Knowledge of Results and Motor Learning: A Review and Critical Reappraisal

Alan W. Salmon
Department of Physical Education
Laurentian University,
Sudbury, Ontario, Canada

Richard A. Schmidt and Charles B. Walter
Department of Kinesiology
University of California,
Los Angeles

Previous analyses of knowledge of results (KR) and motor learning have generally confounded the transient performance effects as shown when KR is present and the relatively permanent (i.e., learned) effects that we argue should be evaluated on a transfer test without KR. In this review, we classify investigations according to this distinction, and a number of new relations emerge between KR and both learning and performance. In addition to the motivational and associational roles of KR, we emphasize that it also acts as guidance, enhancing performance when it is present but degrading learning if it is given too frequently.

Information provided after a response that tells of the learner's success in meeting the environmental goal, often called knowledge of results (KR), is widely regarded as a critical variable in the acquisition of skills. KR is a major topic in most textbooks on human motor learning, and it is generally viewed as the most important variable for determining learning, except possibly for practice per se (Bilodeau, 1966; Newell, 1977). Recently arguments have risen that research on KR, with the usually simple, one-dimensional tasks that have been used, may not tell us much about how humans learn more complex and realistic coordinated movements (e.g., Fowler & Turvey, 1978). We disagree; but even if these views are correct, one cannot deny that KR remains one of the more potent determiners of behavior in simple responses (and often in complex responses as well). To neglect KR as a variable in the study of learning would lessen our understanding of skill acquisition considerably.

Given the attention KR has received, one would think that the principles of its operation would be reasonably well understood by this time. However, as we argue later in this article, the principles of KR, as written in a number of previous textbooks and articles (e.g., Adams, 1971; Ammons, 1956; Annett, 1969; Bilodeau, 1966, 1969; Holding, 1965; Newell, 1977; Schmidt, 1975a, 1975b; Singer, 1980), are at best in need of some conceptual rearrangement and at worst largely incorrect. The general problem is that most experimenters and later reviewers of this work have nearly uniformly failed to separate the temporary, transient effects of KR manipulations from their relatively permanent effects which are considered as being due to learning. As a result, the laws of KR and learning, as stated in the current literature, are, with only a few exceptions, actually the laws of KR and motor performance.

In contrast, a few of the studies in the literature do provide a basis for the conceptual separation of the learning versus performance effects of KR (see McGuigan, 1959, for an early example). The conclusions from these studies, when viewed against the generally accepted notions in the earlier literature, show a number of important contradictions. These contradictions are sufficiently consistent across various motor tasks to indicate some serious difficulties with the ways in which the laws of...
KR for motor learning have been conceptualized. Because of the great theoretical and practical importance of these difficulties with a variable as critical as KR, we reexamine the literature on KR and motor learning. Our goal is to reconceptualize the problem in terms of performance versus learning effects of KR, and to reinterpret the extant literature to detect the common threads that suggest principles of KR’s operation.

We begin with some critical definitional and experimental-design problems that underlie the principles of KR and learning. Next, we summarize the KR literature, categorizing the effects found as being either immediate and transient influences on behavior or relatively permanent effects that are due to learning. Many of these findings about KR and learning and performance contradict earlier notions, and they provide some interesting new insights and future directions. Finally, we examine how these newer principles of KR lead to tentative (pretheoretical) notions of how KR works in human motor-learning situations.

Problems of Definition and Experimental Design

One of the major difficulties in the past surrounding the study of KR and motor learning, in our opinion, has been related to problems of definition of KR, particularly in contrast to definitions of feedback. Information provided by the various sense organs—usually termed feedback—is almost without dispute considered critical for learning new motor actions, and considerable interest surrounds it. However, feedback, as the aggregate of all sensory information about the movements of the body and of environmental objects affected by those movements, and the relations among them, is very difficult to study, largely because the various sources of information are confounded in their effects. For example, it is seldom possible to be certain that visual feedback, for example, was an important factor in learning when it could easily be argued that some form of proprioception was dominant.

More important, though, it was often impossible to manipulate feedback, by delaying the onset of feedback information or altering its precision, its relative frequency, and so on, in controlled ways that are demanded by experimenters. The next best solution, therefore, was to use tasks in which the feedback qualities of the response were seriously degraded, or at least where feedback did not provide meaningful information about the subject’s success. This usually demanded simple tasks where the usual feedback channels were either blocked (through blindfolding, for example) or were rendered meaningless with respect to the subject’s goal. Artificial feedback information could then be provided from the experimenter in the form of KR. Because KR could be controlled and manipulated, it was thus possible to study the effects of at least one kind of feedback—KR—on the acquisition of motor tasks, and thus to understand the principles of its operation.

KR and Feedback Defined

KR is usually defined as augmented (as opposed to intrinsic) feedback, where the KR is additional to those sources of feedback that are naturally received when a response is made, termed response-produced feedback (e.g., Adams, 1968, 1971; James, 1890). Second, KR is about response outcome (in terms of the environmental goal) rather than about the movement per se; consequently, in many tasks KR and response-produced feedback are redundant. However, tasks used in KR research are usually designed so that feedback does not reliably tell about the success in terms of the movement’s goal. Thus, KR is often the only source of meaningful outcome information available to the learner. Furthermore, KR is generally given in a verbal form (or at least is able to be verbalized), and it is usually terminal (as opposed to concurrent). Thus, KR is defined as verbal, terminal, augmented feedback (Schmidt, 1982).

In contrast, augmented feedback about the subject’s own movements has been labeled knowledge of performance (KP) by Gentile (1972). Newell and Walter (1981) refer to these sources of information as kinetic and or kinematic feedback. Although these latter classes of feedback and KR are definitionally distinct, it is not clear that their fundamental mechanisms are different. In learning a springboard dive, for example, it may be that the principles of learning are the same for KR (“Your score was 4.5”) and KP (“You untucked too late”),
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but each could cause the performer to learn something different about the dive, or one could be more efficient than the other in a particular circumstance.

This way of defining KR might seem odd, but we defend it on two grounds. First, KR has been defined in this manner in most previous literature, although there are exceptions. The second defense is a reaction to the notion that seeing one's errors is KR. Of course, this is not KR as defined here. We prefer it this way because KR defines a set of observable operations rather than relying on assumptions about what KR might be doing once inside the system. Believing that seeing one's errors is KR relies on assumptions about what is seen, what is attended to, and how it is processed, whereas a definition of KR in terms of spoken information is not subject to this uncertainty.

Learning Defined

Earlier definitions of learning have differed considerably, and a clear statement of our point of view about learning is critical so that our evaluation of the literature in terms of learning is understood and accepted. The most common and widely accepted definition is that learning is a relatively permanent change, resulting from practice or experience, in the capability for responding. Central to this focus is the strength of this capability as a function of variables associated with practice. Earlier views of learning (e.g., Hull, 1943; James, 1890) did not deal with the nature of this capability; however, more recent thinking has begun to ask about the structure of motor programs (Schmidt, 1982), the sensitivity of error-detection processes (e.g., Adams, 1971; Schmidt, 1975a), or the strength of movement schemas (Schmidt, 1975a). These recent ideas, however, do not change the nature of the problem much. If, for example, performance on a quick action is thought to depend on motor programs, then one asks about those variables in acquisition that contribute maximally to motor-program formation—that is, the capability to perform the rapid actions after practice.

These various capabilities can be regarded as states that underlie, or permit the expression of, a skilled behavior. Thus, in this view, changes in behavior with practice may reflect changes in an underlying capability for responding (i.e., learning), or they may simply reflect one or more temporary processes that affect behavior only while the processes are in effect (e.g., effects of mood, drugs, distractions). Also, the modifier "relatively permanent" is used to imply some persistence of this acquired capability and, although we are not specific about how permanent "relatively permanent" should be, such effects should persist well beyond the practice session, certainly for hours, perhaps for months and years. These notions are critical to the design of experiments on learning.

Designing Experiments on Learning

We focus here on those procedures that allow the separation of the relatively permanent (i.e., learning) effects from those that are transitory and that, therefore, should not be classified as the result of learning (performance effects). This distinction is certainly not new. Griffith (1931) used the notion in separating the performance and learning effects of vision in learning a golf drive. Tolman (1932, p. 364) stressed the need to separate learning and performance effects and cited others who had similar ideas (e.g., Lashley, 1929). Later, Hull (1943) formalized this distinction with his notions of habit strength (sHR) as an acquired capability and of temporary inhibitory factors (e.g., IR) that could be present when various independent variables were manipulated.

Adams and Reynolds (1954; Reynolds & Adams, 1953) popularized an experimental design, similar to the one that Griffith (1931) used earlier, that allowed the objective separation of learning and performance effects. They showed that massed (as compared with distributed) practice depressed rotary-pursuit performance when it was present. When massed subjects were transferred to distributed-practice conditions, however, their performances were nearly as proficient as those for subjects who previously had the same number of distributed-practice trials. Consequently, when the effects of massing on learning were evaluated by performance on a distributed-practice transfer test, after the temporary fatigue-like effects of massing had dissipated, earlier massing had little or no ef-
fected. This general method led to more recent experimental designs that had the goal of separating the immediate performance effects of some variable from the lasting learning effects (e.g., Dunham, 1971; Schmidt, 1982).

**Possible Performance Effects of KR**

The use of transfer designs in experiments manipulating KR seems particularly crucial, yet for some reason experimenters have generally failed to recognize this importance. (McGuigan, 1959, was a notable exception.) KR seems to have many different roles, some of which are to improve responding in a lasting, relatively permanent way. However, it can have other effects, some of which can be viewed as temporary or transient (i.e., performance effects). One example is the well-known motivating or energizing property of KR. When KR is present, subjects are more interested in the task, they work harder, and they persist longer after KR is removed (Arps, 1920; Crawley, 1926; Elwell & Grindley, 1938). Such motivation-like properties may be thought of as temporary phenomena, which can dissipate with a short rest or change in conditions. If these effects of KR made performance more proficient when KR was present, then withdrawing KR could allow performance to deteriorate quickly, much like a change in behavior when the effect of a drug has dissipated.

Another temporary factor is related to the informational properties of KR. KR tells the performer what errors were made and what to do next, providing a strong guidance function for future performance. Just as performance on a series of trials with, for example, physical guidance will be proficient when the guidance is present, performance on a set of trials with KR could be proficient for the same basic reason. Conversely, just as performance deteriorates when physical guidance is removed (see Annett, 1969, and Holding, 1965, for reviews), performance in studies of KR could be deteriorated by the removal of this temporary, guidance-like KR. We present evidence later that KR may work in this general way.

