1994

The Relationship Between Intrinsic and Augmented Feedback in Motor Skill Learning.

David Ian Anderson

Louisiana State University and Agricultural & Mechanical College

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THE RELATIONSHIP BETWEEN INTRINSIC AND AUGMENTED FEEDBACK IN MOTOR SKILL LEARNING

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy in

The Department of Kinesiology

by

David Ian Anderson
M. A., California State University, Long Beach, 1990
December 1994
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The office staff and the fellow graduate students who have helped me during my stay at LSU deserve a special thank you. I could not have completed this project without their assistance. Finally, I owe an enormous debt of gratitude for the support that I have been given by my family in Australia and here in the United States. In particular, I would like to express sincere thanks to my wife Sue, whose constant support and encouragement gave me the strength to complete this work.
Preface

This dissertation is based on a series of experiments that were conducted at the Motor Behavior Laboratory in the Department of Kinesiology at Louisiana State University, Baton Rouge. Chapter 1 provides an overview of the problem under study and gives a brief rationale for the experiments presented in the subsequent chapters. The first experiment, which is presented in chapter 2, has been published in Research Quarterly for Exercise and Sport (1994, Vol. 65, pp. 286-290). The author gratefully acknowledges the permission of Research Quarterly for Exercise and Sport to include this article in the present dissertation. Chapter 3 is based on three further experiments that extend the findings presented in chapter 2. Finally, chapter 4 is a general discussion that provides a synthesis of the findings from the previous chapters.
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Abstract

Four experiments examined the influence of knowledge of results (KR) schedule and the characteristics of intrinsic feedback on the acquisition and retention of a simple motor task. In the first experiment, subjects practiced a one-dimensional aiming movement and were provided with KR either directly after each trial or after a delay of two trials. The results showed that subjects who received KR after a delay of two trials were less accurate in acquisition but more accurate in retention than subjects who received KR directly after each trial. These results were replicated in a second experiment using a two-dimensional aiming movement. However, when a spring was added to the movement to enhance proprioceptive feedback, there were no differences in acquisition or retention for groups that received the two different schedules of KR presentation. While these results were consistent with predictions, the poor level of retention performance demonstrated by both groups was not expected. A third experiment showed that the poor retention performance was not due to subjects' inability to discriminate the cues afforded by the spring. The final experiment then looked at whether insufficient practice was responsible for the poor retention performance of the spring groups. When additional practice was provided, the group that received KR after a delay of two trials again demonstrated superior retention performance to the group
that received KR directly after each trial. These results are interpreted in terms of a proposed relationship between the complexity and salience of intrinsic feedback and dependence on KR. Finally, theoretical and practical implications are discussed.
Chapter 1

Augmented feedback is typically defined as externally presented information about the outcome of a movement or the characteristics of a movement that led to a particular outcome. This source of information is classified as externally presented to distinguish it from the sources of information that are naturally available to a performer to evaluate his/her actions. It is well understood that augmented feedback can play a critical role in motor learning and, as such, its experimental study is of considerable interest to researchers (for reviews, see Adams, 1971; Bilodeau, 1966; Magill, 1993; Newell, 1976; Salmoni, Schmidt, & Walter, 1984; Young & Schmidt, 1992) and to teachers and instructors who use it as a means to facilitate the learning process.

Despite several decades of research, the role of augmented feedback in motor learning is still not well understood (Magill, 1993). One of the most interesting and counter-intuitive issues relevant to the role of augmented feedback in motor learning concerns the optimal way to schedule this source of information. For many years, it was thought that augmented feedback should be provided as frequently and immediately as possible in order to facilitate learning. However, according to a review of research (Salmoni et al, 1984), this conclusion was based on a research design in which the schedule of augmented
feedback was manipulated during the practice of a motor task and learning was determined by the rate of performance improvement on the task, the final level of performance, or both these measures. Salmoni et al. (1984) questioned the assumption that gains in performance during practice reflected gains in learning, a point that has a rather long history in the learning literature (e.g., Guthrie, 1952; Hull, 1942; Tolman, 1929).

The distinction between performance and learning suggests that variables can have temporary (e.g., motivation, fatigue) or relatively permanent (e.g., learning) effects on the capability for performing a skill. The temporary effects are apparent during acquisition when the independent variable is in effect. However, to evaluate the relatively permanent effects it is necessary to allow the temporary effects to dissipate over time and then transfer all subjects to retention or transfer tests in which the practice conditions are equivalent. With respect to augmented feedback manipulations, the retention and transfer test conditions are typically equated for all subjects by withdrawing augmented feedback.

When they considered the learning/performance distinction, Salmoni et al.'s (1984) findings challenged the traditional notion that the optimal way to schedule augmented feedback was to provide it as frequently and immediately as possible. Surprisingly, scheduling
variations that provided augmented feedback more frequently or immediately tended to facilitate acquisition performance at the expense of poor performance in retention. In contrast, scheduling variations that delayed augmented feedback over trials, or presented augmented feedback less frequently, tended to degrade acquisition performance, but facilitated retention performance. Thus, different schedules of augmented feedback had different effects on performance and learning.

Since Salmoni et al.'s (1984) review, a considerable research effort has been undertaken to determine the robustness of the effects produced by various schedules of augmented feedback and to determine why these effects occur. At present, the status of this research effort is difficult to evaluate because researchers generally have chosen to study each of the scheduling manipulations as independent phenomena. Although some attempt has been made to identify the common underlying constructs that unify these lines of research, this attempt generally has failed to provide a purposeful focus and direction for future research.

The effects of delaying KR over trials have received scant attention in the literature. This is unfortunate because the trials-delay of KR manipulation may have more potential to reveal the mechanisms that facilitate retention performance than any of the other scheduling manipulations. One of the purposes of this dissertation is to determine the
effects of delaying KR over trials on the acquisition and retention of a motor task. Previous research has shown that delaying KR over trials can have a detrimental effect on acquisition performance, but a beneficial effect on retention performance (Lavery, 1964; Lavery & Suddon, 1962; Suddon & Lavery, 1962). However, additional research is needed to investigate the trials-delay of KR effects for two reasons. One, it is not clear whether the detrimental and beneficial effects reported in previous studies are robust, because the reports have all come from the same laboratory. Two, recent research has been unable to replicate some of the detrimental and beneficial effects attributed to other schedules of augmented feedback when that research has been conducted in a different laboratory (e.g., Sidaway, Moore, & Schoenfelder-Zohdi, 1991).

A second purpose of this dissertation is to test a hypothesis that certain schedules of augmented feedback facilitate retention performance because they force subjects to attend to and process intrinsic feedback (e.g., proprioception). This hypothesis maintains that if augmented feedback is presented too frequently or in a way that makes it too "easy" for subjects to use, subjects will simply substitute this augmented information for intrinsic feedback. As a result, subjects develop a dependence on augmented feedback and cannot maintain performance when augmented feedback is withdrawn because they have not
attended to and processed intrinsic feedback. Although this hypothesis is favored to explain the beneficial effects of making augmented feedback difficult to use, it is not clear whether retention performance is facilitated because of the characteristics of intrinsic feedback (e.g., Lintern, 1980) or because of the cognitive activities associated with detecting and processing intrinsic feedback (e.g., Lee, Swinnen, & Serrien, 1994). In either case, the answer to this question could provide valuable direction for future research on the scheduling of augmented feedback.

In the first experiment (Anderson, Magill, & Sekiya, 1994), the effects of delaying KR by two trials, relative to providing KR directly after each trial, are determined for the acquisition and retention of an aiming task. If the trials-delay of KR effects are robust, then relative to KR that is presented directly after each trial, a two-trial delay of KR should degrade acquisition performance but facilitate retention performance. In the second experiment, the proprioceptive feedback associated with the aiming task is enhanced by adding spring resistance to the movement. If the characteristics of intrinsic feedback affect dependence on augmented feedback, then adding spring resistance to the aiming movement should facilitate retention performance as effectively as delaying KR over trials. However, it is equally plausible that adding a spring to the movement might increase the difficulty of the task because the cues
afforded by the spring are unfamiliar or difficult to discriminate. It is possible also that the spring might increase the difficulty of the task because it adds another cue for subjects to attend to and therefore increases the complexity of the intrinsic feedback that must be processed. Experiments three and four examined some of the adverse consequences of adding a spring to the movement and attempted to determine how and why spring resistance affects retention performance.

In summary, the dissertation aims to determine whether the beneficial effects of delaying KR over trials are robust and whether these beneficial effects can be attributed to the opportunity to process intrinsic feedback. A third concern is to determine how and why retention performance is affected by manipulations of intrinsic feedback. The results have theoretical value for the role of augmented feedback in motor learning as well as practical value for the way augmented feedback can be scheduled to optimize the learning process. From a theoretical standpoint, the experiments will help to determine whether retention performance is primarily influenced by the opportunity to process relevant cues during acquisition, or by the difficulty of the cognitive processing engaged in during acquisition. The role of augmented feedback would then be to facilitate the conditions during acquisition that lead to the optimal retention of task characteristics. From an
applied standpoint, the experiments will help determine whether the optimal way to schedule augmented feedback is related to the characteristics of the task or the characteristics of the schedule itself.

References to Chapter 1


Chapter 2

Introduction*

The extensive review of the knowledge of results (KR) literature conducted by Salmoni, Schmidt and Walter (1984) has stimulated considerable interest in those schedules of KR presentation that tend to degrade the rate of performance improvement in acquisition, yet facilitate the retention and/or transfer of motor tasks. These schedules can be divided into two general categories. One involves reducing the relative frequency of KR during practice. The other involves delaying KR by a certain number of trials by either presenting KR as specific for each trial, or in summary form after a block of trials. The two variations of schedules in this latter category have been referred to as the trials-delay of KR and the summary KR paradigms respectively.

A primary concern for motor skill learning is to determine the effects of these KR schedules and to understand the mechanisms related to their effects. Recent research has focused on the effects of reducing the relative frequency of KR and presenting KR in summary form (see Magill, 1993a, and Young & Schmidt, 1992, for summaries of much of this work). But, virtually no empirical work has

been conducted on the trials-delay of KR paradigm since the research reported by Lavery (1964a).

The lack of recent interest in the trials-delay of KR paradigm is unfortunate because previous research suggested that the effects produced within this paradigm may be quite powerful and robust. Although Lorge and Thorndike (1935) concluded that delaying KR over trials produced no learning, and Bilodeau (1956) argued that such a delay degraded learning, such conclusions must be viewed with caution because they were based on assessing only the level of performance achieved when KR was present, rather than on no-KR retention or transfer tests (see Salmoni et al., 1984). The issue of how learning is assessed is important here because when appropriate learning tests have been used, quite different conclusions result than when only performance is assessed. For example, Lavery and Suddon (1962) showed that the inferior performance on a series of force production tasks, caused by the delay of KR by either two or five trials, actually resulted in no-KR retention test performance that was superior to a group that received KR directly after each trial (zero-trial delay). These findings were replicated with another force production task (Suddon & Lavery, 1962), where a five-trial delay of KR resulted in inferior acquisition performance and superior retention performance to a zero-trial delay of KR. Finally, using a novel ball tossing task, Lavery (1964a) demonstrated
that when KR was delayed by one trial, retention performance was remarkably superior to a zero-trial delay condition, and this superiority continued to increase on no-KR tests that were given two and four months after the initial acquisition period. The results of Lavery and his colleagues consistently showed that delaying KR over trials was detrimental to performance in acquisition, but beneficial in retention.

However, before having confidence in conclusions based on the results of Lavery and his colleagues, it is important to consider concerns raised by recent research about the reliability of effects produced by other manipulations of KR presentation. More specifically, several researchers have been unable to replicate effects attributed to the presentation of summary KR (e.g., Guay, Salmoni, & McIlwain, 1992; Sidaway, Fairweather, Powell, & Hall, 1992; Sidaway, Moore, & Schoenfelder-Zohdi, 1991) and to the reduction of KR relative frequency (e.g., Sparrow & Summers, 1992). These findings raise the question of whether Lavery's trials-delay of KR results are robust and therefore replicable, or whether they are unique to the conditions characteristic of Lavery's experiments.

With this point in mind, the present research was designed to replicate and extend previous trials-delay of KR results. More specifically, the present experiment sought to determine if, relative to a zero-trial delay of KR, a
two-trial delay of KR would produce the detrimental effects in acquisition and the beneficial effects in retention noted in previous trials-delay of KR studies.

**Method**

**Subjects**

Right-handed male \((n = 10)\) and female \((n = 10)\) undergraduate university students participated in the experiment in exchange for course credit. Subjects were randomly assigned to two groups with the restriction that group sizes were equivalent and each contained an equal number of males and females. All subjects provided informed consent prior to participation in the experiment.

**Task and Apparatus**

The task was a blindfolded, rapidly executed aiming movement to a horizontal target line located 20 cm from a start location. Subjects performed the movement with their non-dominant (left) hand and were encouraged to move rapidly and without hesitation.

A graded target was constructed on a sheet of paper and fixed to a table top. The center of the target was defined by two horizontal lines 210 mm long and 5 mm apart. An additional 35 parallel lines were set at 5 mm intervals above and below the target center. The sections bounded by these lines were numbered from 1 to 35 and \(-1\) to \(-35\) respectively and these units were used to assess error from the target center. The start location was a raised rubber
mound (20 mm X 20 mm in area and 10 mm high, with a 2 mm diameter well located centrally) which was fixed to the table at the center of the bottom edge of the target. Subjects were required to move a pen-shaped stylus that was fitted with a small rubber grip (to ensure consistent grip position). The blindfold consisted of a pair of standard ski goggles with special opaque lenses.

Procedure

Subjects were randomly assigned to either a Delay-0 or a Delay-2 group. The Delay-0 group was provided with KR directly after each trial, while KR was delayed by 2 trials (e.g., KR for trial 1 was given following the movement made on trial 3) for the Delay-2 group. The delay of KR by two trials was chosen on the basis of previous pilot work which indicated that the delay of KR by one or two trials produced similar effects in acquisition and retention for the aiming task used in this experiment.

Upon entering the testing room, subjects were blindfolded and guided to the experimental set-up. Subjects were seated in front of the target so that their nose lined up with the start location. Although subjects were never allowed to see the target, their hand was moved passively around the borders of the target prior to the start of practice. Subjects were told to aim for a location that was directly in front of their nose and half way between the top and bottom edges of the target. KR was given verbally in
terms of the number of units each movement landed beyond or short of the target center. At the end of each trial, the subject's hand was moved passively back to the start location by the experimenter. The inter-trial interval was 15 sec. The acquisition phase consisted of 80 KR trials. Two, 20-trial, no-KR retention tests were then given, one after a 10-min filled interval, and the other on the following day. The 10-min retention interval was filled with a number search task. Subjects were not told that KR would be withdrawn on the retention trials until after the acquisition trials were completed.

Results

The primary dependent variables used to assess performance were absolute constant error (ACE) and variable error (VE). Performance was averaged into blocks of 10 trials for the purposes of analysis. Acquisition and retention data were analyzed with separate (Group x Trial Block) analyses of variance (ANOVA's) with repeated measures on the Trial Block factor. To protect against any violations to the assumptions of sphericity, the probability level for all repeated measures tests was computed using the Greenhouse-Geisser degrees-of-freedom adjustment (Greenhouse & Geisser, 1959).

Acquisition

The group by block means for ACE and VE for the acquisition and retention phases are summarized in Figures
Figure 2.1. Group by block means for ACE in acquisition and retention.
Figure 2.2. Group by block means for VE in acquisition and retention.
2.1 and 2.2 respectively. There was a significant effect of Trial Block for ACE, $F(7,126) = 9.9, p < .001$, and VE, $F(7,126) = 29.1, p < .001$, suggesting that both groups became more accurate and consistent as a result of practice. There was also a significant Group main effect for ACE, $F(1,18) = 6.4, p < .01$, and VE, $F(1,18) = 11.1, p < .01$. The Delay-2 group was less accurate and more variable than the Delay-0 group during acquisition. The Group x Trial Block interactions were not significant.

10-min Retention

The only significant effect on the 10-min retention test was a Trial Block effect for VE, $F(1,18) = 8.6, p < .01$. The tendency for both groups to be more consistent on the second block of trials than the first block can be seen in Figure 2.2.

24-hour Retention

There was a significant Group main effect for ACE, $F(1,18) = 6.8, p < .05$. Figure 2.1 reveals that the Delay-0 group experienced a dramatic loss in accuracy on the delayed retention test while the Delay-2 group was able to maintain the accuracy they had achieved during acquisition and even showed a slight improvement from the first block of trials to the second block. The only other significant finding on the delayed retention test was a Trial Block effect for VE, $F(1,18) = 11.9, p < .01$. Similar to the findings on the
Table 2.1. Means (Standard Deviations) of ACE and VE for Group and Trial Block at Acquisition and Retention Periods.

<table>
<thead>
<tr>
<th>Block</th>
<th>Delay-0</th>
<th></th>
<th></th>
<th>Delay-0</th>
<th></th>
<th></th>
<th>Delay-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACE</td>
<td>VE</td>
<td></td>
<td>ACE</td>
<td>VE</td>
<td></td>
<td>ACE</td>
</tr>
<tr>
<td>ACQ 1</td>
<td>2.8 (1.5)</td>
<td>5.1 (1.6)</td>
<td>5.4 (4.2)</td>
<td>6.9 (2.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQ 2</td>
<td>1.3 (0.8)</td>
<td>2.1 (0.5)</td>
<td>3.5 (3.5)</td>
<td>3.9 (1.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQ 3</td>
<td>1.3 (1.6)</td>
<td>2.3 (0.9)</td>
<td>0.9 (0.7)</td>
<td>2.3 (0.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQ 4</td>
<td>1.3 (1.0)</td>
<td>2.1 (0.6)</td>
<td>1.1 (0.6)</td>
<td>2.2 (0.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQ 5</td>
<td>1.0 (0.5)</td>
<td>2.7 (0.6)</td>
<td>1.2 (0.9)</td>
<td>3.4 (1.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQ 6</td>
<td>0.9 (1.0)</td>
<td>2.2 (0.9)</td>
<td>0.7 (0.3)</td>
<td>2.9 (0.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQ 7</td>
<td>0.6 (0.6)</td>
<td>2.1 (0.9)</td>
<td>1.3 (0.9)</td>
<td>2.3 (1.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACQ 8</td>
<td>1.0 (0.7)</td>
<td>1.9 (0.5)</td>
<td>1.4 (1.1)</td>
<td>2.5 (0.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-min 1</td>
<td>2.7 (2.5)</td>
<td>2.5 (0.5)</td>
<td>1.6 (0.8)</td>
<td>2.7 (1.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-min 2</td>
<td>1.8 (0.8)</td>
<td>1.8 (0.6)</td>
<td>1.3 (0.8)</td>
<td>2.1 (0.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-hr 1</td>
<td>4.7 (3.0)</td>
<td>2.6 (0.8)</td>
<td>2.3 (1.2)</td>
<td>2.3 (0.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-hr 2</td>
<td>5.4 (4.2)</td>
<td>1.7 (0.4)</td>
<td>1.8 (1.2)</td>
<td>2.0 (0.4)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. All values are in units, where 1 unit = 5 mm. ACE = absolute constant error; VE = variable error; ACQ = acquisition; 10-min and 24-hr = 10-min & 24-hour retention.
10-min retention test, both groups decreased their variability from the first block to the second.

Inspection of the ACE standard deviations presented in Table 2.1 gives a better appreciation of the group differences on the delayed retention test. The large standard deviations for the Delay-0 group suggest a large degree of within-group variability. Closer analysis of individual scores indicated that some subjects in this condition showed a drastic loss of accuracy on the delayed retention trials (e.g., 11.3 units of error), others showed a moderate loss in accuracy (e.g., 5.9 units of error), while others performed quite accurately (e.g., 1.5 units of error). In contrast, the within-group variability of the Delay-2 group was reasonably low, as all subjects were able to maintain the accuracy they had developed during acquisition (range = 1.2 to 4.2 units of error).

Discussion

The results of this experiment support and extend earlier findings about the effects of delaying KR over trials (Lavery, 1964a; Lavery & Suddon, 1962; Suddon & Lavery, 1962). Although delaying KR for two trials retarded the rate of performance improvement in acquisition, relative to a condition in which KR was provided after each trial, it facilitated the accuracy, but not consistency, of performance on a delayed no-KR retention test.
An important feature of demonstrating this effect is that it replicates those reported only from Lavery's laboratory and suggests that these effects are robust and not peculiar to that one laboratory. Furthermore, these effects were replicated with a task that has not been previously used with the trials-delay of KR manipulation. However, it should be noted that all of the tasks used in experiments investigating this KR manipulation have involved scaling an already established pattern of movement. Whether the same results hold for more complex tasks or tasks that require the development of a new movement structure remains to be seen.

The present findings complement convergent lines of research which have shown that providing KR directly after each acquisition trial can be detrimental to performance when KR is withdrawn. Many researchers have argued that these detrimental effects are due to insufficient attention to intrinsic sources of information during practice (e.g., Annett, 1969; Lintern & Roscoe, 1980; Salmoni et al., 1984).

A benefit of the trials-delay of KR paradigm is that it appears to have more potential than either the relative frequency of KR or summary KR paradigms to determine the extent to which intrinsic sources of information are processed. This is because learners must pay close attention to intrinsic sources of information when KR is delayed over trials, or no improvement will occur. In
contrast, when KR is given less frequently or in summary form, the learner is not forced to pay close attention to intrinsic sources of feedback because there are always some trials that are immediately followed by KR. While the purpose of this experiment was not to determine the processing operations that led to superior retention performance, these processing operations could quite easily be examined in future research with the trials-delay of KR paradigm.

Interestingly, the proposition that delaying KR over trials benefits learning because it directs attention to task intrinsic feedback is in keeping with a point made by Magill (1993b) concerning the effects of KR delay on learning. He pointed out that depending on the type of activity in which the learner engages during the KR-delay interval, activity during this interval can benefit, hinder, or have no effect on learning. When KR delay interval activities have led to skill learning benefits (e.g., Hogan & Yanowitz, 1978; Swinnen, 1990), those activities encourage task-intrinsic feedback processing in ways similar to what would result when other trials of the same task occur during this interval.

Finally, the data indicate a need to consider individual difference characteristics with regard to optimum schedules of KR. Closer examination of the data, based on the group standard errors, revealed that some subjects in
the Delay-0 group were able to perform just as accurately on the delayed retention test as subjects in the Delay-2 group. Clearly, the effects of the Delay-0 manipulation were inconsistent across subjects. While evidence indicates that task (Sparrow & Summers, 1992) and procedural (Lavery, 1964b) characteristics can influence retention of motor tasks, little attention has been given to the effect of individual difference characteristics. These differences may be reflected in an individual's preference or ability to process certain kinds of sensory information (e.g., Temple & Williams, 1977) or attributes such as motivation orientation (Little & McCullagh, 1989). These individual difference characteristics, along with task and procedural characteristics, must be identified before a comprehensive theory of feedback can be established.

References to Chapter 2


Chapter 3

General Introduction

An important role of augmented feedback during motor skill learning is to direct attention to the relationship between intrinsic feedback and the goal of the task so that performance can be maintained on the basis of intrinsic cues alone. However, this role may be compromised if during practice the learner simply substitutes augmented feedback for task intrinsic sources of feedback. When this occurs, the learner can become dependent on augmented feedback because intrinsic cues are not processed adequately to sustain performance and/or augmented feedback becomes part of the memory representation for the task (e.g., Magill, 1993; Proteau, Marteniuk, & Levesque, 1992; Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991; Young & Schmidt, 1992). If dependence occurs, performance suffers when augmented feedback is withdrawn because this source of information has become essential for performance on the task.

Of the many variables that can be manipulated to encourage or discourage dependence on augmented feedback, the schedule of augmented feedback presentation is thought to be one of the most important (e.g., Salmoni et al., 1984). Schedules of augmented feedback that accelerate the rate of performance improvement in acquisition tend to promote dependence while schedules that retard the rate of
performance improvement in acquisition tend to discourage dependence. For example, Anderson, Magill, and Sekiya (1994) recently investigated the effects of delaying knowledge of results (KR) by two trials on the acquisition and retention of an aiming movement. They found that, relative to KR that was provided directly after each trial, a two-trial delay of KR led to less accurate and more variable performance in acquisition but more accurate performance on a delayed no-KR retention test. Large group differences were found in retention primarily because the subjects trained with KR directly after each trial showed a dramatic loss of accuracy when KR was withdrawn. In contrast, the subjects trained with a two-trial delay of KR were able to retain the performance gains that they had made during acquisition. Presumably, the delay of KR by two trials forced subjects to direct more attention to intrinsic sources of feedback and the relationship between these sources of feedback and the goal of the task.

