CHAPTER 8

Action Preparation

Concept: Performing voluntary, coordinated movement requires preparation of the motor control system.

After completing this chapter, you will be able to

- Discuss why reaction time (RT) can be an index of preparation required to perform a motor skill
- Explain how Hick's law describes the relationship between the number of alternatives in a choice-RT situation and RT
- Describe various task and situation characteristics that influence action preparation
- Describe various performer characteristics that influence action preparation
- Discuss several motor control activities that occur during action preparation

APPLICATION

Many sport, recreation, fitness, and daily activities demonstrate our need to prepare the motor control system to carry out an intended action. For example, many sports events, such as running, swimming, and trap shooting, incorporate the importance of preparation into the rules of the activity by requiring an audible signal warning the competitors to get ready.

Certain performance characteristics of activities also provide evidence of the need to prepare for the action. For example, when you decide to pick up a glass of water for a drink, there usually is a slight delay between your decision and the intended action. In another example, if you are driving a car along a street and another car unexpectedly pulls out in front of you, there is a measurable time delay between the moment you see this and the moment you begin to move your foot off the accelerator and onto the brake pedal. In each of these very different activity scenarios, the initial movement of the intended action is preceded by an interval of time in which the motor control system is prepared according to the demands and constraints of the situation.

Consider the preparation of action from a different perspective. Undoubtedly, at some time or other you have said, following a poor performance in an activity, I wasn't "ready." By saying this, you imply that if you had been "ready" you would have performed much better than you just have. Or, if you work with physical therapy patients, you undoubtedly have heard one tell the therapist, "Don't rush me. If I get out of this chair before I'm ready, I'll fall."

Application Problem to Solve Describe a motor skill that you perform or that you teach other people to perform. Describe the motor control characteristics of this skill that you, or the people you teach, must prepare to perform the skill successfully. Are there situations in which there are fewer or more characteristics to prepare? What are these situations and how do they influence the need to prepare fewer or more motor control characteristics?

DISCUSSION

In chapters 5 through 7, we focused on factors influencing the control of the performance of a skill. Although there was occasional mention of the initiation of the action, we only touched on what is involved in the actual preparation of an intended action. In the present discussion, our interest is in what occurs between the *intention* to act and the *initiation of movement* to perform the action itself. In the motor control literature, researchers sometimes use the term *movement preparation* to designate this activity. However, in keeping with the distinction we made in chapter 1 between actions and movements, we will use the term **action preparation** when referring to this process.

In this context, *preparation* does not refer to the long-term preparation that occurs during the days prior to an event, but to *the specific preparation the motor control system makes just prior to initiating movement.* We will address two preparation issues here. First, how do different skill, performance-context, and personal factors influence the preparation process? Second, exactly what does the motor control system prepare that makes preparation such a critical part of the performance of any skill? But, before we discuss these issues, we will establish how we know that the motor control system needs to be prepared for action.

ACTION PREPARATION REQUIRES TIME

The principle that the motor control system needs preparation before it can initiate an action has its roots in research carried out in the middle of the nineteenth century by Donders (1868–1969), a Dutch physician. This principle is derived from an inference based on the effects of various factors on differences in the amount of time between the onset of a signal telling a person to begin performing a skill and the instant experimenters actually observe the beginning of movement. As you read in chapter 2, we call this interval of time *reaction time (RT).* When considered in the context of action preparation, *RT is an index of preparation* required to produce an action.[1] You may sometimes see this interval of time called as *response-delay* interval. By investigating the factors that increase or decrease this time interval and the mental activities that occur during this interval, we can gain some understanding of the action preparation processes our motor control system engages in to enable us to perform a skill.

One of the things that RT tells us is that preparing to produce voluntary movement takes time. Planned movement does not occur instantaneously. Certain actions and circumstances require more preparation than others. In the following sections, we discuss a variety of factors that influence the amount and type of preparation needed.

TASK AND SITUATION CHARACTERISTICS INFLUENCING PREPARATION

One set of factors that influence action preparation includes characteristics of both the task itself and the situation in which it must be performed.

The Number of Response Choices

An important characteristic of task and performance situations that influences preparation time is the number of response alternatives the performer has to choose from. *As the number of alternatives increases, the amount of time required to prepare the appropriate movement increases.* The easiest way to demonstrate this relationship is by looking at the choice-RT situation you were introduced to in chapter 2. RT increases according to the number of stimulus or response choices. The fastest RTs occur in simple-RT situations, which involve no choices because they have only one stimulus and one response. RT slows down when more than one stimulus and more than one response are possible, as in the choice-RT situation.

The relationship between the amount of RT increase and the number of response choices is so stable that a law, known as Hick's law, was developed that predicts a person's RT when his or her simple RT and the number of choices are known.

[1]When RT is used as an index of action preparation, it is sometimes used to determine the amount of time required for "motor programming," which we discussed in chapter 5.

A CLOSER LOOK

A Historical Look at Donders' Use of Reaction Time to Study Action Preparation

The study of reaction time (RT) as an indicator of mental operations has a history that can be traced back to the middle of the nineteenth century. Scientists were becoming interested in determining the basic elements of thought. The investigation of RT provided a useful means of investigating this question because it represented the time interval between the detection of a stimulus and the initiation of a response to it. Dr. F. C. Donders, a Dutch physician, hypothesized that specific mental operations occur in a specific series of stages during the RT interval and was certain that he could identify each stage. He initiated research that was published in 1868 (Donders, 1868–1969) and continues to influence researchers today. To test his hypothesis, he set up three different "methods" for performing reaction-time tasks.

- *Simple reaction-time task* (Donders called this the *a* method): The participant pressed a telegraph-type key as soon as possible when a light illuminated.
- *Choice reaction-time task* (Donders called this the *b* method): The participant pressed a telegraph-type key as soon as possible with the right hand when the right light illuminated and with the left hand when the left light illuminated.
- *Discrimination reaction-time task* (Donders called this the *c* method): The participant pressed a telegraph-type key as soon as possible when a light of specified color illuminated, but not when any other light illuminated (e.g., respond to the red light, but not to the green light).

Donders reasoned that the RTs for the three tasks would be different because of the different "mental operations" involved in identifying the stimulus and selecting the appropriate response for each task. He developed the following subtraction method to determine the speed of each of the two mental operation stages:

- RT for the *c* task − RT for the *a* task = Amount of time for the *stimulus discrimination* stage
- RT for the *b* task − RT for the *c* task = Amount of time for the *response selection* stage

The simple-RT task provided the baseline RT because it involved only stimulus identification and the selection of one response, whereas the choice- and discrimination-reaction time tasks required the discrimination of different stimuli and the selection of one response from more than one possible response.

Unfortunately, few researchers followed Donders' lead with any degree of effort until after World War II, when in 1952 Hick reported his work concerning the systematic influence of the number of stimulus-response alternatives on RT (which is discussed in this chapter). Since that time, the study of reaction time as a means of understanding the action preparation process, which is now a part of the area of study referred to as *mental chronometry,* has generated a substantial amount of research (for reviews of this research, see Medina, Wong, Díaz, & Colonius, 2015 and Meyer et al., 1988).

Hick's law (Hick, 1952), which is sometimes referred to as the Hick-Hyman law, states that RT will increase logarithmically as the number of stimulus-response choices increases. This means that when we calculate the logarithm of the number of choices in a choice-RT situation and plot the resulting RT on a graph, RT increases linearly as the number of choices increases. The equation that describes this law is Choice RT = k [$\log_2 (N + 1)$], where k is a constant (which is simple RT in most cases) and N equals the number of possible choices. Figure 8.1 illustrates the results of using Hick's equation to predict the choice RTs for one to eight choices, beginning with a simple RT of 200 msec (i.e., one choice; therefore the k in the equation = 200).

The important component of Hick's law is the $\log_2$ function, which you saw previously in chapter 7 in the discussion of Fitts' law. This function is important because it designates that the RT increase is due to the information transmitted by the possible

action preparation the activity that occurs between the intention to perform an action and the initiation of that action; sometimes, the term *motor programming* is used to refer to this preparation activity.

Hick's law a law of human performance stating that RT will increase logarithmically as the number of stimulus-response choices increases.

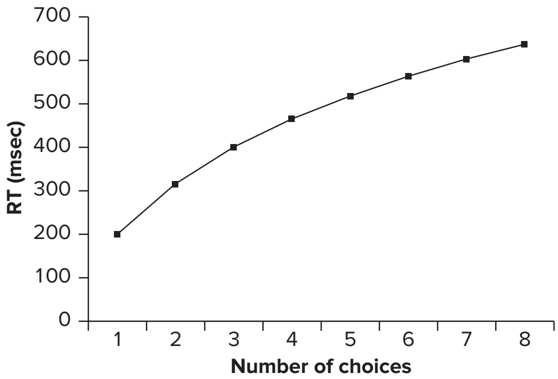

FIGURE 8.1 Predicted reaction times (RTs), according to Hick's law, for one through eight choice-RT situations, based on a simple (i.e., one choice) RT of 200 msec.

choices, rather than to the actual number of choice alternatives. In information theory, *log_2 specifies a bit of information.* A *bit,* short for *bi*nary digi*t,* is a yes/no (i.e., 1/0) choice between two alternatives. In a 1-bit decision, there are two alternatives; there are four alternatives in a 2-bit decision; a 3-bit decision involves eight choices; and so on. The number of bits indicates the smallest number of "yes/no" decisions needed to solve the problem created by the number of choices involved. For example, if eight choices were possible in a situation, a person would have to answer three yes/no questions to determine the correct choice. Thus, an eight-choice situation is a 3-bit decision situation. Accordingly, Hick's law not only correctly predicts that RT increases as the number of choice alternatives increases; it also predicts the specific size of increase to expect.

