How does the nervous system use functional linkages to coordinate movements?

Everybody knows the coordination task in which you try to pat your head and rub your belly at the same time. Here is another one that was going around the Internet a few years ago: While sitting in a chair, lift your foot slightly off the floor and make it go around in small clockwise circles. While your foot is circling use the index finger of your right hand to draw the number 6 in the air. If you are like most people, your right foot will switch directions and start to go in the same direction as your hand. The feeling is most bizarre—it is almost as if some other force has taken over control of your foot.

The issue concerns the problem of coordination—how your central nervous system deals with the task of controlling two or more body segments that are moving at the same time. The steering mechanism of a typical car provides an analogy that helps to understand the solution to the problem (see figure 7.6). The car moves in a direction that is specified by the two front wheels. And yet, we don't have to think about the direction that each wheel is headed because they are linked together with the steering column: you

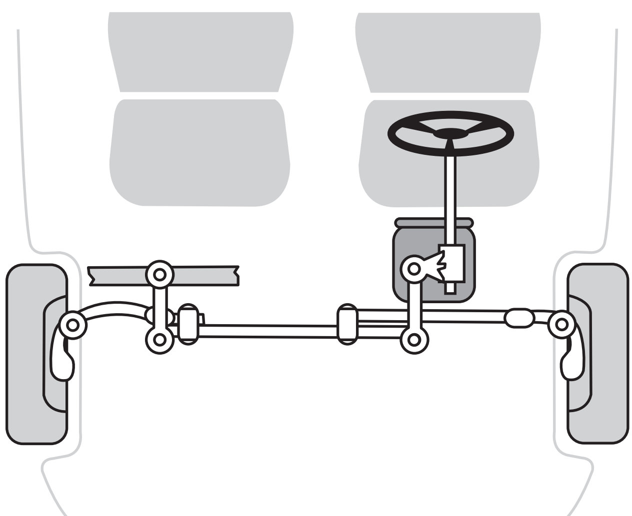

Figure 7.6 The car steering system is a good example of controlling two degrees of freedom (the direction of each front wheel) by reducing to one degree of freedom (controlled by the movements of the steering wheel).

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

move the steering wheel, which causes the steering column to rotate, which in turn causes both front wheels to move by the same amount. The front wheels have a fixed linkage, meaning that any movement of the steering wheel will result in identical changes in both the right and left front wheels. Imagine how different and more difficult the task of steering a car would be if you had separate controls for each wheel!

The steering system reduces the degrees of freedom involved in steering from two to one by means of the fixed linkage. It has solved the problem of coordinating the independently moving two wheels by removing their independence. Our motor control system also has many independently moving parts—degrees of freedom that might otherwise present a problem for us to coordinate if we did not have a central nervous system that provides us with linkages that are both functional and flexible. One of the remarkable features of human movement is that we can achieve the same result using very different routes to success (see “Websites and Silly Walks”).

Take, for example, the task of maintaining balance when standing on a bus or a subway. Suppose you are facing the front of the vehicle when it quickly comes to a stop. The physics of bringing the vehicle to a stop naturally propels your body forward. How do you maintain your balance? Research by Horak and Nashner revealed that we use one of three strategies to maintain or regain balance (illustrated in figure 7.7). Two of the strategies (the left and middle illustrations in figure 7.7) are used to maintain or regain postural stability by making postural adjustments about the ankle or hip, without changing the base of support. The third strategy (right side of figure 7.7) uses a step to stop the forward momentum of our body sway.

Let’s consider just the first two strategies for now. Both involve a collective functional linkage of muscles that span a joint, either the ankle or hip, to bring balance under control. And both use an entirely different set of linkages to do so. This example nicely illustrates how the body organizes a set of degrees of freedom to work together to achieve a common goal, but also illustrates that we are not forced to use an inflexible linkage to do so. We can solve the problem without moving our feet in two very different but effective ways—by invoking either the ankle or hip strategy.

These and many other studies of controlling multiple degrees of freedom at the same time reveal that acts of coordination are sometimes easy and sometimes more difficult to do. Here is another demonstration, provided by researcher Scott Kelso. Shape your hands like two pistols and hold them in front of you, as if you were about to shoot at a target. Now start to rhythmically wiggle just the right index finger back and forth. After a few seconds of wiggling just the right finger start wiggling the left index finger too. Look to see what pattern the two index fingers spontaneously adopt. When I ask the students in my class to do this, almost everyone in the class moves the fingers toward each other and then away from each other. This is called moving in an in-phase pattern and is probably spontaneously adopted because it is the most natural and comfortable timing pattern to use in this