The results of Anderson et al.'s (1994) experiment support previous findings with the trials-delay of KR technique. Delaying KR over trials has produced detrimental effects in acquisition and beneficial effects in retention for the performance of force production tasks (Lavery & Suddon, 1962; Suddon & Lavery, 1962) and a novel ball throwing task (Lavery, 1964). In each case, the beneficial effects of delaying KR over trials have been attributed to
the increased processing of intrinsic feedback necessary to support performance during acquisition.

Some researchers have suggested that the characteristics of intrinsic feedback also may encourage or discourage dependence on augmented feedback. One of these characteristics is the salience of intrinsic feedback. Salience can be defined operationally in terms of the clarity and intensity of intrinsic feedback. Less salient cues are less clear and less intense and therefore more difficult to detect and interpret. It follows that dependence on augmented feedback is most likely to occur when intrinsic feedback is difficult to detect and/or interpret and least likely to occur when intrinsic feedback is easy to detect and/or interpret (e.g., Adams, 1964; Armstrong, 1970; Lintern, 1980; Magill, 1993). Presumably, dependence occurs because subjects simply substitute augmented feedback for intrinsic feedback when intrinsic feedback is less salient.

To test the relationship between dependence on augmented feedback and the salience of intrinsic feedback, Kinkade (as cited by Adams, 1964) had subjects practice a compensatory tracking task where, in addition to the visual feedback intrinsic to the task, concurrent auditory feedback was provided whenever the subject was on target. However, for some subjects, visual noise was used to perturb the target reference so that intrinsic feedback about the target
location was partially obscured. When augmented feedback was removed, only those subjects who had trained with an ambiguous target showed a decrement in performance. Thus, the results supported the proposed relationship between the salience of intrinsic feedback and dependence on augmented feedback.

Although Kinkade used concurrent augmented feedback and a continuous task to investigate the relationship between intrinsic feedback salience and dependence on augmented feedback, it is probable that similar results could be found when augmented feedback is presented after a discrete movement. If so, the salience of intrinsic feedback may be just as relevant to dependence on augmented feedback as the schedule of augmented feedback.

However, there is an important difference in the task used by Kinkade and the typical tasks used to study motor learning when augmented feedback is presented after a movement. In the former case, intrinsic feedback was visually based, whereas in the latter case, intrinsic feedback usually is specified by the proprioceptive system. While it is clear that the salience of visual feedback can be manipulated by enhancing or degrading the visual display, it is less clear how to manipulate the salience of proprioceptive feedback. Several researchers have advocated using a spring to enhance proprioceptive feedback (e.g., Adams, Goetz, & Marshall, 1972; Bahrick, Bennett, & Fitts,
1955; Bahrick, Fitts, & Schneider, 1955), while proprioception can be degraded by blocking afferent nerve pathways through surgical deafferentation or the use of a pressure cuff. In both cases, the effects of the manipulations are difficult to measure. Furthermore, when proprioception is enhanced with a spring, it is possible also that the complexity of intrinsic feedback is increased because the spring provides an additional cue to attend to and process. From this perspective, the salience and complexity of intrinsic feedback may be confounded when proprioception is manipulated. A manipulation designed to enhance proprioception actually may increase the difficulty of the task by increasing the complexity of intrinsic feedback.

Three experiments were designed to address the problem concerning the relationship among the salience of intrinsic feedback, the complexity of intrinsic feedback, and KR dependence. The first experiment attempted to determine if adding a spring to an aiming movement would increase the salience of intrinsic feedback and therefore discourage dependence on KR; similar to the way that delaying KR over trials discourages dependence on KR. The second experiment looked more closely at the salience issue and attempted to determine if subjects are better at discriminating movements made either with or without a spring. Finally, Experiment 3 looked at the relationship between the characteristics of
intrinsic feedback and dependence on KR when subjects are given extended practice on the task.

**Experiment 1**

**Introduction**

Delaying KR over trials has proved an effective way to promote the retention of motor skills (e.g., Anderson et al., 1994; Lavery, 1964; Lavery & Suddon, 1962; Suddon & Lavery, 1962). Presumably, delaying KR over trials benefits retention performance because subjects are forced to process intrinsic feedback from the task and therefore do not become dependent on KR. However, it is not clear how the characteristics of intrinsic feedback influence the extent to which this source of feedback is processed and KR dependence is discouraged. The present experiment attempted to address this problem by manipulating the salience of intrinsic feedback. Salience of intrinsic feedback was operationally defined as the degree to which the clarity and intensity of the intrinsic cues were enhanced. As the task was a two-dimensional aiming movement, it was predicted that the intrinsic cues could be enhanced by adding spring resistance to the movement (e.g., Adams et al., 1972; Bahrick, Bennett, & Fitts, 1955; Bahrick, Fitts, & Schneider, 1955). If so, retention performance might be facilitated, regardless of the schedule on which KR is presented, because subjects might be more likely to process
intrinsic feedback when the intrinsic cues are clear and intense.

The main purpose of Experiment 1 was to test further the robustness of the effects produced by delaying KR over trials and to determine whether these effects could be replicated by manipulating the salience of intrinsic feedback. To test these notions, four groups were created. Each group received KR either directly after each trial or after a delay of two trials and performed the task with or without a spring attached to the stylus that the subject was required to move to the target. Regardless of whether the spring was present or absent, the groups that received KR directly after each trial were predicted to perform more accurately in acquisition than the groups that received KR after a delay of two trials. In contrast, it was predicted that the spring would attenuate the differences in retention between the two schedules of KR presentation.

The two spring groups and the no-spring group that received KR after a delay of two trials were expected to perform more accurately in retention than the no-spring group that received KR directly after each trial. This prediction was based on the assumption that the latter group would be the only group to develop a dependence on KR because subjects in that group would be less likely to process intrinsic feedback. Another important assumption
was that the spring manipulation did increase the salience of intrinsic feedback.

Method

Subjects. Forty right-handed undergraduate university students participated in the experiment in exchange for course credit. Subjects were randomly assigned to four groups with the restriction that group sizes were equivalent (n = 10) and each group contained an equal number of males and females. All subjects provided written informed consent prior to participation in the experiment.

Task and apparatus. The task involved a self-paced, blind aiming movement to a target that was located 80 mm from a start location. The movement direction was away from the midline of the body in the sagittal plane. Subjects performed the movement with the non-dominant hand and were encouraged to complete the movement with a smooth, continuous motion. All movements were made with a pen-shaped stylus that could move freely to the target location on an electronic Calcomp Drawing Board II (Model 33180). Subjects were instructed to hold the stylus as if it was a pencil. A small rubber grip was fitted to the stylus to ensure consistent grip position. For two of the four conditions, a thin piece of rubber tubing (spring), which was attached to the table on which the drawing board was located, was fixed to the stylus. The spring had a pull of 575 grams at the target location. The endpoint location
of each movement was recorded by the drawing board and
relayed directly to an IBM PC computer. A 30 cm high table
was placed above the drawing board. The table served two
purposes: it prevented the subject's view of their forearm,
hand, and the drawing board and it supported an IBM color
monitor that was placed directly in front of the subject's
field of vision, approximately 1 m away. The entire
experiment was controlled by the computer.

Procedure. Subjects were randomly assigned to one of
four groups that were formed on the basis of the presence or
absence of the spring and on the two schedules of KR
presentation. Subjects in the first two groups performed
the task without the spring attached to the stylus and were
provided with KR either directly after each trial (Delay-0)
or after a delay of two trials (Delay-2). In the latter
condition, KR for trial one was provided after trial three,
KR for trial two was provided after trial four, and so on.
Subjects in the final two groups also were given KR either
directly after each trial (Delay-0 SPG) or after a delay of
two trials (Delay-2 SPG), but they performed the task with
the spring attached to the stylus.

At the start of each trial, subjects were instructed to
position the stylus at a pre-defined start location on the
drawing board. The position of the stylus relative to the
start location was displayed on the computer monitor located
in front of the subject. The distances between the stylus
position and the start and target locations displayed on the screen were exactly the same as the distances on the drawing board (i.e., the gain of the display was 1:1). When the stylus was at the start location, the subject pressed down on the drawing board to initiate each trial. The start location and the subject's cursor disappeared from the screen and a target circle appeared. The subject then attempted to move to the target, press down, and return to the start location. KR was provided on the monitor by showing the terminal stylus position relative to the target location as well as a number that indicated how many millimeters the response landed away from the target center. The KR delay and post-KR delay intervals were 2 and 8 sec respectively. All groups performed 80 acquisition trials with KR, followed by two 40-trial, no-KR retention tests that were administered one minute and one day respectively after the acquisition period. Subjects were not informed that KR would be withdrawn on the retention trials until after the acquisition trials had been completed. Groups that performed the acquisition trials with the spring also performed the retention trials with the spring. Similarly, groups that performed without the spring in acquisition also performed without the spring in retention.

Results

The x- and y-coordinates of the movement end-points were recorded for each trial. From these coordinates,
errors in the x- and y-axes were calculated with reference to the target center. The primary dependent variables were radial error (RE) and radial variable error (RVE). RE was calculated as the square root of the sum of the squared deviations in the x- and y-axes, whereas RVE was calculated as the square root of the total sample variance in the x- and y-axes. Trials were blocked into groups of 10 for the purpose of analysis. The mean RE and RVE scores for groups and blocks in acquisition and retention are plotted in Figures 3.1 and 3.2.

The acquisition data were analyzed with a 4 x 2 x 8 (Group x Gender x Trial Block) ANOVA with repeated measures on the Trial Block factor. Retention data were analyzed with a 4 x 2 x 4 (Group x Gender x Trial Block) ANOVA with repeated measures on the Trial Block factor. For all analyses, a p < 0.05 was chosen to protect against Type I errors. The Newman Keuls post hoc test was used to locate any differences indicated by significant main effects. To protect against any violations to the assumptions of sphericity, the probability level for all statistical analyses involving repeated measures was computed using the Greenhouse-Geisser degrees-of-freedom adjustment (Greenhouse & Geisser, 1959). In all statistical tests, neither the Gender main effects nor any of the interactions related to Gender were significant. The Gender factor was subsequently removed from all analyses.
Figure 3.1. Group by block means for RE in acquisition and retention.
Figure 3.2. Group by block means for RVE in acquisition and retention.
Acquisition. There was a significant Trial Block effect for RE, $F(7,252) = 19.6, p < .001$, and VE, $F(7,252) = 25.2, p < .001$, indicating that all groups improved their accuracy and reduced their variability with practice. There were no significant Group effects for RE or VE, although, Figure 3.1 clearly shows that the Delay-0 group was more accurate than all the other groups during acquisition. The Group x Trial Block interactions for RE and VE also were not significant.

1-min Retention. The only significant finding on the first retention test was a Trial Block effect for RE, $F(3.108) = 8.56, p < .001$. As shown in Figure 3.1, the accuracy of performance for all groups deteriorated as the number of retention blocks increased.

24-hour Retention. There was a main effect of Group for RE, $F(3,36) = 3.4, p < .05$. The follow-up post hoc test revealed that the Delay-2 group was reliably more accurate on the second retention test than the other three groups, which were not different from each other. The superiority of the Delay-2 group is clearly evident in Figure 3.1. The only other significant finding for RE on the second retention test was an effect for Trial Block, $F(3,108) = 12.9, p < .001$. The Group x Trial Block interaction just failed significance $F(9,108) = 2.1, p = .07$. Again, Figure 3.1 clearly shows that the performance of all groups deteriorated as the number of retention trial
blocks increased, although performance of the spring groups tended to deteriorate more rapidly than the other groups.

The RVE analysis revealed a significant Trial Block effect, $F(3,108) = 7.1, p < .001$, which revealed that all groups tended to perform with less variability as the number of trial blocks increased. There were no other significant findings for RVE on the second retention test.

**Discussion**

As predicted, the results showed that, relative to delaying KR by two trials, providing KR directly after each trial degraded retention performance when intrinsic feedback was not salient. In contrast, the detrimental effects that resulted from both schedules of KR when proprioceptive feedback was enhanced with the spring were not predicted.

With respect to the hypothesis concerning the effects of providing KR directly after each trial when intrinsic feedback was not manipulated, the results add further support to a growing body of work which has shown that providing KR directly after each trial can have detrimental effects on retention performance. Also, the results support previous findings (e.g., Anderson et al., 1994; Lavery, 1964; Lavery & Suddon, 1962; Suddon & Lavery, 1962) which have shown that retention performance can be facilitated if KR is delayed over trials. Similar to previous research (e.g., Anderson, et al., 1994) the beneficial effects of delaying KR over trials were most pronounced on the 24-hour
retention test. These findings are remarkably consistent and testify to the robustness of the effects produced by this schedule of KR presentation.

Another consistent finding which occurred was the amount of within-group variability associated with each of the KR schedules on the 24-hour retention test. Similar to the findings reported by Anderson et al. (1994) the standard deviation of the Delay-0 group (14.1) was considerably larger than the standard deviation of the Delay-2 group (6.8). The large variability in the Delay-0 group showed that while some subjects were able to perform very accurately when KR was withdrawn, others performed very inaccurately.

With regard to the hypothesis concerning KR dependence when proprioception was enhanced with the spring, the results are more difficult to interpret. However, first it is noteworthy that, as predicted, the spring attenuated the differences between the groups that received KR either directly after each trial or after a delay of two trials. The significance of this result is that it suggests that task characteristics merit serious consideration when the effects of various schedules of augmented feedback are to be assessed. An ostensibly small change in the task characteristics (i.e., adding a spring) can negate a KR scheduling effect that has proved very robust.
A concern for the present research is the poor performance of the spring groups relative to the no-spring groups. If, as hypothesized here and by others, spring tension enhances proprioception, and therefore the salience of intrinsic cues, then why did the spring groups perform less accurately than the no-spring groups on the 24-hour retention test? Surely, they should have performed at least as accurately. There are four possible answers. Each suggests that the spring increases the difficulty of the task. First, the cues that provide information about where the hand is positioned when the spring is present (e.g., force/tension) might be more difficult to discriminate than the cues that provide the same information when the spring is not present (e.g., location, distance). Second, the spring might increase the complexity of the intrinsic information that needs to be processed because it adds an additional cue. Thirdly, the cues afforded by the spring might be unfamiliar and therefore difficult to use when only a limited amount of practice is given on the task (e.g., Bahrick, Fitts, & Schneider, 1955). Finally, the cues associated with the spring may be more difficult to remember because they are encoded differently than cues such as location and distance (e.g., Howarth & Beggs, 1981; Smyth, 1984).

In order to determine which hypothesis or combination of hypotheses was most plausible, two further experiments
were conducted. Experiment 2 examined the hypothesis concerning whether there was any difference in subjects' ability to discriminate among movements made either with or without a spring. In addition, subjects were asked to rate the salience of the cues that were available under spring and no-spring conditions. These ratings were considered important to determine whether subjects perceived that the spring enhanced proprioception and therefore the salience of intrinsic feedback. The third experiment addressed the final three hypotheses, however, it focussed on the possibility that the spring increased the complexity of intrinsic feedback. In this experiment, subjects were given extended practice on the aiming task with the spring attached to the stylus. Also, subjects were required to answer questions about their cue usage during practice.

Experiment 2

Introduction

If movements made without a spring can be discriminated more easily than movements made with a spring, then differences in cue discrimination may offer a parsimonious explanation for the results of Experiment 1. To test this hypothesis, experiment 2 was designed to determine the just noticeable difference (JND) for movements made with and without a spring. Previous research has shown already that cues specifying movement extent are more difficult to discriminate than cues specifying movement location (Magill
& Parks, 1983). Importantly, for the present purposes, extent and location cues have been shown to be encoded differently in memory (e.g., Diewert & Roy, 1978; Laabs, 1973; Smyth, 1984). It is possible that these cues are encoded differently, and therefore remembered differently, on the basis of how easily they can be discriminated. For example, some researchers have suggested that the distinctiveness of an item is critical for memory of that item (e.g., Battig, 1979; Eysenck, 1979). More distinct cues are remembered more effectively.

Based on these ideas, it is possible that the cues afforded by the spring were less distinctive than the cues available when the spring was not present. As a result, the spring cues may have been encoded less effectively and remembered less well. This idea suggests that, contrary to our expectations and those of other researchers, the spring cues actually may have been less salient than the cues available when the spring was not present. To test this notion further, subjects were asked also to rate the salience of the cues that were available under spring and no-spring conditions.

Method

Subjects. Eleven right-handed, undergraduate students (5 males and 6 females) volunteered to participate in the experiment. All subjects were right-handed and all were naive to the task and hypotheses being tested. All subjects
provided written informed consent prior to participation in the experiment.

Task and Apparatus. The task was an 80 mm linear positioning movement that was made on a (600 mm x 400 mm) plexiglass surface. With the dominant hand, the movement was made in the sagittal plane away from the midline of the body. A 300 mm (long) x 50 mm (wide) x 10 mm (high) piece of wood was fastened to the plexiglass. The long axis of the wood was positioned in line with the subject's sagittal plane and served as a guide for the movement. The 80 mm movement distance was marked on the plexiglass with permanent pen. Eight additional marks were placed at 70 mm, 72.5 mm, 75 mm, 77.5 mm, 82.5 mm, 85 mm, 87.5 mm, and 90 mm. These marks were used for the purpose of comparison against the standard. Movement lengths were controlled by placing a physical stop along the movement pathway. The start location also was defined by a physical stop. The movement was made with a standard ball-point pen. The pen was fitted with a small rubber grip to ensure consistent hand placement. In addition, a small piece of elastic tubing (spring) could be fitted to the pen just above the rubber grip. The spring was attached to the plexiglass with a standard screw. The spring had a pull of 575 grams at the 80 mm standard location. The entire apparatus was fixed to a table top.
Procedure. Upon entering the laboratory, subjects were blindfolded and seated in front of the apparatus. Once seated, subjects were read a set of standard instructions. Adapting procedures prescribed by the method of constant stimuli (e.g., Matlin, 1988), subjects were required to make two movements on each trial. The first movement was to a stop at the standard location. After returning to the start location, subjects immediately made a movement to a stop at one of nine variable locations (including the standard location). Each of the nine variable locations was randomly presented as the comparison movement 10 times over the course of 90 trials. Ten comparisons for each location were chosen on the basis of previous pilot work that had indicated almost identical results when either 10 or 20 trials were used for comparison purposes. The subject was instructed to attend to the position of his/her hand and arm at the end of each movement and to verbally respond whether the second end point (variable location) was "shorter" or "longer" than the first end point (standard location). The subjects' responses were recorded by the experimenter.

Each subject performed the task with and without the spring attached to the stylus. All practice trials were completed on one version of the task and then the subject returned on the following day to complete all practice trials on the other version of the task. The order of task presentation was counterbalanced across subjects. After all
trials had been completed, subjects were asked to rate out of 10 the ease with which they had made their decisions with and without the spring, as well as the clarity, intensity, and salience of the cues that were available with and without the spring. In addition, subjects were asked what cues they attended to in order to make their comparisons with the standard location.

Results

Two primary dependent measures were used for each subject. The first was the length of the (JND) that could be detected from the standard location on 50% of the trials. The JND was calculated as the average of the distance that was judged longer than the standard 25% of the time and the distance that was judged longer than the standard 75% of the time. The second dependent measure was the point of subjective equality (PSE). The PSE is the point judged as being equal to the standard on 50% of the trials. The subjects' ratings also were used as dependent measures. However, as the ratings for ease of decision, cue clarity, cue intensity, and cue salience were almost identical, only the data on cue salience were subjected to statistical analysis. Paired T-Tests were used to determine any differences between the dependent measures with and without the spring. The tests were two-tailed because no predictions were made about the direction of any possible
differences. An alpha level of \( p < .05 \) (.025 two-tailed) was used to protect against possible type one errors.

There was no significant difference between the JND with the spring (4.28 mm) and without the spring (3.95 mm), \( t(10) = .53, p > .025 \). Also, there was no difference between the PSE with the spring (73 mm) and without the spring (73.6 mm), \( t(10) = .08, p > .025 \). In both conditions, subjects perceived the standard location as slightly shorter than 80 mm. Similarly, there were no significant differences in subjects' ratings of cue salience, \( t(10) = .39, p > .025 \). On a scale of one to ten, with ten being "very salient," subjects gave the cues with the spring a 5.55 rating and the cues without the spring a 5.73 rating.

**Discussion**

Clearly, the results showed that there was no difference in subjects' ability to discriminate between movements made with and without the spring. The JND and PSE with the spring were almost identical to the JND and PSE without the spring. Also, there were no differences in subjects' ratings of cue salience under spring and no-spring conditions. These findings are important for two reasons. First, they show that the inaccurate performance of subjects who performed with a spring, relative to subjects who performed without a spring, in Experiment 1 could not be attributed to differences in cue discrimination. Second,
and more important, they show that subjects perceived that the spring did not increase the salience of intrinsic feedback. This latter point is significant because it suggests that the spring versus no-spring manipulation did not adequately test the hypothesis in Experiment 1 that the salience of intrinsic feedback is related to KR dependency.

If the effectiveness of encoding is related to cue distinctiveness, then the results also may rule out the suggestion that the cues associated with the spring are difficult to remember because they are encoded less effectively. However, this conclusion is tentative and must be tempered in light of subjects' comments about cue usage. For example, all of the subjects indicated that they had used more than one cue to make their judgements, whether the spring was present or absent. These cues included: end location, movement distance, movement time, and spring tension. Interestingly, four of the eleven subjects reported that the spring tended to confuse them because there was too much information to attend to when it was present. Two of these subjects reported that they were uncomfortable using the spring cues because the cues were unfamiliar.

The subjects' reports suggest that the spring increased the complexity of intrinsic feedback because an additional cue had to be attended to and processed. It follows, then, that the complexity of intrinsic feedback could be just as
relevant to KR dependency as the salience of intrinsic feedback. Adding more cues might divert attention from the cues that are most critical for successful task performance. If so, subjects may require considerable practice on a task when the intrinsic information is complex because sufficient time is necessary to determine which cues are redundant and which cues provide critical information.

Similarly, the amount of practice might be important if the spring cues are difficult to use because they are unfamiliar or if the spring cues are remembered less well because they are encoded ineffectively. For example, Bahrick, Fitts, and Schneider (1955) have suggested that extended practice with KR is needed for effective utilization of cues provided by spring loading. Whether it is to use spring cues more effectively, to strengthen encoding, or to help sift through and find the most critical cues, the amount of practice might determine the extent to which movements made with spring loading are remembered. As a result, extended practice on the task when the spring is present may reveal more about the relationship among task characteristics, the schedule of KR, and KR dependency than is available at present. The next experiment was designed to test this notion.
Experiment 3

Introduction

Experiment 3 looked at the relationship among task characteristics, the schedule of KR, and KR dependency when extended practice on the task was provided. Experiment 2 showed that the poor performance of the spring groups, relative to the no-spring groups, in Experiment 1 could not be attributed to differences in cue discrimination. However, the relationship among task characteristics, the schedule of KR, and KR dependency remains obscure because it is not clear whether the poor performance of the spring groups and the attenuation of the trials-delay of KR effects in Experiment 1 was due to an increase in the complexity of intrinsic information, the unfamiliarity of cues provided by spring loading, or ineffective encoding of cues provided by the spring. Related to either possibility is evidence that the amount of practice is an important variable for learning movements made with spring loading. For example, Adams, Gopher, and Lintern (1977) found no differences in the retention accuracy of positioning movements that were made on either a free-moving or a spring-loaded linear slide after 15 practice trials, but appreciable retention differences after 150 practice trials. The significance of this result is that the larger number of practice trials given by Adams et al. (1977) was almost double the number provided in the present Experiment 1.
Additionally, a relevant concern for the present experiments is that the amount of practice has been shown to determine the effects produced by delaying KR over trials. For example, Lavery and Suddon (1962) had subjects practice a force production task for either 30 or 90 trials with KR provided directly after each trial or after a delay of five trials. They found no group differences in retention after 30 trials but reliable differences after 90 trials. Furthermore, the amount of practice has proved to be a very important factor with respect to other variables that affect motor learning, such as KR precision (Magill & Wood, 1987), concurrent versus terminal augmented feedback (Anderson, 1994), and blocked versus random practice schedules (Shea, Kohl, & Indermill, 1990). Of these variables, KR precision seems to be the most relevant to the present purposes because the precision of KR is related to the quantity and complexity of augmented information. This finding supports the assumption that amount of practice might be an important variable when the complexity of intrinsic information is manipulated.

