Salient features of contextual interference and knowledge of results

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SALIENT FEATURES OF CONTEXTUAL INTERFERENCE
AND KNOWLEDGE OF RESULTS

by

Morgan Steven Kearney

Bachelor of Science
The College of William & Mary
2000

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science Degree
Department of Kinesiology
College of Health Sciences

Graduate College
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Salient Features of Contextual Interference
and Knowledge of Results

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ABSTRACT

Salient Features of Contextual Interference
And Knowledge of Results

by

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The current study investigated the relationship between the contextual interference effect and knowledge of results manipulations. Specifically, three variations of a relative timing task were presented in either a blocked or random schedule, and participants were either required to error estimate or given no instruction concerning estimation. A 2 (Acquisition Context) x 2 (Error Estimation Frequency) ANOVA was used to analyze absolute error (AE), variable error (VE) and a relative timing measure (AE(prop.)). The main effects that there was a blocked advantage during retention. In addition, a 100% estimation advantage existed for AE and VE, but was not present for AE(prop.). These results indicate that the relative difficulty of the task may have been too high to produce a random group advantage and that error estimation of relative timing may have been too much for the participant to process. In conclusion, it was proposed that the two factors may interact, but relative difficulty of the task needs to be taken into account.
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CHAPTER 1

INTRODUCTION

As a robust factor in motor and verbal learning, contextual interference (CI) has been an area of interest in motor learning for more than three decades (e.g., Battig, 1966). The CI effect can be defined as the interference effects in performance and learning that arise from practicing one task in the context of other tasks (Schmidt & Lee, 1999). Research has examined the situations in which the CI effect is manifested as well as possible underlying mechanisms of the effect, touting several theories to explain the effect. However, to date there has been no consensus as to the cause of the CI effect. Two major theories, action reconstruction and elaboration, have been the most widely accepted and have based their explanations on the scheduling of the tasks to be learned. An alternative explanation never before forwarded is that a factor not associated with task scheduling (i.e., knowledge of results) may be at play. That is, in addition to the scheduling of the tasks, the manner in which the participant uses the feedback may cause the CI effect. Therefore, it is the goal of this paper to determine the importance of KR and its relationship to task scheduling in the contextual interference effect.

The CI effect can trace its roots back to Battig's work with verbal learning (1966, 1972, 1979), which was later extended to motor skills by Shea & Morgan (1979). This effect can be
defined as the interference effects in performance and learning that arise from practicing one task in the context of other tasks (Schmidt & Lee, 1999). The effect has demonstrated that a random practice schedule creates a decrease in acquisition scores and an increase in retention scores as compared to a blocked practice schedule (Shea, Kohl & Indermill, 1990; Lee & Magill, 1983; Li & Wright, 2000; Hall, Domingues & Cavasos, 1994). Interestingly, the effect has not been found to be universal, and seemingly similar situations have not elicited analogous results (Del Rey, Wughalter, DuBois & Carnes, 1982; Whitehurst & Del Rey, 1983). It has been suggested that the strength of the effect depends on whether the variations of a skill are from various motor programs or are simply variations of one single program (Magill & Hall, 1990; also see Schmidt, 1975). A possible explanation is that when the same motor program is used, there is not a sufficient amount of difficulty present for the effect to occur.

Efforts were then directed towards determining the underlying mechanisms behind the contextual interference effect and the circumstances under which it is found. One hypothesis is that the effect is due to the fact that the random schedule promotes more comparative and contrastive analyses of the actions required to complete the task (Shea & Morgan, 1979; Shea & Titzer, 1993). This line of work suggests that the random practice schedule allows the learner to compare the responses for each task and thus create a more meaningful representation of a response as well as the ability to distinguish between the different versions. In contrast, the blocked groups are believed to take a more automatic approach, where there is less processing than the random group, resulting in a weaker memory representation.

A different explanation offered is that the action plan of a movement is influenced by
the previous trial and that random practice facilitates forgetting, thus strengthening the memory representation (Lee & Magill, 1983; Lee, Wishart, Cunningham & Carnahan, 1997; Wulf & Lee, 1993). Based on the concept that "forgetting helps remembering" (Cuddy & Jacoby, 1982), this theory proposes that a random schedule promotes the forgetting of an action plan for a given movement and creates the need to reconstruct it when the task is practiced again. During a blocked schedule, the action plan remains in working memory and does not need to be reconstructed, which makes deeper processing unnecessary and prevents a strong memory representation. This theory is then able to account for both acquisition and retention performance for both practice schedules.

Blocked practice outperforms random practice during acquisition due to the availability of the action plan, but the opposite is true during retention because a stronger memory representation exists due to the repeated reconstruction of the action plan.

While these two hypotheses offer two different explanations for the contextual interference effect, they share the common fact that they attribute the underlying mechanism to be based on the scheduling of the tasks. An alternate approach is to examine the effect of KR and how the learner uses it. Defined as verbalizable, terminal augmented feedback about the outcome of a response in terms of the environmental goal (Schmidt & Lee, 1999), it has been established that, in most situations, some KR is necessary for learning (Magill, 1993; Schmidt & Lee, 1999; Shea, Shebilske & Worchel, 1993). In a majority of the studies performed on contextual interference, KR has been presented after every trial in order to assist the learner (Magill & Hall, 1990). A large amount of research has been conducted concerning KR, but similar to contextual interference, the underlying mechanisms have not been pinpointed.
One specific line of research has examined what the learner does with the feedback given to them through error estimation prior to receiving KR. These results have shown that this required estimation increases retention performance (Hogan & Yanowitz, 1978; Swinnen, 1990; Swinnen, Schmidt, Nicholson & Shapiro, 1990), and has even been shown to reverse and enhance previously established results concerning relative frequency of KR (Guadagnoli & Kohl, 2001). It is hypothesized that the error estimation not only causes the learner to utilize the external feedback that is presented, but enables them to error correct through the interpretation of internal sources of feedback (Schmidt & Lee, 1999).

In this light, it may be possible to determine the importance of KR in the contextual interference effect through the use of error estimation. By incorporating error estimation into the standard contextual interference schedules, the relationship between these two variables may be seen. As explained by the elaboration hypothesis, it may be that the practice of several tasks may allow for comparisons between the different variations and create stronger representations of each task. If this is true, than the use of KR is independent of the scheduling effects. But, if an interaction exists, then it is the KR as well as the scheduling that is creating the additive or subtractive effect. These results would suggest that KR and scheduling are not independent of one another, but that they both account for the effects seen in the contextual interference paradigm.

Therefore, the purpose of the current study is to determine if knowledge of results manipulations interact with the traditional contextual interference effect. The task that will be used is similar to that of Lee, Wulf and Schmidt, (1992) where participants will be required to practice three key press tasks, each of which had a different relative timing,
under a blocked or random schedule. In addition, two more groups will practice under a blocked or random schedule, but will be required to estimate the correctness of their response after each trial, but prior to the presentation of KR. Previous research has demonstrated that under a 100% KR acquisition frequency schedule, error estimation increases retention test performance (Hogan & Yanowitz, 1978; Guadagnoli & Kohl, 2001; Swinnen, 1990; Swinnen et al., 1990), and by requiring participants to error estimate under both acquisition schedules, it will be possible to determine which factor is more salient.

Due to the fact that the three tasks to be practiced vary in the relative timing between segments, it is expected that the contextual interference effect will be seen in the two groups that are not error estimating. These groups will serve to re-establish the hypothesis offered by Magill and Hall (1990), with the blocked group outperforming the random group in acquisition and the random group showing superior retention. The authors suggested that these results were due to the fact that the use of different motor programs in each task increases the amount of task difficulty and therefore promotes the CI effect.