To summarize, in addition to the undeniable role for producing learning, KR also has a number of additional roles that seem to have only momentary, transient effects. If so, then care must be taken in the design of experiments on KR to separate the transient effects of KR manipulations from their relatively permanent, or learning, effects. For this reason, we argue, transfer designs are critical for the study of KR and motor learning.

**Transfer Designs**

Essentially, the transfer design for the study of learning involves two distinct phases (Schmidt, 1982). The independent variable of interest (here some variant of KR) is manipulated in an acquisition phase, with different groups usually receiving different treatments. Then, in a transfer phase, all groups are transferred to a common level of the independent variable. Sufficient rest is provided, so that it can be argued that the temporary effects of the KR manipulation have dissipated, and thus the effects remaining are the relatively permanent ones that we wish to attribute to learning. In the simplest case, the group that performs most effectively on the transfer test is argued to have learned most during the acquisition phase.

It might seem obvious that whatever variations of KR lead to the most effective performance in acquisition phase will also lead to the most effective performance in the transfer phase. However, these results do not have to occur. In fact, we later present evidence that the ordering of groups during the acquisition phase can be reversed on a transfer phase; essentially, a manipulation of KR that produces maximum performance in acquisition can produce minimum learning of the task (see Schmidt, 1982).

For studies of KR, the common level of the independent variable to which all subjects transfer is most often a no-KR condition. During the acquisition phase, assume that the learning of the task is occurring at different rates in the different groups. But this learning is confounded (or obscured) by the temporary effects of KR that are present as well. The strong guidance function of KR, as well as its motivational roles, tends to bring all groups to equally high levels of performance, regardless of their actual levels of learning (the acquired capability of responding). A no-KR
transfer test supposedly strips away these temporary effects, allowing the effects of the KR manipulation on learning to be measured.

A second reason for no-KR transfer tests is that no-KR practice tends to stabilize performance, so that a number of no-KR trials can be combined to form a reasonably stable estimate of the relative amount learned during the acquisition phase when KR was manipulated. A transfer test with KR, in contrast, may allow rapid adjustments in behavior with successive trials, and it may even allow a group that learned less in acquisition to catch up either partially or completely during a transfer test. Although it is not essential that the transfer phase have KR withdrawn so learning can be estimated meaningfully, such designs have been the most powerful and have been used extensively as a result.

**Criterion Problem**

A major question of philosophy in such experimental designs is related to the aspect of motor behavior that the experimenter wishes to study. In most practical learning situations, the goal of the practice session is to provide the learner with the capability to perform at some time in the future. A tennis player practices serving in a training session with the goal of being able to use the serve more effectively in an upcoming match. With respect to manipulations of KR, we give KR in learning sessions so that in the future the tennis player can serve the ball without KR. Transfer designs involving a shift to performance under no-KR conditions evaluate learning on that phase of the experiment for which there is good agreement with the practical situations.

Other viewpoints are possible. Some investigators point out that in many practical settings response-produced feedback is redundant with KR, as the learner can see directly the outcome of the action. Should it not be a KR test, rather than a no-KR test, to which all groups are transferred to evaluate the amount learned? We say no. Consider the wide variety of tasks for which the environment is different from trial to trial (e.g., groundstrokes in tennis, traffic patterns when driving). In this example past learning enables the individual to generate the action pattern that deals with that particular trial. The fact that this action might have response-produced feedback afterward which informs about goal achievement is beside the point; such information could not have contributed to the capability for that action because the action precedes the feedback. The argument also holds for the first trial of a perfectly closed skill. Our focus is on those features of the acquisition phase (variants of KR) that lead to this capability to perform.

Other criteria are possible. One important criterion is long-term retention, where the gains in learning would be of interest after months or years of no practice. Another concern is generalizability; some believe that an important goal for the learning session is the capability for transfer to other situations or tasks. We expect that those variations of KR producing the most effective immediate learning (i.e., on immediate no-KR transfer tests) would also be those that provide the greatest long-term retention and generalizability. The evidence, however, is lacking on this point, and our guess could easily be wrong. Thus, we will not deal further with this problem except to suggest that it is critical for future study.

**Problems with Dependent Variables**

In viewing the more than 250 separate investigations on motor learning and KR, we were overwhelmed by the array of tasks and measure of performance that have been used, making it difficult to compare results across studies. In an effort to provide as much integration as possible, we have adopted the following procedures for evaluating the performance and learning effects of independent variables.

Figure 1 shows some hypothetical curves that represent a typical set of results in this area. Assume that KR is manipulated in the acquisition phase and that it is withdrawn (and is therefore constant across groups) in the transfer phase. If performance is scored as a continuous variable (e.g., errors, points received, movement time), then we would conclude as follows: Because the performance of Group 1 was better than that of Group 2 in the acquisition phase, this manipulation of KR has either a performance or a learning effect. Because, and only because, this effect is also
In the following sections we summarize the literature on KR and the acquisition of motor skills. This work is categorized according to the particular ways in which KR has been manipulated.

**Is KR Essential for Learning?**

One of the claims reported in many textbooks and reviews is that not only is KR an important learning variable, but without KR people cannot learn at all. Evidence supporting such a position comes from studies by Bilodeau, Bilodeau, and Schumsky (1959) and Trowbridge and Cason (1932), in which subjects with no KR failed to reduce errors in performance, whereas other groups with KR reduced errors quickly with the same amount of practice. However, from the argument that follows, we feel these claims are overstated.

**Problems of Definition**

One difficulty with the conclusion that KR is essential for learning lies in its definition. Because KR is verbal, terminal, augmented feedback about goal achievement, it is a simple matter to contradict the general statement that KR is essential for learning. Certainly, everyone has learned many skills for which no KR, as defined here, has been provided. Empirically, Archer, Kent, and Mote (1956) and others have shown that KR in terms of time-on-target scores after each trial of a tracking task had nearly no effect on performance as compared with a no-KR condition. Such evidence probably does not mean that error information was unimportant, but rather that response-produced feedback—probably vision—was redundant with KR. The effectiveness of KR for learning seems to be determined, in part,
by the extent to which response-produced feedback can be substituted for it.

**Information about Errors and Learning**

A critical question is whether information about errors from KR or intrinsic feedback is essential for learning. A cursory review of the KR literature seems to suggest that the answer is yes. When no sources of information about errors are present, no learning, or at least no change in performance, is evident. Yet there are a number of investigations that appear to contradict such a position.

Taub (1976; Taub & Berman, 1968) showed that deafferented monkeys could learn to squeeze a bulb on command without any apparent sources of feedback about the successful response. There was a warning cue, and then a shock was delivered to the (normally afferented) cheek unless the bulb was squeezed first. Schmidt (1975a, 1982) argued that the temporal contiguity between the offset of the shock and the squeeze of the bulb could be the basis of learning, and that the results do not contradict the fundamental idea that some source of feedback about performance is essential for learning.

Various studies have given subjects a standard prior to performance, with attempts to match it in various ways afterward (Newell, 1976; Pearson & Hauty, 1959; Solley, 1956; Wrisberg & Schmidt, 1975; Zelaznik & Spring, 1976). In none of these studies was KR given after subjects' movement attempts, and yet there were clear reductions in error with practice (see also Adams & Dijkstra, 1966; McCracken & Schmidt, cited in Schmidt, 1975a). It can be argued (Schmidt, 1982) that the subject is forming a reference of correctness on the presentation movements and then matching the reference with ongoing (intrinsic) feedback during reproduction. Each trial provides another presentation of the reference sensations, strengthening it and making its match on the following reproduction trial more accurate (Schmidt & White, 1972).

Thurndike (1931) gave long strings of line-drawing trials without presentation of the criterion position beforehand and without any KR. No changes in target accuracy were observed, as would be expected without KR or meaningful intrinsic feedback. However, in Seashore and Bavelas's (1941) reanalysis of Thorndike's data, although responding (for one subject) did not become any more accurate with respect to the criterion target position, it did become more stable.1 Thus, practice without KR produced some changes that are probably best regarded as due to learning. However, this phenomenon was clearly absent in another subject, seriously limiting the generality of this conclusion.

Finally, some studies (e.g., Bilodeau, 1956) showed that improvement in performance occurs only after trials in which KR is given, and that no improvement occurs after trials in which KR is withheld. These findings suggest that the blank trials, having no information about errors, were totally ineffective for learning. However, more recent studies (e.g., Annett, 1959; Ho & Shea, 1978; Johnson, Wicks, & Ben-Sira, 1981; see Schmidt, 1982) that examined the relative amount learned on a no-KR transfer test showed that a group with blank trials interspersed between KR trials (during acquisition) was better than a group without such blank trials. This suggests that the blank trials had a positive role in learning. How such trials aided the learning process is worth considering, and is discussed in more detail in the following section.

In reviewing the available literature on KR and learning, we found no evidence that convincingly contradicts the fundamental idea that some form of information feedback (about errors or the movement goal) is critical for learning. Many empirical investigations and everyday experiences contradict the idea that KR (as verbalizable, augmented feedback) is critical for learning, but in each case it is possible to argue that some other form of feedback intrinsic to the task has provided sufficient information for learning.

**Relative and Absolute Frequency of KR**

How often, or under which kind of schedule, should KR be provided to maximize learning

1 This increased stability was not manifested by a decrease over days in the variable error (VE) of the within-day movement endpoints as many have believed. Rather, the average distance moved on a day became more stable with practice. In other words, the across-days SD of the average distance moved on each day decreased with practice.
and performance? Two descriptors of these kinds of scheduling variables are relative frequency and absolute frequency of KR. **Absolute frequency** refers to the absolute number of times in a learning sequence that KR is provided to the learner. If there are 50 trials, and KR is provided on half of them selected randomly, then the absolute frequency of KR is 25, the total number of KRs provided. **Relative frequency** is defined as the absolute frequency of KR divided by the total number of trials given, and it expresses the proportion of trials for which KR was provided. In this case, the relative frequency of KR is 25/50, or 0.5.

**Theoretical Issues**

One important theoretical issue is related to the concept of Thorndike (1914) that KR (or some form of response-produced feedback in tasks that allow it) is critical for learning, strengthening a bond between stimulus and response elements. If so, then a schedule of 50% relative frequency will be less efficient than will be a schedule of 100% relative frequency (total trials constant), owing to the supposed ineffectiveness of the blank trials in the 50% condition. A second concept of Thorndike's is that because KR was considered the critical variable for learning, the variable of absolute frequency of KR would be expected to be a determiner of the amount of learning, and relative frequency of KR would be unimportant, provided that absolute frequency was controlled. As we demonstrate later, the evidence strongly contradicts such a position about the nature of KR and the principles of relative and absolute frequency.