To test whether practice influences the acquisition and retention of spring-loaded movements when KR is either delayed by two trials or presented directly after each trial, the number of practice trials was doubled in the present experiment. Also, the number of subjects was increased in this experiment to increase the power to detect
group differences, which was found to be less than .35 for the acquisition and retention analyses in Experiment 1. If adding a spring to a manual aiming movement increases the complexity of intrinsic feedback then extended practice should lead to more accurate retention performance when KR is delayed by two trials than when KR is provided directly after each trial. This prediction is based on the assumption that delaying KR over trials forces subjects to sift through the intrinsic cues to determine which cues are critical for successful task performance. Extended practice should facilitate this process. In contrast, subjects who receive KR directly after each trial should not benefit from extended practice because they are expected to substitute KR for intrinsic feedback because of the difficulty associated with processing intrinsic feedback when the cues are more numerous. However, if the cues provided by the spring become more familiar (and perhaps more salient) and therefore easier to use as a result of practice, or if the spring cues are coded less effectively than other cues such as location or distance, then no differences should appear in retention. In the former case, both groups should perform accurately in retention because attention should be drawn increasingly to the spring cues as they become easier to use with practice. In the latter case, both groups should perform at an intermediate level in retention because practice should not have a major influence on the way the
cues are encoded, but may influence the strength of the encoded information.

Method

Subjects. Fifty six undergraduate university students participated in the experiment in exchange for course credit. Subjects were pseudo-randomly assigned to two groups on the basis of a 5-trial pre-test without KR. Each group contained 16 females, 12 males, and 4 left-hand dominant individuals. None of the subjects had participated in Experiments 1 or 2.

Task and Apparatus. The same aiming task described in Experiment 1 was used in the present study. Both groups performed the task with the spring attached to the stylus. No modifications were made to the apparatus, task goal, or movement constraints.

Procedure. Two groups were formed that were identical to the spring groups in Experiment 1. The Delay-0 SPG group received KR directly after each trial, while the Delay-2 SPG group received KR after a delay of two trials. The procedures were the same as those used in Experiment 1 with the following exceptions. First, subjects performed a total of 160 trials in acquisition, followed by two 40-trial no-KR retention tests 30 seconds and 24 hours respectively after acquisition. The acquisition trials were spread over two days, with 80 trials performed on each day. Second, subjects were required to perform a 5-trial pre-test prior
to the start of practice on day one and a 5-trial retention test prior to the start of practice on day two. Subjects were given 30-sec breaks after each block of 40 trials and were told that they were free to take a break at any time if they experienced fatigue. Third, the hand position was constrained more than it was in Experiment 1. Subjects were instructed to make a fist around the stylus so that the little finger was as close to the nib of the stylus as possible. These instructions were designed to prevent any extraneous ulnar flexion or extension that might affect movement accuracy. Finally, after the 24-hour retention test, subjects were required to complete an open-ended questionnaire. The questionnaire assessed the cues that were used during practice and the extent to which subjects perceived the spring helped or hindered their learning and performance of the task.

Results

The primary dependent variables were radial error (RE) and radial variable error (RVE). Trials were blocked into groups of 20 for the purpose of analysis, with the exception of the 5-trial retention test that was given prior to the start of practice on day 2. The mean RE and RVE scores for groups and blocks in acquisition and retention are plotted in Figures 3.3 and 3.4.

The pre-test scores are not included in these figures. However, the RE scores were 33.4 mm and 33.7 mm for the
Delay-0 SPG group and the Delay-2 SPG group respectively. The RVE scores were 13.4 mm and 14.1 mm for the Delay-0 SPG group and the Delay-2 SPG group respectively. These scores indicated that the quasi-random assignment of subjects to groups on the basis of their pre-test scores had effectively created equivalent groups at the start of practice.

The acquisition data were analyzed with a 2 x 2 x 4 (Group x Day x Trial Block) analysis of variance (ANOVA) with repeated measures on the Day and Trial Block factors. The 5-trial retention test was analyzed with a one-way ANOVA. The 1-min and 24-hour retention tests were analyzed with separate 2 x 2 (Group x Trial Block) ANOVA's with repeated measures on the Trial Block factor. For all analyses, a \( p < .05 \) was selected to protect against Type I errors. To protect against any violations to the assumptions of sphericity, the probability level for all statistical analyses involving repeated measures was computed using the Greenhouse-Geisser degrees-of-freedom adjustment (Greenhouse & Geisser, 1959).

**Acquisition.** For RE there was a significant effect of Day \( F(1,54) = 20.2, \ p < .001 \) and Trial Block, \( F(3,162) = 44.9, \ p < .001 \), indicating that the accuracy of both groups improved as a function of practice on the task. The Day x Trial Block interaction was also significant, \( F(3,162) = 11.5, \ p < .001 \), as both groups tended to improve more rapidly on day 1 than on day 2. The group effect was
marginally significant, \( F(1, 54) = 3.8, p = .058 \). However, this effect was overshadowed by a significant Group x Block interaction, \( F(3, 162) = 3.0, p < .05 \) and a marginally significant Group x Day x Trial Block interaction, \( F(3, 162) = 2.8, p = .058 \). Figure 3.3 clearly shows that the Delay-0 SPG group tended to perform more accurately than the Delay-2 SPG group on the first trial block of each day and this effect was most pronounced on day 1.

Similar to the findings for RE, the RVE analysis revealed significant main effects for Day, \( F(1, 54) = 32.0, p < .001 \), and Trial Block, \( F(3, 162) = 29.9, p < .001 \), indicating that both groups reduced their variability as a function of practice. The Day x Trial Block interaction was also significant, \( F(3, 162) = 5.4, p < .01 \), as both groups reduced their variability more rapidly on day 1 than on day 2. There were no other significant findings for RVE in acquisition.

5-trial Retention test. Despite the apparent superiority of the Delay-2 SPG group on the 5-trial retention tests in Figures 3.3 and 3.4, there were no reliable differences for RE or RVE.

1-min Retention. The only significant effect for RE was a Trial Block effect, \( F(1, 54) = 18.7, p < .001 \). Figure 3.3 shows that this effect was due to the substantial deterioration in accuracy that occurred from block 1 to block 2. The only finding for RVE was a marginally
Figure 3.3. Group by block means for RE in acquisition and retention.
Figure 3.4. Group by block means for RVE in acquisition and retention.
significant Group effect, $F(1,54) = 3.2, p = .08$, which indicated that the Delay-2 SPG group performed with less variability than the Delay-0 SPG group.

24-hour Retention. There was a significant Trial Block effect for RE, $F(1,54) = 5.6, p < .05$, which revealed that the accuracy of performance for both groups rapidly deteriorated from block 1 to block 2. The Delay-2 SPG group performed more accurately than the Delay-0 SPG group, however, the large group differences apparent in Figure 3.3 just failed significance, $F(1,54) = 3.0, p = .08$. Despite this finding, there was a large effect size of .48. In order to gain a better appreciation of the differences in retention, a 2 x 2 (Group x Phase) ANOVA, with repeated measures on the Phase factor, was conducted on the last block of acquisition and the first block of the 24-hour retention test. The analysis revealed a significant effect of Phase, $F(1,54) = 40.8, p < .001$, and a significant Group x Phase interaction, $F(1,54) = 5.4, p < .05$. These effects are easy to interpret with the aid of Figure 3.3. Clearly, both groups showed a marked deterioration from acquisition to 24-hour retention, but the Delay-0 SPG group showed a greater deterioration than the Delay-2 SPG group. These data provide additional support for the superiority of the Delay-2 SPG group in retention.

There were no other significant findings for RE on the 24-hour retention test and no significant findings for RVE.
However, consistent with Experiment 1, the within-group standard deviation for the Delay-0 SPG group (14.1) was much larger than the standard deviation for the Delay-2 SPG group (6.8).

**Questionnaire Data.** The percentage of subjects in each group who reported using certain cues during practice and who used one or multiple cues during practice, were tabulated and reported in Table 1. In addition to these data, the percentage of subjects in each group who changed cues as practice continued and the percentage of subjects who thought that the spring helped them, also was reported. One of the most interesting findings from these data was that a greater percentage of subjects in the Delay-2 SPG group reported using each of the four cues (hand location, movement distance, movement time, and spring tension) that were available during practice. Furthermore, subjects in the Delay-2 SPG group were much more likely to use multiple cues than subjects in the Delay-0 SPG group.

In order to test the differences in cue usage, a Chi-Square Test was run to determine whether group differences existed for the percentage of subjects who used either one, two, three, or four cues. The test revealed that cue usage was significantly different for the two groups $\chi^2(3) = 36.3$, $p < .0001$. A greater percentage of the subjects in the Delay-0 SPG group used only one cue, while a greater
Table 3.1. Percentages of Cue Type and Number of Cues Used by Subjects in Each Group.

<table>
<thead>
<tr>
<th>Type of Cue</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delay-0 SPG</td>
</tr>
<tr>
<td>Hand Location</td>
<td>57</td>
</tr>
<tr>
<td>Movement Distance</td>
<td>43</td>
</tr>
<tr>
<td>Movement Time</td>
<td>11</td>
</tr>
<tr>
<td>Spring Tension</td>
<td>82</td>
</tr>
</tbody>
</table>

Number of Cues

<table>
<thead>
<tr>
<th>Number of Cues</th>
<th>Delay-0 SPG</th>
<th>Delay-2 SPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>32</td>
<td>04</td>
</tr>
<tr>
<td>Two</td>
<td>43</td>
<td>64</td>
</tr>
<tr>
<td>Three</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Four</td>
<td>0</td>
<td>07</td>
</tr>
</tbody>
</table>
percentage of the subjects in the Delay-2 SPG group used either two or four cues.

A final interesting finding was related to the changes in cue usage that occurred during practice. Only 29 percent of subjects in the Delay-0 SPG group indicated that the cues they used changed with practice, whereas 75 percent of subjects in the Delay-2 group indicated that their cue usage changed with practice. Clearly, subjects in the Delay-2 SPG group used more cues and selectively attended to different cues at different stages of practice. It should be noted also that, ironically, 89 percent of subjects in each group reported that the spring helped them perform the task.

Discussion

The results showed that delaying KR over trials led to less accurate performance in acquisition but more accurate performance on a 24-hour retention test than providing KR directly after each trial. Furthermore, subjects who received KR after a delay of two trials reported using a greater number and variety of cues than subjects who received KR directly after each trial, suggesting that the former subjects processed intrinsic feedback more thoroughly. These results strongly suggest that the complexity of intrinsic feedback is related to KR dependency and consequently to retention performance.

Adding a spring to an aiming movement appears to increase the difficulty of the task by increasing the
complexity of the information provided by intrinsic feedback. The evidence to support this conclusion comes from two sources. First, the deterioration in accuracy from acquisition to retention and across the retention blocks suggests that neither group had developed a strong memory representation for the task. Second, the questionnaire data revealed that subjects perceived that there were multiple cues to attend to and process in the task. From these findings, it is tenable to speculate that subjects tended to rely on KR because of the increased demands that intrinsic feedback placed on attention and information processing. As Miller (1953) has noted, one of the major problems in learning motor tasks is learning to find the relevant cues to discriminate for successful task performance. Obviously, this task becomes more difficult as the number of cues is increased. It is probable, therefore, that both groups developed at least some dependence on KR because it was easier to substitute KR for intrinsic feedback rather than process intrinsic feedback.

However, the degree to which each group became dependent on KR clearly was influenced by the schedule on which KR was received. Consistent with previous work (e.g., Anderson et al., 1994; Lavery, 1964; Lavery & Suddon, 1962; Suddon & Lavery, 1962), delaying KR over trials led to less accurate acquisition performance but more accurate retention performance than presenting KR directly after each trial.
These findings further support the robustness of the effects produced by this schedule of KR presentation.

It appears that delaying KR over trials encourages subjects to process intrinsic feedback more extensively than when KR is provided after each trial. Two results from this experiment provide support for this conclusion and provide insight into how subjects strategically dealt with the intrinsic feedback. First, subjects in the Delay-2 SPG group used multiple and variable intrinsic cues in comparison to subjects in the Delay-0 SPG group. Second, comments from subjects in the Delay-2 SPG group indicated that the delay of KR over trials encouraged subjects to experiment with different cues at different stages of practice. One subject noted, "I am very right handed, so at the beginning I relied on the spring a great deal. Slowly, I was able to refine my hand position and muscle control so that time and distance became easier to judge." Another subject stated, "I would experiment with different cues now and then but movement time was used the most." Similarly, another subject remarked, "More cues were picked up as I went along but I used combinations of these cues as I progressed."

These statements, combined with the other questionnaire data, suggest that subjects in the Delay-2 SPG group analyzed thoroughly the intrinsic cues available in the task. In contrast, subjects in the Delay-0 SPG group
typically used only one cue and rarely reported experimenting with different cues during practice, a pattern consistent with the idea that subjects who received KR directly after each trial directed more attention to the KR than to intrinsic feedback. It is possible that the greater number of cues sampled by subjects in the Delay-2 SPG group allowed these subjects to establish more numerous retrieval routes to task related information in memory. If one cue became inaccessible, another cue could then be substituted for it in order to maintain performance accuracy.

Another finding that is consistent with Experiment 1 and the data from Anderson et al. (1994), is the within-group variability in retention that is associated with each schedule of KR. It appears that, across subjects, the delay of KR by two trials encourages fairly consistent and accurate responding. In contrast, when KR is presented directly after each trial, subjects demonstrate different levels of performance. These findings have strong implications for practitioners because they suggest that, regardless of individual difference characteristics, delaying KR over trials will generally produce accurate retention performance.

The effects of practice in this experiment are less clear than the effects of task characteristics and KR schedule. While reliable group differences were found after 160 trials on the 24-hour retention test, but not after 80
trials on the 5-trial retention test, the group means were quite similar on both tests. These results appear to be discrepant with those from Experiment 1 where there were no differences between the spring groups on the 24-hour retention test that was given after 80 trials. On closer inspection, the results are not as discrepant as they appear.

The data from Experiment 3 are somewhat misleading because they are based on the average of five trials rather than on the average of ten, as was the case in Experiment 1. On the first block of the 24-hour retention test in Experiment 1, there was a noticeable separation between the Delay-0 SPG and the Delay-2 SPG group. However, the most dramatic finding was the rapid deterioration in performance that equalized the group performances from block 1 onwards. These differences obviously were not stable as the number of retention trials increased. It is very likely that the group differences that were apparent on the 5-trial retention test in Experiment 3 would have been much smaller if the test had been based on twenty trials (as in the second 24-hour retention test) instead of five.

If so, the practice effects would support the conclusions of Lavery and Suddon (1962), who maintained that the retention performance of subjects who trained with a 5-trial delay of KR was a function of the amount of practice with that type of KR, while this was not the case for
subjects who trained with KR that was presented directly after each trial. This conclusion is based on the assumption that retention performance increases as a direct function of the amount of experience that is accrued with the cues that are necessary for successful task performance in retention. Presumably, subjects who receive KR directly after each trial do not increase their exposure to these cues as practice continues because their attention always is directed to KR. In contrast, as practice continues, subjects who receive KR that is delayed over trials gain increasing exposure to the cues that are critical for retention performance.

References to Chapter 3


Chapter 4

General Discussion

Influence of KR Schedule on Motor Learning

The schedule of KR primarily exerts its influence in two areas. First, it affects the accuracy of performance in acquisition and retention. Second, it affects the degree to which performances in retention differ from one individual to another. With regard to the accuracy of performance, typically, learners who received KR directly after each trial improved rapidly in acquisition but showed a rapid decline in performance when KR was withdrawn. These effects were particularly apparent on the 24-hour retention test. In contrast, when sufficient practice was provided, subjects who received KR after a delay of two trials improved less rapidly in acquisition, but generally maintained their performance gains when KR was withdrawn. These results were very consistent and add to a growing body of research showing the robustness of the negative effects of delaying KR over trials in acquisition and the positive effects in retention (Lavery, 1964; Lavery & Suddon, 1962; Suddon & Lavery, 1962). Showing better performance with KR clearly is not the same as demonstrating greater learning.

From these findings and others (e.g., Salmoni, Schmidt, & Walter, 1984), it appears that at least one important role of KR is to encourage learners to attend to and process intrinsic feedback so that they learn the relationship
between the intrinsic cues that are critical for successful performance and the goal of the task. When KR is presented directly after each trial learners are likely to substitute KR for intrinsic feedback because the former source of feedback, which is presented in terms of fairly well known scales, provides more exact information than the latter source of feedback (e.g., Annett & Kay, 1957). As a result, a dependence on KR develops and performance suffers when KR is withdrawn.

When, on the other hand, KR is made more difficult to use, it is thought that subjects are much more likely to process intrinsic feedback. Certainly, the questionnaire data from the final experiment support this conclusion. Perhaps, more than any other schedule of KR presentation, delaying KR over trials encourages intrinsic feedback processing because learners must pay close attention to intrinsic feedback or no improvement will occur. Presumably, KR is of limited value unless subjects can compare it with intrinsic feedback from previous movements.

Not only have the present experiments provided evidence that subjects are more likely to process intrinsic feedback when KR is delayed over trials, but they also have provided evidence about the way in which intrinsic feedback is processed when KR is delayed in this manner. An important question posed by Salmoni et al. (1984) was whether task cues were processed to a deeper level or whether different
task cues were processed when KR was difficult to use. The questionnaire data from the final experiment seem to indicate that subjects process a greater variety of cues when KR is difficult to use. It is possible to speculate that exposure to a greater variety of cues creates an opportunity to establish multiple retrieval routes to task related information in memory. If one cue becomes unreliable, it may be possible to access another cue to maintain performance in the absence of KR. In short, it appears that, rather than process cues to a deeper level, subjects may process more cues when KR is difficult to use.

However, this conclusion cannot be stated confidently until further research examines the way in which intrinsic feedback is processed under different schedules of augmented feedback. It is possible that the cognitive effort required to process intrinsic feedback (e.g., Lee, Swinnen, & Serrien, 1994) or the effort required to hold intrinsic feedback in memory and to resist decay and interference are responsible for the beneficial effects of delaying KR over trials. Merely having the opportunity to process intrinsic feedback may not be sufficient to promote retention performance.

Finally, with regard to the influence of the schedule of KR on the degree to which individuals' performances differ in retention, delaying KR over trials appears to encourage much smaller between-subject variability than
providing KR directly after each trial. This finding was remarkably consistent across the three experiments that manipulated the schedule of KR. The primary theoretical implication here is that individual difference characteristics must be considered in research on KR. Clearly, some individuals are immune to the detrimental effects of providing KR directly after each trial. Individual differences related to this immunity may be due to an individual's preference or ability to process certain types of information (e.g., Temple & Williams, 1977) or attributes such as motivation orientation (Little & McCullagh, 1989). Identifying these individual difference characteristics could provide valuable evidence about the information processing operations or individual attributes that are associated with effective learning. Presumably, the information processing operations used by subjects who retain information well when they receive KR directly after each trial are the same operations as those encouraged by difficult schedules of KR presentation.

Relationship Between Task Characteristics and KR Schedule

As early as 1957, Annett and Kay had noted that KR would be used whenever it was introduced to the learner, but it was not known how it would be used from one task to another or from one stage of practice to another. Initially, one of the goals of the present research was to determine how at least one task characteristic, salience of
intrinsic feedback, was related to KR dependency. Earlier, Annett (1961) had suggested that retention performance might be determined by the amount of information provided by augmented feedback in relation to the amount of information provided by intrinsic feedback. Annett predicted that errors in retention would be greatest when the information provided by intrinsic feedback was near minimum and the information provided by augmented feedback was near maximum. Subsequent researchers (e.g., Armstrong, 1970; Lintern, 1980; Kinkade, as cited by Adams, 1964) suggested that the clarity of intrinsic feedback, or the ease with which intrinsic feedback could be detected and interpreted, was the critical feature that determined whether subjects would come to rely on augmented feedback. While this hypothesis seemed to account for many of the findings in the concurrent augmented feedback literature, the present research suggests that it may be more difficult to apply the hypothesis to situations where terminal augmented feedback (such as KR) is provided.

One of the major differences between research on concurrent augmented feedback and terminal augmented feedback is in the types of tasks used. In the former case, continuous pursuit tracking tasks typically have been used. Usually, in these tasks augmented feedback consists of an auditory cue that tells the subject when he/she is tracking within a certain tolerance around the target, while
intrinsic feedback can be picked up directly from the visual display. In these situations, it is easy to manipulate the clarity or salience of intrinsic feedback by enhancing or degrading the visual display. Manipulating intrinsic feedback is not as simple in the types of tasks used with KR because these tasks are predominantly controlled by proprioceptive input. Clearly, this was the case for the aiming task used in the present experiments. While it has been argued that spring loading enhances proprioception (e.g., Adams, Goetz, & Marshall, 1972; Bahrick, Bennett, & Fitts, 1955; Bahrick, Fitts, & Schneider, 1955), the present research suggests that spring loading increases the complexity of the information provided by proprioceptive feedback.

It is very likely that the complexity of intrinsic feedback is another task characteristic related to dependence on augmented feedback. In cases where augmented feedback is presented in the form of KR, complexity of intrinsic feedback may be much more relevant to KR dependence than the salience of intrinsic feedback. Miller (1953) has noted that one of the major problems in learning motor tasks is learning to find the relevant cues to discriminate. From this perspective, it is clear that adding an extra cue would increase the difficulty of this process. If intrinsic feedback is difficult to process, subjects might be more inclined to substitute KR and
therefore become dependent on KR. Making KR less useful, by manipulating the schedule on which it is presented, may prevent this situation. However, the present data suggest that extended practice on the task may be needed for subjects to find and experience the relevant cues. In this respect, the amount of practice might be as relevant as task characteristics to dependence on KR.

Although the issue awaits further research, it is likely that the effects found in the present experiments with KR can be generalized to other forms of augmented feedback. The complexity of intrinsic feedback probably is related to dependence on knowledge of performance (KP) and to augmented feedback that is presented concurrently with performance. The relationship between the complexity of intrinsic feedback and dependence on KP perhaps is more obvious because both KP and KR are presented after a movement and generally the sources of intrinsic feedback are similar. However, the same relationship might hold with concurrent augmented feedback because the complexity of intrinsic feedback could affect how difficult it is to detect and interpret the critical task cues. When this process is made more difficult, dependence on augmented feedback is likely to occur. Interestingly, this idea suggests that increasing the complexity of intrinsic feedback might decrease the salience of the cues that are critical to the task.
Implications for Training

One of the main implications for training individuals to perform motor skills is that delaying KR over trials is an effective means of promoting retention performance. Importantly, for teachers and instructors, the effects of this scheduling manipulation have proved to be very reliable. Furthermore, the effects are very consistent from one individual to the next. This latter finding has obvious relevance for training settings where a number of different people have to be trained to perform the same task. Regardless of individual difference characteristics, delaying KR over trials might be one of the most effective means of facilitating learning and ensuring that each individual attains a similar degree of proficiency on the task.

Another important implication is that seemingly small changes in the task can lead to disproportionate changes in the difficulty of performing that task. If a cue is added or enhanced, attention may be diverted away from other cues that are critical for successful task performance. This implies that, before practice begins, the task must be analyzed carefully to determine which cues are critical for successful performance. The training environment must then be structured to ensure that these cues are processed. In many cases, this might include manipulating the schedule of augmented feedback. If there are multiple cues, or if the
cues are difficult to detect and interpret, it might be more essential than ever to make augmented feedback difficult to use. However, in these situations, considerable practice may be necessary before learners reach the desired level of proficiency on the task.

