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The Science of Drafting - Easy Riding in the Slipstream

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It is common knowledge that drafting, or riding in the “slipstream” behind other riders, reduces aerodynamic drag forces which critically affect the effort required to ride at a given pace. Racers use drafting to increase speed without increased effort. Recreational riders can use drafting to ride longer without fatigue. To be a complete cyclist, full respect and appreciation of the science of drafting should be developed.

In this article, the science of drafting will be explored. Questions we will address in our exploration of drafting science include:

- What is the energy savings while riding behind one, two, and three riders?
- How important is wheel gap to draft effectiveness?
- Do I benefit when someone drafts me?
- What are the "rules" of pacelines?
- How about packs? Are packs as good as pacelines?

What is Drafting?

Drafting in cycling simply means riding in the wake of riders up ahead. While drafting, riders take advantage of an artificial tail wind generated by the movement of other riders through the air in front of them. The presence of this tail wind is easily observed when automobiles pass close to bushes or over pieces of paper, cardboard, etc.

How is the effect of drafting measured? In general, four methods have been used to study drafting. The most expensive method requires a wind tunnel. Chester Kyle, Ph.D. used wind tunnels in the early 1980s to test the effect of drafting on cycling aerodynamics, and we use wind tunnels today (with Dr. Kyle) to evaluate U.S. National Team riders. Riders are positioned in the wind tunnel in various numbers and arrangements and the drag forces are measured directly. A lower cost method to evaluate the effects of drafting involves coast down tests. In these tests, rider and bicycle deceleration rates are measured while coasting in zero wind conditions from initial speeds of up to 35 mph. Since deceleration is directly proportional to the resistive forces acting on the bicycle and rider (aerodynamic and rolling), and since rolling resistance doesn't vary in draft situations, the separate effect of drafting on aerodynamic drag can be calculated.

A third method to study drafting, pioneered by James Hagberg, Ph.D. and his associates, involves the direct measurement of oxygen consumption while riding on the road. Hagberg fabricated a boom-mounted oxygen breathing apparatus that permitted the evaluation of drafting conditions on energy expenditure. Since this method measures physiological response to drafting arrangements, it has direct application to real world situations. The fourth method requires on-board instrumentation to measure bicycle power output. Power output is typically measured at the cranks or at the rear hub. These instrumentation devices have become available in recent years, and we use these devices with U.S. National team athletes (road and track) at the Olympic Training Center in Colorado Springs. Because these on-board instrumentation systems simultaneously measure both speed and bicycle power, uniform speed over lengthy intervals (6 to 7 minutes for the oxygen measurement tests) is not required.

Fortunately for all of us, the results obtained using the different methods are in general agreement. Differences between methods can generally be attributed to unique features of the experimental setup (riders and bicycles used, conditions studied, etc.).

The Effects of Drafting

In general, drafting at speeds above 20 mph will result in an energy savings of between 20 and 40 percent. The factors that cause the effect to vary from 20 to 40 percent, admittedly a huge range, are as follows:

Speed Effect

The faster you ride, the greater the energy savings resulting from a given type of draft (Figure 1). Dr. Kyle determined that when one rider drafts another, the following rider enjoys a 38 percent decrease in aerodynamic drag relative to the leader. Dr. Kyle indicated the 38 percent decrease was constant across speeds (from 15 to 33 mph). However, because a lead riders' energy consumption increases dramatically with speed, the absolute amount of energy saved by drafting increases with speed (e.g., 38 percent of 400 Watts is more than 38 percent of 200 Watts). When Kyle adjusted his estimate to include the effect of rolling resistance on bicycle power output, a total energy savings of 29 percent at 15 mph, and 35 percent at 35 mph resulted.

