~ EQUINE ANATOMY ~

THE BIOMECHANICS OF COLLECTION, PART 1:

Engagement of the Hindquarter

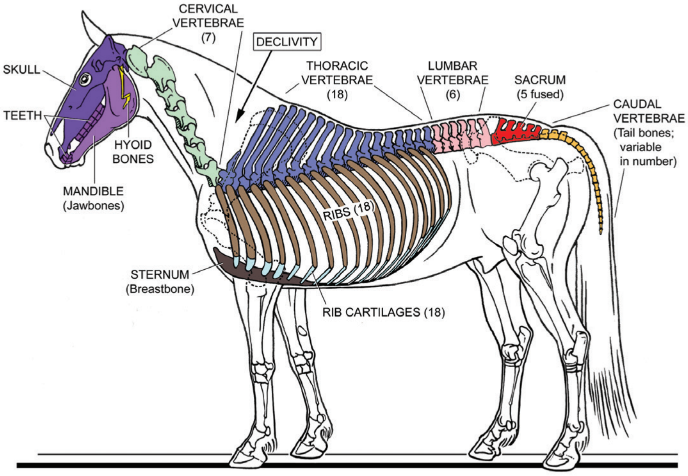
Regardless of discipline, all horsemen work toward collection. Here's what happens in a horse's body.

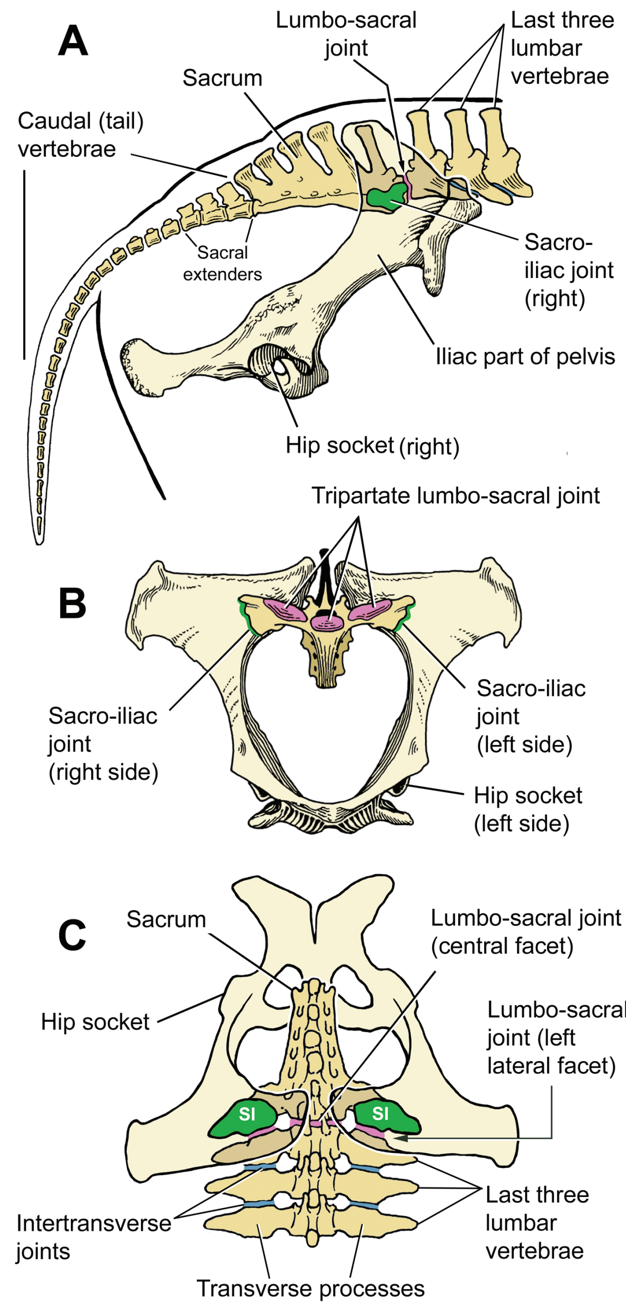
By Deb Bennett, Ph.D.

If you're a denizen of training stables anywhere in the world, you're likely to hear numerous ideas or theories about collection. Collection is highly desirable for making the horse a more powerful, more efficient, and altogether more pleasant ride. Since collection is fundamental to higher levels of performance, it is not surprising that it is widely discussed and debated. Nonetheless, to many people the concept of collection remains obscure, so it's my purpose in this article to define it, describe it, give examples of it in several different disciplines, and finally to suggest some ways of obtaining and developing it in your horse.

Almost any horseman, whether coming from the perspective of dressage or from some form of saddle seat or Western-style riding, will mention that collection depends upon two things: what happens in the horse's rear end and what happens through the neck, at the poll, and in the jaws and mouth. So far, so good; this article details what goes on in the rear and our follow-up part two will deal with the front end. As we take a scientific approach, we'll be considering the anatomy and functioning (biomechanics) of both body zones.

