3 Reflexes, Homeostasis, and the Autonomic Mind

Rational behavior requires theory. Reactive behavior requires only reflex.
—W. Edwards Deming

What human beings consciously wish is often quite at variance with the results their reflex patterns automatically create for them.
—Timothy Leary

Given an organism with a nervous system, the simplest behaviors involve reflexes. If you are sitting in your doctor's office with your feet dangling from the examination table, and the doctor taps on the patellar tendon below your kneecap, your lower limb will jerk forward. We have a good understanding of the underlying mechanism. An afferent (sensory) neuron from the quadricep muscles carries the signal (from the knee tap) to the spinal cord and passes it directly to an efferent (motor) neuron, causing the stretched muscles to contract (figure 3.1). This is a simple monosynaptic reflex arc, where only a single synapse connects the stimulus and response nerve pathways.

A slightly more complex example of a reflex is the corneal blink. If I snap my fingers in front of your eyes, you will blink. The underlying mechanism is the same as for the patellar reflex, except that this is a polysynaptic reflex. That is, there are intervening neurons between the sensory input and motor output neurons, called interneurons. An afferent (sensory) neuron carries a signal to interneurons in the brain stem, and the interneurons pass the signal to efferent (motor) neurons, causing the blink (to protect the eye from external threat).

Whether the doctor taps on your kneecap or snaps their fingers in front of your eyes, the stimulus is causally sufficient for the response (leg swing or eye blink). In both cases, I can offer you a large reward for not swinging your leg when tapped on the knee or not blinking your eye when a finger

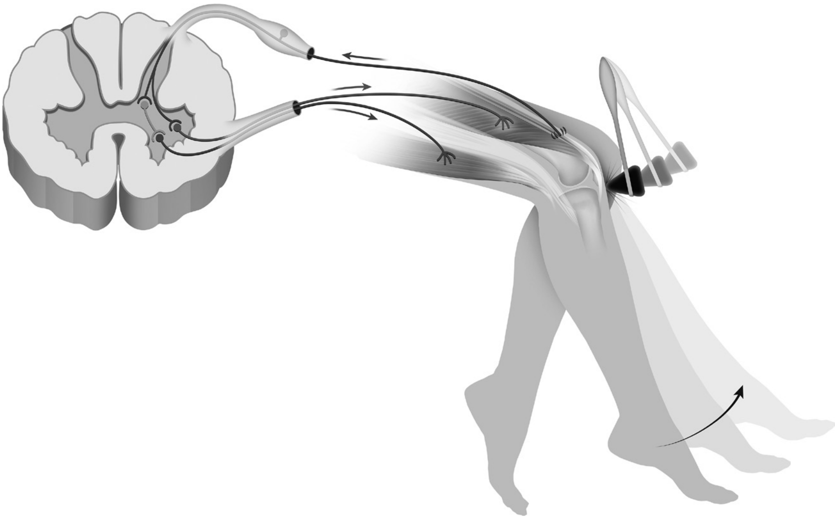

Figure 3.1
A monosynaptic reflex arc. The sensory input (tapping) generates the motor response directly through a monosynaptic reflex arc. There are no intervening neurons between the sensory nerves communicating the tapping signal from the quadricep muscles back to the spinal cord, and the motor neurons from the spinal cord innervating quadricep muscles. The figure also shows the presence of an inhibitory interneuron that serves to relax the hamstring muscle. Drawing by Aldona Griskeviciene.

is snapped in its vicinity. Despite your best efforts, your leg will swing out and you will blink when the respective stimuli are presented. You do not have a choice; the behavior is involuntary and automatic. Reflexes cannot be overruled by reason because the sensory neurons either connect directly or via interneurons to motor neurons without the information going to the brain, specifically the cerebrum, for interpretation. Where these behaviors exist in other species, they are underwritten by similar mechanisms.

However, these systems can also connect with higher-level systems in the cerebral cortex. For example, when a person steps on a sharp object, a sensory neuron carries the signal to an interneuron in the spinal cord. The interneuron communicates with motor neurons, which pull the foot away from the sharp object (polysynaptic reflex). However, if this was all there was to it, the action would probably result in imbalance and falling. So the interneuron also connects to motor neurons controlling the muscles of the other leg to allow for any adjustment needed to maintain balance. The interneuron may also connect with other neurons in the cerebellum and the cerebrum, which will allow for conscious awareness of the event and subsequent voluntary action.