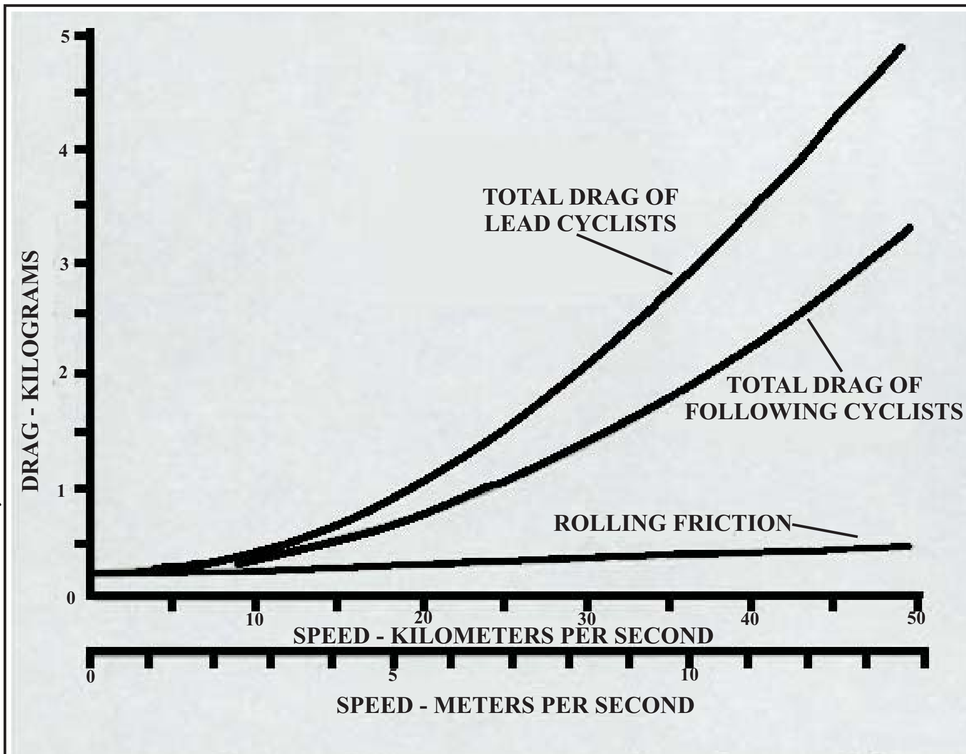

Figure 1 - Resistive drag in kilograms versus bicycle speed for 4 cyclists in a paceline in a racing positions. Wheel gap = 0.30 meters (approximately one foot). Figure adapted from Kyle, 1979.

In Dr. Hagberg's oxygen consumption tests, the total energy savings resulting from drafting a single rider was roughly 18 percent at 20 mph, and 26 percent at 25 mph. The reason for the discrepancy between Dr. Kyle's results and those of Dr. Hagberg's is not completely apparent. Data collected on U.S. National team riders, however, indicate that significantly more than 35 percent savings can be achieved at 25 mph if draft alignment and wheel spacing is carefully controlled. Consequently, the effects of test conditions on the results reported by Kyle and Hagberg may be important.

Pace Line Position Effect

The lead rider in a pace line does not benefit from the drafting process. Although this may seem obvious, some aerodynamicists have suggested that a region of increased pressure forms ahead of the drafting rider, and this increased pressure region may assist the lead rider. To date, however, no measurable effect of drafting on a lead rider has been identified.

By contrast, following riders benefit significantly from drafting. If two riders form a pace line at 25 mph, the front rider consumes the same energy as if riding solo, while the second rider consumes about 27 to 33 percent less energy. Does the draft effect change within the pace line if more riders join in? Surprisingly, there appears to be little difference in energy consumption between the 2nd, 3rd, or 4th positions in a pace line (Figure 2).

The number of riders in a pace line does have a significant effect on the speed at which the group can ride. This group effect occurs because the greater the number of riders participating in the rotating pace line, the more time each rider spends in the lower energy draft positions. Using Dr. Kyle's data, for example, four riders capable of riding 25 mph without the benefit of drafting should be able to ride approximately 27.25 mph at the same total energy expenditure as a group.

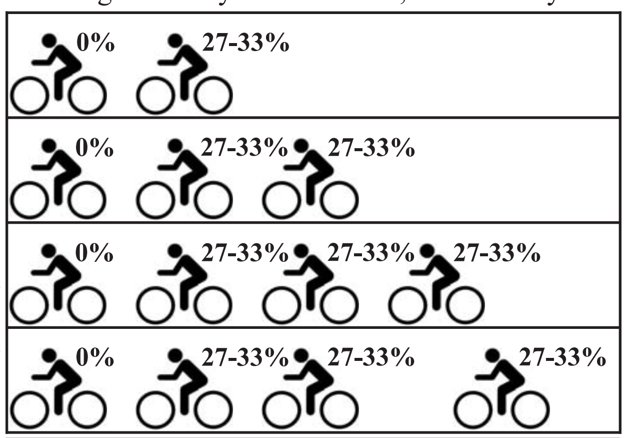

Figure 2 - Effect of different drafting conditions on energy expenditure. Percentage reductions indicates for each rider at a cycling speed of 25mps

Spacing (wheel gap) Effect

As expected, the more closely one rider follows another, the greater the effect of drafting. The 38 percent reduction in aerodynamic drag reported by Dr. Kyle was with a wheel gap of approximately 12 inches. When the gap was increased to 78 inches (a little more than one bike length), the aerodynamic drag savings was reduced to only 27 percent. At world class levels, team pursuiters and team time trialers attempt to maintain their wheel gaps within 6 inches to maximize the advantage of close-gap drafting. Furthermore, the use of 26 and 24 inch wheels in team events is largely motivated by the spacing effect, i.e., smaller wheels place riders in a paceline closer together, which enhances the draft effectiveness.

