CHAPTER 12

AUGMENTED FEEDBACK

One of the most important features of practice is the information learners receive about their attempts to produce an action. Some of this information is inherent in the movement production; we have examined this kind of sensory information in chapter 5; we can also consider information that is presented in an "augmented" form from the instructor, therapist, or coach. This chapter deals with this latter form of information.

Classifications and Definitions

Consider, as the broadest class, all the various kinds of sensory information that people can receive, including all those sources that have to do with the many diverse aspects of our lives. Of course, not all such information is related to our movements: the sound of wind in the trees as we walk through a forest is not relevant in this respect. Of the sources of information that are related to our movements, we can speak of those available (a) before the action, (b) during the action, and (c) after the action. Before the action, sensory information signals the position of your limbs, the sight of a ball flying toward you, the nature of the environmental setting, and so on. During the action, you receive sensory information produced by the movement, such as the way it feels, sounds, and looks. After the action is completed, information is available regarding the result that the movement produced in the environment (e.g., the actions of a ball that has been struck) and, for a brief time, a memory for the how the movement felt, sounded, and looked. This latter class of information is usually termed *movement-produced feedback,* or simply *feedback.* The term "feedback" can be further subdivided into two broad classes: *inherent* feedback (sometimes called "intrinsic" feedback) and *augmented* (sometimes called "extrinsic") feedback.

Inherent Feedback

People can gain information about many aspects of their own movements through various sensory mechanisms. These forms of information are *inherent* to the individual during the action, and result from the movement's execution. For example, you know that an error was made in a basketball shot because you saw that the ball did not go into the basket. Also, the stinging sensations as you land on your back in a pool after a faulty dive inform you that something probably went wrong. Just about every movement we can make has associated with it certain sources of inherent feedback that provide a basis for evaluating those movements. Such feedback is usually rich and varied, containing substantial information regarding performance. Depending on the nature of the movement and the source of inherent feedback, sometimes the performer knows that something has gone wrong before the movement is even completed. The information provided as the movement is executed is sufficiently useful that the movement outcome can often be predicted even before it occurs. At other times the nature of the movement and the source of feedback are such that the evaluation of the movement must occur after it is completed.

In many situations, inherent feedback requires almost no evaluation at all; one sees that the bat missed the ball or one can feel the fall while walking on an icy sidewalk. Thus, some errors seem to be signaled immediately and clearly. But other aspects of inherent feedback are not so easily understood, and perhaps the performer must *learn* to recognize their occurrence and evaluate what the feedback means. Examples might be the gymnast learning to sense whether or not the knees are bent during a movement, or a patient with a recent hip replacement who is learning to put partial weight through the leg while walking with canes. It is thought that inherent feedback is compared to a learned reference of correctness, with this reference acting in conjunction with the feedback in an error-detection process. Without such a reference of correctness, many forms of inherent feedback probably cannot be used to detect errors.

Augmented Feedback

In contrast to inherent feedback, *augmented feedback* is information provided about the action that is supplemental to, or that augments, the inherent feedback. For example, you can receive information from a buzzer when your car's engine exceeds a certain temperature—information that is not normally available during driving. Augmented information can be provided verbally, for example in the presentation of one's time after a 100 m race or the set of scores after a gymnastics or ice skating routine. Even though these various forms of information are not strictly verbal, they are in a form that is capable of being verbalized.

A number of useful dimensions for augmented feedback are summarized in table 12.1. First, one can distinguish between *concurrent* and *terminal* feedback. Concurrent feedback is delivered during the movement (e.g., the information about engine speed that the racing driver receives from the tachometer), while terminal feedback is postponed until after the movement has been completed (e.g., the gymnast's score). Another dimension of augmented feedback is the time at which it is delivered; it can be either *immediate* or *delayed* by some amount of time. The feedback can be verbal (or capable of being verbalized) or nonverbal (e.g., a buzzer indicating that the car's engine is too hot). Also, the performance can be sampled for a period of time, with the *accumulated* feedback indicating the average performance for the past few seconds; or the feedback can be *distinct*, representing each moment of the performance (e.g., feedback from a speedometer). (See Holding, 1965, Annett, 1969, and Singer, 1980, for additional dimensions.)

These various dimensions of augmented feedback should be considered independent of one another. For example, if the augmented feedback is terminal, it could be either verbal or nonverbal, and it might be delayed or immediate. These dimensions, then, should be thought of as separate descriptors of augmented feedback that

TABLE 12.1. Dimensions of Augmented Feedback

Concurrent: Presented during the movement	**Terminal:** Presented after the movement
Immediate: Presented immediately after the relevant action	**Delayed:** Delayed in time after the relevant action
Verbal: Presented in a form that is spoken or capable of being spoken	**Nonverbal:** Presented in a form that is not capable of being spoken
Accumulated: Feedback that represents an accumulation of past performance	**Distinct:** Feedback that represents each performance separately
Knowledge of results (KR): Verbalized (or verbalizable) postmovement information about the outcome of the movement in the environment	**Knowledge of performance (KP):** Verbalized (or verbalizable) postmovement information about the nature of the movement pattern.

define most kinds of feedback commonly used.

Knowledge of Results

One of the important categories of augmented feedback is termed *knowledge of results (KR)*. Essentially, KR is verbal (or verbalizable), terminal (i.e., postmovement) feedback about the *outcome* of the movement in terms of the environmental goal. It forms one combination of the various possible dimensions of augmented feedback (verbal-terminal) shown in table 12.1. Examples are seen when the instructor says "You were 2 m off target that time" or a computer screen presents the symbolic information "long 12" (meaning that the movement was 12 units too long). Knowledge of results can be highly specific, or it can be very general. Knowledge of results can also contain a rewarding component, such as "very good."

It is important to be clear about the use of the term KR. First, note that KR is about movement *outcome* in terms of an environmental goal ("You missed the ball"). KR is *not* feedback about the movement itself ("Your elbow was bent"). Usually this distinction is easily made; in shooting a basketball, for example, the goal and the movement to produce it are clearly separable. But often these two aspects of feedback are difficult to distinguish—for example, in a situation in which the goal of a movement *is* the form of the movement itself, as in a gymnastics move. Occasionally, other terms are used for KR as defined here, such as *information feedback* (Bilodeau, 1966), *extrinsic feedback*, or *reinforcement* (which implies a reward). Despite these inconsistencies, the tendency is to use the term KR as we have defined it here: *verbal, terminal, augmented feedback about goal achievement.* (See the review by Salmoni, Schmidt, & Walter, 1984, for additional distinctions.)

Knowledge of Performance

As already mentioned, an additional kind of feedback information concerns the *movement pattern* that the learner has made (e.g., "Your elbow was bent"). Gentile (1972) called this type of feedback *knowledge of performance (KP)* to distinguish it from KR as defined previously (see table 12.1). Knowledge of performance is probably more related to the feedback that instructors give to their students, being directed toward the correction of improper movement patterns rather than just the outcome of the movement in the environment. Also, KP can refer to aspects of the movement about which the subject is only vaguely aware, such as the behavior of a particular limb in a complex movement. And it can refer to processes in the body about which the subject is normally unaware, such as blood pressure or the activity of a particular motor unit—often referred to as *biofeedback* (Basmajian, 1989).

Research on Augmented Feedback

How do scientists conduct research to understand feedback and learning? What forms of feedback are useful in motor learning, and how are these forms of feedback most effectively presented to the learner? A major problem for such research is that, in most natural situations, it is difficult to *control* the information received by a performer, so the situation is not easy to study. For example, there are many sources of feedback in the task of shooting a basketball, and it is difficult to know which sources are being used at any one time and how they are being used. A typical strategy used by many researchers in motor behavior is to alter the environment or the task (or both) so that minimal feedback information is provided to the subject, and then provide augmented feedback information artificially (in the form of KR or KP) so that the effects can be studied directly. This technique usually involves experiments with tasks that are artificial and novel, but a basic understanding of the functioning of error information can result just the same.

Paradigms for Augmented-Feedback Research

Although many definitions exist (Kuhn, 1962), a *paradigm* often refers to a standardized way of gaining knowledge through research. The study of KR variables[1] in motor learning research was directly influenced by research in experimental psychology, and these traditions remain today (see "Origins of the KR Paradigm"). Seldom stated explicitly is the assumption that the (augmented) KR provided in these artificial learning situations is fundamentally like the (inherent) error information a person would normally receive in a more natural setting. Is it correct to say that the information "You moved 2 cm too far" in a blindfolded linear-positioning movement works fundamentally in the same way as the information received by observing visually a shot missing the basket in basketball? Certainly different processes are involved, but it is entirely possible that the use of the error information is the same in both situations, in that the information provides a basis for changing the movement on the next attempt in order to make it more accurate. If this assumption is correct, then this general method provides a way to come to an understanding of the way in which inherent feedback works to produce learning in natural environments.

The other side of the argument is that such research, using tasks that are so simple and artificial, may have little to tell us about the ways in which the rich and varied sources of inherent feedback work in more natural settings. For now, our assumption will be that the study of KR is one means to understanding the operation of inherent feedback in natural environments. However, you should remember that the principles might not be quite the same in these two situations.

The dominant paradigm for understanding the functions of feedback information in learning is a legacy from the historical influences of experimental psychology (discussed in "Origins of the KR Paradigm"). The KR paradigm frequently uses a movement task that is very simple; the most common task used in early research investigations was the linear-positioning task, for which the person must learn to move a slide or a lever to a given position, usually while blindfolded. In such tasks, the subject cannot evaluate performance outcome without some supplemental information because of the removal of the most potent source of inherent information (vision). If the instruction is to move 20 cm, the subject cannot know for certain whether a given attempt to move that distance was correct or not on the basis of inherent information. True,

Origins of the KR Paradigm

The classic learning theories of Pavlov, Watson, Thorndike, Guthrie, Tolman, Hull, and others during the first half of the 20th century established a framework for research that remains today. One of the dominant approaches was the instrumental conditioning paradigm, influenced largely by Thorndike. The main feature of this approach was the idea that if an animal's behavior was followed quite soon by reward, the behavior was elicited more frequently under these conditions in the future. In theory, an association ("bond") was formed between the situation and the behavior. The association was strengthened if the behavior was repeatedly "reinforced" (by the reward). Thus, the reward was considered instrumental to the occurrence of learning.

A key feature of the instrumental learning paradigm is the assessment of learning by means of experimental extinction—a phrase coined by Pavlov to refer to the *apparent* elimination of the learned response. Extinction is studied in the instrumental learning paradigm during a period of time when the previously rewarded behavior is no longer reinforced. Strength of the conditioned response is measured by the *resistance to extinction,* defined as the continued behavior in the absence of the reward.

The instrumental conditioning paradigm in the study of motor behavior began with Thorndike (1927). Over a period of nine practice sessions, Thorndike's subjects drew lines of 3, 4, 5, and 6 in. The first session was without KR. The next seven sessions saw performance improve steadily with KR. The last session, without KR, resulted in a marked deterioration in performance. In Thorndike's view, learning occurred through strengthening the connection between a stimulus (the movement goal) and a response to that stimulus (the movement), and KR was viewed as instrumental in strengthening that bond. The purpose of the no-KR trials was to study the "strength" of the bond via the resistance to extinction.

The rationale underlying Thorndike's line-drawing experiment was not to study the laws of motor learning, but rather to investigate the generality of his Law of Effect using a motor task. For our purposes, however, Thorndike's experiment is remembered for introducing the KR/no-KR paradigm to a later generation of researchers interested specifically in human motor learning. This influence may also be considered another one of Thorndike's legacies (cf. Adams, 1978).

the feedback from the limb is present to signal the movement details, but the individual likely does not have the reference of correctness against which to evaluate this source of inherent feedback. In some sense, the feedback has not been "calibrated" to the environment. With this kind of task, one can study the use of feedback or KR by "augmenting" information to the subject in a systematic way. The most elementary of these experiments might involve the contrast between providing KR and withholding KR altogether. A more refined experiment might manipulate the time of presentation of the KR, the way in which the KR is presented (e.g., on a computer monitor or verbally, by an experimenter), or the qualitative aspects of the KR (e.g., imprecise or precise). In this way, experiments that vary the nature of the feedback given to the learner can be done in the same ways as experiments about any other independent variable. Thus, the task used must allow control over the relative usefulness of the sources of inherent feedback.

Temporal Placement of KR

Many of the experiments on KR and motor learning are structured so that the temporal relation among the events in a trial is closely controlled. These events are shown in figure 12.1. The subject performs movement 1 (M_1); then, after a period of time called the *KR-delay interval,* the KR for that trial (KR_1) is delivered by the experimenter. The period of time from the presentation of KR until the next movement is termed the *post-KR delay,* during which it is presumed that the person is processing the KR and planning the next movement. The sum of the KR-delay and post-KR-delay intervals is termed the *intertrial interval.* Usually the intertrial interval is on the order of 10 to 20 s, but of course these intervals can be practically any length to serve the purposes of a particular experimental situation.

Learning Versus Performance Effects

In the typical KR paradigm, the variables (such as amount of KR; absolute and relative frequency; precision; length of, and activity during, the KR-delay, post-KR-delay, and intertrial intervals) are typically manipulated over a series of *acquisition* trials, just as we have discussed in chapter 11. After these trials, all the conditions of the particular KR manipulation (preferably involving separate groups of subjects) are transferred to a common condition of KR for additional performance trials. By far the most common *transfer* test is a series of no-KR (or "KR withdrawal") trials. Although other paradigms have been used, the no-KR transfer test has a long history of use in experimental psychology, upon which much of motor behavior research in this area is based (see "Origins of the KR Paradigm").

Salmoni and colleagues (1984) provided a strong argument in support of the typical paradigm, in which a KR variable is manipulated during practice trials and the effects of that manipulation are evaluated in a common, no-KR transfer test. The authors argued that the two phases of the typical KR paradigm permitted a direct comparison of the effects of a KR variable on performance and

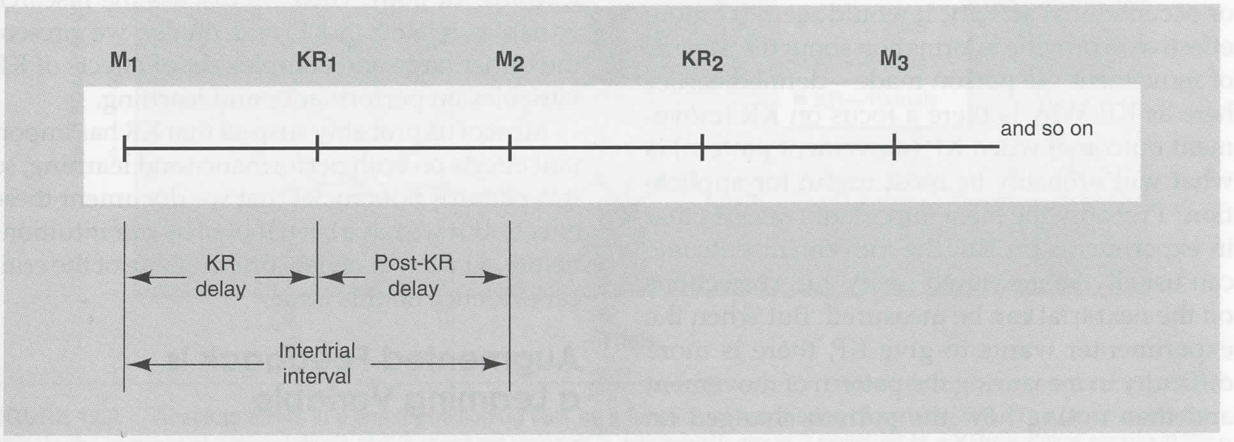

FIGURE 12.1 Temporal placement of events in the knowledge-of-results (KR) paradigm. M_1 refers to movement trial 1. KR_1 refers to the augmented feedback provided about results of movement trial 1.

learning (see chapter 10 for more explanation). Making a distinction similar to other distinctions between learning and performance (chapters 10 and 11), they argued that a KR variable that exerted an influence *only* while being manipulated was a performance variable. A KR variable that exerted an influence after the manipulation was withdrawn (and after the temporary influences had dissipated) was a learning variable.

Several arguments support the preference for the no-KR transfer test over other transfer tests in the assessment of KR effects on performance and learning. One argument is that learning can be addressed in a more steady state under no-KR than under KR trials, since continued improvements in performance are unlikely to occur in the absence of KR (Salmoni et al., 1984). A further contention is that a series of no-KR trials provides a more consistent estimate of performance capabilities and thus a more reliable account of learning effects, since performance is stabilized more in the absence than in the presence of KR (Rubin, 1978). Another argument is that the use of a no-KR test of learning is consistent with many practical applications: Augmented information supplied during training or rehabilitation is often unavailable when "real" performance is required (e.g., in a game situation or when a patient is away from the clinic).