The Predictability of the Correct Response Choice

If a number of possible responses exist in a performance situation and one alternative is more predictable than the others, action preparation time will be shorter than it would if all the alternatives were equally likely. Research evidence has consistently shown that *RT decreases as the predictability of one of the possible choices increases.*

An experimental procedure known as the precuing technique, popularized in the early 1980s by Rosenbaum (1980, 1983), has been commonly used to investigate this relationship. In this procedure, researchers provide participants with differing amounts of advance information about which response must be made in a choice situation. In Rosenbaum's experiments, participants had to move a hand as quickly as possible to hit a signaled target key. There were three response dimensions, all of which involved a two-choice situation: the *arm* to move (left or right); the *direction* to move (away from or toward the body); and the *extent* of the movement (short or long). Prior to the signal to move, the participants could receive advance information (i.e., the precue) specifying the correct upcoming response for none, one, two, or all three of the dimensions. The results showed that as the number of precued dimensions increased, the RT decreased. The benefit of the advance information was that participants would need to prepare only the remaining non-precued dimensions after the "go" signal.

An important finding about the effect of a precue on the time required to prepare an action is that the person must maintain his or her attention to the location of the advance information until the actual signal to move occurs. Eversheim and Bock (2002) showed in a series of experiments that when a person's attention was diverted by some other activity between the precue and the signal to move, the person lost the RT benefit of the advance information.

> **LAB LINKS**
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> Lab 8a in the Online Learning Center Lab Manual provides an opportunity for you to perform choice–reaction time tasks with characteristics that will allow you to experience how Hick's law describes the relationship between the number of choices and RT.

The Influence of the Probability of Precue Correctness

An interesting twist to the precuing situation occurs when the advance information may or may not be correct. The critical factor influencing preparation time in this situation is the *probability* of the advance information's correctness. For example, if a basketball player is defending one-on-one against a player with the ball and knows that the player must either shoot or pass the ball, the defensive player has a 50–50 chance

A CLOSER LOOK

Applying Hick's Law to a Sport Performance Situation

The reaction time of a tennis player waiting to return serve will conform to Hick's law. As the number of stimulus-response choices increases, so too will the player's reaction time. The shortest reaction time will occur if the server always serves to the same location such that the returner can always prepare the same response and doesn't have to discriminate one serve type from another. Of course, this never happens in a game. At the very least, the server will mix up the types of serve so that some go wide, some go down the line, and some go directly toward the body. The returner must prepare for all of these possibilities and select the appropriate response (forehand, backhand, defensive shot) once the serve type has been discriminated. The returner's reaction time will be considerably higher in the case where there are three types of serves to discriminate and three responses to prepare than in the case where the same serve and same response are expectable.

How does the player reduce the stimulus choices in order to reduce the decision and action preparation time? One way is to look for advance cues in the server's action, which might include the ball toss, the trunk rotation, or the arm rotation, to predict the type of serve before the ball makes contact with the server's racquet. We introduced the temporal and event occlusion techniques that researchers use to assess players' ability to pick up these types of advance cues in chapter 6, and we discuss the development of prediction skills further in chapter 9. Another strategy is to pay attention to contextual information that makes it more likely an opponent will choose one action over another. For example, the score in the match, the opponent's known tendencies (particularly on big points), and the weather can all provide clues as to what the opponent is likely to do. This is one reason professional athletes and sporting teams are increasingly employing analysts to scout their opponents before matches. Knowing in advance what your opponents are likely to do in specific situations provides you with a major advantage in responding to their actions. Of course, your opponents can also use this information to their advantage by doing the opposite of what you expect them to do! Researchers who study anticipation and decision making in sport are increasingly calling for more research into how contextual information influences these processes (e.g., Cañal-Bruland & Mann, 2015; Vernon, Farrow, & Reid, 2018).

of guessing what the offensive player will do and preparing an appropriate action. But, if the defensive player knows that when the offensive player is at that specific location on the court, he or she will pass the ball 80 percent of the time, the defensive player will in all likelihood begin to prepare to defend against the player passing the ball. In this situation, the advance information (i.e., the precue) provides the defensive player with an option that is better than 50–50. As a result, especially with only a 20 percent chance of making the wrong choice, the defensive player would probably *bias* his or her action preparation to defend against the player passing the ball.

What advantage would the defensive player gain by biasing his or her preparation in this way? Would it be possible that this preparation bias might be a disadvantage? The answers to these questions depend on whether the defensive player is correct or not in biasing his or her preparation. Research in laboratory settings provides evidence that shows the advantages and disadvantages that can occur in situations like this one. The best example is an experiment by Larish and Stelmach (1982), which has become the model approach to study this issue. Participants received advance information about whether the right hand or the left hand should hit the target. But this information was correct only 20 percent, 50 percent, or 80 percent of the time. The results (shown in figure 8.2) illustrate the **cost-benefit trade-off**

cost-benefit trade-off the cost (in terms of slower RT), and benefit (in terms of faster RT) that occur as a result of biasing the preparation of an action in favor of one of several possible actions (as opposed to preparing as if each possible action were equally probable).

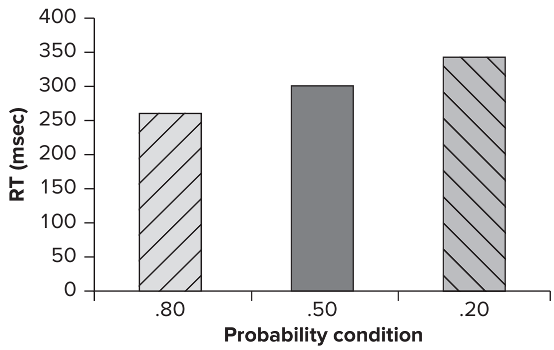


FIGURE 8.2 Results from the experiment by Larish and Stelmach showing the effects on RT of different probabilities of a precue's correctness. Notice the time advantage for the .80 probability condition compared to the time disadvantage for the .20 probability condition. *Source:* Adapted from Larish, D., & Stelmach, G. E. (1982). Preprogramming, programming, and reprogramming of aimed hand movements as a function of age. *Journal of Motor Behavior, 14*, 322–340.

associated with this situation. When there was a 50–50 chance (50 percent correct condition) of the precue's being correct, participants responded as if the task were a two-choice RT task. However, in the 80–20 condition, participants obviously biased their responses to move in the direction of the precued target. When they were correct, there was a benefit; their RTs were *faster* than if they had not biased their responses. However, when they were wrong (the 20 percent case), there was a cost: their RT was *slower* than it was in the 50–50 condition.

Stimulus-Response Compatibility

Another task characteristic that influences the movement preparation time is the physical relationship between the stimulus and response choices. The study of what is termed **stimulus-response (S-R) compatibility** has a long history that dates back to World War II (for a discussion of this history, see Proctor & Reeve, 1990, or Proctor, Vu, & Pick, 2005). This extensive study has shown consistently that *RT will be faster as the relationship between the stimulus characteristics and their required response becomes more compatible.* Conversely, RT will be slower as this relationship becomes less compatible.

Spatial relationship effects. The spatial relationship between the stimulus and response devices is the most common way of considering stimulus-response compatibility. For example, suppose a person has to push one of three keys in response to the illumination of one of three lights. If the lights and keys are arranged horizontally with the key to be pushed located under the light indicating that response, then the situation is more compatible than if the lights are vertical and the buttons are horizontal. A more compatible relationship would lead to faster RTs (and fewer errors) than a less compatible situation.

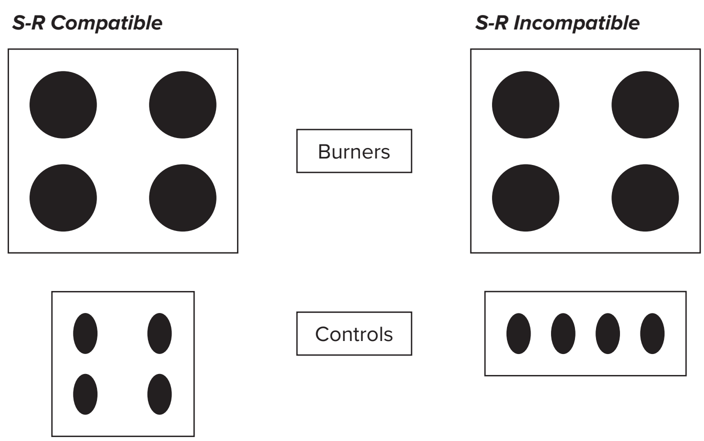
The Stroop effect. A different type of S-R compatibility situation occurs when the appearance of the stimulus suggests one type of response, but the situation requires a different response. The best example of this is the **Stroop effect**, which is a phenomenon that occurs when a person must verbally respond to the ink color of a word that names a color. This phenomenon is named after J. R. Stroop who first reported it (Stroop, 1935). When the word name and ink color of the word are the same, RT is faster than if the word is a different color than its name. For example, if BLUE is the word, people will say "blue" faster when the ink color is blue than when the word name is RED but the ink color is blue. In terms of stimulus-response compatibility, a compatible situation exists when the ink color of a word is the same as the color it names and the person must say the ink color; but an incompatible situation exists when the word is written in a color that is different from the one it names and the person must say the ink color.

