Red Light, Green Light

What factors influence reaction time and its measurement?

Suppose you were driving down a busy neighborhood street and a child appeared from between parked cars to chase after a loose basketball. You would probably respond instinctively by jamming on the brakes as quickly and as hard as possible. Avoiding a tragic accident in this case would depend largely on your capacity to react quickly. In other words, you would want to respond with as small a reaction time as possible. But, even though reaction time represents the simplest and most basic voluntary motor response of all, the scientific study of it reveals that the reaction in this seemingly simple scenario is far more complex than we might expect. Let's begin with some simple ideas.

Consider the sprint start in a 100-meter race at the Olympic Games. After the starter asks the runners to take their positions in the starting blocks and everyone appears ready, the command "Set" is given, followed shortly thereafter by the sound of the starter's pistol, which begins the measurement of the sprinters' reaction times. Starting blocks are equipped with sensors that measure the sudden rise in force exerted against the block as the runners explode from their starting positions. This sudden rise in force is used to identify the end of the reaction time period (figure 5.1). The time between the firing of the starter's gun and the rise in force against the block

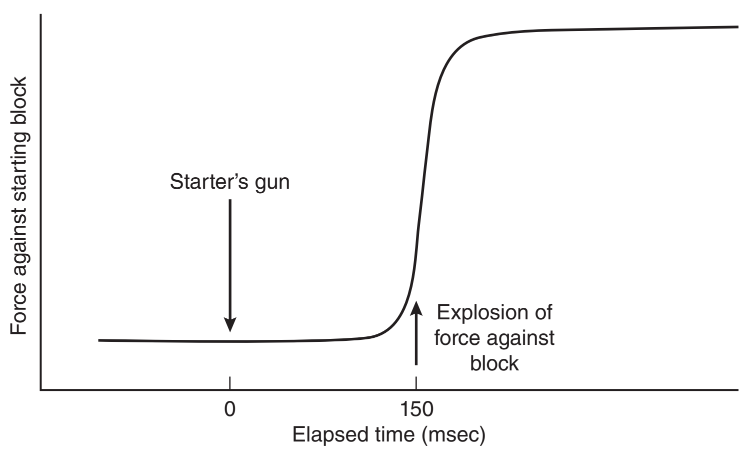

Figure 5.1 The measurement of reaction time in a sprint start. The sudden rise in force against the starting block signals the end of the reaction time.

defines the amount of time the runner needed to process the sound of the gun and initiate the sprint. In this way, reaction time is more strictly defined as the period between the sound of the starter's gun and the initiation of movement and does not really consider what happens after the race has begun.

So, let's reconsider our original issue, concerning the reaction time in responding to the child who has run onto the street. How would reaction time be measured here? Pushing on the brake pedal would actually combine reacting to the sight of the child *and* making a complete voluntary action to depress the brake pedal. Before the foot can touch the brake, though, it must leave the gas pedal. Therefore, one possibility for accurately measuring reaction time in this situation would be to assess the sudden release of pressure from the accelerator, thus signaling the initiation of the movement of the foot toward the brake. (The sudden drop in pressure on the accelerator would be similar to the sudden rise in force against the starting block discussed earlier in measuring the sprint start.) If we wanted to be even more precise, we could measure the sudden rise in activity of the muscles responsible for moving the foot off the accelerator, because they would show an increase in activity just fractions of a second before the foot actually left the accelerator. The point here is that measuring the time it takes to bring the car to a halt would include reaction time, but also the time contributed by many other factors, such as moving your foot quickly and forcefully to the brake, the environment (such as a slippery road), and the car itself (speed and mass). Reaction time would only contribute a small portion to the duration of this braking response.

Now let's consider another important property that influences the duration of a reaction time—what researchers call the amount of information that needs to be processed. Much of that information is contained in the visual signs and symbols that we respond to every day. My computer tells me when it is safe to unplug some hardware, when I should update my virus protection, and when I have a new e-mail in my inbox. Little symbols on my car's dash display that I can see through my steering wheel tell me things such as when it is time for an oil change (and many other things that make no sense to me at all, requiring me to look them up in that little book in the glove compartment). All of these signals differ in terms of the amount of information they convey and what they tell me to do.

We respond the quickest and most reliably to signals that are the simplest—the ones that suggest no choices in how we should respond. Take traffic signals, for instance. They tell us when it is safe to go or stay put and when pedestrians should walk or not walk. Some intersections use a very simple design to indicate information. The simplest signal contains just one light that may flash or stay on all the time. For example, some intersections use a flashing red light to indicate that a stop is required. But, because the light is conveying only one piece of information that never changes, there is really no decision to make—we just do what the light tells us to do.

From T.D. Lee, 2011, *Motor control in everyday actions* (Champaign, IL: Human Kinetics).

