Driving Near the Limits

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This article has two main topics, *vehicle dynamics* and *driving techniques*, and concludes with a brief recap. We'll begin vehicle dynamics by looking at a single tire, because all forces, whether you're accelerating, braking, or turning, are applied through your tires. Next we'll look at understeer and oversteer. Understanding these key concepts is essential to maintain control of your car as you maneuver. Another important aspect of vehicle dynamics is weight shifting. As your car changes speed and direction, the distribution of traction among your tires also changes. Understanding these changes is a key to helping you stay within your car's limits.

By far the best way to improve your driving technique is to get some track time with an instructor sitting beside you, for example by participating in the PCA Driver Education program. However, you will be more successful if you understand some key concepts before you go. We'll first look at making the best use of the gear box. Even some experienced track junkies don't understand how to do this. Finding the best line through a road course is a never-ending job, but there are some general principles to get you into the right neighborhood. Practicing this on the street will make you a safer driver and will keep your passengers more comfortable. Braking and shifting are important both in getting around a course quickly and safely driving to a local store.

Vehicle Dynamics

Before we can talk about driving techniques, we must understand what our car is doing as we maneuver.

Forces on a Tire

First, let's look at the forces on a single tire. Before we can make any sense of how a four-wheeled vehicle responds, we must understand what each of its tires is doing. The only way a car can accelerate is if the pavement pushes against the tire. The same is true of slowing, only the push is in the opposite direction. And when you turn, the force is to the side. If we look at the maximum force that a tire can sustain in every direction, we find it traces a circle, as shown in Figure 1. This is of course an approximation; the maximum force a tire can apply to the side is probably not the same as it is to the front and rear. Since we're considering only general principles here, we'll ignore this.

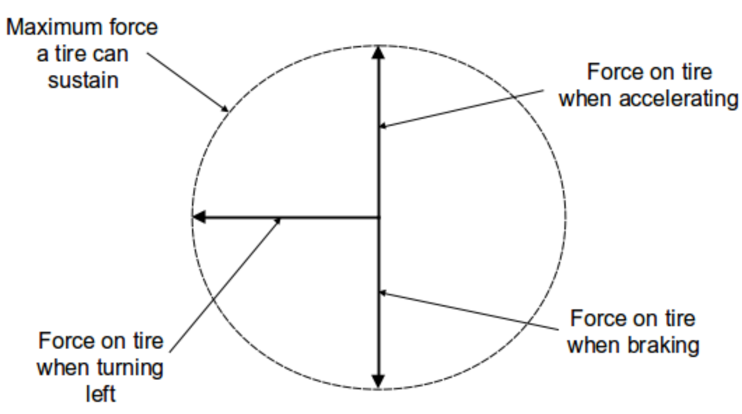

Figure 1. Tire Traction Circle.

The maximum force that a tire can sustain is proportional to the weight it carries, which means that the radius of its traction circle is proportional to the weight on the tire. We will see later that the distribution of weight among a car's four wheels changes as it maneuvers, and we will sketch traction circles for each wheel to show how the traction is distributed. The tread pattern doesn't affect this (again ignoring the subtleties); it's purpose is to help the tire maintain traction when the road is wet. By the way, if the water depth exceeds your tread depth, you are likely to hydroplane at speeds above about 40 mph. If there is oil on the road, you can lose control at much lower speeds and with much thinner layers of liquid.

What happens when we slow and turn at the same time? We can plot the braking force and the turning force, which are at right angles. To find the total force we add the two components graphically by moving the start of the turning force to the end of the braking force, as shown in Figure 2. The graphical sum of these is just an arrow from their start to their end. The order in which we do the addition isn't important; we could have moved the braking force arrow so it started from the end of the turning one. Note that the total force has both a magnitude and a direction. For example, if the two forces are each 70 per cent of the tire's capacity, their sum equals its capacity.

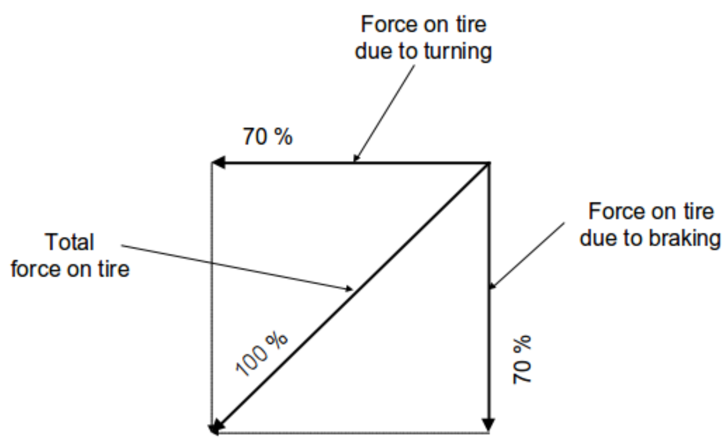

Figure 2. Summing the Forces on a Tire.

Figure 3 may be a more useful way to look at the situation. Actually, this should surprise you, since it shows that if can apply substantial braking and turning effort simultaneously. However, this applies only to a single tire, and most of us prefer cars with four. To maintain control, we must ensure that no tire experiences more force than it can sustain. We'll see soon that this drastically reduces how much braking we can do while in a turn. The chart is symmetric. We could change the x-axis to *turning effort* and the y-axis would become *available braking effort*.

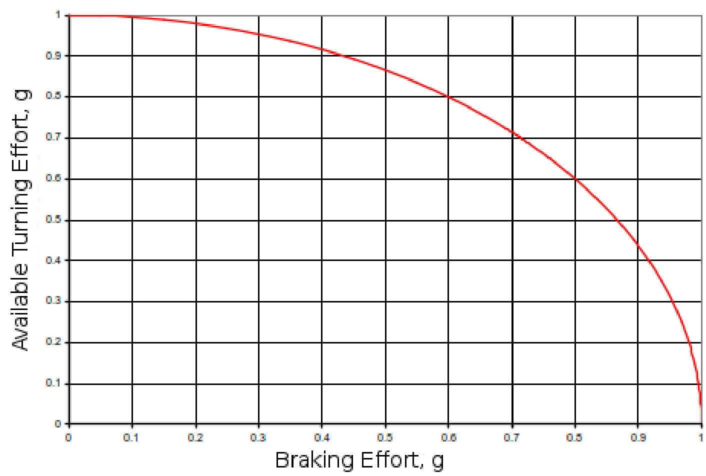

Figure 3. Braking and Turning Traction.