ABOVE: Dr. Deb explains the biomechanical process of collection as the "coiling of the loins," as illustrated by a cheetah with its back rounded and hind feet landing ahead of its front. "Virtually any performance discipline that calls for collection," she explains, "is in the same breath calling for engagement of the hindquarters that comes from loin coiling, so that the body can be pushed upward as well as thrust forward."





COLLECTION AND ENGAGEMENT OF THE HINDQUARTERS

Confusion around collection commonly begins when the term "engagement" is thrown into the mix. To many, it signifies bringing the hocks up under the body—in other words, an aft-to-fore movement of the hocks. A focus on the hocks, however, confuses cause and effect. If the horse's hocks are brought forward in collection, how does this happen? Two factors are primarily involved: forward swing (protraction) of the hind limb as a whole which rotates the head of the femur in the hip socket; and coiling of the loins which is flexion of the joint between the sacrum and last lumbar vertebra (the lumbo-sacral or L-S joint).

The L-S joint—not the hip socket—is functionally the uppermost joint in the horse's hind limb (Figs. 1–3), and it therefore governs hindlimb movement. In a normal horse, loin coiling—which steepens the croup (makes the horse's pelvis angle more strongly downward) while it simultaneously produces a lifting and rounding of the whole of the horse's spine—initiates all movements of the limbs. The dynamics of the spine govern the dynamics of the limbs, not the other way around. Under normal circumstances spinal movement comes first and dictates the scope and type of limb movements that can ensue. In short: collection starts from and is always primarily the product of coiling (flexion) of the horse's loins.

Collection is defined biomechanically as a particular way of using the spine, and it can be maintained in any degree from minimal to maximal. It results when the spine assumes an overall shape in which all its joints—even those at the declivity at the base of the neck (Fig. 1)—are making an effort to flex/coil/rise. When the horse is at a standstill, think of him waking up from a snooze and doing a big "dog stretch" in which he strongly arches his back and neck; that's an example of maximal collection. Minimal collection can be seen in a conformation photo of an alert, relaxed horse, or in a well-halted horse (see Fig. 9A). Collection is even easier to see when the horse is in movement; there, it is defined as that particular spinal dynamic in which the axial bones elastically return (or try to return) to a flexed or coiled shape at least once in every stride, even if extension is called for, and no matter at what

LEFT: FIG. 1. Skeleton of horse with axial elements in color. This subset of the horse's bones includes all the vertebrae plus the skull, jaws, sternum, ribs, rib cartilages, and hyoid bones. The hyoid bones are least familiar to most people; they lie between the jowls and serve to anchor the tongue and support the larynx. All parts of the vertebral chain are formed as upward arches except the lower cervicals and anterior thoracics, which form a declivity or "U" shape at the base of the neck.

ABOVE: FIG. 2. Closeup study of the cluster of joints which connect the horse's lower back (lumbar span) with the pelvis and tail. The pelvis fits over the sacrum and last lumbar vertebra as a lampshade fits over a lamp. The L-S and intertransverse joints permit loin coiling and uncoiling (flexion and extension); they function very differently than the nearby S-I joints. See text for explanation.

