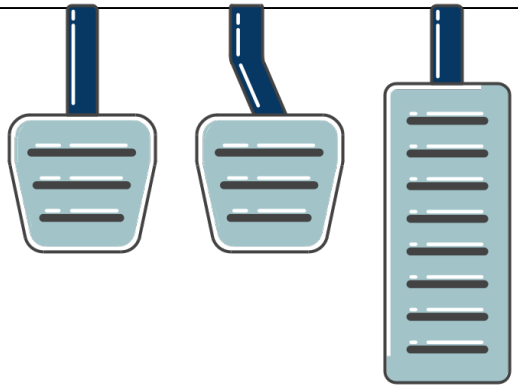
Braking



- Gradual Brake Release
- Trail Braking

"Bring your foot off the brake pedal gently and progressively. The whole sequence should be one gentle, sensitive, flowing movement. You want the nose of the car to come up gently and undramatically... It's not when you brake but **when you take them off that counts**."

– Sir Jackie Stewart
Formula One Driver, from 1965 and 1973, winning three World Championships

Welcome to the PCA Northeast Region's presentation on braking. NER hosts many High-Performance Driver's Education events at some of the best tracks in the Northeast and Canada. Learn more at: https://porschenet.com/activities/driver-education/

At our HPDE track events, this material is presented live to solo drivers in the blue and white run groups. However, this material can benefit drivers with any level of experience. If you're a novice driver working with an instructor or coach, be sure to discuss with them anything you learn here before trying things on the track.

We want to thank Chuck Tucker, from Community.Hagerty.com, for sharing slides that are the basis for this presentation, and Ross Bentley, from SpeedSecrets.net, for all the fantastic racing education material he shares, which has greatly influenced this presentation.

While you may be tempted to try to reduce lap times by pushing harder on the pedal on the right, it is usually the case that the best drivers are fast because of the subtlety with which they press their brake pedal. This presentation will help you learn how to brake correctly by gradually releasing the brakes and carrying your braking into the turn.

Pre-Check

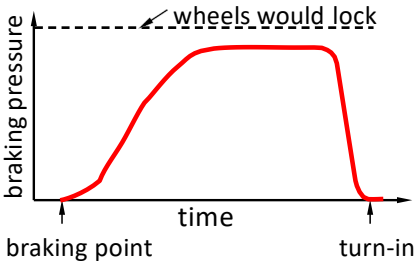
- Do you finish your braking after turn-in?
- Do you begin accelerating at the apex?

Both are good driving techniques.
This presentation focuses on braking.

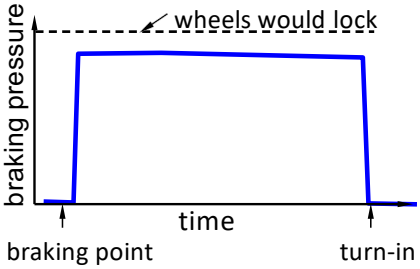
Are you finishing your braking after turn-in? That is, you begin gradually releasing the brakes at some point before turn-in, and you finish releasing the brakes at some point after turn-in. That is a good performance driving technique called trail braking, which any fast driver will do in most turns. Ultimately, that's what we'll talk about today, and we'll begin with talking first about gradually releasing the brake pedal.

What about starting your acceleration out of a turn at the apex? This technique is also essential in performance driving, which we should all be doing. In this session, we're focusing on braking, but as with anything on the track, we want our application of the throttle to be smooth. We should typically be on the throttle, just a little, around the apex and then gradually squeeze the throttle, more and more, until we reach full-throttle by track-out. This concept is covered more thoroughly in our presentation on "Finding Gains."

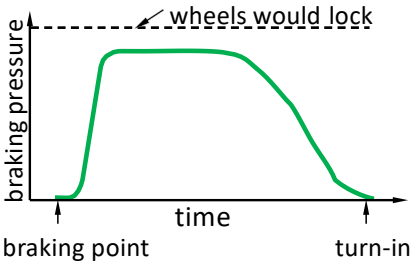
What is your braking like for Turn 1?



gradual on
quick off



full strength
full time



on quickly
off gradually

Which of these looks right to you?

These are graphs showing how hard we're pushing on the brake pedal. The higher the line, the more pressure. If we pushed too hard, the line would go above the level where the brakes would lock. So we want to bring our brake pressure just up to that threshold but not exceed it.

The one on the right is the proper way to brake on the track. What is most important to see in this graph is how the braking pressure is gradually released.

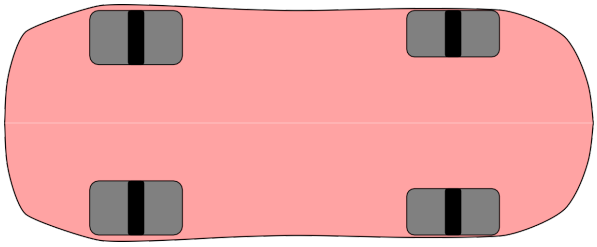
Maybe you brake like the red line on the left when you're on the street. Maybe on the street, you use gradual on and gradual off. This approach is a very comfortable way to drive, which is ok for the street but unsuitable for the track.

The middle box is not good in any setting. The brake application is too abrupt, as is the release of the brake pedal. This technique would unsettle the car and reduce your grip on the track.

The green line is our goal. We get on the brakes quickly (and smoothly) and release the brakes gradually.

Driver controls car through tire contact patches

We can control: Acceleration, Braking and Turning



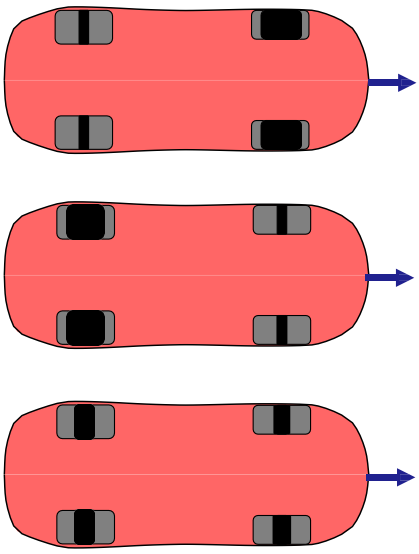
Our tires are how we control the car, and all of our inputs are translated into motion through the tires. For example, when we step on the throttle, we use the traction of our tires to accelerate, and similarly, when we step on the brakes, tire traction is used to slow us down. Same with turning. Our front tires pull us through a corner as we turn the wheel.

What happens when we're at the limit of what the tire can do (limit of traction)? Our tires begin to slip. This doesn't mean we immediately spin out. You've likely heard of cars oversteering. Oversteering is when the back slides out a little, making the car turn more than it would if the back weren't slipping. On the other hand, understeer is when the front tires slip while turning, and the car won't turn as much as we want. Understeer feels like you're going straight, even though you have the steering wheel turned.

We can control acceleration, braking, and turning: How many of these can we control at once? Another way of asking this is: When a tire is braking, can it also be turning? Yes.

We can control two simultaneously—braking and turning or accelerating and turning. You may have heard about the friction circle, which is one way of explaining how we can use the tires for up to two of these at once. We can use 100% of our traction for accelerating, braking, or turning. But, if we want to do some turning and braking simultaneously, we have to share the traction between the two, meaning we can't brake as hard while turning as we could if we were going straight. There is an addendum at the end of this presentation covering the friction circle.

Driver Controls Weight Transfer



Braking: Forward weight transfer

More front grip = better turn in

Less rear grip = allows back to slip

Accelerating: Rearward weight transfer

More rear grip = stable back end

Less front grip = harder to turn

Balanced front-to-rear

Best lateral grip & mid-corner speed

What about Turning?

It's helpful to understand the relationship between weight and traction. The more weight (a.k.a. load) on a tire, the more traction (a.k.a. grip) it will have, and we can control which of our tires have more weight on them. However, as we increase the load on some tires, the load on the other tires decreases. In performance driving, we can use both increased traction and decreased traction to our advantage, and we can use our inputs (brake, throttle, steering) to control which tires have more load.

When we apply the brakes, the weight of the car transfers forward, increasing the load on the tires, resulting in more grip up front. This can help us when we want to use the front tires to turn in.

Similarly, the weight transfers to the back when we apply the throttle, which helps keep the rear end settled and keep it from sliding out. Anyone driving cars with big engines in the rear understands the importance of using the throttle to keep the rear contained.

As we see in the bottom image, balanced means equal traction in the front and rear. Equal traction doesn't necessarily mean equal weight. Front-engine cars are usually heavier upfront. Rear-engine cars are generally heavier in the rear. And Caymans… you know. Even though a car may be heavier at one end, it can still be "balanced." The choice of tire size and suspension setup can be used to account for the difference in weight and produce a car with balanced traction. Lateral grip is maximized hen the load is balanced and this lets you can carry the most speed through a corner. We want to maximize lateral grip when our steering wheel is turned the most, which is usually at the apex.