Why does S-R compatability affect RT? To account for the effect of stimulus-response compatibility on RT, Zelaznik and Franz (1990) presented evidence showing that when S-R compatibility is low, RT increases are due to *response selection* problems. On the other hand, when S-R

A CLOSER LOOK

A Stimulus-Response Compatibility Example in the Kitchen with Potential Serious Consequences

The article by Proctor, Vu, and Pick (2005) described the following example of how S-R compatibility is an important concern for the design of a kitchen appliance. The typical stovetop has four burners, usually arranged in a 2 × 2 layout of two in the front and two in the rear. However, the controls for these burners are organized in ways that vary in the degree of compatibility with the layout of the burners. The following examples illustrate two of these situations:



The selection of the correct controls is easy and fast for the high-S-R-compatible arrangement, but more difficult and slower for the S-R-incompatible arrangement. The potential for making a control selection error, with possible serious consequences, is much higher for the incompatible arrangement, especially in an emergency situation when a fast and accurate response is required.

compatibility is high, response selection processing is minimal, so that any RT changes reflect motor processes related to preparation of the selected response. Weeks and Proctor (1990) further developed this point by demonstrating that the specific response selection problem is due to translation problems involving the mapping of the stimulus locations to the response locations. Because this translation process requires additional time, RT increases.

Foreperiod Length Regularity

A part of the preparation process begins when a person detects a signal indicating that the signal to respond will occur shortly. The interval between this "warning" signal and the stimulus, or "go" signal,

stimulus-response (S-R) compatibility a characteristic of the spatial arrangement relationship between a stimulus and a response. This relationship includes the spatial arrangement of stimuli and the limb movements required to respond to them, and the physical characteristics or meaning of a stimulus and the type of response required. The degree of compatibility influences the amount of preparation time in a reaction time task involving stimulus and response choices.

Stroop effect a type of stimulus-response compatibility situation in which a color's name and ink are the same or different. RT for saying the word is faster when both are the same color than when the word is a different ink color.

Several situation and performer characteristics discussed in this chapter influence a swimmer's preparation to start a race.

Ryan McVay/Getty Images

is known as the **foreperiod**. In simple-RT situations, the regularity of the length of this interval influences RT. If the foreperiod is a constant length, that is, the same amount of time for every trial, RT will be shorter than it would be if the length of the foreperiod varies.

We can attribute the shorter RT associated with constant foreperiods to *anticipation* by the performer. Because it is a simple-RT situation, the person knows before the warning signal what response will be required. And because every trial has the same foreperiod length, he or she knows when the go signal will occur after the warning signal. As a result, the person can prepare the required action in advance of the go signal and initiate it very close to the go signal.

The starts of sprint races in track or swimming illustrate the need to implement an understanding of the effect on RT of a constant foreperiod length. If the starter of these races maintains a constant amount of time between his or her signal for the athletes to get ready and the gun or sound to start running or swimming, the athletes can anticipate the go signal and gain an unfair advantage over other athletes who did not anticipate the signal as accurately. We would expect some variation in the actual initiations of movement because people vary in terms of their capability to time the precise amounts of time typically involved in the RT foreperiods of sprint starts. Interestingly, sprinters are charged a false start if their reaction time out of the blocks is less than 100 msec. Because the processing of the sound from the starter's gun and the preparation and initiation of the start are thought to take at least 100 msec, a RT less than 100 msec is considered to have resulted from anticipation (Lee, 2011).

LAB LINKS

Lab 8b in the Online Learning Center Lab Manual provides an opportunity for you to experience the influence of movement complexity on RT by participating in an experiment that is similar to the one by Henry and Rogers (1960).

Movement Complexity

Movement complexity is typically based on the number of parts to a movement. Research evidence demonstrating the effect of movement complexity on RT was reported primarily in the 1960s through the early 1980s, beginning with the now-classic experiment by Henry and Rogers (1960). They demonstrated that for a ballistic task, which requires both fast RT and fast movement, RT increases as a function of the number of component parts of the required action. Numerous other experiments have confirmed these findings (e.g., Anson, 1982; Christina & Rose, 1985; Fischman, 1984). From a preparation-of-action perspective, these results indicate that the *complexity of the action to be performed influences the amount of time a person requires to prepare the motor control system*.

A question arose from these experiments related to whether, in fact, the key factor is the number of component parts involved in the action. Because

A CLOSER LOOK

The Classic Experiment of Henry and Rogers (1960)

Henry and Rogers (1960) hypothesized that if people prepare movements in advance, a complex movement should take longer to prepare than a simple one. In addition, the increased preparation time should be reflected in changes in reaction time (RT). To test this hypothesis, they compared three different rapid-movement situations that varied in the complexity of the movement. The least complex movement required participants to release a telegraph key as quickly as possible after a gong (movement A). The movement at the next level of complexity (movement B) required participants to release the key at the gong and move the arm forward 30 cm as rapidly as possible to grasp a tennis ball hanging from a string. The most complex movement (movement C) required participants to release the key at the gong, reach forward and strike the hanging tennis ball with the back of the hand, reverse direction and push a button, and then finally reverse direction again and grasp another tennis ball. Participants were to perform all of these movements as quickly as possible.

The results supported the hypothesis. The average RT for movement A was 165 msec; for movement B the average RT was 199 msec; and for movement C the average RT was 212 msec.

The researchers held that the cause of the increase in RT was the increase in the amount of movement-related information that had to be prepared. They proposed that the mechanism involved in this movement preparation was a motor program, similar to a computer program, that would control the details of the sequence of events required to perform the movement.

the amount of time to perform the action and the number of component parts of the action are confounded when actions of different complexity are compared, it is possible that the amount of time required may be the cause of the RT increase. To investigate which of these two factors influenced RT in the Henry and Rogers' experiment, Christina and colleagues carried out a series of experiments that provided support for the Henry and Rogers' conclusion that the number of component parts is the key in the RT increase (for a review of this research, see Christina, 1992).

Movement Accuracy

As the accuracy demands for a movement increase, the amount of preparation time required also increases. Researchers have nicely demonstrated this effect in comparisons of RTs for manual aiming tasks that differed according to the target sizes. For example, Sidaway, Sekiya, and Fairweather (1995) had people perform manual aiming tasks in which they had to hit two targets in sequence as quickly as possible. Two results showed the influence on preparation of the accuracy demands of the task. First, RT increased as target size decreased. Second, when the first target was a constant size, the dispersion of the location of hits on that target was related to the size of the second target. These results have been replicated by additional research (e.g., Fischman, Yao, & Reeve, 2000).

An important aspect of this research is that it extends our understanding of Fitts' law, which we discussed in chapter 7. Fitts' law concerns the increase in movement time associated with the accuracy demands of a movement, regardless of movement complexity. The research we have discussed here by Sidaway and others shows that the increase in accuracy demands also increases the amount of time needed to *prepare* to move. The need for additional time for action preparation in these situations is likely due to the additional preparation required for a person to constrain his or her limb to move within spatial constraints imposed by the smaller target. (See Kourtis, Sebanz, & Knoblich, 2012, for a study that shows the electrophysiological correlates of Fitts' law during action planning.)

foreperiod in a reaction time paradigm, the time interval between a warning signal and the go signal, or stimulus.

The Repetition of a Movement

A well-known characteristic of human performance is that when the performance situation requires a person to repeat the same response on the next attempt, that person's RT for the next trial will be faster than it was for the previous attempt. As the number of trials increases, the influence of the repetitions on RT lessens. Again, as in other performance situations, the decrease in preparation time is due to a reduction in the response-selection process (see Campbell & Proctor, 1993).