Potential Applications of Augmented-Feedback Research

The vast majority of the research on augmented feedback and motor learning has involved information about movement outcome (KR). For a person who has had extensive practice at a sport or occupational activity, it would seem far more effective to provide information about the *patterns* of movement the person made—defined earlier here as KP. Why is there a focus on KR (movement outcome) when KP (movement pattern) is what will probably be most useful for application? Probably the most important reason is that in experiments on KR, the movement outcome can usually be measured easily and corrections on the next trial can be measured. But when the experimenter wants to give KP, there is more difficulty in measuring the pattern of movement and then noting how the pattern changed on the subsequent trial. Until late in the previous century, these procedures were tedious (using film analysis, strip-chart records, and so on), and many motor behavior workers chose not to use them. However, with the use of computing technology and increased emphasis on biomechanical techniques, researchers have examined KP as a source of error information much more frequently. For now, we will assume that the mechanisms involved when the learner receives any type of augmented feedback are essentially the same. That is, we assume that what the learner does with these various kinds of information is identical, the major distinction being that these different kinds of information refer to different aspects of the movement. Thus, for example, the principles that have been discovered for KR would be applicable to situations when KP would be given. This could be incorrect, of course, but until evidence appears to the contrary, we think the assumption is reasonable.

Evaluating the Effects of Augmented Feedback

In this part of the chapter, some of the fundamental principles of augmented feedback for motor learning situations are presented. A number of conclusions can be drawn from the literature, probably because this area has received a great deal of study in motor skills research (for reviews see Adams, 1987; Magill, 2001; Salmoni et al., 1984; Swinnen, 1996; Wulf & Shea, 2004). Also, the effects found are very robust and large relative to those of other variables considered. First, we discuss a basic question: whether or not augmented feedback is a variable affecting performance, learning, or both. Then we discuss the research variables related to KP, and finally, we present the rather large and complex set of effects of KR variables on performance and learning.

Most of us probably suspect that KR has important effects on both performance and learning, so it is perhaps not crucial that we document these effects. But we have been fooled by our intuitions before, so we will review briefly some of the critical evidence on this issue.

Augmented Feedback Is a Learning Variable

Using the paradigm described in the previous section, Bilodeau, Bilodeau, and Schumsky (1959) employed a linear-positioning task with four groups of subjects. One group had KR after the first 19 of the 20 acquisition trials, and a second group received no KR at all in the 20 trials. Two other groups received KR for two and six trials, respectively, before having KR withdrawn for the remainder of the 20 practice trials. The main findings are shown in figure 12.2, where absolute error is plotted as a function of trials for these four groups. The group that had KR provided after trials 1 through 19 showed an initial sharp decrease in error, followed by a more gradual decrease. On the other hand, the group that had no KR at all showed essentially no change in performance over the 20 practice trials. For the remaining two groups, improvement occurred on trials that followed the administration of KR, but the improvement ceased when KR was withdrawn, with slight decrements in performance thereafter.

Did KR affect the learning in this task? As with any other variable that could affect learning or performance, these data can be interpreted in at least two ways. First, we could conclude that the 19-trial KR group learned more than the no-KR group, as evidenced by the fact that they performed more effectively during the practice phase. But another possibility is that KR had affected performance only temporarily, perhaps through some kind of motivational or "energizing" process. Thus, it could be that when these temporary effects of KR are allowed to dissipate with rest (as with fatigue effects), the temporary effects of KR will vanish and performance will regress to the original level (see chapter 10).

Bilodeau and colleagues provided a partial answer to this question when they transferred their no-KR group to the KR conditions for an additional five trials. In the right portion of figure 12.2, the absolute errors on these five trials are plotted together with those for the first five trials of group 19. The size of the errors, as well as the pattern of change with trials, was practically identical for these two sets of trials. That is, the no-KR group in this transfer condition performed nearly the same as group 19 at the beginning of their practice trials. Thus, we can say that the 20-trial no-KR practice sequence for this group did not produce any learning at all, and consequently that KR is a learning variable. And, KR is not just a variable that *affects* learning; rather, when KR is not present in such situations, learning does not occur at all. While Bilodeau and colleagues' study

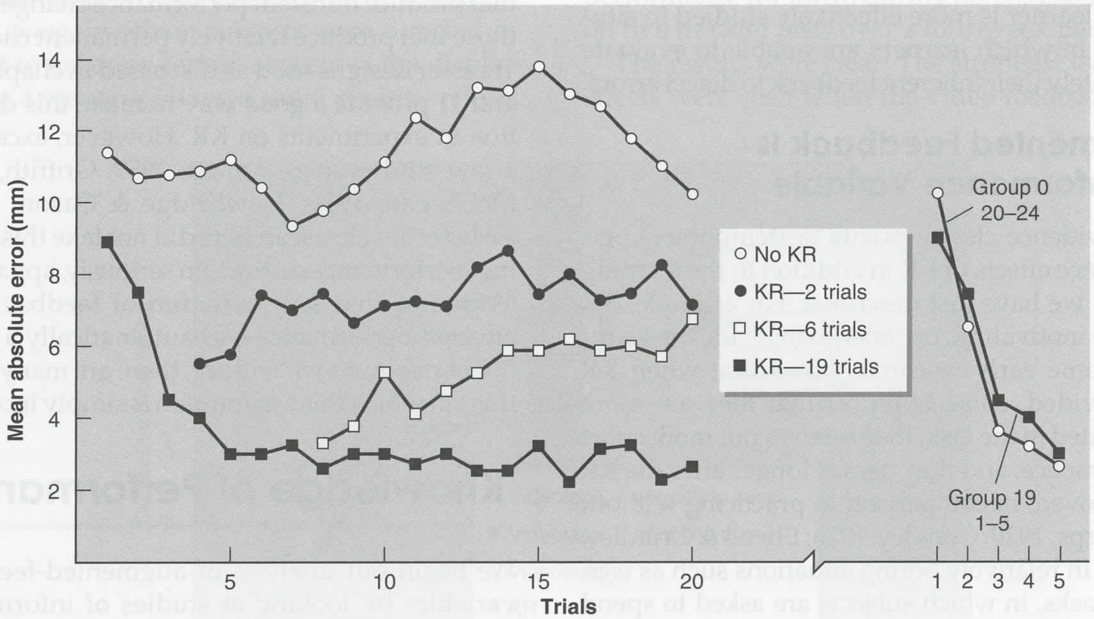

FIGURE 12.2 Absolute errors in a linear-positioning task as a function of knowledge of results (KR). (The group numbers indicate the number of presentations of KR received before KR withdrawal; group 0 switched to a KR condition shown at the right, where its performance is compared to group 19's first five trials replotted from left.)

Reprinted from E.A. Bilodeau, I.M. Bilodeau, and D.A. Schumsky, 1959, "Some effects of introducing and withdrawing knowledge of results early and late in practice," *Journal of Experimental Psychology* 58: 143.

uses a kind of transfer design, it does not use the typical transfer procedures we recommended earlier (chapter 10). Similar conclusions, however, have come from a number of other studies in which relative amount learned was evaluated on no-KR transfer tests (Bennett & Simmons, 1984; Newell, 1974; Trowbridge & Cason, 1932).

Knowledge of results does not always have such dramatic effects on learning motor skills, though, and the reasons often depend on the availability and usefulness of inherent feedback. For example, KR had only minimal effects on performance and learning for a tracking task in which KR was or was not provided after each trial (Archer, Kent, & Mote, 1956; Bilodeau, 1966). Similar effects have been found for learning an anticipation-timing task (Magill, Chamberlin, & Hall, 1991).

Does this mean that augmented information about errors is somehow not important for learning these tasks? Probably not. Rather, while practicing the task, subjects are able to detect their own errors through the inherent feedback (visual in these cases) provided during the normal course of the trial. This visual information probably serves the same function as the verbal KR did in the linear-positioning experiment described earlier. This observation is in accord with the idea that the presentation of information about errors to the learner is more effectively studied in situations in which learners are unable to evaluate accurately their inherent feedback to detect errors.

Augmented Feedback Is a Performance Variable

The evidence clearly points to (temporary) performance effects of KR in addition to the learning effects we have just described. For example, KR can be motivating, or "energizing," for the learners. Some early research shows that when KR is provided, subjects report that they are more interested in the task, they seem to put more effort into practice, and they persist longer after the KR is removed, in comparison to practicing without KR (Arps, 1920; Crawley, 1926; Elwell & Grindley, 1938). In relatively boring situations such as *vigilance* tasks, in which subjects are asked to spend hours monitoring a display for the appearance of a threatening object (e.g., in airport security monitoring), KR about the subject's performance has an "alerting" (or energizing) effect, and it can act to counteract sleep loss (Poulton, 1973). All these phenomena exert strong influences on performance, but weaker effects on learning (e.g., Szalma, Hancock, Warm, Dember, & Parsons, 2006).

Another temporary effect of KR is related to its informational properties, whereby KR informs the subject of the errors that have been made and then indicates what to do next. Thus, KR provides something like *guidance* for the learner. In chapter 11 we presented evidence that guidance is very effective for performance when it is present but that all or part of the beneficial effect can disappear when the guidance is removed (e.g., Armstrong, 1970a; see figure 11.19). In an analogous way, then, KR (acting as guidance) might provide strong informational support for performance when it is being administered, with the benefits disappearing as soon as the KR is removed or the task conditions are changed (Salmoni et al., 1984).

Untangling the Learning Versus Performance Effects

From the previous sections we have seen that variations in KR can have powerful effects on performance when KR is present, but there is good reason to question whether such effects are always "relatively permanent" to the extent that they can be thought of as learning effects. The scientific problem is to distinguish the variables that produce transient performance changes from those that produce relatively permanent changes. Transfer designs used as discussed in chapters 10 and 11 provide a good way to make this distinction in experiments on KR. However, except for a few studies (e.g., Annett, 1959; Griffith, 1931; McGuigan, 1959; Trowbridge & Cason, 1932), early feedback researchers did not take this learning–performance distinction seriously, apparently assuming that any variation of feedback that affected performance was automatically a learning variable. As we will see, there are many situations in which this assumption is simply incorrect.

Knowledge of Performance

We begin our analysis of augmented-feedback variables by looking at studies of information that is provided to learners about the patterns of actions they make. It was Gentile (1972) who termed these kinds of feedback "knowledge of performance." Many forms of KP are possible; they may range from rather casual comments about performance, made by a teacher or coach, to complex feedback generated by computer in a simulator and delivered to the learner online in computer-aided instruction. Some of these kinds of KP are discussed in the following sections.

Video Feedback

It would certainly seem reasonable to think of analog or digital video feedback as a powerful mode in which to present KP. From a motor skills viewpoint, a video will contain a record of the entire performance, and the individual can detect errors directly and attempt to correct them on the next trial. However, for all the logic leading to the use of video feedback, as well as its use in many sport situations, the research evidence suggests that this method of presenting KP, *by itself*, is rather ineffective. Rothstein and Arnold (1976) and Newell (1981) have reviewed this work, finding that numerous experiments fail to show positive effects of these techniques for motor learning. Some evidence even suggests that video feedback might actually hinder learning (Ross, Bird, Doody, & Zoeller, 1985). One suggestion is that video feedback might provide *too much* information, especially if the skill is complex and the viewer does not know which of the many details are important. In support of this notion, Rothstein and Arnold pointed out that studies using *cuing*, in which subjects were directed or taught to examine certain aspects of the display during a viewing, showed more positive effects of video feedback than did studies using undirected viewing.

The benefits of cued or directed viewing of video feedback were shown clearly in a study by Kernodle and Carlton (1992). Subjects practiced throwing a sponge ball with their nondominant arm. After each throw, they were provided with KR regarding the distance thrown (subjects closed their eyes on ball release, making the augmented feedback more important for learning) and were shown video feedback of the trial just completed. One group of subjects was provided only KR, while another group watched a video replay of their own performance, with no additional augmented information. Previous research, however, had shown that combining verbal KP with other forms of augmented feedback can be quite beneficial to learning (Wallace & Hagler, 1979). So, another group received a verbal cue to watch one particular aspect of the movement during the video feedback (e.g., "Focus on the hips during the throwing phase"). A final group, before watching the videotape, was given additional augmented feedback in the form of specific error-correction information (e.g., "Rotate the hips from left to right during the throwing phase"). Figure 12.3 illustrates the subjective ratings of throwing performance (or form) during no-feedback trials on five transfer tests over a four-week period.

The results were clear: The strongest learning effects were seen when the video feedback was

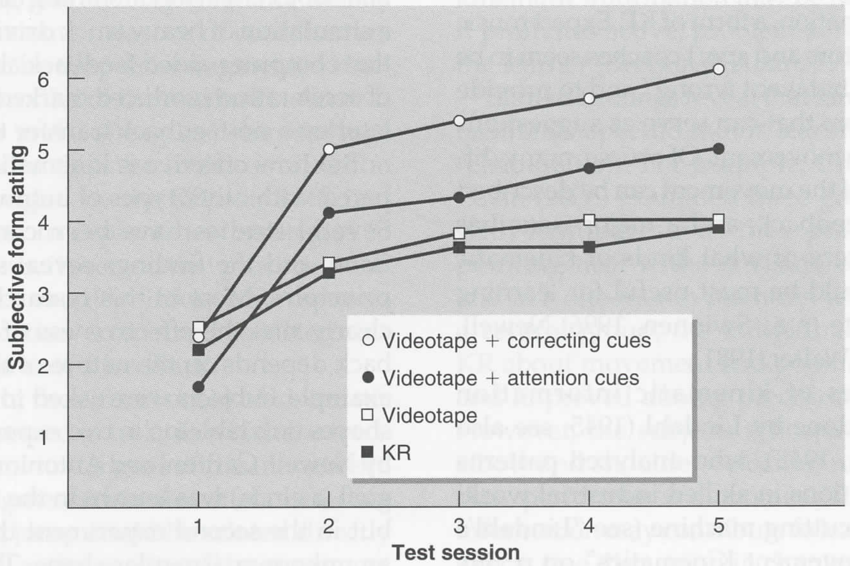

FIGURE 12.3 Throwing performance under various conditions of videotape replays.
Data from Kernodle and Carlton 1992.

accompanied by error-correcting cues, although considerable gains were achieved with the attention-focusing cues as well. The video feedback alone was no better than simply providing KR. Similar results were obtained when measures of distance thrown were analyzed.

It is important to remember that video can also be used to present the performance of a model (chapter 11). However, in both uses of videos as forms of augmented information, research has shown that they are most effective when supplemented with additional, attention-directing augmented information. Practically speaking, information provided in videos is most effective for learning when it is augmented by an instructor who can direct the learner's attention to important details and toward ignoring the irrelevant aspects. This is probably especially so if the learner is a novice, who has less knowledge than an experienced performer about what details in the video are important.

Kinematic Feedback

Recall that *kinematics* refers to measures of "pure motion" without regard to the forces that produced them (chapter 2). Feedback about kinematics involves various measures derived from movement such as position, time, velocity, and patterns of coordination. When coaches or teachers give information about movement patterning (e.g., "You bent your elbow that time"), they are really providing a (loosely measured) form of kinematic information, a form of KP. Expert music or dance instructors and sport coaches seem to be able to sense "what went wrong" and to provide verbal descriptors that can serve as suggestions for change in the movement. Of course, many different features of the movement can be described and used for feedback, and a major issue has been the discovery of what kinds of kinematic information would be most useful for learning and performance (e.g., Swinnen, 1996; Newell, 1991; Newell & Walter, 1981).

Early studies of kinematic information feedback were done by Lindahl (1945; see also Tiffin & Rogers, 1943), who analyzed patterns of foot-pedal actions in skilled industrial workers operating a cutting machine (see "Lindahl's Study Using Movement Kinematics" on p. 39). Lindahl determined the most effective pattern of foot motion from measurements of highly skilled workers and then used this pattern as a "gold standard" for providing feedback about foot action to new employees. Such kinematic feedback greatly facilitated training; in as few as 10 weeks of practice, new trainees could be brought to the level of employees who had nine months of experience. Knowledge of performance about the most effective patterns of actions—not easily observable without additional measurements of the fine details of foot movements, and not easily verbalizable—was apparently critical to the establishment of proper actions in the new performers.

A key feature of kinematic feedback is that it informs the subjects about some aspect of the movement pattern that is otherwise difficult to perceive. In some cases, a whole pattern of multijoint coordination is presented (e.g., by means of analog or digital video), showing important information about the movement of a particular joint in relation to another (e.g., Hatze, 1976). It is possible that the subject could gain this information on his own, but it is unlikely that a learner would focus on the particular aspects that the instructor considers to be critical. Other kinds of information cannot be sensed at all, however, such as relative timing differences in two joints or subtle changes in velocity; and kinematic feedback can allow the learner to become aware of these features. Also, feedback information about subtle aspects of the movement's goal has been shown to be useful; Phillips and Berkhout (1976) had subjects learn gearshifting and acceleration in a simulation of heavy truck driving, and showed that computer-aided feedback about smoothness of acceleration produced marked gains measured later on a no-feedback transfer test.