Based on the present research, it is difficult to comment on the desirability of using spring tension to facilitate movement accuracy. In research where spring loading has facilitated the accuracy of performance in acquisition (e.g., Bahrick, Bennett, & Fitts, 1955) and retention (e.g., Adams, Gopher, & Lintern, 1977) the tasks used have been much more constrained than the task used in the present research. In previous research the tasks have been one-dimensional, with movements further restricted to a single axis. In contrast, subjects in the present experiments were free to move their hand and arm through a three-dimensional space before the movement was terminated on the drawing board. It is possible that the movement constraints accounted for the discrepant findings between the present and previous research. When movements are less constrained there are many more cues to attend to and process. Adding spring tension to these movements complicates the situation even further.

Until further research clarifies the relationship between movement constraints and the effects of spring loading, practitioners should be warned against using
springs and elastic devices to enhance proprioceptive feedback. This warning is particularly relevant for physical therapists who are offered a wide range of products to help rehabilitate their patients. Many manufacturers of elastic rehabilitation devices (e.g., Thera-Band®) claim that their products can be used to enhance proprioceptive feedback. Typically, these products consist of elastic sheets and tubes that can be connected across joints in such a way that resistance is provided when the joint is extended. Obviously, the claim that proprioception is enhanced by such resistance is not backed up by scientific research. Actually, this type of resistance may have a detrimental effect on rehabilitation because it diverts the patient's attention from other cues that could provide important information about the position of the limb(s) in space.

References to Chapter 4


Augmented feedback is thought to be one of the most critical variables for motor learning (e.g., Adams, 1971; Bilodeau, 1966; Newell, 1976) and has been investigated probably more than any other variable that influences motor skill learning (Magill, 1993a). Of the many issues relevant to the role of augmented feedback in motor learning, one of the most interesting and counter-intuitive concerns the optimal way to schedule this information. Recent research has shown that some schedules can suppress practice performance but enhance performance on retention or transfer tests in which augmented feedback is withdrawn. Because these findings challenge traditional assumptions about how to optimize learning, they have the potential to revolutionize the design of instructional settings and to provide evidence for specific mechanisms that either promote or hinder learning. While some of this research has been cited in previous reviews (e.g., Magill, 1993a; Salmoni, Schmidt, & Walter, 1984), there remains a need to unify several separate lines of research before generalizations can be made about the optimal way to schedule augmented feedback and the processes common to effective practice can be identified.

The purpose of this paper is to provide a synthesis of research on four different schedules of augmented feedback that can degrade practice performance but facilitate retention and transfer of motor skills. The possibility
that task and procedural characteristics can influence the efficacy of these schedules will be explored and an attempt is made to compare research within and between the various schedules in terms of these characteristics. Previous reviews on augmented feedback have generally ignored or underemphasized the importance of task and procedural variables. Finally, contemporary explanations for the effects produced by these schedules of augmented feedback will also be discussed as well as implications for learning theory, training, and future research.

Feedback and Augmented Feedback Defined

Feedback can be defined in a number of ways depending on the context in which it operates. In general, feedback refers to all of the response-produced information that is received during or after a movement (Schmidt, 1988). This information can be classified as either intrinsic or extrinsic to the task. Intrinsic feedback refers to information that is normally available during or after a response. These sources of information are inherent in the environment or the response itself and can be picked up directly by the sensory systems. Intrinsic feedback can be further subdivided into sources of information that are either external or internal. External sources of intrinsic feedback can be picked up through the visual, auditory, and tactile systems, while internal sources of intrinsic feedback can be picked up by receptors in the skin, joints,
muscles, and tendons. **Extrinsic feedback** refers to additional information about a response that is not normally available to a performer. This type of feedback is usually supplied by an external source, such as an instructor or experimenter, and involves a supplemental feedback loop that typically serves as a standard against which performance can be compared. It should be noted that it is not always possible to provide a standard against which intrinsic sources of feedback can be compared.

The term **augmented feedback** is used here synonymously with extrinsic feedback to refer to any form of externally presented information about a response that is not normally available to the performer. Augmented feedback can be presented during a response or after a response. The former method of presentation is referred to as **concurrent augmented feedback (CAF)**, whereas the latter is referred to as **terminal augmented feedback (TAF)**. TAF can be divided into two further categories: **knowledge of results (KR)** and **knowledge of performance (KP)**. KR refers to information about the outcome of a response, while KP refers to information about the movement characteristics that led to the outcome of a response (Magill, 1993a). Note that the terms KR, KP, and augmented feedback will be used interchangeably depending on the context in which they are typically used.
Variables Under Study

This review focuses on schedules of augmented feedback that have been shown to suppress practice performance but facilitate retention and/or transfer of motor skills. While augmented feedback schedules can be generated almost endlessly, the schedules under study can be divided into two general categories: concurrent versus terminal schedules of augmented feedback and schedules of feedback that vary the presentation of terminal augmented feedback.

As noted previously, CAF refers to information that is presented while performance is in progress and can provide for moment to moment regulation of a response. In contrast, TAF refers to information that is presented after a response has been completed. The various schedules of TAF reviewed here come from the KR literature and they also can be divided into two general categories. One schedule involves reducing the relative frequency of KR during practice. Two terms need to be defined with reference to this schedule. Absolute frequency refers to the total number of KR trials given during practice, whereas relative frequency refers to the percentage of trials on which KR is given. The other schedule involves delaying KR by a certain number of trials and either presenting a specific KR for each trial or a summary of information after a block of trials. The two variations of this latter schedule have been referred to as
Learning versus Performance Effects

The importance of distinguishing between learning and performance was recognized as early as the 1930's by Tolman (1932) and was popularized in the 1940's by Hull (1943). However, the importance was largely ignored or forgotten after the 1940's until Salmoni et al. (1984) seized upon the learning/performance distinction as a basis for their review of the KR literature. The distinction between learning and performance reflects the premise that variables can have either temporary (e.g., motivational) or permanent effects on the capability for responding. The temporary effects are observable during the acquisition or practice phase where the schedule of augmented feedback is manipulated, but tend to dissipate quickly when augmented feedback is removed. The relatively permanent effects are associated with learning and can be assessed on retention or transfer tests that are provided some time after practice. In both retention and transfer tests augmented feedback is withdrawn.

The distinction between learning and performance effects is important because Salmoni et al. (1984) noted in their review of the KR literature that most of the previous generalizations about augmented feedback were based on the effects of KR on temporary performance rather
than learning. The distinction is equally important for present purposes as this review focuses on those variables that can exert different effects during practice and retention. In keeping with the learning versus performance distinction the review only considers experiments that have provided retention or transfer tests to separate the temporary from the relatively permanent effects of the variables under study.

**Importance of Task and Procedural Characteristics**

The potential for task and procedural characteristics to interact with the schedule of augmented feedback has been generally overlooked or underemphasized. However, Magill (1993a) has suggested that the quality and quantity of task intrinsic feedback may determine if augmented feedback is needed for learning and how and when it should be provided. When intrinsic feedback is high the need for augmented feedback is low. Research has also indicated that task complexity can interact with the schedule on which augmented feedback is presented (Schmidt, Lange, & Young, 1990).

Of all the procedural characteristics that can influence the effects of various schedules of augmented feedback, the number of trials in acquisition and retention, the length of the retention interval, and prior knowledge of a retention or transfer test are considered most important. Sufficient trials in acquisition and retention are necessary to highlight trends in performance. For example, it is
important to know if effects are localized early or late in practice and if performance remains stable, improves, or deteriorates when augmented feedback is removed. The length of the retention interval can give important information about the relative permanence of the effects. Furthermore, if both immediate (less than 10-min after acquisition) and delayed (at least one day after acquisition) tests are given then critical information can be obtained about the memory constructs affected by the manipulations during practice (Christina & Shea, 1993).

Finally, perhaps the most important procedural variable is whether subjects have prior knowledge of a retention test. Miller (1953) has noted that a learner may adopt a completely different attitude or strategy towards a task when they know that a retention test will be given. In support of this notion, research has shown that subjects who are told before training that they will be tested without augmented feedback do better on the tests than subjects who are told after training (e.g., Lavery, 1964a).

Given the potential for task and procedural characteristics to interact with the schedule of augmented feedback, a close examination of these characteristics could provide important information about the conditions most likely to lead to performance reversals in acquisition and retention. Furthermore, an analysis of these characteristics has several practical and theoretical
implications for the role of augmented feedback in motor learning.

**Concurrent versus Terminal Augmented Feedback**

The focus of this section is on those studies that have adequately controlled for the type of augmented feedback presented concurrently or terminally. In order to make comparisons between CAF and TAF, it is important that these comparisons are not confounded by factors such as the sensory channels through which augmented feedback is provided or the amount of information provided by the augmented feedback.

**Effects on Acquisition and Retention/Transfer**

The most prevalent research finding is that subjects who receive CAF typically perform without error in acquisition but show much greater errors in retention than subjects trained with TAF. It is difficult to determine how far subjects trained with TAF regress in retention because acquisition results are rarely reported in these studies.

One of the first studies to compare the effects of CAF and TAF was reported by Annett (1959, experiment 1). Subjects learned to apply a precise pressure on a spring-loaded plunger with visual augmented feedback from an oscilloscope presented either during or after each response. When augmented feedback was withdrawn, the performance of two groups that had received CAF deteriorated rapidly whereas two groups that had received TAF showed only a
gradual decline in performance. The former groups showed generally about three times more error than the latter groups on the retention trials.

Using a similar task and augmented feedback display to Annett (1959), Smyth (1977, experiment 2) found that groups trained with TAF were significantly more accurate in retention than groups trained with CAF. Patrick and Mutlusoy (1982) used a linear slide task with a television monitor display and also found that subjects trained with TAF were significantly more accurate in retention than subjects trained with CAF. Similar benefits for TAF over CAF were found in experiment two, where the compatibility between the actual and the displayed movement direction were changed and in experiment three, where augmented feedback was displayed on a digital voltmeter instead of a television monitor.

With a virtually identical task and augmented feedback display to Patrick and Mutlusoy (1982), Smyth (1978) compared six conditions in which movements were either unconstrained or made to a mechanical stop and augmented visual feedback was either withheld, presented concurrently, or presented terminally. Subjects who practiced with terminal augmented feedback or by moving to a stop performed more accurately in retention than did those who practiced with concurrent augmented feedback, whether or not they also moved to a stop. Using an arc drawing task, Fox and Levy
(1969) found similar retention advantages for subjects trained with TAF rather than CAF. However, the differences were only small and disappeared on the later retention trials. Finally, Vander Linden, Cauraugh, and Greene (1993) found that, compared to CAF, TAF produced reliably more accurate immediate and delayed retention of an isometric force production task.

Task Characteristics

Movement extent and gain. While all of the above studies reported an advantage for TAF over CAF, there appear to be interactions among the type of augmented feedback, movement extent, and the gain (ratio of the size of the actual movement to the size of the movement as it appears on the display) of the display. Generally, errors of overestimation increase as gain increases or movement extent decreases and these effects are most pronounced for subjects trained with CAF. Furthermore, the differences between groups trained with CAF and TAF tend to diminish at gains of 1:1.

The first report of an interaction among CAF, gain, and movement extent was made by Annett (1970). Annett used movement extents of 15 mm, 30 mm, and 60 mm and gains of 1:.85, 1:1.7, and 1:3.4. He found that when subjects were trained with CAF, errors of overestimation in retention increased linearly as a function of increases in gain and decreased linearly as a function of increases in the size of
the movement. Patrick and Mutlusoy (1982, experiments 1 & 2) used a slightly different task, but found very similar results with movement extents of 25 mm, 55 mm, and 75 mm and gains of 1:1, 1:2, and 1:4. In experiment 1, there was actually no difference between the groups trained with CAF and TAF when the gain was 1:1 and in experiment 2, these differences were only small.

This latter finding is consistent with the results of Fox and Levy (1969), who found only small differences (which diminished quickly) in retention between groups trained with CAF and TAF. It should be noted that the task used by Fox and Levy was different from the tasks used by the other researchers because subjects had to draw a 16 inch arc and were allowed to directly view the apparatus and their hand and arm. According to Annett (1970), if the movement extent is large and direct viewing of the response is taken as equivalent to a gain of 1:1, then there should be little systematic bias in reproducing movements that have been practiced with CAF.

Range of movement extent and gain. There is some evidence that the interactions among CAF, gain, and movement extent only operate within a limited range of movement sizes and gains. For example, Smyth (1977) used a similar task and display to Annett (1970) and reported no effect of gain on error when subjects were required to press a metal bar that could only move 3 mm and gains of 1:7.5 and 1:15 were
used. The very small movement of 3 mm coupled with a gain of 1:7.5 (compared to Annett's largest gain of 1:3.4) may have produced a ceiling effect on errors or created so much of a discrepancy between the actual movement and the displayed movement that these two sources of information did not conflict to systematically bias the memory representation for the task.

Procedural Characteristics

Amount of practice and retention interval length.
While it has been suggested that the interactions among CAF, gain, and movement extent may only operate within a limited range of gains and movement extents, it is also possible that the effect of gain dissipates with more practice or with a longer interval between practice and test. For example, Annett (1970) used 10 acquisition trials followed immediately by 10 retention trials and found a strong effect of gain, whereas Smyth (1977) used 50 acquisition trials followed by 5 retention trials after a 10-min interval and found no effect of gain.

Interactions between amount of practice and gain.
Previously, it was noted that the differences between groups trained with CAF and TAF may be small or even nonexistent at gains of 1:1. However, it is also possible that these differences may become more apparent as the number of practice trials increases. A comparison of the experiments by Patrick and Mutlusoy (1982) and Smyth (1978) indicate
that this notion has merit. Using 8 acquisition and 5 retention trials, the former authors found no differences between CAF and TAF groups when the gain was 1:1. However, when 10 acquisition trials were used and the compatibility between the movement direction and the display were changed, small but reliable differences were found between CAF and TAF. Similarly, Smyth (1978) found reliable differences between the two schedules of augmented feedback when 30 acquisition trials and 5 retention trials were given. It is important to note that the task and display used by Smyth (1978) were identical to those used by Patrick and Mutlusoy (1982). The results of Fox & Levy (1969), who found minor group differences in retention with only 8 acquisition trials and a gain equivalent to 1:1, further support the suggestion that the differences between CAF and TAF trained groups may become more apparent with larger amounts of practice when the gain is 1:1.

**Number of retention trials.** The number of trials in retention may also be an important factor relevant to interpreting the effects of CAF and TAF as both Annett (1959) and Patrick and Mutlusoy (1982) reported that differences between CAF and TAF trained groups increased steadily across trials in retention. However, Fox and Levy (1969) found an opposite trend for group differences to decrease in retention. While the differences here may be a reflection of the different gains used by each of these
researchers, the important point is that critical information may be lost or obscured if sufficient trials are not provided in retention.

Instructions and knowledge of a retention test. Finally, it is noteworthy that in all of the studies, except for those by Fox & Levy (1969) and Vander Linden et al. (1993), subjects were informed that they would be required to perform on a retention test without augmented feedback. Furthermore, subjects were specifically instructed to attend to information provided by the response because that was the only information that would be available on the retention trials. In each case, knowledge of a retention test coupled with instruction to attend to the characteristics of the response had no tendency to diminish the detrimental effects of CAF on retention performance. These results suggest that CAF provides a very powerful source of information that is very difficult to ignore. This finding is particularly relevant to the discussion in the following section.

Explanations for CAF Effects

Dependence on augmented feedback. The deterioration in performance that results from the withdrawal of CAF has been explained in a number of similar ways. The most common hypothesis is that subjects develop a dependency on augmented feedback so that when it is withdrawn, performance suffers. Miller (1953) was one of the first to suggest this idea when he stated that the learner will rely on the most
dramatic feedback cue or the cue that is most readily perceived or discriminated. He elaborated, that augmented feedback may be used as a crutch so that the learner does not learn enough about using the intrinsic feedback cues relevant to successful task performance. Since Miller (1953), many authors have reinforced the idea that learners may become dependent on CAF because they simply substitute it for sources of intrinsic feedback that are difficult to perceive or interpret (e.g., Archer, Kent, & Mote, 1956; Armstrong, 1970; Gordon, 1968; Gordon & Gottlieb, 1967; Karlin & Mortimer, 1963; Lincoln, 1954; Lintern, 1980, 1991; Magill, 1993a).

Factors affecting dependence. According to Annett (1961, 1970) the extent to which subjects become dependent on CAF might be determined by the amount of information given by the augmented feedback in relation to the amount of information in the intrinsic feedback. Annett's proposal suggests that dependency, and therefore errors in retention, will be greatest when the information in the intrinsic feedback is minimized and when the information in the augmented feedback is maximized.

Annett's hypothesis is based on the tendency for performance in retention to deteriorate most rapidly with small movement extents and large gains. Assuming that proprioceptive information is relatively impoverished for short movements and fine discriminations (e.g., Fitts,
and an increase in gain represents an increase in the precision with which augmented feedback is specified (e.g., Annett, 1970; Fox & Levy, 1970; Patrick & Mutlusoy, 1982), Annett's hypothesis has the potential to clarify many of the findings in the CAF literature.

Although it is circular to claim that CAF degrades retention performance to the extent that intrinsic feedback is poor, even if correct (Bilodeau, 1966), evidence from other research on CAF supports the claim. For example, Kinkade (1963, as cited by Adams, 1964) had subjects practice a one-dimensional tracking task where the visual feedback intrinsic to the task was supplemented with a concurrent auditory cue when subjects were tracking within a certain tolerance of the target cursor. For some subjects, visual noise was used to perturb the target reference so that it was partially obscured and therefore difficult to perceive. Upon withdrawal of the auditory cue, only subjects who practiced with an ambiguous target showed a decrement in performance. The results support the conclusion that a dependence on augmented feedback is most likely to develop under conditions where intrinsic feedback is relatively impoverished and augmented feedback is clear.

Further thoughts on dependence. One reason that a subject may become dependent on CAF is that it is difficult to attend to more than one source of information at a time. Based on Posner, Nissen, & Klein's (1976) reports that the
visual system dominates over the proprioceptive system in many perceptual and motor tasks, Smyth (1977, 1978) and Patrick & Mutlusoy (1982) interpreted their results as a bias to attend to concurrently presented visual information. It is important to note here that in all the studies reviewed in this section CAF was presented visually. The potential for concurrent visual feedback to dominate proprioceptive feedback more than concurrent feedback presented through another sensory modality has experimental support. Souder, Burroughs, Parker, and Bunker (1975) have shown that in a stylus-maze task the withdrawal of concurrent visual feedback is more detrimental to performance than the withdrawal of concurrent auditory feedback. From this perspective, visual feedback has a stronger tendency than other sources of feedback to distract attention away from proprioceptive feedback. Performance suffers most when visual feedback is withdrawn and performance must be maintained on the basis of proprioceptive feedback alone.

While CAF may distract attention from proprioceptive feedback it is also likely that it distorts the perception of proprioceptive feedback. Based on the tendency for subjects to systematically overshoot the target in retention as a function of gain, Annett (1959) proposed that the two sources of feedback interact, with the more dominant source of feedback biasing the subjective experience of the less
dominant source of feedback. In support of this conclusion Annett (1959) reported that subjects thought that the testing apparatus felt much "stiffer" in the absence of a visual display.

Annett's (1959) findings are relevant to claims made by Proteau and his colleagues (Proteau & Cournoyer, 1990; Proteau, Marteniuk, Girouard, & Dugas, 1987; Proteau, Marteniuk, & Levesque, 1992) that augmented feedback (KR in their case) may become part of the memory representation of the task. Without this information the memory representation for the task is incomplete and performance suffers.

CAF and subjective error detection capabilities. The extent to which CAF distracts attention from, or interacts with, intrinsic feedback may influence the development of a learner's capability to subjectively detect and correct his/her own errors (e.g., Schmidt & White, 1972). This hypothesis is important because it assumes that retention performance is largely determined by the subjective error detection and correction process. There is some evidence that CAF may hinder this process. For example, when asked to estimate their errors in retention, Smyth (1978) found that subjects who received CAF were much less accurate in their estimations than subjects who received TAF or moved to a stop. The former group never recognized overshoots, whereas the latter groups always did.
Final hypotheses. Two final hypotheses have been proposed to account for the deterioration in performance following the withdrawal of CAF. The first hypothesis is that subjects may need to experience error in order to adequately learn a task. The results from Smyth's (1978) experiments, where subjects who moved to a stop were more accurate in retention than subjects who received concurrent augmented feedback, do not support this hypothesis. Finally, Patrick and Mutlusoy (1982) have suggested that differences in movement patterns of responses controlled by visual and proprioceptive feedback may account for differences in retention. The different movement patterns may be associated with different recall characteristics. Clearly more research needs to be done before this hypothesis can be accepted or rejected.

Summary and Conclusions

Overall, the evidence indicates that CAF leads to virtually errorless performance in acquisition but produces significantly less accurate immediate retention performance than TAF. There appear to be interactions among CAF, gain, and movement extent, with errors generally increasing as a function of increases in gain and decreases in movement extent. These interactions may operate only within a limited range of movement extents and gains and they may dissipate with more practice or with a longer interval between practice and retention test.
The most likely reason for the performance deterioration following the withdrawal of CAF is that subjects become dependent on CAF. Presumably, this dependence occurs because CAF distracts attention from, or distorts the perception of, critical intrinsic cues that can be used to support performance in the absence of CAF. In support of this notion, there is some evidence that dependence is most likely to occur when intrinsic cues are difficult to detect or interpret. However, more research is needed before this conclusion can be stated with confidence. Future research needs to clarify several other issues relevant to CAF. These include: the influence of gain and movement extent on the effects of CAF, as well as the influence of the number of practice trials and the length of the retention interval. Finally, it would be fruitful to determine if the detrimental effects of CAF can be replicated when more complex tasks are used or when augmented feedback is presented through a sensory channel other than the visual channel.

Relative Frequency of KR

Introduction

Early ideas about KR relative frequency. Although several researchers in the 1950's and 1960's had suggested that reducing the relative frequency of augmented feedback may discourage subjects from depending on this source of information (e.g., Annett, 1959, 1961; Annett
& Kay, 1957; Miller, 1953), the view that became more generally adopted was that more augmented feedback was better for learning than less augmented feedback (e.g., Adams, 1971; Bilodeau, Bilodeau, & Schumsky, 1959; Trowbridge & Cason, 1932). Based on their research with KR, Bilodeau and Bilodeau (1958) concluded that the absolute frequency of KR was the most important variable for learning. The relative frequency of KR was considered irrelevant because it had been shown that, when the absolute number of KR trials was held constant, the addition of no KR trials made no significant contribution to performance. These trials were considered "neutral" for learning. However, these conclusions were based on performance during practice rather than on retention tests in which KR was withdrawn. A different picture began to emerge when retention tests were added.

New evidence challenges early ideas. Experiments conducted by Baird and Hughes (1972), Ho and Shea (1978), and Johnson, Wicks, and Ben-Sira (1981) examined the learning of simple positioning tasks when the relative frequency of KR was reduced by various amounts. Generally, no significant differences were found during acquisition or retention for groups who practiced with 100% KR or various relative frequencies down to as low as 10%. Although the differences were not significant, lower relative frequencies tended to produce less accurate performance in acquisition
and slightly better performance in retention. Taylor and Noble (1962) found similar results using a more complicated task.

Clearly these findings challenged the traditional view that more KR produces more learning. However, they must be viewed with caution because in each of these studies the relative frequency of KR was confounded with the amount of practice, since the absolute frequency of KR was considered such an important variable to control. In order to keep the absolute frequency of KR constant, the number of practice trials was increased when the relative frequency of KR was decreased. Thus, the beneficial effects of less frequent KR may have been due to different amounts of practice rather than manipulations of the relative frequency of KR. The following section provides a review of those studies that have held the amount of practice constant for all groups receiving various relative frequencies of KR. Although relative and absolute frequencies of KR are confounded in these studies, the designs allow a clearer interpretation of the effects that can be attributed primarily to manipulations of KR.