The Time between Different Responses to Different Signals

There are some performance situations that require a person to respond to a signal with one action and then very quickly respond to another signal with a different action. For example, when a basketball player is confronted by a defensive player in a one-on-one situation, he or she might fake a move in one direction (the first signal) before moving in the opposite direction (the second signal). Each "signal" by the offensive player requires the defensive player to initiate a movement. In this situation, *RT will be slower for the defensive player's second movement than for his or her first.*

The RT delay for the second movement is due to the **psychological refractory period (PRP)**, which can be thought of as a delay period (the term *refractory* is synonymous with *delay*) during which a person cannot select the second movement until after he or she selects and initiates the first. As such, the *PRP reflects a distinct limitation in the action preparation process.*

Figure 8.3 illustrates the PRP using the basketball one-on-one situation described earlier. The player with the ball (Player A) fakes a move to the left but then quickly moves to the right. He or she gains extra time to carry out the move to the right because of the RT delay created by the PRP that

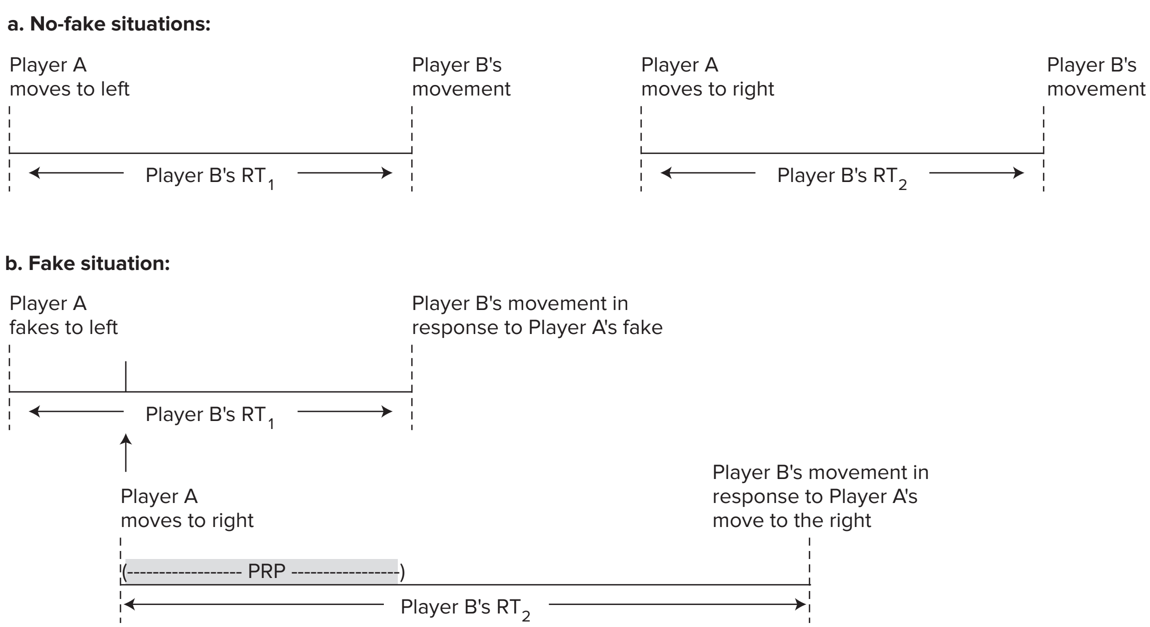


FIGURE 8.3 The psychological refractory period (PRP) illustrated in terms of the time advantage gained by an athlete for moving to the right when it follows a fake for moving to the left. (a) Player B's RT when Player A moves to the left (RT_1) or the right (RT_2), when neither is preceded by a fake in the opposite direction. (b) Player B's RT when Player A first fakes moving to the left but then moves to the right. In this situation, Player A gains extra time to carry out the move to the right because of the increased RT_2 for Player B, which results from the delay caused by the PRP.

results from Player B's initial reaction to the fake. The illustration shows that Player B's RT would be the same amount of time for Player A's move to the right if it had not been preceded by a fake move to the left. But the fake requires Player B to initiate a response to the fake before he or she can initiate a response to the move to the right.

The first evidence of the PRP was published in 1931 by Telford. Since that time, the delay has been demonstrated by numerous researchers and in a variety of settings (for a review of this research, see Lien & Proctor, 2002). Although researchers continue to seek an appropriate theoretical explanation for the PRP, there is general consensus that the delay in responding to the second stimulus is related to the *response selection* demands of the two S-R tasks that must be performed in rapid succession or to the timing of response initiation (Klapp, Maslovat, & Jagacinski, 2018). The response to the second stimulus waits for the completion of the response to the first stimulus. In fact, the PRP can be eliminated if the second stimulus occurs after the response to the first stimulus. The theoretical issue concerns why the second response must wait until the completion of the first response. We will consider this issue in chapter 9.

PERFORMER CHARACTERISTICS INFLUENCING PREPARATION

In addition to task and situation characteristics, certain characteristics of the performer also influence the process of action preparation. We should think of these characteristics as situational, because they refer to the state of the person at the time a skill must be performed. It is important to note here that these performer characteristics typically influence not only the time needed to prepare a voluntary movement but also the quality of its performance.

Alertness of the Performer

An important principle of human performance is that the alertness of the performer influences the time he or she takes to prepare a required action, as well as the quality of the action itself. In two types of performance situations, the role of alertness is especially critical. One type is the RT task, where a person does not have to wait for any length of time beyond a few seconds, but must respond to a stimulus as quickly and as accurately as possible. The other type, involving the long-term maintenance of alertness, is the task for which fast and accurate responding is important, but the signals to which the person must respond occur infrequently and irregularly.

For RT tasks, a way to increase the likelihood that a person is optimally alert and prepared to respond appropriately is to provide some type of *warning signal* that indicates he or she must respond within the next few seconds. Researchers demonstrated the benefit of this warning signal more than a century ago, in the early days of human performance research. In fact, there was sufficient evidence accumulated in the first half of the 1900s to conclude that RT is significantly faster when a warning signal precedes the signal to respond than when there is no warning signal (Teichner, 1954).

An important point is that after the warning signal, there is an optimal length of time for the person to develop and maintain alertness while waiting for the go signal. If the go signal occurs too soon after the warning signal, or if the person must wait too long, RT will be longer than if the go signal occurs sometime between these two points in time. These performance effects indicate that people require a minimum amount of time to develop optimal alertness and that we can maintain that level of alertness for a limited amount of time.

As you can see in figure 8.4, there is an optimal time range during which the go signal should occur following the warning signal. The exact amounts of time to insert in this figure will depend on the skill and situation. However, for simple-RT situations, a reasonable guideline is this: *The optimal foreperiod length should range between 1 and 4 sec.*

psychological refractory period (PRP) a delay period during which a person seems to put planned action "on hold" while executing a previously initiated action.

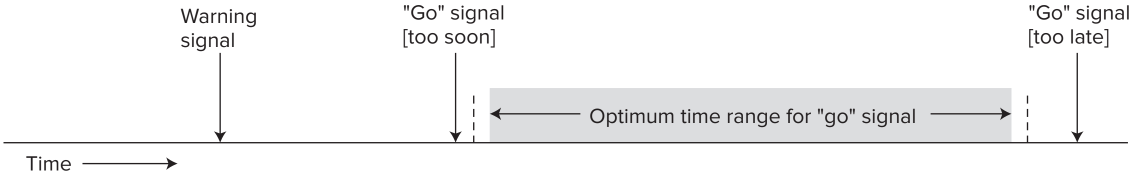


FIGURE 8.4 An illustration of the warning signal to "go" signal time relationship necessary to ensure optimal readiness to respond in a reaction time situation. The actual amounts of time for these events depend on the task and situation in which they are performed.

Vigilance. The long-term maintenance of alertness is known as **vigilance**. In vigilance situations, an individual must perform an appropriate action when he or she detects a signal to act. The problem is that *signals occur very infrequently and irregularly.* There are many vigilance situations in motor skill performance contexts. In sports, a situation involving vigilance occurs when baseball outfielders must maintain alertness throughout an inning in the field despite having only one ball hit their way, out of the many pitches thrown. In industry, workers who must detect and remove defective products from the assembly line will see many products move past them for long periods of time, but only a few will be defective. Similarly, driving a car or track along an uncrowded freeway is a vigilance task when a person drives for an extended time. Lifeguarding at a pool or beach can be a vigilance problem because situations requiring a response are very infrequent during a long shift on duty. Medical personnel often are required to work long hours and still be able to identify symptoms of health problems correctly and perform surgical techniques requiring precise motor control.

In each of these situations, RT increases as a function of the amount of time the person must maintain alertness to detect certain signals. Detection errors increase as well. Scientists first reported this phenomenon during World War II (see Mackworth, 1956). In experiments investigating the detection of signals simulating those observed on a radar screen, results showed that both the RT to a signal and the accuracy of detecting signals deteriorated markedly with each half hour during a two-hour work interval.

Although performance in vigilance situations deteriorates the longer a person needs to remain attentive to the possibility of needing to detect a signal and make a response, lack of sufficient sleep makes vigilance performance even worse. Research has consistently demonstrated that sleep deprivation (i.e., lack of sleep for extended periods of time), insufficient sleep (i.e., sleeping for fewer hours at night than needed), and sleep disruption negatively impact a person's performance in vigilance situations (see for example, Dinges et al., 1997; Drummond et al., 2005). There is general agreement that the best way to overcome sleep-related performance problems is to sleep. However, this option is not always possible, which has led researchers to investigate various stimulants as alternative ways to provide short-term enhancement of performance (e.g., Magill et al., 2003; Wesensten, Killgore, & Balkin, 2005).

