The Physics and Physiology of Rowing Faster: The stroke

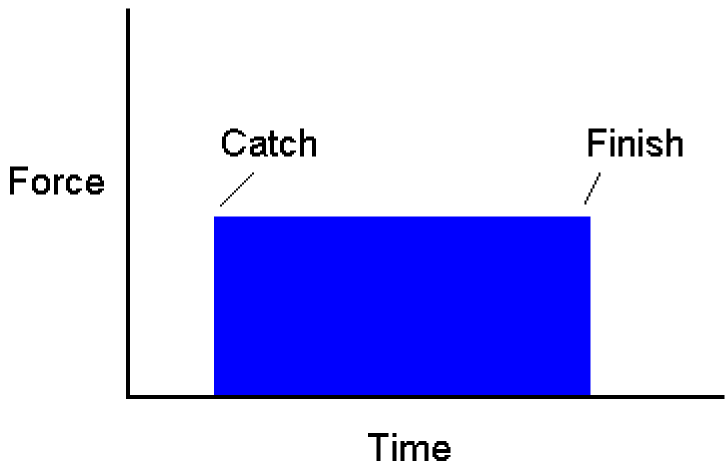
In rowing, as in other sports, performance is a function of both biomechanics (and the mechanical principles that guide it), and physiology. Both in the broad field of sports science and within the narrower realm of coaching rowers, these two areas tend to get dichotomized. You have your biomechanical technicians, and you have your physiologists, either by profession or by emphasis in thinking when coaching or performing there sport. This is not surprising. The same two camps are easy to spot among the cyclists too. The two areas have such different knowledge bases, that specialization is almost essential. However, you come to a point when trying to maximize performance when the two paradigms must merge. The biomechanics of rowing impact the physiology!

I have read my share of rowing books; novels, coaching articles, research literature, etc. So far the only author I have read who has really tried to integrate the physiology and biomechanics is a Dr. Walter Roth from Germany. The best piece I have from him is a translated article that appeared in FISA COACH back in the Fall of 1991. So, up front, I will say that this article is influenced by his work. While I was thinking about this approach before I found his work, he was definitely thinking this way before I was! Another influence has been Matt Diefenbach, a friend and coach who lives in Austin, Texas. Matt is neither a physiologist or a biomechanist, just an excellent coach.   Matt knows what it takes to move boats really fast. More importantly, he knows how to take rowers from where they are, to where they need to be. One of the latest fruits of his efforts now sits in the new US men's 4x that took Europe by surprise in mid-July. I have said before that it is crucial for rowers to develop a clear vision of the stroke they are trying to emulate. Matt has helped me in that vision quest more than anyone. The other influence is me and my own personal rowing experiences. I have rowed badly, and I have rowed well (or at least considerably better than bad). All along the way I have combined the on-water experience with what the research says about biomechanics and physiology.   So what will follow here is some combination of art and science, fact and feeling. I believe it is close to reality, but I welcome criticism.

The Perfect and Impossible Rowing Stroke as a Starting Point

If we could build a rowing robot that mechanically placed, drove and removed the oars in the same manner as human rowers, the force time characteristics of that stroke might look very nearly like this:

Figure 1. Hypothetical Force Time Curve for a Rowing Robot



This is what we call a "Square wave" force curve. It depicts instantaneous acceleration up to peak power, sustained power throughout the drive, and instantaneous deceleration at the finish. Of, course, this is not how humans row, but it gives us a starting point to think about the three phases of the drive sequence. I will call them the catch, the middle drive, and the finish. The depiction above also introduces us to the concept called "rectangularization of the force-time curve." The graphic also introduces two dimensions: FORCE and TIME. Multiplying the magnitude of a force times the duration it is applied gives us the IMPULSE. This is depicted by the area in blue above. It is the average IMPULSE of each stroke that determines boat velocity, not the peak force alone, not the peak power alone, and not the length of the stroke alone. Think about that. You can generate a huge, but brief spike in the force time curve, corresponding to massive peak power, and not move a boat fast.

