Summary fading knowledge of results (Kr): Test for the dynamic acquisition protocols

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SUMMARY FADING KNOWLEDGE OF RESULTS (KR):
TEST FOR THE DYNAMIC ACQUISITION PROTOCOLS

by

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Bachelor of Education
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1984

A thesis submitted in partial fulfillment
of the requirements for the degree of

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[Signatures of Examination Committee Members and Faculty Representative]
ABSTRACT

Summary Fading Knowledge of Results (KR): Test for Dynamic Acquisition Protocols

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The primary purpose of this study was to examine the effects of dynamic acquisition protocols by comparing dynamic and static KR schedules in a single experiment. Five groups of participants (n = 13 per group) completed 90 acquisition trials of a force production task. The analysis of delayed no-KR retention test revealed that the participants in the summary fading KR group performed better than the three static KR groups, indicating that the dynamic acquisition protocols produces more efficient learning than static acquisition protocols. This finding is interpreted as support for Adams’ theory (1971) that the most appropriate acquisition protocol would be one that dynamically manipulates KR from higher frequency at beginning to lower frequency toward the end of the practice. However, the failure in finding the learning effect of reduced KR in this experiment is inconsistent with the conclusion of the previous studies (Guadagnoli et al., 1996, Winstein & Schmidt, 1990). The reasons for this discrepancy are discussed and the future directions are provided.
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CHAPTER I

INTRODUCTION

It is widely recognized that augmented feedback is one of the most important determinants of motor skill learning. In research circles, augmented feedback is known as Knowledge of Results (KR). KR is verbal (or verbalizable), terminal (i.e., postmovement) feedback about the outcome of the movement in terms of the environmental goal (Schmidt & Lee, 1999). The importance of KR in human motor performance and learning has been evidenced by various studies of motor learning in recent decades (see KR reviews of Adams, 1987; Salmoni, Schmidt, & Walter, 1984). Early studies of motor learning (Bilodeau & Bilodeau, 1958; Bilodeau & Schumsky, 1959; Newell, 1974; Trowbridge & Cason, 1932) demonstrated that nearly any variation that increased the amount, precision, and/or frequency of KR improved performance. These studies suggested that increased levels of KR during practice would benefit learning.

Learning is defined as a relatively permanent change in human behavior. In addition to its ability to facilitate learning, KR also produces some momentary, transient effects. A retention or transfer test design is commonly used in motor learning studies to separate these transient effects of KR manipulations from the relatively permanent effects (learning) (Salmoni et al., 1984). One problem of early studies of KR, such as the Bilodeau and Bilodeau studies (1958), is that they did not employ retention or transfer
tests to separate temporary performance changes (e.g., guidance, motivation) from relatively permanent changes. Therefore the conclusions about learning drawn from these experiments are suspect.

Recent evidence from several studies using reduced KR paradigms demonstrated that increasing the frequency, precision, or amount of KR increased practice performance, but these manipulations were less effective at increasing performance (learning) during a retention test without KR. Thus there appears to be an acquisition/retention paradox (Guadagnoli, in press). That is, performance during acquisition (practice trials) is not necessarily indicative of retention performance (learning). The KR paradigms used in previous studies included bandwidth KR (Lee & Carnhan, 1990; Sherwood, 1988), faded KR (Winstein & Schmidt, 1990; Wulf & Schmidt, 1989), summary KR (Guadagnoli, Dornier, & Tandy 1996; Gable, Shea & Wright, 1991; Schmidt, Young, Swinnen & Shapiro, 1989, Schmidt, Lange & Young, 1990; Lavery & Suddon, 1962), and average KR (Yao, Fischman & Wang, 1994; Young & Schmidt, 1992).

In 1984 Salmoni et al. proposed the guidance hypothesis to explain the learning effect of reduced KR paradigms. This hypothesis states that a high frequency of KR during practice guides and directs the learner's performance, resulting in good performance during acquisition. But this guidance role of KR causes the learner to rely on KR too heavily (it becomes a "crutch") so that the learner fails to engage in some important learning activities, such as intrinsic information processing and error detection, which are needed to maintain performance during the retention or transfer tests without KR.
Summary KR, defined as information about a set of performance trials presented after the set is completed (Schmidt & Lee, 1999), is one of the most popular KR manipulations investigated in recent motor learning studies. Summary KR is not a new idea; it can be traced back more than thirty years to Lavery (1962), who was the first to study summary KR. From his results Lavery concluded that the summary KR condition was more effective for learning than the immediate KR condition (where KR is provided after each trial).

Having recognized the effectiveness of summary KR in motor learning, researchers attempted to find the optimal length of summary KR. Schmidt, Young, Swinnen, and Shapiro (1989) studied summary KR lengths of 1 (immediate KR), 5, 10, and 15 trials during acquisition, with a no KR retention test after 48 hours. The task employed was a relatively simple arm movement task where the goal was to make a certain movement pattern in 1000 ms. The results showed all groups improved performance across practice, while increased summary lengths clearly degraded practice performance. However, in a 48 hour delayed retention test without KR, the performance of the experimental groups was the opposite of their performance during acquisition. That is, the 15 KR group showed the best performance and the immediate KR group was the worst. One year later Schmidt, Lange, and Young (1990) completed a similar experiment with the same KR schedules. The only difference was that they used a relatively complex ballistic timing task instead of the simple task employed in the previous experiment. Once again, increasing the summary length of KR depressed performance during acquisition, but in the delayed retention test without KR the 5 KR group performed best, followed by the immediate KR, the 10 KR, and the 15 KR groups. Based on these two
experiments, Schmidt et al. (1990) concluded that there is no universal optimal summary length of KR. The optimal summary length is dependent upon the complexity of the task. In general, a longer summary length KR is better for simple tasks, while a shorter summary length KR works better for complex tasks. The optimal length appears to vary inversely with task complexity.

