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Popular Biomechanics

Mark Rippetoe

The most useful theories are those that simplify our understanding of apparently complicated things. The theory of evolution explains the rather interesting fact that frogs and humans both have two forearm bones, that grasshoppers and catfish share the common pattern of repeated trunk segmentation, and that all of us, including bacteria, use pretty much the same high-energy phosphate system to move things around inside our cells. My observations will never be this profound, interesting, or important. They will not even be that original. But since you apparently have nothing better to read right now, let's just enjoy these next few minutes together as though they will be useful.

Barbell training has been the focus of my attention for the last couple of decades. I am not bored with it yet. Whenever I have the opportunity to train a group of interested, motivated, bright people, I learn as much as they do. It has recently come to my attention that there are objective ways to describe proper form for the basic barbell exercises that are valid for everybody who does them, regardless of their anthropometry. For example, it doesn't matter how long your femurs or how short your back, the bar is going to come off the ground in a deadlift when the bar is directly under the shoulder blades. (For a detailed discussion of the deadlift, see my CrossFit Journal article "A New, Rather Long Analysis of the Deadlift.") This position will place the shoulders slightly forward of the bar and the arms at a slight angle back to it. This is a function of the mechanics of the skeleton, and is true even when form is bad: if the bar is too far away from the shins, and not right against them in a position that minimizes the torque against the hip joint, the bar still leaves the ground from a position plumb to the scapulas. Even if you wanted your back vertical due to the mistaken idea that a vertical back is "safer" than an inclined back, ultimately it doesn't matter because your skeleton cannot pull a heavy weight this way. But any correct pull from the floor—for deadlift, clean, or snatch—will start with the bar directly under the scapulas and against the shins. Any video of a heavy deadlift, clean, or snatch from the side will demonstrate this fact. It will also show that the bar leaves the ground when it is right above the middle one-third of the foot (fig. 1).

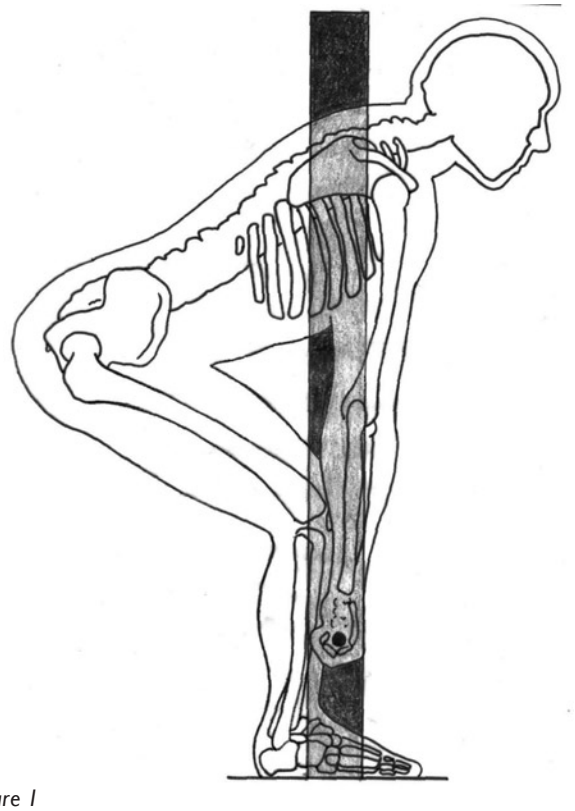

Figure 1

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Why the middle one-third of the foot? Because the weight of the load is distributed over the whole plantar surface of the foot if the load is in balance, and the load in question is the combined weight of you and the bar acting at the ground directly under the center of mass (COM) of this lifter/barbell system. If the weight is disproportionately on the toes or heels, the COM is either forward or behind where it should be to achieve its greatest distribution against the ground. When the weight is light, the mass of the body is the primary factor in balance. As the bar becomes heavier—as you get stronger—it becomes a larger percentage of the load, and the COM of the system gets closer to the COM of the bar. For this reason it is possible to do light weights with form that will be wrong, or ineffectual, at heavier weights, but heavy weights are unforgiving of errors in form that result in unbalanced loads.

It is also a fact that a squat is only in balance when the bar is directly over that same middle one-third of the foot. It doesn't matter where the bar is on your back or shoulders; if the bar is moving straight down or up as it will in any heavy squat that doesn't get dumped on the floor, the bar will never deviate much from a position directly above this place. If it does, it gets out of balance and slows down until it either gets back in balance or gets missed.

With this in mind, it is possible to identify certain aspects of any correct squat, regardless of bar position.