Your tires develop force by slipping – no slip means no force. This is true for both changes in speed and changes in direction. Figure 4 shows the approximate concept. I make no claims about the accuracy of this plot. It shows how it feels to me. Look first at the curve for a street tire. A stable region exists at low slip rates, that is, below the tire's maximum force. Here, if you ask a tire to supply more force, it can do so by increasing the slip. Above the tire's maximum force, the situation becomes unstable. Beyond this, as the slip rate increases, the force actually decreases. As a result, the force drops to a low level and stays there. You are now riding in a ballistic object that has essentially lost contact with the road. The shape of the curve in the unstable region doesn't matter, because the force quickly snaps to it's low ultimate value. Once a tire begins to slide, you've lost control of your speed and direction. The sound of screeching tires is often followed by the sound of crumpling metal.

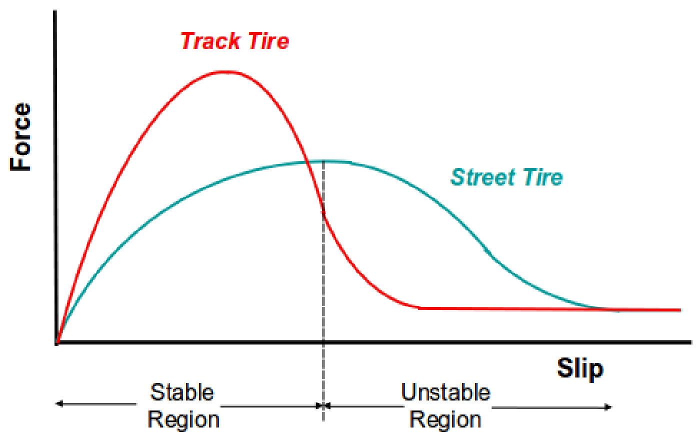

Figure 4. Tire Force vs. Slip

Fortunately, you have considerable warning with street tires. As you approach their maximum traction, the steering will begin to feel mushy and you will hear the tires talking to you. Experienced drivers prefer track tires, which can supply significantly more force. They hang on like a cat on a curtain, right up to their limit, as shown by the red curve in Figure 4. However, because they make less noise and have less slip, you have less warning before they let go. And by the time they do let go, you are moving at significantly higher speed then with street tires. At this point, you need a really good plan B. You shouldn't use track tires until you accumulate significant track skills on street tires. Inexperienced drivers using these will either get into serious trouble or they will never learn to approach the limits. Also, track tires may increase the forces to the extent that they exceed what the suspension can handle. This can produce undesirable changes in geometry and in extreme cases, catastrophic failure.

Understeer and Oversteer

As you approach the maximum speed in a turn, your car can react in one of two ways. The most common reaction for passenger cars is to understeer, which means the car rotates more slowly than you steer; see Figure5. This occurs because the front wheels have less traction (or equivalently, higher slip) than do the rear ones. In extreme cases, they could let go completely. Car companies prefer this characteristic, because the way most drivers react is to reduce the gas or to apply the brakes, and either of these actions increases the traction in the front. We'll discuss the reasons for this in a few minutes. Also, drivers who go into a turn too fast in a car with understeer usually conclude that it was their fault, which means they don't call their lawyers. This too is desirable for car manufacturers.

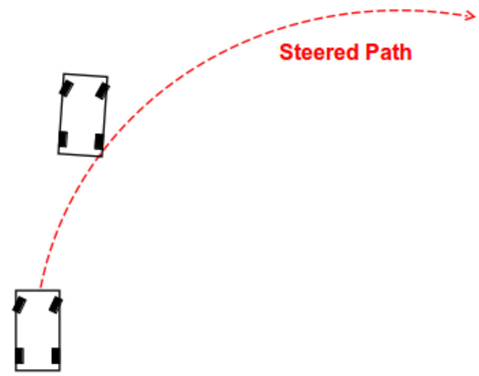

Figure 5. Understeer.

The opposite reaction to high speed through a turn is oversteer, where the car rotates faster than where you've steered, as shown in Figure 6. Although the car pivots excessively, its path can be either inside or outside the steered path. This occurs when the car has more traction in the front than in the rear. We will see later that the proper corrective action is to apply more throttle, which is contrary to most drivers' instincts. They frequently conclude that a defect in the car's design caused the incident and call their lawyers. As a result, passenger car manufacturers seldom sell cars with this characteristic. Race drivers may prefer some oversteer, because it allows them to accelerate through turns. Because acceleration increases understeer and deceleration increases oversteer, an experienced driver can control a car's response in a turn. The process is called *throttle steering*.

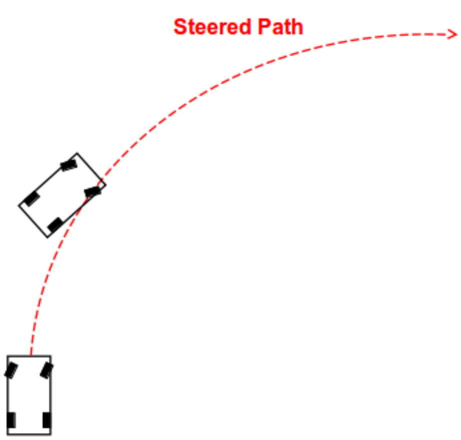

Figure 6. Oversteer.

Forces on a Car

As discussed above, all external forces are applied to a car through its tires. In particular, they are applied where the tires contacts the road. However, inertial forces are applied at the car's center of gravity, which is considerably higher than the contact points of the tires and road; see Figure 7. As a result, when you brake, for example, it tends to rotate the car, pushing its nose down and its rear up. The downward force on the front tires increases and that on the rear tires decreases. Since a tire's traction is proportional to the downforce on it, under braking the traction on the front tires increases and that on the rear tires decreases. The opposite occurs under acceleration.

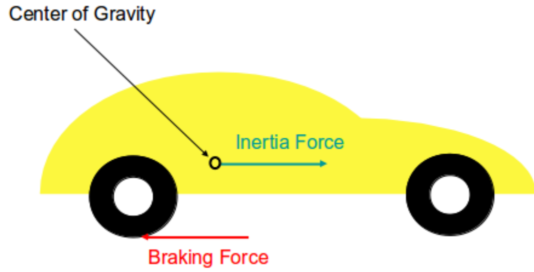

Figure 7. Forces while Braking

This effect is also apparent in turns. For example, Figure 8 shows the rotating effect in a right turn, where the turning force is applied at the road surface and the inertia force at the center of gravity. When turning right the turning force is to the right, and the inertia force is to the left, which leans the car body to the left. The right wheels are barely touching the pavement, which means that they have almost zero traction. Only a very small patch on each right tire is in contact with the road, while each left tire has almost twice its resting area touching. There is no bump in the road here; all the lean is caused by the effect of the turn.