In 1996, Guadagnoli et al. extended Schmidt’s et al. conclusion by suggesting that the optimal length of summary KR is dependent not only upon the complexity of the task, but also upon the level of the learner’s experience. In their study, Guadagnoli et al. conducted two experiments to examine the relationship between the optimal summary length, the complexity of the task, and the level of the learner’s experience. In Experiment 1 the results showed that, as the learner receives more practice, the optimal summary KR length increases. A novice individual performs better during both acquisition and retention if given a shorter KR summary length. As the learner becomes more proficient, a shorter summary length continues to enhance performance in the acquisition phase but degrades performance in the retention test. These results led to the conclusion that when the task is consistent, the longer summary KR length produces superior retention performance for experienced individuals and inferior retention performance for novices. Their second experiment exhibited the interaction between task complexity and the level of the learner’s experience, and how this interaction must be used to determine the optimal summary length of KR. It was found that under short, medium and long KR summary lengths, experienced subjects performing a complex task behaved the same as inexperienced subjects performing a simple task. That is, the relative task difficulty for an experienced individual performing a complex task is similar to that
of a novice performing a simple task. They concluded that the task complexity together with the learner's experience level determines the relative difficulty of the task, and the relative difficulty of the task may be the most important determinant of the optimal length of summary KR. When a person is learning a new skill, the relative task difficulty is dependent on the learner's performance level because the (absolute) task complexity is constant throughout practice. With practice, however, the relative task difficulty decreases because the learner's ability increases. Therefore, to keep the relative task difficulty constant throughout acquisition, the complexity of the task should increase as the learner becomes more proficient (in terms of KR, the frequency of KR provided to the learners should decrease). Accordingly, practice organization should be adjusted as the learner's performance improves. The acquisition protocol should not be static; it should be changed as the learner progresses. This is called dynamic acquisition protocols. This idea has been suggested several times (cf. Adams, 1971) but has rarely been modeled or tested.

Even though reduced KR such as summary KR, average KR, and bandwidth KR produces a better learning effect in some situations than does immediate KR, these manipulations are static manipulations of KR because the KR trials are evenly distributed throughout the acquisition phase. This may not be the best way to produce learning according to dynamic acquisition protocols. Fading KR, in which the frequency of KR provided to the learner is systematically decreased throughout the practice, accords better with the dynamic acquisition protocols. In 1990 Winstein and Schmidt completed an experiment using relative fading KR. In their experiments, KR presented to the fading KR group was progressively decreased from 100% to 25% throughout practice (i.e., as
learner proficiency increased). The results showed that the relative fading KR group produced more accurate performance on a delayed no KR retention test than the immediate KR group.

However, in the Weinstein and Schmidt study, the reduced frequency and dynamic features were confounded. The fading KR manipulated in their experiment was not only a dynamic KR schedule but also one of the reduced frequency KR schedules. So it is difficult to determine if the learning effect was due to the reduced frequency of KR or to the dynamic acquisition protocols.

The current study was based on the experimental designs of Schmidt et al. (1989) and Guadagnoli et al. (1996). The immediate KR, 5 KR, and 15 KR conditions used in the current study were the same KR conditions employed in their studies. Two additional dynamic KR schedules (summary fading KR and reverse summary fading KR) were used in the current study. By comparing both static and dynamic acquisition protocols manipulated in a single experiment, the current study not only separates the role of dynamic acquisition protocols from the role of reduced frequency of KR, but also examines the learning effect of the dynamic acquisition protocols.
CHAPTER 2

LITERATURE REVIEW

Introduction

Knowledge of results (KR) is extrinsic feedback, which has been defined as verbalized post-response information about the outcome of the response in the environment (Schmidt & Lee, 1999). Research suggests that KR is an important variable in the process of learning motor skills. Failure to provide KR generally leads to markedly degraded learning or to no learning in some cases where learners cannot detect their own errors reliably.

KR’s critical role in motor learning can be illustrated in three ways. First, KR is a primary source of information that can be used to correct performance errors made during any given practice attempt (the guidance role). During motor learning, performers compare this information with an internal reference of correctness and make necessary adjustments to generate a new and more accurate response on the next attempt. Second, KR reinforces the correct portion of the response. KR not only provides information about errors in the response, it also tells the performers what parts of the response are correct. Third, KR provides a source of motivation for the learner. KR can make the task seem more interesting, causing the learner to try harder and to expend more effort and attention on the task.
Many researchers have studied KR variables to determine the most effective manipulations of KR. The variables investigated in KR studies mainly include the nature of KR, the frequency of KR, and the temporal locus of KR.

**Precision of KR**

Precision of KR refers to the accuracy of the information provided to the learner. Two kinds of KR information can be provided, quantitative and qualitative. The former refers to the numerical amount of error, the magnitude of the error (e.g., "3 cm left of target" or "5 seconds too fast "). The latter provides only a general description of the error without numerical information (e.g., "too fast,” "left,” or "wrong"). Studies on these topics (Trowbridge & Cason, 1932; Bennett & Simmons, 1984) revealed that performers who received quantitative KR performed more accurately and learned more than those who received qualitative KR. Early studies found that the more precise the KR the more learning occurred. But studies since Trowbridge and Cason have demonstrated that increasing the precision of KR increases performance up to a point, but further increases in precision do not improve performance significantly (Rogers, 1974; Salmoni, Rose, Dill, & Zoeller, 1983). The precision of KR is related to the amount of KR information that must be processed. Too little precision may impede learning because it gives the learner insufficient information on which to base the next movement. Too much precision may degrade learning by leading the learner to focus on errors that are beyond the learner’s ability to control while ignoring errors that could be corrected. Also, the question of KR precision cannot be answered without taking into account the performer’s stage of learning. Magill and Wood (1986) manipulated two groups with
different levels of KR precision in their experiments. They found that both groups
demonstrated a similar amount of error during the early practice trials. During the later
practice trials, however, the group receiving the more precise information feedback began
to perform significantly better than the group receiving the less precise information
feedback. On the basis of their findings, Magill and Wood suggested that more precise
feedback should be withheld until the learner has had enough practice on a task to benefit
from detailed information. During the early stages of learning it may be more beneficial
to provide general (less precise) information about the learner's performance until the
skill level of the performer and his knowledge of the skill's dynamics improves.