A second important theoretical idea was related to analogous variables from animal learning studies involving intermittent reinforcement. One of the most common and important findings from the reinforcement literature is that less-than-100% reinforcement schedules produce poorer performance during an acquisition phase (i.e., while the reinforcement is being provided; see Boren, 1961), but produce markedly superior retention (in our terms, learning) as measured on a no-reinforcement extinction phase (Fantino & Logan, 1979; Skinner, 1938). In other words, both absolute and relative frequency of reinforcement are critical for determining learning. This is quite different from the prevailing idea about KR, which is that relative frequency is not important for learning (e.g., Bilodeau, 1956, 1966). In fact, such differences in effects between the animal (reinforcement) and human motor learning (KR) work have fueled the idea that reinforcement (in animals) and KR (in humans) work fundamentally differently—the former on the basis of reward and the latter on the basis of information to be processed cognitively. Such thinking has been the basis for viewing KR in informational terms in various theoretical accounts of motor learning (e.g., Adams, 1971). These ideas do not withstand a more critical examination of the empirical evidence.

**Absolute Frequency of KR**

**Effects on performance.** Certainly one of the most fundamental findings in motor learning is the positive relationship between the absolute frequency of KR and performance in acquisition. This is evidenced by the general shape of “learning” curves during KR practice, with more KR trials leading to better performance. Examples are numerous, and we know of no important contradictions.

**Effects on learning.** Few investigators have felt the need to determine whether the impressive performance changes that KR produces are relatively permanent, and whether the gains could survive the withdrawal of KR in a transfer test. Trowbridge and Cason (1932) contrasted traditional KR with nonsense KR in acquisition. In a largely ignored portion of their study, subjects were shifted, to a no-KR transfer test (Figure 2). The differences generally remained, suggesting a learning role for meaningful KR.

We found no investigations that contrasted a KR and a no-KR acquisition phase using a no-KR transfer test. If it can be shown, however, that behavior improves while KR is present, and that the behavior remains proficient in a KR-withdrawal phase, then a learning role for KR is strongly suggested. Such findings have been produced by Adams, Goetz, and Marshall (1972; enriched feedback groups) and Newell (1974; high-practice groups). That performance in KR withdrawal is usually less proficient than under KR conditions suggests a performance role for KR as well. Finally,
there are marked parallels between the KR literature and the reinforcement findings in animals. Using an extinction test as a measure of the strength of association (or of the relative amount learned, in our terms), increases in the number of reinforced responses generally increase the number of responses made in extinction trials. Thus, more reinforcement or KR, other things (e.g., the schedule) being equal, leads to more learning.

Relative Frequency of KR

Effects on performance. In tasks where subjects cannot receive information about their own error via intrinsic feedback, it is not surprising that if KR is given 100% of the time (for a given absolute frequency), performance is more effective than if KR is provided on some lesser percentage of the trials. Evidence comes from positioning (Bilodeau & Bilodeau, 1958a; Ho & Shea, 1978; Johnson et al., 1981), force estimation (Annett, 1959), line-drawing (McGuigan, 1959b), key-pressing (Taylor & Noble, 1962), and concept-formation tasks (Bourne & Pendleton, 1958). An exception was Baird and Hughes's (1972) study, which showed no effect. Thus, it is quite clear that increasing the relative frequency increases performance in acquisition.

Effects on learning. The conclusions are somewhat different when the effect on learning, measured by performance on a no-KR transfer test, is examined. A number of investigations show that, with the total number of KR trials (absolute frequency) fixed, decreased relative frequency improves performance on a no-KR transfer test. Such findings have been produced by Taylor and Noble (1962) and Johnson et al. (1981; see Schmidt, 1982, Figure 13-6), and to a smaller degree by Baird and Hughes (1972) and Ho and Shea (1978). All these studies showed that the ordering of groups during the no-KR transfer test was essentially reversed with respect to that in the acquisition phase when KR was present (and was being manipulated between groups). Groups with 100% relative frequency performed the task most effectively in acquisition as compared with groups having smaller relative frequencies.

In a personal communication, R. W. Johnson informed us that the Johnson et al. study failed an attempt to replicate. Consequently, these findings should be interpreted cautiously.
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(from 25% to 75%), but they performed less effectively on a no-KR transfer test of learning.

The conclusion from the studies reviewed here is that decreased relative frequency of KR (absolute frequency constant) increases learning, contradicting the conclusion drawn by Bilodeau (1966, 1969) and many others that relative frequency of KR is unimportant. Another way to view these findings is that the blank trials provided in the sequences for the less-than-100% relative frequency groups may have aided the learning process somehow, contrary to the widely held view (Bilodeau & Bilodeau, 1958a) that such blank trials are essentially neutral. With both animal and human subjects, so called partial reinforcement (where reinforcement is given less than 100% of the time) generally leads to greater learning (as measured on extinction trials) than 100% reinforcement (see Fantino & Logan, 1979; Jenkins & Stanley, 1950; Lewis, 1960).

A possible problem with the motor data, though, is the failure to control for the total number of practice trials. A proper contrast would be between groups with the same number of total trials (for example, 100), with one group having KR on every trial and another having KR randomly on some smaller number (for example, 50) with the expectation that fewer KRs would lead to greater learning. Such controls were used by McGuigan (1959b) and our group; fewer KR trials (i.e., lower relative frequencies) lead to roughly the same amount of learning as groups experiencing more KR trials (100% relative frequency).

These relative-frequency effects can be viewed in a variety of ways. One way supports the hypothesis stated earlier that KR acts as guidance during the acquisition phase. If KR, as guidance, is provided on every trial, the subject comes to rely on that source of error information to maintain performance, and thus does not deal effectively with the other cues in the task that are important for movement learning. When the no-KR trials are then provided, the subjects who had practiced under a 100% relative frequency condition perform poorly because they have not learned the task apart from the crutch-like effects of the KR (Annett & Kay, 1957). Subjects with less-than-100% relative frequency of KR, in contrast, are forced to learn aspects of the task that will carry them through the no-KR trials between presentations of KR. In this view, sufficient KR is needed so that performance is fairly accurate, but not so much KR that the subjects come to rely on it and neglect learning other aspects. The available evidence does not speak to the nature of the most effective scheduling, or how it might relate to task parameters such as open or closed skills, continuous versus discrete skills, and so on. Such questions, in view of this evidence, are significant for future research.

Most importantly for theory in this area, these results and this interpretation of KR as guidance argue that KR does not act only as an associative connection between stimulus and response elements as Thorndike (1931) and others assumed. KR helps the learner to perform the proper response, and then the learning of this response may be accomplished by some other means, perhaps even by mere repetition. These results generally support views of learning such as those of Adams (1971), in which KR acts primarily to guide behavior. According to Adams, the actual learning is accomplished by the accumulation of feedback traces. However, other views of the learning process, such as the development of more effective movement programs, are clearly possible as well. At the same time, these results tend to be contrary to Schmidt's (1975a) schema theory, which holds that no learning should occur without KR (i.e., on the blank no-KR trials). Thus, an important issue for motor learning is how these blank trials aid learning. If they do so by forcing increased utilization of KR or deeper processing of task cues on KR trials, then schema theory can be modified. However, if there is genuine learning on no-KR trials, schema theory as presently stated cannot accommodate it.

**Temporal Locus of KR**

During a trial, when should the KR be provided so that learning and performance are maximized? This issue is old, having been the subject of early articles by Lorge and Thorndike (1935), and the question still continues. For the usual paradigm in KR research utilizing discrete tasks, three intervals can be defined that serve to locate the KR temporally. The intertrial interval is the interval between trials, for example measured from the move-
ment on Trial \( n \) to that on Trial \( n + 1 \). If KR is given, then the interval from the movement until its provision is termed KR delay; and the interval from the KR until the next movement is termed post-KR delay, as shown in Figure 3. The research about the temporal location of KR has focused on essentially two issues: (a) the effect on learning and performance of the lengths of these intervals, and (b) the effect on learning and performance of the interpolated activities performed in these intervals.

Problems of Experimental Design

Fundamental to evaluating the research on the lengths of these intervals is McGuigan's (1959a, 1959b) observation, repeated frequently (e.g., Adams, 1971; Bilodeau, 1966; Schmidt, 1982), that all of these intervals are experimentally confounded. Thus, if the intertrial interval is held constant between conditions, then the post-KR delay decreases as the KR delay increases. Similarly, if the post-KR delay is held constant, then the intertrial interval must also increase as the KR delay is increased. Experiments that manipulate one of these intervals, holding another constant, can be interpreted as studying either of the two varied intervals, not simply those that are of interest to the authors. This problem has been largely ignored by the researchers in this area. The result is that, if this area is viewed critically, there are almost no data capable of informing about the effect of the durations of these intervals unconfounded by some other interval. What is needed is a procedure analogous to that developed by Kappauf (1973), who attempted to separate the confounded effects of chronological age, mental age, and IQ in developmental work.

Next, we grouped together studies for which a given interval is manipulated, indicating what other interval, if any, was confounded with it. In some cases, we have been able to assign the effects to one interval alone, but these conclusions are complex and generally arguable.

KR-Delay Effects

Theoretical issues. Of the three temporal intervals, KR delay has been by far the most actively studied. One important reason is that KR delay in investigations of human motor learning is analogous to the delay of reward in animal conditioning work. In addition, because investigators have known that delayed reward increases trials to criterion goal response in animals (see Tarpy & Sawabini, 1974, for a review), the analogous effect was expected in human motor learning.

A second theoretical issue concerns concepts about what the subject is doing during the KR-delay interval. According to information-processing accounts of learning, the subject must hold in temporary store some aspects of the movement just made until the KR is presented, and then use KR in relation to the memory of the movement just made to plan the movement on the next trial (e.g., Adams, 1971; Schmidt, 1975a). The coexistence of a movement memory and KR is critical for learning. If the KR-delay interval is long, causing the memory of the movement to fade, then when KR does arrive there will be no basis for associative strengthening of the response (or some schema for a class of responses). In addition, there will be no basis for planning the movement on the next trial. Most researchers expected to find that increasing KR delay would degrade the learning process, just as it appeared to do in animals (see Marteniuk, 1981; Schmidt, 1982).