But how effective is kinematic KP when compared with other types of augmented feedback? Several studies have been conducted on this issue, and the findings reveal some interesting principles. Most of this research suggests quite clearly that the effectiveness of kinematic feedback depends on the nature of the task goal. For example, subjects were asked to draw geometric shapes on a tabletop in two experiments reported by Newell, Carlton, and Antoniou (1990). The task goal (a circle) was known in the first experiment, but in the second experiment the task goal was an unknown, irregular shape. The subjects were given one of three types of feedback: (1) KR about the error between their movement and the goal;

(2) a digital image of the pattern plus the KR; or (3) a digital image of the feedback of the produced movement superimposed on a template of the task goal, plus KR. Learning (as measured in a retention test without any augmented feedback) was not affected by the nature of the feedback when the task goal was well known to the subjects (the circle in experiment 1). However, when the task goal was unknown, there was a clear advantage for the group that received the KR plus the augmented feedback superimposed on the task goal. The benefit of augmented kinematic feedback may be optimized when its content specifies information that cannot otherwise be generated from sources such as inherent feedback or from other, less detailed sources of augmented feedback.

The role of task goal information and available sources of feedback may also be related to the findings reported by Swinnen, Walter, Lee, and Serrien (1993). Subjects in this study practiced a discrete, bimanual-coordination task in which the actions of the two limbs were not the same. The left limb was to produce a unidirectional elbow flexion movement. At the same time, a flexion–extension–flexion movement of the right elbow was to be performed. Without practice this coordination task is very difficult to perform, as there is a tendency to make the *same* actions with each arm (see chapter 8). Swinnen and colleagues (1993) found that the capability to perform each distinct limb goal improved little with practice in the absence of augmented feedback. Surprisingly, however, learning was facilitated equally well by KR (a simple outcome measure of coordination performance) and by the precise augmented kinematic feedback profiles of the two limbs. According to Swinnen and colleagues, the findings supported the idea that the limb coordination information provided by the KR was sufficient to enable subjects to explore new strategies to learn the task. Thus, it seemed that practice—and strategies brought about by information sources that affected practice—combined to determine the value of augmented feedback.

In this research, the effectiveness of kinematic feedback was assessed in tasks in which the feedback was identical to the goal of the movement. For example, augmented feedback about a dive or an ice skating jump could be related directly to the movement, as the quality of the movement *represents* the task goal. However, in other skills, the outcome of an action may be quite distinct from the motions that produced it. For example, many different movements can produce the same trajectory of a batted ball.

How does kinematic feedback about movements affect the acquisition of skills in which the movements are not isomorphic with the task goal? A computer-controlled analog of a baseball batting task was developed by Schmidt and Young (1991) to examine these issues. The task required subjects to "strike" a moving-light "object" by passing a movement lever through a coincidence point as the light went by. The goal was to maximize distance, as defined by a combination of the velocity and timing accuracy at the coincidence point. On the basis of research suggesting that a particular movement pattern produced the best outcome scores (Schmidt & Young, 1991), Young and Schmidt (1992) conducted a study to assess what kinematic feedback variables facilitated learning when presented in relation to the optimal movement pattern. Their findings revealed that each kinematic variable manipulated (mean or variability of the reversal point; mean or variability of the time of the reversal) tended to facilitate the acquisition of that kinematic variable in the production of the movement. However, only the kinematic feedback about the mean reversal point was more effective than outcome KR in maximizing performance outcome. The effects of KP appear to be enhanced, however, when an optimal movement pattern is not used as a reference criterion, again suggesting that the kinematic information may be most useful when it promotes active, problem-solving activities in the learner (Brisson & Alain, 1996a, 1996b).

Similar findings reveal that kinematic feedback facilitates specific motor learning outcomes in rehabilitation. For example, Cirstea, Ptito, and Levin (2006) examined three groups of patients with hemiparesis as they practiced an arm-pointing task without vision over 10 sessions and in a one-month retention test. Compared to a control group, the individuals who received KR about movement end point steadily learned and improved aiming precision, but not speed. However, the subjects who received KP about elbow and shoulder velocities mainly improved *these* performance outcomes. Thus, augmented information may contribute to learning specificity effects (see discussion in chapter 11).

These specificity effects may help to resolve the curiosity about the effectiveness of kinematic feedback relative to certain attentional focus manipulations. In previous sections of the book we discussed findings regarding the impact on performance (chapter 4) and learning (chapter 11) of instructions to focus one's attention. In most cases, research has shown that instructions to attend to an "external" source of information were beneficial for performance and learning, compared to instructions to focus on an "internal" source of information (Wulf, 2007). In the context of the present discussion, it might be correct to say that KP directs the learner to focus attention on an internal source (e.g., the motions of a limb), whereas KR directs the learner's attention to the impact of the movement on the environment (i.e., externally). From this perspective, even though KP might provide more information than KR, one might anticipate that KR holds an advantage over KP in terms of directing the learner's attention to a more appropriate focus.

As an example, subjects in a study by Shea and Wulf (1999) practiced the stabilometer and received concurrent feedback about the position of the platform relative to the horizontal. Some subjects were told that the feedback represented a line on the platform (external group) while others were told that this feedback represented their feet (internal feedback). The results over two days of practice and a no-feedback retention test (on day 3) are shown in figure 12.4. Compared to the internal group, the external group performed more accurately both early and later in practice. The differences were small at the start of the retention test, but the external group continued to improve their performance in the retention test compared to the internal group. These findings have been replicated in a tennis serve task (Wulf, McConnel, Gärtner, & Schwarz, 2002) and in stroke rehabilitation (Cirstea & Levin, 2007), although further work is necessary to dissociate the specific effects of attention-focusing instructions and augmented feedback. Nevertheless, these findings are important in that they provide the beginnings of a better understanding of both the potentially positive and negative influences of kinematic feedback on performance and learning.

Biofeedback

Going a step further, feedback can be given about features of the movement that are not perceived directly—a key feature of *biofeedback training*. If a particular biological process (e.g., blood pressure) is measured electronically and used as feedback, then subjects can learn to voluntarily control these (normally unconscious) processes (see Richter-Heinrich & Miller, 1982, for a review). Years ago, Basmajian (1963) gave subjects visual and auditory feedback of their own electromyograms (EMGs) and showed how such information

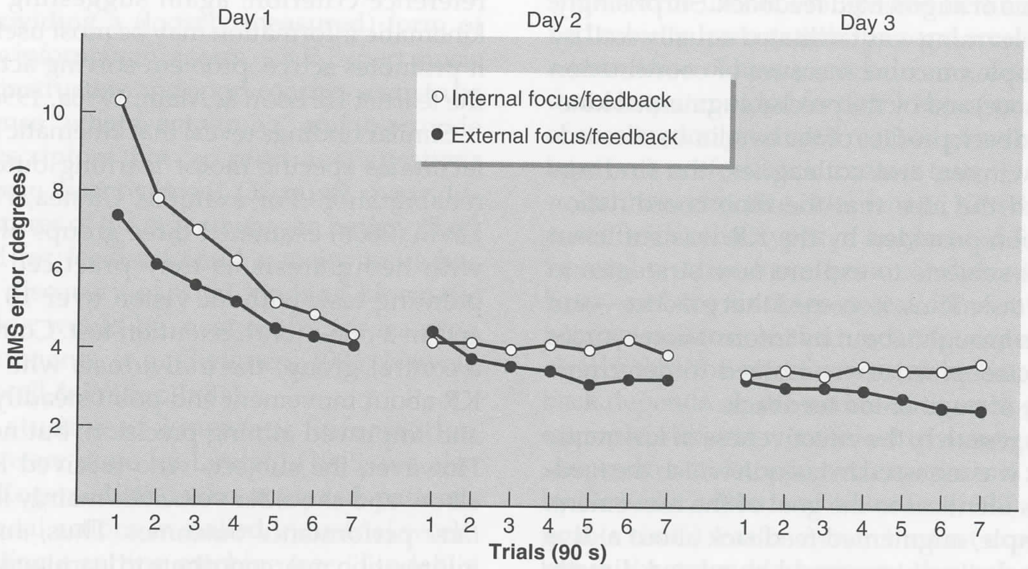

FIGURE 12.4 Effects of internal- versus external-focus feedback in acquisition (days 1 and 2) and in retention (day 3).

Reprinted from *Human Movement Science*, Vol. 18, C.H. Shea and G. Wulf, Enhancing motor learning through external-focus instruction and feedback, pages 553-571, Copyright 1999, with kind permission from Elsevier.

could allow the subject to learn to control a single motor unit, something that is not normally under voluntary control. This general idea has been tried (with only moderate success) in teaching subjects who are deaf to speak, with the subjects' sounds being transformed into visual information presented on a television screen (Nickerson, Kalikow, & Stevens, 1976). Mulder and Hulstijn (1985) showed that feedback information about the EMG from the muscles controlling the big toe contributed to learning toe movements, and that the gains remained even after the feedback was removed.

Brenner (1974) and Lang (1974) argued that there is a close relationship between these biofeedback procedures for training unconscious processes on the one hand and kinematic feedback for motor learning on the other. If such a relationship exists, however, then it is possible that biofeedback would be expected to have some adverse effect in motor learning as well (Yiu, Verdolini, & Chow, 2005). As we will see later, augmented feedback that is provided instantaneously with the completion of performance is beneficial for performance but can degrade learning. Clinical treatment of speech disorders, for example, is one research area in which continuous, instantaneous feedback may have an adverse effect on rehabilitation (for a review see Maas et al., 2008).

Kinetic Feedback

Whereas kinematic measures are variables describing pure motion, kinetic measures are descriptors of the *forces* that produce the kinematic variables. We have long recognized that muscular forces and the durations over which they act are fundamental outputs of the central structures thought to organize movements; the impulse-timing theory discussed in chapters 6 and 7 is one statement of that basic view. As a result, researchers have often thought that feedback in terms of kinetics would be a "natural" kind of information for the motor system to use for learning.

Some early work supports this view. English (1942) utilized force feedback from a trigger squeeze to facilitate riflery training. Howell (1956) had subjects learn a runner's sprint start and recorded forces applied against a strain gauge (a force sensor) that was attached to the foot plate in the starting blocks. The forces recorded during the time of the action provided a *force–time curve,* which was shown to subjects after each trial as a form of kinetic feedback. Subjects could use this information to *optimize* the form of the force–time curve (i.e., to produce a maximum impulse). Newell and Walter (1981) and Newell, Sparrow, and Quinn (1985) have provided similar examples with other tasks. The effects of this extra information are relatively permanent too, as they persist in a short-term no-feedback retention test (Newell et al., 1985) as well as in tests that occur after a long delay interval (Broker, Gregor, & Schmidt, 1993; van Dijk, Mulder, & Hermens, 2007).

There is good reason to remain cautious about the benefits of using kinetic feedback for the attentional focus reasons mentioned in the previous sections. If the provision of kinetic feedback encourages the learner to adopt an internal focus of attention in performance, then the potential benefit of this rich form of augmented feedback might be overshadowed by the consequences of the ineffective attentional focus.

Knowledge of Results

We now turn our attention to the vast amount of research on KR—augmented information about the movement outcome. Experiments in this research area have frequently used very simple tasks, such as blindfolded limb-positioning tasks and timing tasks. The reason is that with these kinds of tasks, very little if any learning at all can occur in the absence of KR. In this way, the relative effectiveness of various manipulations of KR can be examined in terms of their impact on the learning process.

Precision of KR

The *precision* of KR refers to the degree of exactness of the information provided to the learner. For example, if the subject's goal was to make a 10 cm movement and the actual movement was 10.13 cm, KR could be provided in a variety of ways. At the most general or *qualitative* level, the subject could be told that the movement was either "right" or "wrong." However, differing degrees of precision could be substituted for these general feedback statements of "right" or "wrong."

In the case of "wrong," one could give more precise KR by saying "long" or "short," meaning that the person moved beyond or short of the target. One could give still more precise KR by saying "wrong by 1," meaning 1 mm off target.

Or, one could say "long 0.1," meaning that the movement was 0.1 mm too long, or "long 0.13," meaning that it was 0.13 mm too long. The KR could be even more precise than this, measuring movement accuracy to finer *quantitative* degrees (e.g., in nanometers).

In the case of "right," the experimenter would need to define, exactly, what movement outcome would satisfy the criterion that distinguished "right" from "wrong." In the early work of Trowbridge and Cason (1932), for example, lines were considered to be correct if drawn within 1/8 in. of the 3 in. goal. In such a case, the "correctness" of the movement is defined relative to a "bandwidth," defined as the degree of acceptable error tolerance around the goal. Various combinations of qualitative and quantitative forms of KR have been examined, and these manipulations have rather large effects on performance and learning.

Qualitative Versus Quantitative KR

The most basic question concerning the precision of KR is the kind of information that is presented. Information about the *direction* of the error is presented in some, but not all, forms of KR. Information can also be provided about the *magnitude* of the error, irrespective of direction. Some of these forms of KR have information about both factors (e.g., "long 13"). Generally, the evidence suggests that there is some benefit to providing information about magnitude of error, but this information is far more useful if the direction is also specified. Knowing that an error was made in a particular direction gives a strong indication of the ways in which the movement must be modified next time but information only about magnitude does not.

Another key issue is related to the precision of the KR, and the classic study in this area was conducted by Trowbridge and Cason (1932). Four groups practiced drawing 3 in. lines for 100 trials. One group never received KR. Another group received nonsense syllables after drawing each line (a control condition). A third group received qualitative KR in the form of "right" (if the line was within ±1/8 in. of the goal) or "wrong" from the experimenter. The last group was given precise, directional KR (longer or shorter) in terms of the exact deviation, in eighths of an inch, from the goal length. During both acquisition and a no-KR transfer test that followed immediately after practice, accuracy was greater for the precise and the right–wrong KR groups than for either the nonsense-KR or the no-KR group (figure 12.5). Furthermore, precise KR was more accurate than

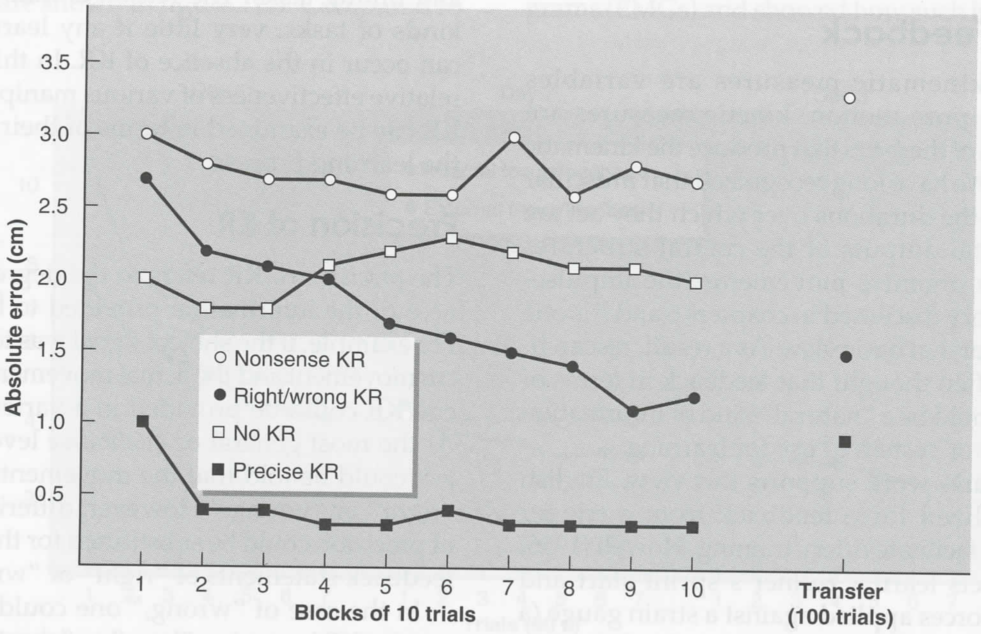

FIGURE 12.5 Qualitative and quantitative knowledge of results (KR) effects in acquisition and transfer. The No-KR group did not perform the transfer rest.

Data from Trowbridge and Cason 1932.

the right/wrong type of KR. These effects have been replicated often (Bennett & Simmons, 1984; Magill & Wood, 1986; Reeve, Dornier, & Weeks, 1990; Salmoni, Ross, Dill, & Zoeller, 1983), supporting the conclusion that precise, quantitative KR is generally more effective for learning than qualitative KR.

These techniques do not permit the separation of information about precision of KR from information about the direction of reported error. Studies conducted since the Trowbridge and Cason experiment have separated these effects and have generally shown that the more precise the KR, the more accurate the performance, up to a point, beyond which no further increases in accuracy are found as KR is made more precise (for reviews, see Newell, 1981; Salmoni et al., 1984). Subjects presumably know that they cannot be responsible for errors smaller than a certain size (e.g., 1 mm), as the movement control mechanisms themselves are more variable than this. Therefore, it is likely that subjects "round off" very precise KR to a more meaningful level of precision.