For the groups that are error estimating, it is less clear as to how they will perform. It is hypothesized that both groups will outperform their no-estimation counterparts, but it is difficult to determine whether or not an interaction will exist. Based on earlier explanations of the effects of contextual interference and error estimation prior to receiving feedback, it is predicted that an interaction will be found, with an increase in performance for both estimation groups with a decreased contextual interference effect. Previous work has shown that estimation is beneficial to retention (Hogan & Yanowitz,
1978; Guadagnoli & Kohl, 2001), but there are also merits in the elaboration hypothesis for contextual interference. It may be possible that the random schedule promotes spontaneous error estimation, causing KR utilization to be a factor in increased retention, but the scheduling may also be beneficial because several tasks are in working memory concurrently. Because of this, several programs are being encoded and decoded intermittently, allowing for comparisons to be made between the different variations of the task. Regardless of error estimation, this is not possible in a blocked schedule. Therefore, it is predicted that the scheduling of practice as well as the utilization of KR are not independent, with both factors playing a role in the contextual interference effect.
CHAPTER 2

REVIEW OF LITERATURE

Introduction

The goal of this chapter is to introduce the concepts of contextual interference (CI) and knowledge of results (KR). Both topics have been researched for decades and there is an extensive body of knowledge on both subjects. This chapter will serve to review the concepts and lines of research that are pertinent to the present study. Of specific interest are the explanations for the CI effect and the manipulations of the use and presentation of KR during practice.

Contextual Interference

The contextual interference effect can trace its roots back to William Battig's work with verbal learning (1972, 1979). In 1979, specifically, he expanded his concept of intra-task interference to what is now known as contextual interference. The original definition only accounted for discrepancies between the trials of the same task, whereas the revised version also included the effect of other tasks that were being learned concurrently. Consequently, the task learned, the practice schedule, as well as
processing could be considered as possible sources of interference. These changes across trials were then grouped and labeled as contextual variety, which were suggested to produce more elaborate and distinctive processing, leading to increased retention. Battig then contended that this increase in contextual variety would also make the encoding less context dependent (e.g. Tulving, 1979), and thus facilitate retention in different situations.

These conclusions drawn by Battig concerning the contextual interference effect began with his early work with paired associates in 1972. Five groups of subjects were given lists stimulus-response word pairs to be learned and these groups differed in the schedule of presentation of the stimulus terms and the stimulus-response pairs. The group with the least amount of contextual interference was given the largest blocks of practice. In this group, labeled Group 12, all of the stimulus terms of a list were practiced, immediately followed by practice of the stimulus terms of the next list. After all lists were presented, subjects in this group were then presented with the stimulus-response pairs and were practiced in a similar manner. At the other extreme, Group 1 was given the stimulus terms of the first list, followed by the stimulus-response pairs for that same list before continuing on the next. The three other groups received similar practice schedules whose block schedules varied between one and twelve (2, 4 and 6).

The result showed that Group 12 performed best during the acquisition phase of the experiment, followed by groups 6, 4, 1 and 2 respectively. More importantly, during a free recall test, the trend was reversed and Groups 1 and 2 performed best and Group 12 performed the worst. These findings were the first that Battig produced in support of his idea that contextual interference enhanced delayed retention tests. Group 1, which had the largest amount of contextual interference during practice, showed a slower acquisition
of the stimulus-response pairs, but illustrated a greater performance during free recall of
the pairs. These findings led Battig to continue this line of research in verbal learning,
and later refine his definition of contextual interference.

Shea and Morgan (1979) were interested in Battig's finding and attempted to apply
the theory of contextual interference to the acquisition and retention of motor skills. The
primary goal of their study was to compare the effects of blocked (low interference)
practice to that of random (high interference) practice on the acquisition and retention of
three similar motor skills. The task required the participants to carry out one of three
movement patterns with their forearm as quickly as possible. After warning and stimulus
lights were presented, the participants picked up a tennis ball, knocked over three wooden
barriers and placed the ball in a new location. The three movement patterns were
illustrated on cards in front of the participants with stimulus lights below each card. The
total reaction time was measured as the time from the onset of the stimulus light to the
completion of the required movement.

The practice schedules were then varied between high and low levels of interference.
All subjects practiced the three requisite tasks an equal amount, but the order was varied.
The high interference group was given a random practice schedule whereas the low
interference group was given a blocked schedule, where all eighteen trials of each task
were practiced before continuing on the next block. Each participant performed a total of
54 trials during the acquisition period. Following acquisition, participants were given
either a ten-minute or ten day retention test. In both cases, participants were given both
blocked and random schedules for the retention test. Two transfer tests were given
following the retention trials, where one skill was considered novel and of equal difficulty and the other was novel with increased difficulty due to increased number of segments.

For the most part, the results supported Battig’s (1972) findings. During acquisition, the blocked group performed better than the random group although the performance of the two groups converged by the end of practice. For the ten-minute retention test, regardless of retention schedule, the random group outperformed the blocked group. During the ten-day retention test, the random acquisition/blocked retention group performed the best, but the blocked acquisition/blocked retention group outperformed the random acquisition/random retention group, contrary to Battig’s (1979) conclusions. The transfer tests did, however, follow the interference conclusions as the random group surpassed the blocked group in both retention tests.

Shea and Morgan (1979) were the first to investigate the contextual interference effect with regard to motor skills, and they were able to demonstrate that this effect applied to motor skills in several ways. Primarily, a high level of interference was shown to inhibit acquisition and later aid retention. Also, the study was able to support Battig’s (1979) contention that higher levels of interference eliminated contextual dependency. The random group was able to maintain performance when the retention scheduling was switched to blocked whereas the blocked acquisition group performed poorly when the retention test was given in a random manner. In addition, the transfer tests illustrated that the random group could adapt to novel tasks, regardless of relative difficulty. The authors offer an explanation similar to Battig’s in the sense that the random schedule required multiple levels of processing in order to acquire the task. This deeper processing led to delayed acquisition, but increased retention, regardless of context or delay.
The results found by Shea and Morgan (1979) then sparked a line of research that still continues today. While the contextual interference effect was the common topic of interest, the results were found to vary. Many of the studies replicated the barrier knock down task (Shea and Morgan, 1979) completely, while others used variations of the task or created a task of their own. It has been hypothesized that the demands of the task could possibly account for the variability in the results (Magill & Hall, 1990).

The variations of the barrier knock down task involve changing the timing goal of the segments. Originally, Shea and Morgan (1979) required subjects to complete the task “as quickly as possible”, and did not place any time restraints on the specific segments of the movement. Later studies replicated this work (e.g. Lee & Magill, 1983: exp 1 and 2; Shea & Zimny, 1988; Wood & Ging, 1991), while others chose to set a criterion movement time for the task (Gabriele, Hall & Buckolz, 1987; Gabriele, Hall & Lee, 1989; Lee & Magill, 1983: exp 3; Proteau, Blandin, Alain & Dorion, 1994). In both cases, the results for acquisition and retention were found to be similar to the original work.

Other researchers have also chosen to investigate this phenomenon using very different tasks. Studies have required participants to take part in anticipation tasks (Del Rey, 1982, 1989; Del Rey, Wughalter & Whitehurst, 1982) as well as force replication (Shea, Kohl & Indermill, 1990). The interesting point to note about the final study is that an open loop task was used to test their hypothesis. The authors believed that a barrier knock down task inherently offered concurrent feedback due to the nature of the task. By using a force replication task, the movement was rapid and therefore, feedback was not available to the participant unless provided by the experimenter. In addition, the study
sought to determine the impact of increasing the number of trial on retention. The results indicated that the retention effect was not only affected by the practice and retention schedules, but also by the amount to which the task was practiced. The authors found that after only 50 practice trials, the blocked group performed better under a random retention schedule, but as the number of acquisition trials increased to 400, the random practice groups performed better regardless of retention schedule. Another interesting point to note is that the blocked practice group actually performed worse under a random retention schedule as acquisition trials increased. The results in this study support the idea that increasing the amount of contextual interference can enhance retention but sufficient practice is necessary.