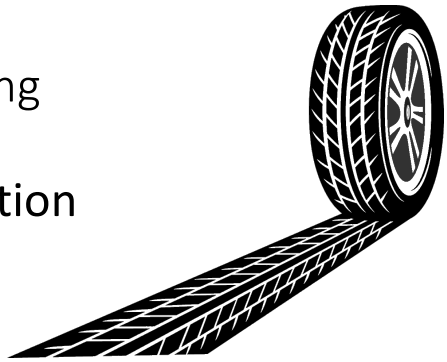
When driving, we achieve a balanced car by giving the car the input that results in having the appropriate load on all tires. For most cars, this requires a bit of throttle, called maintenance throttle or balance throttle. We're not accelerating, and we're also not coasting. A little throttle will balance the car and provide us with the most traction in the middle of a corner.

Weight transfer happens when we're turning too. Which tires have the most weight (and therefore most traction) when turning? The outside tires. When turning right, more weight is on the left tires, and vice versa.

Quick-and-simple driving physics

Driver controls weight transfer
- Using Braking, Accelerating and Turning

More weight on a tire = more load & traction
- But less traction for other tires



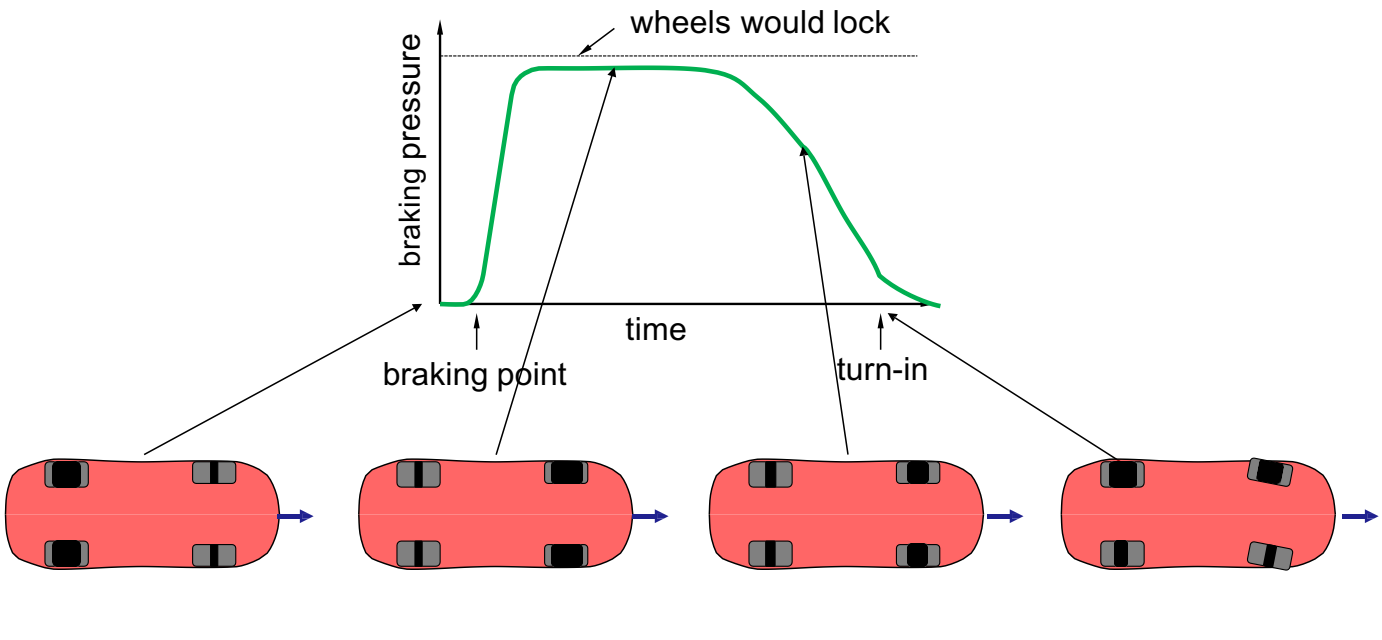
Tires have a limited amount of traction
- Smooth driving = easier to stay within limit
- Smoothly approach the limit for greater traction

At the track, we always talk about being smooth: giving the car smooth inputs with our hands and feet. Considering traction, we want to approach the limit of traction smoothly. Doing this gives the weight of the car time to transfer to the tires, which means they'll have more traction. More weight = more traction.

Smooth doesn't mean slow. The car weight transfers quickly, but not instantly. The rate depends on your car, its suspension, and its weight. Stiffer suspensions transfer load to the tires faster. If you make sudden, quick inputs, you're asking the tire to do things before the load has transferred to that tire and before it has more traction from the increased load.

On the track, we brake hard at first and then gradually release the pedal. However, this doesn't mean we slam on the brakes. Even though we're braking hard initially, we should still apply the pedal smoothly. Work on feeling the weight transferring to the front during braking, and let this guide you on how fast to apply the brakes.

Releasing the brake gradually - balances the car at turn-in



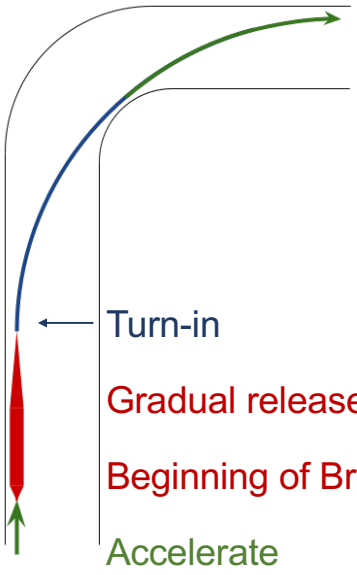
This visualization shows the car on the left accelerating, with all the weight transferred to the back.

Then, at the braking point, the driver quickly and smoothly gets to full braking, and we see the weight has transferred to the front tires, which are doing all the work to slow the car down using as much traction as they have.

As the driver gradually releases the brakes, we see the dark contact patch on the front tires getting a little smaller as the weight transfers off the front a little and the traction balances a little more.

Shortly after turn-in, the driver is fully off the brakes, and we see the load is balanced between the front and rear tires (i.e., front and back patches are the same size), and that the load has transferred to the outside. So, balanced front to back, but with significantly more load on the outside tires.

Why release gradually?



Allows driver to gauge entry speed
- And adjust braking force accordingly (safer)

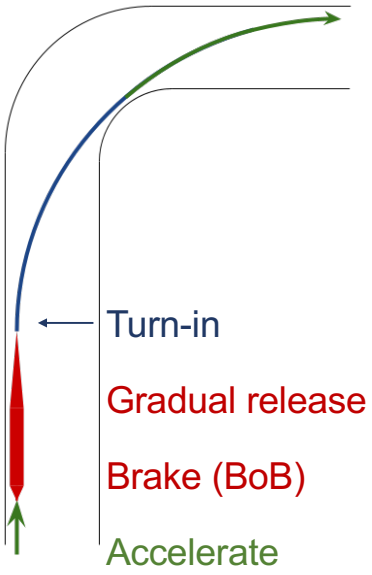
Rapid brake release = nose lifts
- Momentary reduction in front grip/turning capability

Gradual release = maintain some load on front
- Extra grip for direction change

You've heard that a gradual brake release is the right way for performance driving. This is because it lets us adjust our braking level more easily, which is safer and means we're more likely to be at the speed we want for turn-in.

If we release too abruptly, the nose will come bouncing up, and our front tires won't have as much traction for a brief moment. Often, this will be right around when we're turning in, just when we need the front tires to grip the most. Instead, a gradual brake release keeps load on the front tires, providing the load and grip we need as we begin our turn.

To practice better brake release



Begin by releasing the brakes gradually

- a few car lengths before turn-in
- Notice how the car feels as you turn it in
- Work up to being off brakes very close to turn-in
  - Maybe just after turn-in?

This is performance driving and it's **safer**

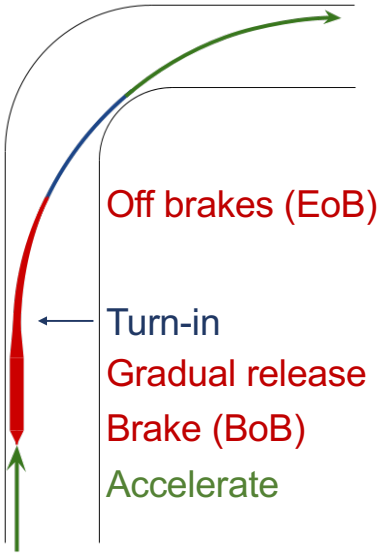
- Light then heavy: leaves no room for error
- Heavy then light: allows you to adjust
  - Too much speed? Keep braking heavily

You may already have a gradual brake release, and this is just review, but it doesn't hurt to practice this consciously. Be very intentional about releasing the brakes and feeling the car reacting. You should be able to feel the nose coming up a bit. And, as you become more comfortable with feeling the car, that will be what guides your foot. The feel of the car, ultimately tells you how much braking you can use. Check out this article by Tarheel BMW CCA about what they call Chauffeur Braking: https://tarheelbmwcca.org/Chauffeur%20Braking.doc.