Reflexes have also been co-opted for more complex functions involved in monitoring and regulating internal bodily functions controlled by the autonomic nervous system (ANS). The ANS innervates the smooth muscles (internal organs), cardiac muscles, and glands. It monitors blood pressure, salinity, core body temperature, blood pH, and blood glucose levels and controls heart rate, digestive activity, breathing, salivation, and sexual arousal, among other things. Two competing subsystems of the ANS are the sympathetic and the parasympathetic systems. The sympathetic nervous system is arousing. It prepares the body for the fight-or-flight response when under threat. It will increase the heart rate, dilate blood vessels and air passages, and stop energy-intensive processes such as digestion and urination. The parasympathetic system is calming. It is sometimes referred to as the “feed and breed” or “rest and digest” system. It maintains the body at rest, decreases blood pressure and heart rate, and induces digestion and bodily secretions. A third subsystem is the enteric nervous system, which controls the gastrointestinal tract.

In the case of respiration (figure 3.2), chemoreceptors monitor CO_2 levels (and to a lesser extent O_2 levels) of blood in the aorta and pH levels in the cerebrospinal fluid surrounding the brain and send the information to the breathing control center in the brain stem. Efferent nerve impulses from the brain stem, sent via the intercostal and phrenic nerves, result in contraction of inspiratory muscles and expulsion of CO_2-laden air. This stimulates the stretch receptors in the lungs. These receptors are part of a reflex arc. The stimulation inhibits inspiration to prevent damage to the lungs and chest cavity from excessive stretching and allows for expiration. After each inhaling breath, the inspiration center is reflexively inhibited, automatically allowing exhalation, so breathing is maintained in part by series or chains of automatic reflex actions, not reasoned decision-making.

Blood glucose levels are maintained largely through biochemical reactions (figure 3.3). Eating a meal increases blood glucose levels beyond the normal homeostatic “set” point (approximately 90 mg / 100 ml). This causes the pancreas to release insulin into the bloodstream and signals the liver to take up any excess glucose and store it as glycogen, causing the blood glucose levels to drop. If glucose levels drop below the set point (e.g., due to not having eaten for a while), the pancreas will secrete glucagon into the bloodstream, which will signal the liver to start converting stored glycogen into glucose and releasing it into the bloodstream to restore levels to normal.

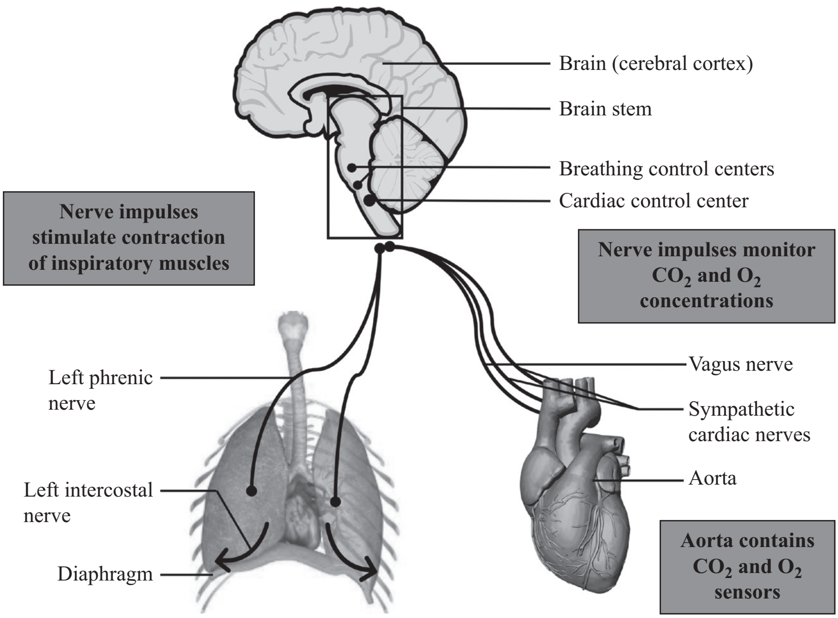

Figure 3.2
Control of respiration by the autonomic system, in part by a series of reflex actions with control centers in brain stem structures.