While strong evidence has been presented for the existence of the contextual interference effect, support has not been universal. For example, in a study performed by Whitehurst and Del Rey (1983), the contextual interference effect was not found in retention or transfer. The study required participants to complete a rotary pursuit task that was varied using different speeds of the turntable. Similar results were found by Turnbull and Dickinson (1986) where a limb-positioning task was used. These results illustrate that the contextual interference effect is not universal and that situations do exist where practice schedules do not seem to have an effect on retention or acquisition.

**Generalizability of the CI effect**

Results such as these have led to some authors proposing that the amount of interference created by practicing variations of a task depends on whether or not these variations are controlled by the same or different motor programs. To understand this hypothesis, it is necessary to examine the work done by Schmidt (1975, 1988). In
Schmidt's schema theory, it is argued that a motor program is a memory representation of a specific class of movements. Certain invariant features then define these classes. Specifically, Schmidt (1988) suggested certain movement characteristics such as the relative timing, the relative force and the sequence of the events. If several actions share these characteristics, they can be considered to be in the same class of movements, and thus are controlled by the same generalized motor program.

Since there are obviously an innumerable number of ways to complete a task while keeping the aforementioned invariant features constant, Schmidt describes the concept of parameter modification. These characteristics are the overall duration of the movement, the overall force, relative size of the movement and the muscle groups utilized. In other words, if these features are altered, the same motor program is used, but the parameters are altered to create a different movement.

In their discussion of Schmidt's schema theory, Magill and Hall (1990) give an example that helps explain this concept. If a participant is practicing throwing a ball at a target and they use three different throwing patterns, such as overhand, sidearm and underhand, they are utilizing three different motor programs because different movement patterns are being used to complete the task. On the other hand, if the participant throws the ball at the target with the same throwing pattern but with varying speeds, the same motor program is being used but the parameters of overall force and duration are being altered. In both cases, the goal of the movement is the same, but the movement is altered in a different fashion.

Under this theory, it has been proposed that whether or not a variety of movements stem from the same motor program determines the effect of contextual interference.
(Magill & Hall, 1990). The hypothesis is two-fold. First, if a series of movements stems from the same motor program, then the contextual interference effect will either not be seen in a blocked versus random practice schedule, or a mixed schedule of blocked followed by random practice will lead to the best results. In order for this to occur, the task would be varied so that the relative timing, sequence or spatial configuration remained the same. Support for this can be found in experiments whose task involved parameter modification of a task (Whitehurst & Del Rey, 1983; Pigot and Shapiro, 1984; Turnbull & Dickinson, 1986).

The second half of the hypothesis put forward by Magill and Hall (1990) is that when the movements to be learned are controlled by different motor programs, the contextual interference effect will be present. The invariant features of the task are modified (e.g. sequence of movements in barrier knock down task, Shea & Morgan, 1979), and different motor programs are required to complete each variation. It was suggested that by doing this, the variation in practice schedules created different levels of contextual interference. In turn, this increase in contextual interference resulted in different amounts of task difficulty. When the task becomes more difficult (random practice as compared to blocked practice), higher levels of retention and transfer are achieved. Support for this part of the hypothesis can be found in several experiments that involve different multi-segment tasks (Shea & Morgan, 1979; Gabriele et al., 1987; 1989; Lee & Magill, 1983; Shea et al., 1990).

One important study to note is by Wood and Ging (1991), who looked directly at the concept of task similarity. In a task similar to the barrier knock down task, participants were required to complete a given aiming pattern as quickly as possible. The groups were
either given high similarity (different sizes of the letter ‘N’) or low similarity (different spatial configurations) tasks and practiced in a random or blocked schedule. As predicted by the previously mentioned hypothesis, (Magill & Hall, 1990), the contextual interference effect was only seen in the group that performed the tasks with low similarity.

The heart of this hypothesis lies in the concept of task difficulty. By having different motor programs controlling different variations, the task difficulty is greater than parameter changes in the same motor program (Magill & Hall, 1990). Battig’s later work discussed this idea and proposed that the contextual interference effect could be a function of the difficulty of the task (Battig, 1979). The authors return to the example of throwing a ball at a target and contend that using three different throwing styles (i.e. three different motor programs) is more difficult than changing only the speed of the ball (i.e. three parameters). Through the use of different motor programs, each variation requires the participant to restructure the essential features of the task, and thus increases inter-task difficulty. By this logic then, the contextual interference effect could be seen in parameter modification provided sufficient inter-task difficulty is established.

While this hypothesis offers a possible explanation as to what aspect of the task creates the effect, it still does not discuss the mechanism within the system that causes the differences in acquisition and retention. There has been little disagreement as to the fact that the cause is most likely cognitive (Shea & Morgan, 1979; Lee & Magill, 1983; Shea & Zimny), and Gabriele et al. were even able to demonstrate the contextual interference effect through mental imagery practice. Several explanations have been offered but it does not appear that a definite answer has been reached.
**Elaboration explanation**

When he completed his work on the contextual interference effect, Battig (1966, 1972, 1979) not only described his findings, but also offered an explanation. He believed that the increases in retention and transfer was due to an increased number and variety of encoding processes that were not present during trials of low contextual interference. Battig contended that through the use of different strategies, the distinctiveness and elaborateness of the memories were increased. In the typical high interference schedule (i.e. random), several tasks are present in working memory. If this is true, the participant has an opportunity to strengthen the memory representation of the task by comparing it to the other variations at every trial. Since the to-be-learned tasks are different, the memory can be strengthened by these contrasts. Also, it is suggested in this explanation that due to the different strategies used to learn these tasks, the learner has several pathways to retrieve the memory and that memory would be more distinct than the other task memories.

Research by Shea and colleagues supported this theory (Shea & Morgan, 1979; Shea & Zimny, 1983; 1988), and gave an explanation that was specific for motor skills. In agreement with Battig's work (1979), the researchers proposed that it was the increased distinction and elaboration of the memory that caused the increase in retention and transfer. In a high contextual interference situation, several skills are present in working memory and force the learner to use various strategies to process the information. Not only does this create the possibility for the learner to compare intra-skill trials, but the opportunity to compare inter-skill trials, thus strengthening the memory representation of
the skills. This explanation is very similar to the original, but was devised in order to be applied to the learning of motor skills.

Further support for this idea involved the use of explicit memory tests. The idea of intention to learn was a variable that Morgan (1981) examined to test the elaboration explanation. By informing the participants that they were going to be tested, retention was facilitated for both practice schedule groups in a multi-segment task. This was interpreted by Shea and Zimny (1983) as support for the explanation claiming that intention to learn created the opportunity to elaborate on the skills learned. In similar work, (Zimny, 1981; Shea and Zimny, 1988) used verbal reports to shed some light on the strategies used by the participants. This information illustrated that learners under random practice used various strategies and made multiple comparisons between tasks in order to facilitate learning. In contrast, the blocked group reported signs of almost automated responses and very few processing strategies. The authors conclude that the comparisons and multiple strategies used in random practice resulted in more elaborate processing and stronger memory representations.