Not only is hard braking followed by a gradual release the right way for high-performance driving, but it's also safer. Alternatively, If we were to brake lightly initially and keep increasing the brakes so that we're at the perfect speed when we turn-in, we wouldn't leave ourselves any room for error. So, we should start with heavy braking and then gauge your speed, releasing more if you can or staying on heavier braking if you need to slow down more. A gradual release of the brakes is critical to smooth, controlled, and fast driving.

Maybe you stay on the brakes a little past turn-in. Holding some brake pressure (not full threshold braking) past turn-in is a good technique called trail braking. This light braking will give the front tires that little bit of extra traction to make a good turn-in and avoid pushing or understeering. Trail braking and is the focus of the second half of this presentation. First, it's essential to master releasing the brake pedal gradually, and it's worth practicing a gradual brake release.

Why release gradually?



Allows driver to gauge entry speed
- And adjust braking force accordingly (safer)

Rapid brake release = nose lifts
- Momentary reduction in front grip/turning capability

Gradual release = maintain some load on front
- Extra grip for direction change

Carry a little brake past turn-in = **trail braking**
- Fastest way to the apex

Above, we talked about how critical it is to have a gradual brake release for smooth, controlled, and fast driving, and we discussed the first three bullet points above.

Notice that the diagram here is slightly different diagram than on the earlier slide. This diagram showing the driver carrying their braking past turn-in. Their Beginning of Braking (BoB) is the same and they gradually release the brakes before turn-in, but they don't get to the End of Braking (EoB) until after turn-in. This technique, called trail braking, is a faster way to the apex and is the focus of the remainder of this presentation. You must be able to smoothly and gradually release the brake pedal to properly execute trail braking.

Trail Braking

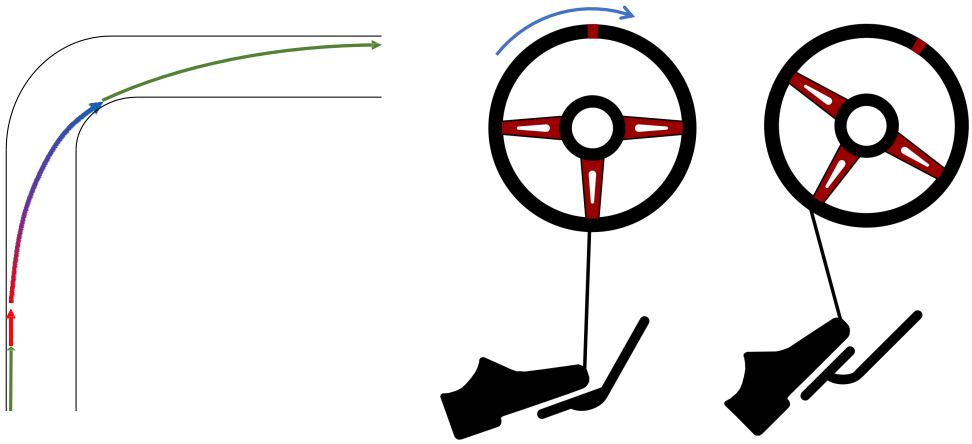
according to Ross Bentley

When you gradually release, ease, or "trail" your foot off the brake pedal **while turning into a corner**. If you've completed your braking entirely and your foot is off the pedal at the point you begin to turn into the corner, then you have not trail braked at all. If you have even the slightest amount of brake pedal pressure on while turning into the corner, then you are trail braking.

Here is what Ross Bentley says about Trail Braking. Ross is an excellent, prolific writer and teacher of high-performing driving and racing. If you're unfamiliar with his work, it's worth checking out. He wrote one of the go-to books on racing called Speed Secrets, and you can learn more at speedsecrets.com. In addition, he has many free guides, one of which is called Performance Driving Illustrated. It is a quick read with a wealth of info, including trail braking.

In summary, you're trail braking anytime you're on the brakes after turn-in.

Turning and Braking



- Your foot and your hands are connected
- As you turn the wheel, release the pedal
- Smooth connected inputs

Earlier, we learned that we leverage our tires' traction for braking, turning, and acceleration, and we can ask our tires to do up to two of these at once. When we're giving two inputs, the tire has to split its traction between the two. Let's consider braking and turning.

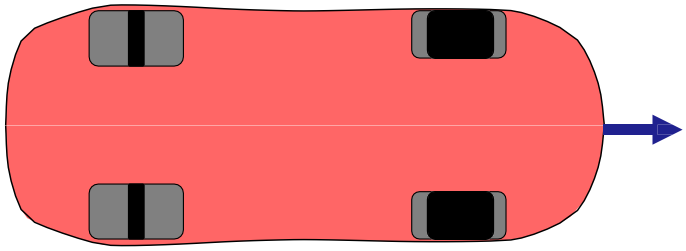
We can ask our tires to use all of their traction to slow us down. This is called threshold braking, which means we're trying to use 100% of the tires' traction to slow the car. Imagine that we're threshold braking in a straight line. If we were also to ask the tire to turn while it's using 100% of its traction for braking, we would be asking too much of it. As a result, it wouldn't be able to turn and would keep sliding straight ahead.

We must release a little on the brake to add some steering. Let's imagine we back off to 80% on braking; that leaves us with 20% of the traction for turning. Back off on the brakes even more, and you can put in more steering.

Look at the picture above and imagine a string connecting your foot to the steering wheel. When your foot is all the way down, at 100% braking, your steering wheel needs to be straight. When your foot comes up a little, as you gradually release the brakes, you'll have a little slack in the string, which you can take up by turning the wheel a little. Lift your foot more, and you can turn the wheel some more. The string represents the connection between your hands and your feet. More steering requires less pedal, which applies to both the brake pedal and the throttle.
Another way to understand how to use the tire's traction most efficiently is through the friction circle, which is covered in an addendum at the end of this presentation.

Two Initial Reasons for Trail Braking

- Helps use all front traction = better turn-in
- Keeps load on front tires = better rotation



"Trail braking is about adjusting the balance and changing direction of the car."
- Ross Bentley

Trail braking helps with turn-in. It enables you to use all of the front tires' traction in the corner and minimize or eliminate understeer. If you don't trail brake and suddenly take your foot off the brake pedal as you turn in, there will be a moment when you are not using all of the front tires' traction. That means the tires will have to work hard to turn and you could have been carrying a little more speed.

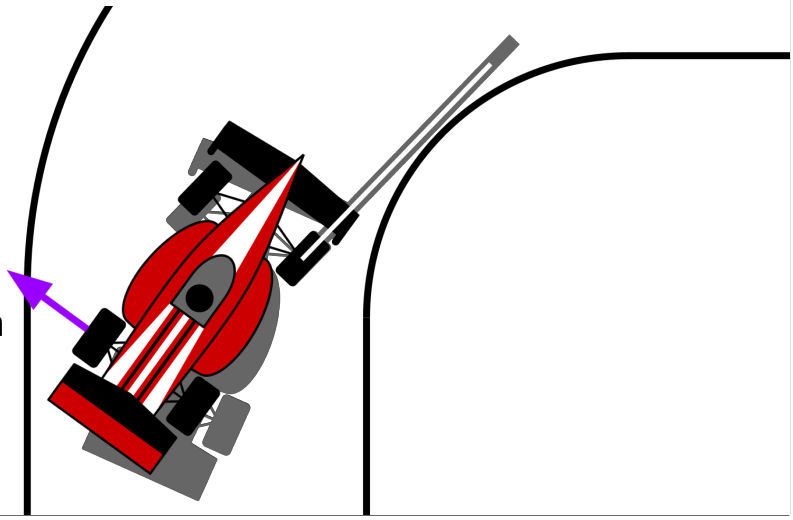
Trail braking also helps with rotation. Braking deeper into the corner keeps load on the front tires, which helps the car "rotate." Rotation allows the car to turn with less steering input. We'll look at this in detail on the next slide.