A more complicated signal uses a two-light system. At a toll booth, for example, the red light indicates that you must stop and drop coins in the collection bin. The red light goes off and a green light comes on when the required amount has been received. The light tells you to keep your foot on the brake while the red light is on and not to remove it until the light changes from red to green. There is now a choice in what action to take. No decision needed to be made in the previous example of the flashing red light—you just did what the lone signal indicated that you should do. At the toll booth, however, you need to understand what the signal is (green or red), decide what it means (stay or go), and then act in an appropriate manner.

The common traffic intersection light is more complicated. The three-light system includes an amber light between the periods of green and red. The three-light system is an interesting one because two of the lights have definitive stimulus–response mappings: green means "go" and red means "stop" (or "don't go"), but what does the amber light tell you to do? The amber light is a warning signal that informs you that a red light is about to appear, and the change of the traffic signal from green to amber suggests that you need to instantaneously process all of the current traffic factors and make an appropriate response from one of two choices: either proceed through the intersection or stop before entering it. You use information at your discretion to make the decision based on various factors, such as your current speed, the distance from entering the intersection, road conditions, and your mental state. In a sense, the three-light traffic signal requires one of four possible responses: green means "go," red means "stop," and amber means "go or stop."

Some traffic lights have a fourth light, indicating a protected left turn. The fourth light might be a left-pointing arrow that then turns green, then amber, then red. If I am in the line of cars waiting to make a left turn, the choices about how to act have now become quite numerous. In other words, the traffic signal becomes more and more complex as the number of lights and responses to be made gets larger and larger.

Many researchers believe that uncertainty is the primary cause of complexity and equate the amount of information to be processed with the uncertainty about an event. The reaction time paradigm has been the most frequent scientific method used to study the effects of uncertainty on motor behavior. For example, suppose I asked you to rest your left middle finger on the A key on your keyboard, your left index finger on the S key, your right index finger on the K key, and your right middle finger on the L key. I can now manipulate the amount of information you are required to process by varying the choices you need to make.

Let's start simply by simulating the no-choice traffic light. With all four fingers resting on the keys as described, I tell you that a white box in the center of your computer screen will turn green for a brief moment every few seconds or so. You do not have to be concerned with having to make a choice about what the color of the box is and what finger to use to make the response; you simply have to press K when the box turns green (or more simply, when the box changes color, because it can only change from white to green). Your reaction time should be very fast.

Now let's make the task a little more complicated. Now the white box may turn either green or red. As before, I tell you to press K when the box turns green, but to press S when it turns red. You still don't have to be concerned with using the middle finger on either hand to make a response, but you do have to choose between index fingers, depending on the color to which the white box has changed. Your reaction time will be slower as a result of the decisions involved—detecting the color of the box and deciding which index finger to use to press a key.

I could then use four colors, with each of the four fingers mapped to respond to a specific color. But, you get the idea by now—reaction time will be even slower than before. More important, however, this experiment has demonstrated a fundamental feature of behavior—that the time required to process information (as measured by reaction time) is related directly to the amount of information to be processed. More precisely, the information to be processed includes reducing the uncertainty about what the stimulus color is and which finger is the appropriate one to use to make a key press response. In fact, this feature of behavior is so fundamental that it has been called a law of behavior, Hick's law, after the researcher who first applied information theory to explain why reaction times increased linearly every time the experimenter doubled the number of available choices.

I don't want to leave you with the impression that we respond to traffic signals as fast as possible. In fact, the traffic intersection is a good example of a situation in which we usually sacrifice speed to ensure that our decision is correct (also see "Pouring Coffee" in chapter 3). But the basic principle in understanding how to respond to traffic lights of varying complexity remains the same: the amount of information to process to respond appropriately is a direct result of the number of options available. Choice reaction time experiments nicely illustrate the concept that information is synonymous with the amount of uncertainty to resolve to make an informed decision.

Self-Directed Learning Activities

1. Define *reaction time* in your own words.
2. Provide everyday life examples of reaction situations that involve one choice, two choices, three choices, and four or more choices.
3. Look up the empirical equation that defines Hick's law. What does each of the terms in the equation refer to in Hick's law?
4. Find a web-based demonstration of Hick's law and conduct an experiment in which you measure reaction time as a function of the number of stimulus–response alternatives. Plot and describe your data; then fit your data to the linear equation used in Hick's law.

Notes

- Unfortunately, many drivers interpret the three-light system as follows: red means "stop," green means "go," and amber means "go faster."
- Here is a fun demonstration of the speed–accuracy trade-off in a reaction time task from BBC Science & Nature:

  www.tinyurl.com/speedaccuracy

Suggested Readings

Schmidt, R.A., & Lee, T.D. (2011). Human information processing. In *Motor control and learning: A behavioral emphasis* (5th ed., pp. 57-96) Champaign, IL: Human Kinetics.