Eason, Beardshall, and Jaffee (1965) nicely demonstrated that alertness deterioration contributes to the performance decrements associated with long-term vigilance. They provided physiological evidence consistent with decreases in vigilance performance over one-hour sessions. Skin conductance in participants decreased, indicating increased calming and drowsiness over the session. In addition, participants' neck tension steadily increased, as their nervous systems attempted to compensate by increasing muscle activity in the neck.

Attention Focused on the Signal versus the Movement

Many motor skills, such as sprints in track and swimming, require a person to move as fast as possible when the signal to move occurs. In these situations, there are two important components, the RT and the movement time (MT). To prepare to initiate his or her movement, the person can focus

A CLOSER LOOK

Vigilance Problems Resulting from Closed-Head Injury

Closed-head injury involves brain damage and often results from an auto accident or a fall. Numerous cognitive and motor problems can accompany this type of injury, depending on the area of the brain that is damaged. Included in the problems associated with closed-head injury is difficulty sustaining attention over a period of time in vigilance situations.

Loken et al. (1995) provided evidence for this difficulty by comparing patients with severe closed-head injuries to non-brain-injured people. All participants observed on a computer screen sets of two, four, or eight small blue circles (1.5 mm diameter). On some trials, one of the circles was solid blue (this occurred on only 60 percent of the 200 trials). When participants detected the solid blue circle, they were to hit a specified keyboard key. The set of trials lasted 20 min, with only 2 to 5 sec between trials.

The authors pointed out that the following results were most noteworthy because they added to previous knowledge of vigilance problems related to closed-head injury. *In contrast to the non-brain-injured participants,* the patients showed that their:

1. **overall vigilance performance** was differentially affected by the complexity of the stimulus array on the computer screen (i.e., detection performance decreased as the set size of circles increased)
2. **detection time latency** (RT) increased as a function of the length of time engaged in performing the task (i.e., the amount of time taken to detect a solid blue circle increased linearly across the 200 trials)

on the signal itself (a *sensory set*) or on the movement required (a *motor set*). Research evidence, first provided by Franklin Henry (1960), indicates that which of the two components the performer consciously focuses attention on influences RT.

However, because Henry's results were based on the participants' opinions of what their sets were, Christina (1973) imposed on each participant either a sensory or a motor set to initiate a fast arm movement. The sensory-set group was told to focus attention on the sound of the go signal, a buzzer, but to move off the response key as fast as possible. The motor-set group was told to focus on moving as quickly as possible. Results showed that the sensory-set group had an RT 20 msec faster than that of the motor-set group. Interestingly, MT was not statistically different for the two groups. Thus, participants' focusing of attention on the signal and allowing the movement to happen naturally shortened the preparation time required and did not penalize movement speed, yielding a faster overall response time.

Jongsma, Elliott, and Lee (1987) replicated these laboratory results in a sport performance situation. They compared sensory and motor sets for a sprint start in track. To measure RT, the authors embedded a pressure-sensitive switch in the rear-foot starting block. They measured MT as the time from the release of this switch until a photoelectric light beam was broken 1.5 m from the starting line. Results showed that for both novices and experienced sprinters, RT was faster for the sensory-set condition.

WHAT OCCURS DURING PREPARATION?

On the basis of the discussion so far, you can see that the process of preparing an action is complex. It includes perceptual, cognitive, and motor components. One way to demonstrate that the preparation process includes these components is to divide an EMG recording of the RT interval into components by using a technique known as *fractionating RT,* which was introduced in chapter 2.

Evidence from Fractionating RT

As we described in chapter 2, to fractionate RT, the EMG recording taken from the agonist muscle involved in a movement is divided into two

vigilance maintaining attention in a performance situation in which stimuli requiring a response occur infrequently.

A CLOSER LOOK

A Summary of Task and Performer Characteristics that Influence the Amount of Time Required to Prepare an Action

Characteristics that *Increase* Action Preparation Time

- An increase in the number of movement alternatives
- An increase in the unpredictability of the correct movement response alternative
- Following an expectation bias toward performing one of several movement alternatives, the required movement is not the one expected
- An increase in the degree of spatial incompatibility between environmental context features and their associated movements
- An increase in the irregularity of foreperiod lengths in an RT situation
- No previous experience (i.e., practice) performing the task in the required situation
- A decrease in performer alertness
- An attention focus on the movement rather than the "go" signal

Characteristics that *Decrease* Action Preparation Time

- A decrease in the number of movement alternatives
- An increase in the predictability of the correct movement response alternative
- Following an expectation bias toward performing one of several movement alternatives, the required movement is the one expected
- An increase in the degree of spatial compatibility between environmental context features and their associated movements
- An increase in the regularity of foreperiod lengths in an RT situation
- An increase in the amount of experience (i.e., practice) performing the task in the required situation
- An appropriate level of performer alertness
- An attention focus on the "go" signal rather than the movement

distinct components (see figure 2.3). The first is the *premotor* component (sometimes referred to as electromechanical delay). The EMG signal does not change much from what it was prior to the onset of the signal. However, shortly after the onset of the signal, the EMG signal shows a rapid increase in electrical activity. This indicates that the motor neurons are firing and the muscle is preparing to contract, even though no observable movement has yet occurred. In this period of time, the *motor* component is the increased EMG activity preceding the observable movement.

The premotor and motor components of RT represent two distinct activities that occur prior to observable movement and reflect different types of movement preparation processes. The premotor component includes the perceptual or cognitive processing of the stimulus information and preparing the movement features of the required action. The motor component begins the actual motor output phase of a movement. During this time, the specific muscles involved in the action are firing and preparing to begin to produce observable movement.

By fractionating RT, we can gain insight into what occurs during the action preparation process. Researchers look at which of these RT components is influenced by the various factors we discussed earlier that influence RT. For example, Christina and Rose (1985) reported that the changes in RT due to increases in *response complexity* were reflected in increases in the premotor component. For a two-part arm movement, the premotor component increased an average of 19 msec over that for a one-part arm movement, whereas the motor component increased only 3 msec. Siegel (1986) found that RT increased linearly as *movement durations* increased from 150, through 300 and 600, to 1,200 msec, the length of the premotor component also increased linearly. The motor component, on the other hand, remained the same length until the response duration became 1,200 msec; then it showed a slight increase. Sheridan (1984) showed that the premotor component was also responsible for RT increases due to increases in *movement velocity*. However, Carlton, Carlton, and Newell (1987) found changes in both the premotor and motor components by altering *force-related characteristics* of the response. Similar changes in both premotor and motor components were reported by Davranche, Burle, Audiffren, and Hasbroucq (2005) in their investigation of the basis for the improvement in choice-RT performance that occurs while *performing a submaximal exercise*.

Postural Preparation

This postural preparation process is commonly referred to as *anticipatory postural adjustments.* The term "anticipatory" indicates that prior to the execution of an intended action or movement, there are additional muscles that activate, a process that occurs nonconsciously. Researchers typically use EMG recordings to investigate these muscular activities. The demonstration of anticipatory postural adjustments presents further support for the complexity and sophistication of the motor control system. Although numerous experiments have been reported that provide evidence for the postural preparation activities that precede the initiation of an intended action, we will consider only a few examples. These examples include actions that involve simple and complex limb movements as well as whole-body movements. These research examples show us that all of the actions we perform, even those involving the simplest of movements, require a complex synergistic system of muscles to work together.

Weeks and Wallace (1992) asked people to perform an elbow-flexion aiming movement in the horizontal plane while standing in an erect posture. Participants learned to make this movement in three different velocities defined by criterion movement times. The authors made EMG recordings from various muscles of both legs and the responding arm. The results showed that a specific sequence of supporting postural events occurred. For each movement velocity, the muscles of the contralateral and ipsilateral legs (biceps femoris and rectus femoris) activated *prior to* the onset of the arm agonist muscles (biceps brachii). And as the arm velocity increased, the onset of the anticipatory postural muscle activity occurred at an earlier time prior to arm agonist muscle activation. The authors also found different onset orders for the various postural muscles.

More recently, Bonnetblanc, Martin, and Teasdale (2004) found that for an arm-pointing movement at different-sized targets (5, 10, and 25 cm wide) while standing, leg muscles not only activated before the arm began to move (similar to what Weeks and Wallace found), but the amount of activation of specific muscles also varied according to the size of the target. For example, as target size decreased, EMG activity increased in the erector spinae but decreased in the tibialis anterior and the rectus femoris of the quadriceps. When considered in relation to Fitts' law, which we discussed in chapter 7, these results suggest that the relationship between movement time and movement accuracy demands has a basis in the preparation of the movements. In addition, these results provide evidence of muscle preparation differences associated with the relationship between RT and movement accuracy as reported by Sidaway and others, which we considered earlier in this chapter.