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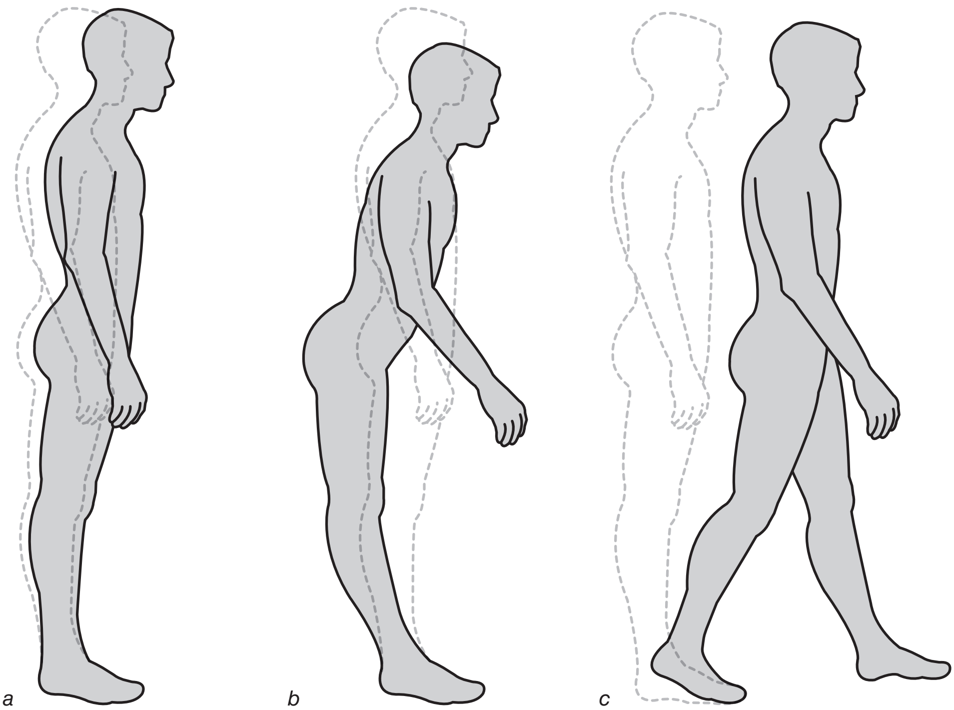

Figure 7.7 Balance control strategies: *(a)* ankle strategy; *(b)* hip strategy; *(c)* step strategy.

situation. Note that there is no fixed linkage that requires the fingers to coordinate in this manner. Rather, the fingers are spontaneously linked to engage in a pattern that allows both fingers to move simultaneously, with little effort or attention required to keep each of them under control. Instead of a fixed linkage, the central nervous system has created a movement pattern, or functional linkage, that allows the timing of two separate body segments to be controlled as easily as one segment.

Although we spontaneously tend to adopt an in-phase pattern in this case, as intentionally acting human beings with functional linkages, we are not compelled to wiggle our fingers in just this one pattern, as the two front wheels of a car are compelled to do. Hold your pistols out again but now move them in the same direction. That is, move both index fingers to the right, then to the left, then right, and so on, which is called moving in an antiphase pattern. This pattern (used by many automakers in their windshield wiper fixed linkage systems) is also an easy one to maintain. The flexibility of the central nervous system has permitted us the functional capacity to move in either an in-phase or antiphase pattern with relative ease.

But these are not the only patterns that we can use to simultaneously wiggle our fingers. In fact, with practice we can learn to perform essentially any one of an infinite number of timing patterns for these two degrees of

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freedom, of which only two patterns are inherently simple to produce. And, some people can actually move a foot in clockwise circles while writing the number 6 with the index finger. They have managed to overcome the tendency of the central nervous system to coordinate these two moving segments in the most natural functional linkage—that is, moving both in the same direction. Achieving each separate goal while moving both limbs at the same time has been achieved because of practice. A new functional linkage has been learned that allows this pattern of foot and hand movements to be performed together with ease and efficiency. They have solved a puzzle that requires motor learning. Lots more is said about learning in part III of this book.

Self-Directed Learning Activities

1. Define the term *degrees of freedom* in your own words.
2. How does a linkage change the degrees of freedom in performing a task?
3. Explain the difference between a fixed linkage and a functional linkage.
4. Design and conduct an experiment in which a person sits in an elevated chair and swings one upper limb and one lower limb at the same time. What natural functional linkages do you find?

Notes

- The trick of the foot and tracing the number 6 will work only if you make your 6s starting at the top and going in a counterclockwise direction.
- Controlling many independently moving parts at the same time is called the degrees of freedom problem; it was first described by the Russian scientist Nikolai Bernstein in the 1930s.

Suggested Readings

Horak, F.B., & Nashner, L.M. (1986). Central programming of postural movements: Adaptation to altered support surface configurations. *Journal of Neurophysiology, 55,* 1369-1381.

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Kelso, J.A.S. (1995). *Dynamic patterns: The self-organization of brain and behavior.* Cambridge, MA: MIT Press.

Schmidt, R.A., & Lee, T.D. (2011). Coordination. In *Motor control and learning: A behavioral emphasis* (5th ed., pp. 263-296) Champaign, IL: Human Kinetics.

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