weight-bearing part of the stride.

Force plates have been instrumental in the analysis of all sorts of gaits, though collecting data is tedious because each leg must be examined separately (the 2' by 4' force plate, the largest currently available, won't accommodate all four feet at once, and couldn't generate clear data if it did). A great deal of accuracy is required when a horse is ridden over the force plate, and there are, of course, a lot of hits and misses.

Still, the results generated by force plate studies have yielded a great deal of information about the kinds of pressures exerted on the horse's various joints and on the hoof wall and sole. One of the more interesting findings, yet to be published, is that the joint between the long and short pastern bones (often referred to in shorthand as P1 and P2), long thought to be essentially rigid, does, in fact, flex to some extent when the horse moves. Lanovaz first noticed it when watching a video of a racehorse in motion, and confirmed it upon examination of videos of horses performing slower gaits.

Certain physiological conditions can dramatically change the forces a horse's limb exerts on the force plate. "We did a study of the movements of neurologic horses," says Clayton, "looking at how the legs moved. Sometimes they would swing the leg wide, for example, and we could detect that. Then we looked at how the legs hit the force plate when they were in motion, because you could often see them slap their feet down as if they didn't know quite where the ground was." Abnormalities in the flight arc of the hoof, the manner of hoof placement, the width of the horse's base of support, and the consistency (or lack thereof) between strides were all tip-offs of neurological problems. "The force plate is the quickest and easiest (method) for detecting certain problems," says Clayton. "We can have output within 10 or 15 minutes—so clinically it can be a very useful tool."

Computer software designed by Lanovaz can generate an animated stick figure which represents the equine limb, complete with arrows which represent the amount and direction of the force acting on the leg as it impacts with the ground and then lifts off again, and with "balloons" of different colors, which represent the amount and type of torque placed on each joint throughout the cycle of a single stride. As the limb swings through its flight and stance phases, forces concentrate and dissipate, demonstrating the leg's ability to act like a spring against the earth.

A horse doesn't even need to be moving, however, to generate interesting data on a force plate. One of the current studies in Clayton's lab examines "postural sway" in horses. She explains, "When a person stands on two feet, perfectly balanced, the muscles are slightly adjusting their position all the time. If you were to look at the center of pressure, which is the center of the force distribution on the feet, you would see that what actually happens is that your position of balance moves a little bit away from equilibrium, and then your body catches it and throws it back. So based on the input from your eyes and inner ear, and what you feel through the nerve receptors in your joints, if you start to sway way over, your brain registers that you've gone too far, and you move back (over your center). In people with certain neurologic diseases, the amount of postural sway increases, so they sway further—forward and back as well as side-to-side.

"People normally have more front-to-back sway, and only a little side-to-side," she continues. "But a person with Parkinson's disease, for example, has less front-to-back sway, because the muscles are a bit more tense, so the ankles don't move as much. But they also get more side-to-side sway.

"I've been intrigued by this for a long time, and I wanted to look at horses to see what their postural sway patterns looked like. So when I came to MSU and we didn't have a good runway for high speed data collections, it seemed like the perfect time to look at postural sway.

"The way we collect the data is that we have the horses stand with their front feet or their hind feet on the force plate, and we take four readings of 10 seconds each. In people they do 30 second intervals, but getting horses to stand for that length of time is difficult. We don't even know for sure how long we *need* to have them stand," Clayton adds. "We don't know if we could do it in five seconds, or if we really should be going for longer than 10, so that's something we hope to look at."

"Statistical mechanics are used to look at different aspects of the balance on the force plate. We end up drawing a little graph (called a stabilogram) which shows the direction and the velocity of the movements, side-to-side and front-to-back. Then we can measure from one point to the next. We take measurements 2000 times a second, and these are displayed 100 times a second, so every 20th point (appears on the graph). We can look at the velocity of the movements from measurement to measurement, where the center is for all these measurements, how far out (the horse) goes from side to side and front to back, and what the average distance is from each point to the center. Using computer analysis, we can get answers on these questions fairly quickly. But we still need to look at different methods of analysis to see what's the best for picking up problems."

What has the team found so far? "We collected data from a group of normal horses," says Clayton, "and found that horses normally have more side-to-side sway and only a little front-to-back sway, which is the opposite of humans. I think that's because they have front and hind legs stabilizing them. We examined them both sighted and blindfolded. Then we looked at some horses with neurological diseases. First of all we took a horse with vestibular disease (compromised balance due to a tumor or other condition of the vestibulocochlear nerve), and (the difference) was really obvious—we saw this huge difference between the normal horses and this horse. So then we started looking at EPM and wobbler horses; that's what we're working on at the moment, to see whether this might be something that could be used as a non-invasive diagnostic test for neurologic disease." (Wobbler syndrome and equine protozoal myelitis can be difficult to differentiate from each other, as afflicted horses often move in a very similar fashion, and each disease is, in itself, challenging to diagnose.)