Frequency of KR

How often should KR be presented to maximize learning? In the KR research
literature, this question is considered first with regard to the absolute and relative
frequency of KR. Absolute frequency refers to the total number of times in a learning
sequence that KR is provided to the learner. Relative frequency is the absolute frequency
of KR divided by the total number of trials. Bilodeau and Bilodeau (1958) were the first
to investigate this issue. In their experiment, which used an arm positioning task, four
different groups received KR according to the following schedule: (1) after every trial,
(2) after every third trial, (3) after every fourth trial, and (4) after every tenth trial. In this
case, all groups received KR ten times (the same absolute frequency), but the number of
practice trials differed for each group (10, 30, 40, and 100 trials). The results showed that
even though the groups differed greatly in terms of the relative frequency of KR (100%,
33%, 25%, 10%), when the absolute frequency was equated the groups did not differ in
performance. This suggested that the most important aspect of KR in this experiment was the absolute frequency, and the relative frequency of KR was unimportant. The problem with the Bilodeau and Bilodeau (1958) experiment is that retention tests were not used to separate the temporary effects (called performance effects) of KR manipulations from the relatively permanent effects (called learning effects). Salmoli et al. (1984) believed that a no KR retention test after acquisition is the best way to separate performance effects from learning effects. Different conclusions may be drawn when learning is measured by performance on a no KR retention test. The studies of Ho and Shea (1978), Johnson et al. (1981), and Baird and Hughes (1972) employed no KR retention tests to measure learning. The findings of these studies differed from that of Bilodeau and Bilodeau in that the groups with the smallest relative frequencies of KR had the most accurate performance. These studies demonstrated that reduced relative frequency of KR increased learning and suggested that the relative frequency of KR is an important variable for learning. Several recent studies, such as experiment 1 in Weinstein and Schmidt's study (1990) and Wulf and Schmidt's study (1989), support this conclusion.

Extending this line of research, recent studies have investigated the effects of other variations of the reduced frequency of KR. Sherwood (1988) was one of the first researchers to study bandwidth KR. In studies of bandwidth KR, KR is provided only if the learner's errors are outside some predefined band (limit) of correctness. If the error is within the error band, no KR is provided, which indicates to the learner that performance was acceptable. In Sherwood's study, subjects in three different KR conditions tried to learn a rapid elbow flexion movement in as close to 200 ms (target timing) as possible.
In the 0% bandwidth condition, information about movement time was given after every trial; in the 5% bandwidth and 10% bandwidth conditions, information about movement time was given only if the responses were 5% (10 ms) or 10% (20 ms) slower or faster than the target time (200 ms). The results demonstrated that, even though there was no significant difference on acquisition performance for the three conditions, the 10% bandwidth condition produced the best performance on a no KR retention test. Because KR is withheld on acquisition trials for which the performance is relatively correct, bandwidth KR reduces the relative frequency of KR and produces better learning than the KR condition that provides KR after every trial. Similar results have also been reported by Lee and Carnhan (1990a), Reeve, Dornier, and Weeks (1990), and Butler, Reeve, and Fischman (1996).

An alternative method of reducing the frequency of KR is known as faded KR. Faded KR provides a higher frequency of KR early in practice and lower frequencies of KR later in practice. Winstein and Schmidt (1990) conducted one of the most often cited experiments on the learning effect of faded KR. In their experiment 2, the two treatment groups differed in the frequency of KR presentation during the acquisition phase. One group received KR following each trial (100% KR), while the other group (fading KR group) received KR after every trial (100%) at the beginning of the practice, and then progressively less often until the frequency was 25% at the end of practice. The results showed no KR frequency effects during acquisition and on the no KR immediate retention test, but the fading KR group produced performed more accurately than the 100% KR group on a delayed no KR retention test.
In the summary KR method, KR is withheld from the learners for a block of trials and then is presented after the last trial in the block is completed. The learners receive KR about their performance on every trial, but cannot use this information to adjust performance until the entire block of trials is completed. The original summary KR study was completed by Lavery (1962) over 35 years ago. He studied three conditions across 6 days of acquisition: (1) summary KR presented after a block of 20 trials, (2) immediate KR presented after every trial, and (3) a combination of the two conditions, where the summary KR was given in addition to immediate KR. During the acquisition phase the summary KR group committed more errors than either the immediate or both conditions groups. But in the delayed no KR retention test, the summary KR group maintained its acquisition phase performance, whereas the immediate and both conditions groups displayed considerable decline in performance from the acquisition phase. The summary KR condition was more effective for learning than either the immediate KR and both conditions.

Extending the early work of Lavery, researchers searched for the optimal number of trials to summarize. In 1989 Schmidt, Young, Swinnen, and Shapiro conducted an experiment in which four different summary KR schedules were evaluated with a simple ballistic linear slide reversal task. These schedules were: (1) immediate KR provided after each trial, (2) 5 KR (summary KR provided after each block of 5 trials), (3) 10 KR (summary KR provided after each block of 10 trials), and (4) 15 KR (summary KR provided after each block of 15 trials). In the acquisition phase when each group was given KR according to its own KR schedule, all groups showed improvement in performance across practice, while increased summary lengths clearly degraded
performance. However, in the 48 hour delayed retention test without KR, the performance of the experimental groups was the opposite of performance during acquisition, with the 15 KR group showing the best performance and the immediate KR group being the worst. One year later Schmidt, Lange, and Young (1990) completed a similar experiment with the same KR schedules, but using a relatively complex ballistic timing task instead of the simple task employed in the previous experiment. Once again, increasing the summary length of KR depressed performance in the acquisition phase. However, on the delayed retention test without KR, the 5 KR group performed best, followed by the immediate KR, the 10 KR, and the 15 KR groups. Based on these two experiments Schmidt et al. (1990) concluded that there is no one optimal summary length of KR. The optimal length is dependent upon the complexity of the task. In general, longer summary length KR is better for simple tasks, and shorter summary length KR works better for complex tasks. The optimal summary length might vary inversely with task complexity.