Figure 8. Cornering Forces

Weight-shifting

A good way of visualizing how maneuvers affect traction is to look at the sizes of the areas of the tires' contact patches. Understanding this is the key to understanding vehicle dynamics. The discussion will be clearer if we assume the car has equal front and rear weight distribution and equal-sized front and rear tires, such as on a Boxster or a Cayman. In this case, the weight on each tire is equal, and since a tire's traction is proportional to the weight on it, each tire here has equal traction. Figure 9 shows a car from above with the contact patches indicated by the black rectangles. Since the car is moving in a straight line at constant speed, all the patches are the same size.

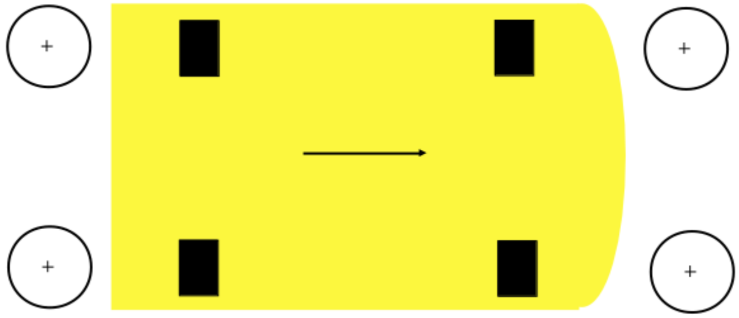

Figure 9. Constant-speed Tire Contact Patches.

Figure 9 also shows a traction circle for each tire, and since each caries equal weight, the radii are also equal. The circles show the traction available at each wheel, not how much force is actually applied, and here all the forces are zero. Most tires are inflated to pressures of about 30 pounds per square inch, Our cars weigh about 3000 pounds, which means that at 30 psi, they need a total of about 100 square inches of contact patch area, or 25 square inches per tire. All the forces on the car, whether accelerating, braking, or turning, are applied through these small areas. This is our least interesting plot, since the car is neither turning nor changing speed.

When we accelerate, the weight shifts to the rear, which increases the maximum available rear-wheel traction. Remember that this happens because the car's center of gravity is higher than the center of effort of the accelerating force. As a result, the contact patch areas increase for the rear tires and decrease for the fronts, which causes similar changes in the traction circles. The higher the center of gravity the greater will be the weight transfer. Figure 10 shows the situation. The black arrows show the forces on the rear tires (assuming the rear wheels are powered), and the red arrows those on the front tires (assuming those are powered).

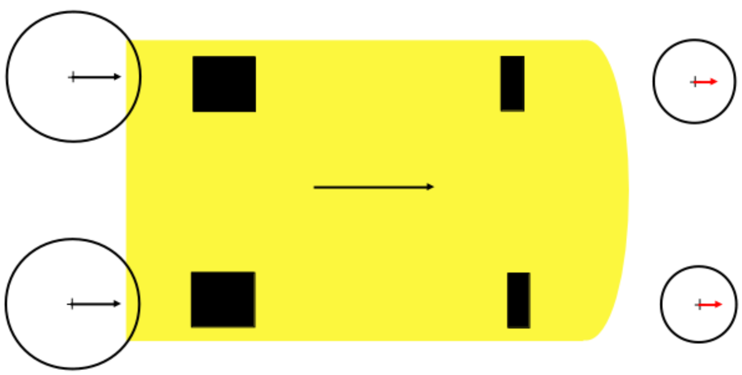

Figure 10. Accelerating Tire Contact Patches.

The available traction is proportion to the area of the contact patch, which means under acceleration the rear tires have increased traction. However, the total force on the driven tires depends on engine torque. If this exceeds the available traction, the wheels will spin, which of course kills the force and hence the acceleration. This is an advantage for rear-wheel drive cars, because the rear-wheel traction increases when they need it, but it has the undesirable effect of reducing the steering effort you can apply under acceleration.

Front-wheel drive cars are at a disadvantage under acceleration because the driving wheels have less traction available. Four-wheel driven cars must be designed carefully. The higher their acceleration, the less traction is available in the front wheels. Some sort of front-to-rear limited slip or stability management is needed in cars with all-wheel drive, especially for high-performance ones. Here we assume this and show lower accelerating forces on the front wheels (shown in red); otherwise, the acceleration will be limited by the front wheel traction.

Under braking, the weight and hence the maximum available traction shift to the front wheels. The radii of the traction circles are proportional to the size of the area in the associated tire contact patch, as shown in Figure 11. This is why your front brake pads are larger than your rear ones and why braking systems are biased to place more effort on the front. These design features allow you to make use of the increased front-wheel traction available under braking. Note that under braking all cars have four-wheel drive.

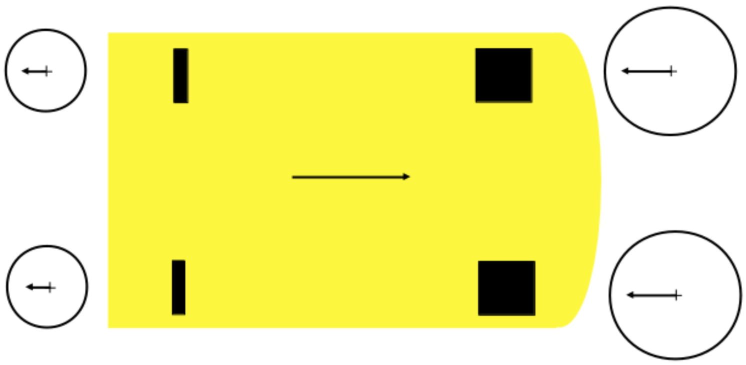

Figure 11. Braking Tire Contact Patches.

Engineers who design brake system must compromise. If the road traction is very good, the weight shift is pronounced under hard braking, and the optimum bias is to put most of the braking effort on the front. However, if we drive this design in slippery conditions, the maximum weight shift under braking is much less, and the front wheels may well lock up long before the rear ones can exert any significant force. As a result, without ABS, either the front or the rear wheels can lock up first, depending on road conditions. Again, the sizes of the contact patches show the maximum available traction. They say nothing about how much force each wheel applies to the car, which depends on how hard you stomp on the brakes and the brake bias. Of course, these interact, since the areas of the contact patches are affected by the braking effort.

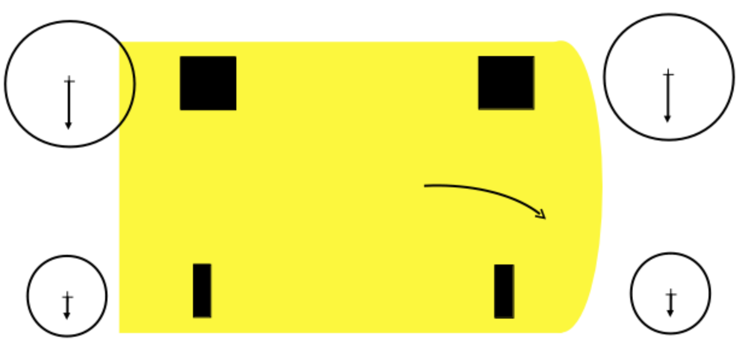

Figure 12. Turning Tire Contact Patches.