While verbal reports do seem to offer evidence for the elaboration explanation, there has been some contention as to the accuracy of these accounts (Nisbett & Wilson, 1977). In an effort to re-establish this evidence, a study was performed by Wright (1991) that required participants to engage in additional processing between trials during blocked practice. The concept was that if the effect during the random schedule was due to an increased amount of processing, the group with additional inter-task processing should show better retention than a group involved solely in blocked practice. The results
illustrated that retention was in fact enhanced when increased processing was required and could be interpreted to support the elaboration theory.

**Action Plan Reconstruction Theory**

A separate explanation of the contextual interference effect was presented by Lee and Magill (1983; 1985). Their argument was that, instead of an increased amount of elaboration, high levels of interference caused specific information concerning execution of a task to be forgotten due to the intervening practice of the other variations of the skills. It was hypothesized that the information concerning the ‘action plan’ that is constructed previous to initiating a response is what is lost and deeper processing is required to complete each trial. This concept is based on a line of work performed by Jacoby and colleagues (Jacoby, 1978; Jacoby & Dallas, 1981; Cuddy & Jacoby, 1982).

The statement that “forgetting helps remembering” (Cuddy & Jacoby, 1982) seems to contradict itself, but it is actually an observation about the spacing effect. When several practice trials of the same task are separated by a large number of intervening trials, the forgetting that occurs tends to benefit later recall as compared to several trials that practiced consecutively. The belief is that the amount of processing during a skill depends on what is remembered from the last time it was processed. If the material has been forgotten, then the information will be more fully processed than if a strong memory representation existed. The central issue here is that the strength of a memory representation depends on the number of times that the information is fully processed. In terms of contextual interference, random practice promotes “forgetting” due to the intermittent nature of the schedule. The previous action plan needs to be discarded in order to perform the skill in the current trial and then later reconstructed when that skill...
appears again. For the blocked schedule, very little processing needs to be performed prior to performance because the correct action plan is already in working memory from the previous trial. This lack of processing and easy availability of action plans not only explains the poor retention but also accounts for the increased performance in acquisition. In terms of Schmidt’s Schema Theory (1975), the action plan is based on the selection of a motor program and the correct parameters. This is performed prior to the initiation of the response, so when certain parameters are forgotten, more effortful processing is required to create the action plan and a stronger memory representation is formed as a result.

This action plan reconstruction view was conceived based on the non-repetitive nature of the random schedule. One experiment (Lee & Magill, 1983) replicated the interference effect with blocked and random practice, but also added a serial schedule group, where different variations of the task were practiced in successive trials. According to the elaboration theory, the serial group would perform between the blocked and random groups during retention because the predictability of each trial would reduce the cognitive effort needed to perform the tasks. The results showed that the serial group performed similarly to the random group, a finding that led the authors to offer these findings as support for the reconstruction view.

In a later study, Lee, Wishart, Cunningham and Carnahan (1997) approached this theory from a different angle. The authors used both blocked and random practice, but also added a group called “random plus model”. In this group, the participants practiced in a random order, but before each trial, visual and auditory information was given concerning the nature of the next response. The idea was that this information would
serve to guide the performer and reduce the reconstruction efforts normally afforded to this group. In acquisition, this group performed well, similar to the blocked group. In retention however, performance was hindered in both immediate and delayed tests. By using the information provided, the normal effects of a random schedule were negated as seen in the performance in both acquisition and retention.

Finally, the question arises as to the effect of invariant feature changes compared to those of parameter alterations. The prediction offered by Magill and Hall (1990) states that the level of the interference would be based on what is changed between task variations. If different motor programs are used, then a robust effect will be found. If only parameters are varied, then the effect would be reduced, but still possible based on the scale and number of parameters changed. Research on this prediction has been conducted and so far, the evidence supports the reconstruction hypothesis (Hall & Magill, 1995; Lee, Wulf & Schmidt, 1992; Wulf & Lee, 1993).

**Retroactive Interference**

A different view concerning the contextual interference effect examines that the possibility that a blocked schedule creates a disadvantage compared to a random schedule. The main concept in this theory is the interference between variations of the task to be learned. In a blocked schedule, where A, B and C are the tasks to be learned, it is hypothesized that retroactive interference may affect the retention performance of A and B while proactive interference may affect the retention performance of B and C (Meeuwsen, 1987). These authors demonstrated this by providing a retention test after each block, and comparing it to normal blocked and random schedules. The results showed that retention after each block was better than a normal blocked practice with
retention tests at the end of all blocks, and similar to the random schedules. Through research using methods that varied the retroactive interference, some support has been given for this theory (Del Rey, Liu & Simpson, 1994; Shea & Titzer, 1993).

While several explanations as to the control mechanisms behind the contextual interference effect, there is still debate concerning the cause. Since there are a variety of situations that the effect has and has not been seen, it has been suggested that the different hypotheses should not be seen as competing but rather as complimentary (Schmidt & Lee, 1999). Also, it has been established that the effect is certainly not global in nature, so the characteristics of these boundaries as well as the underlying causes need to be established in order to truly understand this concept.

Knowledge of Results

Knowledge of results (KR) has been found to be one of the most important factors in the acquisition and retention of a skill (Bilodeau, 1966; Newell, 1976). For the purpose of this review, it is defined as verbalizable, terminal augmented feedback about the outcome in terms of the environmental goal (Schmidt & Lee, 1999), which means that it is an outside source of information that is provided once the task has been completed. An important point to note is that the information presented concerns the outcome of the movement, rather than the quality of the movement itself (known as knowledge of performance).

KR research traces its roots back to the implementation of instrumental conditioning theories by Thorndike (1927) on human learning. The theory is based on the idea that a certain behavior of an animal could be elicited by the immediate presentation of a reward.
The concept behind this was that an association was formed between the desired response and the reward so that the animal learned to give the response more frequently. The larger the number of practice trials given, the stronger the association and more likely the animal would respond in the desired fashion. The important points to note are that the conditioning stimulus was not always present and that the presentation of that stimulus depended on the response of the animal. This creates a situation where the animal's response is reinforced, but is still voluntary. The strength of this association was then tested by measuring its resistance to extinction. This was done by removing the conditioning stimulus (the reward) and measuring how many trials took place before the conditioned response was eliminated.

Thorndike (1927) took the concept of instrumental conditioning and applied it to learning in humans. Over a period of nine practice sessions, participants were required to draw lines that varied in length from three to six inches. The participants received KR during all sessions except for the first and the last. With KR, there was a noticeable improvement in performance, but later deteriorated during the final no-KR trial. Thorndike believed that learning occurred through the strengthening of the connection between the movement goal and the movement, and that the presentation of KR increased the likelihood of a correct response. Also, this connection was believed to be unconscious and that each correct response would strengthen this connection. While it was not Thorndike's intention to study motor learning and the effects of KR, this is the origination of the KR/no-KR paradigm. While this line of research was intended to measure the eventual extinction of the behavior, this paradigm has been used almost universally to measure the quality of the behavior in later motor learning experiments.
One of the first problems encountered in this line of research was whether or not KR affected the learning of a skill or simply altered the current performance. Learning has been defined as a set of internal processes that result in a relatively permanent change, due to practice or experience, in the capability for responding (Salmoni, Schmidt & Walter, 1984; Schmidt and Lee, 1999) whereas performance effects can be considered more transient and have been shown to be affected by the state of the learner (Poulton, 1973; Payne, 1970; Payne & Dunman, 1974) or the guidance effect of KR (Armstrong, 1970). It has also been shown that the presentation of KR has a motivational effect where the learner becomes more interested in the task and persists longer after the KR has been removed (Arps, 1920; Elwell & Grindley, 1938). Support for the idea that KR is a learning variable has also been found in comparing groups that either received KR or not (e.g. Bilodeau, Bilodeau & Schumsky, 1959).