Bandwidth KR

An alternative to giving either qualitative or quantitative KR is provided by the *bandwidth KR* method (Sherwood, 1988). With this method the nature of augmented feedback is determined by a bandwidth about the movement goal. In most studies using this method, qualitative KR in the form of "correct" or "right" is provided to the subject when the performance outcome lies *within* the boundaries of correctness as defined by the bandwidth (similar to the KR provided by Trowbridge & Cason [1932]). However, when performance *exceeds* the bandwidth, the experimenter provides the learner with specific KR that gives both the magnitude and the direction of error. This method is probably what many teachers and therapists do spontaneously—correcting relatively poor performance and rewarding relatively good performance.

Bandwidth KR has rather substantial effects on performance and learning. In fact, the research suggests that learning is facilitated as the bandwidth becomes *larger*. There is probably an optimal bandwidth size, although more research needs to be done to establish what this might be. Sherwood (1988) conducted one of the first studies in this area (see also Annett, 1959). Subjects were to learn to achieve a rapid elbow flexion movement time as close to 200 ms as possible. Subjects in a control (no bandwidth) group (0% BW in figure 12.6) were told their exact movement time after each trial. In two other

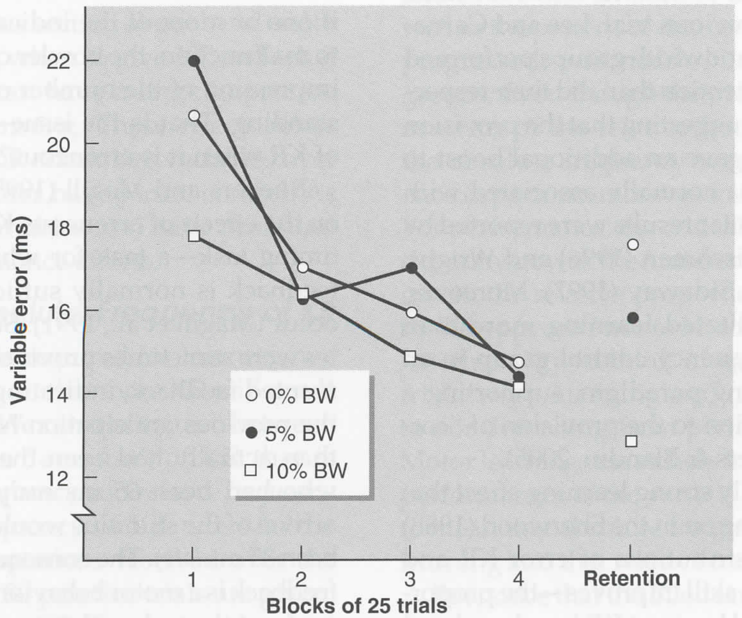

FIGURE 12.6 Bandwidth knowledge-of-results (KR) effects in acquisition and retention.

Reproduced and adapted from Table 1 and 2 with permission of author and publisher from: Sherwood, D.E. Effect of bandwidth knowledge of results on movement consistency. *Perceptual and Motor Skills*, 1988, 66, 535-542. © Perceptual and Motor Skills 1988.

conditions, subjects were given movement-time KR only if their outcomes exceeded a tolerance limit around the MT goal (±5% or ±10%). Performance inside the bandwidth received no *explicit* KR—which subjects had been instructed to interpret as meaning that their MT had been correct. Although these bandwidth conditions had no differential effects on acquisition performance, as can be seen in figure 12.6, the no-KR retention test performance was positively related to the size of the bandwidth.

Sherwood's experiment uncovered a number of important issues regarding KR and the learning process. For example, one consequence of the bandwidth KR procedure is that as the tolerance limits are increased (5% to 10%), the proportion of trials supplied with *error KR* diminishes. As will be seen later in this chapter, less frequent error KR in acquisition also improves learning. So, one question is whether or not the bandwidth effect is more than just a reduced KR frequency effect. To examine this question, Lee and Carnahan (1990a) used bandwidth groups of 5% and 10% together with *yoked* control groups; the control groups received KR on the same trials as their yoked counterparts in the bandwidth groups. However, the key difference was that a bandwidth subject interpreted no KR to be feedback that the previous trial performance had been "correct." For the yoked controls, the absence of KR revealed nothing about the previous trial. Lee and Carnahan found that the bandwidth groups performed more effectively in retention than did their respective control groups, suggesting that the provision of the "correct" KR gave an additional boost to learning beyond that normally associated with less frequent KR. Similar results were reported by Butler, Reeve, and Fischman (1996) and Wright, Smith-Munyon, and Sidaway (1997). Moreover, bandwidth KR facilitated learning more than a yoked relative-frequency control group in an observational learning paradigm, supporting a high cognitive function to the provision of "correct" feedback (Badets & Blandin, 2005).

Another potentially strong learning effect that could have been going on in the Sherwood (1988) study is that the distributions of error KR and correct KR change as skill improves—the proportion of trials followed by error KR is reduced and the proportion of "correct KR" trials is increased. This seems to be an important component of bandwidth KR effectiveness, as methods of reducing the size of the bandwidth over the course of practice, keeping the proportions of error and correct KR relatively constant, have been ineffective (Goodwin & Meeuwsen, 1995; Lai & Shea, 1999).

As suggested earlier, these effects make considerable sense and have been replicated in experiments in which a golf chipping task was learned (Smith, Taylor, & Withers, 1997). The essence is that, when assisting people in learning a new skill, you might provide help when they are doing something wrong, but not when they are correct (in other words, "If it ain't broke, don't fix it"). The key seems to be in deciding when is the best time to intervene and provide augmented feedback. If an optimal bandwidth exists for each person, its size would likely depend on a number of factors that may change with practice and task demands (Lee & Maraj, 1994).

Erroneous KR

Imagine a situation in which the provider of augmented feedback is *inaccurate* in giving the feedback. For example, in older bowling alleys, an illuminated indicator at the end of the lane provided KR in terms of how many pins were left standing after the first ball was bowled. Since there are times when one pin is hidden from the bowler's view by another pin, the augmented feedback from the pin indicator can reveal information that the bowler cannot directly see. But, if one or more of the indicator lights happened to malfunction, the bowler could get an incorrect impression of the number of pins that were still standing. That is the issue—what is the impact of KR when it is erroneous?

Buekers and Magill (1995) conducted studies on the effects of erroneous KR in an anticipation-timing task—a task for which inherent (visual) feedback is normally sufficient for learning to occur (Magill et al., 1991). Subjects in these studies were sometimes provided with incorrect augmented feedback, indicating that the accuracy of the previous anticipation had been 100 ms later than actually had been the case (e.g., someone who had been 65 ms *early* in anticipating the arrival of the stimulus would be told that she had been 35 ms *late*). The consequence of this *erroneous* feedback is a motor behavior whereby the subjects perform the task with a constant error (CE) of up to −100 ms. These effects are relatively long lasting, with large negative CEs occurring after one week in a no-KR retention test (Buekers, Magill,

& Hall, 1992; Vanvenckenray, Buekers, Mendes, & Helsen, 1999) and in transfer tests to novel stimulus speeds (McNevin, Magill, & Buekers, 1994). The findings have been replicated in other types of timing tasks (Ryan & Fritz, 2007; Ryan & Robey, 2002), as well as in a soccer ball kicking task in which visual feedback provided by a video was erroneous (Ford, Hodges, & Williams, 2007).

These erroneous-KR effects indicate that the accuracy of augmented feedback has very powerful effects on performance and learning, whereby subjects negate or discount the accuracy of their own error-detection capabilities in favor of trusting the validity of the (erroneous) augmented feedback. The impact of erroneous KR appears to be the strongest when it is presented on every practice trial during acquisition. Studies in which trials with erroneous KR are alternated with trials providing correct KR (Buekers, Magill, & Sneyers, 1994), and those in which trials with erroneous KR follow a practice period with correct KR (Buekers & Magill, 1995), show diminished performance effects and no learning effect of erroneous KR. Thus, *periodic* KR that is counterintuitive to inherent feedback may not be as disruptive to learning as the situation in which the learner is consistently faced with conflicting augmented information.

Schedules of KR

We saw in the previous section about bandwidth KR that determining when to give KR and what type of KR to give can have a large impact on performance and learning. These effects relate closely to a class of KR-*scheduling* variables over which the experimenter has specific control. As we will see, these variables also have profound learning and performance effects.

Relative- and Absolute-Frequency of KR

If error information is required for learning, we might reasonably expect that more KR will result in stronger learning. We can distinguish between two measures of the "amount" of KR that is provided: *absolute frequency* and *relative frequency* of KR. Absolute frequency of KR refers to the number of KR presentations received over the course of practice. If 80 practice trials are given, and the person receives KR after every other trial for a total of 40 presentations, then the absolute frequency of KR is 40. On the other hand, relative frequency of KR refers to the *percentage* of trials on which KR is provided. It is the number of times KR is given divided by the total number of trials, multiplied by 100 for conversion to a percentage. In this example, the relative frequency of KR is $(40 / 80) \times 100 = 50\%$.

Which of these two KR-scheduling variables is the more critical for learning? Bilodeau and Bilodeau (1958) were the first to investigate this question, using a task in which subjects turned a knob to a target position in the absence of vision. For the four different groups, KR was provided after (a) every trial, (b) every third trial, (c) every fourth trial, or (d) every 10th trial, producing relative frequencies of KR of 100%, 33%, 25%, and 10%, respectively. The number of trials performed by these groups, however, was adjusted so that all groups were presented KR after 10 trials; therefore, the group with 100% relative frequency received 10 trials, the group with 33% relative frequency received 30 trials, and so on. Thus, the experiment involved groups that had different relative frequencies, but constant absolute frequencies (10) of KR.

The results for each of the four groups are presented in figure 12.7. Only the trials *immediately following* the presentation of KR are plotted. This is, of course, every trial for the group with 100% relative frequency of KR, only one-third of the trials for the group with 33% relative frequency, and so on. The amount of error on each trial, as well as the pattern of change of the errors as trials progressed, was nearly the same for the four groups. Even though the groups differed greatly in terms of the relative frequency of KR, when the absolute frequency was equated, no difference in performance was found between groups. For performance, the critical feature of KR in this experiment was the number of times that KR was given; the relative proportion of trials followed by KR appeared not to be an important variable. Another way to think of this is that the no-KR trials were meaningless, neither contributing to nor detracting from performance of the task. Motor learning researchers initially took the equal performances of the various groups in figure 12.7 to mean that absolute frequency is important for learning and that relative frequency is irrelevant.

But notice that the Bilodeau and Bilodeau study did not use a transfer design to separate the performance effects of relative frequency from the learning effects. Hence, we actually have no way of knowing whether varying relative frequency

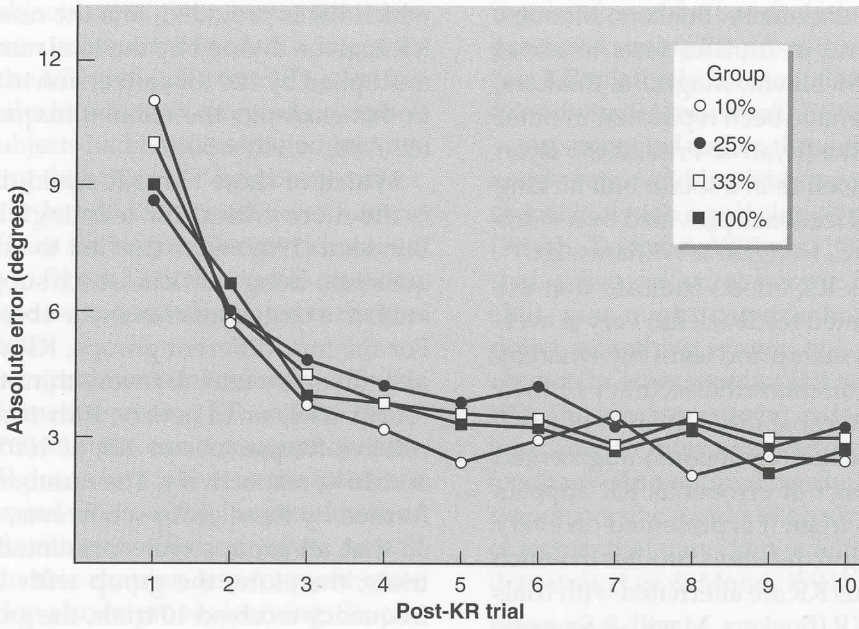

FIGURE 12.7 Absolute errors in positioning for trials immediately following knowledge of results (KR). (Group numbers indicate the percentage relative frequency of KR.)

Reprinted from E.A. Bilodeau and I.M. Bilodeau, 1958, "Variable frequency knowledge of results and the learning of simple skill," *Journal of Experimental Psychology* 55: 379.

affected learning. More recently, experimenters have included these transfer tests, and the effects on learning have been mixed. Some studies showed that reduced relative frequencies of KR produced learning effects that were *as large as* those in 100% KR conditions (e.g., Lee, White, & Carnahan, 1990, experiment 2; Sparrow & Summers, 1992, experiment 1; Winstein & Schmidt, 1990, experiment 1). Yet, using similar tasks and slightly modified methods, other experiments showed that reduced relative-frequency conditions produced *more* learning than 100% KR conditions (e.g., Lee et al., 1990; Sidaway et al., 2008; Sparrow & Summers, 1992; Sullivan, Kantak, & Burtner, 2008, adults; Vander Linden, Cauraugh, & Greene, 1993; Weeks & Kordus, 1998; Weeks, Zelaznik, & Beyak, 1993). Similar effects have also been found when the provision of KR is reduced in an observational learning paradigm (Badets & Blandin, 2004; Badets, Blandin, Wright, & Shea, 2006).

An example is provided in figure 12.8 (from Winstein & Schmidt, 1990, experiment 2). Notice that there are no differences between the 100% and 50% relative-frequency groups in acquisition, as Bilodeau and Bilodeau (1958) had found. However, in 5 min and 24 h no-KR retention tests, a clear learning effect was shown that favored the 50% group. Thus, it seems that instead of being irrelevant for learning, reduced relative-frequency effects may be beneficial to learning!

This general result has surprised many because it says that the no-KR trials, instead of being meaningless for learning as they appeared to be in the Bilodeau and Bilodeau (1958) study, contributed to the learning in some way. This contradicted a long-held suspicion that practice without feedback was useless for learning. Further, this contribution was not manifested during practice when the KR was present, but was seen in a delayed retention test. Decreasing relative frequency certainly does not diminish learning and may actually facilitate it.

But there is one additional concern with these studies. When the relative proportion of trials that are followed by KR is reduced, a confounding variable arises. Compared to a 100% KR condition, if the total number of trials during practice is held constant, then reduced relative frequency of KR also results in reduced *absolute* frequency of KR. If the researcher decides to make the absolute frequency the same as in the 100% condition, then the total number of trials must be increased for the reduced relative-frequency group. In all the studies cited here, the total number of trials was kept constant. Thus, the effects of reduced relative frequency must be considered in light of

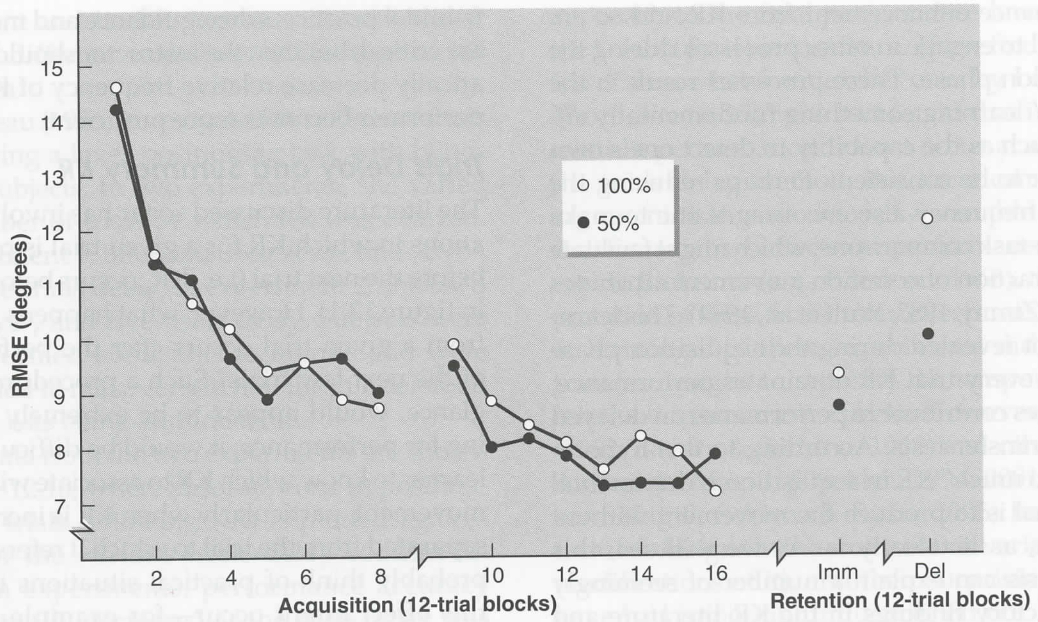

FIGURE 12.8 Effects of 100% versus 50% relative frequency of knowledge of results (KR) in acquisition and retention.

the fact that fewer KR presentations were given. When we recall that learning increases with the number of KR presentations, perhaps it is not surprising that the effects of relative frequency are rather mixed. It may very well be that the positive effect of reducing the relative frequency has been offset by the negative effect of fewer KR presentations. This certainly contradicts the earlier conclusions that providing more feedback is all-critical for motor learning. And, note that delayed no-KR transfer tests were required in order to show these effects—further supporting the use of such transfer designs in motor learning research.