In a turn, the weight and available traction shift to the outside tires. The slip of each outside tire equals the slip of its inside mate. Since the outside tire carries more weight, it will carry a larger share of the turning force. In fact, the force on each tire is roughly proportional to the area of its contact patch, and hence is roughly proportional to its traction capacity. Thus, in a turn the forces are self-equalizing, and we don't have to control them as we do with braking forces, and in four-wheel drive cars, accelerating ones. Although each inside tire must slip at the same rate as its outside mate, the front and rear tires often slip at different rates. If you experience understeer, it just means that your front wheels are slipping more than are your rear ones. Similarly, oversteer means that the rear tires slip more.

When we brake while turning, the available traction shifts to the outside and to the front. See Figure 13, which shows a car turning right.

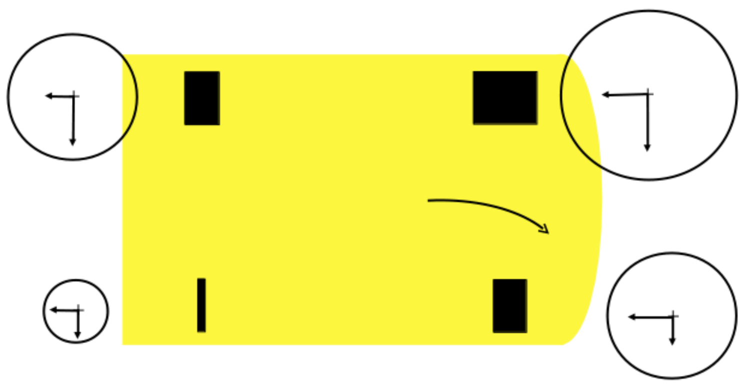

Figure 13. Braking while Turning Tire Contact Patches.

The outside (left) front tire has the largest traction circle and the inside rear the smallest. Unfortunately, the forces are distributed differently than the available traction. First, look at the turning forces. The two outside tires have equal turning forces. The forces on the inside tires are also equal, but are smaller. The two front tires have equal braking forces, and while the braking forces on the rear tires are also equal, they are smaller. Remember that the total force on each tire is the graphical sum of the turning and breaking forces. Here we see that the inside rear tire is right at its traction capacity, although the others still have considerable margin, especially the outside front. Earlier we looked at the traction circle for a single tire and concluded that we could apply considerable simultaneous braking and turning efforts, but with four tires, we must be much more cautious. Without ABS, we must brake carefully to avoid locking up the inside rear tire. If the car understeers, modest braking will increase the front traction and will help to overcome it. For cars that oversteer, braking is exactly the wrong strategy.

Accelerating while turning reduces the available front traction and the traction available on the inside tires, as shown in Figure 14, where the car is turning right. We'll first look at the turning forces, which are the same whether the car is coasting, accelerating, or braking through the turn. In a rear-wheel drive car without stability management or a limited-slip differential, the accelerating forces applied to the rear wheels are equal. However, the inside rear tire has less traction and unless we are careful with the throttle, it can break loose.

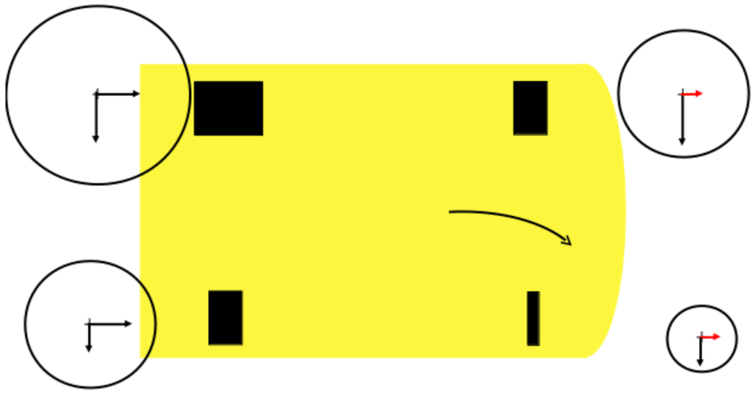

Figure 14. Accelerating while Turning Tire Contact Patches.

This situation is especially difficult for all-wheel driven cars, because of the extreme differences in available traction among the wheels. Limited-slip differentials or stability management are almost mandatory to allow acceleration through a turn. The reduced available front traction tends to increase any understeer and to decrease any oversteer. Many cars with good handling can be throttle-steered; in a turn. Increasing the throttle will produce understeer and decreasing it will produce oversteer. This is a common skid-pad exercise in driving schools.

Figure 15 shows the maximum speed you can carry through a turn at neutral throttle.

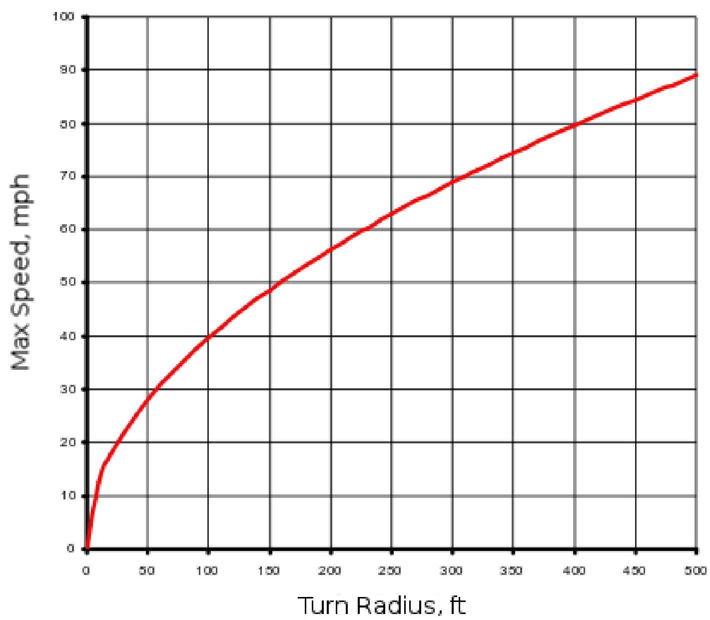

Figure 15. Maximum Speed vs. Turning Radius.

This assumes the car can maintain 1 g of lateral acceleration through a turn, which is true only for high-performance cars with good tires. Most street cars can achieve only lower speeds. However, the shape of the curve is true for all cars and all conditions. Looking at this should give you some comfort, since it shows that the maximum speed you can carry through a turn does not change drastically as the radius changes. For example, if you can go through a 400-foot turn at 80 mph, reducing the radius to 200 feet means you must reduce your speed only to 56 mph. In other words, cutting the radius in half requires you to reduce your speed by only 30 per cent.