Through the use of Thorndike's (1927) KR/no-KR paradigm and what is called a retention test, the two effects can be separated. During, the first phase of the experiment, known as acquisition, the groups are presented with a task, and KR is varied in whatever way the experimenter chooses. Differences between groups cannot be attributed to learning because of the possible confound of performance effects. To remedy this, a retention test is used, where all groups are brought to a common level of the independent variable (i.e. the KR manipulation). In most cases, the transfer test is a no-KR test that is delayed in order to dissipate the temporary effects of KR. Not only does the elimination of KR to the participant reduce the temporary effects of KR, but it also helps stabilize the responses of the participant. Without KR, learning becomes attenuated and helps illustrate whether or not learning occurred during acquisition.
Once a methodology that measured possible learning rather than performance enhancement had been established, researchers began to alter different aspects of KR in order to determine the effect it had on the learner. The body of research on this subject is quite extensive and will be divided into the following three sections: precision of KR, scheduling of KR and interpolated activities during KR intervals. While the various subdivisions only examine different aspects of the same concept, no one salient feature has been found to be the critical factor in enhancing learning with KR.

**Precision of KR**

The precision of KR involves the amount of accuracy in the information given. This aspect of KR can be manipulated through the type of information that is presented or the criterion that determines whether or not KR is given. In both cases, it is the accuracy of the information that is being manipulated.

One of the most basic manipulations of precision is through the use of qualitative or quantitative information. Trowbridge and Cason (1932) conducted an experiment where the experimental groups either received qualitative (i.e. right/wrong) or quantitative (directional error) information concerning their response. In both acquisition and retention, the quantitative group outperformed the qualitative group, and both groups outperformed the no-KR control group. KR was shown to be beneficial for learning and that quantitative information was more useful, possibly due to its more accurate nature. These results have been tested and replicated in several studies (Reeve, Dornier & Weeks, 1990; Salmoni, Ross, Dill & Zoeller, 1983) as well as the finding that increased precision leads to more accurate performance, to a point (Salmoni et. al., 1984).
Another manipulation of precision is with the criterion that KR is given. Based on the accuracy of the response or the demands of the participants, KR may not be given on every trial. Response based KR, known as bandwidth-KR, varies the type of KR received based on the performance of that trial. If within a certain range of the correct response (usually given in a percentage), the KR is qualitative (i.e. "correct"). If outside that range, then KR concerning the magnitude and direction of the error is given. One of the first studies in this area used a timing task with two bandwidth groups (5% BW and 10% BW) and a control group (0% BW). The results on a no-KR retention test revealed that learning was positively related to bandwidth size (Sherwood, 1988).

A similar variation is learner-determined presentation of KR where, regardless of the outcome of the trial, the participant decides whether or not to receive KR. Work in this area allowed one group to request KR, while another group was given the same absolute amount of KR, but the schedule was determined by the experimenter. Results showed that retention is facilitated by learner-determined presentation (Chen & Hendrick, 1994; Hendrick & Chen, 1995). Both bandwidth KR and learner-determined presentation of KR are based on the idea that KR is most beneficial when necessary, as determined by the previous response. The significance of the KR could become more meaningful because of a sufficiently incorrect response or a demand from the participant. More research is needed in this area due to the dynamic nature of these manipulations and differences between participants.

**Schedule of KR**

Inherent to bandwidth and learner-determined KR, is the scheduling of the KR that is to be received. Only in situations where KR is given after every trial, or never at all is
there no opportunity for the schedule to be manipulated. This area of research not only focuses on the amount of KR that is given to a participant, but the frequency and order in which it is presented.

The first manipulation of scheduling involves the relative and absolute frequency of the KR. There have been large debates concerning this area due to the fact that certain confounds exist when frequencies are manipulated as well as what KR is actually used for when presented to participants. Research has been extensive but results have supported several conflicting theories.

Relative frequency has been defined as the percentage of trials that KR is given and absolute frequency refers to the number of KR presentation received during practice. In order to test the impact of one, it is important to keep the other one constant and the only way to do this is to alter the total number of practice trial. The confound that inherently exists is that any difference between groups in retention could be caused by the manipulated frequency, or by the changes to the total amount of practice in order to keep the other KR frequency consistent. Because of this, and the incongruous results, the effects of relative and absolute frequency are not completely understood.

The first to look at this problem were Bilodeau and Bilodeau (1958) using a knob turning task. KR was manipulated such that four groups received different relative frequencies, but the same absolute frequency by altering the total number of trials. The results illustrated that, during acquisition, there were no performance differences between the groups. This led researchers to believe that the no-KR trials were meaningless and had no effect on learning. Unfortunately, retention tests were not conducted to determine if the effects were transient or learning effects.
This problem was later remedied by including retention tests and keeping the total number of trials between groups constant. Not only was absolute frequency varied, but also the results from different studies seemed to contradict one another. One group of experiments suggests that a higher frequency of KR will result in better retention during a no-KR transfer test. Early information processing theories suggest that KR is used to test a hypothesis about the previous response and that each tested hypothesis strengthens the memory representation of the response (Adams, 1971, 1987; Schmidt, 1975). Therefore, this hypothesis testing can only take place when KR is present after each trial. When KR is removed, only what has already been learned can be strengthened (Adams, 1971). Thus, according to these early views, 100% KR will serve to maximize learning effects. Studies have been conducted that support this idea (Lee, White & Carnahan, 1990; Sidaway, Moore & Schoenfelder-Zohdi, 1991; Sparrow & Summer, 1992; Dunham & Mueller, 1993), and especially in complex tasks (Guadagnoli, Dornier & Tandy, 1996; Wulf, Shea & Matschiner, 1998). Even when reduced frequency groups were varied in the scheduling of KR, it was shown that a 100% KR group outperformed them in retention (Lai & Shea, 1999).

The more recent opposition to this view is based on what is known as the guidance hypothesis. It states that a high level of KR frequency can serve to guide the upcoming response (Salmoni et al., 1984; Schmidt & Bjork, 1992). When this happens, it is hypothesized that participants fail to use additional memory processes that could enhance memory development. A low level of processing combined with the continual presentation of KR allows the learner to decrease performance error, but may not allow for significant learning (Schmidt & Lee, 1999). The prediction from this point of view is

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that KR frequencies less than 100% will allow for the most learning and has been supported in the work of several studies that manipulated KR frequency during acquisition (e.g. Nicholson & Schmidt, 1991), summary KR (e.g. Schmidt, Young, Swinnen & Shapiro, 1989) as well as continuous concurrent feedback (Kohl, Fiscaro & Erbaugh, 1993; Schmidt & Wulf, 1997).

One possible explanation for these conflicting results may lie in what the performer is doing with the KR that they are receiving. Participants in all of the groups are simply given different schedules of KR and told to minimize their error. If Adams' (1971) idea that KR is used to test responses is correct, the participant must utilize the KR given to them in order to response test. Since none of the previously mentioned experiments instructed participants on what to do with the KR, different participant strategies may account for the difference in results across the various studies (Guadagnoli & Kohl, 2000).

**Interpolated Activities during KR Intervals**

The questions raised about what participants do between trials can be partially accounted for by forcing them to complete some sort of task. By using interpolated tasks, researchers can occupy the learner before KR is given as well as when no KR is provided at all. Using this technique, its possible to know what the participant is doing cognitively and examine the effects when the secondary task is related to or completely independent of the primary task.

One approach was to determine if any cognitive activity concerning the primary task by introducing interference before or after the presentation of KR. In a study by Shea & Upton (1976), participants were required to perform two movement tasks with KR...
delayed by 30 seconds. The two groups differed based on whether the KR delay interval was filled by other movements or rest. In both the acquisition and retention results, the unfilled KR-delay group outperformed the filled KR-delay group and these results have also been supported through the use of more complex skills (Marteniuk, 1986; Swinnen, 1990).