The effects of relative frequency appear to be clearer if the method used for reducing the presentations of KR is a "fading" procedure. Here, giving *fewer* KR presentations (trials constant) seems to greatly improve learning (Sullivan et al., 2008; Winstein & Schmidt, 1990; Wulf & Schmidt, 1989). The method usually involves providing KR relatively often during the initial stages of practice and then gradually withholding the presentation of KR more and more toward the end of practice. This method actually has an effect very similar to what naturally happens when using the bandwidth KR procedure, because skill improvements increase the likelihood that performance will lie within the bandwidth so that the provision of error KR will be withheld.

However, one further complication arises when we consider the effects of reduced relative frequency as a function of the task that is learned. Experiments have shown that when subjects practice several versions of a generalized motor program, reduced relative frequency of KR facilitates the learning of invariances common to the movement pattern, but not the parameterization characteristics (Wulf, Lee, & Schmidt, 1994; Wulf & Schmidt, 1989; Wulf, Schmidt, & Deubel, 1993).

A possible explanation for the relative-frequency effect in motor learning was suggested by Salmoni and colleagues (1984; see also Schmidt, 1991a; Schmidt & Bjork, 1992; Schmidt & Shapiro, 1986; Winstein & Schmidt, 1990). When KR is given on every trial (relative frequency of 100%), this condition is very effective for performance when KR is present, because of a number of temporary factors already discussed (e.g., guidance, motivational, and energizing properties). However, the subject comes to rely too heavily on this information and fails to process information necessary for learning the task in a relatively permanent way; subjects use KR as a "crutch." Subjects in conditions of lower relative frequency, however, do not have such a strong performance enhancement from KR and so are "forced" to engage in other processes during the acquisition phase. These processes result in the subjects' learning something fundamentally *different*, such as the capability to detect one's own errors or to be consistent. Perhaps reducing the relative frequency also encourages one to make between-task comparisons, which might facilitate the abstraction of common movement attributes (Shea & Zimny, 1983; Wulf et al., 1994). This learning is not revealed during the acquisition phase because every-trial KR dominates performance, but it does contribute to performance on delayed no-KR transfer tests. According to this hypothesis, "too much" KR in acquisition is detrimental if the goal is to produce the movement without KR later, as it usually is. As we will see, this hypothesis can explain a number of seemingly contradictory findings in the KR literature and has been supported by some recent experiments to be discussed in sections that follow (e.g., Guadagnoli & Kohl, 2001).

A few practical implications are possible. First, KR is certainly important for learning, as the results generally say that increasing the amount of feedback, other things being equal, is beneficial to performance and learning. But KR can be given too often; in these cases learners come to rely too heavily on its motivating or guiding properties. This enhances performance during practice in which KR is present, but it is probably detrimental to learning as measured on a delayed test in which the learner must perform without KR. Also, relative frequency of KR should be large in initial practice, when guidance and motivation are critical; but then the instructor should systematically decrease relative frequency of KR as the performer becomes more proficient.

Trials Delay and Summary KR

The literature discussed so far has involved situations in which KR for a given trial is presented before the next trial (i.e., KR_n occurs before $trial_{n+1}$ in figure 12.1). However, what happens if the KR from a given trial occurs *after* the performance of the next few trials? Such a procedure, at first glance, would appear to be extremely disrupting for performance; it would be difficult for the learner to know which KR to associate with which movement, particularly when KR is increasingly separated from the trial to which it refers. We can probably think of practical situations in which this effect might occur—for example, when a learner performs a number of trials in a series, *after which* the instructor or therapist gives information about each trial or maybe about just one of the trials in the series. In such situations, the first trial in the sequence is separated from its KR by the intervening trials.

This method of giving KR was given the term *trials delay* by Bilodeau (1956, 1966, 1969). In contrast to what occurs in the usual KR paradigm, we see in figure 12.9 that one or more trials is interpolated between a given movement and its KR. In figure 12.9*a*, M_1 and KR_1 are separated by M_2—there is a one-trial delay between a given movement and its KR. In figure 12.9*b* there is a two-trial delay, with two trials separating a given

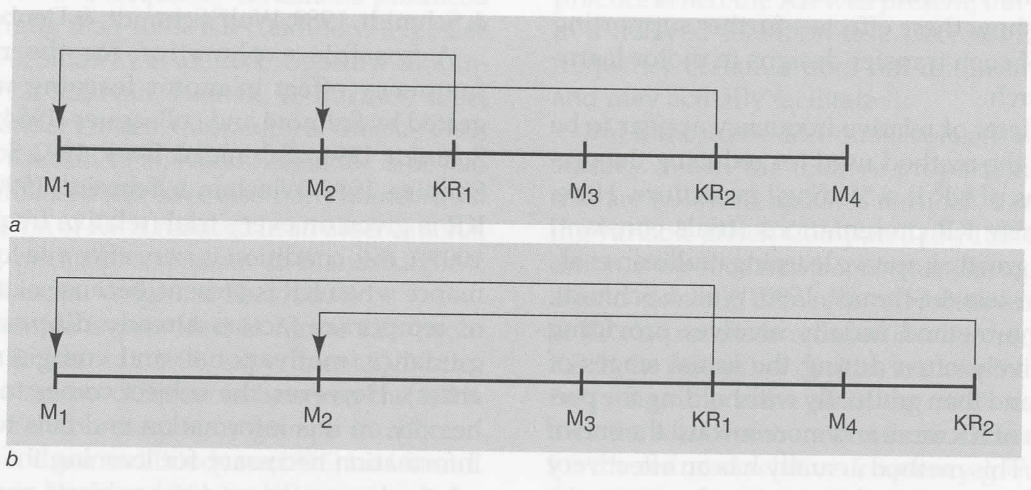

FIGURE 12.9 The trials-delay technique, showing a trials delay of *(a)* one and *(b)* two. (A given movement and its knowledge of results [KR] are separated by other trials of the same task.) M_1 refers to movement trial 1. KR_1 refers to the augmented feedback provided about results of movement trial 1.

movement and its KR. You can probably think of many different variations of this type of KR paradigm.

Bilodeau (1956) investigated the effects of trials delay using a lever-positioning task with blindfolded subjects. In two experiments, she varied the number of trials by which KR was delayed. In experiment 1, Bilodeau used zero-, one-, two-, and three-trials delay; in experiment 2, she used zero-, two-, and five-trials delay. Subjects were fully informed about this technique and were questioned to make certain that they understood how KR was being administered.

The data from the two experiments are shown in figure 12.10, where absolute error in positioning (for trials following KR) is plotted against trials for the various trials-delay conditions. For both experiments, performance accuracy systematically decreased as the trials delay was increased. This can be seen both in the "rate" of approach to the final performance level and in the level of final performance. These findings differed somewhat from earlier ones by Lorge and Thorndike (1935), who had found that improvement in performance did not occur at all under the trials-delay method. But there can be little argument that trials delay is a variable that has drastic negative effects on performance. In the earlier literature (e.g., Bilodeau, 1966), the interpretation of these trials-delay effects was in terms of learning, but these experiments did not use transfer designs to separate the temporary and relatively permanent effects. However, Lavery (1962; Lavery & Suddon, 1962) and others (e.g., Anderson, Magill, & Sekiya, 1994, 2001; Anderson, Magill, Sekiya, & Ryan, 2005) have used transfer designs in the study of this variable (and modifications of it), and their surprising results have had important influences on our thinking about how KR operates.

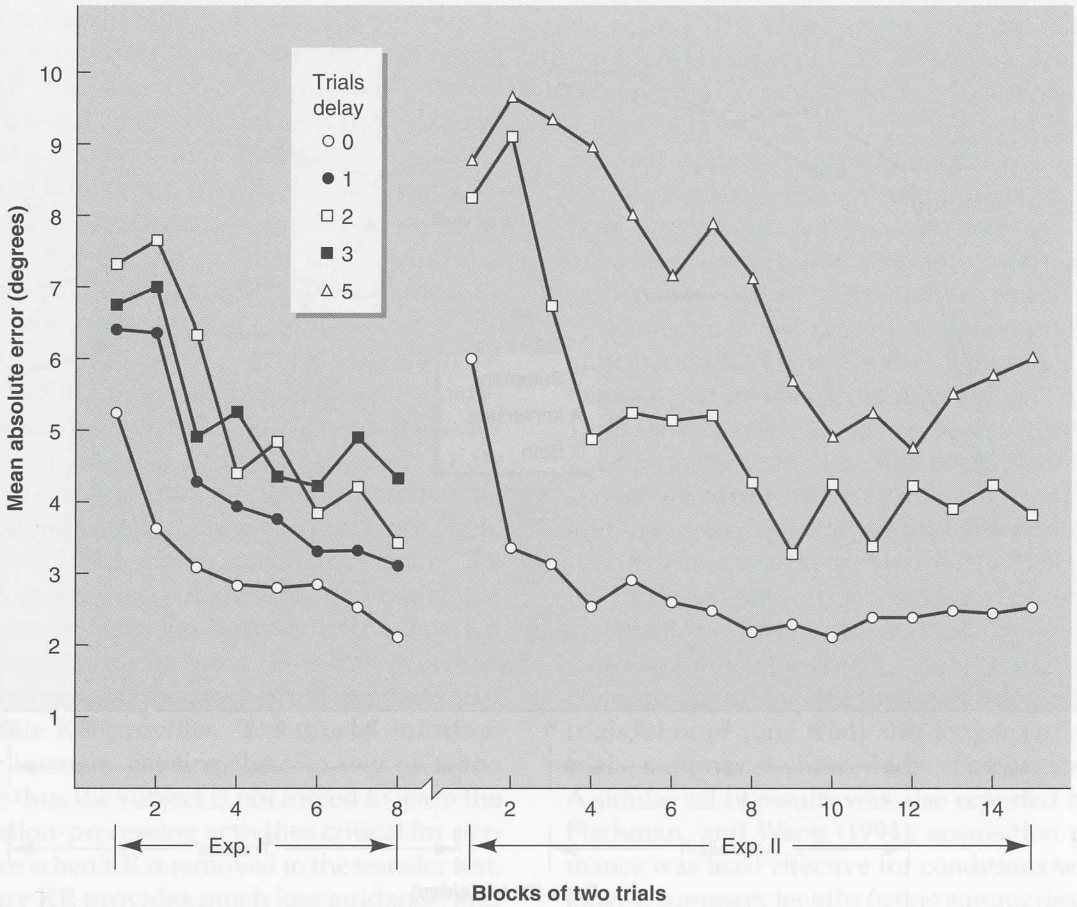

FIGURE 12.10 Absolute error in positioning as a function of the amount of trials delay in two experiments. (The group label indicates the number of trials separating a movement and its knowledge of results [KR].)

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Lavery (1962) used several tasks in which a ball was propelled up a track to a target. Three methods were used to give KR. One was the usual condition in which KR is given after every trial, called "Immediate." A second method was "Summary," in which the performance on every trial in a 20-trial sequence was shown, but only after the 20th trial had been completed; no KR was given after each trial as in Immediate. This summary technique was more or less the same as the trials-delay technique, as the KR for trial 1 was separated from its trial by the other 19 movements in the block, trial 2 by the next 18, and so on. Finally, the third condition involved *both* the immediate postmovement KR and the summary, labeled "Both." After an initial no-KR practice day, five days of practice were given under these conditions.

Performance on all the tasks averaged together is shown in figure 12.11. In acquisition, the number of correct trials was far smaller for the Summary group than for the two groups with KR after each trial (i.e., Immediate and Both). The addition of the summary information to Immediate to create Both did not improve performance very much relative to providing the usual postmovement KR (Immediate), so it is clear that the major determinant of performance was the immediate KR. But we knew this before, as this pattern of results is similar to the pattern in the study by Bilodeau (1956) in that performance in acquisition (while KR was present) was hindered by the trials-delay technique.

Now consider the measure of relative amount learned in this experiment—the performance on the transfer trials on days 7, 8, 9, 10, 37, and 93 for which no KR was provided at any time. The group that was formerly least accurate (i.e., Summary) was now the most accurate, and the other two groups, which had been the most accurate

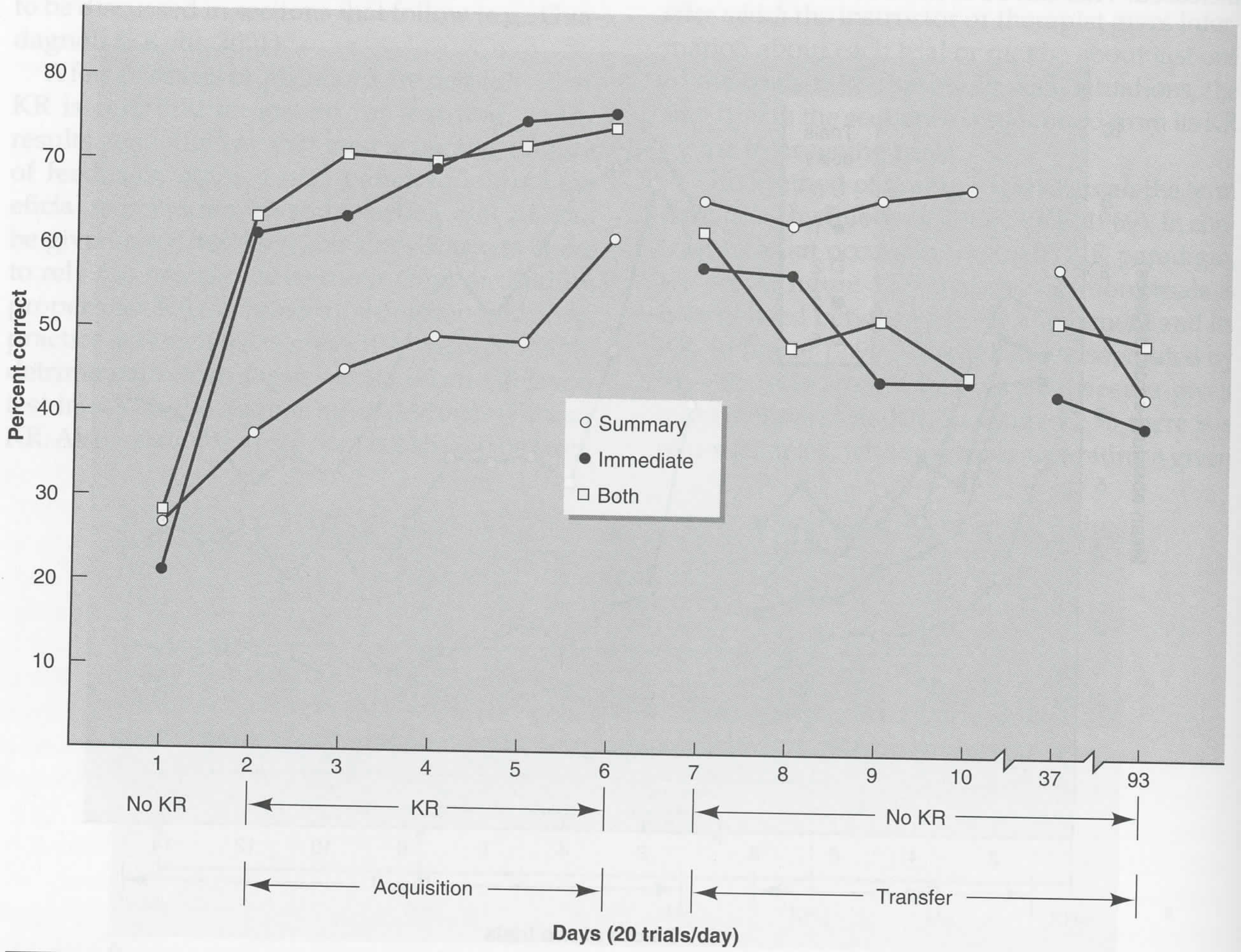

FIGURE 12.11 Percentage correct trials for various summary knowledge-of-results (KR) conditions. (Immediate had KR after every trial; Summary had KR about every trial presented after each block of 20 trials; and Both had both forms of KR.)

Reprinted, by permission, from J.J. Lavery, 1962, "Retention of simple motor skills as a function of type of knowledge of results," *Canadian Journal of Psychology* 16: 305.

(i.e., Immediate and Both), were now the least accurate. Furthermore, the latter two groups appeared to have lost accuracy with each successive no-KR day, while the Summary group did not. The effects persisted to day 37 but were essentially gone by day 93.