At the top of the squat:

- All the skeletal components that support the bar—the knees, hips, and spine—will be locked in extension so that the muscular components have to exert only enough force to maintain this resting position
- The bar will be directly over the mid-foot

At the bottom of the squat:

- The spine will be held rigid in lumbar and thoracic extension
- The bar will be directly vertical to the middle of the foot
- The feet will be flat on the ground
- The thighs will be parallel to the vertical plane of the foot
- The acetabulum, or hip joint, will be lower than the top of the patella

Now, you're free to deviate a little between top and bottom, but if you don't start and stop as described, you're wrong mechanically and the squat will be harder than if you were right. And, actually, if the bar stays in the correct vertical position over the mid-foot on the way down and up, you are doing it right. Your skeleton is solving the problem of how most efficiently to use your muscles to get the job of squatting done. It does so within the constraints imposed on it by the physics of the barbell/body/gravity system we all lift within. (And no, this does not vindicate the Smith machine. There is a gigantic, bottomless ocean of willingly misunderstood difference between a machine that makes the bar path vertical and a squat that is executed correctly enough to have a vertical bar path. Muscle and skeleton should do the job of keeping the bar path vertical, not grease fittings and floor bolts.)

If the bar path is vertical, two other squat variables can be analyzed. The angle of the back—that is, the general plane of the torso—will vary with the position of the bar on the torso, either on the back for a back squat or on the frontal deltoids for a front squat. And the position of the knees—the front-to-back distance from the back of the butt to the front of the knees—will vary with both back angle and stance. If the above five non-varying criteria for the bottom position are met, bar position and stance will control all the other position variables in all styles of squat.

The position of the bar on your back determines what the trip down and up will look like from the side. In a deadlift, the bar is always hanging from the arms and is always under the shoulder blades until it passes the knees, so the back angle is essentially predetermined, though of course it varies according to individual anthropometry. But the front squat, high-bar back squat, and low-bar back squat are all done with different back angles. Each causes the skeleton to move in a different way between the top and the bottom of the movement. This is because the bar position on the trunk varies relative to the hip and knee. When the bar is on the back, either on top of the traps in the high-bar or "Olympic" squat or just below the spine of the scapula in the low-bar squat, the back will be inclined forward at an angle that will place the bar over the mid-foot. The higher the bar on the back, the more vertical the back angle will be to make this happen (fig. 2). This means that a high-bar squat must have a steeper back angle than a low-bar squat if form is to be correct. A

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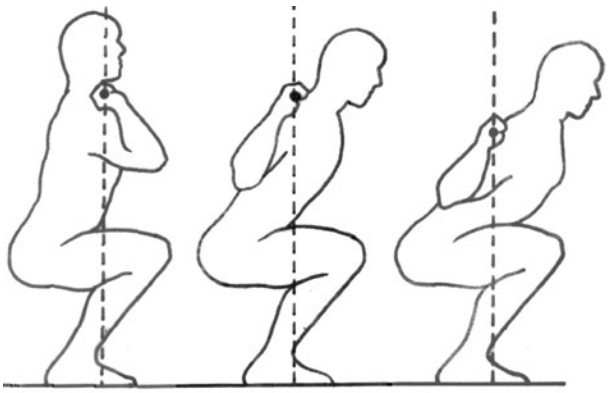

Figure 2

front squat places the bar at roughly the same level as a high-bar squat, but across the depth of the chest on the anterior deltoids, requiring the back angle to be so steep as to approach vertical.

A near-vertical back will result in a knee position much forward of that in a low-bar back squat; the high-bar squat is intermediate between the two. A knees-forward back-vertical position at the bottom produces a more acute knee angle, an already shortened hamstring, and a more extended hip. The front squat is therefore a much more quad- and glute-dominant movement than the low-bar back squat, since these are the muscles that remain in a position to contribute to the lift. This is also what's wrong with knees too far forward in the back squat: it is undesirable not because having the knees too far forward will destroy them but because of the detrimental effect it has on hip extension.

The vertical back position of the front squat seems like it would result in a more direct compressional load on the spine than the back squat's inclined angle would produce. This is partially true. The lower back is in a nearly vertical position, but the upper back has a much tougher job because the load it is holding up is farther away from the spine. The bar in a back squat, low-bar or Olympic, sits directly on top of the muscles that are holding it directly over the mid-foot. The front squat places the bar all the way across the depth of the chest, which in a bigger guy might be 12 inches away from where it would be sitting in a back squat. This is a much longer lever arm than no inches at all and presents a mechanical challenge to the muscles that maintain thoracic extension (it is very common to get pretty sore between and just below the shoulder blades when first starting the exercise). So while the lower back is vertically compressed, unless you are flexible enough to be capable of actually leaning back a little with the bar on your anterior delts, your thoracic erector muscles have a lot of work to do. This results in a gradual shift from compression to torque from low back to upper back, so things are not as simple as they may seem. The load on the lumbar spine in the front squat is friendlier (partly because it will be lighter) as long as the upper erectors are able to maintain position, and for this reason many people find it easier on the low back to front squat. And anything that gets too heavy gets dropped automatically before death can occur.