An interpretation of these results is that the pre-KR delay is necessary for some sort of information processing concerning the task to be learned. Marteniuk (1986) suggested that the secondary task required some higher level planning processing during the delay while others propose that the new task may cause the primary task to be lost from short-term memory (Schmidt & Lee, 1999). By losing the “feel” for the movement, the KR becomes less effective for comparison.

Similarly, research has been conducted by filling the KR-delay with information pertinent to the task to be learned. Researchers still require the participants to be occupied with a specific task, but that task is directly related to the primary goal. Hogan and Yanowitz (1978) either required participants to error estimate their responses prior to the presentation of KR, or gave them no instruction during the delay. In acquisition, there were essentially no differences between groups, possibly due to the guidance effect of the KR. In retention, however, the error estimation group maintained performance almost perfectly whereas the no estimation group became progressively worse. A possible explanation was that the added error estimation strengthened the memory representation by creating an error detection capability for the learner. This work was replicated more recently in a line of research by Swinnen and colleagues (Swinnen, 1990; Swinnen, Schmidt, Nicholson & Shapiro, 1990) where the original paradigm was extended to other
tasks and retention tests. Results from this line of research did support the original work performed by Hogan and Yanowitz (1978), but the findings were not universal. One problem that was discovered was the possibility that the no-estimation group was engaging in spontaneous estimation.

In a study by Guadagnoli & Kohl (2000), the concept of error estimation was extended past previous research. In earlier studies (Adams & Goetz, 1973; Hogan & Yanowitz, 1978; Schmidt & White, 1972; Sherwood, 1996; Swinnen, 1990), the estimation group outperformed the no-estimation groups during retention tests, but in all cases, both groups received a KR frequency of 100%. In contrast, this study not only manipulated error estimation, but also varied relative frequency of the KR received. This was done in order to determine if error estimation was the only salient feature that caused the increase in learning. The results demonstrated that the salient feature was not simply error estimation or KR frequency, but the interaction between these two factors. The 100% KR-100% estimation group performed the best during retention tests while the 100% KR-0% estimation group performed the worst. When the KR frequency was reduced (20% relative frequency), there was no difference between the two error estimation groups and the results were between the two 100% KR groups. The authors suggest that the differences in learning could be attributed to different amounts of hypothesis testing between groups (Adams, 1971, 1987; Schmidt, 1975). The 100% KR-100% estimation group created an error estimation after every trial that could be tested with KR statements. The 20% KR groups were not given nearly as much KR to test their estimations and the 100% KR-0% estimation group was most likely guided by the frequent KR because no post-trial estimation was required. The authors interpreted these
results to signify that KR is useful only when it serves to test a response hypothesis (i.e. error estimates) but will serve to guide future responses if a response hypothesis is not present (i.e. guidance hypothesis; Salmoni et al., 1984). The authors concluded that how one is engaged before receiving KR is not independent of how one uses that KR.

While the body of research is large, and KR has been called the single most important variable in learning (Schmidt & Lee, 1999), the underlying function of this variable can only be hypothesized. In a positive sense, KR has been considered to be informational, motivational and/or associational. Research has suggested KR can serve to reduce the uncertainty about the correctness of a response (Newell, 1991), increase the amount of practice through an increase in motivation (Schmidt & Lee, 1999) or create an association between internal commands and certain responses (Schmidt, 1975).

In contrast, certain aspects of KR have been identified that degrade learning. In the situation where KR is given on a very frequent schedule, the feedback can actually serve to guide the learner to the correct response. While this will obviously increase acquisition performance, retention becomes attenuated. Known as the guidance hypothesis, research has shown that reduced frequencies of KR actually facilitate learning as compared to a 100% KR schedule (Salmoni et al., 1984; Schmidt, 1991; Schmidt & Bjork, 1992). The concept is that too much KR prevents deeper processing during acquisition and other methods for error detection are ignored. Error detection can also be learned through internal processes but these inherent sources of information may be blocked due to the availability of KR. Finally, KR may also cause the participant to error correct when no correction is necessary. It has been suggested that when corrections are made on an essentially correct response may actually create a detriment in learning (Schmidt, 1991).
While KR has been identified as one of the most important features of learning (Bilodeau, 1966), there is debate as to the ideal presentation of it, based on precision, scheduling and what to do with the information. An important point to note is that the learner, the task and the environment all have an effect so there is no one ideal presentation of KR. Because of this, it is necessary to understand the mechanisms behind the effects of KR. Once these factors are understood more clearly, it will be possible to apply KR to individuals in the most efficient manner.
CHAPTER 3

METHODOLOGY

Participants

Participants were 40 volunteers from the University of Nevada, Las Vegas. All participants were informed as to the requirements of the task, but were naïve to the expected outcome. Informed consent was obtained prior to data collection and participants were debriefed upon completion of the experiment.

Design

The study was a 2(Acquisition Context) x 2(Error Estimation Frequency) between-subjects design. The two levels of Error Estimation Frequency were 100% and 0%. The 100% groups were required to evaluate their response-produced error after every trial. The 0% groups were not given any instruction concerning error estimation after each trial.

The two levels of Acquisition Context were Blocked and Random. All participants were presented with three blocks of 30 trials (90 total acquisition trials). For the Blocked groups, the same target timing sequence was presented thirty times within a block, but varied across blocks. The order in which each timing sequence was presented was counterbalanced across
participants. The Random groups were given acquisition trials on the timing sequences in an unsystematic sequence such that ten trials of each variation were presented in each block of 30. The sequencing was created such that no more than two trials of the same variation occurred consecutively.

The retention interval was 24 hours and all subjects performed one block of five trials at each of the three target timing sequences (total of 15 trials) under a serial pattern (A,B,C,A,B,C...). The dependant measures of interest were constant error (CE), variable error (VE) and a relative timing error measure termed AE(prop.). Absolute Error (AE = (Σ|X-T|/N) was used to determine the absolute deviation between the goal and actual total time of each trial. Variable Error (√(Σ(X-M)^2/N)) was used to determine the participant’s amount of variability around their own average score. Finally, AE(prop.) was taken from a study by Lai, Shea, Wulf, & Wright (2000), and this error term was computed as the sum of the absolute differences between the goal percentages and the actual percentages of the total time for each segment. This measure represents an estimate of the accuracy of relative timing performance.

Apparatus and Task

The apparatus used consisted of a Gateway 2000 microcomputer with a standard ‘QWERTY’ typewriter keyboard and fourteen-inch monitor. The monitor was positioned at the participant’s midline and approximately at eye level. The keyboard was positioned so that the required keys could be reached comfortably and easily.

The task was adapted from a study by Lee, Wulf & Schmidt (1992). The participant was required to sequentially press four keys (1, 2, 3, and 4) on the left side of a computer...
keyboard with the four fingers of their right hand. (Figure 1.) Prior to each trial, the goal time for each of the three movement segments was presented on the computer monitor. There were a total of three sequence variations to be practiced. In all cases, the total goal movement time was 900 ms. The participants were asked to be as accurate as possible with regard to the relative goal segment times. Feedback for each segment was presented after each trial under each of the goal segment times. If the participants pressed the keys in an incorrect fashion, the trial was removed, but not repeated.

Procedure

Prior to data collection, participants were assigned to one of four groups. The groups differed in terms of error estimation conditions (0% or 100%) and acquisition context conditions (blocked or random).