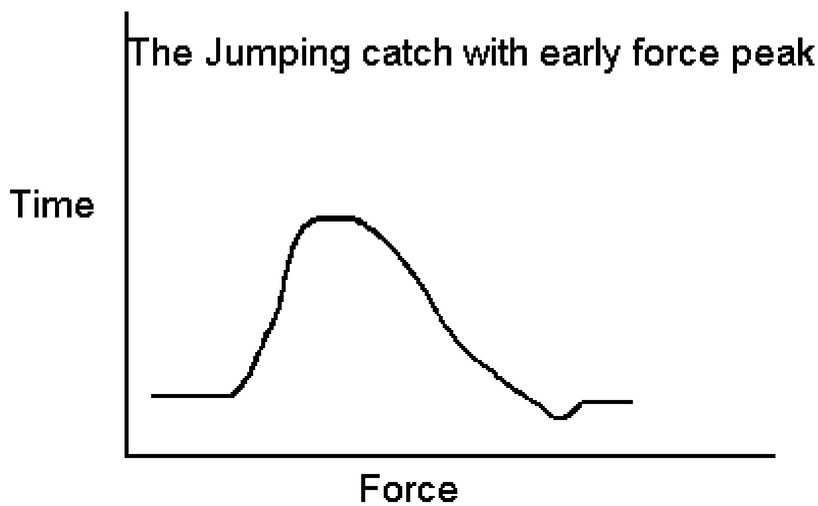
Now here is a major connection between physics and physiology: Average IMPULSE (and the frequency of those impulses) generated by a rower during a 2000 meter race is going to correlate closely with the maximal oxygen consumption in absolute terms (liters/min). So physiology constrains the total area under the force time curve. That is not difficult to buy into. However, the next step may be harder to take. Physiology also has a lot to say about the optimal shape of that force time curve.

Three Approaches to the Drive: The Hard Catch, The Hard Finish, or the Fat Middle

Next I am going to present three composite force time curves which represent different rowing styles that are observed among rowers. The force curves represent what is happening at the handles or oarlocks, not the force vector contributing to forward propulsion. What is happening at the handles describes the force production of the rower, and that is what matters physiologically. We will connect that with the impact of an arcing blade on propulsion momentarily.

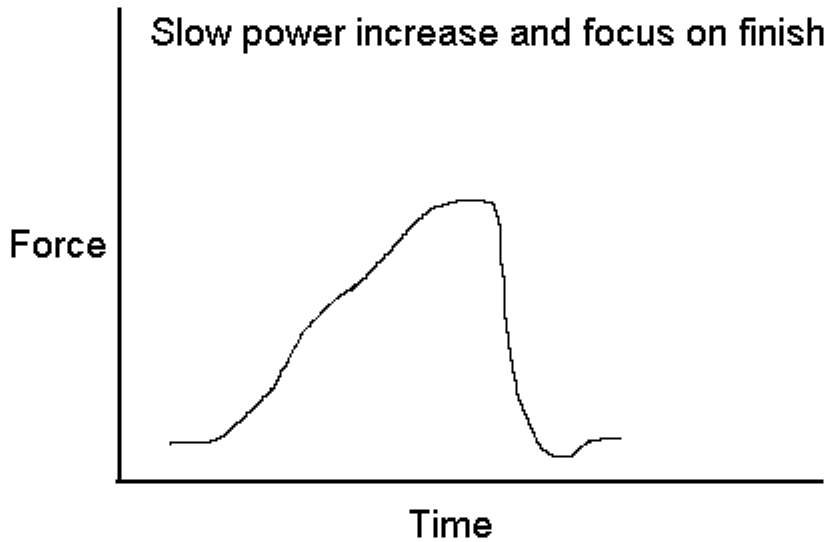
1. The Jumping Drive

If we try to copy the first aspect of the robot rowing curve above, the instantaneous peak power onset at the catch, then we are talking about focusing on very rapid and explosive engagement of the legs. This style is associated with "jumping out of the catch" in order to help rowers or crews visualize the goal of quickly engaging the oar and achieving high peak force early in the stroke. As in a jump, the work is done early and the remainder of the extension through to the finish is almost inertial in character.



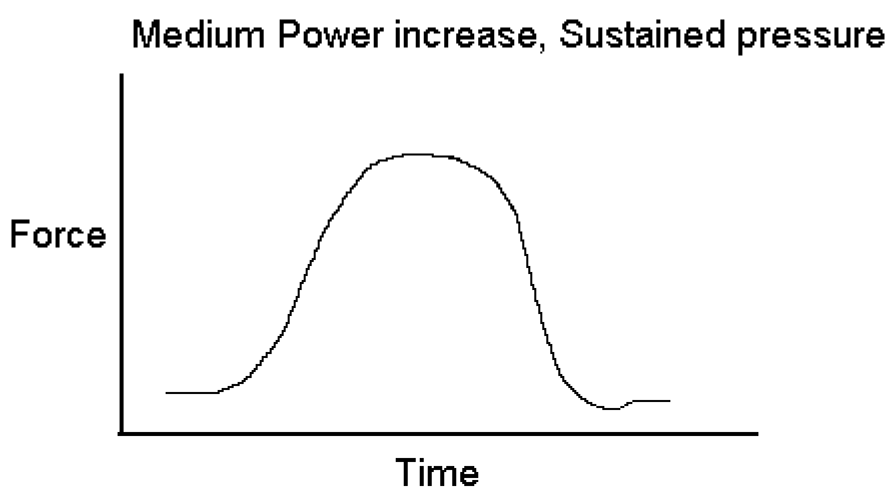
2. The Big Finish Drive

Another approach to the stroke involves trying to achieve maximum power between mid-drive and the finish of the stroke. In this case, the force-time curve looks like this:



Finally, we have a force time curve that I will call a "fat middle" curve. In this style the rower is trying to achieve sustained power throughout the drive, without overemphasizing either end excessively. This stroke is typified by a flattened force peak.