Driving Techniques

While the best way to learn how to drive is to sit behind the wheel with an instructor beside you as you drive around a track, we can introduce the basic concepts here. I would never suggest this to a group of 16-year-olds with shiny new licenses, but you can safely practice most of these on the street at legal speeds. Just be careful not to alarm your fellow drivers or the local police.

Gear Selection

To make the best use of the power available from your engine, you want to select the gear that maximizes the accelerating force. Figure 16 illustrates this for an ’87 911. The red lines show the engine rpm vs. speed for each of the five available gears. The red numbers on the right are rpm. The green curves are more interesting. They show what we actually want to know – how much total force the rear wheels apply to the road at full throttle, which is shown by the green numbers on the left. You get the best acceleration by taking the engine up to its rev limit in every gear before you shift. Any time you shift up, you lose accelerating force. I have heard experienced track drivers claim that you should shift at the engine’s torque peak, and this plot shows that just isn’t true.

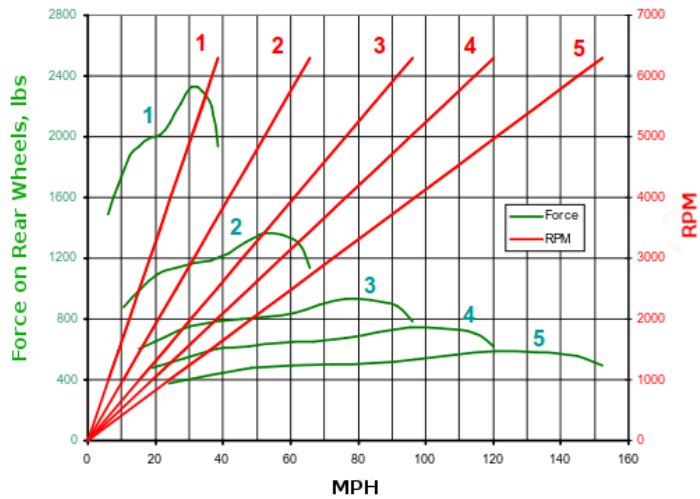

Figure 16. ‘87 911 Accelerating Force.

Note the large difference between first and second. This is a street car, and the gear ratio for first has been chosen to make it easy to get the car moving. A car designed for racing would have a smaller difference between first and second. Since a 911 has about 1800 pounds on its rear tires, you can break the rear wheels loose over much of the range in first gear. I used the data in the owner’s manual to make this and the following plots, and all assume no losses in the gearing. If you put the car on a dyno, you would get different results, but these are accurate enough to show you about where to shift.

Figure 17 is the same plot for an ‘02 Boxster S, and it shows the advantage of a six-speed transmission. First is still a “get the car rolling” gear, but the gap between first and second at the shift point is smaller than for the five-speed 911. Since a Boxster has only 1500 pounds on its rear wheels, you can break the rear wheels loose anywhere in first gear. The gap between second and third is quite small at the shift point, and the subsequent gaps are completely closed, which means that the optimum shift points for a Boxster S occur at slightly less than the rev limit. Top speed for this car is 161 miles per hour, and I stopped the plot here.

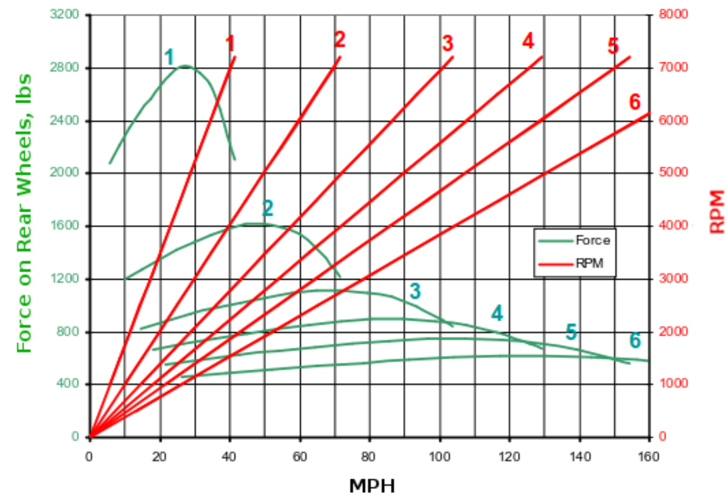

Figure 17. ‘02 Boxster S Accelerating Force.

As Figure 18 shows, the legendary 930’s 4-speed gearbox leaves large gaps between the gears. Whenever you upshift, you lose substantial accelerating force. The narrow torque curve doesn’t help either. However, the optimum shift strategy is still the same – take it up to the rev limit before you shift.

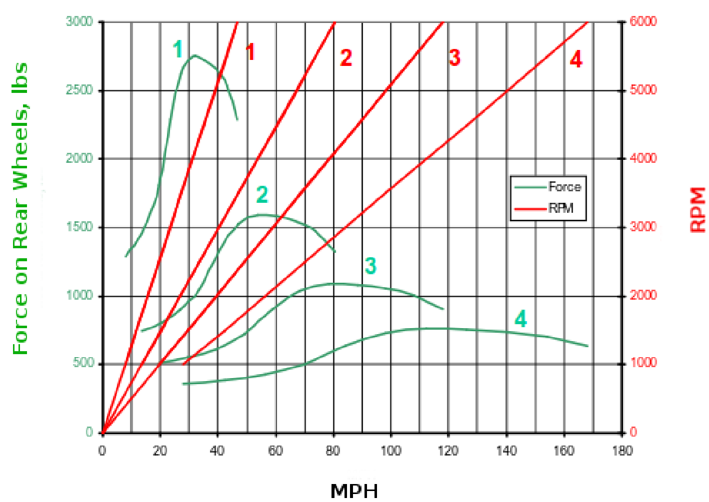

Figure 18. ‘82 930 Accelerating Force.

Turning Strategy

Up to now, we have been looking at how your car reacts to changes in speed, direction, and gearing. Now we’ll consider what this implies about how you should drive the car. We have seen that the larger our turning radius, the faster we can go through the turn. This means that we should adjust our line through each turn so that it is the largest possible constant-radius arc. You should approach the turn at its outside edge, brake just enough to slow the highest speed that its radius allows, and set your steering so that you graze the inside edge at its apex, and exit at the outside edge. At drivers’ ed, instructors frequently say, “You paid for the whole track; you should use the whole track.” Figure 19 shows the strategy.

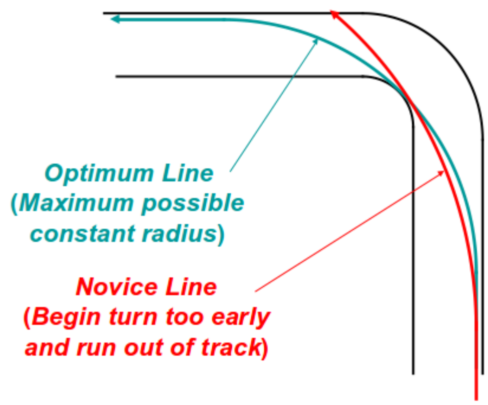

Figure 19. Apexing a Turn.