The optimal length is also dependent upon the learner's ability. In 1996 Guadagnoli et al. conducted two experiments to examine the relationship between optimal summary KR length, the complexity of the task, and the level of the learner's ability. In experiment 1 the results showed that as a learner receives more practice the optimal summary KR length increases. A novice performs better during both acquisition and retention if given a shorter summary KR length than if given a longer summary KR length. As a learner becomes more proficient, a shorter summary length continues to enhance performance in the acquisition phase but degrades performance on the retention test. These results led to the conclusion that, when the task is constant, the longer
summary KR length produced superior retention performance for experienced individuals and inferior performance for novices. The results of their experiment 2 exhibited the interaction of the task complexity and the level of the learner's ability, both of which must be considered to determine the optimal summary length of KR. The relative difficulty of a motor task for an experienced individual performing a complex task is similar to that of a novice performing a simple task, and the relative task difficulty for an experienced individual performing a simple task is opposite that of a novice performing a complex task. Guadagnoli et al. concluded that the relative difficulty of a task is dependent on both the complexity of the task and the level of the learner's ability. And optimal summary KR length is dependent on the relative difficulty of the motor task.

Instead of providing KR about each trial after a block of trials, as is done with summary KR schedules, average KR gives learners only their mean performance over the entire trial block. The effectiveness of average KR schedules has been demonstrated by Young and Schmidt (1992), who compared the retention test performance of an average KR group with that of a group that received KR after every trial. Results showed that average KR was more effective for learning than KR given after every trial. In 1994 Yao, Fischman and Wang manipulated average KR and summary KR in a single experiment. They found that the average KR condition and summary KR condition produce similar learning effects.

The studies discussed above concerning variations of reduced frequency of KR all support the conclusion that lower frequencies of KR degrade performance during acquisition but enhance retention performance when compared to an immediate 100%
Kr schedule. One possible explanation for this phenomenon is the guidance hypothesis (Salmoni, 1984) which states that high frequencies of Kr provide a strong guiding function for performance when Kr is present, producing high performance during acquisition. Because Kr after each trial is so effective at maintaining performance, the learner comes to rely on it. This dependence is assumed to prevent or inhibit the learner from processing other task related error information, thus preventing the development of other response capacities such as more consistent movement patterns or the ability to process error information internally. This may result in degraded performance later, particularly under conditions where Kr is withdrawn and the guiding properties of Kr are no longer available. Reduced Kr, which does not possess this strong guidance property, produces lower performance during acquisition but forces the learner to engage in additional mental processing during acquisition, which benefits performance during the no Kr retention test when the guidance property of Kr is no longer available.

Temporal Locus of Kr

The temporal locus of Kr refers to the time when Kr should be provided to produce maximal learning. Kr can be located at any of three defined intervals. The intervals are the Kr delay interval, the Kr post delay interval, and the inter-response interval. Previous studies of the temporal locus of Kr have focused on two aspects: (1) the effects on learning and performance produced by varying the length of these intervals, and (2) the effects on learning and performance produced by activity during these intervals.
The KR delay interval is the time between the completion of a response and the presentation of KR. Some early animal studies (Hamilton, 1929; Roberts, 1930) concerning the effect of delaying the reward showed that even small delays produced large effects on animal learning. The researchers expected that analogous effects would be exhibited in human motor learning. However, numerous investigators did not find any reliable effect of KR delay on performance during the acquisition phase. In 1935 Lorge and Thorndike first completed an experiment to examine the effects of KR delay on human learning. During a target hitting task KR was provided after delays of 1, 2, 4, and 6 seconds for four different groups of learners. All groups exhibited similar performance with no statistical differences, indicating the KR delays had no effect. A series of five experiments manipulating KR delay were completed by Edward and Ina (1958). In these experiments such tasks as a level positioning task and a micrometer dial turning task were employed, and the KR delay interval ranged from a few second to seven days. The results of these experiments were consistent with those of Lorge and Thorndike (1935) that failed to find effects of KR delay on motor performance. Adams (1971) stated "...delay of KR has little or no effect on acquisition." Recent studies have used retention tests to separate the temporary effects from the relatively permanent effects of KR delay. Even though some studies indicated that increased KR delay degrades learning (Mulder and Hulstijn, 1988; Dyal, 1966; Schmidt, 1975; McGuigan, 1959b), numerous studies demonstrated no effect, or at best a very small effect, of KR delay on learning. But it is too early to conclude that KR delay is not critically important to learning a motor skill. Magill (1989) believed that the KR delay interval may affect factors that are not revealed by performance scores.
Studies that investigated the effects of activity during the KR delay interval have provided different results. In some cases activity during the KR delay interval does not affect learning, but in other cases activity during the KR delay interval has negative effects on learning. In 1962 Ryan and Bilodeau had learners either move their hands to their laps between trials or keep them on the levers at the end position, and this activity had no effect on learning. Boulter (1964) filled the KR delay interval with verbal and/or motor activities and found no effects on learning. More recently, Marteniuk's (1986) experiment also supported this conclusion. In contrast, Shea and Upton (1976) had learners perform two different positioning movements. One group was asked to perform other positioning movements during the KR delay interval and the other group just rested during the KR delay interval. Results showed that the KR delay activity group performed worse than did the empty interval group both during acquisition and on retention tests, suggesting that activity during the KR delay interval was detrimental to learning. In Marteniuk's (1986) study three experimental groups were used; one received KR immediately after each trial, the second group did another familiar two component movement during a 40 second KR delay interval, and the third group had to learn a new two component movement during the 40 second KR delay interval. The third group, which had to learn a new task during the KR delay interval, performed worse than the other two groups by the end of 20 acquisition trials. These results indicated that the effect of activity during a KR delay interval is dependent on the nature of the activities interpolated. Learning is degraded if the interpolated activity is an attention-demanding task that diverts required attention from the essential underlying learning processes in which the person is engaged during this interval. If the interpolated activity during
the KR delay interval does not require attention demanded by the underlying learning processes, then there is no negative effect on learning (Magill, 1989).