Effects on Acquisition and Retention/Transfer

Research with CAF. Before considering the effects of reducing the relative frequency of KR it would be useful to briefly examine research in which the relative frequency of CAF was reduced. In general, the results of this research
were equivocal. Some studies reported no advantages for reducing the relative frequency of CAF, while others reported small but unreliable advantages. In one of the earliest reports, Goldstein and Rittenhouse (1954) found no significant retention differences between groups that practiced a tracking task with the aid of an additional auditory cue that was presented on either 100% or 50% of the acquisition trials. Furthermore, there were no differences between groups that received 50% CAF on a random or alternating schedule, although both these groups showed sharp rises in performance when the auditory cue was present and sharp declines when it was removed.

Using the force production task described earlier, Annett (1959, experiment 2) also had subjects practice with either 100% concurrent visual feedback or 50% concurrent visual feedback that was given on alternate trials or on alternate blocks of five trials. When augmented feedback was withdrawn, both 50% groups performed more accurately than the 100% group but the differences between groups were not significant. Similarly, Fox and Levy (1969, experiment 2) found small but unreliable benefits for subjects who practiced an arc drawing task with 50%, compared to 100%, schedules of CAF.

Research with KR. At present, it is very difficult to make generalizations about the effects of reducing the relative frequency of KR because different methods have been
used to schedule KR when it is not presented on every trial. More will be made of this point in a later section. There is some evidence that reducing the relative frequency of KR is detrimental to performance in acquisition, although the evidence is not very strong. Generally, reducing the relative frequency of KR has little effect on acquisition or immediate retention, but it can facilitate performance on delayed retention tests.

As part of a larger study designed to investigate the effects of the precision, delay, and schedule of KR, McGuigan (1959) compared groups that received KR on either 100%, 50%, or 10% of trials on a line drawing task. The 100% group showed significantly better performance in acquisition, but there were no group differences in retention. Sparrow and Summers (1992) reported that errors on a positioning task significantly increased as KR was systematically decreased from 100% to 10%. This finding occurred in experiment 1, where subjects learned to move to a specific location and in experiment 2, where subjects learned to move a specific distance. However, in both experiments, these differences diminished with practice and were not apparent in immediate and delayed retention. In contrast, Ho and Shea (1978, experiment 2) found no differences between a 100% KR group and a 50% KR group in the acquisition or immediate retention of a simple positioning task.
Using a more complicated lever patterning task, Winstein and Schmidt (1990) found no differences in acquisition or immediate retention between groups that received 100% KR or 33% KR. In experiments 2 and 3, there were no acquisition or immediate retention differences between 100% and 50% KR groups, however, the 50% KR groups performed significantly better on delayed retention tests, even when KR was presented on one of these tests. Wulf and Schmidt (1989) found no differences in acquisition or immediate transfer for groups that received 100% KR or 67% KR on a relative timing task. However, the 67% group was significantly more accurate on a delayed retention test. In a second experiment, Wulf and Schmidt (1989) reported reliably superior immediate and delayed retention performance for a group that received no-KR during acquisition on one of three task versions that shared the same relative timing structure. Wulf, Schmidt, and Deubel (1993) found no acquisition, retention, or transfer differences in overall performance for groups that received 100% KR or 63% KR on a lever patterning task. However, there was some evidence that less frequent KR aided learning of the relative timing and relative force characteristics of the task and inhibited learning of the overall timing and overall force characteristics. Finally, Vander Linden et al. (1993) provided some of the strongest evidence for the benefits of less frequent KR. They found no differences in
acquisition between groups that received either 50% KR or 100% KR on an isometric force production task, but reliable differences in favor of the 50% group on immediate and delayed retention tests.

Research with bandwidth KR. The effects of KR relative frequency have also been examined in a paradigm referred to as bandwidth KR. In this paradigm KR is only presented if a subject's response falls outside a predetermined tolerance around the task goal. Thus, the proportion of trials on which a subject receives error information is related to the subject's performance. It should be noted, however, that the absence of error information indicates that the task goal has been achieved. Therefore, unlike the subject who receives less frequent KR, the subject who practices with a bandwidth schedule of KR can evaluate the correctness of each response. Research suggests that the bandwidth technique has little effect on performance accuracy in acquisition and retention, but can lead to reliably more consistent performance in retention (Lee & Carnahan, 1990; Lee, White, & Carnahan, 1990; Sherwood, 1988). The implications of these findings are discussed in a later section.

Task Characteristics

Task complexity may influence the effectiveness of reducing the relative frequency of KR. Reduced relative frequency of KR had little impact on the retention of the
simple positioning tasks used by McGuigan (1959), Ho and Shea (1978), and Sparrow and Summers (1992), however, it tended to benefit the retention of the more complex relative timing tasks used by Wulf and Schmidt (1989), Winstein and Schmidt (1990), and Wulf, Schmidt, and Deubel (1993). This interpretation must, however, be cautioned because there are also important procedural differences between these two groups of studies. It is not clear how to interpret the results of Vander Linden et al. (1993), who found reliable retention differences on an isometric force production task, in terms of the influence of task characteristics on the effects of less frequent KR.

**Procedural Characteristics**

Fading is an important scheduling technique. An inherent procedural problem with the relative frequency of KR paradigm is that there are various ways to schedule less frequent KR. For example, when the relative frequency of KR is 50%, KR could be given on every other trial, on every other block of five trials, more frequently at the start of practice and less frequently at the end, and so on. Of the various methods to schedule less frequent KR, the most important to consider is whether lower relative frequencies of KR are given on a fixed or a faded schedule. In contrast to the fixed schedules used by McGuigan (1959), Sparrow and Summers (1992), and Vander Linden et al. (1993), Ho and Shea (1978), Winstein and Schmidt (1990), Wulf and Schmidt
(1989), and Wulf et al. (1993), systematically reduced (faded) KR across the practice session. The idea of fading is that more information is given early in practice, when it is needed most, and then systematically withdrawn to avoid the potential for dependence on this source of information to develop. The faded schedules appeared to attenuate the group differences in acquisition, yet benefitted delayed retention performance. Based on unpublished data, Schmidt (1991a, 1991b) has also suggested that fading may facilitate retention more than other schedules of less frequent KR. Furthermore, it is interesting to note that with sufficient practice a group that receives 50% KR on a faded schedule can actually outperform a 100% KR group in acquisition (Winstein & Schmidt, 1990).

Delayed versus immediate retention tests. It is not clear whether the benefits of less frequent KR are most pronounced on immediate or delayed retention tests. Both Winstein and Schmidt (1990) and Wulf and Schmidt (1989, experiment 1) found no reliable benefits in immediate retention, but reliable benefits in delayed retention, for groups that received less frequent KR. However, Vander Linden et al. (1993) and Wulf and Schmidt (1989, experiment 2) reported reliable benefits in immediate and delayed retention. However, it should be noted that subjects in the latter experiment were required to learn multiple task variations and KR was not provided on one of these
variations. It is not clear whether these procedural variations influenced the effectiveness of less frequent KR.

Knowledge of a retention test. There is some evidence that knowledge of a retention test can facilitate the retention performance of subjects who receive 100% KR. Sparrow and Summers (1992, experiment 2) reported that subjects who received 100% KR, and were warned in advance of a retention test, demonstrated more accurate delayed retention performance than subjects who received 100% KR and were not warned of a retention test. The group differences only just failed significance.

Type of KR. Finally, it is interesting to note that the benefits of less frequent KR were most apparent in the studies that used visual KR as opposed to verbal KR. While there is no direct evidence of an interaction between the type of KR and the scheduling of KR, these findings may be consistent with Posner et al.'s (1976) contention that the visual system tends to dominate the other sensory systems. In this case, subjects may have been more likely to attend to the visual KR rather than the characteristics of the response specified by the other sensory systems. A reduction in the relative frequency of visual KR could have allowed attention to be directed to more important aspects of the task. However, this interpretation should be viewed with caution because the studies that used visual KR also used more complex tasks and a faded KR schedule. It is not
clear which factors, or combinations of factors, were responsible for the beneficial effects of less frequent KR.

**Explanations for Frequency Effects**

Although the evidence for increased learning from less frequent KR is only moderately strong, several hypotheses have been advanced to explain why learning might benefit from fewer KR presentations. Winstein and Schmidt (1990) have reviewed four of these hypotheses: the specificity hypothesis, the spaced-retrieval hypothesis, the consistency hypothesis, and the guidance hypothesis.

**Specificity hypothesis.** The specificity hypothesis suggests that retention performance is facilitated when the retention conditions are most similar to the acquisition conditions. Hence, less frequent KR in acquisition benefits no-KR retention performance because of the similarity between the conditions in acquisition and retention. The reverse occurs when KR is given on every trial in acquisition. Winstein and Schmidt (1990, experiment 3) provided strong evidence against the specificity hypothesis when they found that a group receiving 50% KR in acquisition performed significantly more accurately on a 100% KR retention test than a group receiving 100% KR in acquisition.

**Spaced-retrieval hypothesis.** The spaced-retrieval hypothesis attributes superior retention to the opportunity for retrieval practice during acquisition. Less frequent KR
may provide the opportunity for retrieval practice because subjects can not always rely on the information specified by KR to plan and evaluate their next response. Instead, they must access other sources of task related information or retrieve information from previous responses to plan and evaluate no-KR responses. The spaced-retrieval hypothesis is similar to the specificity hypothesis because it implies that retention performance increases when the similarity between the processing operations required in acquisition and retention increases. Retrieval practice in acquisition is then a form of transfer-appropriate processing (Bransford, Franks, Morris, & Stein, 1979; Lee, 1988) as task related information must be retrieved from memory in retention. It should be noted that the spaced-retrieval hypothesis is difficult to test and whether it is accepted or rejected awaits further research.

Consistency hypothesis. The consistency hypothesis suggests that response stability during acquisition promotes retention performance because the process of updating response-production memory structures is accomplished more effectively with a stable action pattern. Too frequent KR is thought to induce "maladaptive short-term corrections", which hinder the development of a stable action pattern.

Findings with the bandwidth KR technique have been used to support the consistency hypothesis. For example, Sherwood (1988) and Lee, White, and Carnahan (1990) have
shown that the bandwidth technique tends to produce less variable performance in acquisition and reliably less variability in retention. However, these results must be interpreted with caution because variability in acquisition is not associated with more accurate performance in retention. Furthermore, Lee and Carnahan (1990) have shown that different results can be found when bandwidth KR or reduced relative frequency of KR are provided during acquisition. Bandwidth KR has been shown to produce significantly less variable performance in acquisition and retention than reduced relative frequencies of KR, but no differences in the accuracy of performance. These results highlight the differences between these two paradigms that were noted previously.

The main problem faced by the consistency hypothesis is that it is difficult to establish a clear link between variability in acquisition and performance in retention. Ho and Shea (1978, experiment 2) found that no-KR trials were significantly less variable than KR trials in acquisition, but there were no differences in retention. In contrast, Sparrow and Summers (1992) found that less frequent KR increased performance variability in acquisition, but had no effect on retention. Presently, the research evidence from studies on the relative frequency of KR seems to weigh against the consistency hypothesis because the link between
variability in acquisition and performance in retention has not been clearly established.

**KR salience hypothesis.** Another hypothesis related to the consistency hypothesis suggests that less frequent KR might make the content of KR more salient and therefore more informative. Winstein and Schmidt (1990) have proposed that subjects systematically drift away from the goal response when KR is presented less frequently, so that when KR is presented the error in performance and the necessary correction are more readily perceived. Sparrow and Summers (1992) have shown that a systematic drift away from the target goal does occur when KR is presented less frequently, however, the drift only occurs when the presentation of KR is predictable and not when it is random. This finding, along with the failure of Sparrow and Summers (1992) to demonstrate any group differences in retention, may make it difficult to specify the exact relationship between performance drifts in acquisition, KR salience, and retention performance.

**Guidance hypothesis.** Finally, the guidance hypothesis, reformulated recently by Salmoni et al. (1984), restates the notion that subjects may become dependent on augmented feedback if it is presented too frequently or in a form that is too easy to use. Salmoni et al. (1984) maintain that the guidance-like properties of KR may be both beneficial and detrimental to performance. Guidance can be beneficial
because it directs learners to the goal of the task and keeps the learner interested and motivated (e.g., Annett, 1961; Elwell & Grindley, 1938; Smode, 1958), but guidance can be detrimental if the learner comes to depend on it. Similar to previous researchers, Salmoni et al. (1984) suggested that dependence may mean that KR becomes part of the memory representation of the task (e.g., Proteau et al., 1987, 1992), or KR distracts attention from the processing of important intrinsic cues that must be relied upon when KR is withdrawn (e.g., Annett, 1969; Lintern 1980, 1991). Although the guidance hypothesis provides a means to interpret the effects of KR relative frequency, there is no evidence to directly support it because it is very difficult to determine whether 100% KR or reduced relative frequency of KR groups process information differently during acquisition. Furthermore, the guidance hypothesis does not provide specific suggestions about what processing differences to expect.

Summary and Conclusions

Compared to a 100% KR schedule, reducing the relative frequency of KR can be detrimental to acquisition performance, however, these effects are localized early in practice and are attenuated if KR is faded across practice. Generally there are small differences in immediate retention between groups that receive 100% KR or relative frequencies less than 100%, although advantages typically favor lower
relative frequencies. The benefits of less frequent KR are most apparent on delayed retention tests. There is some evidence that less frequent KR is more effective with more complex tasks, however, the fading of KR across practice appears to have a bigger impact on the effectiveness of less frequent KR than task complexity. The most likely explanation for the advantage of reducing KR frequency is that it provides learners with more of an opportunity to process important intrinsic cues that can be used to support performance in the absence of KR. It is not clear whether these cues are processed more extensively or if the learner is able to process a greater number of cues or a different set of cues. In contrast, learners who receive more frequent KR are more likely to become dependent on KR either because they have been distracted from processing intrinsic sources of information or because KR has become part of the memory representation for the task. However, there is some evidence that these detrimental effects can be attenuated if, prior to the start of practice, subjects are informed that they will have to perform on a retention test without KR.

**Summary KR**

**Introduction**

**Comparison with less frequent KR.** The summary KR paradigm is similar to the relative frequency of KR paradigm because KR is presented less frequently in both
cases. However, unlike the relative frequency of KR paradigm, the summary KR paradigm confounds the number of KR presentations with the simplification or abstraction of information. For example, researchers have typically provided summary KR in a graphic form and allowed the amount of information in the summary (i.e., the number of trials summarized) to covary with the frequency of KR presentation. More abstraction is required of the learner when more trials are included in the summary. There are exceptions to the usual method of allowing the number of trials in the summary and the frequency of KR presentation to covary, however, and these exceptions will be examined more closely in a later section.

An early example. Before reviewing the effects of summary KR, it is worth examining one of the earliest summary KR studies to gain a better understanding of how the technique is implemented. Two experiments were conducted by Baker and Young (1960), where subjects learned to draw 4-inch lines on a piece of paper. In the first experiment, KR was presented verbally after each trial (every-trial KR), while in the second experiment KR was presented graphically after each block of 20 trials (summary 20). The verbal KR consisted of a "right" or "wrong" statement, whereas the graphic KR consisted of a card with the letters "R" or "W" listed in a column. Comparisons between the two experiments showed that the summary 20 group performed less accurately
on the 3rd, 4th, and 5th acquisition days, but there were no group differences on the first day of retention. However, the every-trial KR group was able to maintain its performance across the remaining four retention days, whereas the summary 20 group showed a general decline in performance. While this study provides a good introduction to the summary KR technique, the results must be viewed with caution because comparisons were made across experiments and the type of KR (i.e., verbal vs graphic) was confounded.

**Effects on Acquisition and Retention/Transfer**

There is very strong evidence that, relative to every-trial KR, summary KR degrades the acquisition of motor responses. However, support for the superiority of summary KR in retention is mixed. The weight of evidence suggests that summary KR produces superior performance to every-trial KR, but there are some important contradictions to this general finding.

**Studies showing a retention benefit.** One of the first experiments to note that summary KR could produce different effects in acquisition and retention was reported by Lavery (1962, experiment 1). Lavery found that a summary of 20 trials significantly degraded the acquisition of three force production tasks, but led to significantly better retention performance than every-trial KR. Similar results have been reported in other studies that have used simple force production tasks. For example, Smith (1963) found that a
summary of 10 trials led to reliably less accurate performance in acquisition, but reliably more accurate performance in retention than every-trial KR, while Gable, Shea, and Wright (1991, experiment 1) reported similar findings for summaries of 8 and 16 trials relative to every-trial KR.

Similar results have also been found with more complex tasks. Using a ballistic timing task, Schmidt, Young, Swinnen, and Shapiro (1989) reported that summaries of 10 and 15 trials led to reliably less accurate performance in acquisition than a summary of 5 trials and every-trial KR, with errors in acquisition systematically increasing as summary length increased. No effects were found in immediate retention, but the relative group performances reversed in delayed retention as longer summary lengths led to systematically better performance. Similarly, Schmidt, Lange, and Young (1990) reported that the acquisition of a coincident timing task was systematically degraded as summary lengths increased from 1 to 15. However, a summary of 5 trials led to the most accurate performance in immediate and delayed retention. Using a golf putting task, Wright, Snowden, and Willoughby (1990) also reported that a summary of 5 trials led to less accurate acquisition performance, but more accurate retention performance than every-trial KR.
Finally, it is interesting to note that Young and Schmidt (1992, experiment 2) reported that average (the average of five trials) KP, given about the positional characteristics of the arm during a coincident timing task, led to retention benefits similar to those reported for summary KR. However, it is important to keep in mind that average KP is slightly different from summary KP because, in the former case, only one piece of information is provided about a given block of trials.

Studies not showing a retention benefit. In contrast to the above findings, there is some evidence that every-trial KR can produce retention performance that is as good as, or better than, summary KR. For example, Sidaway, Moore and Schoenfelder-Zohdi (1991) used the same ballistic timing task as Schmidt et al. (1989) and reported that every-trial KR led to reliably more accurate performance in acquisition and retention than a summary of 15 trials. Sidaway, Fairweather, Powell, and Hall (1992) reported similar results, although they found no retention differences between groups that received every-trial KR or a summary of 15 trials. Finally, Guay, Salmoni, and McIlwain (1992) found mixed results with an angular ballistic timing task. Performance in acquisition tended to be less accurate for summaries of 10 and 15 trials compared to a summary of 5 trials and every-trial KR. The summary of 5 trials led to slightly better immediate transfer performance in experiment
one, but there were no group differences in early and delayed retention tests. In experiment 2, there were no meaningful differences in immediate transfer or retention between summaries of 5 and 10 trials and every-trial KR.

Task Characteristics

There is evidence that task complexity can interact with the length of the summary interval. Complex tasks appear to benefit most from shorter summaries, whereas simpler tasks appear to benefit most from longer summaries. The strongest support for this conclusion was provided by Schmidt et al. (1990), who found an optimal summary length of 5 trials (compared to summaries of 10 and 15 trials and every-trial KR) for the retention of a multi-dimensional coincident timing task. In contrast, Schmidt et al. (1989) and Gable et al. (1991) found that the retention of a ballistic timing task and a force production task respectively, generally improved as summary lengths systematically increased up to 15 or 16 trials.

Procedural Characteristics

Knowledge of a retention test. Knowledge of a retention test can attenuate the superiority of summary KR over every-trial KR. This point was clearly shown by Lavery (1962), who found reliable differences between groups that received a summary of 20 trials or every-trial KR when subjects were not informed of a retention test until after acquisition, but no differences when subjects who received
every-trial KR were informed of a retention test and specifically instructed to attend to movement cues that might be useful in retention. It is also possible that knowledge of a retention test was responsible for Sidaway et al.'s (1991, 1992) inability to find any benefits for summary KR. Prior to the start of practice, Sidaway (personal communication, October, 1993) has noted that his subjects were specifically told that they would receive a no-KR retention test after their practice period.

Other procedural variables. Due to limited evidence, it is difficult to make any firm conclusions about the influence of other procedural variables on the effects of summary KR. However, there is some indication that, with sufficient practice, summary KP can lead to more accurate acquisition performance than every-trial KP (e.g., Young and Schmidt, 1992). This finding runs counter to expectation because the majority of studies have reported reliably detrimental effects of summary KR on acquisition performance - although these effects are sometimes only localized early in practice (e.g., Gable et al., 1991). Clearly, more research is needed to clarify the role of the amount of practice on the effects of summary KR.

Explanations for Summary Effects

KR frequency or information in the summary? Earlier, it was noted that the summary KR technique confounds the presentation frequency of KR with the simplification or
abstraction of information. Thus, it is difficult to determine whether summary KR effects are due to a reduction in the frequency of KR presentation or to the amount of information contained in the summary or some combination of both. Several researchers have attempted to address this question by controlling the presentation frequency of KR and varying the number of trials in the summary. This technique has produced mixed results.

At this time, it is not possible to determine if the summary KR effects primarily result from a reduction in the frequency of KR presentation or from the amount of information in the summary. For example, Sidaway et al. (1991, 1992) found no acquisition or retention differences between any 15 trial summary lengths, regardless of whether all 15 or the last 7, 3, or 1 trials were included in the summary. Similarly, Wright et al. (1990) found no acquisition or retention differences between 5 trial summary lengths that had all 5 trials or only the last trial included in the summary. On the other hand, Gable et al. (1991, experiment 2) found that the amount of information in the summary can influence retention performance. On a delayed retention test, a summary of 16 trials led to less variable performance than a 16-trial summary length that had only the last two trials included in the summary. Similarly, Guay et al. (1992, experiment 2) found that a 5 trial summary length, which included the previous ten trials
in the summary, led to reliably more accurate delayed retention performance than simple summaries of 5 and 10 trials. These latter studies suggest that, when the presentation frequency of KR is kept constant, retention performance may benefit most when more information (i.e., a greater number of trials) is included in the summary.

**Specificity hypothesis not supported.** The two experiments reported by Schmidt et al. (1990) provide strong evidence against the specificity hypothesis. In the first experiment, a 5 trial summary led to more accurate retention performance than summaries of 10 and 15 trials, while in the second experiment, a 5 trial summary led to more accurate retention performance than every-trial KR, even though KR was provided on the retention test. In both cases, the specificity hypothesis predicts that the 5 trial summary should lead to the least accurate retention performance because the retention context is least similar to the acquisition context for this group. Clearly, the prediction is not supported by the data.

**Mixed support for consistency hypothesis.** Similar to research on the relative frequency of KR, it is difficult to establish a link in the summary KR literature between variability in acquisition and performance in retention. Guay et al. (1992) found that the groups receiving more frequent KR presentations were more variable in early acquisition, but these trends tended to reverse as practice
continued (most notably in experiment 2). Also, Wright et al. (1990) found that the group that received a 5 trial summary length, with only the last trial included in the summary, was reliably less variable than the groups that received a 5 trial summary or every-trial KR. No other studies found reliable group differences based on variability in acquisition, although Schmidt et al. (1989) noted a trend for variability to decrease as summary length increased, whereas Sidaway et al. (1991) reported a trend for the groups that received the shortest summary lengths to demonstrate the least variability.

**KR salience hypothesis not supported.** There is some evidence that argues against the notion that KR salience increases because performance tends to drift away from the target when KR is presented less frequently. For example, Sidaway et al. (1992) found no evidence for systematic drifts in performance across sequences of no-KR trials. The salience notion predicts that performance should gradually worsen across no-KR sequences so that when KR is provided the nature of the error and the necessary correction are more obvious.

**Implications for ideas about dependence.** The summary KR research has important implications for the guidance hypothesis and the various notions about the dependence that can develop on augmented feedback. It is interesting to note that Lavery (1962), who was one of the pioneers of the
Summary KR research, relied heavily on the ideas of Miller (1953) and Annett (e.g., Annett, 1959, 1961; Annett & Kay, 1956, 1957) to interpret his findings. He strongly believed that too frequent augmented feedback could distract the subject from learning important intrinsic task cues, especially when the augmented feedback was difficult to ignore and intrinsic cues were difficult to detect. This conclusion was strongly supported by Lavery's (1962, experiment 2) data which indicated that the detrimental effects of every-trial KR could be attenuated if subjects were informed of a retention test and specifically instructed to attend to intrinsic feedback.