In terms of the five dimensions being used to classify behaviors, the function of the autonomic system is to monitor the internal environment of organisms and maintain it within a certain optimal range. The acceptable range and respective countermeasures are preset. An organism cannot *decide* via reason to release insulin into the bloodstream only when glucose levels exceed 50 mg / 100 ml or 150 mg / 100 ml or choose not to increase heart rate while undertaking physical exertion. The autonomic system responds automatically. Furthermore, an organism cannot *learn* to breathe or release insulin into the bloodstream. That knowledge is encoded into the genome and hardwired into the ANS. Systems simply come online as needed.

Most importantly, there is a very tight causal coupling between stimulus and response. Normally, certain stimulus changes are causally sufficient (and sometimes necessary) for certain behavioral changes. More accurately, given the constraints of normal biology, and appropriate *ceteris paribus* clauses, certain events and changes will be causally sufficient (and sometimes necessary) for other events or changes. In the case of the patellar reflex (knee-jerk), the tapping of the tendon activates a sensory neuron

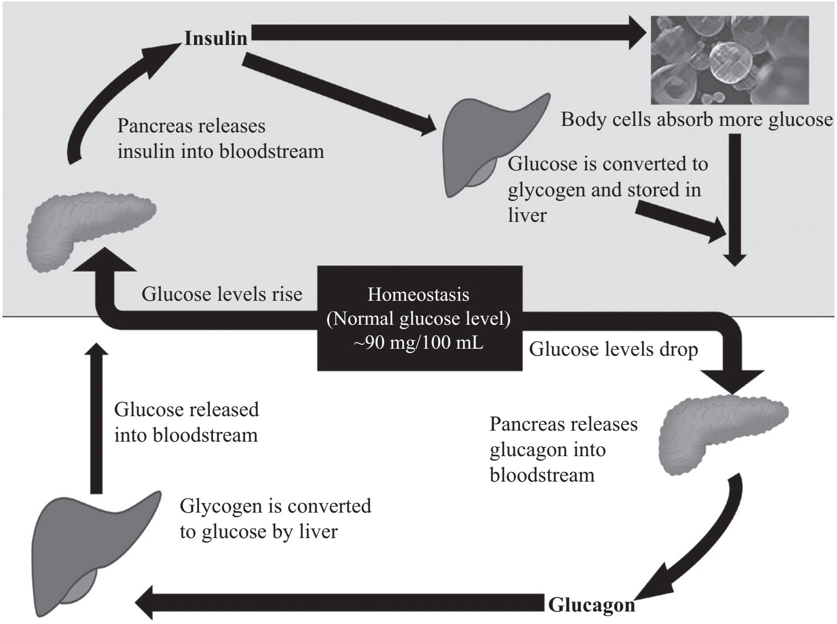

Figure 3.3
Homeostatic control of blood glucose levels by the autonomic system.

which in turn directly activates a motor neuron, resulting in a stretching of the quadriceps muscles and subsequent knee-jerk. How the sensory signal is generated can of course vary, but its generation is necessary and sufficient for the motor response. (One can consciously move one's leg through different neural pathways, but the resulting motion will be different.) Similarly, if glucose levels drop below a certain point, other things being equal, the pancreas will secrete glucagon into the bloodstream. If glucose levels do not drop below a set point, it will not do so, other things being equal.

Where exceptions occur, they can be explained either in terms of multiple pathways to a behavioral response or in terms of complex causal relations involving multiple factors and individual differences in these factors. The corneal blink provides an example of the first exception. Snapping my fingers near your eyes is sufficient but not necessary for you to blink. You can also blink as a result of dry eyes and conscious effort. An example of the second exception is provided by viral infections. The presence of the appropriate virus is necessary for someone to display the symptoms of COVID-19. However, not everyone exposed to the virus comes down with the symptoms of COVID-19. This seems to violate the sufficiency condition and looks like an exception to the tight causal leash. Not so. It means we do not fully understand the causal story. Symptoms of COVID-19 require the presence of the virus, but may also require the presence of properties X, Y, and Z, which can exhibit differences among individuals. If the virus plus the necessary properties are present, that will be necessary and sufficient for displaying the symptoms of COVID-19.