As you go through the turn, you'll apply just enough throttle to keep your speed constant. If you have to adjust your steering while turning, you've done it wrong. You can practice this on the street, but of course you'll apex the center line instead of the left edge of the pavement and you won't be at maximum speed. You will find that you can carry a surprisingly high speed quite comfortably. Novices tend to turn too early, which causes them to run out of track. You can see this every day on the street where drivers turn onto four-lane roads and have to go across both lanes as they complete the turn. Invariably, they've started the turn too soon, and at the apex they are pointed at the opposite curb. Good track (and street) drivers have learned to go deep into turns before turning the wheel.

Most drivers have no idea how fast their cars can stop. Maximum braking effort occurs with about ten per cent tire slip. Since the tires are on the threshold of locking up, we call this condition *threshold braking*. As we saw previously, once you lock up your wheels, you have thrown away most of the available traction. ABS is for emergencies only; if it comes on, you are braking too hard. It's not designed for continuous service, and if you use it every time you stop it can fail in surprisingly short time, as some beginning drivers' ed participants have discovered. If you don't have ABS, locking up a wheel is your indication that you're braking too hard. Beginning drivers' ed participants typically brake far to timidly and usually spend a fair amount of time working on threshold braking. Don't practice threshold braking on the street. Other drivers don't expect it, and you risk being rear-ended. It is also very difficult to learn at local street speeds, because stopping distances are so short and braking times so brief. This skill is best learned at high speed on a track.

Heel-and-toe Technique

The fastest way around a track is to accelerate as long as you possibly can, and when you must slow down, to brake as late as possible when going into a turn. This means you must learn to shift quickly while braking in such a way that you don't break the driving wheels loose when you pop the clutch. The technique is called "heel-and-toe" braking. This is not double-clutching, which is not used on the track. Begin the sequence with the gas pedal to the floor. Next move your right foot to the brake and mash it down hard enough to enter threshold braking. After the car has slowed sufficiently, depress the clutch with the left foot. Make the shift, and during it, while the clutch is depressed and while mashing the brake, blip the gas pedal with your right foot. Figure 20 shows the sequence, where the height of the traces show how far the pedals are depressed.

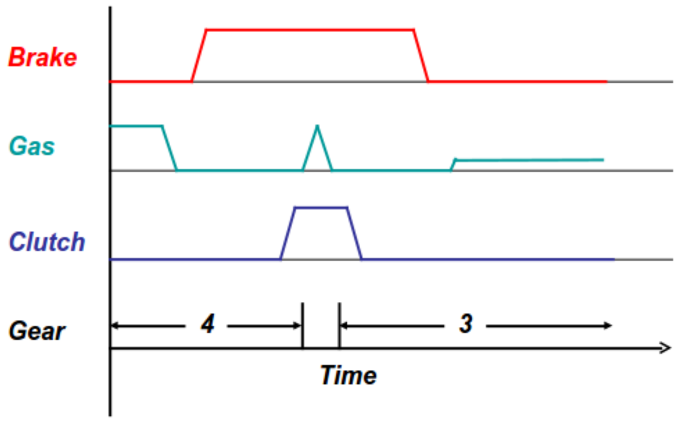

Figure 20. Heel-and-toe (Shifting while Braking).

How you do this depends on the geometry of your pedals. I keep the ball of my foot on the brake and twist my foot so that the heel is over the gas pedal. Then I quickly rotate my foot so that its right side blips the accelerator while the left side continues to depress the brake; Figure 21 shows the position. Complete the shift, and release the clutch. Continue to brake until you've slowed to the desired speed; then accelerate as needed. As a result of this, when you release the clutch, the engine's rpm doesn't change. Without doing this, the rear wheels will chirp, and going into a turn is the worst possible place to lose traction.

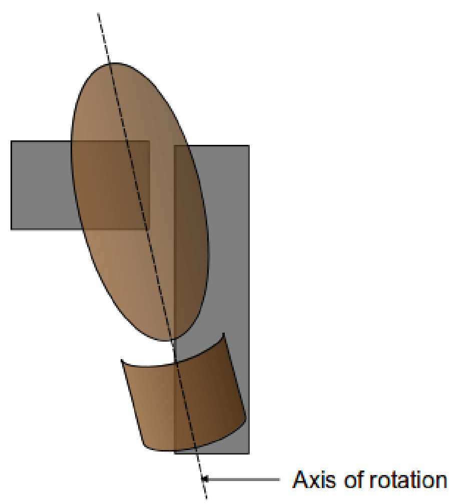

Figure 21. Heel-and-toe Foot Position.

Porsche pedals are designed to make heel-and-toe braking easy. The pedals are right next to each other, and during hard braking the brake pedal is about the same distance from the floor as the accelerator. First practice this while parked with the engine off. Then turn on the engine, and try it with the parking brake set and the car in neutral. You want to jab the accelerator hard but briefly, typically for about a second. Once you are comfortable with the movement, go for a drive on the street and try it in a straight line. Keep you braking effort light; you don't want to alarm your neighbors. Your goal is to be able to come off the clutch quickly and to have the engine going the right speed so that there is no commotion. After you are comfortable doing this in a straight line, try it going into a turn. I use heel-and-toe braking every time I shift going into a turn on the street. This insures I'm in a comfortable gear and ready to apply some gas during the turn. Don't try this on a track, until you are completely comfortable with it on the street. There are a lot of things competing for your attention approaching a turn there. It's exactly the wrong place to introduce something new unless it's almost automatic.

Other Gear-change Techniques

If you haven't mastered heel-and-toe, you'll sequentially brake and shift, shown in Figure 22. This begins the same way as with heel-and-toe – with the gas pedal to the floor. Next move your right foot to the brake and mash it down hard enough to enter threshold braking. Toward the end of braking, depress the clutch with the left foot, make the shift, and keep the clutch depresses. When your braking is complete and while the clutch is depressed, blip the gas pedal with your right foot. Since you are no longer braking, this doesn't involve and tricky maneuvers with your right foot. When you release the clutch, the engine's rpm won't change, and the rear wheels won't chirp. However, you have to allow time between the end of braking and the start of the turn to blip the throttle, so the process will take longer than with heel-and-toe. This means you will have to begin braking sooner.