The post KR delay interval is the time between the presentation of the KR and the production of the next response. Manipulating the length of the post KR delay interval could be expected to affect learning in either of two ways. First, if the post KR delay is too short, the learners will not have sufficient time to plan the next response correctly, resulting in degraded learning. Second, if this interval is too long, the learners will forget the KR, or parts of it. However, these expectations have not received empirical support. During the acquisition phase, although shortening the post KR delay interval did have a slightly detrimental effect on performance accuracy in both adults (Weinberg, Guy, & Tupper, 1964) and children (Gallagher & Thomas, 1980), increasing this interval did not produce any effect at all. When using retention tests to measure learning effects, decreasing the post KR delay interval also degrades learning, but only when KR delay is held constant, and not when the inter-response interval is held constant. Salmoli et al. (1984) observed that it was the inter-response interval, and not the post KR delay interval, that seemed to be the more important variable for learning. When activity is interpolated during the post KR delay interval, learning is not much affected. In 1983 Lee and Magill conducted an experiment using three groups. The two experimental groups were called the "motor" and "non motor" groups, and they were required to complete some activities during the post KR delay interval. The control group, called the "rest" group, did nothing during the post KR delay interval. The two experimental groups produced more errors than the control group during acquisition. On the no KR retention test, however, there were no significant differences between groups. Because of
these findings, they concluded that activity during the post KR delay interval, even activity that demands problem-solving, did not interfere with the learning of the criterion task.

Adams' theory about KR and the stages of learning

According to Adams's closed-loop theory (1971), learners pass through two distinct stages as they practice a skill. These two stages are the verbal-motor stage and the motor stage. In the verbal-motor stage, most of the improvement in performance is verbal-cognitive in nature, learning what to do rather than how to improve the motor patterns. Adams stated that in the verbal-motor stage of learning, before their internal information processing ability is fully developed, the learners' error corrections are based on KR and verbal transformations of KR. Therefore more KR during this stage helps the learners to correct errors and improve the next response. The verbal-motor stage ends when it evolves into the next stage, the motor stage, where the error reported by KR has become acceptably small. In the motor stage the correct response has been repeated for some time and the learners' internal information processing ability is highly developed. At this point KR can be eliminated and yet learning can continue even though KR is withdrawn.

Acquisition/retention paradox

The acquisition/retention paradox was proposed by Guadagnoli (in press). This paradox revealed the relationship between acquisition (practice performance) and
Figure 1  Learning Curve Model
retention (i.e., learning). That is, practice performance is not necessarily indicative of learning. Figure 1 is a graphic called learning curve model that might properly explain the essence of the acquisition/retention paradox. Several important points are illustrated in this figure. First, practice performance decreases as the task difficulty increases; the more difficult the task, the worse the practice performance. Second, the learning curve shows that the relationship between practice performance and retention performance (learning) relative to task difficulty is in the form of an inverted V. Too low or too high practice performance, as well as too great or too little task difficulty, result in poor learning. Third, optimal (highest) learning occurs only around a certain point, called the challenge point (CP). Learning increases with increasing task difficulty up to the CP, because the learner is being optimally challenged to enhance learning. Increasing the task difficulty beyond the CP will decrease learning. Finally, optimal learning does not occur during the highest practice performance. A moderate level of practice performance will yield optimal learning, indicating that high performance during acquisition is not necessarily indicative of optimal learning.

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CHAPTER 3

METHODS

Participants

Participants were 65 college aged students from the University of Nevada Las Vegas. Prior to the study all participants signed an informed consent. All participants were naïve to the purpose of the study.

Experimental Design

This experiment was a 5 (KR condition) x 7 (Block) mixed design. The 5 levels of KR condition were immediate KR, 5 KR, 15 KR, Summary Fading KR, and Reverse Summary Fading KR. The 7 levels of Block were acquisition blocks 1-6 and one retention block. KR condition was a between-subjects factor and Test was a within-subjects factor. The dependent variable of interest in this experiment was root mean square error (RMSE).

Apparatus

A static force measurement system incorporating an amplifier, a Gateway 2000 microcomputer, and an internal 16-channel A/D interface (Metrabyte DAS-1600) were
Figure 2  Diagram of experimental task
used in this experiment (Figure 2). A force transducer, which monitored force production, was mounted on a tripod and positioned at the participant's midline, approximately chest high. The computer monitor which provided the KR was placed at the participant's midline at approximately eye level.

Procedure

Based on the protocol used by Guadagnoli et al. (1996), the task used in this experiment was to reproduce a predefined target force displayed on the computer monitor. This target force was designated by a horizontal line at the middle of the computer screen. The participant attempted to produce the force by striking a padded force transducer with the dominant fist. The force actually produced by the participant was displayed on the screen as a vertical line projecting from the horizontal target line. If the vertical line was above the target line, it indicated that the force used by the participant was too great. If the vertical line was below the target line, it indicated to the participant that too little force had been used. If the vertical line was on the target line, it indicated that the correct amount of force had been used. The length of the vertical line was directly proportional to the magnitude of the force used. One Newton of force was represented by 8.45 error units. KR was provided by the vertical line on the screen in such a way that participants could correct their error (deviation from the target line) in future trials.