The upshot of all this technical analysis is that back angle is determined by bar position. But wherever the bar is on your back, it will be right over the middle of your foot, and your feet will be flat on the floor, or your mechanics will be less than efficient.

Another immutable criterion for correct form is that your thighs will be aligned with your feet. This also keeps the feet flat, removes any non-linear loading (twisting) of the knees, and ensures the participation of the adductors in the lift if the stance is wide enough to require it. Toe angle—and therefore knee angle if the feet are parallel to the thighs—is determined largely by stance width. A close-stance squat can be done either with toes out or toes pointing forward with only a slight angle, maybe just five or ten degrees. But the knees have to move straight forward to keep the thighs parallel to the feet; the knees always follow the toes to preserve the linear relationship between the patella, the patellar tendon, and the tibial plateau. These three things need to stay in a nice straight line if the knee is to continue to work without undue wear, especially under a load. And this is why the knee voluntarily lines up this way in any unweighted squat. Next time you stand up from a seated position take note of the alignment of your knees and feet.

The wider the stance, the wider the foot angle and the wider the knees will have to be to keep the thighs parallel to the feet. At closer stances, with more forward-pointing toes, the knees will travel farther forward than they do at wider knee angles. This is because the narrower the stance, the longer the distance from the front of the knee to the back of hip. And the longer this distance, the more the knees must travel forward to accommodate it (fig. 3). A close stance with toes pointed out will display the same knees-forward position that a moderate stance at the same foot angle will. At very wide

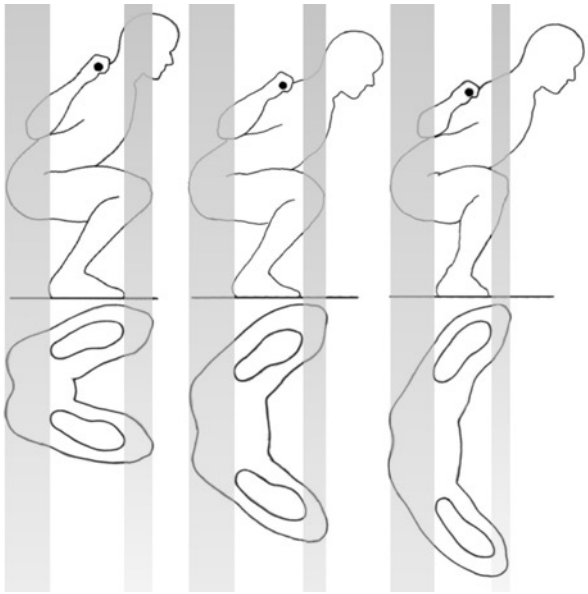

Figure 3

stances like those favored by powerlifters using squat suits, there is very little forward travel of the knee at all, and the shins tend to stay nearly vertical. But a wide stance will not work if the toes are pointed forward, because of the twist it places in the knee; this is about the only squat stance that is really anatomically wrong. I prefer heels at shoulder width for the generalized effects, but other stances can be used correctly as long as the knee is not twisted.

Feet flat on the ground are another important indicator of balance, and the coach learns to look for "air" under the heels as a sign of subtle mechanical problems. Most people who squat in those stupid "shocks" running shoes have learned how to squat balanced on the ball of the foot out of necessity, so it can be done. The point is that optimum engagement of the hip extensor muscles, the "posterior chain," cannot take place in this position, and that is what makes it wrong (that is also what makes weightlifting shoes a good place to spend a little money). Lots of form problems get embedded in lots of motor pathways; the reason we are having this discussion about objective technical markers for good form is to help identify the why and how of correct. Feet flat on the ground are absolutely essential for the engagement of all the muscles that make a squat correct. And "flat" refers to the pressure of the weight distributed evenly across the sole of the foot, not the angle of the foot against the floor that might well be the product of a weightlifting shoe.

The depth of the squat is determined empirically by observing the relationship between the hip joint and the top of the patella. These landmarks are easy to see from the side: the hip joint is behind the apex (the most pointy part) of the folds in the shorts made when the hips bend, and the top of the kneecap is clearly visible on the knee even through sweats. Depth is important for hundreds of reasons you already know, so I won't go into it here. Just remember: if in doubt, it's high. Ass-to-ankles is not absolutely necessary, and if it requires a relaxation of the lower back arch to get there, it's wrong. Breaking the plane of parallel is good enough, deeper is better, but excessive depth to satisfy an arbitrary ideal that cannot be attained with useful weights is counterproductive.