The mechanisms underlying the autonomic system are a combination of reflex arcs, chemical reactions, and homeostasis, which we understand at the level of neuronal signaling and underlying biochemistry. In terms of brain systems, the brain stem and hypothalamus structures, widely available across the evolutionary spectrum, are involved (see chapter 10).

This characterization of the autonomic system as autonomous of instinctive, associative, and reasoning systems is incomplete. For example, the level of satiety or hunger will also affect the engagement of instinctive, learned, and (in humans) reasoned food-foraging behaviors (chapters 11 and 12). Some autonomic systems can be modulated through volitional choice, to a limited extent. In the case of breathing, for instance, voluntary signals from the cerebral cortex to the medulla and pons can modulate the automatic breathing process, *within a certain range*, when it comes to such actions as singing or swimming. The extent of this control varies among individuals. Most of us certainly cannot will ourselves to stop breathing altogether or will ourselves to feel warm in an ice bath, but some people, such as the "Iceman," William Hof, make credible claims of being able to do the latter (Carney, 2017). There is also some controversial evidence that meditation techniques allow certain individuals to "reach down" with their voluntary systems into the autonomic systems and control body temperature, heart rate, breathing, pain, and even immune system responses (Benson et al., 1982; Heathers et al., 2018; Kox et al., 2014).

Autonomic systems can also feed information upward to modulate what should be volitional processes, including reasoning processes. Here is a personal anecdotal example. When I was a graduate student, I would come home late in the evening and several times a week my wife and I would then walk to the supermarket to purchase groceries. In the midst of this routine, my wife would sometimes have occasion to ask me, "Why are you upset?" I would reply, sincerely, that I was not upset. Despite my denials, she noticed that I was snapping at her. This is conscious, volitional behavior. If I have a reason to be upset with her, it could even be considered rational behavior. For example, if I did not really want to go shopping and I believed that she was unnecessarily pressuring me to do so, that would be a reason for my snapping behavior. But I had no such reasons, so my behavior cannot be explained using the machinery of rationality. After several repetitions of these episodes, she figured out the problem and the solution. I was cranky because I was hungry. Indeed, it is reported that cravings for carbohydrates result in feelings of anxiety, fatigue, and tension. Satisfying the craving increases energy levels, resulting in feelings of happiness. No beliefs or reasons were involved in my snapping behavior. It was just low blood sugar level (figure 3.3). My wife began carrying chocolate bars with her, and every time I became cranky, she would give me one, and all would be well. This is an example of lower-level systems modulating higher-level systems and reminds us that the cognitive system is tethered to these simpler systems. My wife's actions also serve as an example of how higher-level cognitive systems can modulate lower-level systems.

Continuing with the low-blood-sugar example, a study of experienced judges making parole decisions reported that favorable rulings directly after a food break were 65% and dropped to nearly 0 prior to a food break (Danziger, Levav, & Avnaim-Pesso, 2011).

Many of the processes controlled by autonomic systems also have affective components associated with them; that is, they are associated with *feelings*. One obvious example is sexual arousal, but it is also pleasant to breathe, to quench thirst and hunger, and to maintain a normal body temperature. Disruptions in autonomic systems lead to unpleasant feelings. For example, low blood sugar can lead to hunger pangs and irritability, not being able to breathe leads to feelings of suffocation, and heart failure can lead to severe chest pains. I will signal the role of affective arousal or feelings in each of the four types of behaviors that we will discuss and then address it more comprehensively in chapter 11.

* * *

The autonomic system constitutes a coherent and interesting, albeit simple, kind of mind, widely available on the phylogenetic tree and quite adequate for monitoring and regulating predictable internal environments, but its adequacy for monitoring and responding to unpredictable *external* environments seems less obvious. It is certainly a nonstarter for explaining rationality, but it does have the potential to modulate rational processes, as illustrated by the anecdotal example of my own low blood sugar level and the data from the study of parole judges. In the next several chapters, we will consider the kinds of minds more suitable for navigating changing external environments.

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