3. The FAT MIDDLE Drive



Now, don't try to visually compare the area under the curves in the drawing above because they are not to scale. However, mentally comparing the areas is worthwhile. Remember, physiological capacity is going to constrain the area under the force time curve. In a short race of say 300 meters, it is constrained almost completely by the **anaerobic capacity** (muscle mass and pH buffering capacity) of the rower or crew. However, in a 2000 meter race (or even a 1000 meter masters race), the **aerobic capacity** (cardiac pumping capacity plus specific muscle endurance) of the athlete will account for about 80-85% of the performance power. So, you can change the shape of the curve with technique, but you're not going to magically increase the average IMPULSE by some huge percentage. However, I think that optimizing the SHAPE of your force curve through the drive can result in significantly better average speed over a 2000 meter race. We are trying to find the rowing stroke that allows us to maintain the best combination of applied power and technical stability from the first 500 through to the finish line.

So, which style is best? For a 2000 meter race or longer, the answer appears to be The FAT MIDDLE drive, especially in the single. The reasons are both physiological and biomechanical. First, the Physiological.

1. producing very steep force-time curves is VERY energetically costly. In order to reach peak power very quickly, the muscles call even more dominantly on the Fast twitch motor units. Consequently, for the same IMPULSE, the rower accumulates lactic acid more rapidly then if the force production were distributed over a longer time period. This reason makes the jump catch ineffective for more than a 10 or 20 strokes, or a 500 meter sprint at best.

2. A force-time curve based on the "Big Finish" creates similar problems. Whether by conscious choice or due to bad technique (like missing water at the catch), many athletes try to "jerk" the oar to greater velocity from the mid-drive through the finish. This time the physiological consequence is a focus of loading on the muscles of the back and shoulders. So, the IMPULSE is the same or a bit smaller, but the quantity of muscle mass generating the force is reduced, and local lactic acid production increases. This stroke pattern is never effective, even for a few hundred meters!

3. The Fat Middle Drive represents a happy medium. The catch is still important. Early leg drive is still critical, but the action is controlled and extended through the entire leg extension, not brutal and cut short. The athlete is trying to extend the power application over a longer time period. Peak force during the stroke will probably be slightly lower than that achieved with a hard, jumping catch. Even distribution of force application and lactate production over the entire rowing muscle mass is emphasized. When I say even distribution, I mean relative to the size of the muscle mass involved. Every muscle group is contributing in proportion to its mass and leverage. The rower must be "equally fit" in all the rowing muscles to achieve this.

The Biomechanical Advantages

The Fat Middle drive is also the preferred approach biomechanically. An oar travels an arc centered at the oarlock. The component of the rower's force production that contributes to forward propulsion is relatively lower at the catch and finish, and higher in the middle of the drive. Therefore a force-time curve which focuses the majority of the impulse at the time when the oar is sweeping between 70 and 110 degrees is going to result in greater boat velocity. It is not hard to see how two rowers with the same aerobic capacity and IMPULSE development can have very different 2k race times, if one rower distributes his force production more optimally, and directs more of his applied power towards boat propulsion.

The Fat Middle drive does not abandon the important idea of a quick catch and firm leg drive, it merely optimizes it. The force- time curve is rapid enough to fully load the oar well before the 70 to 110 degree arc area begins, storing energy in its structure that will be released nearer the finish, but not so rapid as to spill excessive energy into moving water instead of the boat.

The firm pressure early combined with proper forward extension of the shoulders at the catch also places the muscles of the upper back and posterior shoulder in a position of stretch. This stretch is important for optimizing the force production of these muscles at mid-drive and through to the finish in the same way that a jumper first stretches his quads by sinking down before reversing the movement and exploding upwards. Without enough preliminary stretch of the muscles force production is sub-optimal. This is another reason why the style emphasizing a "big finish" comes up highly ineffective. The muscles being emphasized in that style are not effectively pre-loaded with a strong leg drive.

Application to Training

The style in which you row has profound and very specific effects on your physiological makeup. I have one study which demonstrated this difference brilliantly by examining the bowmen and the strokes in a group of pair sweep rowers. Because of the positions of the oars relative to the boat, the rowers employed different force time curves in order to keep the boat moving straight. They had different muscular enzyme characteristics and lactate profiles as a result. Physiological adaptation is THAT specific. If you are a rower who has been rowing ineffectively for years, then two things are going to conspire against you if you try to change your technique. They can be overcome, but you need to understand them in order to overcome them.