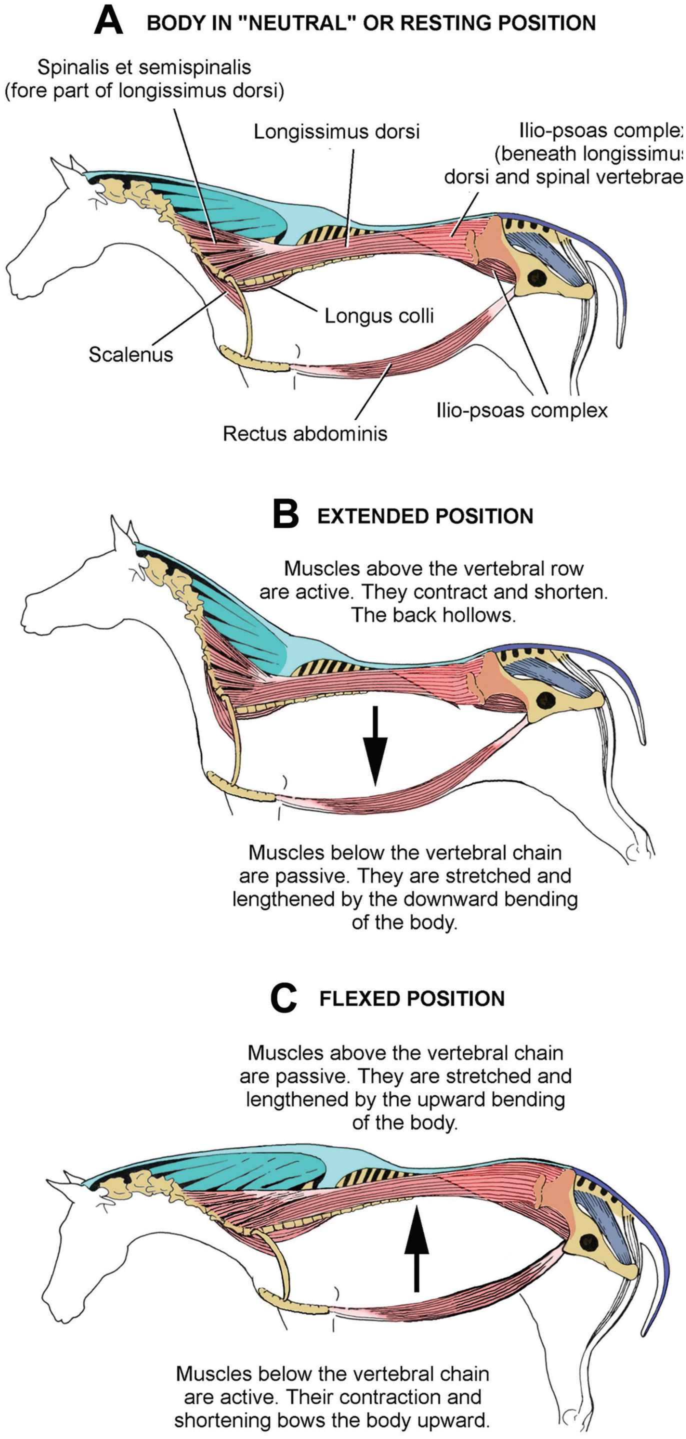


FIG. 3. The total flexibility or up-down range of motion of the freespan of the horse's back is about 5 degrees, much less than in cats or dogs. Nonetheless its elasticity is crucial to normal equine locomotion. Note that it is contraction of the muscles lying below the vertebral chain that empower upward bowing (flexion, coiling) of the back, while it is muscles lying above the vertebral chain whose contraction causes the back to hollow (extend, uncoil). In collection, the back oscillates both upward and downward; collection is maintained even when downward oscillation is large (as in passage) so long as the back elastically rebounds upward with each stride. Collection is lost, and movement becomes both abnormal and pathogenic, when the muscles along the horse's back (those under the saddle) remain in contraction all the time and thus act to "freeze" the back into the downward position.

gait (Figs. 5, 6, 8, 9).

The bottom line: if the horse fails to coil its loins in movement, or if it holds its spine in a continually extended/inverted position (hollows the back, see Fig. 4B), *even if it brings its hocks forward it is not collected.*

FUNCTIONAL ZONES OF THE SPINE

The horse's spine is part of its axial skeleton (the limb bones by contrast comprise the appendicular skeleton). The axial skeleton includes not only the spine but the skull, teeth, jaws, and hyoid bones and the ribs, rib cartilages, and sternum (Fig. 1). The spine itself is divided into sections: cervical, thoracic, lumbar, sacral, and caudal.

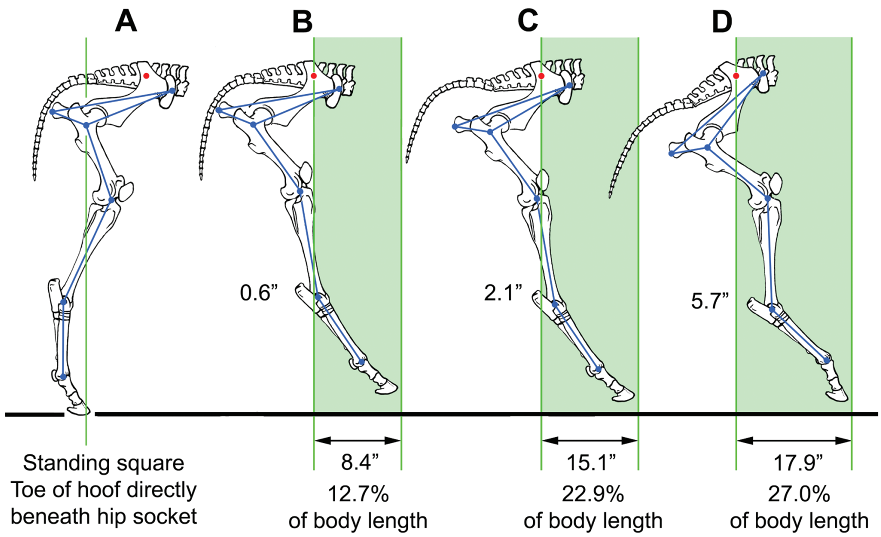
Each section of the spine is made up of a chain of vertebrae of similar form which therefore have similar movement capabilities. In total the cervical joints (green in Fig. 1) permit five different kinds of movement: rotation about the long axis of the spine (head tilting), translation or side-to-side slippage (head twirling), flexion or upward arching, extension/inversion (downward sinking/hollowing), and lateral flexion both left and right. At the front, the first cervical vertebra articulates with the skull, and at the rear the last or 7th cervical vertebra articulates with the thorax; both of these joints function as cervical joints. (We'll investigate important functions of these joints in our next installment.)