Effects on performance. When the data are analyzed with respect to the effects of KR delay on performance during the acquisition phase (i.e., when KR is still present), numerous investigators did not find any reliable effects. When KR delay is varied and the post-KR interval is held constant (KR delay confounded
with intertrial interval), Bourne and Bunderson (1963), with a concept-formation task. Boucher (1974), Koch and Dorfman (1979; rapid movement), Marteniuk (1981), McGuigan (1959), and Saltzman, Kanfer, and Greenspoon (1955) failed to find reliable effects on performance. When KR delay is varied and the intertrial interval is held constant (KR delay confounded with post-KR delay), Becker, Mussina, and Persons (1963), Bilodeau and Ryan (1960), Boulter (1964), Dyal (1966), Dyal, Wilson, & Berry (1965), Larre (1961), Noble and Alcock (1958), Ryan and Bilodeau (1962), Schmidt and Shea (1976), Schmidt, Christenson, and Rogers (1975; rapid task), Swinnen, Schmidt, and Shapiro (1984), and Timmons and Wiegand (1982; simple task) found no effects of KR delay on performance. Archer and Namikas (1958), using the delay of a tone indicating that the subject had contacted the target during a tracking-task trial, also found no effect. However, this is most likely due to the failure of KR of any sort to have effects in tracking tasks with ample intrinsic feedback (e.g., Archer et al., 1956).

In contrast, Bourne (1957) showed with a concept-formation task that performance was more effective with immediate KR than when it was delayed by 8 s (confounded with decreased intertrial interval). In motor tasks, Gallagher and Thomas (1980) and Timmons and Wiegand (1982; complex task) found that decreased KR delay (confounded with increased post-KR delay) improved performance in children. Greenspoon and Foreman (1956) found that decreased KR delay (also confounded with increased post-KR delay) improved performance. This study, however, failed to replicate; see Bilodeau (1966). Koch and Dorfman (1979; slow movement) showed smaller errors with shorter KR delay (confounded with longer intertrial intervals). In the investigations that do show some effects, increased KR delay generally degrades performance.

Not all of the investigations on KR delay confounded the other intervals, however. Bourne and Bunderson (1963) varied KR delay and post-KR delay factorially in a concept-formation task, so that the effects of all three intervals could be separated. They found that as the KR delay interval was increased, holding either intertrial interval or post-KR delay interval constant, there was nearly no effect of KR delay independent of the effect of post-KR delay and perhaps the intertrial interval.

For motor tasks, Denny, Allard, Hall, and Rokeach (1960) used three groups with constant post-KR delay; they found that increased KR delay (confounded with increased intertrial interval) degraded performance. However, when they used an additional control condition with intertrial interval held constant, but with varied KR delay (immediate or 20 s), the effect of KR delay appeared to be quite small, suggesting that the KR-delay effects with constant post-KR delay were artifacts caused by the confounded covariation of the intertrial interval. However, McGuigan, Crockett, and Bolton (1960) produced the opposite conclusion, with KR delay having detrimental effects on performance even when the intertrial interval was held constant. Simmons and Snyder (1982) showed that decreased KR delay (with a confounded increased post-KR delay) improved performance on a rapid timing task. Bilodeau and Bilodeau (1958b), in making use of a number of between-experiment contrasts, argued that KR delay is relatively unimportant for performance, with most of the effects being caused by the simultaneous changes in intertrial interval. However, we are disappointed that no mean performance data are presented; consequently, their trends cannot be evaluated directly.

In summary, there are numerous studies that failed to show any effects of KR delay on movement performance when KR is present. Of those that have shown effects, the changes in performance can be accounted for by concomitant variation in either the post-KR delay, the intertrial interval, or both. The general conclusion, then, is that KR delay is not a variable that affects performance when KR is present. To this point, nothing has been said about KR delay and motor learning.

Effects on learning. In this section, we discuss those studies that have involved some type of transfer design or retention test. Koch and Dorfman (1979) examined the effect of KR delay (confounded with intertrial interval) using two versions of a rapid-timing task. When a 200-ms movement time was used, there were no important differences between the delayed (45 s) and immediate (5 s) KR conditions. However, for the 500-ms movement time, it...
appears that transfer performance was more accurate for the immediate-KR conditions, and that there was far less decrement in performance over subsequent no-KR trials. This suggests that immediate-KR groups had learned the task more effectively. Surprisingly, though, these large differences did not achieve significance. But Swinnen et al. (1984) found that immediate KR degraded learning relative to a condition with an 8-s delay (confounded with post-KR delay). Dyal et al. (1965), Dyal (1966), and Mcguigan et al. (1960) with line drawing, Schmidt and Shea (1976) with a rapid positioning task, Schmidt et al. (1975) with rapid timing, and Boulter (1964) with slow positioning failed to find any effect of KR delay (confounded with post-KR delay). However, Dyal (1966) showed that subjects with different response biases in acquisition performed differently on a no-KR transfer test as a function of KR delay in acquisition, suggesting that KR delay affected learning in some way. Schmidt et al. (1975), using a kinesthetic weight-recognition task, found that more KR delay in acquisition (confounded with post-KR delay) degraded perceptual learning; they interpreted this as an interference in the acquisition of recognition memory. Finally, Mcguigan (1959b) found strong indications that a 30-s delay of KR resulted in greater error in a transfer than either 15 s or immediate KR (confounded with intertrial interval), but the effect achieved only borderline levels of significance (p = .10). Marteniuk (1981) also failed to find an effect.

A contrast with other kinds of responses is revealing here. In various verbal or discriminative tasks, Brackbill (1964) and her colleagues (Brackbill, Boblitt, Davlin, & Wagner, 1963; Brackbill, Isaacs, & Smelkinson, 1962; Brackbill & Kappy, 1962; Brackbill, Wagner, & Wilson, 1964) found that increased KR delays (confounded with changes in post-KR delay) lead to slightly decreased performance when KR is present, but lead to improved performance on a transfer test (i.e., increases learning), similar to Swinnen et al. (1984). Yet Schmidt et al. (1975) showed that KR delay (confounded with post-KR delay) seemed to degrade perceptual learning. Also, Tarpy and Sawabini (1974), in a review of the delay of reinforcement in animal conditioning, concluded that delayed reward degrades the rate of achievement in acquisition (i.e., degrades performance, as we argue in Figure 1), yet increases trials to extinction when reward is removed (i.e., increases learning). These findings are interesting in that they generally support the hypothesis that reinforcement acts as guidance, with immediate reward providing more guidance and perhaps leading to a reliance on such feedback for performance, and hence poorer performance in a transfer test indicating learning. Such effects are not present in the literature on human motor learning, as discussed previously, suggesting that these two situations may be fundamentally different.

Our analysis of the evidence has found ten investigations that speak to the question of KR delay and motor learning; the remainder (as cited in the previous sections) deal only with the effects of KR delay on performance. In these ten studies, there are hints that shortening KR delay might degrade learning, and the remainder suggest no effect of KR delay on learning. It is interesting to note that KR-delay effects have been found in verbal-learning studies and in animal reinforcement, but increased KR delay in those settings seems to increase learning. In view of the small number of investigations in the motor realm that deal with KR-delay effects on learning, additional work to reconcile the verbal–motor differences in effect of KR delay would be a valuable contribution.

Post-KR Delay Effects

Theoretical issues. The post-KR delay interval is thought of as the period during which the subject uses KR to produce a movement that is different, hopefully more accurate, than the last one. Thus, the information-processing view of KR and learning has much to say about the kinds of effects expected by altering the length of the post-KR delay interval. If the post-KR delay is too short, the subject will not have sufficient time to plan the next movement properly, and the performance, if not the learning, of the task will suffer as a result. This delay should interact with the task complexity, in that very simple responses should require less time for effective next-response planning. An optimum post-KR delay is expected, with intervals that are too long, producing decrements in performance and learning due to forgetting over the long intertrial interval.
Effects on performance. The majority of studies on post-KR delay have involved constant intertrial intervals, so that the post-KR delay is confounded with KR delay. Under this procedure, Archer and Namikas (1958), using a tracking task, Becker et al. (1963), Bilodeau and Bilodeau (1958b), Bilodeau and Ryan (1960), Bole (1976), Boucher (1974), Noble and Alcock (1958), Ryan and Bilodeau (1962), Schmidt et al. (1975), Schmidt and Shea (1976), Swinnen et al. (1984), and Timmons and Wiegand (1982; simple task) failed to find reliable effects of post-KR delay on performance during acquisition. When the KR-delay interval was held constant, so that the post-KR interval was confounded with intertrial interval, Bilodeau and Bilodeau (1958b), Dees and Grindley (1951), and Magill (1977) also found no effects on performance.

In other studies, however, effects have been found. With post-KR delay confounded with KR delay, Greenspoon and Foreman (1956) found that longer post-KR delays produced more accurate performance. For 7-year-old children, Gallagher and Thomas (1980) found that longer post-KR delays facilitated performance. Simmons and Snyder (1982) found decreased errors with increased post-KR delay, and Denny et al. (1960) found a slight, but nonsignificant, improvement in performance as the post-KR delay increased. Finally, Timmons and Wiegand (1982; complex task) found increased performance as post-KR delay increased, and the decrement in performance at short (1 s) post-KR delays on the complex task was absent on two simpler tasks.

In the concept-formation literature, Bourne and Bunderson (1963), Bourne, Guy, Dodd, and Justesen (1965), Croll (1970), and White and Schmidt (1972) found increased performance in acquisition, decreased trials to criterion, or both when the post-KR delay interval was increased. Such effects have given a great deal of support for the idea that, in concept-formation tasks, planning analogous to that involved in generating a new motor act was required. Indeed, in the motor literature, when the KR delay is held constant so that the post-KR delay is confounded with the intertrial interval, two studies (Weinberg, Guy, & Tupper, 1964; Veraboff, 1973) found that their shortest post-KR intervals (1 and 10 s, respectively) depressed performance. However, Denny et al. (1960) found that a shortened post-KR delay improved performance, as measured by number of trials to criterion.

A few of the investigators in this area have attempted to separate the effects of these intervals with special control conditions. Using concept-formation tasks, Bourne and Bunderson (1963) showed that the post-KR delay was more important than KR delay in determining performance. With motor tasks, Denny et al. (1960) found that effects of increased post-KR delay seemed to be mainly determined by the intertrial interval. However, with intertrial intervals held constant, there were still slight, non-significant decreases in error with increased post-KR delays.