1. The thousands or millions of strokes you have taken have resulted a motor program that is basically "hard-wired." Without great concentration, your body will quickly fall back into that pattern because it is the "path of least resistance" from a motor control (coordination) standpoint.

2. While the way you row may not be optimal in the big scheme of things, your body has adapted specifically to it. So, it will feel optimal even when it isn't. If you try to row differently, it will feel worse initially. You will be quickly exhausted when you start really using your legs, for example. So, you will tend to fall back into the familiar pattern for this reason as well.

Newton's First Law has an important training correlate. A body trained one in one technique for years likes to continue training that way, and resists outside efforts painfully!

This all brings me back to my friend Matt, and to coaching the rowing stroke. In a perfect world, a good coach gets a rower when they are about 13 or 14 years old and teaches them how to row. The coach teaches a rational, effective rowing technique and they have young athletes who are very responsive to learning new coordination patterns. The greatest gift of youth is learning coordinative patterns, not strength and power. The rower becomes technically proficient long before they are strong enough to really row fast. The rower grows into their good technique as their body matures and training volume and intensity ramp upward.

In the real world, many rowers are introduced to the sport relatively late and when they are, their models for good rowing are often either poor or non-existent. Maybe you are one of these real-world rowers. I am, and I have the "battle scars" to prove it. Fortunately I happened to meet a really good coach. Based on my experience, here is what you should expect from a coach if you are to ever really fundamentally change your rowing technique for the better.

1. That coach needs to have a clear vision of what they are trying to accomplish in the rowing stroke. If the coach is not sure what they want and why they want it, then you sure as heck not going to figure it out.

2. The coach (and you) have to be willing to break things down to their structural fundamentals and rebuild the stroke. This is hard and often seems counter-productive at first. For example, in the year before my teammates and I won masters Nationals in the US we often rowed in a 4x one at a time, legs only for kilometers, rotating through the boat. The experience was excruciating, but effective. We reprogrammed our motor pattern to better utilize the leg drive while maintaining the correct upper body posture, whether at 14 strokes a minute or 41. I have seen coaches in action who see the same mistakes but can't correct them because they only know how to say "quick catch" or "sit tall" instead of how to use drill methods and pictures to convey to a rower what a quick catch or synergistic drive sequencing feels like and how to achieve it again and again until the new becomes the norm.

In essence, a good coach has to be willing to be treat you like a kid even though you are a slow learning adult. And a rower who really wants to get better has to allow themselves to be broken down and rebuilt.

3. You need the luxury of time and a lot of sessions for reinforcement. Radical technical changes don't stabilize overnight. The athlete has to not only learn the new coordination pattern, but also has to adapt physiologically to the unique demands of a new force-time curve. If you change the stroke, you change how the muscles are performing the work. You will use some muscles more than you ever have, often to great surprise. You will have to reproduce the perfect, powerful stroke at low ratings before you can hope to repeat it for 240 strokes at race pace. Why do we row at these low rates like 18 so much anyway, if we race at 36? By rowing at low rates you can ingrain the proper force-time curve on your stroke before you are sufficiently adapted to reproduce it for 2000 meters

at race pace. The coordinative adjustments required to row the same technique at a higher rate come quicker than the biological adaptations necessary to support that effort.

UPDATED 7-23-97. Just after I posted this article on the MAPP, I recieved a comment from a rowing coach that is worth including here.

Stephen, I think you article on the 'fat middle' of the stroke may be a little confusing to some readers. I agree that a square wave stroke would be ideal, with the maximum pressure being applied throughout the stroke, however I think the graph depicting a 'fat middle' is a little misleading. Some people might think that you should pull harder during the middle of the stroke. I have always been coached to accelerate the oar handle to the body, applying force right up to the tapdown. I have also been coached to put the oar in the water while moving still moving toward the stern. Thus the blade will already be in full contact with the water when you begin your drive. I don't think people should compromise and strive for a 'fat middle' stroke, I think the ideal should be sought and if the resulting stroke is a fat middle then so be it. I think you should explode at the catch, drive like hell through the middle, and continue pulling until you can barely fit in a clean tap down. Of course, that's just my opinion...

Bill Waugh

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It is a great description of the stroke. I think that Bill and I are actually in quite good agreement. We both want to see a stroke that emphasizes applying force hard and continuously all the way to the finish. The result is a squared off force-time curve (but continued acceleration through to the finish). My argument is that if you go over a fine line and sell out **TOO** much at the catch, trying to achieve that instantaneous peak power, the physiology suggests that 50 strokes into the race the curve will destabilize and the result will be loss of average speed over the full race length. This outcome has been suggested by the German data from Walter Roth. I hope the confusion is reduced, but let me know if I am making a mess out of rowing technique!