**Summary KR and subjective error detection.** Finally, there is evidence that implicates summary KR with the development of subjective error detection capabilities. These capabilities are thought to facilitate performance in retention because responses can be evaluated in the absence of augmented feedback. In support of this notion, Schmidt et al. (1990, experiment 1) reported that subjects in the summary group that performed most effectively in retention were more sensitive to their own errors than subjects in the other groups. The groups that had the lowest capability to detect their own errors performed with the least accuracy in retention. Although the error detection capabilities were not strong for any of the groups, these results highlight the importance of subjective error estimation capabilities
in learning and the role that the presentation of augmented feedback might have in developing these capabilities.

Summary and Conclusions

Summary KR consistently and reliably degrades performance in acquisition with errors generally increasing as summary length increases. The weight of evidence suggests that summary KR also benefits immediate and delayed retention, although there are some exceptions to this general finding. There is probably an optimum summary length for each task, with more complex tasks benefiting most from shorter summary lengths and simpler tasks benefiting most from longer summary lengths. It is not clear whether the summary effects are due to a reduction in the frequency of KR presentation or to the number of trials included in the summary or some combination of both.

Whatever the specific mechanism, it appears that summary KR provides the learner with the opportunity to attend and process important intrinsic cues that can be used to support performance in the absence of KR. While every-trial KR is thought to discourage this type of processing, it is interesting to note that if subjects are informed of a no-KR retention test prior to the start of practice and specifically instructed to attend to cues that might be useful on that test, then every-trial KR can lead to retention performance equal to that of summary KR.
Trials-Delay of KR

Introduction

Comparison with summary KR. The trials-delay of KR technique is similar to the summary KR technique because in both cases KR is delayed over trials. However, KR is presented for only one trial at a time in the trials-delay of KR paradigm. For example, if KR was delayed by two trials, then the subjects would not receive KR from trial one until after trial three, KR from trial two would not be given until after trial four, and so on. As a result, the frequency of KR presentation is always 100%, but the number of trials that intervene between each trial and its KR can vary by any amount.

Early research. Two early experiments conducted with the trials-delay of KR technique suggested that delaying KR over trials was detrimental to performance in acquisition. First, Lorge and Thorndike (1935) used a novel ball throwing task to determine the effects of delaying KR by various time intervals after the response or by one trial. They concluded that delaying KR by one trial produced no improvement in performance. In contrast, Bilodeau (1956) found that delaying KR by one, two, three, or five trials led to improvement on a positioning task, but error increased as a function of increases in the number of trials that intervened between each trial and its subsequent KR. However, it is not possible to assess the effects of these
manipulations on learning because retention or transfer
tests were not used.

**Effects on Acquisition and Retention/Transfer**

Although only a few studies have been conducted with
the trials-delay of KR technique, researchers have
consistently found that delaying KR over trials degrades
performance in acquisition, but facilitates performance in
retention. In one of the first attempts to examine the
trials-delay of KR technique, Lavery and Suddon (1962,
experiment 2) found that delaying KR by five trials led to
less accurate acquisition performance, but more accurate
retention performance than when KR was not delayed over
trials. These results were replicated with a similar force
production task by Suddon and Lavery (1962). Lavery (1964b)
also replicated Lorge and Thorndike's (1935) experiment with
the ball tossing task and found benefits for delaying KR
over trials. Delaying KR by one trial led to less accurate
performance in early acquisition than when KR was not
delayed over trials, but remarkably superior performance on
a series of retention tests that were given up to four
months after the initial acquisition period. Finally,
Anderson, Magill, and Sekiya (1994) looked at the effects of
delaying KR by either zero or two trials on the learning of
an aiming task. They found that the delay of two trials led
to reliably less accurate and more variable performance in
early acquisition, but reliably more accurate performance on a delayed retention test.

**Task Characteristics**

There is no evidence to suggest that task characteristics influence the effects of the trials-delay of KR technique. Similar trends in acquisition and retention were found for aiming, force production, and ball tossing tasks. However, it should be noted that these tasks are all relatively simple and whether the trials-delay of KR effects hold for more complex tasks remains to be determined. It is possible that there may be an optimal number of trials over which KR should be delayed depending on task complexity.

**Procedural Characteristics**

**Number of trials in acquisition and retention.** The conclusions that can be made about the effects of delaying KR over trials can be biased by the number of trials provided in acquisition and retention. With respect to the number of acquisition trials, Lavery and Suddon (1962) found no retention differences between groups that had KR delayed by five trials or zero trials when only 30 trials were provided in acquisition, however large retention differences were found between these two groups when 90 acquisition trials were provided. These discrepancies appear to be a function of the level of performance reached in acquisition, rather than the relative amount forgotten during the retention interval, because after 30 trials the groups that
did not have KR delayed over trials were vastly superior to the groups that had KR delayed by five trials. However, in retention, the latter groups maintained the level of performance they had attained during acquisition, while the former groups regressed to this level. As a result, there were differences in the relative amounts of information retained after 30 trials, but not on the absolute levels of retention performance.

Furthermore, Lavery (1964b) has shown that, with sufficient practice, delaying KR by one trial can actually lead to better performance in acquisition than when KR is not delayed over trials. The former schedule began to show an advantage over the latter schedule after approximately 80 practice trials.

The experiment by Lavery (1964b) also highlights the importance of the number of trials in retention. In the second and fourth retention tests, group differences did not become apparent until after 40 and 30 no-KR trials had been given respectively. From that point on, the retention curves for the two groups separated markedly because the performance of the group that had KR delayed by one trial steadily improved while the performance of the other group steadily declined. If the number of retention trials had been less than 40, very different conclusions would have been reached in this experiment.
Number of trials over which KR is delayed. Finally, one of the most obvious procedural differences that can influence performance in acquisition and retention is the number of trials over which KR is delayed. Lavery and Suddon (1962) and Suddon and Lavery (1962) used five-trial delays, whereas Lavery (1964b) and Anderson et al. (1994) used one- and two-trial delays respectively. Similar results were found regardless of the number of trials in the delay. Unfortunately, while Bilodeau (1956) has shown that acquisition performance deteriorates when the number of trials over which KR is delayed is systematically increased from one to five trials, there is no corresponding evidence to suggest that these trends would reverse in retention.

Explanations for Trials-Delay Effects

Consistency hypothesis not supported. There is some evidence in the trials-delay of KR literature that challenges the consistency hypothesis. According to Winstein and Schmidt (1989), frequent KR encourages "maladaptive short term corrections" which hinder the development of a stable action pattern and subsequently make it difficult for the learner to effectively update response-production memory structures. Anderson et al. (1994) have suggested that the delay of KR over trials actually further encourages "maladaptive short term corrections" as subjects attempt to compensate for responses that have already changed since the degree of error in those responses is
signalled. In support of this conclusion, Anderson et al. (1994) noted that a two-trial delay of KR led to reliably more variable performance in acquisition than a zero-trial delay of KR. However, the two-trial delay of KR was associated with more accurate retention performance than the zero-trial delay of KR. These findings clearly run counter to the predictions of the consistency hypothesis.

**Implications for ideas about dependence.** There is also some evidence that supports Lavery's (1962) contention that KR distracts the performer from learning important intrinsic task cues. This is the type of distraction that is thought to lead to a dependence on KR. According to Suddon and Lavery (1962), if KR is presented in such a way that subjects can use cues that can be used in the retention trials, then retention should be a direct function of the amount of practice with that type of KR. On the other hand, if KR presentation does not affect the use of cues that can be used in retention, then retention should not necessarily be a function of the amount of training with that type of KR.

In support of this conclusion, Lavery and Suddon (1962, experiment 2) found that a five-trial delay of KR led to better retention performance after 90 trials than it did after 30 trials. In contrast, retention performance was the same for groups that received 90 and 30 trials when KR was not delayed over trials. The implication is that the five-
trial delay encouraged subjects to perceive and use intrinsic task cues while the zero-trial delay did not. As a result, retention performance increased as a function of the amount of practice with a five-trial delay of KR, but not as a function of the amount of practice with a zero-trial delay of KR.

Comparison with research on KR delay. The proposition that delaying KR over trials benefits learning because it directs attention to task intrinsic feedback is in keeping with a point made by Magill (1993b) about the effects of KR delay on learning. He pointed out that depending on the type of activity in which the learner engages during the KR-delay interval, learning can be enhanced, degraded, or unaffected. When learning is enhanced (e.g., Hogan & Yanowitz, 1978; Swinnen, 1990) the activities in the KR-delay interval encourage task-intrinsic feedback processing in ways similar to what would result when other trials of the same task occur during this interval. Interestingly, this proposition applies equally well to the effects of summary KR as it does to the effects of delaying KR over trials.

Summary and Conclusions

Delaying KR over trials reliably degrades acquisition performance, with errors apparently increasing as a function of increases in the number of trials over which KR is delayed. Provided enough trials are given in acquisition,
delaying KR over trials reliably benefits retention and it can also benefit performance in acquisition. Although there is no evidence of any interactions between the trials-delay of KR and task characteristics, it is possible that there is an optimal number of trials over which KR should be delayed depending on task complexity. Once again, the most reasonable explanation for the benefits of delaying KR over trials is that it encourages subjects to perceive and process important intrinsic task cues that can support performance in retention.

**Implications**

**Implications for Learning Theory**

The question asked at the beginning of this review was, Why do schedules of augmented feedback that tend to retard the rate of performance improvement in acquisition benefit learning, while schedules of augmented feedback that tend to accelerate the rate of performance improvement in acquisition hinder learning? The first step to answering this question has been to consider the empirical evidence.

**Summary of findings.** It has been shown that reducing the relative frequency of KR, presenting KR in summary form, and delaying KR over trials can slow the rate of performance improvement in acquisition. These scheduling variations have also been shown to benefit retention performance. There is also evidence that task and procedural characteristics can interact with these schedules. For
example, less frequent KR appears to benefit retention performance only when more complex tasks are used and/or KR is systematically faded across practice. Procedural and task characteristics appear to interact when KR is presented in summary form, with more complex tasks benefitting most from shorter summary lengths and less complex tasks benefitting most from longer summary lengths. It is also probable that the optimal number of trials over which KR should be delayed to produce the most effective retention performance is dependent on characteristics of the task.

In contrast to the above findings, it has been shown that CAF and every-trial KR can accelerate performance improvement during acquisition at the expense of poor performance in retention. Task and procedural characteristics can also interact with these schedules. For example, errors in retention increase for subjects trained with CAF as a function of increases in gain and decreases in movement extent. Furthermore, there is some evidence that the detrimental effects of CAF are less apparent if intrinsic cues are easy to detect and interpret. Similarly, the detrimental effects of every-trial KR can be attenuated if, prior to the start of practice, subjects are informed of
a retention test and specifically instructed to attend to intrinsic cues that might be useful during retention.

A shift of focus. At this point it is necessary to qualify what is meant by the terms "beneficial" and "detrimental" and then to shift the focus of this review to those schedules that have been labelled as detrimental to retention performance. Rather than benefit learning, schedules of augmented feedback that retard the rate of performance improvement in acquisition also tend to retard the rate at which task-related information is forgotten over the retention interval. As a result, performance in retention remains similar to that demonstrated at the end of acquisition. This feature is common to all of the studies reviewed in this paper. In contrast, schedules of augmented feedback that tend to accelerate performance improvement in acquisition, also tend to accelerate the rate at which task-related information is forgotten over the retention interval. However, this finding is not common to all of the studies reviewed in this paper. For example, those studies that reported no reliable group differences in retention were also the studies in which the groups that improved most rapidly during acquisition showed little or no performance decrement in retention.

The common thread that ties all the studies in this review together is the schedule that provides augmented feedback during or directly after every response. The
effectiveness of any manipulation that varies the schedule of augmented feedback is always determined with respect to performance related to this schedule. The various scheduling manipulations are only deemed effective if the schedule that provides augmented feedback during or directly after each response leads to poor retention performance. Perhaps, then, the more appropriate question is, Why is augmented feedback, when provided more frequently, more immediately, or generally in a way that is easy to use, sometimes beneficial and sometimes detrimental for learning? Although evidence suggests that this type of feedback is more often detrimental to learning than beneficial (particularly when presented concurrently), What are the characteristics of the situations where it is either detrimental or beneficial? Are there mechanisms that can facilitate learning regardless of the schedule on which augmented feedback is presented?

Evaluation of hypotheses. With one exception, the hypotheses reviewed by Winstein and Schmidt (1990) provide few clues to these questions. The specificity hypothesis may predict retention performance under very specific circumstances, however, there is sufficient evidence (e.g., Schmidt et al., 1990; Sidaway et al., 1991; Winstein and Schmidt, 1990) to suggest that the similarity between conditions during acquisition and retention is not a major determinant of retention performance. The consistency
hypothesis has similar problems because of the difficulty in establishing a link between variability in acquisition and poor performance in retention. Research which has shown that variability in acquisition can be beneficial for learning (e.g., Anderson et al., 1994) is particularly damaging to this hypothesis. Finally, the spaced-retrieval hypothesis may explain the detrimental effects of providing augmented feedback in a form that is easy to use, but clearly would have problems explaining the possible benefits of this type of augmented feedback.

The guidance hypothesis appears to be the most likely to account for some of the discrepancies in the research literature because it maintains that augmented feedback can have both beneficial and detrimental effects on learning. According to this hypothesis, learning may be compromised if the subject develops a dependence on augmented feedback, either because the augmented feedback becomes part of the task that is learned (e.g., Proteau & Cournoyer, 1990; Proteau et al., 1987, 1992) or, because the subject does not adequately process intrinsic feedback. However, while the guidance hypothesis can explain why dependence on augmented feedback is detrimental to learning, independent of the schedule of augmented feedback, it does not specify the characteristics of the acquisition context that are likely to lead to dependence. The hypothesis simply states that dependence might develop if augmented feedback is presented
too frequently or in a way that is easy to use. However, there is enough evidence to suggest that these conditions alone are not sufficient to produce dependence because of the potential for task and procedural characteristics to interact with the schedule of augmented feedback.

A modified guidance hypothesis. Nevertheless, despite these limitations, with some modifications the guidance hypothesis can generate testable hypotheses about the conditions that are most likely to cause dependence on augmented feedback. Many of the ideas about the variables that can influence the relationship between intrinsic and augmented feedback need to be reconsidered in order to develop appropriate modifications.

Previous notions about dependence on augmented feedback emphasized the need to consider task and procedural characteristics because these characteristics were thought to exert an important influence on the way in which intrinsic and augmented feedback were processed. According to many researchers (e.g., Annett, 1961; Annett & Kay, 1957; Bahrick, Fitts, & Schneider, 1955; Lintern, 1980, 1991; Lintern, Roscoe, & Sivier, 1990; Miller, 1953), the goal in any learning situation is for subjects to learn the relationship between intrinsic and augmented feedback. For these researchers, the role of augmented feedback in motor learning is to clarify intrinsic feedback so that the
learner develops a capability to evaluate his/her performance on the basis of intrinsic feedback alone.

The potential for dependence on augmented feedback exists because this source of information is typically more salient than intrinsic feedback. Annett and Kay (1957) have noted that augmented feedback is usually presented in terms of fairly well known scales, whereas intrinsic feedback signals have no labels. As mentioned in a previous section, Annett (1961) believes it is possible to predict dependence based on the relative amount of information given by intrinsic and augmented feedback. When intrinsic feedback is difficult to detect or interpret and augmented feedback is obvious, learners are likely to rely on augmented feedback to maintain performance.

These ideas are very similar to Posner, Nissen, and Klein's (1976) notions about visual dominance as well as notions about the resolution of conflict between discrepant sources of feedback (e.g., Buekers, Magill, & Sneyers, 1994; Buekers & Magill, in press). The key similarity is that subjects tend to process and rely on the most compelling or dominant source of information, whether or not that source of information is most effective for task performance/learning.

The primary implication from these ideas about dependence on compelling sources of information is that they can be incorporated into a testable guidance hypothesis.
Dependence on augmented feedback, and its associated negative effects on retention performance, is most likely to occur when intrinsic feedback is difficult to detect or interpret and augmented feedback is presented in such a way that it is difficult to ignore (e.g., too frequently, too immediately, and so on). Intrinsic feedback signals may be difficult to detect or interpret for a number of reasons: they may occur briefly, they may be imbedded within a succession of other signals, they may involve a poorly developed discrimination (such as proprioception), they may be just above threshold, or there may be insufficient time to assess them. In any case, the effectiveness of any schedule of augmented feedback can only be determined based on whether dependence on this source of information is likely to develop. And, dependence is most likely to develop when intrinsic feedback is not very salient.

The importance of information salience. The concept of information salience has more widespread implications for an understanding of the way augmented feedback functions in motor learning. Magill (1993a) has already noted that the clarity of intrinsic feedback can be used to determine when augmented feedback is likely to benefit, hinder, or have no effect on motor learning. In addition, the notion that information salience can influence which sources of feedback are processed is related to contemporary learning theories.
The emphasis placed on attending to various sources of perceptual information is consistent with Gibson's (1969) informational perspective on learning. This perspective maintains that learning is a process of perceptual differentiation, whereby information becomes easier to discriminate with practice. From this viewpoint, skill develops as sensitivity to critical sources of perceptual information increases. Lintern (1991) has noted that clarification or enhancement of critical sources of information will enhance learning/transfer, whereas concealment or distortion will impede learning/transfer. Similarly, emphasis on well learned, easily learned, or non-functional cues will have no effect on learning/transfer. The critical sources of information must, therefore, be carefully evaluated before augmented feedback is incorporated into the learning situation. Sensitivity to these sources of information may never fully develop if augmented feedback directs attention away from them.

Cognitive effort. Another factor relevant to the processing of intrinsic feedback is the effort required of such processing. Some researchers (e.g., Lee, Swinnen, & Serrien, 1994) argue that cognitive effort expended during practice has a critical impact on the learning process, with more effort leading to greater learning. Lee et al. (1994) have also argued that learning to interpret one's own intrinsic feedback requires cognitive effort and that
retention performance should naturally suffer if augmented feedback distracts attention from the effortful processing of intrinsic feedback. While this interpretation offers one explanation for the benefits of processing intrinsic feedback, it should be viewed with caution because it is not clear whether superior retention performance results from the opportunity to detect and interpret intrinsic feedback or the effort required to process this source of information.

Implications for Training

Dependence can be discouraged. The goals of any training situation are to maximize performance during acquisition and retention/transfer. The use of augmented feedback can facilitate these goals provided the learner does not become dependent on it. The weight of evidence suggests that any variation that makes augmented feedback more difficult to use can decrease the likelihood of dependence. Presumably, dependence does not occur when augmented feedback is difficult to use because subjects are forced to direct more attention to interpreting intrinsic sources of feedback and relating these sources of feedback to the goal of the task. However, the beneficial effects of scheduling variations that make augmented feedback difficult to use are usually associated with negative effects on early acquisition performance. These negative effects may be a concern if motivation or compliance with the training
program is a potential problem. However, the hypothesis advanced in the previous section suggest that altering the schedule of augmented feedback presentation is only one way to discourage dependence on this source of information. Dependence may also be discouraged if the task provides obvious intrinsic feedback, if the intrinsic feedback is enhanced, or if instructions direct attention to intrinsic feedback.

The task needs to be carefully analyzed. With these ideas in mind, the primary implication for training is that the task must be carefully analyzed before the most appropriate schedule of augmented feedback can be determined. The task must be analyzed in terms of its complexity, the cues that are critical for successful performance, and the clarity of these cues. If the task is complex and/or intrinsic cues are salient, then acquisition and retention/transfer performance may benefit most from a presentation schedule that allows augmented feedback to be used easily and frequently. Examples of such tasks include many video games and tracking tasks in which clear visual feedback is available and KR is provided in terms of a cumulative score or average error from the target. On the other hand, if the task is relatively simple and intrinsic cues are obscure, a presentation schedule that makes augmented feedback more difficult to use may be advisable. Examples of these tasks include simple positioning or aiming
movements that are made in the absence of concurrent visual feedback, such as the movements involved in touch typing or in controlling an aircraft or space craft.

Task and procedural characteristics can influence retention. In both cases, additional benefits are possible if learners are gradually weaned from augmented feedback by fading it across the practice session and if learners are instructed to attend to important intrinsic cues, or if these cues are enhanced or dramatized (e.g., by adding resistive forces to a movement). However, it should be cautioned that successful performance may depend on more than one cue and/or different feedback loops may control different aspects of a response (e.g., Adams, 1964). This means that if certain cues are enhanced they may dominate other important cues, that would subsequently go undetected. Cue enhancement is not recommended unless all the cues that are relevant to successful performance can be emphasized.

Problems with CAF. The schedule most likely to encourage dependence on augmented feedback is concurrent presentation. Evidence indicates that dependence may be impervious to instructions that direct attention to intrinsic sources of feedback, but may be prevented if intrinsic cues are easy to detect (e.g., Kinkade, 1963, as cited by Adams, 1964). Dependence may also be discouraged if CAF is presented through a sensory channel, such as the auditory channel, that is not likely to conceal or distort
information from other sensory channels. For example, auditory augmented feedback may facilitate acquisition and retention/transfer performance for a task that requires the perception of clear visual intrinsic feedback. A specific example might be the addition of an auditory cue when subjects are off target on a tracking task. If CAF cannot be organized in a way that avoids sensory conflict, it is probably best to provide this type of augmented feedback on a very infrequent and unpredictable schedule. However, even this schedule may need to be combined with appropriate attention directing instructions to obtain the best results.

Level of learning is important. Another training consideration is the level of learning achieved by the trainee and the amount of practice time available. Evidence from Winstein and Schmidt (1990) suggests that less frequent KR can be handled more effectively if the task has been practiced for some time with more frequent KR. If the same holds for other schedules of augmented feedback, then this procedure may be one of the best ways to maximize acquisition and retention/transfer performance. Furthermore, the results of Lavery (1964b) and Young and Schmidt (1992) suggest that more demanding schedules of augmented feedback can eventually lead to better acquisition performance than less demanding schedules if enough practice is provided.
An exploration period may be beneficial. An effective training method may be to allow the learner to experience the task before augmented feedback is presented. Both Miller (1953) and Lintern (1991) have suggested that an opportunity to explore the dynamics of the task or the equipment can benefit learning. Based on Gibson's (1969) ideas, Lintern (1991) has argued that an exploration period can benefit perceptual discrimination of the responses required in the task. The learner must be able to discriminate among responses before these responses can be tied to an externally supplied scale, and this process could be hindered if augmented feedback is introduced too early during practice.

KP versus KR. Another important consideration for training is the type of augmented feedback provided. Young and Schmidt's (1992) results suggest that KP may function more effectively than KR for certain tasks. This notion makes intuitive sense since KP directs attention to critical task cues, rather than to the outcome of the response. For this reason, KP may function differently from KR and it may be possible to provide KP more frequently or more immediately without the danger of promoting a dependence on this source of information. This consideration is important for physical educators and coaches because in the majority of kicking, throwing, catching, and hitting skills involved
in various sports, KP is the most often used form of augmented feedback.

The appropriate learning attitude. Finally, the present research has implications for the attitude that needs to be encouraged in the learner. Miller (1953) has noted that the average student in any training situation will be motivated to 1) avoid appearing foolish, 2) get high scores, and 3) graduate from the training program as quickly as possible. As a result, training must be organized so that there is no conflict between working for high scores and learning the critical aspects of the response. Encouraging an appropriate learning attitude is important because of the natural tendency for subjects to want to take the shortest route to the goal. Augmented feedback may provide the shortest route to the goal at the expense of poor retention of task-relevant information.

Learner characteristics may be important. The characteristics of the learner are also important here because certain individuals have a preference for processing different types of information (e.g., Temple & Williams, 1977) or are motivated by different aspects of a task (e.g., Little & McCullagh, 1989). These individual difference characteristics deserve special attention because certain individuals can be drawn to one source of information or the other regardless of the schedule on which augmented feedback is presented. Prior knowledge of subject characteristics
may be a crucial determinant of the most appropriate schedule of augmented feedback.

**Summary.** In summary, this section maintains that augmented feedback must be structured so that subjects are encouraged to attend to intrinsic feedback. The optimal schedule depends on subject, task, and procedural characteristics and may change as the learner progresses from one stage of practice to the next.