In summary, it is tempting to conclude that whenever KR delay is confounded with post-KR delay (intertrial interval constant), post-KR delay has no effect on performance (as found in at least nine experiments), suggesting that the intertrial interval is the only critical variable for performance. However, there are at least three exceptions where increased post-KR delay decreased error even when intertrial interval was held constant. Bourne and Bunderson's (1963) clean separation of these various effects for concept-formation tasks points to post-KR delay as the critical variable, with the intertrial interval being relatively ineffective. Perhaps the most that can be said about the post-KR delay interval is that short post-KR delays degrade performance in spite of a disturbing number of studies with null effects. Not all of the effects can be attributed to the covariation in the intertrial interval as some have claimed (e.g., Adams, 1971; Bilodeau & Bilodeau, 1958b).

Theoretically, the degraded performance from too-short post-KR delay intervals is consistent with the hypothesis that information-processing activities leading to effective next-response planning are disturbed if the learner does not have sufficient time after KR (see also Schendel & Newell, 1976). This evidence suggests something about the role of post-KR delay in the temporary, moment-to-moment adjustments in motor responding necessary to achieve or maintain target accuracy.

Effects on learning. When the relative amount learned is evaluated on a no-KR
transfer test, the effects of post-KR delay appear to be clearer than its effects on performance. When the intertrial interval is held constant (with post-KR delay confounded with KR delay), Archer and Namikas (1958), using a tracking task, Becker et al. (1963), using a line-drawing task, Schmidt et al. (1975), with rapid timing, and Schmidt and Shea (1976), using a positioning task, failed to find that alterations in post-KR delay (and, hence, in KR delay) affected motor learning. However, Schmidt et al. (1975) found that lengthening the post-KR delay interval (confounded with KR delay) increased learning in a kinesthetic recognition memory task. When the KR delay was held constant so that post-KR delay varied with the intertrial interval, Dees and Grindley (1951), using a knob-turning task, found that greater post-KR delay led to improved performance on a no-KR transfer test. (This variable failed to affect performance in acquisition when KR was present.) Verabioff (1973), using a positioning task, found that the longest post-KR delay (and, hence, the longest intertrial interval) led to most learning.

The small amount of evidence that is available suggests that a lengthened post-KR interval enhances learning as measured on a transfer test, but only when the intertrial interval covaries with post-KR delay. Such evidence suggests that the critical variable for motor learning is the intertrial interval because, when it is held constant, no effects of post-KR delay on learning are found. This is not to deny the possibility that short post-KR delay intervals will interfere with learning as they appear to do with performance, but no experiments with short post-KR delays have used a transfer paradigm in order to evaluate this possibility.

Theoretically, the available evidence does not strongly implicate the activities in the post-KR interval in the learning process, as many have claimed (e.g., Adams, 1971; Schendel & Newell, 1976), mainly because the critical tests of post-KR interval duration, especially as they interact with task complexity and age of the learner, have simply not been conducted. As it is, the present evidence provides little support for the concept that the duration of an empty post-KR interval is important for skill acquisition.

**Intertrial Interval Effects**

**Theoretical issues.** As reviewed in the previous few sections, the general impression from the literature is that KR delay is largely impotent, and that post-KR delay effects are probably caused by a covariation of the intertrial interval (although there are exceptions, as noted). Based on these observations, many have argued (Blodeau & Bilodeau, 1958b) or theorized (Adams, 1971) that the intertrial interval is the main determinant of learning, with longer intertrial intervals decreasing learning.

**Effects on performance.** When the post-KR delay interval is held constant, so that the intertrial interval and KR delay covary, the evidence about the effect of intertrial interval on motor performance is mixed. Koch and Dorfman (1979; 200-ms task), Saltzman et al. (1955), and McGuigan (1959b) failed to detect any effect of intertrial interval on performance. In contrast, Koch and Dorfman (1979; 500-ms task) found that longer intertrial intervals produced slightly greater errors, and Simmons and Snyder (1982) found that increased intertrial intervals increased errors markedly. In the concept-formation literature, Bourne (1957) found that increased intertrial intervals produced decrements in performance. When the KR delay interval was held constant so that the intertrial interval covaried with post-KR delay, Dees and Grindley (1951), Magill (1977), and Simons and Snyder (1982) found no effect, whereas Verabioff (1973) and Weinberg et al. (1964) found that increased intertrial intervals improved performance.

In the few studies that used control conditions to separate the effects of the three variables, evidence is again mixed. Bourne and Bunderson (1963), with a concept-formation task, found that increasing the intertrial interval reduced errors, but only when the post-KR delay was covaried with it. In contrast, Bilodeau and Bilodeau (1958b) argued that the critical variable is the intertrial interval, with increased durations leading to poorer performance regardless of the values of KR delay or post-KR delay, but we do not find their data particularly convincing.

To summarize, when effects do occur, lengthening the intertrial interval (covaried with KR delay) reduces performance, but it
improves performance when it is covaried with post-KR delay. The nature of the effect of the intertrial interval on performance is not clarified by this literature, and it certainly seems premature to suggest a simple relationship between intertrial intervals and performance, as many have done.

**Effects on learning.** When the intertrial interval was covaried with KR delay in acquisition, Koch and Dorfman (1979) found no learning effects on a transfer test, whereas McGuigan (1959b) found that increased intertrial intervals led to increased learning. Dees and Grindley (1951) covaried post-KR delay and intertrial interval and found that increased intertrial intervals also increased learning. Contrary to the situation with the effect of intertrial interval on performance, it is clear that increased intertrial intervals, whether they are covaried with KR delay or post-KR delay, tend to increase learning. The fact that one study failed to report such findings (Koch & Dorfman, 1979), coupled with the small number of investigations in this area, suggests the need for more work with this variable in terms of motor learning.

These tentative conclusions about the positive effects of intertrial interval length on learning raise some serious theoretical problems. Many investigators (e.g., Adams, 1971; Bilodeau & Bilodeau, 1958b) concluded from the literature that increased intertrial-interval length tended to decrease learning. However, all studies on which that conclusion was based failed to use transfer designs. When such transfer designs were used, the conclusions were reversed, with increased intertrial intervals tending to increase—not decrease—learning. Of course, theories (e.g., Adams, 1971) that predict that the relationship between learning and intertrial interval length is negative will surely be wrong if the relationship between learning and intertrial length is a positive one as the evidence suggests.

**Interpolated Activities**

A number of investigators have examined the various KR intervals by using interpolated activities. If an interpolated task performed during one of the intervals interferes with performance and learning, then insight into the nature of the information processing activities in that interval is provided.

**KR-Delay Interval**

**Effects on performance.** Using relatively simple tasks, information-processing activities of various kinds have been inserted into the KR-delay interval. Ryan and Bilodeau (1962) had subjects either move their hands to their laps between trials or keep them on the levers at the end-position with no effect on performance. Boulter (1964) filled KR delay with verbal and/or motor activities with no effects on performance.

However, when the task or the interpolated activities were more demanding, effects became apparent. Shea and Upton (1976) had subjects practice two positions, with movement to each in succession on a given trial. During the 30-s KR delay, subjects either sat quietly or moved to two additional positions, recalling each as in a short-term memory paradigm. These interpolated activities greatly interfered with performance during the acquisition trials when KR about the two movements to be learned was provided (Figure 4). Later, Marteniuk (1981) had subjects learn a relatively complex lever movement with four reversals and interpolated other activities within the KR-delay period. Marteniuk found that when subjects merely performed another simpler movement in KR delay, there were slight detrimental effects on performance in acquisition. However, in another experiment, when subjects had to learn the interpolated movements, after being provided KR on them as well as on the main task, the decrements in performance were much larger. This happened even if the subjects had to learn (with KR) a number-guessing task, showing that it was probably some capacity limitation, and not simply the interference among movements, that degraded performance.

Two factors differentiate the Shea and Upton (1976) and Marteniuk (1981) studies from the earlier work. First, the main task to be learned in each case was quite complex, being actually two separate positions in Shea and Upton’s study and a four-segment pattern in Marteniuk’s study. Another factor, as pointed out by Marteniuk, is the feature that the subjects had to learn the interpolated tasks, and providing KR on these tasks as well as the main task seemed to produce marked decrements in performance on the latter. Perhaps the interpolated activities interfered with the memory of
the movement to be learned, providing a poorer basis for planning the next movement, thereby depressing performance. Paradigms using simpler movements (e.g., Boulter, 1964), with relatively undemanding interfering tasks, failed to find such effects. In sum, it appears that if the task to be learned or the interfering tasks are sufficiently demanding, interfering activities in KR delay will degrade performance.

Effects on learning. Both Shea and Upton's (see Figure 4) and Marteniuk's performance effects in acquisition carried over to the transfer sessions (with no KR and no interpolated activities), suggesting that the activities in the KR-delay interval during acquisition depressed learning on the task. Even though Boulter (1964) found that the interpolated activities in his study did not affect performance in acquisition, they did degrade performance on the transfer test; motor interpolated activities produced less learning than the verbal, and motor-plus-verbal activities produced the least amount of learning. These studies show that interpolated activities—either verbal or motor—provided during the KR-delay period in acquisition degrade learning. They suggest that the activities may be blocking important information-processing activities or memory of the just-completed movements that may be critical for learning. More research with this paradigm is needed.

Effect of subjective error estimates. Not all activities interpolated in the KR delay interval degrade learning, as shown by Hogan and Yanowitz (1978). Here, and in our later work, some subjects were asked (others were not) to estimate their own errors during KR delay on a ballistic timing task, and this activity had no important effects on performance in acquisition when KR was present, as shown in Figure 5. However, when shifted to a no-KR transfer test, subjects who were asked to estimate their own errors performed much more accurately than those who were not, suggesting that the additional task of estimating one's errors increased learning of the task.

Two important points can be made from these studies. First, learning was increased by the estimates; yet this added learning was not manifested on the acquisition trials when KR was present. This fits with our perspective of KR as guidance, where KR is such a powerful determinant of performance when it is present that the effect of other variables on learning is not evident until the temporary effects of KR are stripped away in the transfer test. Second, forcing the subject to process other aspects of the task (i.e., his or her own error estimates) produces gains in learning, perhaps by shifting the learner's attention away from KR in the acquisition trials. This finding has important practical implications. Perhaps, as Schmidt (1982) has indicated, performance in transfer...
is enhanced because learners are better able to evaluate their own performances in the absence of KR, or perhaps it is because subjects learned the action more effectively. In either case, studies can be made of these initial findings in the future.