Which group learned the most? Using the performance on the transfer/retention test as the measure of relative amount learned, as described earlier, we are forced to conclude that the Summary (trials delay) condition was more effective for learning than either the Immediate or the Both condition. Notice that this is yet another example showing that the most effective condition for performance in acquisition was the least effective for learning! The basic experiment was repeated by Lavery and Suddon (1962), but with the same trials-delay methods as used by Bilodeau (1956), and the results were nearly the same as the findings shown in figure 12.11.

At first glance, we might be drawn to the interpretation that the summary KR per se was in some way effective for learning, providing a benefit over and above the normally useful immediate-KR condition. But look again. If summary KR was "good" for learning, then we should expect the Both group (which also had summary KR) to have benefited in a similar way. To the contrary, though, we see that the Both group performed almost identically to the Immediate group, both in the acquisition phase and in the no-KR transfer phase. One view is that, when KR was added to the normally effective summary-KR procedure to form the Both group, it *lowered* the level of learning to that of the Immediate group. In our interpretation (see Salmoni et al., 1984; Schmidt, 1991a; Schmidt, Young, Swinnen, & Shapiro, 1989), it was not that summary KR was necessarily responsible for the beneficial effect seen in learning, but that immediate KR was *detrimental* to learning! This interpretation is in keeping with the guidance hypothesis that immediate KR provides "too much" information for learners, causing them to rely on it too heavily; thus the subject is not forced to learn the information-processing activities critical for performance when KR is removed in the transfer test. Summary KR provides much less guidance, and presumably forces the subject to learn the task in a somewhat different way, perhaps by prompting the learner to gather information through alternative feedback sources (Anderson et al., 2005).

Optimizing Summary Length

It would seem that summary KR could easily be overdone, with summaries of so many trials that the guidance properties of KR would be minimal. Such thinking leads to the idea that there could be an *optimal* number of trials to be summarized, and that this optimum might also vary with task complexity in some way. In an experiment by Schmidt and colleagues (1989), summary KR was provided as a graph of performance against trials and was given either after each trial (an immediate-KR procedure) or after 5, 10, or 15 trials. In a relatively simple movement-timing task, increased summary length systematically degraded performance in the acquisition phase when KR was present, as Lavery had found earlier. But surprisingly, in a delayed no-KR transfer test, the most accurate performance was achieved by the group that had (in acquisition) received the 15-trial summaries, with systematically increasing error as the acquisition summary length decreased. The effect appeared to be related to long-term retention, with systematically poorer retention as the summary length decreased. The longest summaries produce the most learning; no clear optimal summary length was evident. Similar findings were also reported by Gable, Shea, and Wright (1991), with subjects in a 16-trial condition performing most effectively and no evidence for an optimal summary size.

In another investigation using a more complex, anticipation-timing task with KP provided rather than KR, summaries given after either 1, 5, 10, or 15 trials (Schmidt, Lange, & Young, 1990) were used as in the study just described. Figure 12.12 shows the performance in acquisition and on 10 min and two-day delayed no-KP transfer tests. Again, increasing the summary length degraded the performance in the acquisition phase, with systematically lower scores as the summary length increased. But in the no-KP transfer tests, the most effective summary length for learning was five trials; shorter (one trial) and longer (10 and 15 trials) summaries showed less effective learning. A similar set of results was also reported by Yao, Fischman, and Wang (1994); acquisition performance was least effective for conditions with the longest summary lengths (using summaries of 1, 5, and 15 trials). In the no-KR retention test, however, the five-trial summary condition was superior to both the every-trial and 15-trial summary conditions (see figure 12.13 on p. 417).

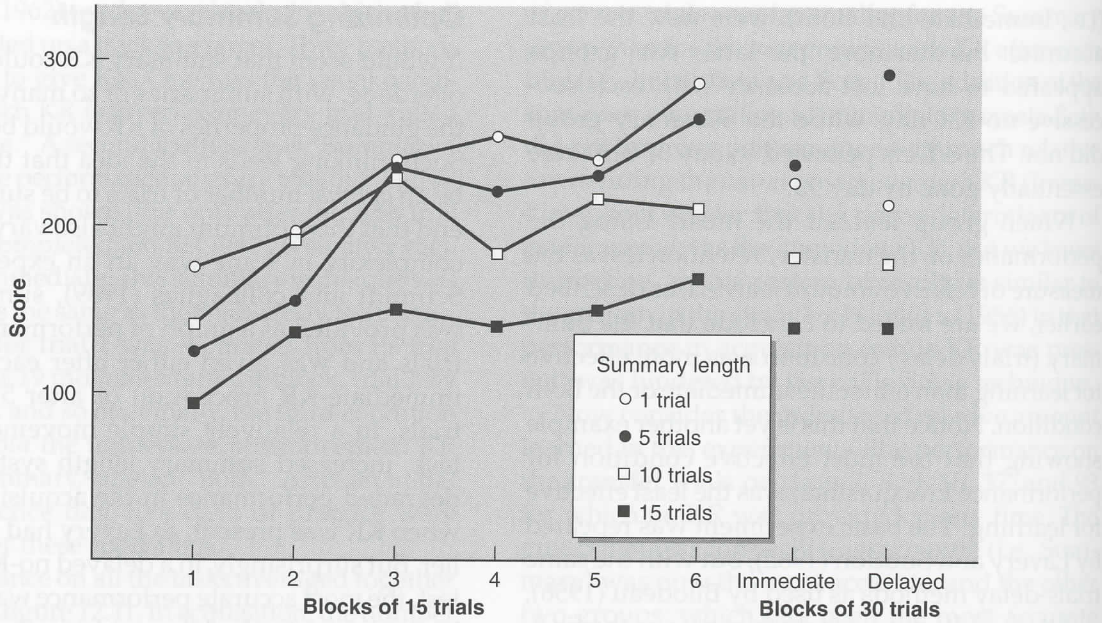

FIGURE 12.12 Performance score for various numbers of trials included in a summary-feedback presentation for acquisition (left) and immediate and delayed retention (right).

It seems clear from these studies that if optimal summary lengths do exist, these are likely to be task specific, perhaps in relation to the task's complexity. Such conclusions are supported in a clever experiment by Guadagnoli, Dornier, and Tandy (1996). In this study, Guadagnoli and colleagues had subjects learn simple and complex versions of a force production task. For the simple task, the largest (15 trials) summary condition produced the most learning; however, for the complex task, the smallest (one trial) summary group was optimal. These findings provide support for Schmidt and colleagues' (1990) suggestion that optimal summary-KR sizes are dependent on the amount of information provided in the summary, which is determined largely by the complexity of the task.

Statistical Summaries of KR

In many summary-KR experiments, performance on a series of trials is presented to the subject in the form of a graph that organizes the augmented feedback about *all* of the trials in summary fashion. When multiple KR presentations need to be given, the information is more readily understood when given graphically than when given numerically (Cauraugh, Chen, & Singer, 1993), perhaps because the numeric information overloads the processing capabilities of the learner. However, there is an interesting variant of the summary procedure that has been called *average KR*. Here, instead of providing KR about a block of trials in the summary, the average of the block of trials is determined and this mean score is provided as KR. In this way, the average represents a *statistical summary* of the block of trials rather than a *graphical summary*. In the study by Yao and colleagues (1994) discussed in the previous section, two additional groups of subjects received summary KR that was provided as a statistical average of either 5 or 15 trials. The results for a temporal measure of performance are presented in figure 12.13 (the findings for a spatial measure were similar).

As described in the previous section, acquisition performance was related inversely to the summary size, and no-KR retention performance was most accurate for the five-trial summary group and least effective for the every-trial group. Of particular interest, however, was that the groups receiving average summaries performed similarly to the groups that received graphical summaries. This was consistent for both acquisition and retention and for both the five-trial and 15-trial summary

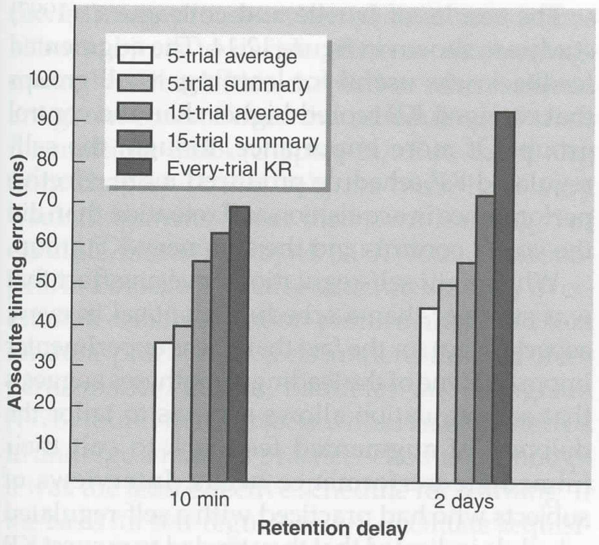

FIGURE 12.13 Absolute timing errors for various summary- and average-KR (knowledge of results) conditions.

conditions. These data suggest that the learning and performance effects of summary KR may be similar regardless of whether the summary is presented as a graph or as a statistical average (see also Weeks & Sherwood, 1994; Young & Schmidt, 1992). The similarity of effects of graphical and statistical forms of summary KR is also explained well by the guidance properties of KR, as the two methods work in similar ways to reduce the guiding properties of augmented feedback. But attempts to further tease apart the specific impact of KR summaries have had mixed success (Guay, Salmoni, & Lajoie, 1999; Guay, Salmoni, & McIlwain, 1992; Sidaway, Moore, & Schoenfelder-Zohdi, 1991; Wright, Snowden, & Willoughby, 1990).

Blocked Versus Random KR

Up to this point, most of the research we have reviewed has involved augmented feedback about one information source, such as KR for movement time or end-point accuracy. But consider the scheduling implications if there were many sources for which feedback could be provided. Suppose, for example, one were to provide KP about the gait of a stroke patient along with several forms of KP. Many potential sources of feedback could be used, but the amount of feedback would likely be overwhelming if all the feedback sources of information were provided at once. So, therapists intuitively withhold much of this feedback.

Now, suppose that only one source of feedback were used. On what basis is this one source to be chosen? Is it the one that has the most important impact on performance, the one that is most important for a safety concern, or the one that meets some other criterion? Moreover, if augmented feedback is provided relatively often, can it be about the same information source or different sources? These ideas have not been addressed frequently in research, although some interesting findings about scheduling have been reported using KR as augmented feedback (Lee & Carnahan, 1990b; Swanson & Lee, 1992).

Subjects performed a three-segment timing task in the Lee and Carnahan (1990b) study, with a specific timing goal for each segment. All subjects were given KR about one segment after each trial. The question was whether KR should be presented repeatedly on the *same* segment for a series of consecutive trials (blocked-KR schedule) or whether KR should be given about a *different* segment on each successive trial (random-KR schedule).[2] The results were rather surprising: The random-KR schedule was more effective for both performance *and* learning of the task. In acquisition, KR was beneficial when it was provided for a given segment, but performance deteriorated once KR was withdrawn from that segment (see also Swanson & Lee, 1992). Blocked KR focused learners only on the segment about which they were currently receiving KR, whereas random KR encouraged subjects to process information about all three segments on each trial.

These results suggest another way in which KR can have an overly directive or guiding function. In terms of the guidance hypothesis, blocked KR may have been directing the subject's attention to the one segment on which KR was being delivered, and treating that segment as just one part of the whole task. When KR was shifted elsewhere, it guided the subject to a different part of the task, again decomposing the task into parts. These conclusions should be considered with caution, however, until more research has been conducted using different tasks and feedback sources (e.g., Wulf, Hörger, & Shea, 1999).

Self-Regulated KR

To this point in the discussion of KR variables, we have directed our focus toward variables that are under the direct manipulation of the experimenter. We now turn our attention to a different experimental approach to deciding when to present KR (Huet, Camachon, Fernandez, Jacobs, & Montagne, 2009; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle, Kim, & Singer, 1995; Wulf & Toole, 1999). In this paradigm, subjects perform a movement task and are presented with the *option* of receiving augmented feedback or not. For example, subjects in a study by Janelle and colleagues (1997) practiced throwing a ball at a target with their nondominant limb. Transitional KP was provided in a manner similar to that in the Kernodle and Carlton (1992) study discussed earlier. A control group received no KP, and another group received a summary-KP statement after every fifth trial. The group of most importance here followed a self-regulated schedule, in which KP was provided only when subjects asked to receive the augmented feedback. The final group was another control group that was *yoked* to the self-regulated group—the KP delivery schedule for each subject in this yoked group was matched to a member of the self-regulated group. In this way, the yoked control subjects received the same number of KPs as the self-regulated subjects, and on the very same trials in the acquisition schedule sequence. The key difference was that the subject in the self-regulated group actively chose which trials would receive KR; the yoked controls did not.

The results of Janelle and colleagues' (1997) study are shown in figure 12.14. The augmented feedback was useful for learning, as all groups that received KP scored higher than the control group. Of more importance, though, the self-regulated KP schedule produced more effective performance in acquisition and retention than did the yoked controls and the summary-KP group.

Why might self-regulation have an effect that was stronger than a schedule identical in every aspect except for the fact that it was experimenter imposed? One of the leading hypotheses suggests that self-regulation allows subjects to tailor the delivery of augmented feedback to suit their immediate performance needs. Interviews of subjects who had practiced with a self-regulated schedule indicated that they tended to request KR after trials in which performance was believed to have been relatively effective, rather than after ineffective performances (Chiviacowsky & Wulf, 2002). In response to this finding, Chiviacowsky and Wulf (2005) performed a nice experimental test by comparing self-regulated conditions in which subjects made the determination to receive KR either before or after the trial. They found a benefit for learning when self-regulation occurred after the trial.

These findings, however, represent a puzzle in the literature. Self-regulation appears to facilitate

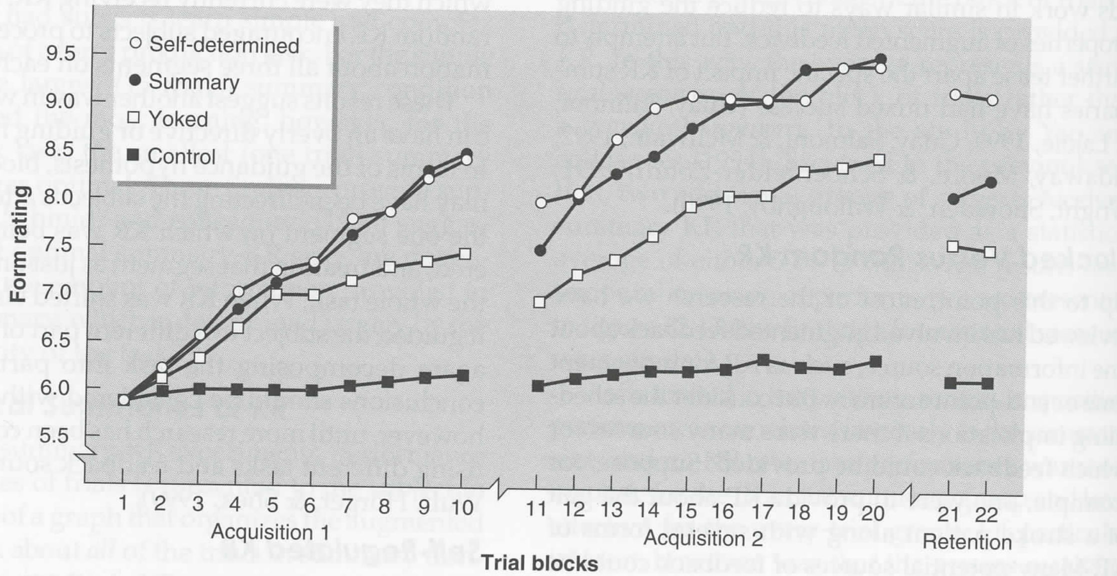

FIGURE 12.14 Effects of a learner-determined feedback schedule in acquisition and retention relative to a frequency-yoked control group, a no-feedback control group, and a summary-feedback group.

the learning process when practice conditions allow subjects to decide when to receive augmented feedback (this chapter) or when subjects are given control over the scheduling of trials for multiple tasks (chapter 11). But, recall also from chapter 11 that subjects often have very weak judgments about their own learning. For example, Simon and Bjork (2001) found that subjects in a blocked practice schedule severely overestimated their retention performance, and that random practice subjects underestimated their performance. Earlier, Baddeley and Longman (1978) found that subjects would have preferred to undergo a massed practice schedule, although it was the least effective schedule for learning. If the basis for self-regulation is to facilitate acquisition *performance*, then why is *learning* not detrimentally affected, as we have seen in situations such as the contextual-interference effect? How can these findings be reconciled?