Upon arrival at the lab, the participant was asked to sit in a chair next to a table. A computer screen was in plain view and the keyboard was placed within reach at the edge of the table. The participant was instructed that the task was to press a sequence of keys (‘1’, ‘2’, ‘3’, ‘4’) so that the timing between key presses matched the target times presented on the computer screen. The target times ranged from 200 to 400 milliseconds (ms) for each segment. The goal of the task was to produce a timing sequence as similar as possible to the presented target sequence. The participant was further instructed that the response could be initiated once the target force was removed from the screen. Each response was then displayed as the actual time in milliseconds for each segment of the sequence, with the target sequence at the end of each trial.
Figure 1. Key Press Task
For all conditions, KR was provided after a delay of 8000 ms after the removal of the target sequence. The delay in KR presentation was assumed to be long enough to execute a response and process response-produced feedback. All participants were informed that the direction of the error would be helpful, but the goal of the task was to minimize the magnitude of the error. Once KR was presented, it remained on the screen for 4000 ms, and there was a 2000 ms delay before the presentation of the next sequence.

Participants in the 0% estimation condition were given no instruction as to what they should do during the inter-trial delay. Participants in the 100% estimation condition were asked to estimate their response-generated error after the completion of each trial. The participants estimated their error by determining whether each segment was too fast or too slow before KR was presented.

Participants performed the timing sequence variations for one day of three blocks of 30 trials (total of 90 trials), with a 90 second delay between blocks. The retention interval was 24 hours for one block of five no-KR trials at each of the three target forces (15 total trials). The participants were tested under a serial sequence and were not required to error estimate at any point during the retention test.
CHAPTER 4

RESULTS

Acquisition and retention data were analyzed independently and in all cases, mean AE, VE and AE (prop.) were used in the analyses.

Absolute Error

Acquisition data were analyzed using a 2 (Acquisition Context: blocked and random) x 2 (Error Estimation Frequency: 100% and 0%) x 18 (Block: 1-18) analysis of variance (ANOVA) with repeated measures on the last variable. The analysis revealed main effects for Error Estimation Frequency, F(1, 36) = 14.65, p<.05, and Block, F(17, 612) = 16.14, p<.05, with a decrease in error across blocks for all conditions (Figure 2.). This indicates that there was some sort of learning effect as practice progressed.

Retention data were analyzed using a 2 (Acquisition Context: blocked and random) x 2 (Error Estimation Frequency: 100% and 0%) ANOVA. The analysis revealed main effects for Acquisition Context, F(1, 36) = 8.97, p<.05 and Error Estimation Frequency, F(1, 36) = 11.40, p<.05. Analysis of main effects indicated an advantage for the Blocked groups over the Random groups as well as an advantage for the 100% groups over the 0% groups (Figure 3.). The Acquisition Context main effect is a less common variation of the CI effect and it can be seen that error estimation reduces error during retention.

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Figure 2. Acquisition-Absolute Error
Figure 3. Retention-Absolute Error

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Variable Error

Acquisition data were analyzed using a 2 (Acquisition Context: blocked and random) x 2 (Error Estimation Frequency: 100% and 0%) x 18(Block: 1-18) ANOVA with repeated measures on the last variable. The analysis revealed main effects for Error Estimation Frequency, \( F(1, 36) = 6.83, p<.05 \), and Block, \( F(17, 612) = 14.37, p<.05 \), with a decrease in error across blocks for all conditions (Figure 4.). Once again the gradual decrease in error suggests that there was some sort of learning effect present across practice.

Retention data were analyzed using a 2 (Acquisition Context: blocked and random) x 2 (Error Estimation Frequency: 100% and 0%) ANOVA. The analysis revealed main effects for Acquisition Context, \( F(3, 39) = 7.58, p<.05 \), and Error Estimation Frequency, \( F(1, 36) = 19.96, p<.05 \). In addition, a Acquisition Context x Error Estimation Frequency interaction was found, \( F(1, 36) = 7.25, p<.05 \), which indicates some sort of relationship between the two factors (Figure 5.). When estimation was required, the blocked advantage disappeared between groups and the two acquisition context groups performed similarly.

AE(prop.)

Acquisition data were analyzed using a 2 (Acquisition Context: blocked and random) x 2 (Error Estimation Frequency: 100% and 0%) x 18(Block: 1-18) ANOVA with repeated measures on the last variable. The analysis revealed main effects for Error Estimation Frequency, \( F(1, 36) = 29.17, p<.05 \), and Block, \( F(17, 612) = 4.45, p<.05 \). A Block x Error Estimation Frequency interaction was also found, \( F(17, 612) = 2.72, p<.05 \).
Figure 4. Acquisition-Variable Error
Figure 5. Retention-Variable Error
decrease in error across blocks for all conditions (Figure 6). Even though certain significant relationships were found, there did not seem to be any consistent improvement across trials, and it may be that relative difficulty was too great for this aspect of the task to be mastered.

Retention data were analyzed using a 2 (Acquisition Context: blocked and random) x 2 (Error Estimation Frequency: 100% and 0%) ANOVA. The analysis revealed a main effect for Acquisition Context, $F(1, 36) = 5.02, p<.05$ with the Blocked groups outperforming the Random groups. All other main effect and interactions failed significance (Figure 7.). What is interesting to note here is that regardless of whether or not the participant was required to error estimate, the differences between the Random and Blocked groups remained the same.
Figure 6. Acquisition-AE(prop.)
Figure 7. Retention-AE(prop.)
CHAPTER 5

DISCUSSION

The purpose of the current study was to determine the nature of the relationship between error estimation and contextual interference. Participants were required to either to estimate or not estimate their response-produced errors under random or blocked acquisition schedules. All four groups were then given a no-KR retention test where no instruction concerning error estimating was given. Performance was then assessed using AE, VE and AE(prop.).

As mentioned earlier, absolute error (AE) is a measure of overall accuracy in a task. In the current study, AE illustrated the average deviation from the total goal time, disregarding direction. Variable error (VE) is a measure of variability about the participant’s mean. This measure gives no indication of the performer’s accuracy, but rather evaluates the consistency of responding in regard to total movement time. Finally, AE(prop.) is defined as the sum of the absolute differences between the goal proportions and the actual proportions for each segment (Lai, Shea, Wulf, & Wright, 2000). This term demonstrates the accuracy of relative timing performance. Taken together, these terms made it possible to assess the consistency and accuracy of the total movement time as well as the correctness of the relative timing between each movement segment.
Possibly due to the fact that each error term represented different aspects of the data, different relationships were found to exist. During acquisition, there was a learning effect across trials for both AE and VE. As practice increased, there was a decrease in error with the most improvement occurring during earlier blocks. This effect is typical of contextual interference manipulations, but did not hold true for AE(prop.). Indeed, there was a great deal of variability across acquisition blocks rather than a progressive decrease in error through acquisition. Such a pattern suggests that the task was quite difficult and not well mastered in regard to the AE(prop.).

After a 24-hour delay, subjects completed a retention test consisting of one block of fifteen no-KR trials. This test was used to infer the amount of learning that resulted from acquisition practice. For all error terms, a main effect was found for acquisition context. In all cases, the groups that had trained under a blocked protocol performed superior to the groups that trained under a random protocol. The data also revealed an error estimation main effect with the groups required to error estimate performing superior to those who did not for both accuracy and variability of responding (AE and VE, respectively). No such main effect was found for AE(prop.)

Finally, an Estimation x Acquisition Context interaction was found for VE, with the blocked advantage being apparent for the no-estimation conditions but not for the estimation conditions. The blocked group outperformed the random group without estimation, but the groups performed similarly when estimation was required. It may be that there is a natural amount of response variability that prevented the blocked group to continue improving when estimation was required. Due to the fact that VE measures consistency, this inherent variability around the mean may have prevented the blocked
advantage from being maintained. It could be that this upper limit is reached by both
groups and any further improvement may not be possible across the fifteen trial retention
block.