"At the moment, we haven't yet gotten to the stage where we can actually use this as a diagnostic test, but we've had a few horses where the owners have brought them in as lame, the clinicians here at MSU have been convinced it was neurologic, and we've been able to put (the horses) on the force plate to look at their sway patterns. Then we can say to the owner, 'Here's the amount of sway in a normal horse ... and here's your horse.' It's fairly convincing.

"I don't know yet whether we'll be able to use sway patterns to say, 'that horse is a wobbler and that one has EPM'. Who knows—it may be possible. It may be that wobblers have certain patterns that are distinct from EPM—whether it's unilateral or bilateral, forelimbs or hind limbs. We haven't seen enough horses to be sure yet."

Laminitic and navicular horses, both of which have characteristic ways of rocking their weight off the most painful parts of their feet, are two more possibilities for postural sway analysis. "What I would be interested in doing with laminitic horses," says Clayton, "is looking at how they're weight-bearing, and seeing if we could monitor that as a way of knowing when or how to change their treatment. Imagine if you could say, 'This horse has changed since yesterday, the center of pressure has moved, so today is the day to change his shoeing', or whatever. If we could detect certain changes in weight-bearing that precede the coffin bone dropping or rotating, for example, we might have some warning. Things like that are worth looking at."

Yet another application for postural sway analysis is the effect of certain drugs on the horse's balance and stability. "We're also planning to use this technique to look at things like the effect of different tranquilizers," says Clayton. "We could use it to look at the effect of age, too. Old people and young people are less stable, and we need to look at that in horses. The study needs funding—for about $20,000, we could do a huge amount. But it has quite a few possibilities."

There's still much work to be done, she adds. "We need to look at how the horse stands on the force plate, and how that might affect the results, for one thing. With people, you can tell them to 'put their feet there and stand still for 30 seconds', but getting a horse to stand four-square, especially if he's got a neurologic condition, isn't easy. What's the effect on the readings if a horse stands a little base-narrow, for example? We don't know yet. So we've got to look at that effect, and whether we can correct for it, and also the effect of head movements, such as the horse swinging his head to shoo away a fly, on the side-to-side sway. There are a lot of things about the technique that need to be looked at. And then we need to examine a whole lot more normal horses, and a whole lot more horses with known diagnoses. That will help us define what's normal and what's not, and which might be the best way of differentiating what's normal from what's not on an individual horse basis."

What's Going On In The Hock?

Clayton's lab team is currently seeking funding for an ambitious biomechanical analysis of the equine tarsal (hock) joint, a most misunderstood part of the anatomy, and site of a great many lameness problems. The team hopes to develop a fully functional, 3-D computer model of the hock joint, which would be used as an interactive tool for investigating the causes and mechanisms of tarsal joint disease, as well as the effects of different kinds of therapy. Based on computed tomography (CT) scans and anatomical dissections, as well as videographic data which isolate the hock, electromyography of working hock joints, and force plate data which calculate the forces on the hock, the computer model will eventually demonstrate the ways the 10 major bones that contribute to the tarsal joint, and all the supporting ligaments and tendons, work together to make the hock function as a weight-bearing joint. Once the model is completely developed, it will be applied to study the effects of external stress on the anatomy of the hock, and help us understand factors like these:

- How different hock conformations (straight, cow-hocked, sickle-hocked) might contribute to soundness or lameness
- Joint instability (hock joints that wobble or rotate during weight-bearing)
- The stresses placed on the hock during sports maneuvers like piaffe, sliding stops, or jumping
- How mechanical differences, like changes in footing or farriery, might alter the health of the hock
- Tarsal joint diseases such as developmental orthopedic disease (DOD), plantar fasciitis, or deep flexor tendinitis
- The effect of surgical procedures such as joint "fusions," severing the lateral digital extensor tendon, or cutting the cunean tendon.

Bits And Bitting

Although choosing an appropriate bit for an individual horse has long been called a "science,"we actually know very little about how horses respond physiologically to bits and bridles. In particular, we have a poor understanding of why horses accept or resist the bit, and what actually goes on, from an anatomical point of view, when we put a bit in a horse's mouth. This study, which is partially completed and is awaiting more funding, is planned in several stages, the first of which is a detailed anatomical examination of the contact areas of the bridle with the head and neck, and the function of the joints that determine head and neck position. Diana Rosenstein, DVM, of MSU's radiology department at the College of Veterinary Medicine, has completed an exploration of the temporomandibular joint, which, in Clayton's words, "is quite a big blank area; we don't know an awful lot about it. Using radiology and CT scans, Rosenstein has developed a technique for tapping (the joint), getting the needle in there to take out fluid or inject into the joint, which will help us learn more about it." Anatomical dissections and scintigraphy (bone scans) will help provide other pieces of the puzzle, and help Clayton's team define what the "normal" sizes and relationships of the various structures are. (This should be a tremendous help to those of us who try to choose bits to match our horse's tongue size, height of palate, and individual preferences, without really being able to tell whether those measurements fall within normal parameters!).