Participants were assigned randomly to one of five groups with 13 participants in each group. Each group received a different KR condition. These conditions were immediate KR, 5 KR, 15 KR, Summary Fading KR (SF), and Reverse Summary Fading...
KR (RSF). During the acquisition phase, all participants in all groups completed 6 blocks of 15 trials (90 trials total) of the force production task. KR was provided to the participants in each group according to that group's KR condition. The immediate KR group received KR after every trial; the 5 KR group and 15 KR group received KR after every 5 and 15 trials respectively; the SF group received KR after every trial in the first 2 blocks, after every 5 trials in the second 2 blocks, and after every 15 trials in the last 2 blocks; the RSF group received KR after every 15 trials in the first 2 blocks, after every 5 trials in the second 2 blocks, and after every trial in the last 2 blocks (the reverse order of the SF group). When KR was displayed, the KR delay was 500 ms after the trial for which KR was given (e.g., after five trials for the 5 KR group). Once displayed, the KR remained on display until the entire block of 15 trials was completed. Twenty-four hours after acquisition all participants performed a retention test consisting of one block of 15 trials without KR.

Measurement

Since the goal of the participants in the current experiment was to reproduce a predefined target force, the participants were required to complete each trial with minimum error. RMSE measures performance error by measuring the total variability around a target for a set of responses (Henry, 1976). It is an appropriate representation of composite scores for participants’ response accuracy (biases) and response variability (Wulf & Lee, 1993; Schmidt & Lee, 1999). RMSE is computed as the root mean square of the sum of the each response minus the target value divided by the number of the trials. Constant error (CE) is a measure of average error in responding; it represents the
amount of deviation from the target but does not consider the consistency of each trial. Variable error (VE) is a measure of response inconsistency (variability).

Data Analysis

Acquisition and retention data were measured separately. Mean RMSE for acquisition was analyzed using a 5 (KR Condition) x 6 (Block) analysis of variance (ANOVA) with repeated measures on the last factor. Mean RMSE for retention was analyzed using a one-way (KR Conditions) ANOVA.
CHAPTER 4

RESULTS

RMSE was plotted in Figure 3 as a function of KR condition and acquisition and retention blocks.

Acquisition

Mean RMSE for acquisition data was analyzed using a 5 (KR Condition) x 6 (Block) analyses of variance (ANOVA) with repeated measures on the second factor. The analysis revealed that the KR Condition x Block interaction was significant, $F(20, 300) = 3.18, p<0.05$. A test of simple main effect revealed that the interaction was the result of substantial group differences on the first block, but not always on subsequent blocks. The main effects for block indicated that general trend of errors decreased across practice for all groups, $F(5, 300) = 44.6, p<0.01$. A Duncan's test of KR conditions revealed that the 15 KR group committed significantly more errors than the other four groups in block 1, and the immediate KR and SF KR groups committed significantly fewer errors than the 15 KR group in block 6 (Figure 3).

Retention

Mean RMSE for retention data was analyzed using a one-way ANOVA with the single factor being KR Condition. The analysis revealed a significant effects, $F(4, 60) =$
Figure 3 RMSE for acquisition and retention
3.69, p<0.05 (Figure 3). A Duncan’s follow-up revealed that the mean for the SFKR group yielding superior retention results than the other groups. No other comparisons were significant.
CHAPTER 5

DISCUSSION AND FUTURE DIRECTIONS

Discussion

The primary purpose of this study was to examine the effects of dynamic acquisition protocols by comparing dynamic and static KR schedules in a single experiment. The results demonstrated that the participants in the SF KR group produced significantly fewer errors (RMSE) on the no KR delayed retention test than the participants in the other four KR groups, indicating that dynamic manipulation of the KR frequency during acquisition produced more learning than static manipulation. This finding was consistent with Adams's motor learning theory (1971). In his theory Adams hypothesized that, when in an early stage of learning (the verbal-motor stage), the learner is primarily concerned with understanding what is to be done and how performance is to be evaluated rather than determining the most efficient way of meeting the task demands. The novice learner needs more guidance from KR to understand the basic movement goals, and compares the KR with his intrinsic information processing to correct errors for future trials. After sufficient practice the learner's intrinsic information processing system has been strengthened, and learning progresses to the advanced stage, the motor stage. During this stage the need for augmented error information is decreased, and too much KR may hamper the learner's attempts to determine the most efficient way of
meeting task demands. Adams even argued that in the later stage of learning the learner could ignore KR and his learning could still continue. Even though Adams' opinion that the learner could continue to learn without KR during the final stage of learning was challenged (e.g., Schmidt, 1975), Adams appears to be correct that the KR requirement changes with the learner's proficiency at the task. The most appropriate acquisition protocol would be one that dynamically manipulates KR from a higher frequency at the beginning to a lower frequency as practice progresses.

The results of the present experiment can also be interpreted as support for the learning curve model (Figure 1) proposed by Guadagnoli (in press). This curve demonstrates the relationship between performance, learning, and task difficulty. From this curve, it is obvious that practice performance decreases as task difficulty increases. The critical relationship, however, is that between practice performance and retention performance (learning). Both too high and too low performance during practice, as well as too great and too little task difficulty, produce poor learning. Only around a certain point, called the optimal challenge point, is learning optimal. Practicing at this challenge point throughout acquisition will maximize learning. To challenge the learner at this challenge point throughout the acquisition phase, the task must be made more difficult as the learner becomes more proficient at the task. One way to do this is by dynamically manipulating the frequency of KR, with a higher frequency during the early period of acquisition and a gradually reduced frequency as practice progresses.

It is important to note that the SF KR condition has both the reduced KR frequency feature (42% relative frequency) and the dynamic acquisition protocol feature. Since there was no benefit to reducing KR (there were no significant differences between
the two static groups of reduced KR frequency and the immediate KR group), the results of this experiment may be interpreted to suggest that the superior learning effect of the SF KR group was produced by the dynamic acquisition protocol rather than the reduced KR or a combination of both. In addition, the results also showed that the RSF KR group, which also employed a dynamic acquisition protocol, performed worse than the 3 static protocol groups on the retention test, but the results did not achieve significance. This result was also agreement with the above conclusion because the learners in the RSF KR group received few KR trials during the early stages of acquisition and more KR trials during the latter stages of acquisition, which degraded the development of error detection capacities during acquisition. These findings suggest that the benefit of the dynamic acquisition protocol on learning had a specific direction. KR should be presented with higher frequency during the early stages of learning, and with reduced frequency as the learner becomes more proficient at the task.