**Implications for Future Research**

The general theme that has emerged from this review is that learning will suffer if subjects become dependent on augmented feedback. Almost any manipulation of the schedule of augmented feedback can discourage dependence, however, this discouragement usually occurs at the expense of poorer performance in acquisition. Furthermore, augmented feedback schedules can be generated endlessly and the effectiveness of any schedule is dependent on a number of other variables that can also influence learning. It is premature to begin searching for optimum schedules before the effects of these other variables are determined.

What variables promote dependence on augmented feedback? Future research needs to determine the variables that are most likely to promote dependence on augmented feedback. Contemporary research has directed scant attention to these variables because contemporary notions about dependence are vague and difficult to test. However,
arguments made previously in this paper suggest that there are specific task, subject, and procedural characteristics that can influence dependence and these characteristics can be readily manipulated.

**Task characteristics and dependence.** A specific question is how these characteristics influence the perception of intrinsic feedback when augmented feedback is maximally salient or useful. Task characteristics can be tested by examining different tasks that provide various amounts of intrinsic feedback. Annett (1970) has suggested that movement extent is at least one characteristic that can influence the amount of intrinsic feedback available. Alternately, critical intrinsic cues can be enhanced, concealed, or distorted. According to Bahrick et al. (1955) the intensity of proprioceptive feedback can be enhanced if resistive forces are added to a movement. Additional elasticity is thought to improve the spatial accuracy of a movement, whereas additional viscous damping and mass can improve temporal accuracy.

**Subject characteristics and dependence.** The importance of subject characteristics has been summarized poignantly by Adams (1964, p. 191), who remarked - "One cannot help but wonder about individual differences that reside in the cesspool of the error term and often constitute the major source of variance in an experiment." This comment is appropriate because previously mentioned research suggests
that subject characteristics can interact with the type of augmented feedback provided (e.g., Little & McCullagh, 1989; Temple & Williams, 1977). Knowledge of specific subject characteristics and the way these characteristics interact with augmented feedback would have considerable theoretical and applied value. The knowledge could help to uncover certain processing operations that lead to effective learning and clearly it would provide specific guidelines to help individualize practice.

**Procedural characteristics and dependence.** There are a number of procedural characteristics that warrant examination. The most obvious is the influence of specific instructions to attend to intrinsic feedback. Lavery (1962) has already shown that such instructions can be beneficial if they are combined with prior knowledge of a retention test. The influence of the number of acquisition trials is another important procedural characteristic because rival hypotheses predict different effects from various amounts of practice. Proteau and colleagues (e.g., Proteau & Cournoyer, 1990; Proteau et al., 1987, 1992) argue that dependence on augmented feedback should increase as the number of practice trials increases because augmented feedback becomes part of the task. In contrast, Fleishman and Rich (1963) have suggested that subjects tend to rely on the most dominant cues early in practice and less dominant cues later in practice. These hypotheses could easily be
tested by comparing the retention performance of groups that receive various amounts of practice.

The time available to process intrinsic feedback can also influence the effects of augmented feedback. For example, Swinnen, Schmidt, Nicholson, and Shapiro (1990) have argued that instantaneous augmented feedback can block the spontaneous evaluation of response-produced feedback. This notion is similar to previous comments which suggest that intrinsic feedback may be difficult to detect if insufficient time is provided to assess it.

CAF versus TAF. The effects of the temporal location of augmented feedback deserve special attention. Evidence indicates that CAF may function differently from TAF. CAF appears to be the most detrimental schedule for motor learning, presumably because CAF is more likely to influence the perception of intrinsic feedback than any schedule of TAF. Research needs to determine if CAF is a viable way to schedule augmented feedback. Lintern (1991) has suggested that there are methods to implement CAF effectively into the training situation, but these methods have received scant attention. Furthermore, Patrick and Mutlusoy (1982) have suggested that different movement patterns may result from CAF and these movement patterns may be associated with different recall characteristics. Based on the proliferation of contemporary training devices that provide
CAF, future research needs to address issues related to the provision of this form of augmented feedback.

**KR versus KP.** Finally, there is a need to consider how the type of augmented feedback influences the acquisition and retention of motor tasks. Comments made in a previous section implied that KP may function quite differently from KR because KP directs attention to characteristics of the response rather than the outcome of the response. If, for this reason, KP does function differently from KR, then it may be possible to provide KP in such a way that it accelerates the rate of performance improvement in acquisition but does not cause the poor retention performance typically associated with dependence on augmented feedback.

**Summary.** In summary, future research needs to determine the task, procedural, and subject characteristics that are most likely to promote dependence on augmented feedback. Once these characteristics are identified research should then attempt to determine optimal types and schedules of augmented feedback, given the characteristics that will be present during learning. Whatever characteristics interact with the processing of intrinsic and augmented feedback, these characteristics must be identified before a comprehensive theory of feedback can be established.
Appendix B

Additional References


Appendix C

Letters Requesting and Granting Permission From Research Quarterly for Exercise and Sport
July 8, 1994

Nancy H. Rosenberg
Acting Associate Editor
Research Quarterly for Exercise and Sport
1900 Association Drive
Reston, VA 22091

Dear Nancy,

I would like to formally ask permission from Research Quarterly for Exercise and Sport to use the manuscript titled, "A Reconsideration of the Trials-Delay of Knowledge of Results Paradigm in Motor Skill Learning" by David I. Anderson, Richard A. Magill, and Hiroshi Sekiya as part of my dissertation at Louisiana State University. The Graduate school at LSU requires written permission from the relevant authority for any published articles that are to be used as part of a dissertation. The article is currently in press and should appear in the September, 1994 issue of your journal. I hope this letter is a satisfactory request for permission to use the manuscript. However, if there are any additional forms I need to file or procedures I need to adhere to would you please let me know as soon as possible. I look forward to your reply.

Sincerely,

David Anderson
July 21, 1994

Mr. David Anderson
112 Long Fieldhouse
Baton Rouge, LA 70803

Dear Mr. Anderson:

We are glad to grant permission for you to make use, as part of your dissertation at Louisiana State University, of your manuscript for the article titled “A Reconsideration of the Trials-Delay of Knowledge of Results Paradigm in Motor Skill Learning” by David I. Anderson, Richard A. Magill, and Hiroshi Sekiya, that will be published in the September 1994 issue of Research Quarterly for Exercise and Sport.

Sincerely,

Nancy H. Rosenberg
Acting

Nancy H. Rosenberg
Appendix D

Scaled Version of the Target Used in Chapter 2
Appendix E

Human Consent Form
Human Consent Form

I understand that my participation in this experiment is purely voluntary and I can withdraw at any time without penalty. However, I must attend all sessions in order to get full class credit in exchange for participation in the experiment. Also, I understand that all data will be kept confidential and not used for any purposes other than this experiment.

Name:

Social Security #: 

Class instructor:

Signature: 
Appendix F
Instructions for each Experiment
Chapter 2.
Instructions for Delay-0.

This experiment investigates the speed with which fine motor skills are acquired. The task is a blindfolded aiming movement from a start position to a target. Your movement will be made with a pen-shaped stylus on a graded target that is fixed to a table top. Once the experimenter positions your hand on the start location, he will say "GO". After this signal you will move forward in a smooth, continuous movement and press down where you think the target is located (do not hesitate or hover over the target before you press down). The experimenter will tell you a number that corresponds to where you landed on the target. The smaller the number the closer you landed to the target. A negative number means that you undershot the target, while a positive number means that you overshot the target. Zero indicates that you hit the target. After feedback has been provided, the experimenter will move your hand back to the start location.

You will be given 80 trials to improve the accuracy and consistency of your movements. Following these 80 trials, you will be given a 10-min break and then another 20 trials. You will be required to return on the following day to complete and additional 20 trials.

Note: Before you start practice, the experimenter will move your hand around the borders of the target. The target is located directly in front of your hand and approximately half way between the top and bottom borders. If you have any questions, please ask them now.

Additional instructions for Delay-2

... The experimenter will tell you a number that corresponds to where you landed on the target. However, this feedback will be delayed by two trials (i.e., you will not receive feedback from trial one until after trial three, and so on).
Chapter 3. Experiment 1.
Instructions for Delay-0 and Delay-0 SPG.

This experiment investigates the speed with which fine motor skills are acquired. The task is a simple aiming movement from a start position to a target. Your movement will be made with an electronic pen on an electronic drawing board that is covered by the table in front of you. Some subjects will perform the movement with a spring attached to the pen. Although, you will not be able to see your hand or the drawing board, the computer will show you where you are positioned on the drawing board and where each movement landed in relation to the target. After you position the pen on the drawing board and press down, the target will appear on the computer screen (the distance from the start to the target, as it appears on the screen, is exactly the same as the distance you are required to move). You then move toward the target in a smooth, continuous movement and press down again (do not hesitate or hover over the target before you press down).

You will be given a total of 130 trials to improve the accuracy and consistency of your movements. After each trial, you will receive feedback on the computer screen. The feedback will show you how close to the target you landed. One minute breaks will be given after each block of 40 trials. You will be required to return on the following day to complete an additional 40 trials. If you have any questions, please ask them now.

Additional instructions for Delay-2 and Delay-2 SPG.

... After each trial, you will receive feedback on the computer screen. However, the feedback will be delayed by two trials (i.e., you will not receive feedback from trial one until after trial three, and so on).
Chapter 3. Experiment 2.

This experiment investigates how accurately movements can be discriminated when they are made with and without spring tension. The task requires you to move a pen along a trackway until you contact a physical stop. On each trial you will move to a standard location, return to the start, and then move immediately forward until you contact the stop at another location. You will be asked to indicate if the second movement was shorter or longer than the movement to the standard location. You will perform 90 trials with a spring attached to the pen and 90 trials without the spring attached to the pen. However, the trials either with or without the spring will be performed on two consecutive days. A short break will be provided after each block of 30 trials. At the end of the experiment you will be required to answer some questions about the two tasks. If you have any questions, please ask them now.
This experiment investigates the speed with which fine motor skills are acquired. The task is a simple aiming movement from a start position to a target. Your movement will be made with an electronic pen on an electronic drawing board that is covered by the table in front of you. In addition, you will perform the movement with a spring attached to the pen. Although, you will not be able to see your hand or the drawing board, the computer will show you where you are positioned on the drawing board and where each movement landed in relation to the target. After you position the pen on the drawing board and press down, the target will appear on the computer screen (the distance from the start to the target, as it appears on the screen, is exactly the same as the distance you are required to move). You then move toward the target in a smooth, continuous movement and press down again (do not hesitate or hover over the target before you press down).

On day one, you will perform 5 trials without feedback followed by 80 trials with feedback. On day two, you will perform 5 trials without feedback, followed by 120 trials. Finally, on day three, you will perform another 40 trials. However, if you feel fatigued at any time, feel free to take a break.

Note: After the first 5 trials, you will be given additional instructions about the feedback you will receive. If you have any questions, please ask them now.
Appendix G

Chapter 3 Experiment 3 Questionnaire
1. What cues (e.g., final hand position, movement distance, movement time, spring tension) did you use to make your movements more accurate during practice?

2. Did the cues that you used change with practice?

3. How well could you remember and use the movement cues when feedback was withdrawn?

4. Do you think that you performed accurately when feedback was withdrawn?

5. Did the spring help or hinder you in this task?
Appendix H

Chapter 2 Experiment Data and ANOVA Tables
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### Table H.5 ANOVA Table for ACE in 24-hour Retention

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### Table H.7 ANOVA Table for VE in 10-min Retention

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Appendix I

Chapter 3 Experiment 1 Data and ANOVA Tables
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186
### Table I.3 ANOVA Table for RE in Acquisition

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### Table I.4 ANOVA Table for RE in 1-min Retention

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### Table I.6 ANOVA Table for RVE in Acquisition

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Appendix J

Chapter 3 Experiment 2 Data and T-Test Tables
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Table J.1 Data Table for JND, PSE, and Salience.
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Appendix K

Chapter 3 Experiment 3 Data and ANOVA Tables

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Table K.1: Data Table of RE for Trial Blocks in Acquisition and Retention.

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| a,b,c,d | e,f,g,h,i,j,k,l,m,n,o,p,q,r,s,t,u,v,w,x,y,z |

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### Table K.3 ANOVA Table for RE in Acquisition

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### Table K.7 ANOVA Table for Acquisition-Retention Interaction

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<td>94.395</td>
<td>29.914</td>
<td>.0001</td>
<td>.0001</td>
</tr>
<tr>
<td>Blocks x Group</td>
<td>3</td>
<td>3.509</td>
<td>1.17</td>
<td>.371</td>
<td>.7742</td>
<td>.7666</td>
</tr>
<tr>
<td>Blocks x Subject(Group)</td>
<td>162</td>
<td>511.202</td>
<td>3.156</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day x Blocks</td>
<td>3</td>
<td>51.514</td>
<td>17.171</td>
<td>5.435</td>
<td>.014</td>
<td>.0021</td>
</tr>
<tr>
<td>Day x Blocks x Group</td>
<td>3</td>
<td>9.056</td>
<td>3.022</td>
<td>.957</td>
<td>.4168</td>
<td>.4078</td>
</tr>
<tr>
<td>Day x Blocks x Subject(Group)</td>
<td>162</td>
<td>511.791</td>
<td>3.159</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table K.9 ANOVA Table for RVE in 5-trial Retention

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>32.140</td>
<td>32.140</td>
<td>1.647</td>
<td>.2048</td>
</tr>
<tr>
<td>Residual</td>
<td>54</td>
<td>1053.788</td>
<td>19.515</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table K.10 ANOVA Table for RVE in 1-min Retention

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>GG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>24.797</td>
<td>24.797</td>
<td>3.17</td>
<td>.0806</td>
<td></td>
</tr>
<tr>
<td>Subject(Group)</td>
<td>54</td>
<td>422.427</td>
<td>7.823</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>1</td>
<td>8.929E-5</td>
<td>8.929E-5</td>
<td>5.8E-5</td>
<td>.9939</td>
<td>.9939</td>
</tr>
<tr>
<td>Blocks x Group</td>
<td>1</td>
<td>3.975</td>
<td>3.975</td>
<td>2.619</td>
<td>.1114</td>
<td>.1114</td>
</tr>
<tr>
<td>Blocks x Subject(Group)</td>
<td>54</td>
<td>81.97</td>
<td>1.518</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table K.11 ANOVA Table for RVE in 24-hour Retention

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>GG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>15.526</td>
<td>15.526</td>
<td>2.003</td>
<td>.1628</td>
<td></td>
</tr>
<tr>
<td>Subject(Group)</td>
<td>54</td>
<td>418.612</td>
<td>7.752</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>1</td>
<td>7.050</td>
<td>7.050</td>
<td>3.331</td>
<td>.0735</td>
<td>.0735</td>
</tr>
<tr>
<td>Blocks x Group</td>
<td>1</td>
<td>.214</td>
<td>.214</td>
<td>.101</td>
<td>.7515</td>
<td>.7515</td>
</tr>
<tr>
<td>Blocks x Subject(Group)</td>
<td>54</td>
<td>114.291</td>
<td>2.116</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix L

Computer Programs for Chapter 3 Experiments 1 and 3
DECLARE FUNCTION BinStr2Bin% (B$)
DECLARE SUB Mouse (m1%, m2%, m3%, m4%)
DECLARE SUB MOUSERANGE (x1%, y1%, x2%, y2%)
DECLARE SUB MouseInstall (mflag%)
DECLARE SUB MouseNow (leftButton%, rightButton%, XMUSE%, YMUSE%)
SCREEN 8: CLS: COLOR 11
MouseInstall mflag%
MOUSERANGE 4, 4, 635, 195
DIM X(170) AS INTEGER, Y(170) AS INTEGER
DIM TAR(300) AS INTEGER, MOU(300) AS INTEGER
DIM MT(170)
CLS: CIRCLE (5, 5), 4, 10: GET (1, 1)-(9, 9), TAR: CLS
LINE (1, 5)-(9, 5), 12: LINE (5, 3)-(5, 7), 12: LINE (4, 3)-(4, 7), 12: LINE (6, 3)-(6, 7), 12
GET (1, 1)-(9, 9), MOU
************************************************************************ DATA FILE *****************************************************
CLS: INPUT "NAME"; N$
INPUT "DAY1  > 1 or DAY2 --> 2 DAY%"
IF DAY% = 2 THEN GOTO DAY2
OPEN "A:" + N? + ".DAT" FOR OUTPUT AS #1: CLOSE #1: CLS
************************************************************************ DAY 1 *******************
PREERR = 0
FOR TR% = 1 TO 130
GOSUB TRIAL
IF TR% = 90 AND COND% = 2 THEN GOSUB LAST2KR
IF TR% = 10 OR TR% = 50 OR TR% = 90 THEN GOSUB BREAK
NEXT TR%
CLS: LOCATE 10, 20: PRINT "Thank you very much! See you tomorrow!"
END
************************************************************************ DAY 2 *******************
DAY2:
FOR TR% = 131 TO 170
GOSUB TRIAL
NEXT TR%
CLS: LOCATE 10, 25: PRINT "Thank you very much!"
END
************************************************************************ KEYSUB ********************************************************
KEYSUB:
Fl% = 1
RETURN
************************************************************************ SHORT BREAK (30-SEC) ************
BREAK:
T5 = TIMER
LOCATE 10, 20: PRINT "Let's have a 30-sec break!"
IF TR% = 10 THEN PRINT CINT(PREERR / 10)
IF TR% = 10 THEN INPUT "No delay --> 1 or Delay --> 2 "; COND%
DO
LOOP UNTIL TIMER - T5 > 30
BREAK
RETURN
************************************************************************ LAST 2 KR ********************
LAST2KR:
T3 = TIMER
LOCATE 1, 35
PRINT "Error = "; CINT(SQR(((320 - X(89)) * .3125) ^ 2 + ((80 - Y(89)) * .8))
CIRCLE (320, 80), 8, 10
PUT (X(89) - 4, Y(89) - 4), MOU, XOR
DO LOOP UNTIL TIMER - T3 > 3
CLS
DO LOOP UNTIL TIMER - T3 > 10
T4 = TIMER
LOCATE 1, 35
PRINT "Error = CINT(SQR(((320 - X(90)) * .3125) ^ 2 + ((80 - Y(90)) * .8))
CIRCLE (320, 80), 8, 10
PUT (X(90) - 4, Y(90) - 4), MOU, XOR
DO LOOP UNTIL TIMER - T4 > 3
CLS
RETURN

'*************** TRIAL LOOP **********************
TRIAL:
F1% = 0: ON KEY(1) GOSUB KEYSUB: KEY(1) ON
CLS
TI = TIMER
PRINT "Trial #"; TR%
PRINT "Locate the pen to the start position and push down"
PUT (320 - 4, 180 - 4), TAR, XOR
DO
MouseNow leftButton%, rightButton%, XMUSE%, YMUSE%
LOOP UNTIL ABS(YMUSE% - 180) < 30
DO
PUT (320 - 4, 180 - 4), TAR, XOR
PUT (XMUSE% - 4, YMUSE% - 4), MOU, XOR
FOR T% = 1 TO 200: NEXT T%
LOCATE 1, 1: PRINT "X="; XMUSE%
LOCATE 2, 1: PRINT "Y="; YMUSE%
LOCATE 1, 1: PRINT "X="; XMUSE%
LOCATE 2, 1: PRINT "Y="; YMUSE%
LOCATE 1, 1: PRINT "X="; XMUSE%
LOCATE 2, 1: PRINT "Y="; YMUSE%
LOOP UNTIL leftButton% = -1
CLS
PRINT "Trial #"; TR%
PRINT "Move the pen to the target"
CIRCLE (320, 80), 8, 10
DO
MouseNow leftButton%, rightButton%, XMUSE%, YMUSE%
LOOP UNTIL leftButton% = 0
MI = TIMER
DO
MouseNow leftButton%, rightButton%, XMUSE%, YMUSE%
LOOP UNTIL leftButton% = -1
MT = TIMER
IF MT - MI > 1 OR MT - MI < .5 THEN GOTO CANCEL
X(TR%) = XMUSE%; Y(TR%) = YMUSE%; MT(TR%) = MT - MI
T2 = TIMER
CLS
'*************** error for pretest ***************
IF TR% < 11 THEN PREERR = PREERR + CINT(SQR(((320 - X(TR%)) * .3125) ^ 2 + ((80
IF TR% < 11 OR TR% > 90 THEN GOTO NOKR
DO
LOOP UNTIL TIMER - T2 > 1
IF COND% = 2 THEN GOTO DELAYKR
LOCATE 1, 33
PRINT "Error = "; CINT(SQR(((320 - X(TR%)) * .3125) + 2 + ((80 - Y(TR%)) * .8
CIRCLE (320, 80), 8, 10
PUT (X(TR%) - 4, Y(TR%) - 4), MOU, XOR
GOTO POSTKR

DELAYKR:
IF TR% < 13 THEN GOTO POSTKR
LOCATE 1, 27
PRINT "Error (Trial #"; TR% - 2; "); "; CINT(SQR(((320 - X(TR% - 2)) * .3125
CIRCLE (320, 80), 8, 10
PUT (X(TR% - 2) - 4, Y(TR% - 2) - 4), MOU, XOR
POSTKR:
DO
LOOP UNTIL TIMER - T2 > 4
CLS
NOER:
DO
LOOP UNTIL TIMER - T2 > 4
DO
LOOP UNTIL TIMER - T1 > 10
IF FI* = 1 THEN GOTO TRIAL
OPEN "A:\" + N$ + ".DAT" FOR APPEND AS #1
WRITE #1, X(TR%), Y(TR%), MT (TR*)
CLOSE #1
RETURN
CANCEL:
TC1 = TIMER
CLS ; LOCATE 15, 20
IF MT - MI > .75 THEN
PRINT "Cancelled! Move the pen faster!": BEEP: BEEP
ELSEIF MT - MI < .5 THEN
PRINT "Cancelled! Move the pen slower!": BEEP: BEEP
END IF
DO
LOOP UNTIL TIMER - TC1 > 4
CLS
GOTO TRIAL

' ************************************************
' ** Name: MouseInstall **
' ** Type: Subprogram **
' ** Module: MOUSSUBS.BAS **
' ** Language: Microsoft QuickBASIC 4.00 **
' ************************************************

' Determines whether mouse is available and resets all mouse parameters.
'
' EXAMPLE OF USE: MouseInstall mflag%
' PARAMETERS: mflag% Returned indication of mouse availability
' VARIABLES: (none)
' MODULE LEVEL
' DECLARATIONS: DECLARE SUB Mouse (ml%, m2%, m3%, m4%)
' DECLARE SUB MouseInstall (mflag%)'

SUB MouseInstall (mflag%) STATIC
    mflag% = 0
    Mouse mflag%, 0, 0, 0
END SUB

' ************************************************
** Name: MouseNow  **  
** Type: Subprogram  **  
** Module: MOUSSUBS.BAS  **  
** Language: Microsoft QuickBASIC 4.00  **

Returns the instantaneous state of the mouse.

EXAMPLE OF USE: MouseNow leftButton%, rightButton%, xMouse%, yMouse%

PARAMETERS:
- leftButton% Indicates left mouse button state
- rightButton% Indicates right mouse button state
- xMouse% X location of mouse
- yMouse% Y location of mouse

VARIABLES:
- m2% Mouse driver parameter containing button press information

MODULE LEVEL DECLARATIONS:
DECLARE SUB Mouse (m1*, m2*, m3*, m4%)
DECLARE SUB MouseNow (leftButton*, rightButton*, xMouse*, yMouse*)

SUB MouseNow (leftButton*, rightButton*, xMouse*, yMouse*) STATIC
    Mouse 3, m2*, xMouse*, yMouse*
    leftButton* = ((m2* AND 1) <> 0)
    rightButton* = ((m2* AND 2) <> 0)
END SUB

** Name: MouseRange  **  
** Type: Subprogram  **  
** Module: MOUSSUBS.BAS  **  
** Language: Microsoft QuickBASIC 4.00  **

Sets mouse range of motion.