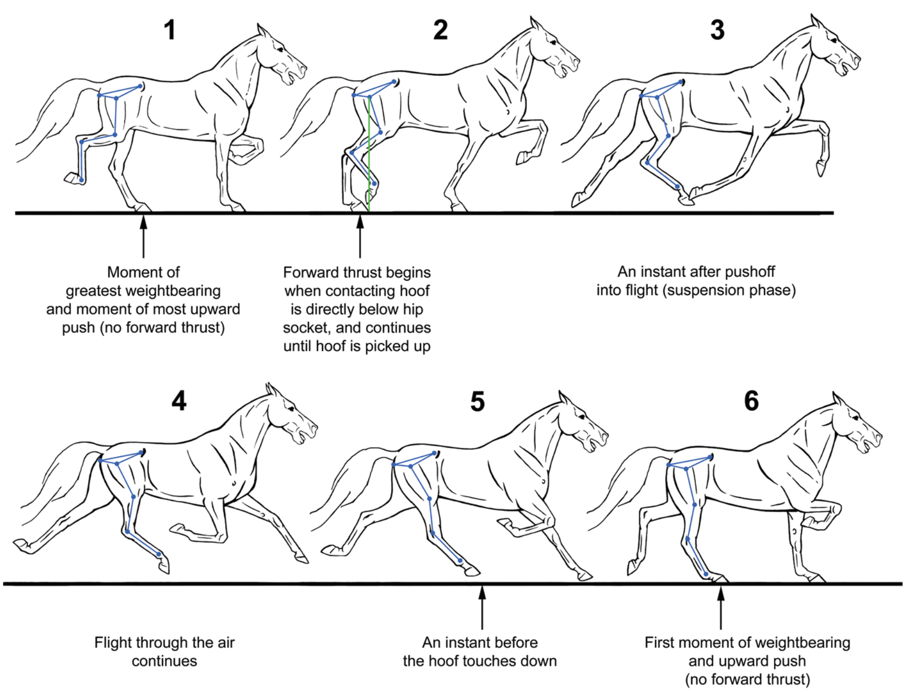
In each successive section behind the neck, movement capabilities get fewer. The thoracic vertebrae (blue) can move in only three ways: flexion, extension/inversion, and lateral flexion. The permitted amount of these movements is limited in the anterior thorax by the close spacing of the long vertebral dorsal processes that form the withers, by a heavy ligament covering, by the presence of the scapulas to either side, and by the fact that the more anterior rib cartilages are quite short and stout and thus permit little movement of the ribcage. The part of the thoracic section behind the withers is more flexible; it is the place where the rider sits and where her legs are directly in contact with the horse's body, and thus movements of this part of the spine and ribcage are those that riders are likely to be most aware of.

The lumbar vertebrae (pink) lie between the level of the cantle and a line connecting left and right points of hip. The first three lumbar vertebrae can flex up, down, and to either side, but the last three develop articulations between the "side wings" or transverse processes (Figs. 2A, 2C) which totally prevent lateral flexion. The last three lumbar vertebrae are thus capable of only two classes of movement, flexion and extension/inversion—in other words, the only movements they can make are to coil or uncoil.

The sacrum (red) is made of five vertebrae which are fused solidly together and thus no movement at all can occur within the sacrum. It functions like a pump handle, a lever upon which anchor the muscles which coil and uncoil the L-S joint (Fig. 2A). As a unit, it can make one type of movement: up/down. If the horse did not have a stiff, rodlike sacrum, collection would be impossible.

The sacrum is made functionally longer and thus more effective (a longer pump handle) by the first two or three tail vertebrae, which are stouter than the others and joined to the rear end of the sacrum by heavy ligaments which sometimes actually ossify, thus cementing these tailbones to the sacrum (Fig. 2A). The





part of the dock that appears from the outside to be free of the body is structured internally by the rest of the tailbones (gold). These are variable in number; horses have been recorded with as few as zero and as many as 28 caudal vertebrae. The joints between tailbones are formed as simple, rounded bumpers, enabling the tail to take on the shape of a rainbow arch, an inverted "scorpion-tail" shape, or for sections of it to counter flex and thus to appear kinked. Due to its relative thinness, the tailbone's overall flexibility is greater than that of any section of the spine except the neck, but nonetheless its movements are limited to up/down and side to side.