One possibility suggests that the mere *decision* to receive augmented feedback or not engages the learner in the process of self-assessments during practice (see also Cleary, Zimmerman, & Keating, 2006). As we will discuss later on page 426 in "How Augmented Feedback Can Degrade Learning," factors that encourage the processing of inherent feedback are usually considered strong learning variables. Another suggestion, offered by Chiviacowsky and Wulf (2005), is that the strong tendency to request feedback after "good" trials could mean that the KR is serving a strong motivational role—confirming the learner's hunch that the trial's performance was indeed "good" (similar to the rationale underlying the bandwidth KR effect). Support for or rejection of these ideas awaits further research.

Temporal Locus of KR

The next two sections deal with the question of *when* KR is presented in the events prior to and following a practice trial. The question really concerns the three intervals defined in figure 12.1—the KR delay, the post-KR delay, and the intertrial interval—and the ways in which experimentally altering these intervals affects learning and performance. The problem is complicated by the fact that when one of the intervals is lengthened experimentally (e.g., KR delay) and another is held constant (e.g., post-KR delay), then the third interval (in this example, the intertrial interval) must also increase. The effects of the KR delay and the intertrial interval are then *confounded*, so that any resulting change in learning cannot logically be attributed exclusively to either one of them. This fact sometimes makes it difficult to be certain about the particular roles these intervals have in the learning process, as we see in the following sections.

KR-Delay Interval

The KR-delay interval is the amount of time KR is delayed after a movement. Many experimenters have examined feedback delays and motor learning, beginning with Lorge and Thorndike (1935). For a variety of reasons, scientists have always expected to find that increasing the KR delay degrades learning. One reason is that analogous effects in instrumental learning in animals are particularly strong (Lieberman, Vogel, & Nisbet, 2008). Delaying the reward (e.g., a pellet of food) slightly in time from the animal's bar-press movement has large effects on animal learning, and delaying the reward too much eliminates learning completely (Fantino & Logan, 1979; Tarpy & Sawabini, 1974). Scientists expected something like this for KR delay in human motor learning as well. A second reason is that because movement information is lost rapidly from memory (e.g., Adams & Dijkstra, 1966), learning should be less effective as the feedback delay from the associated movement is increased. This would seem to weaken the possibility for the learner to *associate* commands for the movement with its actual outcome—a concept critical to many early theoretical ideas about learning.

However, as reviewed by Salmoni and colleagues (1984), the experiments in human motor learning examining the delay of KR have almost uniformly failed to show that increasing the KR delay has any effect at all. For example, Lorge and Thorndike (1935) used delays of either 1, 2, 4, or 6 s and found no effect in an acquisition phase; but no transfer design was used here to evaluate effects on learning. Perhaps the delay was not sufficiently long. Other studies have used much longer delays ranging from a few seconds to a few minutes; one study even used a delay of one week! Whereas a few studies have shown small, somewhat inconsistent effects on performance, the majority of research has shown no effect (e.g., Schmidt & Shea, 1976). Recent work has used various transfer designs to assess the temporary versus relatively permanent effects of KR delay. There are numerous studies showing no effects, or at best very small effects, and we must doubt that delaying KR has a *detrimental* effect on motor learning.

In contrast, there is some evidence to suggest that detriments to learning can occur if the KR delay is *too short*. Swinnen, Schmidt, Nicholson, and Shapiro (1990) compared groups of subjects who received KR after each trial—either at a short delay after performance was completed (3.2 s) or *instantaneously* upon completion of the trial. As illustrated in figure 12.15, acquisition performance was not affected on the first day of practice by the KR conditions. Performance improvements increased steadily for the delayed-KR group on a second day of practice, but not for the instantaneous-KR group. Learning, as measured in no-KR retention tests after various time intervals, was also facilitated by having KR delayed for a short time. It seems that the instantaneous KR enhanced performance to a point, but retarded both continued improvement and retention after that.

The degrading effects of instantaneous KR are strikingly similar to the effects of concurrent KR, discussed in the previous chapter, in the study by Armstrong (1970b). Take another look at figure 11.19 (p. 387). In chapter 11 we discussed how guided practice degraded learning of a spatial-temporal pattern, relative to a terminal-feedback condition. Armstrong also included a condition in which augmented feedback was presented concurrently, as the subject performed the task. Although this concurrent feedback had a positive influence during practice, it severely degraded learning as seen in the transfer phase, suggesting that the concurrent feedback provided only a temporary boost to performance. These detrimental learning effects have been replicated often (Maslovat, Brunke, Chua, & Franks, 2009; Ranganathan & Newell, 2009; Schmidt & Wulf, 1997; Vander Linden et al., 1993); but they can be lessened by reducing the relative frequency of trials accompanied by concurrent feedback (Camachon, Jacobs, Huet, Buekers, & Montagne, 2007; Park, Shea, & Wright, 2000). This evidence supports the interpretation that frequent, concurrent feedback results in a learning effect that is

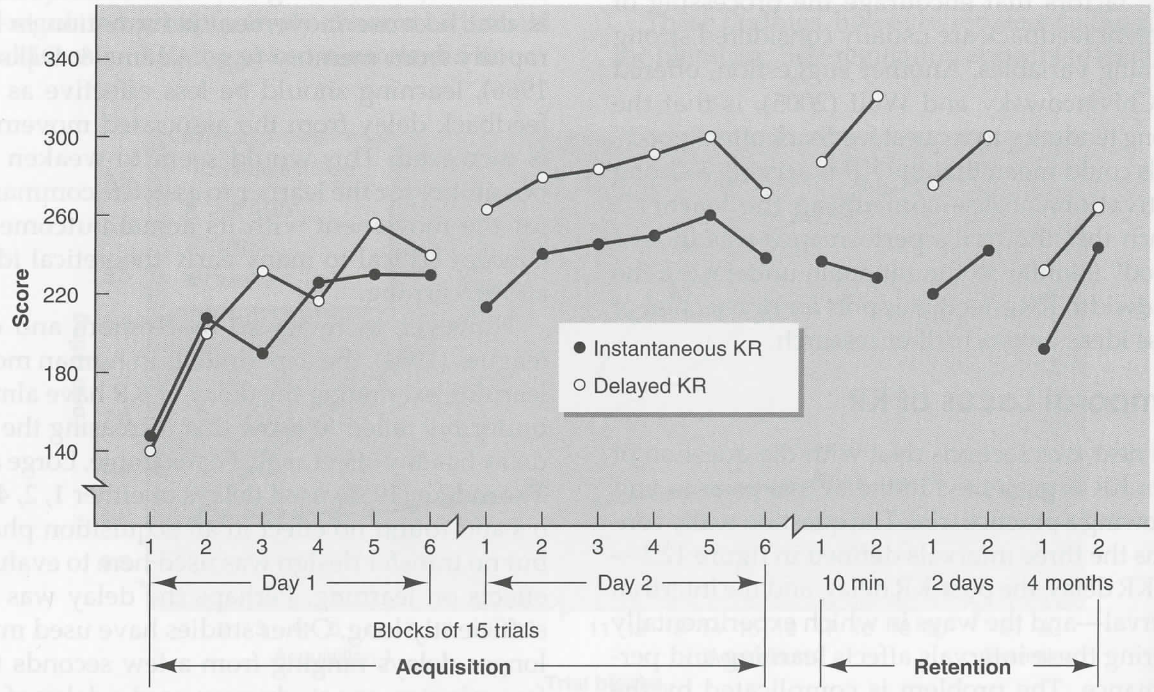

FIGURE 12.15 Performance scores of instantaneous- and delayed-KR (knowledge of results) conditions in acquisition and retention.

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highly dependent on maintaining the provision of concurrent information to support performance.

Post-KR-Delay Interval

Next, consider the other portion of the intertrial interval—the post-KR-delay interval, or the time between the presentation of KR and the production of the next movement. In contrast to the hypothesis that the subject is trying to remember the aspects of the movement during the KR-delay interval, during the post-KR-delay interval it appears that other processes are occurring. In particular, KR has now been delivered, likely indicating that the movement was incorrect in some way. Now the learner must generate a movement that is *different* from the previous one, hopefully one that is more correct. So, in contrast to the hypothesis that during the KR-delay interval the learner is storing movement information, in the post-KR-delay interval the learner is thought to be an active and creative movement problem solver.

If the subject is actively processing KR to change the movement during post-KR delay, then shortening the post-KR-delay interval past a certain point should decrease learning in the task, as the person would not have sufficient time to develop an effective new movement. Some support for this view exists in the verbal learning literature using *concept-formation tasks* (e.g., Bourne & Bunderson, 1963; Bourne, Guy, Dodd, & Justesen, 1965; Croll, 1970; White & Schmidt, 1972). The literature on motor learning and performance, however, does not show close parallels to these findings for concept formation. In the acquisition phase, decreasing the post-KR-delay interval does have slight detrimental effects on performance accuracy in both adults (Weinberg, Guy, & Tupper, 1964) and children (Gallagher & Thomas, 1980), but no transfer designs were used in these studies to assess learning effects. When transfer designs are used, however, decreasing post-KR delay also degrades learning, but only when KR delay is held constant, not when the intertrial interval is held constant. Salmoni and colleagues (1984) argued, therefore, that it was the intertrial interval that seemed to be the important one for learning. But there is still some evidence that learning might be reduced when the post-KR delay is very short. Taken together, the evidence does not suggest that the length of this interval, per se, is very important for learning. But this is not to deny the role of processes that occur here, as they could occur quite rapidly for these very simple motor tasks, and varying the length of the interval might not severely limit processing.

Intertrial Interval

The intertrial interval, or the sum of KR delay and post-KR delay (figure 12.1), has been the object of considerable *indirect* study—mainly because it covaries when either one of the intervals composing it varies, and not because of much interest in the intertrial interval per se. According to a review by Salmoni and colleagues (1984), there are many conflicting results on intertrial-interval effects for performance during the acquisition phase, obtained from a variety of experimental procedures; little generalization seems possible. McGuigan (1959) and Dees and Grindley (1951) have shown, however, that increasing the intertrial-interval length increases learning as measured on no-KR transfer tests, similar to distributed-practice effects discussed in chapter 11. Perhaps longer intertrial intervals result in increased forgetting of the *solution* to the motor problem generated on the previous trial and thus require an active generation of the motor program again on the next trial. These forced generations could be very important for the learning process, as has been inferred from the contextual-interference literature discussed in the previous chapter.

Interpolated Activities During KR Intervals

What is the effect of requiring the learner to perform various activities during otherwise "empty" KR intervals? This question is motivated by an information-processing viewpoint about KR according to which certain other activities could interfere with various processes that occur during these KR intervals and thus the effects should be seen in learning of the task. As we will see, however, various interpolated activities either have no influence, a positive effect, or a negative impact on learning, depending on the nature of the interpolated activity and the delay interval during which it is interpolated.

Interference During the KR-Delay Interval

The influence of various activities during the KR-delay interval may be referred to as "interfering" if they distract the learner from processing the inherent feedback from the performance just completed. For example, Shea and Upton (1976) had subjects perform linear-positioning movements, but *two* positions were to be practiced and learned on each trial rather than one. On a given trial, the subject would produce movement 1, then movement 2, then would engage in the performance of other movements (or would rest if in the other condition); then after 30 s the subject would receive KR about movement 1 and movement 2, then engage in the next trial, and so on. Filling the KR-delay interval increased absolute error on the acquisition trials, indicating that the extraneous movements had a negative effect on performance. And, in the no-KR transfer trials it seemed clear that the decrements in performance caused by the extraneous movements did, in fact, interfere with the learning of the tasks. Marteniuk (1986), Swinnen (1990), and Lieberman and colleagues (2008) provided similar results using more complex motor tasks.

What is happening here? One interpretation of these findings is that the subjects usually engaged in various information-processing activities during the KR-delay interval and that the requirement of the extraneous movements in some way interfered with this processing, degrading learning as it did. What kind of processing might this be? Marteniuk (1986) argued that the interference is from relatively high-level planning processes. But it is also possible that the subject must retain in short-term memory the sensory consequences of the movement until the KR is presented so that the two can be compared. The retention of information is important in order to develop an error-detection capability (capability to detect errors based on inherent feedback sources). If other movements are required, then there will be either a blocked capacity to hold the information in short-term memory or a reduced precision of the inherent feedback, resulting in less effective use of KR when it is presented.

Subjective Estimations During the KR-Delay Interval

Support for the interpretation just outlined is provided in situations in which subjects are *encouraged* to undertake error estimation during the KR-delay interval. Hogan and Yanowitz (1978) asked some subjects to estimate their own errors in a ballistic-timing task prior to receiving KR on each trial. In an acquisition session with KR present, there were essentially no differences between these subjects and another group of subjects who did not estimate their errors. But in a transfer test without KR, the subjects who were estimating maintained performance nearly perfectly, whereas those subjects who did not estimate regressed systematically over trials. One interpretation is that the estimation conditions in acquisition forced the subjects to attend to their own movement-produced (inherent) feedback to a greater extent than the no-estimation conditions did, thus enabling them to acquire an error-detection capability. This capability was not particularly useful in acquisition because of the powerful guiding properties of KR. But in no-KR transfer, subjects who had gained this error-detection capability through estimation in acquisition were able to maintain performance, whereas the no-estimation subjects were relatively unaware of their own errors and drifted off target. Swinnen (1990; Swinnen et al., 1990) extended and refined the Hogan-Yanowitz paradigm in various ways, using different tasks and transfer tests, in an attempt to understand these phenomena more completely. Overall, there continues to be support for the notion that asking for error estimation in acquisition is effective for learning as measured on no-KR transfer tests.

But some additional experiments suggest that these effects might be more complex than originally conceptualized. Two recent studies have revealed this to be the case. In one study, Liu and Wrisberg (1997) investigated the effects of subjective estimations of movement form error in a throwing task by the nondominant limb (Kernodle & Carlton, 1992). Subjects in two groups saw the outcome of their throw either immediately or after a 13 s delay. In two other groups, the subjects provided subjective estimates of their throwing *form* either just after seeing the outcome of the throw or during the delay interval. As shown in figure 12.16, the performance of these two subjective estimation groups was more accurate in retention than that of the two groups who did not estimate their movement form. From the perspective suggested earlier, this result is rather surprising because in the immediate + estimation group, the subjective estimation occurred after the KR, not during the KR-delay interval, which is typical of most studies of this type. One view of the

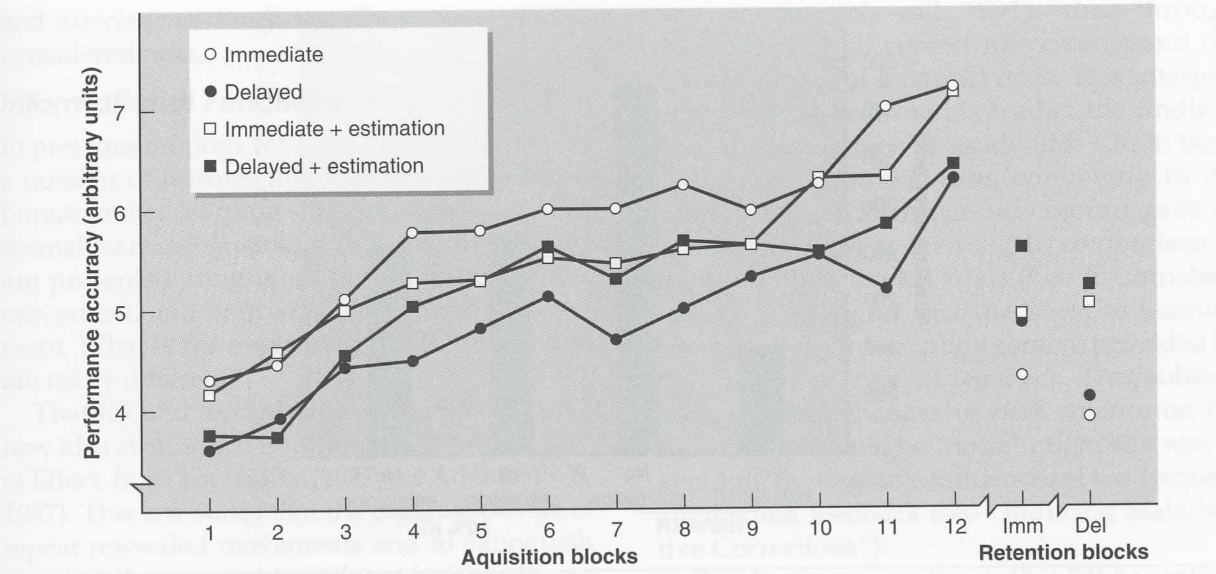

FIGURE 12.16 Combined effects of feedback delay and estimation in the acquisition and retention of a throwing task using the nondominant limb.

From J. Liu and C.A. Wrisberg. Adapted with permission from *Research Quarterly for Exercise and Sport*, vol. 68, pgs. 145-151. Copyright 1997 by the American Alliance for Health, Physical Education, Recreation and Dance, 1900 Association Drive, Reston, VA 20191.

results is that merely estimating something that will be confirmed or corrected by the augmented feedback is not enough—perhaps one needs to estimate something about the performance itself, which is then supplemented by other augmented information and used in the problem-solving process.