EXAMPLE OF USE: MouseRange xl%, yl%, x2%, y2%

PARAMETERS:
- xl% Upper left corner X coordinate
- yl% Upper left corner Y coordinate
- x2% Lower right corner X coordinate
- y2% Lower right corner Y coordinate

VARIABLES: (none)

MODULE LEVEL DECLARATIONS:
DECLARE SUB Mouse (m1*, m2*, m3*, m4%)
DECLARE SUB MouseRange (xl%, yl%, x2%, y2%)

SUB MouseRange (xl%, yl%, x2%, y2%) STATIC
    Mouse 7, 0, xl%, x2%
    Mouse 8, 0, yl%, y2%
END SUB

CLEAR
DIM X(170) AS INTEGER, Y(170) AS INTEGER
DIM MT(170)
DIM AEX(17), AEY(17), CEX(17), CEY(17), VEX(17), VEY(17)
DIM EX(17), EY(17), RMS(17), RMSVE(17)
DIM AMT(17), MTSD(17)
CLS
INPUT "SUBJECT NAME"; N$
OPEN "A:" + N$ + "DAT" FOR INPUT AS #1
FOR TR% = 1 TO 170
  INPUT #1, X(TR%), Y(TR%), MT(TR%)
NEXT TR%
CLOSE #1
FOR TB% = 1 TO 17
C% = 0: AEX = 0: AEY = 0: CEX = 0: CEY = 0: SX = 0: SY = 0: RMS = 0: VEX = 0: VEY = 0: RMSVE = 0: CEXX = 0: CEYY = 0: MT = 0: MTSD = 0
FOR T% = 1 TO 10
  TR% = (TB% - 1) * 10 + T%
  IF Y(TR%) > 180 - 37.5 THEN GOTO SKIP1
  C% = C% + 1
  AEX = AEX + ABS(X(TR%) - 320) * .3125
  AEY = AEY + ABS(80 - Y(TR%)) * .8
  CEX = CEX + (X(TR%) - 320) * .3125
  CEY = CEY + (80 - Y(TR%)) * .8
  CEXX = CEXX + X(TR%)
  CEYY = CEYY + Y(TR%)
  SX = SX + X(TR%)
  SY = SY + Y(TR%)
  RMS = RMS + SQR(((X(TR%) - 320) * .3125)
  MT = MT + MT(10) / C%
SKIP1:
FOR T% = 1 TO 10
  TR% = (TB% - 1)
  IF Y(TR%) > 180 - 37.5 THEN GOTO SKIP2
  VEX = VEX + ((X(TR%) - SX / C%) * .3125 / 2
  VEY = VEY + ((Y(TR%) - SY / C%) * .8 / 2
  MTSD = MTSD + (MT(TR%) - MT / C%) ^ 2
SKIP2:
FOR TB% = 1 TO 17
  AEX(TB%) = AEX / C%
  AEY(TB%) = AEY / C%
  CEX(TB%) = CEX / C%
  CEY(TB%) = CEY / C%
  VEX(TB%) = SQR(VEX / C%)
  VEY(TB%) = SQR(VEY / C%)
  EX(TB%) = SQR(CEX(TB%) ^ 2 + VEX(TB%) ^ 2
  EY(TB%) = SQR(CEY(TB%) ^ 2 + VEY(TB%) ^ 2
  RMS(TB%) = RMS / C%
  RMSVE(TB%) = SQR(VEX(TB%) ^ 2 + VEY(TB%) ^ 2
  AMT(TB%) = (MT / C%) * 1000
  MTSD(TB%) = SQR(MTSD / C%) ^ 1000
NEXT TB%
'*************** PRINT OUT ***************
LPRINT ; LPRINT "SUBJECT : "; N$ ; LPRINT
LPRINT "TB", "AEX(X)", "CE(X)", "VE(X)", "E(X)"
FOR TB% = 1 TO 17
  LPRINT USING "###.##
  TB%; AEX(TB%); CEX(TB%); VEX(TB%); EX(TB%)
NEXT TB%
LPRINT
LPRINT "TB", "AEX(Y)", "CE(Y)", "VE(Y)", "E(Y)"
FOR TB% = 1 TO 17
  LPRINT USING "###.##
  TB%; AEY(TB%); CEY(TB%); VEY(TB%); EY(TB%)
NEXT TB%
LPRINT
LPRINT "TB", "RMS", "RMSVE", "AveMT", "MTSD"
FOR TB% = 1 TO 17
    LPRINT USING "###.## T B % ; RMS(TB%); RMSVE(TB%); AMT(TB%); MTSD(TB%)
NEXT TB%
LPRINT
END

**********************************************************************
***** Trial delay experiment *****
Programmed by Hiro
**********************************************************************
DECLARE FUNCTION BinStr2Bin% (B$)
DECLARE SUB Mouse (ml%, m2*, m3*, m4*)
DECLARE SUB MOUSERANGE (xl%, yl*, x2%, y2*)
DECLARE SUB MouseInstall (mflag*)
DECLARE SUB MouseNow (leftButton*, rightButton%, XMUSE%, YMOUSE%)
SCREEN 8: CLS : COLOR 11
MouseInstall mflag*
MOUSERANGE 4, 4, 635, 195
DIM X(250) AS INTEGER, Y(250) AS INTEGER
DIM TAR(300) AS INTEGER, MOU(300) AS INTEGER
DIM MT(250)
CLS : CIRCLE (5, 5), 4, 10: GET (1, 1)-(9, 9), TAR: CLS
LINE (1, 5)-(9, 5), 12
LINE (5, 3)-(5, 7), 12: LINE (4, 3)-(4, 7), 12: LINE (6, 3)-(6, 7), 12
GET (1, 1)-(9, 9), MOU
'******* DATA FILE ******
CLS : INPUT "NAME"; N$
INPUT "DAY (1, 2, or 3) "; DAY*
IF DAY* = 1 THEN
    GOTO DAY1
ELSEIF DAY* = 2 THEN
    GOTO DAY2
ELSE
    GOTO DAY3
END IF
OPEN "A:" + N$ + ".DAT" FOR OUTPUT AS #1: CLOSE #1: CLS
DAY1:
PREERR = 0
FOR TR% = 1 TO 85
    GOSUB TRIAL
    IF TR% = 85 AND COND% = 2 THEN GOSUB LAST2KR
    IF TR% = 5 OR TR% = 45 THEN GOSUB BREAK
NEXT TR%
CLS : LOCATE 10, 20: PRINT "Thank you very much! See you tomorrow!"
END
**************************************************************************
DAY2:
INPUT "No delay --> 1 or Delay --> 2 "; COND%; CLS
FOR TR% = 86 TO 210
    GOSUB TRIAL
    IF TR% = 170 AND COND% = 2 THEN GOSUB LAST2KR
    IF TR% = 90 OR TR% = 130 OR TR% = 170 THEN GOSUB BREAK
NEXT TR%
CLS : LOCATE 10, 25: PRINT "Thank you very much! See you tomorrow!"
END
**************************************************************************
DAY3:
FOR TR% = 211 TO 250
    GOSUB TRIAL
NEXT TR%
CLS : LOCATE 10, 25: PRINT "Thank you very much!"
END

************** KEYSUB ****************************
KEYSUB:
    FL% = 1
RETURN

************** SHORT BREAK (30-SEC) **************
BREAK:
    T5 = TIMER
    LOCATE 10, 20: PRINT "Let's have a 30-sec break!"
    IF TR% = 5 THEN PRINT CINT(PREERR / 5)
    IF TR% = 5 THEN INPUT "No delay ---> 1 or Delay ---> 2 "; COND%
    DO
        LOOP UNTIL TIMER - T5 > 30
    BEEP
RETURN

************** LAST 2 KR ***********************
LAST2KR:
    T4 = TIMER
    LOCATE 1, 35
    PRINT "Error (Trial #"; TR% - 1; ") = "; CINT(SQR(((320 - X(TR% - 1)) * .3125)
        CIRCLE (320, 80), 8, 10
    PUT (X(TR% - 1) - 4, Y(TR% - 1) - 4), MOU, XOR
    DO
        LOOP UNTIL TIMER - T4 > 3
    CLS
    DO
        LOOP UNTIL TIMER - T4 > 10
    T4 = TIMER
    LOCATE 1, 35
    PRINT "Error (Trial #"; TR%; ") = "; CINT(SQR(((320 - X(TR%)) * .3125) * 2 +
        CIRCLE (320, 80), 8, 10
    PUT (X(TR%) - 4, Y(TR%) - 4), MOU, XOR
    DO
        LOOP UNTIL TIMER - T4 > 3
    CLS
RETURN

************** TRIAL LOOP ****************************
TRIAL:
    FL% = 0: ON KEY(1) GOSUB KEYSUB: KEY(1) ON
CLS
T1 = TIMER
PRINT "Trial "; TR%
PRINT "Locate the pen to the start position and push down"
    PUT (320 - 4, 180 - 4), TAR, XOR
    DO
        MouseNow leftButton%, rightButton%, XMOUSE%, YMOUSE%
        LOOP UNTIL ABS(YMOUSE% - 180) < 30
        DO
            PUT (320 - 4, 180 - 4), TAR, XOR
            MouseNow leftButton%, rightButton%, XMOUSE%, YMOUSE%
            PUT (XMOUSE% - 4, YMOUSE% - 4), MOU, XOR
            FOR T% = 1 TO 200: NEXT T%
            'LOCATE 1, 1: PRINT "X="; XMOSUE%
            'LOCATE 2, 1: PRINT "Y="; YMOUSE%
            PUT (320 - 4, 180 - 4), TAR, XOR
    DO
PUT (XMOUSE% - 4, YMOUSE% - 4), MOU, XOR
FOR T% = 1 TO 200: NEXT T%
LOOP UNTIL leftButton% = -1
CLS
PRINT "Trial #"; TR%
PRINT "Move the pen to the target"
CIRCLE (320, 80), 8, 10
DO
MouseNow leftButton%, rightButton*, XMOUSE*, YMOUSE%
LOOP UNTIL leftButton% = 0
MI = TIMER
DO
MouseNow leftButton%, rightButton*, XMOUSE%, YMOUSE%
LOOP UNTIL leftButton% = -1
MT = TIMER
'IF MT - MI > 1 OR MT - MI < .5 THEN GOTO CANCEL
X(TR%) = XMOUSE%: Y(TR%) = YMOUSE%: MT(TR%) = MT - MI
T2 = TIMER
CLS
*************** error for pretest ***************
IF TR% < 6 THEN PREERR = PREERR + CINT(SQR(((320 - X(TR%)) * .3125) ^ 2 + ((80 - Y(TR%)) * .8)^2))
IF TR% < 6 THEN GOTO NOKR
IF TR% > 85 AND TR% < 91 THEN GOTO NOKR
IF TR% > 170 THEN GOTO NOKR
DO
LOOP UNTIL TIMER - T2 > 1
IF Cond% = 2 THEN GOTO DELAYKR
LOCATE 1, 33
PRINT "Error = "; CINT(SQR(((320 - X(TR%)) * .3125) ^ 2 + ((80 - Y(TR%)) * .8)^2))
CIRCLE (320, 80), 8, 10
PUT (X(TR%) - 4, Y(TR%) - 4), MOU, XOR
GOTO POSTKR
DELAYKR:
IF TR% = 6 OR TR% = 7 THEN GOTO POSTKR
IF TR% = 91 OR TR% = 92 THEN GOTO POSTKR
LOCATE 1, 27
PRINT "Error (Trial #") TR% - 2; "); CINT(SQR(((320 - X(TR% - 2)) * .3125
CIRCLE (320, 80), 8, 10
PUT (X(TR% - 2) - 4, Y(TR% - 2) - 4), MOU, XOR
POSTKR:
DO
LOOP UNTIL TIMER - T2 > 4
CLS
NOKR:
DO
LOOP UNTIL TIMER - T2 > 4
DO
LOOP UNTIL TIMER - T1 > 10
IF F1% = 1 THEN GOTO TRIAL
OPEN "A:\" + N$ + ".DAT" FOR APPEND AS #1
WRITE #1, X(TR%), Y(TR%), MT(TR%)
CLOSE #1
RETURN
CANCEL:
TC1 = TIMER
CLS : LOCATE 15, 20
IF MT - MI > .75 THEN
PRINT "Cancelled! Move the pen faster!": BEEP BEEP
ELSE IF MT - MI < .5 THEN
PRINT "Cancelled! Move the pen slower!": BEEP BEEP
END IF
DO
LOOP UNTIL TIMER - TC1 > 4
CLS
GOTO TRIAL

' ** Name: MouseInstall **
' ** Type: Subprogram **
' ** Module: MOUSSUBS.BAS **
' ** Language: Microsoft QuickBASIC 4.00 **
'******************************************************************************

' Determines whether mouse is available and resets all mouse parameters.

' EXAMPLE OF USE: MouseInstall mflag%
' PARAMETERS: mflag% Returned indication of mouse availability
' VARIABLES: (none)
' MODULE LEVEL
' DECLARATIONS: DECLARE SUB Mouse (ml%, m2%, m3%, m4%)
' DECLARE SUB MouseInstall (mflag%)
' SUB MouseInstall (mflag%) STATIC
  mflag% = 0
  Mouse mflag%, 0, 0, 0
END SUB

'******************************************************************************

** Name: MouseNow **
** Type: Subprogram **
** Module: MOUSSUBS.BAS **
** Language: Microsoft QuickBASIC 4.00 **

Returns the instantaneous state of the mouse.

' EXAMPLE OF USE: MouseNow leftButton%, rightButton%, xMouse%, yMouse%
' PARAMETERS: leftButton% Indicates left mouse button state
            rightButton% Indicates right mouse button state
            xMouse% X location of mouse
            yMouse% Y location of mouse
' VARIABLES: m2% Mouse driver parameter containing button press information
' MODULE LEVEL
' DECLARATIONS: DECLARE SUB Mouse (ml%, m2%, m3%, m4%)
' DECLARE SUB MouseNow (leftButton%, rightButton%, xMouse%, yMouse%)
' SUB MouseNow (leftButton%, rightButton%, xMouse%, yMouse%) STATIC
  Mouse 3, m2%, xMouse%, yMouse%
  leftButton% = ((m2% AND 1) <> 0)
  rightButton% = ((m2% AND 2) <> 0)
END SUB

'******************************************************************************

** Name: MouseRange **
** Type: Subprogram **
** Module: MOUSSUBS.BAS **
** Language: Microsoft QuickBASIC 4.00 **
**Sets mouse range of motion.**

**EXAMPLE OF USE:**

```
PARAMETERS:
  xl%  Upper left corner X coordinate
  yl%  Upper left corner Y coordinate
  x2%  Lower right corner X coordinate
  y2%  Lower right corner Y coordinate
```

**VARIABLES:**

```
MOUSERANGE (xl%, yl%, x2%, y2%) STATIC
  Mouse 7, 0, xl%, x2%
  Mouse 8, 0, yl%, y2%
```

**DESIGN**

```
DECLARE SUB Mouse (m1%, m2%, m3%, m4%)
DECLARE SUB MouseRange (xl%, yl%, x2%, y2%)
```

```
SUB MOUSERANGE (xl%, yl%, x2%, y2%) STATIC
  Mouse 7, 0, xl%, x2%
  Mouse 8, 0, yl%, y2%
END SUB
```

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**Dave's trial delay experiment**

```
DIM X(250) AS INTEGER, Y(250) AS INTEGER
DIM MT(250)
DIM AEX(50), AEXY(50), CEX(50), CEY(50), VEX(50), VEY(50)
DIM EX(50), EY(50), RMS(50), RMSVE(50)
DIM AMT(50), MTS(50)
CLS
INPUT "SUBJECT NAME"; N$
OPEN "A:" + N$ + ".DAT" FOR INPUT AS #1
FOR TR% = 1 TO 250
  INPUT #1, X(TR%), Y(TR%), MT(TR%)
NEXT TR%
CLOSE #1
FOR TB% = 1 TO 5
  C% = 0: AEX = 0: AEXY = 0: CEX = 0: CEY = 0: SX = 0: SY = 0: RMS = 0
  VEX = 0: VEY = 0: RMSVE = 0: CEXX = 0: CEYY = 0: MT = 0: MTS = 0
  FOR T% = 1 TO 5
    TR% = (TB% - 1) * 5 + T%
    IF Y(TR%) > 180 - 37.5 THEN GOTO SKIP1
    C% = C% + 1
    AEX = AEX + ABS(X(TR%) - 320) * .3125
    AEXY = AEXY + ABS(80 - Y(TR%)) * .8
    CEX = CEX + (X(TR%) - 320) * .3125
    CEY = CEY + (80 - Y(TR%)) * .8
    CEEX = CEEX + X(TR%)
    CEYY = CEYY + Y(TR%)
    SX = SX + X(TR%)
    SY = SY + Y(TR%)
    RMS = RMS + SQRT(((X(TR%) - 320) * .3125) ^ 2 + ((80 - Y(TR%)) * .8) ^ 2)
    MT = MT + MT(TR%)
  NEXT T%
  SKIP1:
  FOR T% = 1 TO 5
    TR% = (TB% - 1) * 5 + T%
    IF Y(TR%) > 180 - 37.5 THEN GOTO SKIP2
    VEX = VEX + ((X(TR%) - SX / C%) * .3125) ^ 2
    VEY = VEY + ((Y(TR%) - SY / C%) * .8) ^ 2
```

---
MTSD = MTSD + (MT(TR%) - MT / C%)^2

SKIP2:
NEXT T%

AEX(TB%) = AEX / C%
AEX(TB%) = AEX / C%
CEX(TB%) = CEX / C%
CEY(TB%) = CEY / C%
VEX(TB%) = SQR(VEX / C%)
VEY(TB%) = SQR(VEY / C%)
EX(TB%) = SQR(CEX(TB%)^2 + VEX(TB%)^2)
EY(TB%) = SQR(CEY(TB%)^2 + VEY(TB%)^2)
RMS(TB%) = RMS / C%
RMSVE(TB%) = SQR(VEX(TB%)^2 + VEY(TB%)^2)
AMT(TB%) = (MT / C%) * 1000
MTSD(TB%) = SQR(MTSD / C%) * 1000

NEXT TB%

'*********** PRINT OUT **********************
LPRINT : LPRINT "SUBJECT : "; NS; LPRINT
LPRINT "TB", "AEX(X)", "CE(X)", "VE(X)", "E(X)"
FOR TB% = 1 TO 50
  IF TB% = 2 OR TB% = 18 OR TB% = 19 OR TB% = 35 OR TB% = 43 THEN LPRINT
  LPRINT USING "###.##"; TB%; AEX(TB%); CEX(TB%); VEX(TB%); EX(TB%)
NEXT TB%

FOR I% = 1 TO 2: LPRINT : NEXT I%
LPRINT "SUBJECT : "; NS; LPRINT
LPRINT "TB", "AEX(Y)", "CE(Y)", "VE(Y)", "E(Y)"
FOR TB% = 1 TO 50
  IF TB% = 2 OR TB% = 18 OR TB% = 19 OR TB% = 35 OR TB% = 43 THEN LPRINT
  LPRINT USING "###.##"; TB%; AEY(TB%); CEY(TB%); VEY(TB%); EY(TB%)
NEXT TB%

FOR I% = 1 TO 2: LPRINT : NEXT I%
LPRINT "SUBJECT : "; NS; LPRINT
LPRINT "TB", "RMS", "RMSVE", "AveMT", "MTSD"
FOR TB% = 1 TO 50
  IF TB% = 2 OR TB% = 18 OR TB% = 19 OR TB% = 35 OR TB% = 43 THEN LPRINT
  LPRINT USING "####.##"; TB%; RMS(TB%); RMSVE(TB%); AMT(TB%); MTSD(TB%)
NEXT TB%
LPRINT
END
Appendix M

Stress/Strain Characteristics of the Spring used in Chapter 3 Experiments
Spring Stiffness

Figure M.1. Stress/strain characteristics of the spring used in Chapter 3 experiments.
Appendix N

Representative Sample of Responses to Questionnaire
in Chapter 3 Experiment 3

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1. What cues (e.g., final hand position, movement distance, movement time, spring tension) did you use to make your movements more accurate during practice?

The tension in the elastic and the distance and relative direction from the start point. I found the target to be slightly to the left (or that's what it felt like to me).

2. Did the cues that you used change with practice?

Not really; at first I was just stabbing at the target, but when I paid attention to the elastic and direction I got closer.

3. How well could you remember and use the movement cues when feedback was withdrawn?

I felt like I could remember in general, but without the feedback I couldn't be sure.

4. Did the spring help or hinder you in this task?

Most definitely helped.

5. Do you think you performed accurately when feedback was withdrawn?

Not really. About as accurately as I could, going by memory.
M.N. Delay-O

1. What cues (e.g., final hand position, movement distance, movement time, spring tension) did you use to make your movements more accurate during practice?
   I used the distance error to correct and the spring tension to correct my guesses.

2. Did the cues that you used change with practice?
   No

3. How well could you remember and use the movement cues when feedback was withdrawn? I used the spring tension when there was no feedback.

5. Do you think you performed accurately when feedback was withdrawn?
   Not sure

4. Did the spring help or hinder you in this task?
   The spring helped me.
1. What cues (e.g., final hand position, movement distance, movement time, spring tension) did you use to make your movements more accurate during practice? The quicker I responded the more accurate I was. The spring tension helped.

2. Did the cues that you used change with practice? No.

3. How well could you remember and use the movement cues when feedback was withdrawn? I think I did fine by using the same cues.

4. Did the spring help or hinder you in this task? It helped because it gave me a tension reference.

5. Do you think you performed accurately when feedback was withdrawn? I don't know.
C. V. DÉLANY-Z

1. What cues (e.g., final hand position, movement distance, movement time, spring tension) did you use to make your movements more accurate during practice?
   - Tension from the rubber band a major component.
   - Movement of my hand assessed by timing and feedback from rubber band.
   - Lateral movements only slightly altered from feedback.

2. Did the cues that you used change with practice?
   Picked up more cues as I went along but used combination of these cues as I progressed.

3. How well could you remember and use the movement cues when feedback was withdrawn?
   Could remember the cues but didn't know how accurate they were.

4. Do you think you performed accurately when feedback was withdrawn?
   Yes, but probably made same mistakes as did in practice.

4. Did the spring help or hinder you in this task?
   Help.
M.H.  DELAY-Z

1. What cues (e.g., final hand position, movement distance, movement time, spring tension) did you use to make your movements more accurate during practice?
   I tried to use movement distance, movement time, and spring tension to make my movements more accurate. I found that movement time worked more accurately for me and spring tension did not work at all.

2. Did the cues that you used change with practice?
   I would experiment with different cues every now and then but movement time was used the most.

3. How well could you remember and use the movement cues when feedback was withdrawn?
   Not that well because I counted on the feedback to tell me whether or not I was moving in a straight line. I believe I remembered well enough to get into the vicinity of the target w/o passing it.

5. Do you think you performed accurately when feedback was withdrawn?
   Not as accurately as I had when given feedback.

4. Did the spring help or hinder you in this task?
   The spring hindered my performance because I could not get used to the tension produced when I moved and I could not measure it to help my movements become more accurate.
1. What cues (e.g., final hand position, movement distance, movement time, spring tension) did you use to make your movements more accurate during practice?
   Movement distance, spring tension, elbow distance from the edge of the table

2. Did the cues that you used change with practice?
   Yes - when I first started I was using movement distance then I started to add some of the other cues I mentioned.

3. How well could you remember and use the movement cues when feedback was withdrawn?
   I used the cues pretty much the same as when I was getting the delayed feedback.

4. Did the spring help or hinder you in this task?
   It helped because I used it as a cue.

5. Do you think you performed accurately when feedback was withdrawn?
   No -
Vita

David Ian Anderson was born on the 21st of December, 1965 in Melbourne, Australia. The family moved to Sydney shortly thereafter, where David attended primary and infants school in Seaforth and later completed his high school years at Pittwater House Grammar School in Collaroy. In 1987, David graduated from Kuring-gai College of Advanced Education with a Bachelor's Degree in Physical Education. A year later, he moved out to the United States to attend graduate school at California State University, Long Beach (CSULB) and was awarded a Master of Arts in Physical Education in 1990. From there, David moved to Louisiana to continue graduate school in the Department of Kinesiology at Louisiana State University. On the 6th of June, 1992 David married Suzanne Torre from Modesto, California. The couple had met previously while attending CSULB. Sue and David lived in Louisiana for two years and are presently living in Modesto, California.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: David Ian Anderson

Major Field: Kinesiology

Title of Dissertation: The Relationship Between Intrinsic and Augmented Feedback in Motor Skill Learning

Approved:

Richard A. McAllister
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September 26, 1994