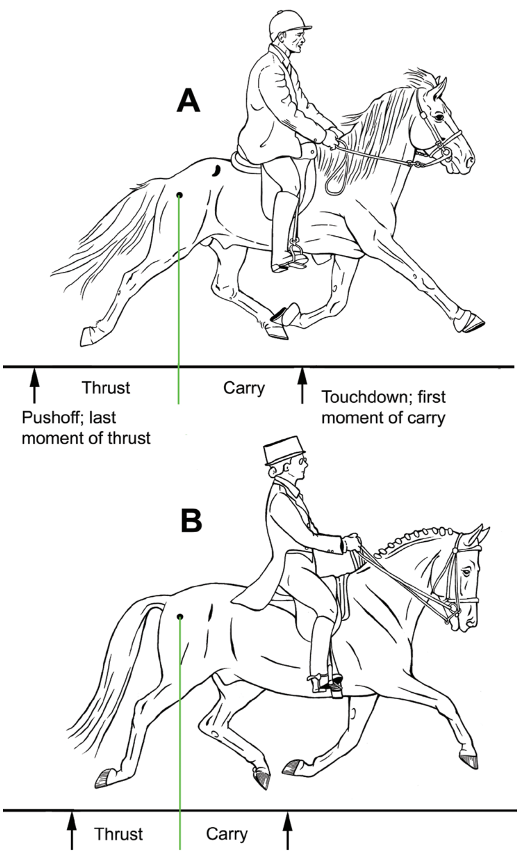
A CLUSTER OF CRUCIAL JOINTS

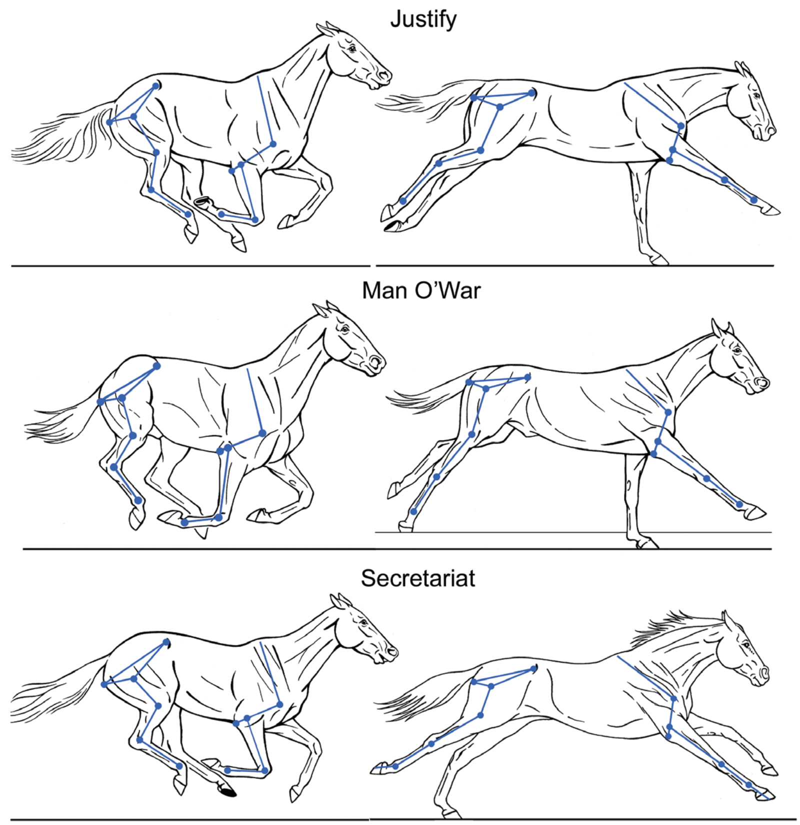
The sacrum, L-S joint, the last three lumbar vertebrae, and the pelvis articulate at several key points. Five joints cluster together in a zone only eight inches long and wide near the peak of the croup (Fig. 2). Three of these joints (marked in pink) comprise the L-S connection and are meant to move; they are crucial to collection.

Two joints, the left and right sacro-iliac joints (marked in green), are not meant to make much movement. They serve to stabilize the pelvis and fix its position relative to the sacrum and lumbar vertebrae. These joints are frequently the target of chiropractic manipulation, because horses (like people) can sprain the short, stout ligaments rimming these joints which serve to hold the pelvis and sacrum together. When that happens there is pain and often misalignment of the pelvis with respect to the vertebral chain. This can occur in any dimension or in all three; that is, the pelvis can be twisted laterally so that (in a horse) one hipbone comes to lie in front of the other, it can be rotated so that one hipbone lies higher than the other, or it can be steepened,

TOP: FIG. 4. Comparative study of engagement of the hindquarter in a 15-hand horse. **A.** At a standstill; this is the reference configuration. The toe of the horse's hoof lies below the hip socket; the resting angle of the pelvis is 10 degrees and the angle at the hip is 81 degrees. **B.** The result when the horse does not flex the L-S joint but merely swings the femur forward 15 degrees: the hock is advanced 0.6" while the toe of the hoof comes forward 14". **C.** Result when the horse flexes the L-S joint 10 degrees (average for trotting) and swings the femur forward 15 degrees: the hoof is brought forward two inches farther. **D.** Result when the horse flexes the L-S joint 30 degrees (average for galloping) and swings the femur forward 15 degrees. 18" of advancement translates to nearly 15 feet of advancement per 100 gallop strides, about 8 feet more than the horse who does not use his back. To get the same advantage by breeding a taller horse (which does not use its back), the animal would have to be more than 20 hands high.

BOTTOM: FIG. 5. These film frames were made by Eadweard Muybridge at the behest of Standardbred fancier Leland Standford more than 100 years ago. The horse is one of Standford's racing Morgans named Abe Edgington (foaled about 1860; by Stockbridge Chief Jr., a grandson of Black Hawk, out of Blue Bonnet by Tom Crowder). He was being driven to a high-wheeled sulky in the mouth-open style of the day; I have extracted the images of the horse for this analysis. The maximum change in pelvic angle (which equals the amount of loin coiling) is 10 degrees; this is typical for horses trotting with enough vigor to create suspension. The maximum change in hip angle (the amount the head of the femur rotates in the hip socket) is 30 degrees. Note that these six frames represent only one-half of a full stride; after this sequence, it would be repeated on the opposite diagonal before the stride starts over again at Frame 1.