Another study (Guadagnoli & Kohl, 2001) offers a related idea regarding the combined effects of subjective estimation and reduced relative frequency of KR. Subjects performed 150 trials in a force-estimation task followed by a no-KR retention test one day later. Four groups were formed based on the factorial combination of relative frequency of KR (100% vs. 20%) and error estimation (every trial vs. no estimation). The 100% relative-frequency condition produced the most accurate retention, but only if accompanied by error estimation during practice (see figure 12.17). If KR was provided on every trial in the absence of any error estimation, then this condition produced the most error in retention. The performance of the other two groups showed that error estimation on every trial was only moderately effective when KR was presented on only 20% of the trials, but that reduced relative frequency was moderately effective even in the absence of error estimation (perhaps due to spontaneous estimation in this group).

These two experiments suggest that error estimation is an important factor in the use of augmented feedback in motor learning. The contribution of error estimation to learning appears to be diminished if it is not accompanied by augmented feedback (Guadagnoli & Kohl, 2001). Yet it also appears that estimating something about performance that encourages the learner to interpret the augmented feedback provides a boost to learning as well (Liu & Wrisberg, 1997).

The issues about error detection are important for theoretical reasons, but there is a strong practical application also. We can think of the self-detected error as a kind of substitute for KR, as it informs the subject about the size and direction of the error that was just made. It is unfortunate that nearly all the focus in learning environments is on performance and that there is almost no concern for the development of the learner's error-detection capacity (but see Schmidt & White, 1972). If procedures could be developed for increasing the strength of error detection, then learners could develop hypotheses about their performance that could then be checked against the objective information provided later in the form of augmented feedback from the teacher or coach. Effective teachers and coaches attempt to establish such error-detection

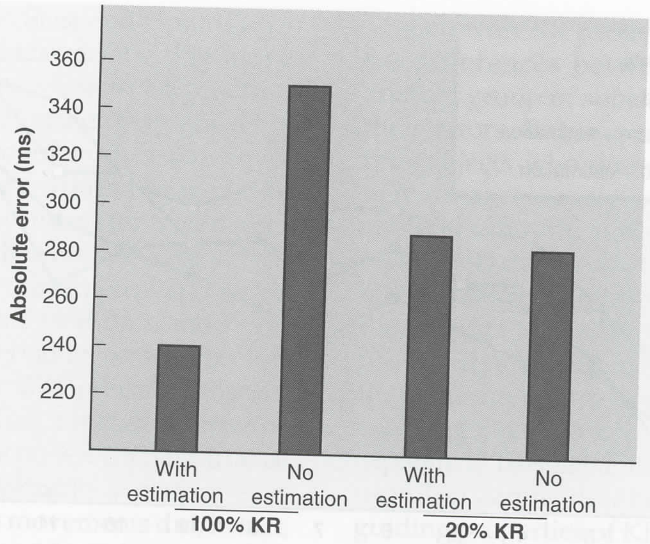

FIGURE 12.17 Combined effects of feedback frequency and estimation in the retention of a force production task.
Data from Guadagnoli and Kohl 2001.

capabilities that can be effectively used for self-evaluation when the teacher or coach is not present.

Interference During the Post-KR-Delay Interval

The focus of processing activities during the KR-delay interval is on movement-produced inherent feedback. During the post-KR delay, however, the processing activities are likely focused on using augmented feedback to alter movement behavior on the next attempt. A number of early experimenters who interpolated activities in the post-KR interval showed that performance was degraded (e.g., Boucher, 1974; Rogers, 1974; but see Magill, 1973), but these studies did not use transfer procedures to assess learning (see Schendel & Newell, 1976, for a discussion). Later experimenters who used transfer tests produced mixed results. Swinnen (1990) and Benedetti and McCullagh (1987) found that interference during the post-KR delay was detrimental as measured in a no-KR retention test; Lee and Magill (1983a, 1987) found no detrimental effects of interpolated activities measured in a transfer test; and Magill (1988) found that such activities were actually beneficial. The rather equivocal nature of these findings makes it difficult to infer practical applications. However, given the comparative strength of these effects, it would appear that instructors should be more concerned about extraneous activities in the KR-delay interval than in the post-KR-delay interval.

Theoretical Issues: How Does Augmented Feedback "Work"?

The previous sections have presented various separate facts in connection with the functioning of augmented feedback in motor learning situations. Some of these have obvious relevance for practical situations, whereas others have distinct implications for how we believe feedback operates in humans to facilitate learning. In this section, we consider some of these implications.

How Augmented Feedback Can Enhance Learning

The research presented in this chapter suggests three possible ways in which KR and KP operate to affect learning in a positive way, and theories of learning have generally adopted one or more of these positions. Both KR and KP are considered to have *informational, motivational,* and *associational* functions. These concepts are considered next.

Informational Functions

In previous sections we have drawn attention to a number of features that are common to KR in human motor learning situations and reward in animal learning situations. Both KR and reward are presented contingent on the nature of the movement, and both are given after the movement. What is the evidence that KR and reward are really different?

That KR and reward might be similar is not a new idea at all, and it is the foundation of the Law of Effect, from Thorndike (1927; see Adams, 1978, 1987). This law states that the organism tends to repeat rewarded movements and to extinguish (or avoid) movements followed either by no reward or by punishment. For motor learning, according to this concept, KR indicating small errors or no error was thought to be a type of "reward," and KR indicating large errors was thought of as "punishment." In this way, the movements followed by nonreward were eliminated, and those followed by reward (i.e., zero or small error) tended to be repeated, leading to decreasing errors with practice.

However, numerous lines of evidence suggest that humans do not use KR as proposed by this interpretation of the Law of Effect. First, when KR is not presented (on no-KR trials), subjects tend to *repeat* the given movements rather than to eliminate them. Only when KR is presented do subjects change their movement behaviors, and then quite clearly in the direction of the target. It would seem that subjects are not using the KR as a reward, but rather as *information* about what to do next. In addition, even a short delay of reward in animal learning severely retards acquisition, and delaying reward by 30 s or so can eliminate learning. Of course, we do not find these effects at all in humans, as the delay of KR seems to have no effect on motor learning. Thus, reward in laboratory rats and KR in humans seem to involve fundamentally different principles of operation (see "Elwell and Grindley on Knowledge of Results").

For these major reasons, the current belief about augmented feedback is that it produces learning more by the provision of *information* about what was wrong with the previous trials—and by *prescriptive* means to improve performance (Newell, 1991)—than through the rewarding of correct movements and the "punishment" of incorrect ones. This interpretation would seem to contradict the findings from manipulations of bandwidth KR; in these experiments, information conveying to the subject that performance was correct gave an additional boost to learning in comparison to the learning in no-KR trials (Lee & Carnahan, 1990a). We suggest that the boost to learning came from the information content provided by this "no error" type of feedback. That subjects resist making changes to performance on the basis of what could be "noise" might be a way of avoiding the negative influences of too-frequent augmented feedback (see "Inducing Maladaptive Corrections").

One further suggestion is that KR has *optimal* informational value when the learner is *uncertain* about the reliability of his inherent sources of information. A dictionary provides a useful analogy here. The dictionary is like KR in that it is an externally available, objective, and reliable source of knowledge, providing augmented information such as the spelling or meaning of a word. The decision to consult a dictionary arises because we have questioned the reliability of our inherent knowledge; we do not consult the dictionary otherwise. Thus, the dictionary provides the means for assessing (and improving) the reliability of our spelling knowledge. One hypothesis arising from this analogy is that augmented feedback can be optimally useful when the subject asks for it—a concept that has received support from recent experiments (see the earlier section on self-regulated KR).

Motivational Functions

As mentioned earlier, receiving information like KR and KP can play a strong motivating, or "energizing," role. Augmented feedback may make the task seem more interesting, keep the learner alert, cause the learner to set higher performance goals, and generally make boring tasks more enjoyable. Some of the effects of motivation are probably performance phenomena, which can be expected to subside when the feedback is withdrawn after training. But there is an indirect learning effect that should not be ignored. When learners are highly motivated, they are inclined to practice more often, longer, and with more intensity and seriousness. Of course, deliberate

They said it . . .

Elwell and Grindley on Knowledge of Results

Elwell and Grindley (1938) provided the first major challenge to Thorndike's ideas regarding the role of KR in motor learning; this is developed more completely in three subsequent papers (Dees & Grindley, 1951; MacPherson, Dees, & Grindley, 1948, 1949). They suggested that KR provided more than just a rewarding function, and their arguments formed the basis for what was later called the *informational* role of KR. The authors stated:

"In the acquisition of a muscular skill, such as that described in the present paper, the learning cannot be regarded merely as the strengthening of the tendency to repeat movements which have been 'rewarded' (by a high score). If a subject missed the bull's-eye he tried, next time, to correct for his error by altering his response in the appropriate direction. . . . Knowledge of results, when the movement was not completely successful (i.e., when it did not result in a bull's-eye) introduces also a tendency towards a specific kind of variation of the response which has just been made. We may call this the 'directive effect' of knowledge of results." (p. 51)

practice per se is a critical variable for learning, and any factor that increases it will almost surely enhance learning (Ericsson, 1996; Ericsson, Krampe, & Tesch-Römer, 1993). Recent evidence suggests that there may be a more direct effect on learning as well (Chiviacowsky & Wulf, 2007; Lewthwaite & Wulf, 2010), which may require revised views of the motivational role of feedback in the future.

Associational Functions

A different view is that KR is associational—providing associations between stimuli and movements. One version of this concept is provided within schema theory (Schmidt, 1975b), according to which KR is thought to operate associationally as well as in the ways that Adams (1971) has suggested (both theories are discussed in more detail in chapter 13). In schema theory, with respect to rapid movements that are presumably controlled by motor programs, the person associates the KR received on a trial (a measure of what happened in the environment) with the parameters of the generalized motor program (GMP) that were issued to produce that outcome in the environment. With practice, the learner comes to develop a rule (or schema) about the relationship between what the limbs were "told to do" and "what they did when told to do it." On this basis, knowing what kinds of internal commands tend to produce certain kinds of movements, the learner has a way of selecting the parameters of the movement on future trials. Thus, in this view, KR serves more than a guidance function toward the target; it also provides a rule about the relationship between internal commands and the outcomes that were produced in the environment.

How Augmented Feedback Can Degrade Learning

Another view of how KR works is that it guides the learner to making the correct movement. Thus, when the learner makes a movement, KR informs the person about how the movement was inadequate, and the learner then changes the movement to one that (hopefully) will be more adequate. Augmented feedback thus carries inherent "instructions" about which aspects of the movement should be changed, as well as about the directions those changes should take. According to this position, KR does not provide any direct strengthening of the movement but creates it indirectly by guiding the person to the proper action. Once the proper actions are being produced, other processes take over to help the person learn the task.

This view is fundamental to Adams' (1971) learning theory, which says that KR presented after each trial of a slow positioning movement guides the person toward the correct location. Then, as the learner achieves positions close to the target, she also receives kinesthetic feedback associated with the proper position, and this feedback forms an internal representation of being at the target (a reference of correctness). This internal representation becomes stronger with each successive trial near the target and thus provides an increasingly effective means for detecting errors. Thus, according to Adams, KR has a guidance role in driving the subject closer and closer to the target so that a reference of correctness can be formed.

Considered in this way (as envisaged by Adams, 1971), the guiding influences of augmented feedback on learning should always be positive. As we have seen, however, in some experiments the KR effects showed that increased guidance *degraded* learning (leading to doubts about Adams' theory; see chapter 13). We consider reasons why feedback can degrade learning in the next sections (see also Salmoni et al., 1984; Schmidt, 1991a; Schmidt & Bjork, 1992).

Blocking Other Processing Activities

When augmented feedback is provided frequently, immediately, or otherwise in such a way that various processing activities are not undertaken, then there will likely be a decrement in learning. One of the negative influences of augmented feedback may be to *block* the processing of inherent sources of feedback, which then leads to the failure to learn error-detection capabilities for this task. Augmented feedback is often a very salient source of information, and one that will be attended to even when doing so may not be in the learner's best interest (Buekers et al., 1992). The presentation of instantaneous KP (Swinnen et al., 1990), which was discussed earlier, is an example of a case in which the saliency of the augmented feedback is maximized. We interpret results of this type as suggesting that the augmented feedback blocked the processing of alternative sources of information and reduced the learning effectiveness of the practice session as measured in retention.

Inducing Maladaptive Corrections

One of the fundamental views about the directive function of augmented feedback is that it tells the learner what went wrong and how to fix it. As we found in our discussion of precision of KR, more precise KR can be beneficial, but only up to a point. The idea is similar here. When each trial is followed by information about errors, there is a tendency for the subject to make a change for the next trial based on that error. The problem is that motor performance is variable, and a change meant to correct a very small error might actually make the error larger on the next trial. The idea is that KR induces movement variability, not all of which is adaptive in producing improved learning. Sometimes augmented feedback can have maladaptive corrective properties (R.A. Bjork, personal communication), in which case withholding feedback (and stabilizing performance) seems to be beneficial for learning. Presenting information that encourages a subject to correct an action that was essentially accurate may have a detrimental impact on learning (Schmidt, 1991a; Schmidt & Bjork, 1992).

Bandwidth KR effects illustrate how maladaptive corrections may be avoided. Under bandwidth KR conditions, there exists a zone of acceptable error within which movement is considered correct. Defining the actual width of the band of correctness, as well as what would be considered maladaptively corrective and what would be considered too imprecise, is a challenge for future research. However, we suspect that an *optimal KR bandwidth* may be closely related to the precision of an individual's motor control capabilities, although even within an individual this is likely to change (e.g., with learning and aging).

Summary

Feedback is that class of sensory information that is movement related, and it can be classified into two basic categories—*inherent* (intrinsic to the task) and *augmented* (supplementary to the task). Two major classes of augmented feedback include KP, which is information about the form of the movement, and KR, which is verbal postmovement information about performance outcome. Much research suggests that the provision of augmented information is the single most important variable for motor learning (except for practice itself, of course).

Information about the learner's movements (KP) can be given through video feedback, recordings of the force–time characteristics of the movement (kinetics), or representations of the movement trajectories (kinematics); and all these appear to have positive effects on performance and perhaps on learning. The impact of KP on learning appears to be strongest when it precisely specifies information that is critical for movement efficiency and that cannot be obtained from other sources of feedback.

Research on KR precision shows that performance improves with increases in precision up to a point, with no further increases in performance thereafter. Presenting combinations of qualitative and quantitative KR, based upon a goal-related bandwidth of correctness, has strong implications for both application and theory.

Early research indicated that the *relative frequency* of KR (the percentage of trials on which KR was given) was irrelevant for learning, whereas the absolute frequency (the number of KR presentations given) was the critical determinant. More recent data using transfer designs contradict this position, indicating that both are clearly important. Trials on which no KR is given appear to contribute to learning in the task, but not as much as the KR trials do. The trials-delay and summary-KR procedures, in which the KR for a given movement is separated from the movement by other trials, were shown to produce detrimental effects on motor performance but positive effects on learning.

The effect of delaying KR, that is, the effect of the interval from the movement until KR is presented, has been found to be negligible for learning most motor tasks, as long as KR is not presented too soon after performance. Filling this interval with activities not related to the task degrades learning. However, filling this interval with activities related to the task, such as subjective estimation processes, enhances learning. If the post-KR-delay interval—the interval from the KR until the next movement—is too short, subjects appear to have difficulty generating a new and different movement on the next trial. However, filling this interval has uncertain effects on learning.

Augmented feedback appears to have several possible mechanisms for enhancing learning. It acts as *information*. It acts to form *associations* between movement parameters and resulting action. And it acts in a *motivational* role. Augmented feedback also has a guidance property that can enhance performance but degrade learning.

Student Assignments

1. Prepare to answer the following questions during class discussion:

a. Choose any skilled trade that would require motor learning (e.g., carpenter). Provide examples for each of the different kinds of inherent and augmented feedback that could be useful in learning this trade.

b. Using one of the augmented-feedback examples from the answer in 1a, describe how the temporal locus of presenting this information to the learner would affect learning.

c. Models, physical guidance devices, and augmented feedback are methods of providing external sources of information to the learner. Compare and contrast these methods in terms of their potential effect in a learning environment.

2. Find a research article (published in the past five years) that examines the influence of knowledge of performance on the performing or learning of a motor skill.

Web Resources

This Web site describes augmented feedback teaching devices to facilitate motor learning:

www.thespeedstik.com/

This Web site offers golf swing training aids:

www.dwquailgolf.com/training/your_pro_swing_trainer.html

Notes

[1] Although we have distinguished between various types of augmented feedback, of which KR is one, we will generally refer to many aspects of this work in relation to the term KR. However, exceptions will be made when a clear distinction is necessary.

[2] Note the differences between the use of these terms and the use of random and blocked practice in chapter 11. In that work, the same task is repeated in blocked practice, and switching between tasks occurs in random practice. In the Lee and Carnahan experiment, the same task is performed on each trial, but KR is given either about the same segment over a series of trials (blocked KR) or about a different segment on successive trials (random KR).