Note that braking as late as possible isn't one of the initial reasons for trail braking. Trail braking does help you brake later, ultimately improving lap times. However, your initial focus should be carrying your braking into the turn and moving your End of Braking (EoB) later. Once you are comfortable with that, you can start moving your Beginning of Braking (BoB) later. Ross Bentley has a short article that emphasizes this and says, "Trail braking is about adjusting the balance and changing the direction of the car." https://speedsecrets.com/braking-its-what-separates-the-best-from-the-rest/

Rotation of the Car

- Rotation: Turning car with less steering
- More weight up front = less weight in back = less rear grip
- Rear tires slide a little to the outside
  - Points car toward apex
    - Straighter steering
    - More throttle
    - Greater apex speed

Car turns using rotation
- With less steering



Rotation vs Oversteer?

What does it mean that "trail braking helps with rotation?" When we're trail braking, we're keeping more weight up front. This means the front tires will have more grip than when the car is in a neutral or balanced stance, and the rear tires will have less grip. More load/grip up front means the car will be more responsive to our steering input, and we'll have to give less input.

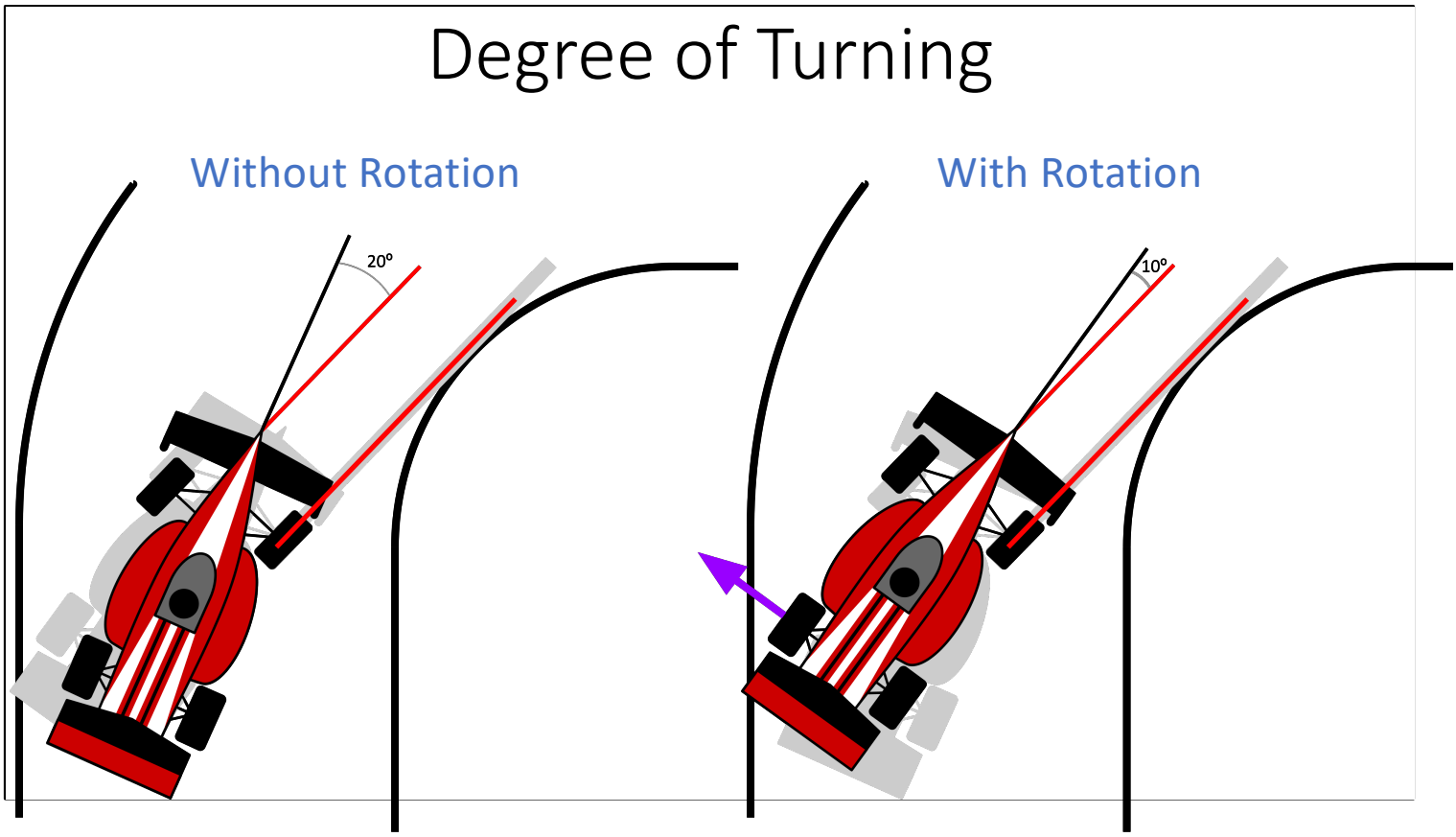
More load up front will also leave the car with less load/grip in the rear. Consequently, the rear tires will have less traction and will be willing to slide out a little. In the image above, the purple arrow indicates the rear tires sliding out a little due to trail braking. The grey car underneath did not rotate because the driver did not trail brake. For the grey car, the front wheels have to be turned more, and they have to work harder to make it to the apex.

More weight on the front tires and less on the rear means the car turns more easily (rotates) with less steering input.

Rotation is similar to oversteer, but it's worth thinking of them differently. Oversteer can be considered a property of a car that isn't as balanced as it could be. Oversteer is something the driver has to deal with and compensate for. Rotation is something the driver asks a car to do. The more balanced a car is, the easier it is to control the amount of rotation. Maybe you can think of rotation as *induced* oversteer. It is a good thing, whereas unwanted oversteer is not good.

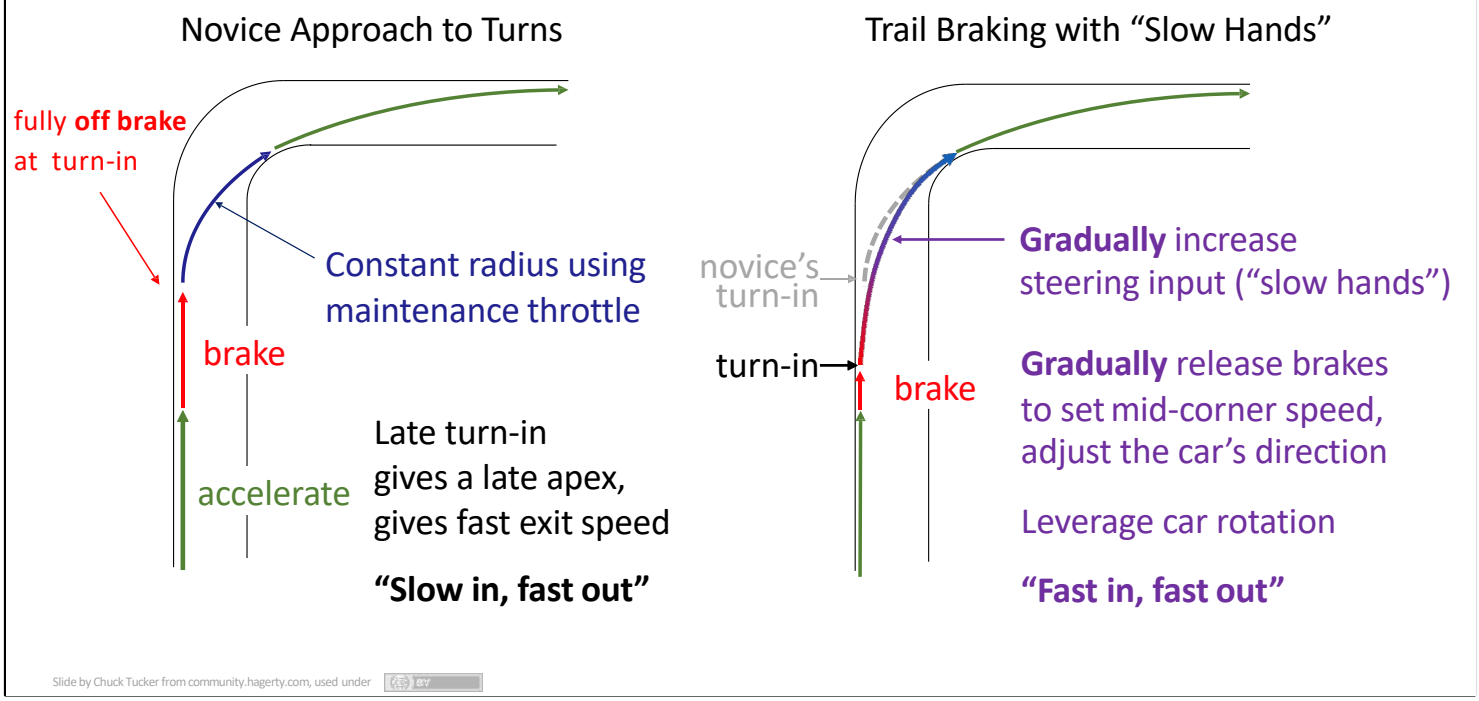
A benefit of rotation is that our wheels are straighter as we approach the turn. Straighter wheels provide better grip. This better grip lets you brake more later into the turn (prolonged trail braking). Straighter wheels also let you apply more throttle and we cover this in the "Finding Gains" presentation. As a general rule: the less you turn the steering wheel, the faster you can go.