If some overlap between the drafting riders' front wheel and the lead rider's rear wheel exists, alignment is not ideal (the drafting rider is to one side of the lead rider) and a decrease in draft effectiveness occurs. Dr. Kyle commented on this situation because it arose several times in his experiments. Kyle indicated only a 0 to 30 percent reduction in aerodynamic drag in the overlap position (depending on the magnitude of the overlap and the side-to-side spacing), compared to a 38 percent drag reduction for the aligned drafting condition with a 12 inch wheel spacing. Given the negative effect on draft advantage and the inherent danger of riding in this position, it is wise to avoid the overlap situation in pacelines.

Body Size and Positioning Effect

The effect of drafting a large, upright rider is obviously greater than drafting a small rider in a tucked, aerodynamic position. But how large is the effect? Dr. Kyle reported that an upright rider in an upright pace line experienced a greater percentage reduction in wind resistance than a rider in a racing position in a racing position pace line. As Kyle pointed out, however, the upright rider consumes more energy than the racing position rider, because of the effect of position on baseline aerodynamic drag. Kyle did not study the effect of a streamlined, racing position rider drafting an upright rider.

With U.S. National team pursuiters, we also see a marked influence of rider size, shape, and position on draft effect. In summary, large riders, and normal size riders with wide shoulders, provide an advantageous 'slipstream' for following riders.

Arrangement Effect

We've indicated that with the exception of the lead, position within a paceline has no effect on draft effect. How about pack riding? Dr. Hagberg reported a 39 percent reduction in energy expenditure when riding at the back of an 8-rider pack. This energy savings is compared to his 27 percent reduction in paceline drafting. Kyle studied a single pack of three riders in an open V-formation (Kyle actually ran his tests in a 200 meter long hallway!) and found a reduced draft effectiveness for the single rider in the rear. Kyle's arrangement, however, placed no rider immediately forward of the drafting rider.

Applying Principles of Draft

Having developed some understanding of drafting, we can now apply what we know to racing, training, and just plain riding.

- When drafting, try to stay directly behind other riders if possible. In packs, align yourself with at least one bicycle ahead of you.
- Six- to twelve-inch wheel gaps are safe and effective for experienced riders. As wheel spacing increases, so does aerodynamic drag in the drafting position.
- Over a given race course or training ride, you can ride faster in a paceline for the same energy expenditure. Don't be alarmed when you discover you and your riding group are speeding along some 2 to 3 mph faster than you normally ride alone.
- At the same speed, you spend considerably less energy while drafting. Maybe you feel under the weather one day, or need a recovery day after a hard week. Sitting on somebody else's wheel at your usual pace will save you energy, and save your legs.
- Riders behind you are resting. Being in front is a great place to be to if you're trying to build endurance, but at a third more power than everyone else, you probably won't last long in this position.
- In races, select larger riders to draft if possible, or riders who sit more upright on their bicycles. Saving your resources in this manner may leave you with just that extra burst of energy needed to place in the top group.
- When your competitors are drafting you, stay aerodynamic. Keeping streamlined reduces the effective draft your opponents receive from you, and therefore they must tap deeper into their energy stores.
- We've established that the effect of drafting on energy expenditure increases with bicycle speed. Headwinds also increase the effectiveness of a good draft.
- In cross winds, draft behind and slightly to the downwind side of the lead rider. The stronger the cross wind, the more to the side of the lead rider you should be. Be careful to monitor dangerous wheel overlap in these circumstances.
- Weaker riders can survive in pacelines due to the reduced energy expenditure in the draft positions. Weaker riders, however, can slow a paceline. To drop a weaker rider, accelerate the paceline while the weaker rider is in the rear position and hold the increased pace until they drop back.

For the Beginner: Learning to Ride in Pacelines

- Play it safe at first. Ride an entire bike length behind other riders when learning to draft. Here, you'll have time to react to sudden changes of direction or pace. Don't reduce your wheel spacing until you can hold a steady, smooth pace at a constant wheel spacing.
- Follow experienced riders at first. Experienced riders ride in straight lines with minimal changes of pace. If you find yourself behind a jerky, hesitant rider, increase your wheel spacing.
- Don't become mesmerized by the wheel in front of you. Pay attention to upcoming events such as turns, bumps, etc..
- When it's your turn to lead, maintain the pace in effect before you took the lead position. If you encounter a hill while leading, slow down gradually and maintain a steady effort.
- While leading, you're responsible for avoiding hazards. Stay away from the edge of the road, be alert, and make early reactions to obstacles or pot holes. Don't lead your paceline into trouble.
- When finishing your turn at the front, look left to check clearance and to signal the following riders that you are pulling off, ease to the left and back off the power to the pedals to move rearward relative to the paceline. Apply power while abreast of the last rider (and be sure it is the last rider) to avoid being dropped as you assume the back position.
- Enjoy the rest while drafting.