Another purpose of this experiment was to retest the hypothesis that reduced KR frequency promotes learning. An attempt was made to replicate the results of the studies of Schmidt et al. (1989) and Guadagnoli et al. (1996), by using the same KR schedules. However, the results from this experiment failed to find differences between the 5 KR, the 15 KR, and the immediate KR conditions, indicating that reduced KR frequency did not differentially enhance learning. This result was inconsistent with the previous findings that reduced KR frequency enhances learning (Schmidt et al., 1989, 1990; Winstein et al., 1990).

One possible reason for this discrepancy can be explained by findings of experiments of Lai and Shea (1998, 1999) investigating the role of reduced frequency of
They found that the reduced KR effect appears to be reproducible in practice for a variety of tasks or different versions of the same task. But in experiments involving practice with a single task goal learning was inconsistently enhanced by reduced KR frequency. In their discussion they argued that one of the major reasons for these results was that the learning effect with the variable tasks created a different effect from that with learning a single task. In these experiments, practice with variable tasks is more likely to create the conditions under which the additional processing opportunity afforded by reduced KR are critical to learning. In contrast, the learner's processing capacities may typically be challenged to a lesser extent in practice with a single task. Since there was only one task goal employed in the current experiment (i.e., one predefined target force the subjects tried to reproduce), the failure to find the benefit of reduced KR in this experiment was consistent with the finding of Lai and Shea's studies (1999). Besides this, insufficient practice was more likely a direct explanation for this discrepancy. Compared with the experiments that were heavily cited in this study (Guadagnoli et al., 1996, Weinstein et al., 1990) the number of the practice trials in current study was relative low (90 trials). In Experiment 1 of Guadagnoli et al. (1996) study, participants practiced a motor task over three consecutive days in which 45, 150, and 300 practice trials were used for these three days, respectively. The results showed that the reduced KR groups performed better than the immediate KR group after the practice of the second day. That is, using the same task as the current study, the learning effect of reduced KR occurred after 195 trials of practice. Thus, the number of practice trials used in current experiment (90 trials) was less than half the amount used in the Guadagnoli et al. study. This lower amount of practice may be responsible for a lack of a differential learning effect between
the KR groups. Likewise, in Experiment 1 of Winstein and Schmidt's study (1990), reduced KR groups needed 198 practice trials to produce learning effects.

Future directions

Since SF KR group showed better performance than the three static groups in retention test, a conclusion can be made that a dynamic schedule of KR frequency in acquisition produces more learning than a static schedule. Furthermore, because there was no significant difference between two reduced KR groups (5 KR, 15 KR) and immediate KR group, it is suggested that this learning effect might be produced by a dynamic acquisition protocol rather than a reduced KR schedule, or a combination of both. A problem with this interpretation is that the KR frequency manipulated in SF KR group and the two static reduced KR groups was different (5 KR, 15 KR). That is, the relative frequency of KR in 5 KR group (20%) and 15 KR group (6.67%) was relative low compared with SF KR group (42%). In addition, as mentioned above, a reduced KR schedule is likely to enhance learning when variable tasks are used but not when a single task is used. Also, the amount of practice in current experiment might have been insufficient to significantly alter processing abilities. Therefore it might be premature to make the conclusion that the reduced KR schedules do not aid in facilitating the learning process. Taken together, to better investigate the role of the reduced KR and the relationship between dynamic acquisition protocols and reduced KR with different practice conditions (variable task goals vs. single task goal), three factors should be considered when designing experiments in future studies. First, the frequency of KR manipulated in static acquisition condition should be the same as that in dynamic
acquisition condition, making sure that the role of reduced KR and the role of dynamic acquisition protocols can be definitely separated. Second, the variable task or different versions of the same task can be added to examine the effect of the dynamic acquisition protocols when participants complete a variety of tasks or different versions of the same task. Third, practice amount should be sufficient to allow the processing abilities to be changed.
INFORMED CONSENT  
MOTOR BEHAVIOR LABORATORY

You are invited to participate in a study of human motor behavior. If you decide to participate, each experimental session will last less than 20 minutes. There are no known risks involved in your participation. This information is based on a large body of experience with similar tasks.

Any information obtained in connection with this study that can be identified with you will remain confidential. If you give us permission by signing this document, we plan to publish the results in an appropriate journal.

Your decision whether or not to participate will not prejudice your future relations with the University of Nevada Las Vegas. If you have any questions please ask the experimenter. A telephone number to call if there are any questions is (702) 734-1492. Thank you for participating in this project.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE BELOW INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INSTRUCTIONS AND INFORMED CONSENT.

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APPENDIX II

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proc anova;
   CLASS GROUP;
   model T1-T6=GROUP;
   REPEATED BLOCK 6;
   MEANS GROUP/DUNCAN;RUN;
;
proc means N MEAN STDERR STDEV;
   by GROUP;
run;
Analysis of Variance Procedure
Class Level Information

Class Levels Values
GROUP 5 1 2 3 4 5

Number of observations in data set = 65

Analysis of Variance Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subject Effects

Source: BLOCK
DF    Anova SS   Mean Square   F Value  Pr > F    G - G    H - F
      5   6018.40175385 1203.68035077  44.60  0.0001    0.0001    0.0001

Source: BLOCK*GROUP
DF    Anova SS   Mean Square   F Value  Pr > F    G - G    H - F
    20  1714.51762821  85.72588141   3.18  0.0001    0.0005    0.0002

Source: Error(BLOCK)
DF    Anova SS   Mean Square
   300  8097.11411795  26.99038039

Greenhouse-Geisser Epsilon = 0.5748
Huynh-Feldt Epsilon = 0.6470
Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: T1

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha = 0.05 df = 60 MSE = 85.57966