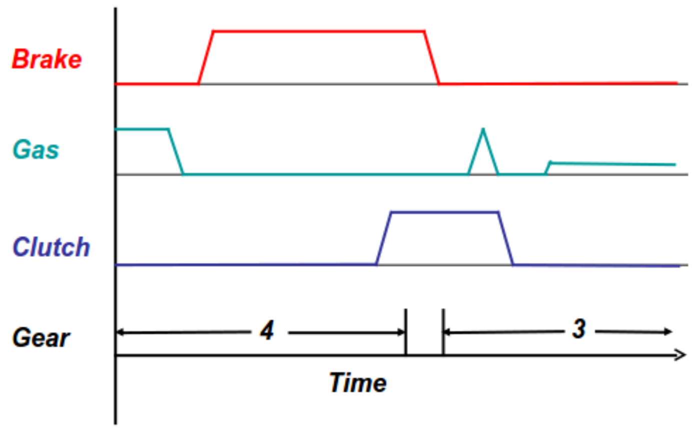

Figure 22. Sequential Braking and Shifting.

The purpose of double-clutching is to get all the gears moving at the right speed to mesh easily during a shift. It is essential in vehicles without synchro-mesh gearboxes. This is a slow shift, although when done properly it results in a very smooth one. Braking is not involved during the shift, so you needn't do anything cute with your feet. Begin with your foot on the gas pedal. Release the throttle, make a normal shift to neutral and release the clutch. While in neutral, blip the gas to bring the engine and gears up to the correct speed. Then make a normal shift to the desired gear. Finally, apply the desired amount of gas; see Figure 23. While I have never used this on a track, I employ it often on the street when down-shifting into a corner.

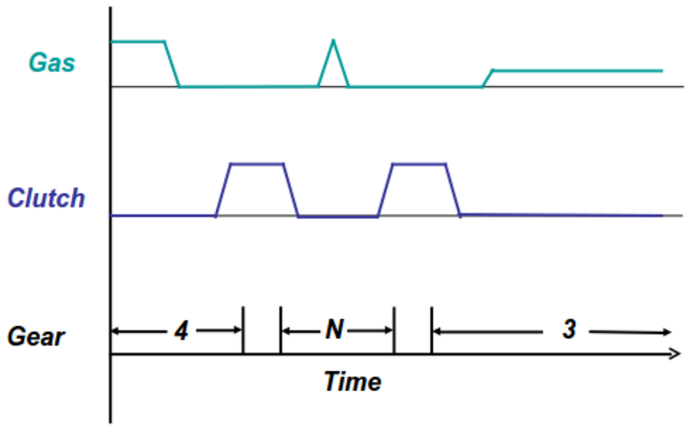

Figure 23. Double-clutching.

Throttle Control in Turns

We've already discussed taking the proper line through a turn. Now we'll add shifting, braking, and accelerating through it. Approach the turn at the outside edge of the track, usually under full braking. If you're comfortable with heel-and-toe, complete your downshift toward the end of braking; otherwise, complete your braking before making the downshift. In any case, complete your braking and shifting before beginning the turn, especially if you are a beginning track driver; see Figure 24

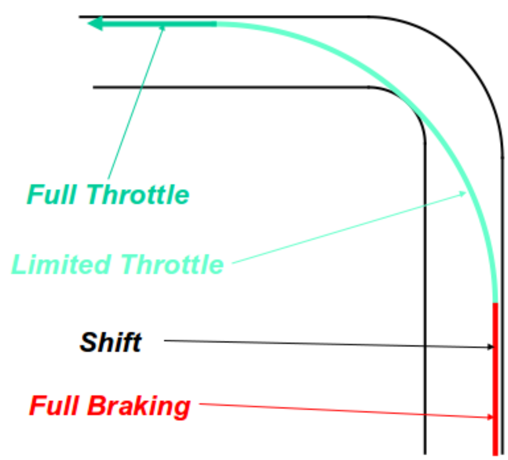

Figure 24. Turning Sequence.

In tight turns, very experienced drivers may enter the turn carrying some brake to keep weight on the front wheels and so to rotate the car quicker. Any time you make a turn, you are inducing some wheel slip, which will tend to scrub off speed through the turn. To prevent this, you will probably carry a little throttle all the way through the turn. Beginning at the apex, you will probably begin to increase the throttle so the gas pedal is to the floor as you exit. Once you are on the straight, you will carry full throttle until you approach the next turn. Except when turning, if one of your feet is not to the floor, you're not trying hard enough. Experienced drivers modify their lines to accommodate special circumstances, such as gradient, road surface, and adjacent turns.

Recap

The maximum force a single tire can sustain is independent of the direction of the force, which means that the force it can apply to the car lies within a circle. The radius of this circle is proportional to the weight the tire is carrying. We can think of any force of having two components – one perpendicular to the car's motion, the turning force, and one parallel to the car's motion, the braking or accelerating force. The total force is the graphical sum of these two components. Again, it must lie entirely within the traction circle. See Figure 25.

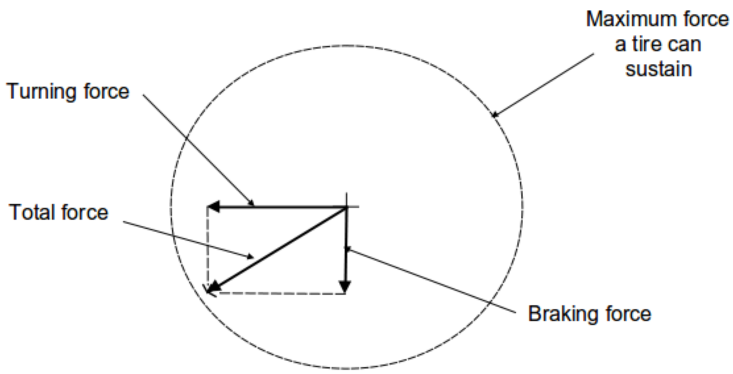

Figure 25. Tire Traction Circle.

As you approach the maximum speed in a turn, your car can react in one of two ways. The most common reaction for passenger cars is understeer, which means the car turns more slowly than you steer. This occurs because the front wheels have less traction (or equivalently, higher slip) than do the rear ones. To correct for understeer, you reduce throttle or apply more brake The opposite characteristic is oversteer, which means the car rotates faster than you steer. To correct for oversteer, you reduce braking or apply more throttle. See Figure 26.

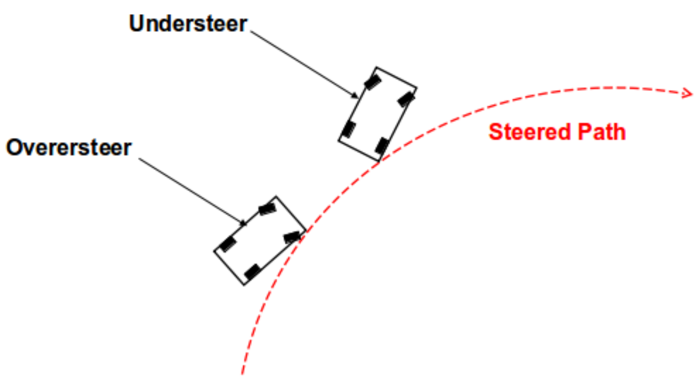

Figure 26. Understeer and Oversteer.