The press can be described in a similar way.

In the starting position for the press:

- Knees, hips, and lumbar and thoracic spine are all locked in extension
- The bar rests on the deltoids or chest, depending on individual flexibility and body shape
- Elbows are in front of the bar
- The bar is directly over the mid-foot

At the top of the press (fig. 4):

- Knees, hips, lumbar and thoracic spine, and elbows are all locked in extension
- Scapulas are elevated (i.e., "active shoulders")
- The bar, the scapulas, and the mid-foot will be vertically aligned

During the trip up from the starting position to the top, the bar path should also be vertical and directly over the mid-foot. If it deviates from this position a little as it travels forward around the head, the COM is kept over the mid-foot by leaning back slightly, to the extent necessary to balance the bar deviation. This should be minimized by keeping the bar close to the face during the press so that the bar doesn't get so far away forward that it cannot be pressed efficiently.

The clean and the snatch are more complicated than the slow lifts because they travel so much farther and utilize movement around so many joints. But like the press, any deviation of the bar from alignment over the mid-foot is compensated for by movement of the body that keeps the COM of the system in balance over that point. Both lifts start and finish with the bar

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in the same relationship to the mid-foot that the other barbell exercises do, with a bunch of added complexity in between to keep the bodybuilders away from the bumper plates. Any discussion of the subtleties therein is best left to my betters.

The point of this rather dry discussion is that there are objective ways to quantify proper form in the basic barbell movements, to allow us to understand better what we're seeing when we watch people lift. These criteria are based on skeletal considerations that do not vary with anthropometry, even though the individual expression of these criteria will. There are many ways to screw up the lifts, but an understanding of what we should be looking for at crucial places in the movements reduces the number of ways we are likely to do so. It also gives us some objective anatomical data to on which to base our discussions of good form and best practices for lifting.

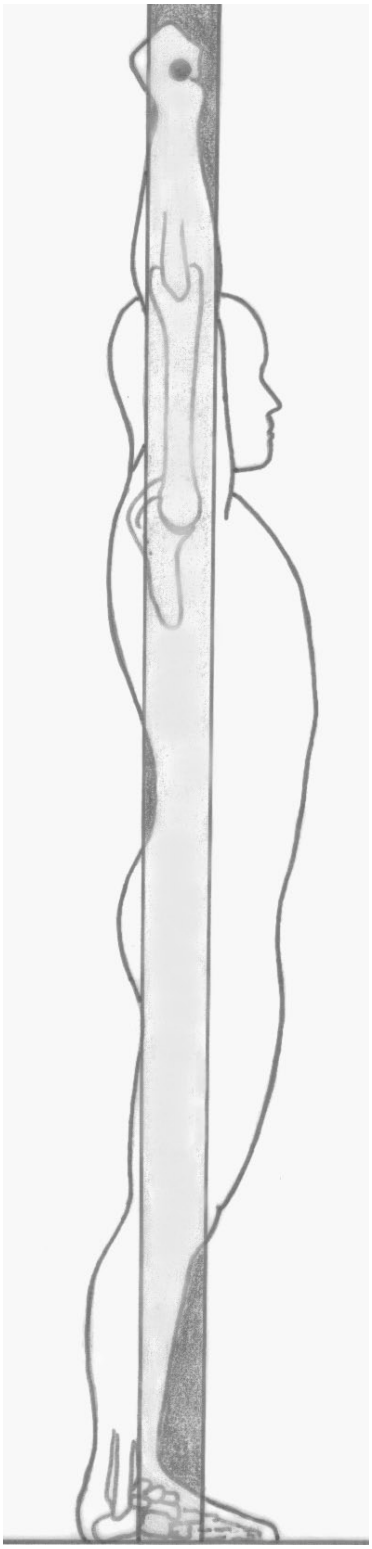

figure 4

Mark Rippetoe is the owner of Wichita Falls Athletic Club and CrossFit Wichita Falls. He has 28 years experience in the fitness industry and 10 years experience as a competitive powerlifter. He has been certified as an NSCA Certified Strength and Conditioning Specialist since 1985 and is a USA Weightlifting Level III Coach and Senior Coach, as well as a USA Track and Field Level I Coach. He has published articles in the *Strength and Conditioning Journal*, is a regular contributor to the *CrossFit Journal*, and is the co-author (with Lon Kilgore) of the books *Starting Strength: A Simple and Practical Guide for Coaching Beginners* and *Practical Programming for Strength Training*.

Illustrations courtesy of Lon Kilgore

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