LEFT: FIG. 6. Trotting horses shown in mid-suspension (mid-flight). **A.** An Icelandic stallion ridden by Vignir Siggeirsson in a vigorous extended trot. **B.** Connemara-Thoroughbred gelding Seldom Seen ridden by Lendon Gray in a high-quality passage. Both horses were national champions in their respective divisions. Note the different balance of upward push vs. forward thrust in the two styles of trot: the flight distance is longer in the Icelandic horse because the object of extension of stride at the trot is to cover as much ground as possible. The passage, by contrast has much more "bounce," the result of considerable upward push.

RIGHT: FIG. 7. Comparison of coiling and extension of the spine in three champion racehorses. These comparisons were made from the best available photos, some going back to the 1920's. The camera angle varies and this introduces a certain amount of error, so the measurements of loin coiling in this case are only accurate to plus or minus 2 degrees. Nonetheless they make the point that great racehorses run by coiling (and uncoiling) their loins. The difference in Justify between maximum coiling and maximum extension is 34 degrees; in Man O'War it is at least 27 degrees; in Secretariat it is 21 degrees. The femur swing in Justify is 24 degrees; in Man O'War about 5 degrees; and in Secretariat 22 degrees. Man O'War uses his back much more than femur protraction to achieve forward placement of the contacting hind hoof; Justify uses it somewhat more; Secretariat uses both about equally. Want to come home from a day at the track with some jingle in your pocket? Observe the horses as they come out of the saddling paddock and go to load into the gate. Then bet the trifecta on the three that show the most "wooka-wooka" (and you can throw away the racing form).

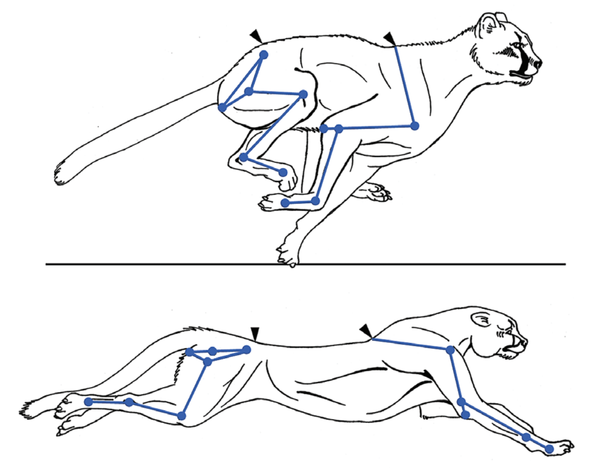
so that the front end of the pelvis comes to sit higher relative to the sacrum than nature intended. The latter displacement is the most common and results in the blemish that horsemen refer to as a "hunter bump" or "racking bump."

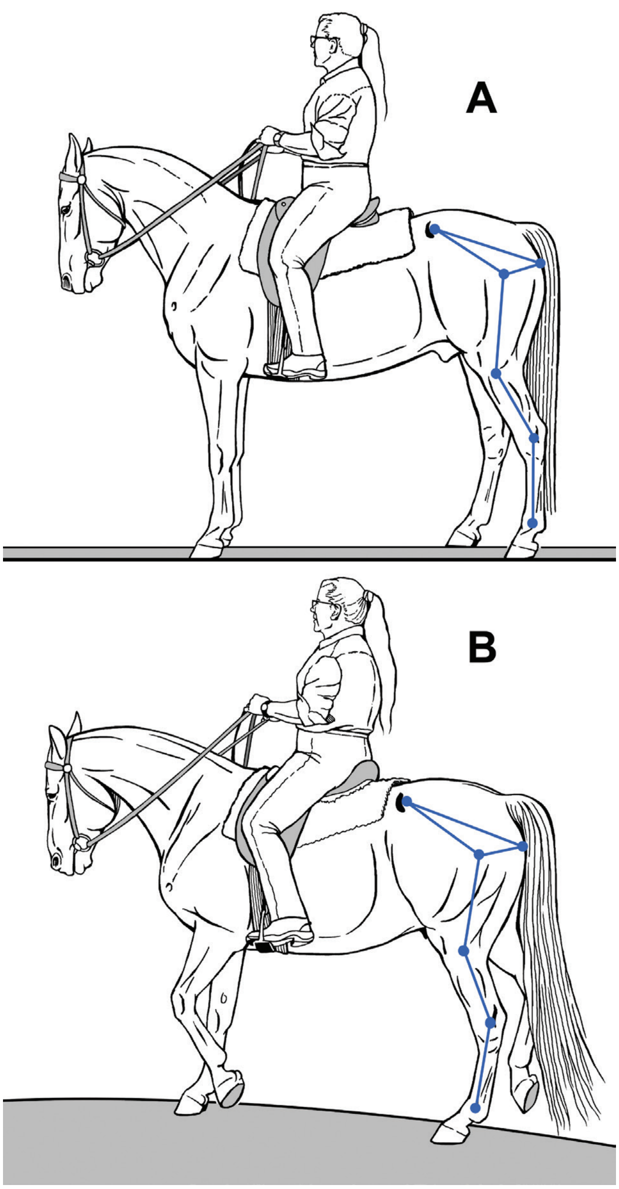
The inter-transverse articulations, which occur where the transverse processes or "side wings" of the last three lumbar vertebrae abut, are marked in blue (Fig. 2C). They work with the pink L-S articulations in loin coiling (flexion) and uncoiling (extension). Like the L-S joint, they are capable of almost no lateral flexion nor of any movement except coiling and uncoiling.