Degree of Turning



The diagrams here are to emphasize that when the car rotate, the driver provides less steering input.

Trail Braking, Earlier Turn-in, and "Slow Hands"



Here we see a comparison between what we might call a novice's turn vs. one which uses trail braking to help the car turn more as they get closer to the apex. You can see in the right diagram that the driver has turned in earlier than the driver on the left. Their initial steering input is slight, and they gradually increase their steering as they release the brake pedal. You can see the gradual brake release represented in the diagram as the line turns from red to purple to blue at the apex.

"Slow-in, fast-out", as we see on the left, is a valuable concept. An important thing to take away from this concept is that you want to approach a turn and its apex with the car under control. If you have it in your head that you should come into the turn as fast as possible, you'll likely be spending all your efforts (and all your traction) just trying to keep the car under control. Doing this will usually screw up your line and almost always mean you'll have to delay getting on the throttle, resulting in fast-in, slow-out. You never want slow-out. However, if you can enter a turn more quickly, with the car under control, and still exit the corner fast, then you have fast-in, fast-out, which is even better!

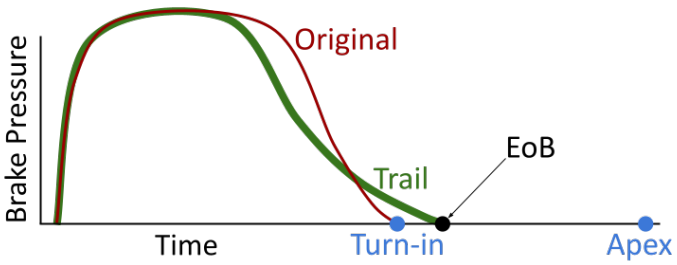
Using "slow hands," we turn in a little earlier, initially with less steering than we see in the so-called novice approach. And as we further release the brakes, we put in more steering, such that we're turning more sharply as we approach the apex. To execute this line and still get your apex, at some point, you have to "turn" the car more than you ever would have using the novice approach. And, naively, that means we need to go a little slower to turn the wheel more. However, if we achieve the extra turning because the car is rotating, then we may not have to slow down as much. Since the car rotated, our front wheels can be straighter, and they can maintain grip at a higher speed.

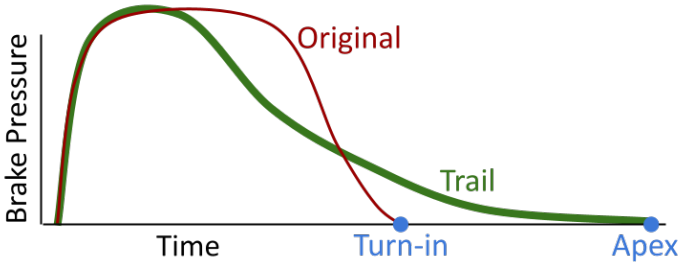
So, theoretically, we can get through a turn faster by leveraging trail braking to keep some load on the front tires, which helps us with turn-in, and lets the back end cause the car to rotate, meaning we have to turn less and carry more speed.

Doing this can be a delicate little dance, managing the brake pedal and the steering wheel while being prepared to control how much we let the back slide using our hands and feet. It takes time to learn how a car feels when doing this. Take things slowly at first. Try the slow-hands line on a turn you're comfortable with, but don't worry about maintaining the same speed. Slow things down a little as you're trying this, get used to it, and then build your speed back up. Read on for some more tips on adding trail braking to your driving.

Adding Trail Braking to Your Driving

1. Keep BoB the same (**B**eginning **o**f **B**raking)
   - BoB before turn-in. EoB after turn-in.
2. Begin gradually releasing brake just a little earlier
   - Lengthen braking zone: less time at heavy pressure, more at light pressure
   - Carry a little more speed at turn-in
3. Be patient on the throttle. Wait until apex to begin accelerating.
   - Develop the habit of decelerating to the apex, not accelerating.





If you have nailed the gradual brake release, adding trail braking should be very natural, and you might already be doing this. If you are already trail braking a little, you can work on increasing the distance over which you carry the brakes after turn-in.

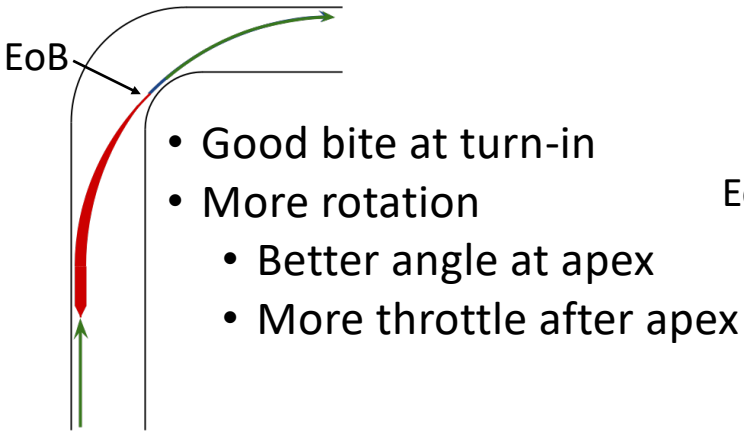
When working on adding trail braking or increasing the amount of trail braking, keep your Beginning of Braking (BoB)the same. Adding trail braking doesn't mean you have to begin braking later. Sticking with the same BoB and releasing the brakes earlier will mean you have a higher speed at turn-in, which is good. Since you're still on the brakes a little, you're no longer at the threshold of braking and your tires have some traction for turn-in.

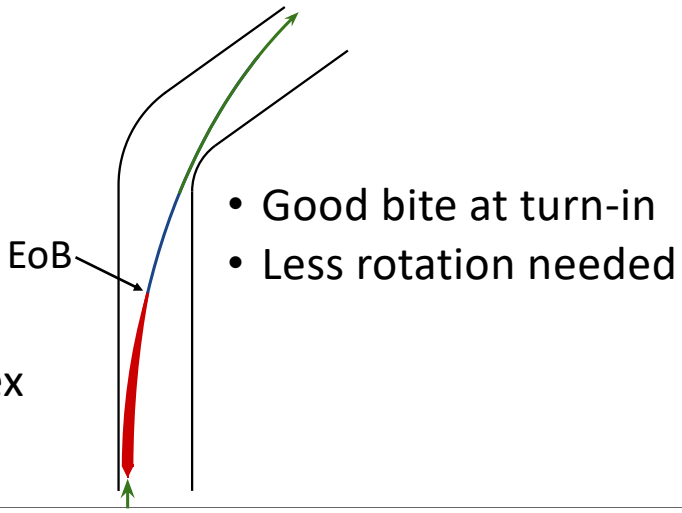
Keep the BoB the same, release the brakes a little sooner and carry more speed through turn-in. Once that feels good, release the brakes even sooner and carry a little more speed at turn-in. Now, you'll find you have to trail brake for a longer distance to bring the speed down to your mid-corner speed, where you want to have transitioned to maintenance throttle and then begin accelerating after the apex.

As you're working on this, you may find that you're slower as you approach the apex. Over-slowing at this stage ok since you're practicing. However, when over-slowing, many people will feel a tendency to start accelerating before they get to the apex. Resist this urge. There are some turns where it might be best to begin accelerating before the apex due to things such as camber or elevation changes in the track. But, in general, you don't want to be accelerating to the apex. If you feel the need to start accelerating early, then on the next lap, release the brakes a little earlier and carry a little more speed at turn-in Focus on carrying speed into the turn and developing the habit of decelerating to the apex.

Should trail braking be used in every corner?

- **Slower, tighter turns:** later EoB, deeper trail braking
- **Faster, sweeping turns:** earlier EoB
- **Fastest turns:** throttle at turn-in, no trail-braking





Should we trail brake in every corner? No. But, we should trail bake in most corners.

Slower, tighter turns:
You'll notice the biggest gain from trail braking in tighter, slower corners. Here you want to use extra front load to help rotate the car (and avoid understeer). This rotation means the front wheels are turned less at the apex (not working as hard, have better traction), and you can get on the throttle earlier. The closer your wheels are to straight, the more throttle you can use.

Faster turns:
In faster corners, we often don't trail brake as much. We'll likely come off the brakes earlier in the turn (trail braking just a little past turn-in). We want to leverage the extra load up front to get a good turn-in, but we don't want to transfer too much grip to the front tires because we want to keep the rear wheels planted in these higher-speed turns. It's a balance between using the brakes to get grip for the initial turn-in, carrying speed into the turn, and balancing the car by shifting weight to the rear as we release the brakes and ultimately squeeze on the throttle.