Postural preparation effects have also been shown for leg movements. For example, in a study by Mercer and Sahrmann (1999), people of three age groups (8–12, 25–35, and 65–73 years), who had no neuromuscular impairments, performed two types of stair-stepping movements: stepping onto a stair step with one foot (the "place task") and stepping onto a stair step with one foot and then putting the other foot on the step (the "step task"). The experimenters analyzed EMG recordings from four muscles of the stance leg (tibialis anterior, gastrocnemius-soleus, hamstring, and gluteus maximus) and two muscles of the moving leg (rectus femoris and gluteus maximus). When the experimenters analyzed the EMG results in terms of the onset (i.e., activation) times for each muscle for all participants, they found that the tibialis anterior (TA) of the stance leg was the first muscle to activate. On average, it activated 215 msec *before* the initiation of movement by the opposite leg for the stepping task and 307 msec *before* movement initiation for the place tasks. This initial activation of the TA in the stance leg ensured postural stability when the opposite leg stepped forward. Another

A CLOSER LOOK

Anticipatory Postural Adjustments in Hemiparetic Stroke Patients Compared to Healthy Adults

Following a stroke, people commonly experience paralysis on one side of the body (i.e., hemiparesis). One of the motor control characteristics influenced by hemiparesis is the impairment of the anticipatory postural adjustments of the trunk and limbs prior to an intended movement of either a paretic (i.e., paralyzed) or nonparetic limb. A study by Dickstein, Shefi, Marcovitz, and Villa (2004) provided some insight into this problem by investigating the anticipatory postural adjustment characteristics of specific trunk muscles for arm and hip flexion movements.

Participants: 50 hemiparetic men and women (mean age = 72 years) who had experienced a stroke approximately one month prior to the study. The stroke in all patients involved the middle cerebral artery. Some had left hemiparesis and some had right hemiparesis. In addition, 30 healthy men and women (mean age = 71 years) were involved as a healthy control group.

Tasks: Flexion (as fast as possible) of (1) *paretic arm* of the patients and left arm of the controls; (2) *nonparetic arm* of the patients and right arm of the controls; (3) *paretic hip* of the patients and left hip of the controls; (4) *nonparetic hip* of the patients and right hip of the controls

EMG recording: *Posterior trunk (back muscles):* bilateral lumbar erector spinae and latissimus dorsi muscles; *anterior trunk (abdominal muscles):* bilateral rectus abdominis and external oblique muscles; *arm flexors:* anterior deltoid and biceps brachii muscles; *hip flexors:* rectus femoris muscles

Results:

Task: ***Paretic and left arm flexion***

Stroke patients & healthy controls	1. Activation of contralateral back muscles prior to ipsilateral back muscles 2. Activation of erector spinae muscles prior to arm flexor muscles
Stroke patients	Longer delay for onset of activation of ipsilateral back muscles

Task: ***Nonparetic and right arm flexion***

Stroke patients & healthy controls	1. Activation of contralateral back muscles prior to ipsilateral back muscles 2. Activation of both back muscles prior to arm flexors
Stroke patients	Longer delay for onset of activation of ipsilateral erector spinae muscle

Task: ***Paretic and left hip flexion***

Stroke patients & healthy controls	Concurrent activation of contralateral and ipsilateral abdominal muscles
Stroke patients	Longer delay for onset of activation of abdominal muscles

Task: ***Nonparetic and right hip flexion***

Stroke patients & healthy controls	1. Concurrent activation of contralateral and ipsilateral rectus abdominis muscles 2. Activation of contralateral external oblique muscles prior to ipsilateral external oblique muscles
Stroke patients	Longer delay for onset of activation of abdominal muscle

Conclusions: The longer delay for the onset of back and abdominal muscles indicates that the anticipatory postural adjustment activity of these muscles is impaired in hemiparetic poststroke patients. The implication of these results for physical rehabilitation is that treatments should include the enhancement of activation levels of these trunk muscles on the paretic side of the body, with special consideration given to the latissimus dorsi, external oblique, and rectus abdominis muscles.

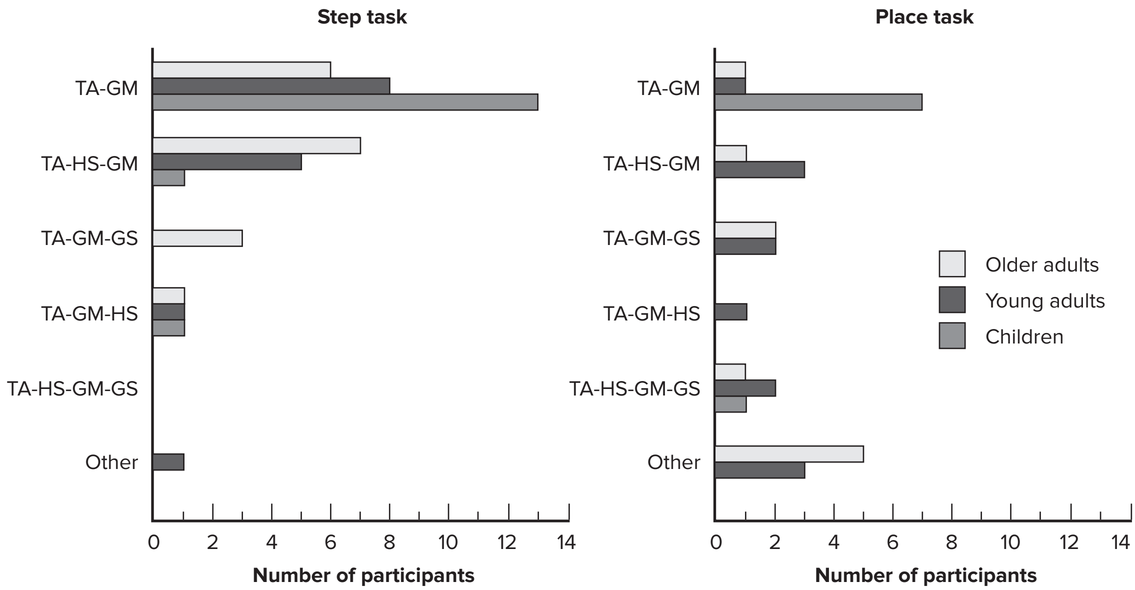


FIGURE 8.5 Results of the experiment by Mercer and Sahrmann (1999) showing the number of children, young adults, and older adults who exhibited specific "preferred" sequences of muscle activation for the stance leg for the place and step tasks. Each sequence indicates the order of activation for the muscles listed (TA = tibialis anterior, GM = gluteus maximus, HS = hamstring, GS = gastrocnemius-soleus). *Source:* Figure 4, p. 1149 in Mercer, V. S., & Sahrmann, S. A. (1999). Postural synergies associated with a stepping task. *Physical Therapy, 79,* 1142–1152.

important result of this experiment is the variety of muscle activation sequences demonstrated by each participant and across the participants for each task. Figure 8.5 shows the specific muscle activation sequences exhibited for the two tasks and the number of participants in each age group who displayed each sequence on at least 75 percent of the trials (which the experimenters referred to as representative of a "preferred" sequence). These results demonstrate that no specific sequence of muscle activation characterized all or any one of the participants for either task.

Finally, would you expect anticipatory postural adjustments to precede a simple movement like tapping your index finger on a tabletop while sitting in a chair? Two researchers in Italy (Caronni & Cavallari, 2009) reported that prior to the activation of the prime mover muscles for this tapping activity (i.e., the flexor digitorum superficialis) several upper-limb and upper-back muscles activated in specific sequences that served to stabilize the upper limb during the finger tapping movements.

The sequences of muscle activation reported in these experiments demonstrate that the preparation of postural stability is an important part of action preparation. The experiments show that *postural preparation involves organizing a flexibly organized synergy* of muscles. This conclusion is important because movement scientists traditionally have assumed that postural muscle preparation is rigidly temporally organized. The advantage of the flexibly organized synergy is that anticipatory postural activity can occur according to the person's equilibrium needs for specific situations.

Preparation of Limb Movement Characteristics

An essential part of the action preparation process is selecting and organizing the specific movement characteristics of the limbs to perform according

A CLOSER LOOK

Achieving a Standing Posture from Various Sitting Postures: An Example of How Functional Demands Affect Action Preparation

Changing from a sitting posture to a standing posture (referred to as a sit-to-stand action) is a common everyday activity that provides a good example of how the motor control system adapts to allow the same action to occur from a variety of initial postural positions. Shepherd and Gentile (1994) presented evidence of this adaptability by having healthy adults sit in different postures on a chair (an erect trunk, a fully flexed trunk, and a partially flexed trunk, i.e., flexed between the fully flexed and erect positions), and then stand. Analyses of the various joint movements involved in this action showed this:

- *In the erect and partially flexed sitting postures:* The knee began to extend before the hip joint began to extend.
- *In the fully flexed sitting posture:* the hip joint began to extend before the knee began to extend.

These different initiation patterns of joint movements illustrate how functional demands influence the order of muscle activation in preparing an action. Because different sitting postures will require different support, propulsion, and balance characteristics during the sit-to-stand action, the order of the initiation of movement of the knee or hip joints is a critical factor in enabling a person to carry out the intended action without losing balance.

to the dictates of task constraints and characteristics. Because an individual often can perform the same action using several different limbs or different segments of the same limb, he or she must specify and prepare the limb or limb segments to be involved in performing a given task.