MAGNIFICATION FROM LOIN COILING: THE BACK

If the horse's hind limb be likened to a pendulum that can swing back and forth, the L-S joint is positioned at the top where, by the laws of physics, any movement it makes will be magnified the further down the limb you look. Magnification manifests in five aspects of back and hindlimb movement: elastic up-down oscillation of the back, engagement of the hindquarter, step, stride, and in pushing the body upward (carriage) vs. pushing it forward (thrust).

Loin coiling makes the horse's back feel and function more elastically, and thus makes it much easier and more pleasant to sit on even when he goes very fast. I have my own word to describe this feel, which I share because while it's funny and memorable, it's also a helpful analogy. A normal horse's spine is not rigid like a tabletop in movement but oscillates up and down (Fig. 3). My word for this is "wooka-wooka"—like the sound a diving board makes when somebody bounces on it. Like a diving board or a





good fly-fishing rod, the horse's spine is thicker at the rear end where it is anchored to the pelvis but becomes thinner and whippier as you go forward through the thorax to the withers. Every rider should seek the "wooka-wooka" feel as a sign that their horse is making the effort to achieve and maintain collected posture.

MAGNIFICATION: ENGAGEMENT OF THE HINDQUARTER

Film analysis shows that whether the horse is galloping or trotting, the average amount of forward swing of the femur at the hip socket is about 15 degrees (Figs. 4, 5, 6, 7). If a 15-hand horse does not coil the loins at all yet swings the hindlimb forward by this amount (Fig. 4B), his hoof will be set down about 14 inches ahead of the L-S joint. If, however, the horse also coils its loins only 10 degrees—the average amount seen in trotting (Fig. 5)—he will bring the hind hoof forward about 16 inches, a significant increase. If the horse coils the loins 30 degrees—the average amount seen in cantering, galloping, slide-stopping, and in the moment before he jumps a fence—he will bring the hind hoof forward about 18 inches relative to the L-S joint.

The maximum amount that a horse can flex the L-S joint (as measured by the total change in angle from that seen at a halt to that seen during maximal effort) is about 35 degrees, which in a 15-hand horse would result in forward displacement of the hind hoofs of about 24 inches. This is extremely important in racehorses; teaching a racehorse to use its back is a far more effective way to get him across the finish line first rather than breeding a taller horse.

Back flexibility is the secret to speed. This is true for all types of cursorial mammals, although the degree of flexibility differs by species. A horse cannot flex its L-S joint (or its lumbar and thoracic spine as a whole) as much as can cats or dogs. This is because the joints between cat and dog vertebrae are shaped to permit more movement than those of the horse, and because carnivores have a much longer lumbar span and only 11 pairs of ribs, many fewer than horses. Film analysis shows that a cheetah running flat-out at over 60 miles per hour (Fig. 8) achieves a total range of spinal flexibility (full extension

TOP: FIG. 8. A cheetah cruising at something less than its top speed, around 60 mph. The cat can maintain this speed for about three minutes. Note that the flexibility of its back is much greater than that of any horse; total change from extension to collection is 52 degrees, and total protraction of the femur is 60 degrees.

BOTTOM: Fig. 9. Here I am on my Morgan-related gelding Oliver (his conformation photo appears in the article "Hindlimb Structure and Motion" that appeared in *The Morgan Horse*, Oct. 2020, Vol. LXXIX No. 7). In view **A**, I have just brought him to a halt out of a vigorous working pace. The angle of Oliver's pelvis in the conformation photo is 9 degrees; in this view it is twice that, an indication that his L-S joint is flexed, his lumbar span is rounded, and that he is collected. Of course, collection shows through the forequarter also in the arching of the neck and the effort to raise the base of the neck (these aspects will be discussed in detail in our next installment). In view **B**, I am setting it up to make it easy for Oliver to step back one step at a time. He responds by first coiling his loins an additional 4 degrees (his pelvis tilts downward 22 degrees) and then lifting the left diagonal pair of feet. This stepping-back exercise is highly effective at strengthening the muscles (rectus abdominis, iliopsoas, and longus colli, see Fig. 3) that empower collection. Even in this gentle, slow bit of work, Oliver "sits down behind" about 10 degrees (the product of flexing not only the lumbar and L-S joints but stifle and hock also). This is as much as a horse typically lowers the hindquarters in more difficult forms of work such as piaffe or racing trot or pace, so the advantage is that no special talent or advanced skills are needed, and the exercise can be repeated often and worked into any training session.

to full flexion) of over 50 degrees. No horse, not even the most talented racehorse, can do this (Fig. 7)—and that is why the top speed that a racehorse can achieve (about 36 mph) is only about half that of a cheetah (somewhere between 60 and 70 mph). Back flexibility translates to engagement of the hindquarters because of course, insofar as the horse brings his hind hoof forward, he will necessarily bring forward the stifle and hock joints also.