Fastest turns
For the fastest turns, it's usually good to have some maintenance throttle at (or right around) turn-in to balance the car and overall grip (plant the rear end). For many of these turns, you won't be braking at all. Maybe just a little lift to get some front grip.

The image on the left is ideal in that it shows the driver on the brakes all the way to the apex. That's impressive. You can optimize lap times by decelerating all the way to the apex, such that you're on the edge of your grip the entire way through the turn. However, it's not likely what we're achieving when we're out there, and it's not what we should be trying to achieve as we're learning. Start small. Focus on getting good traction with the front wheels at turn-in. As you gain experience with that, you may feel comfortable fully releasing the brakes later and later into the turn (closer to the apex). You'll see very few drivers out there who carry the braking all the way to the apex, and being able to do this is highly dependent on the turn, the car, and the track conditions.

The amount of trail braking needed for a specific corner isn't set in stone. You'll need to be dynamic in your approach as the difference in corners (sharpness, camber, elevation changes), vehicle setup, track temperature, driver focus, and so on will affect the balance of your car and the amount of trail braking required. Given all this, trail braking is about feeling and reacting to how the car moves underneath you as you turn in and approach the apex. An important skill to develop is being able to feel the weight transfers in your car.

Every car is different. Cars with a lot of weight in the back can have a tendency to kick out. Begin gradually and learn how your car feels and behaves. A good initial goal is just to see how turn-in *feels* while maintaining just light brake pressure. You can build from there.

Trail Braking Tips

- Feel the car. What felt different turning-in with some brake pressure?
  - Did you need to turn less?
  - Did you turn in sooner?
  - Did you need to start unwinding sooner (car rotating better)?
- Were you slower at turn-in? Begin initial release earlier next lap.
- **Look ahead!**
  - Before turn-in: look at the apex (or beyond)
  - After turn-in: look at track-out
- Smooth, slow hands
  - Fast hands = overworked tires, reduced traction

The specifics of trail braking will be different for every car and every turn. Vehicle weight, tires, aero, track camber, and elevation all affect the traction a car has and how it will slow. To figure out how to best trail brake for you, work on feeling and responding to the car. How much does the nose dive when you brake? What does the back end feel like? If your car have lots of front dive and lots of oversteer, then even more gradual and smooth inputs are needed. Keep your hands and your feet connected: As your hands turn-in, your foot needs to come up on the brake pedal. Again, react to the movement or feeling of the car.

Try to notice the difference in your line and your inputs as you add trail braking. Maybe you turned a little less and a little earlier due to the rotation. Were you early or late at the apex? Adjust on the next lap.

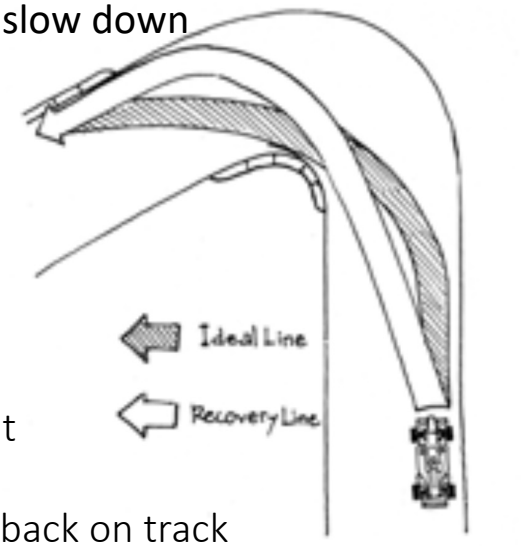
You're still on the brake, at least a little, at turn-in, this may result in being little slower at turn-in (which is not the ultimate goal). The adjustment to fix this, when you're working on trail braking, is to begin gradually releasing the brake pedal sooner. Initially, keep the beginning of braking the same, and as you progress, begin releasing the pedal sooner. If it feels too slow at turn-in, release even earlier next lap, so that you're carrying more speed at turn-in.

What are you doing with your eyes? Loop up and look ahead. This will help in so many ways. A notable benefit of this is that it will help you feel the rotation of the car and quickly compensate with your hands by unwinding as needed.

Remember, keep your eyes up and your inputs smooth.

Recovery from Under-braking

- Lengthen braking zone, increase time for you to slow down
  - Point car to have a long runway
  - Stay on brakes past apex, mostly straight line
  - Turn after apex, after slowing
- Still too much speed? **"Drive off straight"**
  - Maximize time on pavement; minimize speed
  - **Drive** off track, into the grass, under control
  - Steering wheel straight as you leave pavement
  - Release brakes briefly as you leave pavement
  - Then smooth inputs until slow enough to get back on track



When working on braking or anytime driving on the track, you may find yourself carrying too much speed into a corner such that you can't safely turn in. You can adjust. It's important to stay relaxed and provide smooth inputs. Stay on the brakes longer, past the apex. Straighten out and lengthen your line. Pick a path that gives you the most runway.

You can see in the diagram the driver turned in a little early and then carried a straight line, braking past the apex until they were slow enough to turn sharply and stay on the track.

Maybe you still have too much speed and need to go off the track. Drive off under control. Don't spin off. Straighten your steering wheel and release the brakes a little as you cross the edge. You want the car to be balanced as you exit the track. After that, start braking and steering smoothly so you can come back on track. The grass will feel like ice compared to the track, so keep everything smooth and keep your eyes up.

"To me, braking is the single most important skill in road racing. I personally don't practice the old adage about braking only in a straight line. I like to cut the corner early and get the car set up early – even with the brake still on... When you get off the brakes is just as important as when you get on them."

– **Jim Clark,** Two-Time Formula One World Champion

from an article he wrote in 1964 for the
Double 500 at Bridgehampton race program titled "*Braking... Key to Better Lap Times*"

End of Presentation
Extra Slides &
Reference Material Follow

There are a few more slides below for you to consider. Due to time constraints, we don't cover these in our live at-track classroom sessions, but it's valuable info to read on your own.

Consider Weight Balance

- What happens with too much trail braking?
  - (What does “too much” mean?)
- What happens with not enough trail braking?
  - (What does “not enough” mean?)

Too much trail braking? Not enough? In either case, it means we didn’t have enough grip for the car to do what we want.

If we used too much brake, through the turn, that will typically mean that we stayed on the brakes harder or longer than we should have. As we turned our steering wheel, more and more, we didn’t release the brakes sufficiently. So, we have extra weight on the front tires and they’re feeling great: Lots of grip, no understeer. But, what’s going on with the rear tires? Less grip! They’re helping the car rotate. The back is sliding to the outside. And, at this point, releasing the brakes more will help balance the car and regulate that rotation (and preventing over-rotation). If we don’t release the brakes enough, the rotation can become too much (over rotation), and now we’re pointed too far to the inside of the turn. Maybe the back will keep coming around and you’ll be sideways or spin. But, that’s not usually what happens and it would have to be excessive over braking for that. You can collect the car with two things: release the brakes a more to get more weight in the back and ”open your hands”. That means, unwind the steering wheel a little. Maybe you even have to counter steer a little (i.e. turn the wheel in the opposite direction of the turn to compensate for the over-rotation of the car).

When you do this, the car will kind of be sliding sideways. The back tires are sliding out because of the over-rotatino and you’ve adjusted the front tires to point in a direction to stop the rotation, resulting in the whole car sliding toward the outside of the turn. This sliding of the rear will act like braking and slow you down. This is sometimes called scrubbing speed.

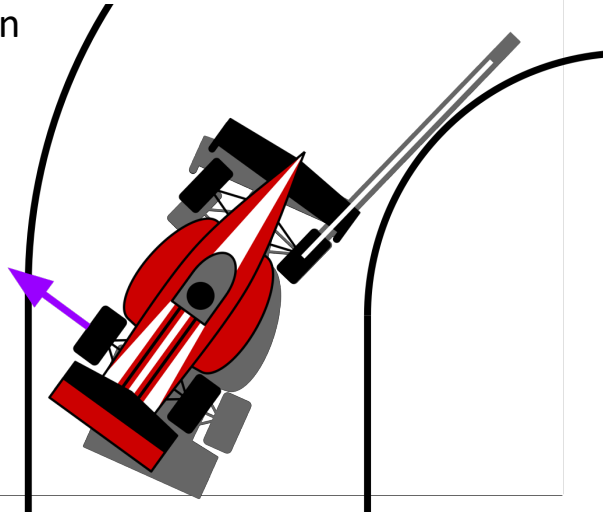
So, typically when someone over trail brakes, the back will start to over-rotate, they will compensate with their foot (less brakes) and hands (open steering wheel) and the car will slide sideways a little, causing them to lose speed, and then they get back on it. But, now they're much slower mid turn an aren't carrying as much speed at track out. It's usually no more dramatic than this… just a little lost lap time.