One feature of limb movement a person must prepare is the *direction* or directions in which the limbs must move. For a very rapid movement, a person may prepare several different directions before initiating the movement. Another feature related to direction preparation is the *trajectory* the limb will follow during movement. For a task requiring a ballistic movement and spatial accuracy, an individual must prepare in advance, constraining the limb movement to meet the accuracy constraints of the task. In addition, as we discussed in chapter 7, a person catching a ball must prepare his or her hand and finger movements before the oncoming ball reaches him or her.

Preparation of Movements for Object Control

When the action to be performed involves manipulating an object, a part of the preparation process involves specifying certain movement features needed to control the object. The following are two of those features involved in this aspect of movement preparation.

Force control. An important movement feature prepared prior to manipulating an object is setting the amount of force required to lift or move the object. As an illustration of this type of preparation, think about situations in which you have looked at an object and, because of certain characteristics, judged it to be heavy. But when you began to lift it, you discovered it was light. Undoubtedly, you lifted the object much more quickly and higher in the air than you had intended. Why did you respond in this way? The reason is that because of certain observable characteristics of the object, such as a beverage can that looks unopened although it is actually empty, you anticipated that a certain amount of muscular force would be required to lift the object. This anticipated amount of force was used to prepare the musculature for the lifting action.

Researchers have used this common everyday experience to provide evidence that the movement force characteristics are prepared in advance of the manipulation of objects. For example, Butler

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Performance Expectations as Part of Action Preparation

Often overlooked in the study of motor learning and control is the role of motivation to perform a skill. A motivational variable known as *performance expectancies,* which refers to a performer's expectations of how he or she will perform a skill, is particularly relevant to the action preparation process. A study by Stoate, Wulf, and Lewthwaite (2012) presents a notable example of the influence of a performer's expectancies on the person's quality of performance, with particular emphasis on the efficiency of that performance (with the term *efficiency* referring to the amount of energy used to perform a skill, i.e., lower energy use indicates higher efficiency). In addition to presenting an experiment designed to test their performance expectancy effect hypothesis, the authors also provide an excellent review of research describing the motivational effects of various forms of influencing expectancies for both novice and skilled performers. It is important to note here that this same performance expectancy phenomenon was discussed as an essential part of the OPTIMAL theory of motor learning, which we discussed in chapter 5.

The "Performance Expectancy Effect" Hypothesis

Because a performer's expectancies about an upcoming performance will influence the outcome of that performance, variables that influence those expectancies will affect the quality of the performance, especially in terms of movement efficiency.

The Experiment

Participants: Male and female members of a running club (average age of 26 years), who had been running close to 50 km per week for an average of 8 years.

Task and Procedures: Participants ran on a treadmill on two days. The first day involved establishing their baseline performance characteristics engaging them in a standard graded exercise test for a maximum of 20 min. On the second day participants ran for 20 min on the treadmill at a speed equivalent to 75 percent of their maximum oxygen consumption, which had been determined on day 1. Prior to and after the day 2 running session, participants were given questionnaires asking them to rate the ease of their running.

Two groups were formed on day 2. After running for 10 min, the *Enhanced Expectancy* group received feedback about their oxygen consumption every 2 min for the duration of their run. They were told that their oxygen consumption was in the top 10 percentile for their age and gender. The *Control* group was not given any feedback about their oxygen consumption while they ran.

Performance Evaluation: Oxygen consumption, heart rate, and perceived exertion were measured for all participants.

Results: The primary result was that oxygen consumption rates were comparable between the two groups for the first 10 min but then systematically decreased for the Enhanced Expectancy group for the remainder of the 20-min running session. No change in oxygen consumption rate occurred for the Control group.

Conclusion

Movement efficiency can be influenced by performance expectancies that are associated with information that persuades the performer that he or she has an efficient technique. As a result, these expectancies become part of the action preparation process.

et al. (1993) showed that when men did not know the weight of a box that looked like it was filled with heavy objects, they performed with a jerking motion. Movement kinematics of these lifts showed that velocities at the shoulders and knees were much higher than the velocities when the men knew the actual weight of the box. In a similar type of study, researchers in The Netherlands (van der Burgh, van Dieën, & Toussaint, 2000) found that when healthy male participants were asked to pick up and lift a box as quickly as possible, an unexpected increase of 5 or 10 kg of weight resulted in their initially activating low-back muscles similar to when they had lifted the lighter, no-added-weight box, which indicated that no force control adjustment was made prior to the initial lift of the box with the increased weight. Supporting this point was the finding that just prior to the grasp and initial lift of the box, muscle activity didn't differ for the increased and no-added-weight boxes, which indicated similar force control preparation activity.

Another example of the preparation of force control can be seen in handwriting. To prepare to write with a pen, a person needs to specify the amount of grip force on the pen as well as the amount of pressure to apply on the writing surface. Research (e.g., Wann & Nimmo-Smith, 1991) has shown that experienced writers adjust the amount of pen pressure on the writing surface according to the characteristics of the surface to allow energy-efficient, continuous, fluent motion. In contrast, children with handwriting problems often grip the pen with excessive force and use excessive pen pressure on the writing surface.

End-state comfort control. When you reach to grasp an object that you plan to do something with, how do you position your hand to grasp the object? According to an increasing amount of research, we grasp objects based on what we plan to do with them. This means that when we grasp the object our hand position is based on the position that will feel the most comfortable to complete the action—do what we intended to do with the object. For example, if you want to pick up a cup that is upside down on a table so that you can fill the cup with water, you will probably pick up the cup with the grip that will be most comfortable when you place the cup upright in order to fill it, even if this grip feels rather awkward when you initially grasp the cup.

The typically spontaneous grasp position based on the final position of the hand when the object is used in its intended way is a phenomenon known as the end-state *comfort effect.* Stated simply, this effect is "the tendency to take hold of an object in an awkward posture to permit a more comfortable, or more easily controlled, final posture once the object is brought to its target position" (Zhang & Rosenbaum, 2008, p. 383). The significance of the end-state comfort effect is that it demonstrates an important feature of object control that is part of the action preparation process. This feature involves the planning of the final hand posture that will be the most comfortable or easiest to control. Several studies have reported support for this effect since it was first reported by Rosenbaum and Jorgenson (1992) (for reviews of this research, see Fischman, Stodden, & Lehman, 2003; Rosenbaum, Cohen, Meulenbroek, & Vaughan, 2006). Results from a series of experiments by Cohen and Rosenbaum (2004) indicate that the preparation of hand posture in this way demonstrates that the preparation process for prehension actions involves planning that is based on the generation of a new plan or the recall of an action that was successfully used in similar situations in the past.

Of the several hypotheses proposed to explain the end-state comfort effect, one that continues to gain support is the precision hypothesis (e.g., Herbort & Kunde, 2019; Rosenbaum, van Heutgen, & Caldwell, 1996; Short & Cauraugh, 1999). This explanation proposes that precision in limb positioning will be greater, the movement will be faster, and control over the object will be better when a person's limb is in a comfortable position. Thus, to ensure a faster and more accurate final limb and object position, a person prepares movement characteristics according to the comfort of the final rather than the starting position of the limb. Although this strategy may require some awkward hand and arm postures when picking up an object, it enables the person to more effectively and efficiently achieve the object manipulation goal. Interestingly, people will choose their non-dominant hand over their dominant hand to perform a task if the end-state comfort will be higher for their non-dominant hand (Coelho, Studenka, & Rosenbaum, 2014).

Preparation of Sequences of Movements

Playing the piano, typing on a keyboard, and speaking are examples of skills that involve the sequencing of series of movements. Two types of research evidence indicate that short sequences of these movements are prepared in advance of the initial movement. One is the systematic increase in RT as movement complexity increases, which we discussed earlier in this chapter. The other evidence is that the kinematic characteristics of hand and

Playing the piano is an example of a skill that involves the preparation of sequences of movements.

Kim Steele/Getty Images

finger movements during typing and piano playing and the lips, tongue, and jaw during speaking are modified by what elements in the sequence of movements come before or after them. (e.g., Engel, Flanders, & Soechting, 1997; Soechting & Flanders, 1992). For example, in the Engel et al. study, skilled pianists played short excerpts from three piano pieces that each contained two phrases. The first few notes were played identically with the right hand, but after that point the notes were played differently. In one piece, the first four notes ascended and the next two notes descended. Pianists typically play the first note in this phrase with the thumb, the next note with the index finger, and continue until the fourth note is played with the ring finger. As the phrase descends, the pianists use the same fingers in reverse order. In a second version of the phrase, the first four notes ascended, as before, but the next two notes continued to ascend. Pianists will now reposition the hand after the third note so that the fourth note is played with the thumb and the remaining two notes are played with the index finger followed by the middle finger. Two aspects of the results provided evidence for movement preparation in advance. First, the high consistency of the timing of key depresses and releases and the hand and finger kinematics within each pianist suggested advance preparation. Second, the timings and movement kinematics of the phrase that descended were different from those when the phrase continued to ascend and the differences were apparent from as early as the second note onward. So, even though the first three notes were identical and were played with the same fingers, their timings and kinematics were modified for the second variation of the phrase in anticipation of repositioning the hand so that the fourth note could be played with the thumb. In other words, the first few notes of the two phrases were prepared in distinct ways even though these notes were identical and were played with the same fingers.