MAGNIFICATION: STEP VS. STRIDE

Loin coiling that increases the distance that the hind hoof is brought forward magnifies both length of step and length of stride. It is very important to distinguish between the two. The size of a hind step is defined as the distance measured between the toe of a hoofprint made by the left hind and the toe of the hoofprint made by the right hind limb that lands immediately thereafter.

It's easy to see how loin coiling magnifies the horse's hind step, but it also—and much more importantly—magnifies the animal's stride. Stride is defined as the distance that can be measured between the toe of a hoofprint made by the left hind and the toe of the next left hind hoofprint when the horse is making an ordinary effort *compared with* the distance between the same two hoofprints when the horse is making a maximum effort.

Stride length thus has nothing to do with how widely apart two feet may spread, but rather is a measure of the length of flight or "suspension," when the horse has no feet in contact with the ground (Figs. 5, 6, 7). Stride length is more significant to superior performance than step length because the period of suspension is the only time the horse can fully respond to rider requests to change speed, direction, or gait. Obedience almost always requires the animal to alter the timing, or even rearrange the order, in which his feet hit the ground, and this can be done only when he has no weight upon his feet.

> **Teaching a racehorse to use its back is a far more effective way to get him across the finish line first than breeding a taller horse.**

This crucial training insight is easy to prove to yourself: stand on your right leg, and while you are standing on it, try swinging it forward or back. Not possible, right? Flying changes of lead are the litmus test of this truth in horse training, but in reality, it applies to all movements, transitions, and figures. Teaching a horse how to step back one step at a time, for example, is a practical and useful exercise for increasing his ability and willingness to flex the L-S joint (and arch the whole of the spine), thus enhancing his ability to collect (Fig. 9).

MAGNIFICATION: PUSHING THE BODY UPWARD VS. PUSHING IT FORWARD

Coiling the loins enables the horse to set the contacting hind hoof down well forward under the body. In such position it can both carry the body (push it upward) and thrust it forward (Figs. 5, 6). To achieve suspension, the body must be pushed upward and not merely forward; the obsession that many of today's dressage-influenced riders have with the necessity of "going forward" tends to obscure this fact. Consider throwing a baseball from the pitcher to the catcher: because the distance that the ball will fly through the air is short, its trajectory can be almost flat. However, if the center fielder wants to throw the ball home—a much longer distance—he must throw it upward and not just forward. Given an equal amount of effort, the more the horse pushes itself upward, the longer the period of suspension will be, the longer the time the ball will be in the air.

In order to propel itself forward, one or more of the horse's hoofs must be in contact with the ground. Then the muscles that straighten out the joints of the limb and that swing it backward push the limb *downwards and backwards* against the earth. Only from this—a very clear example of the physics law of equal and opposite reactions—can the horse go "forward," i.e. upwards and forwards. On the other hand, during the period of suspension when no feet are in contact with the ground, neither forward thrust nor upward carriage can occur.

In real life, the forward movement of a horse's body consists of a series of arcuate [shaped like a bow or arc] bounces which can be visualized if the horse is lunged in a dark area while wearing a surcingle equipped with a battery-powered light. The shape of the arcs described by the light will vary depending upon the gait the horse is using, the amount of effort he is making, and how much he is coiling his loins and thus how far forward of the hip socket the contacting hind hoof is when it touches down (Figs. 5, 6).

The farther back the contacting hind hoof is set down, the flatter will be the horse's arcs of motion. If the hind hooves touch down behind the hip socket in the thrust-only zone (Figs. 5, 6), the only effect that their contact with the earth can have is to push the body forward. If instead the hind hooves touch down ahead of the hip socket in the carry zone, the horse's body will be pushed not only forward but upward.

Virtually all the low and high "airs" of haute école (passage, piaffe, levade, pesade, terre-a-terre, mézair, ballotade, courbette, capriole), as well as rollbacks and pirouettes, call for very deep engagement of the hind hoofs. Somewhat less is appropriate for collected, medium, and extended trot, good quality park and English pleasure trot, pace, rack and stepping-pace, gallop, and (ga)lope. In short, virtually any performance discipline that calls for collection is in the same breath calling for engagement of the hindquarters that comes from loin coiling, so that the body can be pushed upward as well as thrust forward. The reverse is also true: note that if collection originates as loin coiling, then all great racehorses (trotters, pacers, and gallopers) run in collection. ■

In our next installment: Raising the Base of the Neck