The scrubbing (or braking-like action from the sliding of the back tires) is a consequence of tire induced drag. Rear wheels are pointing (and rolling) in one direction, but since the back end is sliding out a little, they're actually moving in a slightly different direction then they're pointing. The angle between the direction the tires are pointing and the direction they're moving is the slip angle. The greater the slip angle, the more drag (more slowing) you'll get. This actually happens anytime the car rotates. Appropriate rotation (i.e. not over-rotation) not only helps us turn the car without providing as much steering input. It also helps us slow the car without providing as much braking input.

For a more thorough and mathematical explanation of this, check out Josh the Engineer: "**Explained: Tire Induced Drag":**
https://www.youtube.com/watch?v=6wQ2brcEcuU

Too much Rotation?

- "Unwind the wheel" or "Counter steer" as needed
- When entering a turn, always be thinking about unwinding
  - Beginning to unwind at the apex is good technique
  - Prepares you to compensate for over rotation

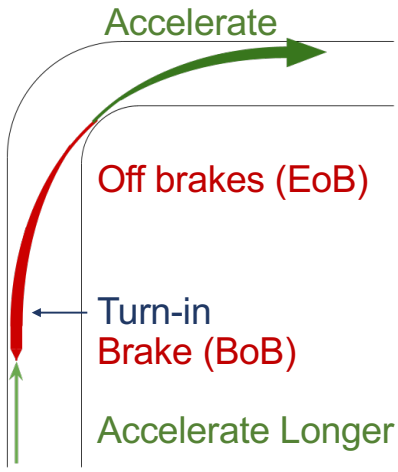


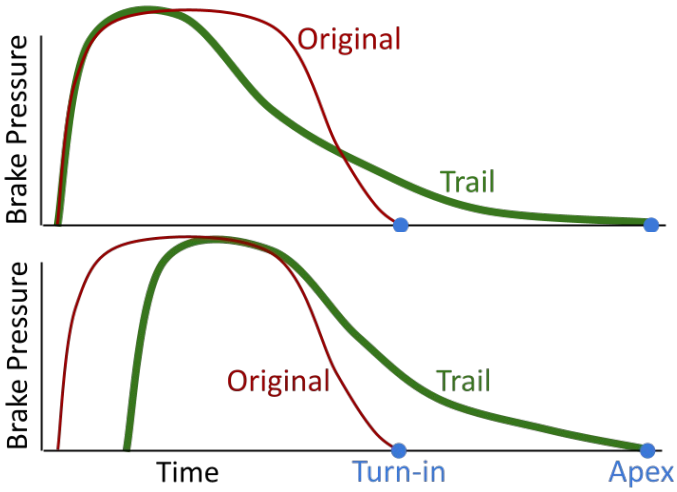
As you're practicing trail braking (and anytime you're entering a turn), be prepared for the car to rotate. Rotation is a good thing until you get too much. Over-rotation is something to prepare for, not something to worry about. As the car rotates, you can control the amount with the steering wheel. Unwind the wheel (i.e., straighten the steering) to compensate for rotation and stop the rotation. If you get too much rotation, unwind more or counter-steer.

When entering a turn, always be thinking about unwinding the wheel. If you're always prepared to unwind, any extra or unexpected rotation will be no big deal and will only require a little unwinding of the wheel to control the car. Additionally, it's good to have unwinding in your head because a goal should be to unwind as earlier as possible. Unwinding should usually start at the apex. The sooner you begin unwinding, the sooner you can get on the throttle and the faster you'll go. Unwinding from apex to trackout is covered more in our presentation on "Finding Gains."

Can I Brake Later?

Yes. Shift BoB later. Carry more braking past turn-in.



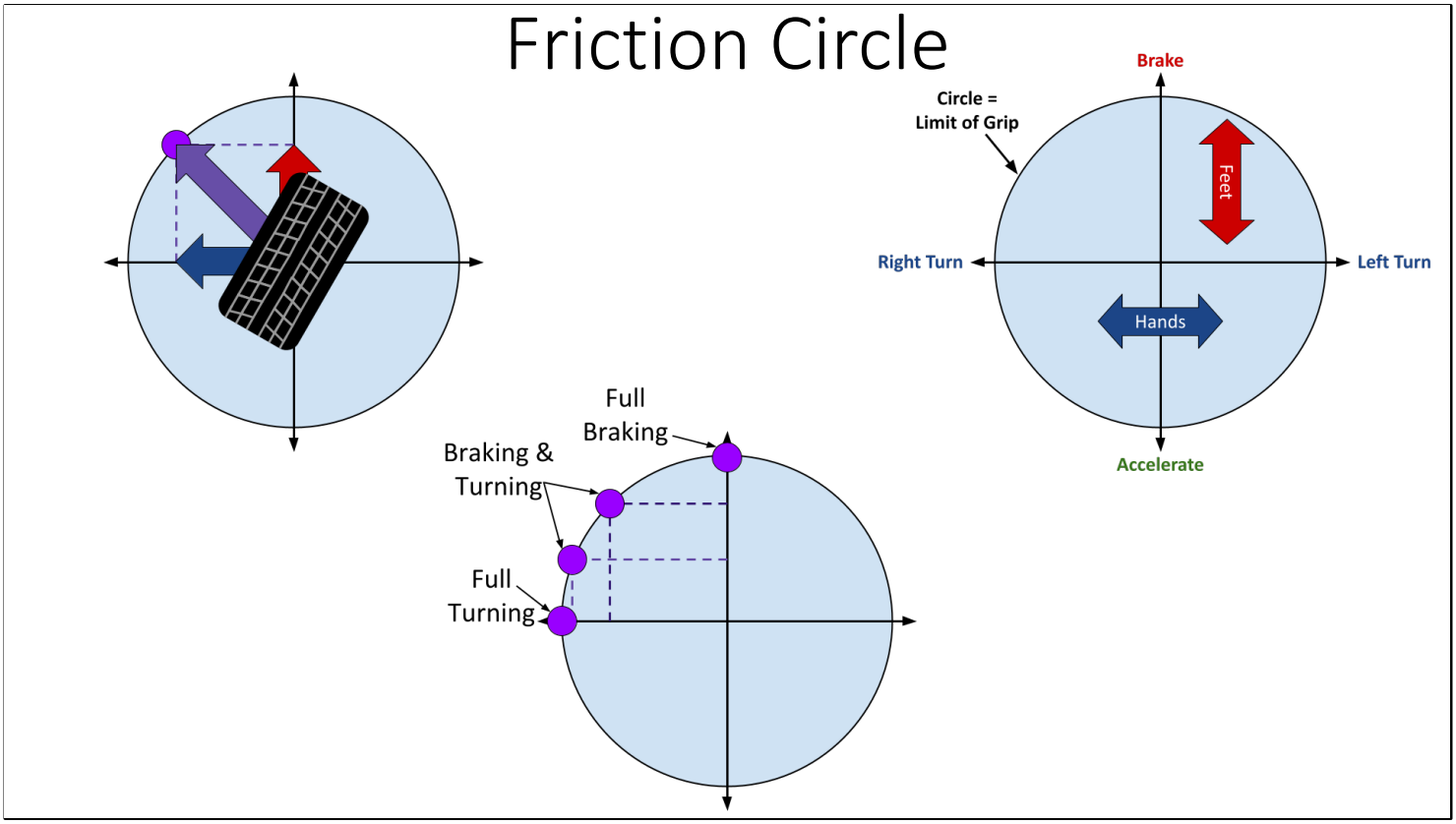


Driving closer to the limit = Less room for error

Trail braking will usually let you begin braking a little later. Compare the top braking graph to the bottom; you can see the driver on the bottom started braking later than the original, so-called novice braking approach.

Remember that late braking is not one of the main reasons we called out for why we trail brake. Those reasons are to keep the load on the front tires to help with turn-in and to help the car rotate. These will result in notable improvements in lap times. We talked about keeping the same BoB when introducing trail braking and beginning your gradual brake release earlier, which will result in a higher turn-in speed and require you to carry your braking deeper into the corner. Once you're comfortable with the increased corner entry speed and the needed trail braking to achieve the proper mid-corner speed, you can start shifting your BoB later. Doing this will require you to use threshold braking longer until you're closer to the turn-in point. As a result, you'll be driving closer to the limit, leaving less room for error.