In light of these sequential movement preparation characteristics, it's worth noting that slower performance is not always due only to preparation processes. For example, a common characteristic of people with Parkinson's disease (PD) is moving slowly when performing a movement sequence. In a study by Smiley-Oyen, Kerr, and Lowry (2007), an analysis of adults with PD performing sequential manual aiming movements to 1, 3, 5, and 7 targets showed that the slow movement speed (i.e., bradykinesia) was due to both movement planning and execution strategies.

Rhythmicity Preparation

Many skills require that the component movements follow specific rhythmic patterns. We can see this characteristic in any of the various types of gait, performance of a dance sequence, shooting of a free throw in basketball, and so on. In some of these activities, the participant can take time before performing it to engage in some preperformance activities that are commonly referred to as rituals. Interestingly, rhythmic patterns also characterize preperformance rituals and appear to influence performance. Although this relationship has not been widely studied, the few research studies investigating it have consistently shown a positive correlation between the rhythm of the preperformance routine and the success of the performance itself (e.g., Jackson, 2003; Southard & Amos, 1996; Southard & Miracle, 1993; Wrisberg & Pein, 1992). In terms of the preparation of action, the preperformance rituals

TABLE 8.1 Types of Behaviors Involved in Preperformance Rituals in Activities Investigated by Southard and Amos (1996)

Activity	Behaviors in Preperformance Rituals
Golf putt	1. Swinging the putter back and forth without contacting the ball 2. Pause; no movement for 1 sec or more 3. Moving the toes or either foot up and down 4. Swaying the body back and forth without swinging the putter 5. Lifting the putter vertically
Tennis serve	1. Bouncing the ball with the racquet or the hand not holding the racquet 2. Pause; no movement for 1 sec or more 3. Moving the racquet forward to a position in front of the body waist high 4. Moving the racquet back from the front of the body and then forward again 5. Moving the racquet to a ready position in order to initiate serving the ball
Basketball free throw	1. Bouncing the ball 2. Pause, no movement for 1 sec or more 3. Bending at the knees or waist 4. Moving the ball upward with the arms 5. Spinning the ball 6. Bringing the ball to an initial shooting position

Source: Table based on text and table 1 (p. 290) in Southard, D., & Amos, B. (1996). Rhythmicity and preperformance ritual: Stabilizing a flexible system. *Research Quarterly for Exercise and Sport, 67,* 288–296.

would appear to stabilize the motor control system and orient it to engaging in a rhythmic activity.

The Southard and Amos (1996) study will serve as a good example of how these researchers have determined that such a relationship exists. They video-recorded fifteen basketball free throws, golf putts, and tennis serves for experienced university men who had established rituals for each of these activities. Each video recording was analyzed to determine the preperformance behaviors each participant used on each trial. The types of behaviors for each activity are listed in table 8.1. It is important to note that although each of the behaviors was observed, individual participants did not exhibit every behavior. The researchers also analyzed the total time to perform the ritual and the relative time for each behavior in the ritual, which was the percentage of time engaged in each behavior in the ritual. Results showed a moderately high .77 correlation between the relative time for the ritual behaviors and successful performance. This relationship suggests that the consistent relative timing of preperformance ritual behaviors may be an important part of the successful performance of closed motor skills that provide an opportunity for the performer to engage in preperformance rituals.

Mack (2001) provided additional evidence that the consistent performance of the components of a preperformance routine is more important than the total amount of time taken to perform the routine. Although he did not assess the relative time of the components of a routine, he compared the influence of altering a normal routine in terms of its duration and component activities. He found essentially no influence on the free-throw shooting performance of university basketball players when they had to double the amount of time they normally took for their pre-shot routine, but a decrease in performance when they had to include some new activities in their normal routine.

In a study by Cotterill, Sanders, and Collins (2010), elite golfers in England (handicap range of 0–2) were interviewed about their preperformance routines. Two results are especially relevant to our discussion. First, the use of rhythm was commonly indicated as part of the routine. For example, one golfer stated that prior to a shot, “I then step in, and set up and one-two, I just think one-two, one-two, the words occupy my mind, while the rhythm is timed for my back swing and forward swing” (p. 56). Second, the interviews indicated not only the individual differences of the routines used, but also the consistency within the individual golfers in their use of the routines. A subsequent study showed that elite golfers had developed different routines for different types of shots (Cotterill, Collins, & Sanders, 2014).

SUMMARY

To perform a motor skill, a person prepares the motor control system just prior to performing the skill.

- The preparation process requires time, which is commonly measured by reaction time (RT); the amount of time required depends on a variety of task, situation, and personal characteristics. When used in this way, RT is an index of the preparation time needed to perform a skill.
- *Task and situation characteristics* that influence the amount of time required to prepare an action include:
  - ► the number of movement response alternatives (i.e., choices) in the situation from which the performer must choose only one; Hick’s law describes the relationship between RT and the number of choices.
  - ► the predictability of the correct movement response alternative when there are several from which to choose
  - ► the probability of precue correctness
  - ► the degree of stimulus-response compatibility
  - ► the regularity of the length of the RT foreperiod
  - ► movement complexity
  - ► movement accuracy demands
  - ► the amount of movement response repetition involved in a situation
  - ► the amount of time available between different movement responses; when the time between two responses is short, the psychological refractory period (PRP) will influence the initiation of the second response
- *Personal characteristics* that influence the amount of time required to prepare an action include:
  - ► the degree of the performer’s alertness
  - ► attention focus on the signal to move or on the movement required at the signal
- The premotor and motor components of the RT interval, which can be identified by fractionating the interval on the basis of EMG recordings from the agonist muscles, provide insight into the extent to which various preparation activities involve perceptual, cognitive, or motor processes.
- Motor control activities that occur during action preparation include:
  - ► postural organization
  - ► limb movement characteristics
  - ► object control movements
  - ► sequencing of movements
  - ► movement rhythmicity

POINTS FOR THE PRACTITIONER

- In situations in which people must make a decision about which of several alternative actions to perform:
  - ► Provide specific cues for them to use to reduce the number of “stimulus choices” in the situation on which to base the decision.
  - ► When it is possible to do so, provide specific advance information about which action will most likely need to be performed.

- When designing performance environments in which people will need to perform different movements to different stimuli, design the spatial relationship between the locations of the stimuli and their associated movements to be as spatially compatible as possible.
- If a person must perform a skill that requires him or her to initiate movement as quickly as possible to a specific "go" command:
  - Provide a warning signal, such as "get ready," before the command.
  - Allow a brief amount of time between the warning and command signals, but don't make this interval of time so long that the person will not be optimally prepared to move on the command.
- To obtain a reliable indication of how quickly a person can initiate movement to a specific command, have the person perform several successive repetitions of the activity and make the interval of time between the "get ready" and "go" signals different for each repetition.
- The degree of accuracy required by a movement will influence the amount of time a person needs to initiate the movement. Encourage the person to focus his or her movement preparation on the accuracy demands imposed by the environmental context and not on the movements that will be performed.
- When teaching an athlete to fake movements to gain an advantage over an opponent, emphasize the need to perform the fake as convincingly as possible so that the opponent initiates movement in response to the fake and then to perform the intended movement as soon as possible.
- When working with people who will perform skills in vigilance situations, provide strategies for them to take breaks from a sustained and continued maintenance of attention in the situation in which they must perform. These strategies will differ according to the demands of the situation.
- When helping people rehabilitate functional skills or activities of daily living, give attention to the postural preparation requirements of the situation in which the skills or activities will be performed. The muscles involved in the postural preparation process are as critical to the success of performing an activity as are the muscles involved in performing the activity itself.

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STUDY QUESTIONS

1. Discuss how we can use reaction time (RT) as an index of the preparation required to perform a motor skill.
2. Discuss how Hick's law is relevant to helping us understand the characteristics of factors that influence motor control preparation.
3. What is the cost-benefit trade-off involved in biasing the preparation of an action in the expectation of making one of several possible responses? Give a motor skill performance example illustrating this trade-off.
4. (a) Describe the relationship between stimulus-response (S-R) compatibility and the time needed to prepare to perform the action required. (b) Describe two examples of S-R compatible and S-R incompatible situations that you might experience.
5. Describe the Stroop task and what performance of it tells us about what we do when we prepare to perform an action.
6. Describe two performer characteristics that can influence action preparation. Discuss how these characteristics can influence preparation.
7. Select a motor skill and describe two motor control features of that skill that a person prepares prior to the initiation of performance of the skill.
8. Discuss how a preperformance routine can involve rhythmicity preparation and why this type of action preparation benefits performance of the action.

Specific Application Problem:
You are working in your chosen profession. Describe how you would take into account in helping people learn or relearn skills

(a) the anticipatory postural preparation aspects of the activities a person must perform and
(b) one other motor control characteristic that is an important part of the action preparation process.