Post-KR Delay Interval

Effects on performance. Various potentially interfering activities have been placed in the post-KR delay interval for simple motor tasks. McGuigan, Hutchens, Eason, and Reynolds (1964) had subjects move their hands to the starting position in linear positioning either immediately after KR or 10 s after KR, but this variable had no significant effect. When other simple interpolated activities have been used, Blick and Bilodeau (1963), Magill (1973, 1977), and Hardy (in press) found essentially no effect on performance. Boucher (1974) found a small detrimental effect on performance, but only for the early blocks of trials in the learning sequence.

Finally, Lee and Magill (1983) found that both verbal and motor interpolated activities interfered with performance of a rapid motor task in acquisition. This study differed from the earlier ones in a number of ways. First, the task was rapid and more complex than earlier positioning tasks have been. Second, the interpolated activities also had KR, so that these tasks had to be learned over trials just as the main task was. This study seems to provide an important new direction, and future efforts should be able to unravel roles of the verbal versus motor interfering activities, the role of KR for the activities, and the complexity of the task to be learned. At least some activities in post-KR delay can degrade performance, suggesting that this interval is critical for next-response planning.

Effects on learning. McGuigan et al. (1964) found no performance effects of returning the hand to the starting position either immediately or after a 10-s delay. However, this delay facilitated learning as measured on a transfer test. In Lee and Magill (1983), the detrimental effects on performance discussed in the previous section did not carry over to the no-KR transfer test; consequently, we must regard these effects of the interpolated activities in acquisition as performance phenomena not related to learning of the task. It is interesting to ask why various processes leading to next-trial performance can be degraded by these interfering activities and yet the learning processes acting at the same time are not.
Trials-Delay Procedure

One important qualification about the effects of the KR-related intervals concerns the so-called trials-delay procedure, where one or more additional trials are inserted between a given trial and the KR that refers to it. Figure 6 shows a trials delay of 1 (one interpolated action; top) and a trials delay of 2 (two interpolated responses; bottom). In principle, any number of trials could be inserted. A variant is to provide a summary KR after a given number of trials (e.g., 20), where KR for each of the previous trials is presented at that time. The trials delay for Trial 1 would be 19 (with Trials 2 through 20 inserted between Trial 1 and its KR). The trials delay for Trial 20 would be zero (because no trials are inserted between it and its KR), providing a kind of average trials delay of 10.5.

Trials-Delay Effects on Performance

Using the trials-delay procedures defined above, Lorge and Thorndike (1935), Bilodeau (1956), and Lavery (1964a; Lavery & Suddon, 1962) found large decrements in performance during acquisition trials as compared with immediate KR conditions. Bilodeau (1956) provided the most systematic relationship between the amount of trials delay and subsequent performance; her findings are reproduced in Figure 7. In one experiment (left), trials delay was manipulated at 0, 1, 2, or 3 trials, whereas in the second experiment (right) trials delay was set at 0, 2, and 5 trials. Clear and unmistakable decrements in performance occurred as a function of the number of trials by which KR was delayed, with both a slower rate of error reduction and larger errors at the asymptote as the trials delay was increased. Using various summary techniques, Smith (1963) and Lavery (1962) found analogous results. Subjects with 10- and 20-trial summaries had poorer performances than those with immediate-KR conditions while KR was present in the acquisition phase.

Such clear effects on performance are predictable from a variety of viewpoints about how KR functions. They also fit with our position that KR is acting as guidance. When the KR is delayed by a number of trials, subjects are less able to use the KR in relation to the memory of the trial to which the KR has referred, and less effective planning of a next response is expected. Such effects could be caused by forgetting the earlier response over time, by interference with its memory via the interpolated trials (although Larre, 1961, found that other similar movements—not trials in the sequence—do not cause such decrements), or by both.

Trials-Delay Effects on Learning

Some of the studies previously discussed included no-KR transfer tests, and they permit an evaluation of the effects on learning. Smith (1963) and Lavery (1962) used a summary trials-delay procedure, and Lavery (1964b), Lavery and Suddon (1962), and Suddon and Lavery (1962) used the trials-delay technique. Whereas the trials-delay technique depressed performance in acquisition, it enhanced performance in transfer. Trials delay appears to be a variable that depresses performance and enhances learning.

Data from Lavery's (1962) original experiment are shown in Figure 8. To the left are
Figure 7. Absolute error in positioning for two experiments where trials delay of KR was manipulated. (See Bilodeau, 1956.)

Figure 8. Percent correct responses for various trials-delay 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. The labels were used by Schmidt, 1982, and do not appear in Lavery’s report. See Lavery, 1962.)
the acquisition performances for groups with a 20-trial summary, with immediate KR in the usual way after each trial, and with both immediate and summary KR procedures. Performance in acquisition was depressed by the "Summary" condition. It seems clear that the critical factor is the provision of the immediate KR, as the "Both" condition behaves nearly the same as the "Immediate" condition. However, on the transfer test, which in this study occurred on Days 7 through 10, 37, and 93 (all without any KR), the ordering of the groups was reversed: the "Summary" group performed best in transfer, with "Immediate" and "Both" performing more poorly and at the same level. These differences persisted over 37 days, but appeared to dissipate by the Day 93.

These data are particularly strong in suggesting a guidance function for immediate KR. When the "Summary" condition was used, performance was poor in acquisition, and subjects may have been forced to process task cues more effectively in order to deal with the relatively infrequent information about errors. This appeared to enhance learning, as measured on the transfer test. However, subjects in the "Immediate" condition may have focused too heavily on KR in acquisition to maintain performance, to the neglect of learning the task, and they suffered in transfer. Further, subjects with both forms of KR apparently chose to use the information involved in immediate KR, and performance was depressed in transfer to a level equivalent to that in the group with only immediate KR.

Additional experiments by Lavery (1962, 1964b) manipulated instructions, in effect warning subjects before they began the acquisition phase that a transfer test would be given. As before, acquisition performance was depressed for the "Summary" condition relative to "Immediate" (the "Both" condition was not used). However, as compared with data in Figure 8, there was less difference in performance on transfer trials, although the "Summary" condition was still most accurate. This finding suggests that when subjects know a transfer test is coming, they are clever enough not to rely on the easy performance gains with KR. Rather, such instructions may force subjects to focus more heavily on the cues in the task, resulting in increased learning. These findings have potentially great practical significance in the design of learning settings, but additional work is necessary to fill in the missing details about scheduling, maximizing transfer performance, and so on.

**Precision of KR**

KR precision refers to manipulations that alter the accuracy of the error report. Least precise is KR such as "long," meaning simply that the subject moved too far. To this precision can be added, such as "long 10" or even "long 10.245." Thus, one can think of precision as the number of significant figures presented in the KR message or, alternatively, as the size of the smallest units of distance (or time, force, and so on) represented by the right-most digit in the KR.

Two kinds of information can be provided in KR—distance and magnitude of error—and KR researchers have frequently confounded them. For example, in one of the earliest studies on this topic, Trowbridge and Carson (1932) gave qualitative KR (e.g., "right" or "wrong") and quantitative KR (e.g., "long 2"). They found that the quantitative KR group performed more accurately and learned more than the quantitative KR group (see Figure 2). However, this manipulation confounds the directional with the precisional aspects of KR. Consequently, this work does not necessarily indicate that precision per se was involved.

**Theoretical Issues**

The major theoretical issue about KR precision is related to information-processing accounts of KR. In this case too little precision is expected to leave the learner with insufficient detail on which to base the next movement, so increased precision should increase performance and learning. However, too much precision may be harmful in that it could cause the learner to focus on levels of errors that are far beyond motor control, ignoring more important aspects of the task. Many investigators have suspected that KR precision should be low in early practice and higher later as the learner becomes more proficient, and that it should be lower for children. Finally, there may be an optimal KR precision for performance and learning.
Effect of KR Precision on Performance

Using a variety of tasks, many studies show no effects of precision on performance. For example, Gill (1975), Jensen, Picado, and Morenz (1981), Newell and Kennedy (1978), Shapiro (1977), Smoll (1972), and Thomas, Mitchell, and Solomon (1979) reported no important effects of KR precision during the acquisition phase when KR is present.

However, a number of investigators reported reliable effects of precision on performance. Although Lincoln (1954) showed that increased precision degraded performance on a cranking test, Bilodeau (1953), with a knob-rotation task, Hunt (1961), with a tracking task, Magill and Wood (1983), with a rapid movement pattern, McGuigan (1959b), with line drawing, Newell and Carlton (1980), with linear positioning, and Noble and Broussard (1955), Rogers (1974), and Salmoni, Ross, Dill, and Zoeller (1983), with knob-turning tasks, found beneficial effects of increased precision. The general trend is that increasing precision from imprecise levels increases performance to a point, but then further increases in precision do not aid performance much. However, the effect found by Salmoni et al. (1983) vanished if subjects were instructed clearly about what the KR meant in relation to the micrometer apparatus they were using, leading the authors to suggest that the KR-precision effect is perhaps better related to learning about KR than it is to learning about motor responding.

Rogers' (1974) demonstration of an optimum KR precision is important. Knob turning was the task, and the KR was given with either zero (e.g., "too long"), one, two, or four significant digits of accuracy. The two-digit accuracy condition produced the smallest errors in acquisition, and the four-digit condition had nearly as many errors as the zero-digit condition. In a subsequent study, Rogers reported that this optimum KR precision disappeared if the post-KR interval was increased, and here the most precise KR led to the most accurate performance. This interaction between KR precision and post-KR delay probably means that with increased time for processing KR and generating a new response subjects can make use of high levels of precision, whereas with short post-KR delays it might be detrimental and confusing to them. Newell and Kennedy (1978) provided some support for the hypothesis that the optimum precision level for performance increases with age.

Effect of KR Precision on Learning

Gill (1975), Jensen et al. (1981), and Lincoln (1954) failed to find any effect of precision on performance during a no-KR transfer test, and Thomas et al. (1979) found that precision increased learning only for the 4th-grade subjects (not for Grade 2). In contrast, Magill and Wood (1983), McGuigan (1959b), and Salmoni et al. (1983) found that the most precise condition in acquisition tended to produce the most accurate performance in the transfer test. However, the learning effect vanished in the Salmoni et al. (1983) study if subjects were instructed about the exact meaning of the KR. Lavery (1964c) reported that increased KR precision had no effect on performance at immediate transfer, but led to greater performance on a transfer test delayed 7 days. The finding that the learning effect of KR precision only manifests itself after some time has elapsed (Lavery, 1964c; McGuigan, 1959b) may present a significant conclusion about the effectiveness of these KR manipulations for long-term retention.

Overall, there is evidence that increased precision of KR leads to increased learning. However, the findings appear to be somewhat inconsistent, and more work is needed before we can confidently place KR precision on a list of learning variables.