It's better not to force yourself into late braking. Focus on the gradual brake release, the connection between your hands and foot, and your end-of-braking point. Develop a sense of how the car feels when you're doing this and how close you are to the traction threshold. When you're comfortable with all that, braking a little later should feel natural. Do this in small increments because you will inevitably overshoot at some point and brake too late. If it's just a small increment, you'll feel it at turn-in (you'll be going too fast), and you can then make minor adjustments to lengthen your line, brake a little longer, miss your apex a little bit, continue to slow the car past the apex, and then get back on line.



The friction circle is another way of understanding how we can use our tire for up to two inputs: braking & turning or accelerating & turning. You can also do any one of those by themselves. When doing two at once, the tire will split its traction between the two. When turning, you can not brake as hard as you could if you were going straight, or the tire will exceed its traction and begin to slide.

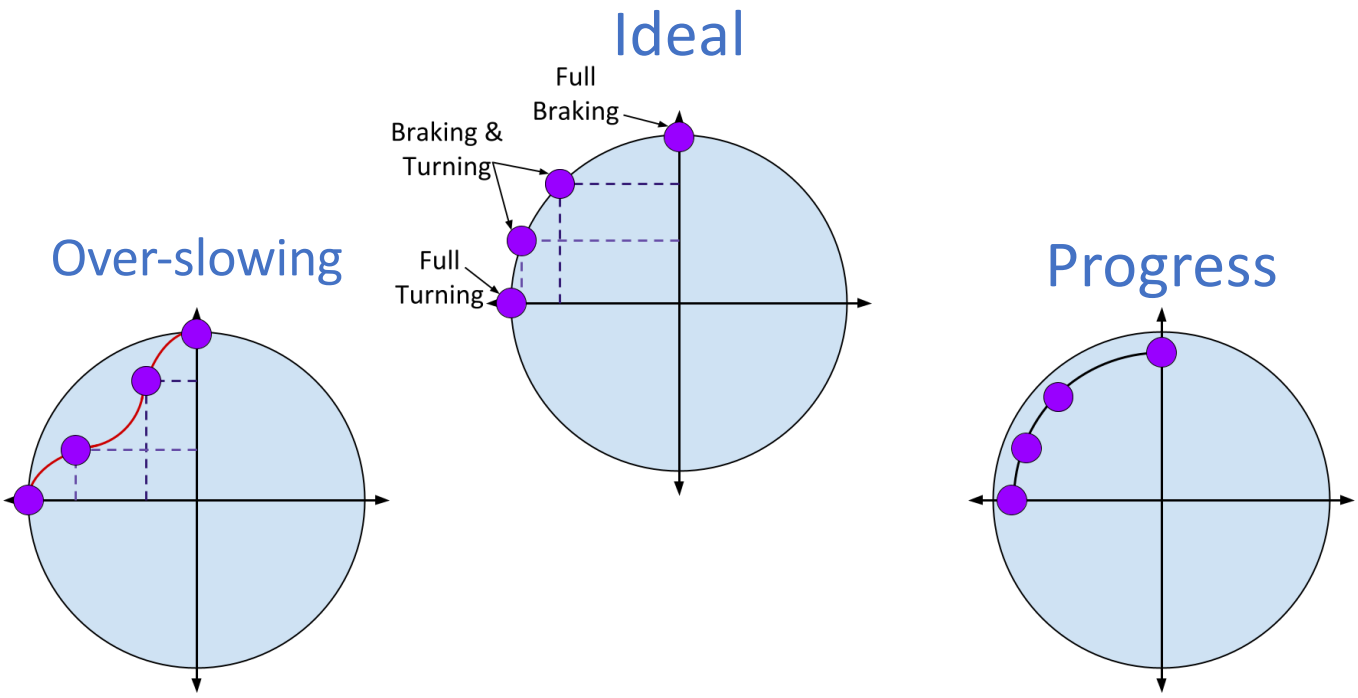
In the left diagram, the tire is braking and turning to the right. Consequently, the driver feels a force pulling them forward in the car, represented by the red arrow. The driver is also being pulled to the left, shown by the blue arrow. The purple arrow represents the combined forces, and ends at the circle's edge, meaning the tire is at the limit of its grip.

When the combined forces (braking and turning) stay within the circle (the limit of grip), the tire will perform well. However, if you ask for too much braking, turning, or a combination of the two, the arrow will end outside the circle, and the tire will exceed its grip and begin to slide.

The labels in the diagram in the upper right may feel reversed to you: "Brake" is at the top, and "Right Turn" is on the left. It would be reasonable to reverse everything, however these diagrams align with the how things feel to the driver. They also align with what you might see on a g-force meter, often part of our driving telemetry systems.

The bottom diagram shows a driver at four points in their turn: full (straight-line) braking, braking and turning at two points as they approach the apex, and turning with balance throttle. At each point, the driver has executed perfectly and is at the edge of the grip. They have released the brakes just enough to turn the wheel as much as they need and are carrying enough speed at the apex that they are at the limit. If the driver only used some of the traction (e.g., not braking at the threshold or not carrying enough speed), the purple ball would be inside the circle rather than at the edge.

Three Different Approaches to a Turn



Here we see three different hypothetical ways a driver could take a turn. At the top is the ideal, in which the driver perfectly manages braking and steering to always be at the edge (i.e., at the limit of the tire's grip.)
On the left, the driver has achieved threshold braking but over-slowed and didn't carry the maximum speed as they approach the apex. This is likely because they over-broke. However, by the apex (i.e., at full-turning), they're once again at the limit of grip, meaning they are carrying a good mid-corner speed.

On the right, we see a driver who is very consistent in using the traction of the tire. They're at ~90% through the entire process of braking, turn-in, and approaching the apex. They could be braking harder and carrying more speed through the turn. However, this is labeled "progress" because when learning and constantly improving, this approach to a turn may serve you better than the approach on the left. Being able to feel your car and maintain consistent use of your traction is a great skill. You'll likely be able to improve more quickly by pushing your approach closer to the edge incrementally and consistently throughout a turn.

Be careful to avoid getting stuck in the pattern on the left. It's easy for this to feel very fast and can lead to complacency or bad habits.

Further Reading

- Ross Bentley, Speed Secrets:
  - Performance Driving Illustrated
  - Braking – It's What Separates The Best From The Rest
- Friction Circle:
  - PCA Chicago Region and VBOX Motorsport (video)
  - AutoWeek and Driver61.com
- Blayze.io: Trail Braking Overview
- TheDrive.com: Easy Ways to Drop Lap Times
- NASASpeed.news: How to Rotate a Car
- Driver61.com Oversteer and Trail Braking

Glossary of Braking Terms (Adapted from Instructor Summit *HPDE Curriculum Guide*)

- **braking point**: The point approaching a turn where the brakes are first applied. Same as beginning of braking. May also refer to a visual reference point used to begin braking.
- **braking zone**: An area on track where brakes are applied before a turn. Some braking zones have distance markers next to the track to serve as visual reference points for the beginning of braking.
- **breathe**: To very slightly reduce throttle application or brake pressure. Example: "Breathe off of the throttle just before the kink to transfer weight to the steering tires."
- **brush braking**: A technique of applying and releasing the brakes gradually with minimal brake pressure. May be used to transfer weight to the front of the vehicle and promote steering response as much as, or in place of, reducing velocity.
- **end of braking (EoB)**: The point where a driver has fully released the brakes. For beginners this is usually near the turn-in point. When a driver is trail braking, the end of braking will come well after turn-in.
- **slow hands**: Moving the steering wheel more gradually, especially when entering a turn. The opposite of fast hands. Skilled drivers learn to vary the rate at which they dial in steering angle, especially during corner entry, to get the most out of their car's traction.
- **threshold braking**: A braking technique that uses the maximum traction of the tires to slow the vehicle. Typically used when a fast straight is followed by a slow corner. The goal in threshold braking is to apply as much brake pressure as possible without locking up the tires. In cars without ABS, this requires considerable skill and practice. Since ABS employs threshold braking, the driver of a vehicle so equipped can flirt with ABS activation to know when they are at the threshold/limit
- **trail braking**: Overlapping a gradual release of the brake pedal with progressively increased steering in the entry phase of a turn. When well executed, trail braking takes full advantage of the car's grip in combined turning and deceleration. Highly skilled drivers use trail braking to induce a small amount of controlled oversteer, rotating the vehicle toward the apex as they turn in and ultimately using less steering angle
- **understeer**: A state of chassis balance where the front tires are gripping less than the rear tires. Also called "push" or "tight." Small, controlled amounts of understeer may be induced by throttle steering or intentionally applying too much steering angle. Large or uncontrolled amounts feel like the front tires are "washing out," or "plowing" and may result in leaving the track. 196, 201, 205
- **weight transfer**: A change in the way that downward load is distributed among the vehicle's contact patches. Weight transfer is induced by accelerating, decelerating, or turning. Applying the brakes creates weight transfer from the rear tires to the front tires, while turning the car at speed creates weight transfer from the inside tires to the outside tires.