Later, Clayton hopes to work with horses with a history of difficulty in accepting the bridle, taking a history and then examining their heads, backs, necks, and limbs both at rest and while being ridden or driven. She suspects that characteristic patterns of resistance will emerge. "We plan to use fluoroscopy, a video X ray technique, so you can see the horse moving the bit around in his mouth. And then we're looking at putting sensors on different parts of the bridle—under the poll, and so on, to see how much pressure you actually get with different bits."

Naturally, a large part of the responsibility for resistance to the bridle lies with the rider or driver of the horse. Riders, in fact, have such a huge influence over a horse's balance and grace (either enhancing it, or severely compromising it!) that Clayton considers them worthy of study as well.

Horse And Rider Interactions

Stick-on sensors also might provide the key to some of the great intangibles of riding sport horses, by finally quantifying what many instructors can't describe, and many riders know only as "feel". Clayton describes the project graduate student Wes Singleton, an instructor and former Grand Prix jumper rider, is tackling: "What we're going to do is develop the technology to measure things like the tension in each rein, the pressure under each seatbone, the pressure under the (rider's) thighs and calves, and so forth. We'll be able to measure both the amount and the timing—so for instance, if we had you, as a rider, do a half-halt, we'd be able to see not only how it affects the horse's stride, but also how your half-halt is different from mine. There would be sensors on each rein, and probably more sensors built into a pad on the saddle" (or conceivably, into the rider's pants!).

"(Wes) wants to take science into the coaching realm and use it as a practical tool," says Clayton. "We're visualizing things like having a video of you riding your horse along, and in the corner there might be a little figure of a rider that would light up in different places depending on the pressure changes. So you could see when you are collapsing a hip, for example—and even *how* you're collapsing your hip, as there's more than one way!"

Such instant feedback opens the imagination to some intriguing possibilities. "There are so many things in riding that are very hard for people to grasp," she says. "You say to somebody, 'When the horse gets soft in your hand, relax' ... and so often, when you say that, the rider throws away the contact. This will give us a way to say, 'When you relax, you've got to maintain this much tension', and at least give the rider some sort of a yardstick, so we can make corrections: 'That's not enough, you need this much more'." Clayton visualizes the sensors aiding in defining nebulous dressage concepts like "riding the horse from leg to hand,"or "riding from the inside leg to outside rein." "With this technology," she says, "you could just look at the screen and say, 'Now you've got it, now you've lost it.' The goal is to provide riders with immediate feedback."

Clayton hopes the sensors will be wireless—or, if wired, they'll attach to a little data recorder attached to the saddle in some sort of simple way. Once the technology is in place, the first step is to use the sensors in purely descriptive studies with one rider, so that the team can identify the tension and pressures in various sites as a horse is ridden around. "We'll start with one rider until we get the technology worked out, and then we'll look at different riders on the same horse, and the same rider on different horses. That will be the next stage. And then we'll try to apply it as a coaching tool, once we know a little more about what we SHOULD see."

Although this study is still in its infancy (Singleton is currently working on the engineering for the sensors), it holds tremendous promise for riders and coaches worldwide. Meanwhile, the lab is already equipped with a "saddle pressure pad" which has been instrumental in measuring saddle fit and pressure points in various horses. It's placed between the saddle and the horse; unfortunately, however, it's not wireless, so its use is limited to a longeing circle which can accommodate the length of its umbilical cord to the data recording equipment. It also "is not really adequate for what we want to do now," says Clayton, "because the readings it generates combine saddle fit with the rider's effect, and we want to be able to isolate those two factors." But riding bareback on the pressure pad has already yielded some interesting graphs and given a hint of what's to come.

Dressage Movements, Demystified

One of the mainstays of Clayton's work has been the analysis of certain movements required of dressage horses—which are not always what they appear to be! During a sabbatical stay at Utrecht University in the Netherlands in 1995-96, she worked with Grand Prix level dressage riders and horses to investigate the kinematics and kinetics of piaffe, the highly collected trot-on-the-spot that so many horses find so difficult, as well as collected walk, trot, and canter, rein back, and passage. She has also spent much time examining, frame by frame, videotapes from the Atlanta Olympic Games in order to isolate the pattern and temporal characteristics of maneuvers like the walk pirouette. With the McPhail Chair's emphasis on the sport of dressage, this work will no doubt continue to be a highlight of her work at MSU.