Alternate Forms of KR

Numerous investigators have asked about the different ways in which information about a subject's performance can be presented. Accordingly, an impressive variety of different forms of feedback information have been tried in learning paradigms, for example, feedback about the forces produced (Howell, 1956), the patterns of interlimb coordination (Hatze, 1976; Robb, 1968), or movements of the entire body via videotape replays (e.g., Rothstein & Arnold, 1976) or film. If our strict definition of KR is used, these sources of error information do not fit well into this review of KR. Such sources of error information deal with
the patterns of action produced by the subject, not the nature of the response outcome in relation to some external goal as KR is. Even so, there are a number of interesting parallels to the work on KR and to research directions that are becoming important for motor learning. A brief summary of the major findings in this area is presented.

**Kinematic and Kinetic Feedback**

Pioneering studies by English (1942) and Howell (1956) used feedback about the forces applied (i.e., kinetics) during rifle shooting and sprint starting, respectively. Various forms of kinematic feedback (or KP as defined by Gentile, 1972) were later used, where the information referred to the space-time descriptions of the actions (e.g., Hatze, 1976; Wallace & Hagler, 1979). Newell and his colleagues (e.g., Newell & Walter, 1981; Newell, Quinn, Sparrow, & Walter, 1982) provided recent reviews of this work.

Studies using kinetic and kinematic feedback have had mixed results. In simple tasks where only one degree of freedom is involved (e.g., linear positioning, rapid arm moves), discrete information about certain aspects of the action (e.g., time to peak force) generally has not been as effective as the usual KR about response outcome. When more continuous descriptions such as force-time curves are used, advantages are seen in performance over and above KR. Newell, Quinn, Sparrow, & Walter (1982) suggested that continuous measures are better for feedback than are discrete measures. However, it is also possible that the discrete measures that have been studied are not well aligned to what the motor system can use in improving behavior.

From the point of view represented here, the most serious drawback of this work is that transfer designs are seldom used, so that the learning effects of these feedback sources cannot be separated from the immediate effects. When such designs have been used (Newell, Sparrow, & Quinn, 1982), the effects appear to carry over into no-feedback transfer tests, suggesting that these effects are learning effects. These forms of feedback hold a great deal of promise for motor learning and yet, from our perspective, they have not been evaluated carefully in experimental designs that permit statements about their relatively permanent effects. In this way the work in this area has paralleled the work on KR. An important research direction will be the analysis of various forms of feedback on learning in the general tradition of Newell and his colleagues (e.g., Newell & Walter, 1981). Not only will it have practical implications, but also the various forms of feedback that work will likely be those aspects of the responses that the subject controls. In this way, the learning research could provide a great deal of information about movement control.

**Videotape Replays**

The playback of the learner's behavior on a videotape replay system actually represents an instance of kinematic feedback, but it seems distinct because the learner can receive a view of the entire body in action rather than just a static representation of a small part of it. A large number of studies have been done on videotape replays since the late 1960s, with the key review in this area by Rothstein and Arnold (1976).

Videotape replays have not been as successful as might be expected. However, a number of studies do report beneficial effects, and the key distinction seems to be that the learners were directed to certain aspects of the videotape displays rather than simply being allowed to view their performances without any direction or instruction (e.g., Del Rey, 1971; Rothstein & Arnold, 1976). Without any such direction, beginning learners might be ineffective in detecting features of the displays that are critical for performance, and the irrelevant aspects of the display might even be distracting. In the studies that used directed viewing procedures, videotape replays were quite effective as a device for enhancing learning. Rothstein and Arnold (1976) also noted that such replays were generally more effective for advanced learners than for beginners. Perhaps advanced performers knew what to look for in the displays, whereas the beginners did not.

**Overview**

Both of these research directions seem to hold a great deal of promise for the future. We are not surprised that such feedback is
Table 1
Summary of Various Effects of KR on Performance and Learning

<table>
<thead>
<tr>
<th>Increases in variables</th>
<th>Effects on motor performance</th>
<th>Effects on motor learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute frequency of KR</td>
<td>Enhanced</td>
<td>Enhanced</td>
</tr>
<tr>
<td>Relative frequency of KR</td>
<td>Enhanced</td>
<td>Degraded</td>
</tr>
<tr>
<td>KR delay slightly</td>
<td>None or slightly degraded</td>
<td>None or degraded</td>
</tr>
<tr>
<td>Post-KR delay</td>
<td>Enhanced slightly</td>
<td>Enhanced, if KR delay constant</td>
</tr>
<tr>
<td>Intertrial interval</td>
<td>Mixed, unclear</td>
<td>Enhanced, if KR delay constant</td>
</tr>
<tr>
<td>Interpolated activities in KR delay</td>
<td>Degraded, if demanding</td>
<td>Degraded</td>
</tr>
<tr>
<td>Interpolated activities in post-KR delay</td>
<td>Degraded, if demanding</td>
<td>None</td>
</tr>
<tr>
<td>Trials delay of KR</td>
<td>Degraded</td>
<td>Enhanced</td>
</tr>
<tr>
<td>KR precision</td>
<td>Enhanced</td>
<td>Enhanced</td>
</tr>
</tbody>
</table>

effective for learning, because coaches and teachers have been providing such feedback about performance for decades. Statements such as "Your arm was bent that time" are, after all, forms of kinematic feedback, and they are suspected to be more effective for learning than is simple outcome information. Rather than being substitutes for teachers, however, these more modern techniques with computer displays and videotape replays emphasize the need for effective teachers and coaches to instruct on the use of such feedback sources, as well as to direct changes in behavior to produce more effective performance on subsequent trials.

Summary and Discussion

Our analysis of the studies (over 250) involving manipulations of KR and motor performance and learning reveals a number of interesting principles. These are summarized in Table 1. The effects of increasing the particular independent variable on performance or learning are noted also.

Principles of KR and Performance

In considering the effects of these variables on performance when KR is present, performance is increased by increasing the absolute and relative frequency of KR and by KR precision. Increased interpolated activities in both KR delay and post-KR delay tend to degrade performance if either they or the learning task are demanding enough, and performance is strongly degraded by increased trials delay. The effects of the durations of KR delay, post-KR delay, and the intertrial interval are not particularly potent for performance. Where effects are seen, these intervals are confounded with each other, and the effects are mixed and generally unclear. However, it does appear that too-short post-KR delays can degrade performance. With respect to earlier reviews of KR (e.g., Adams, 1971; Annett, 1969; Bilodeau, 1966, 1969; Newell, 1977), these effects on performance are essentially those which have been described previously. These principles are important not only for describing the regulatory role of KR for behavior, but also in suggesting ways that performance can be improved in the acquisition phase of relatively complex tasks where the guidance function of KR is critical.

However, the most important outcomes from this review in our opinion are the effects of manipulations of KR on motor learning (i.e., when performance effects are evaluated on no-KR transfer tests as measures of relative amount learned). Such results, also summarized in Table 1, reveal a number of important principles, some violent contradictions to earlier beliefs about KR, and some glaring absences in our knowledge.

Principles of KR and Learning

Absolute frequency effects are as had been expected previously: More trials with KR generally lead to more learning as measured on a no-KR transfer test. Relative frequency effects, in contrast, are different. Studies clearly show that as the relative frequency decreases, learning increases. However, these results should be viewed cautiously until controls for total number of trials are run. These findings provide a number of interesting possibilities for understanding how KR works, including
the idea that subjects attend to other sources of feedback when KRs are infrequent or subjects attempt to make behavior more consistent between KR presentations. It is interesting to ask whether relative frequency of KR exerts its effects primarily on recognition memory, recall memory, or both. Knowing how learning is accomplished on the blank trials between KR presentations is fundamental to an understanding of motor learning in general, and our present understanding of these processes is poor. Important future directions are indicated here.

Studies dealing with the temporal placement of KR in the trial sequence provide a vast array of conflicting findings, experimental confounds, and unclear results. A few principles of these intervals have emerged, when relative amount learned is measured on a transfer test. KR delay appears to have no effect, except that a very short KR delay did degrade learning in one study. When post-KR delay is covaried with the intertrial interval, with KR delay being held constant, increasing both of them tends to increase learning. Findings that increased intertrial intervals tend to enhance learning are contrary to earlier views (e.g., Bilodeau, 1966); and Adams's theory, which predicts that increased intertrial intervals degrade learning, must surely be in error in this regard. It is not clear whether the intertrial interval or the post-KR delay interval is the source of these effects. These intervals generally seem to be of little importance, but additional work should be done with more demanding motor tasks before this conclusion is finally accepted. Decrement's in learning have been found when various information-processing activities are inserted into the KR-delay interval, but analogous effects have not been found for the post-KR delay interval. It could be that the processes that are blocked in KR delay are important for learning, but that blocking next-response planning in post-KR delay is important for performance only and not for learning.

A major surprise from this review has been the analysis of trials-delay effects on learning. Even though trials delay degrades performance (relative to immediate KR) when KR is present, it enhances learning as measured on a no-KR transfer test. Numerous studies are reasonably clear on this point. It is interesting to ask how subjects can learn so well when they are performing so badly in acquisition. The answer may lie in the information-processing strategies that trials delay forces on the subjects, with more attention directed to intrinsic task feedback than to KR. These results support the guidance hypothesis for KR described earlier.

With increased precision of KR, learning simple tasks appears to be enhanced but only to a point, beyond which no further gains occur. Overall, this variable tends to be not very powerful for learning, but more work is needed with transfer tests to clarify its role in various situations.

**Theoretical Considerations: How does KR Work?**

Our review raises a number of large and small theoretical issues, and in the final sections of the review we treat some that we consider to be most important. In most of these cases, the fundamental question is how KR works to produce learning.

**Motivational role of KR.** One important effect of KR that has not been heavily emphasized is its motivational or energizing role. Early studies (e.g., Arps, 1920; Crawley, 1926; Elwell & Grindley, 1938) indicated that when KR was not given, subjects tended to become bored. When KR was given, it caused subjects to try harder, to practice longer after KR was withdrawn, and generally to be more interested in the task. This work suggests a direct motivational role for KR in performance, where more effort and attention are brought to bear on the task when the KR is present. It also suggests an indirect learning function where the learner engages in more effective or efficient practice sessions or practices longer after the session is formally completed. Certainly, if KR increases the amount of practice received, then this motivational aspect of the KR variable will be important for learning.