A useful way to visualize how traction is distributed among the tires is through tire contact patches. The available traction is proportional to the weight on the tire, which in turn is proportional to the area of the contact patch. The turning forces are higher on the outside tires, which is fortunate, because these have more available traction. The two front tires have equal braking forces, and while the braking forces on the rear tires are also equal, they are smaller. In the situation of simultaneous turning and braking, the inside rear tire has the least traction available. See Figure 27.

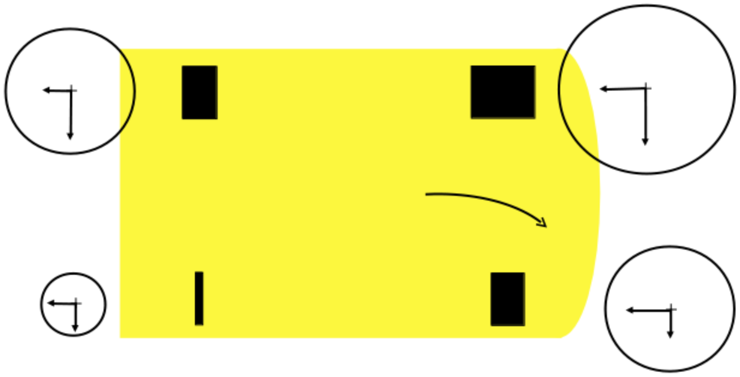

Figure 27. Braking while Turning.

Your owners manual has the information you need to figure out the optimum shift points. For every Porsche I've looked at, the optimum shift point is at or very near the rev limit, regardless of how many speeds it has. See Figure 28.

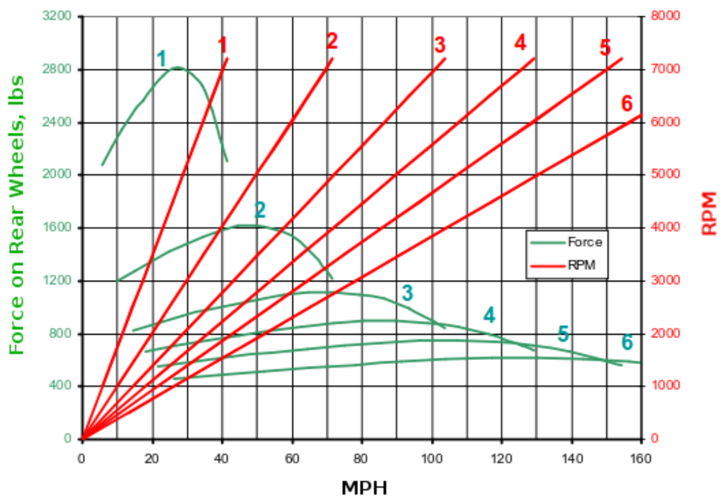

Figure 28. '02 Boxster S Accelerating Force.

While you can safely practice many of these techniques on the street, please wait for track days to explore your and your car's limits. Children, pets, and other drivers don't expect a car to come through a turn at high speed, and the consequences can be tragic.

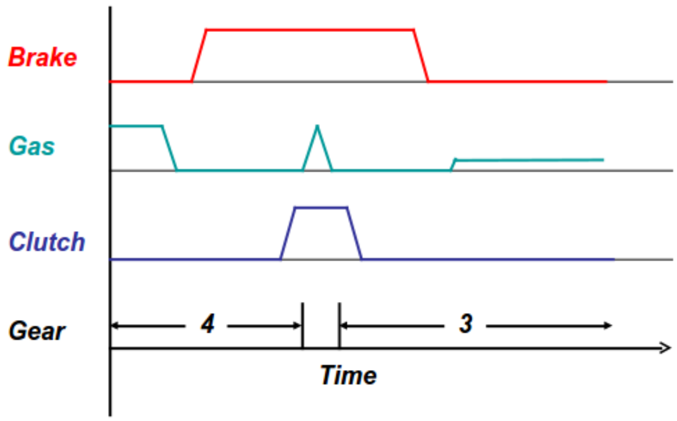

Figure. 29. Heel-and-toe (Shifting while Braking.)

Mastering heel-and-toe braking is essential for efficiently moving through a turn. Begin the sequence with the gas pedal to the floor. Next move your right foot to the brake and mash it down hard enough to enter threshold braking. After the car has slowed sufficiently, depress the clutch with the left foot. Make the shift, and during it, while the clutch is depressed and while mashing the brake, blip the gas pedal with your right foot. How you do this depends on the geometry of your pedals. I keep the ball of my foot on the brake and twist my foot so that the heel is over the gas pedal. Then I quickly rotate my foot so that its right side blips the accelerator while the left side continues to depress the brake. The next slide shows the position. Complete the shift, and release the clutch. Continue to brake until you've slowed to the desired speed; then accelerate as needed. As a result of this, when you release the clutch, the engine's rpm doesn't change. Without doing this, the rear wheels will chirp, and going into a turn is the worst possible place to lose traction.

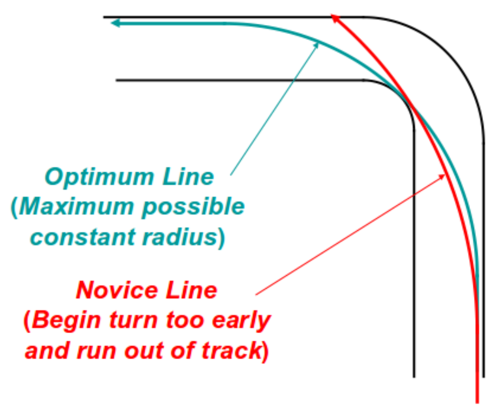

Figure 30. Turning Sequence.

This plot summarizes the default strategy for taking a turn. Approach the turn at the outside edge of the track, usually under full braking. If you're comfortable with heel-and-toe, complete your downshift toward the end of braking. Complete your braking and shifting before beginning the turn, especially if you are a beginning track driver. In tight turns, very experienced drivers may enter the turn carrying some brake to keep weight on the front wheels to rotate the car quicker. Any time you make a turn, you are inducing some wheel slip, which will tend to scrub off speed through the turn. To prevent this, you will probably carry a little throttle all the way through the turn. Beginning at the apex, you will probably begin to increase the throttle so the gas pedal is to the floor as you exit. Once you are on the straight, you will carry full throttle until you approach the next turn. Except when turning, if one of your feet is not to the floor, you're not trying hard enough. Experienced drivers modify their lines to accommodate special circumstances, such as gradient, road surface, and adjacent turns.