Number of Means 2 3 4 5
Critical Range 7.258 7.635 7.884 8.065

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Duncan Grouping</th>
<th>Mean</th>
<th>N</th>
<th>GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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<td>3</td>
</tr>
<tr>
<td>B</td>
<td>21.822</td>
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<td>5</td>
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<td>18.120</td>
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<tr>
<td>B</td>
<td>14.086</td>
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<td>4</td>
</tr>
</tbody>
</table>

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: T2

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha = 0.05 df = 60 MSE = 33.51527

Number of Means 2 3 4 5
Critical Range 4.542 4.778 4.934 5.047

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Duncan Grouping</th>
<th>Mean</th>
<th>N</th>
<th>GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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<td>13</td>
<td>3</td>
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<tr>
<td>A</td>
<td>17.854</td>
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<tr>
<td>B</td>
<td>11.156</td>
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<tr>
<td>B</td>
<td>11.064</td>
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<tr>
<td>B</td>
<td>9.919</td>
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<td>4</td>
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</table>
Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: T3

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05  df= 60  MSE= 28.95956

Number of Means  2  3  4  5

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Duncan Grouping</th>
<th>Mean</th>
<th>N</th>
<th>GROUP</th>
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<tr>
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<td>5</td>
</tr>
<tr>
<td>A</td>
<td>10.979</td>
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<tr>
<td>A</td>
<td>10.591</td>
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<td>B</td>
<td>8.725</td>
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Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: T4

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05  df= 60  MSE= 13.84726

Number of Means  2  3  4  5
Critical Range  2.920 3.071 3.171 3.244

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Duncan Grouping</th>
<th>Mean</th>
<th>N</th>
<th>GROUP</th>
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</thead>
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<td>A</td>
<td>10.098</td>
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<td>A</td>
<td>8.030</td>
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### Analysis of Variance Procedure

**Duncan's Multiple Range Test for variable: T5**

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

\[
\text{Alpha} = 0.05 \quad \text{df} = 60 \quad \text{MSE} = 21.63445
\]

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Means with the same letter are not significantly different.

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<th>Duncan Grouping</th>
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<th>GROUP</th>
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<td>A</td>
<td>13.826</td>
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<td>B</td>
<td>11.157</td>
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<td>B</td>
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### Analysis of Variance Procedure

**Duncan's Multiple Range Test for variable: T6**

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

\[
\text{Alpha} = 0.05 \quad \text{df} = 60 \quad \text{MSE} = 15.56588
\]

<table>
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<th>5</th>
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Means with the same letter are not significantly different.

<table>
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<th>GROUP</th>
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<td>B</td>
<td>8.155</td>
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APPENDIX III

SAS PROGRAM

DATA ANALYSIS

FOR RETENTION
data Summary-Fading KR;
***RETENTION DATA AND ANALYSIS ***;
input Group T1;
cards;
    1  14.45
    1  7.27
    1  6.76
    1  24.66
    1  9.96
    1 11.02
    1  8.30
    1 28.79
    1  8.37
    1  9.77
    1 14.08
    1 17.04
    1 16.23
    2 12.30
    2 24.80
    2 10.18
    2 13.49
    2 11.35
    2 14.51
    2 15.57
    2 18.11
    2 24.60
    2 11.82
    2  6.98
    2 16.51
    2 17.83
    3  8.45
    3 11.09
    3 19.02
    3 13.61
    3 23.19
    3  8.22
    3 10.80
    3 16.18
    3  7.43
    3 16.04
    3 10.56
    3 20.76
    3 21.03
    4  6.17
    4  6.48
    4 13.92
    4  9.88
    4 15.16
    4  9.51
    4  7.92
    4  5.92
    4  5.66
    4  6.24
    4  7.37
    4  5.53
    4  9.5
5  37.97
5   8.25
5   9.92
5  26.71
5  15.30
5   6.37
5  12.01
5   9.36
5  16.26
5  27.22
5  19.22
5  17.48
5  19.04

proc anova;
   CLASS group;
      model T1=group;
      MEANS group/DUNCAN;RUN;
proc means N MEAN STDERR STDEV;
   by group;
run;
Analysis of Variance Procedure

Class Level Information

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Number of observations in data set = 65

Analysis of Variance Procedure

Dependent Variable: T1

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<th>Source</th>
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<th>Sum of Squares</th>
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<th>Pr &gt; F</th>
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<tbody>
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<td>142.54628077</td>
<td>3.69</td>
<td>0.0095</td>
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<tr>
<td>Error</td>
<td>60</td>
<td>2318.68466154</td>
<td>38.64474436</td>
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<tr>
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<tr>
<td>Total</td>
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</tr>
</tbody>
</table>

R-Square   C.V.   Root MSE   T1 Mean
0.197373   45.12248   6.21648971   13.77692308

Source     DF  | Anova SS | Mean Square | F Value | Pr > F |
GROUP       4   | 570.18512308| 142.54628077| 3.69    | 0.0095 |
Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: T1

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

\[ \text{Alpha} = 0.05 \quad \text{df} = 60 \quad \text{MSE} = 38.64474 \]

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Means with the same letter are not significantly different.

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<th>GROUP</th>
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<tr>
<td>A</td>
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Analysis Variable : T1

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<th>Std Dev</th>
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<tbody>
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<th>Std Dev</th>
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<tbody>
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GROUP=3

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GROUP=4

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REFERENCES


VITA

Graduate College
University of Nevada, Las Vegas

Changjiang (River) Sun

Mailing Address:
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Las Vegas, NV 89119

Degrees:
Bachelor of Education, 1984
Beijing University of Physical Education

Thesis Title:
Summary Fading Knowledge of Results (KR):
Test for the Dynamic Acquisition Protocols

Thesis Examination Committee:
Chairperson, Dr. Mark Guadagnoli, Ph.D.
Committee Member, Dr. Dick Tandy, Ph. D.
Committee Member, Dr. Mark Hoffman, Ph. D.
Graduate Faculty Representative, Dr. Alice Corkill, Ph. D.