A second motivational role in which KR rewards correct actions and punishes incorrect actions is also possible (see Adams, 1968, 1978). There is ample evidence that this aspect of KR influences choice behavior, such as whether to do a few more trials before ending practice or whether to perform a task in one way as opposed to another (e.g., Rushall &
Siedentop, 1972). However, evidence reviewed here does not strongly implicate this role for KR in situations in which the subject's problem is to improve the motor control over a given motor response (but see Payne & Artley, 1972). Although rewards may indeed function to alter motor control, the evidence for this role of KR is not strong, and other hypotheses about the motivational functions of KR seem more clearly supported. Finally, as emphasized by Locke and his colleagues (e.g., Locke, Cartledge, & Koeppel, 1968), KR may have a goal-setting function similar to the general view of KR as an energizer discussed previously.

An associational function of KR. A second major way in which KR might work is the old idea that KR acts to form associations between stimulus and response. Of course, such ideas can be traced to Thorndike's (1927) Law of Effect. According to this view, and the many versions that others have used, KR strengthened the bond between some stimulus and a response, so that repeated practice of the movement with KR allowed the learner to produce the proper response under the given stimulus conditions. According to the Law of Effect, no learning can occur unless KR is provided (or unless subjects can generate their own subjective reinforcement as Adams, 1971, and Schmidt, 1975a, 1976, have argued). However, there is a problem with the effect of relative frequency of KR, where decreasing the relative frequency (by increasing the number of no-KR trials in a sequence) enhances learning. Such a theory cannot explain why such neutral responses should lead to increased learning. Reward may be part of the function of KR, but it appears not to be the entire function.

Others have viewed KR in different associational ways. For example, many have argued that KR serves to calibrate the motor system to the outside world. The subject's own internal scale of movement distance is imperfectly related to the outside-world measures of centimeters, and KR seems to associate a target position of the arm with the label (i.e., KR) in terms of physical units of distance. Over trials, a new relation is formed, so that the person moves more effectively to the goal position (Newell & Boucher, 1974; Schmidt, 1975a).

A variant of this idea is presented in schema theory (Schmidt, 1975a, 1976). In this situation KR acts to form associations among features of the response so that rules or schemas are created. One of these is called the recall schema, which relates commands to the motor system with the outcome of the movement in the environment (i.e., to KR). Another is the recognition schema, which relates the sensory qualities of the past movements and movement outcomes (KR).

We find the evidence for this view of KR convincing but indirect. First, a considerable amount of data has been accumulated showing that variability in practice leads to greater learning of the task, as measured on a novel transfer test without KR, than constant practice. A schema interpretation of this evidence (e.g., Shapiro & Schmidt, 1982) is that variability builds stronger rules (schemas), and that these rules are then an advantage when novel performances are attempted. Second, because these rules are presumably formed on the basis of an association between certain features of the movement and KR, this associational role of KR is supported.

A guidance role for KR. The strongest and most interesting viewpoint about KR to emerge from this review is that KR acts as guidance. This is not a new idea, as many have discussed this role either informally (e.g., Annett, 1959, 1969; Elwell & Grindley, 1938; Holding, 1965; Salvendy & Harris, 1973) or formally (Adams, 1971). KR provides information about response outcome, the subject uses the information to generate a new response on the next trial that is more accurate than the previous one, and performance improves with increased trials with KR. Such a viewpoint is consistent with the improved performance that results from (a) both increased relative and absolute frequency of KR, (b) longer post-KR delay, (c) increased KR precision, (d) fewer interpolated activities in KR delay and post-KR delay, and (e) perhaps decreased KR delay. All of these effects on performance can be encompassed by the idea that they are caused by the guidance properties of KR—that is, some feature of KR that influences its effectiveness for helping the learner to achieve the target and to stay there.

This guidance role for KR and performance
has been recognized for some time (e.g., Annett, 1969; Holding, 1965). What has not apparently been considered previously (but see Salvendy & Harris, 1973; Tomlinson, 1972) is the idea that if KR acts like guidance to make performance effective when KR is present, then it should also act like guidance when it is removed. The guidance literature generally shows that, when guidance is present, performance is good; indeed, it is seldom even meaningful to measure performance here because guidance prevents the subject from making errors. To some extent, KR acts in the same way, keeping performance in check. However, when guidance is removed, performance generally worsens, often to the point where in a transfer test it is poorer after guided practice than after unguided practice (e.g., Armstrong, 1970; Battig, 1954; Holding, 1965; Lincoln, 1954; Salvendy & Harris, 1973). Indeed, even normal vision can be thought as guidance; Griffith (1931) showed that vision enhanced performance in acquisition of a golf drive, but depressed learning of it as measured on a transfer test with vision. Exceptions to this conclusion are available, however (e.g., Fox & Levy, 1969). KR appears to act in much the same way. Conditions where KR is given on every trial have been shown to be inferior for learning as compared with conditions with trials delay or with blank trials interspersed. This suggests that the role of KR as guidance has forced the subjects to concentrate (or rely) too much on KR for immediate performance, so that the task is not learned effectively.

If this guidance role for KR is recognized, it is suggested that we think about KR in learning situations in much the same way that guidance is considered in training. For example, just as too much guidance can degrade learning, so can too much KR. Evidence has already shown that a decreased relative frequency of KR can enhance learning. Also, procedures that force the subject away from this reliance on guidance should be useful. Asking the subject to guess the performance before KR is given should focus attention on the task and its sensory qualities, and away from a reliance on KR (Hogan & Yanowitz, 1978). Also, giving KR in ways that makes it difficult for the subject to relate to behavior should be helpful. The trials-delay procedure and Lavery's (1962) use of summary KR after a series of trials have been shown to enhance learning. There is much potential for research in examining ways in which KR can be presented to enhance learning, with strong benefits for practical application as well.

These general findings are suspiciously similar to so-called context effects, which have been studied in motor learning by Shea and Morgan (1979) and Lee and Magill (1983). A large class of variables that affects the ways in which the subjects perform the task in acquisition has been shown to influence learning as measured on a transfer test. Shea and Morgan, for example, showed that random presentations of different versions of a movement-speed task produced better learning (on a transfer test) than did blocked presentations. Such evidence can be interpreted to mean that the more difficult presentation of trials in random order caused the subjects to process the task cues at deeper levels, or at least to process different task cues, leading to enhanced learning (but see Adams, 1983, or Baddeley, 1978, for a critique of this viewpoint). The relation of this work to studies of varied and constant practice in experiments testing predictions from schema theory is striking, as Shea and Morgan suggest (see also Shea & Zimny, 1983). The parallel with KR research is that if certain KR manipulations make KR more difficult to use, then subjects might learn differently or more effectively. This is in keeping with the effect seen with trials delay and relative frequency of KR. This link is tenuous at present, but it deserves attention because it has the potential to unify a number of separate lines of research related to KR with those dealing with other effects of practice.

3 These authors have recognized that augmented feedback (e.g., visual or auditory) aids performance when the feedback is present, but degrades performance when the feedback is removed; this is consistent with our notion that guidance is effective for performance and can be inhibitory for learning. However, they do emphasize that KR also has this role.

4 Tomlinson (1972) discusses attention to KR as a stimulus set and attention to the task as a response set. In our terms, a stimulus set is effective for performance when KR is present, but not effective for learning as measured on a no-KR transfer test.
This idea suggests that KR guides the subject to the appropriate response, and then the subject learns the response by other means, not necessarily by the mechanisms suggested by Thorndike (1927) or by schema theory. One hypothesis that has not received serious consideration is that of repetition. KR guides the subject to the correct action, and then repeating the movement at the goal position serves to strengthen the action or its recognition memory. KR might serve no role in this later strengthening process except to keep the learner on target so that more repetitions are experienced.5 What, then, is the role of mere repetition? Saying, over and over again, the Pledge of Allegiance, where no errors are made and no KR is provided, seems to lead to subjectively increased learning. Could it be that repeating responses that are generally correct on each trial leads to learning in the same general way? Very little research is devoted to this kind of question. In view of the suggestions for this guidance role for KR, examinations of the role of mere repetition in motor acquisition (perhaps similar to the Seashore & Bavelas, 1941, study using line drawing) would be productive.

Conclusions

In closing, we emphasize three major points that have emerged from this review. The first relates to paradigms and designs for studying the effects of KR. A dominant theme has been that transfer tests, usually under no-KR conditions, are essential for unraveling the temporary effects of KR manipulations from their relatively permanent learning effects. When this is considered, the literature reveals findings that produce reasonable agreement, although there are a discouraging number of inconsistencies across studies examining the same variables, perhaps because the number of acquisition trials generally viewed has been so small. Acceptance of this viewpoint about transfer tests implies altering one's terminology. In our terms, when a variable affects performance during the acquisition phase where KR is present and is being manipulated, we say that the difference could be the result of either (temporary) performance effects or (relatively permanent) learning effects. To say, as many do, that this manipulation has affected acquisition or that subjects learned faster is unclear and potentially misleading. Next, the performance on a transfer test will be the primary, if not only, criterion of relative amount learned. Groups performing more effectively do so, in our view, because of the relatively permanent effects that the KR manipulation provided in the acquisition phase. Proposed changes in terminology should be viewed cautiously. But, in this case, we feel that such a viewpoint brings additional order to an area where there has been much confusion and that these changes are worthwhile.

A second point is that, when the learning versus performance effects of KR are separated, a number of contradictions to previously held principles of KR occur. These new principles, if they can withstand future tests, provide a number of difficulties for theoretical views of learning based on the functioning of KR and raise new possibilities for thinking about how KR works in producing changes in behavior and learning. At the head of the list of these pretheoretical ideas is the notion that KR acts as guidance. We would not want to argue that this guidance role is the only one for KR, as others are possible and probable (e.g., the motivating or energizing function of KR and its role in the formation of associations). Perhaps this is why an understanding of KR has been so elusive: It acts in many ways simultaneously.

Finally, our proposal that KR acts as guidance makes us wonder about the idea that KR is the most powerful variable for learning and performance. Our guidance interpretation of KR suggests that too much emphasis has been placed on KR for learning. Perhaps it is more reasonable to say that all KR does is guide the subject to the proper target behavior, with other processes that are not well understood (e.g., simple repetition) being the critical determinants of learning. In this view, KR has a much smaller role for learning than others have given it, and our attention would be focused on those other factors that do determine

5 This viewpoint is similar to Adams's (1971) views of perceptual-trace formation. In this situation, KR has among other things a guidance role for bringing the subject to the target position. Then feedback from the movements forms a collection of traces that represents the feedback qualities of the target position.
learning. These issues are certainly preliminary in nature, but they should fuel an interesting debate about this important set of processes in motor acquisition.

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