The variety of results reported above is interesting because each error term represents
a different aspect of the data. Due to the nature of each dependent measure, it is possible
to draw conclusions as to how the groups relate to each other. For example, the
acquisition context main effect found across all groups revealed a blocked advantage
during retention. Although this blocked advantage has been seen elsewhere (e.g.,
Guadagnoli et al., 1999; Shea et al., 1990), it is less common than the random advantage
typically seen in contextual interference (CI) paradigms (e.g., Shea & Morgan, 1979). The
difference noted in the present experiment could be explained by the relative difficulty of
the task in this and other studies. Sometimes these differences are quite subtle in method
but dramatic in impact. For example, the current experimental design was based on a line
of research investigating the CI effect for relative timing tasks (Lee, et al., 1992; Lai,
Shea, Wulf, & Wright, 2000), and yet the results where quite different than the previous
study. In the both studies, participants were required to perform a key press task. In the
Lee et al. (1992) study one finger was used to press all keys, but in the current study, each
key was pressed by a different finger (i.e., four fingers were required to complete the
task). When AE and AE(prop.) values were compared across studies, performance was
worse for participants in the current study relative to Lee et al. (1992). This suggests that
the task variation used in the current study was more difficult than the one used in the
earlier studies. Since it has been demonstrated that with tasks of higher relative difficulty
a more blocked schedule is preferred (Guadagnoli et al., 1999), the increased difficulty in
the present study could account for the blocked advantage during retention. Other studies have shown that a blocked advantage can be created due lack of experience on the part of the learner (Guadagnoli et al., 1999; Shea et al., 1990). This notion is consistent with Gentile's (1972) stages of learning model where a more stable practice schedule (i.e. blocked) is recommended for beginners so that they can get the idea of the movement. Therefore, a blocked advantage is a form of the CI effect when task difficulty is relatively high. The results in the current study serve to support the idea that the CI effect is robust enough to be found across both conditions of error estimation.

AE(prop.) provides salient evidence for the relative task difficulty of the present experiment. There was a main effect for error estimation for AE and VE but not AE(prop.). A commonality between the first two error terms is that they are representative of the performance in regard to total movement time while AE(prop.) measures relative timing between movement segments. The total movement time is a more general aspect of the task compared to the relationship between each segment. In order to evaluate relative timing, participants would not only have to evaluate three segments per trial, but also compare each one to the other two. It is likely that this comparison was too difficult to carry out within the time allowed. Evaluation of total movement time should be relatively easier because only one estimation is required per trial and performance is always compared to the same goal movement time (i.e. 900 ms). In regard to Gentile's theory (1972), the current data are in line with the idea that beginners focus more on the framework of the movement rather than specifics. The AE(prop.) values did not change across estimation conditions possibly because the participants were not focusing on relative timing but the estimating groups did have an
advantage for the total time error measures, which indicates that the participants were at least error estimating about the total movement time. By altering the relative difficulty of the task through participant experience level or task difficulty, there may be a different effect on more specific aspects of the movement, such as relative timing errors.

In order for the relationship of the two factors to be examined, the original intent of the experimenter was to first establish a Random group advantage during retention so that the effect of error estimation could be analyzed during the most common form of the CI effect. The research by Lee et al. (1992) was used to derive the task used in the current study, but contradictory results were then found. This prevented a direct comparison of the typical CI effect with the current findings, but interesting conclusions can still be drawn. The blocked advantage found in the current study raised the issue of relative task difficulty during practice. Due to this new issue, the direction of the research changed slightly, but a more complex relationship was then found to exist due to this diversion.

In the current study, it was hypothesized that there would be an interaction between error estimation and the contextual interference effect. Through the use of various error terms, both interactions and lack of interactions were found between the four groups. However, with the adaptations from previous research, the current study found differences that apparently contradicted earlier findings (Lee, et al., 1992; Lai et al., 2000). The variation of the results between studies indicates that task difficulty and participant experience need to be taken into account. In previous studies, it has been shown that experience levels not only influence the CI effect (Shea, et al., 1990), but also affect a participant's ability to error estimate (Schmidt & White, 1972). Because of this, it may be that the effect of KR manipulations on acquisition context varies with
participant experience and task difficulty. In conclusion, the current data suggests that there is a relationship between the CI effect and KR manipulations that is also dependent on the relative difficulty of the task.
APPENDIX A

SAS OUTPUTS

data MO;
***ACQUISITION DATA AND ANALYSIS***;
input EST CI T1-T18;
cards;

(INsert DATA HERE)
;
proc anova;
   CLASS EST CI;
   model T1-T18=EST CI EST*CI;
   REPEATED TEST 18;
   MEANS EST/DUNCAN;RUN;
   MEANS CI/DUNCAN;RUN;
Proc sort;
   by EST;
run;

proc means N MEAN STDERR STDEV;
   by EST CI;
run;

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APPENDIX B

SAS OUTPUTS

AE ACQUISITION

The ANOVA Procedure

Repeated Measures Analysis of Variance
Tests of Hypotheses for Between Subjects Effects

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The ANOVA Procedure

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

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AE RETENTION

The ANOVA Procedure

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VE ACQUISITION

The ANOVA Procedure

Repeated Measures Analysis of Variance
Tests of Hypotheses for Between Subjects Effects
The ANOVA Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subject Effects

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VE RETENTION

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AE(prop.) ACQUISITION

The ANOVA Procedure
Repeated Measures Analysis of Variance
Tests of Hypotheses for Between Subjects Effects

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The ANOVA Procedure
Repeated Measures Analysis of Variance
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## APPENDIX C

### PRACTICE SCHEDULES

#### Acquisition Schedules

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General Information:

You are invited to participate in a study of motor behavior. You must be at least 18 years of age in order to be eligible and if you decide to participate, the experimental session will take a total of 40 minutes across two consecutive days of testing. The task that will be required of you is based on established research and your participation will help add to the body of knowledge in the field of motor behavior.

Procedure:

Essentially you will be asked to press several keys on a computer keyboard in a specific order and time. The goal is to minimize the amount of error between the required time and the actual time. Information concerning your performance on each trial will be presented and the trials will be divided into blocks in order to allow sufficient rest periods. At any time during data collection, you have the right to withdraw from the study and any questions you have will be answered after the completion of the data collection.

Benefits of Participation:

By volunteering for this study, you will have the benefit of being an active participant in the research process. In addition, the knowledge gained from this experiment will be communicated to you after the completion of data collection.
Risks of Participation:

During this study, you may experience some discomfort during data collection. If at any point, you have any concerns about the procedures, please let me know so that I may be able to answer your questions.

Contact Information:

If you have any questions, please ask the experimenter. A telephone number to call if there are any questions is (702) 895-1241. This telephone number is associated with the Motor Behavior Laboratory. Additionally, you may call the Office for the Protection of Research Subjects at (702) 895-2794 if you have any questions concerning your rights.

Voluntary Participation:

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your relations with the university. You are encouraged to ask questions about this study at the beginning or any time during the research study.

Confidentiality:

Any information obtained in connection with this study that can be identified with you will remain confidential. No reference will be made in written or oral materials that could link you to this study. All forms associated with this study, including this informed consent, will be stored in a locked cabinet at UNLV. If you give us permission by signing this document, we plan to publish the results in an appropriate journal.

Participant Consent:

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE BELOW INDICATES THAT YOU ARE OVER THE AGE OF 18 AND HAVE DECIDED TO PARTICIPATE HAVING READ THE INSTRUCTIONS AND INFORMED CONSENT. A COPY OF THIS FORM WILL BE GIVEN TO YOU.

_________________________________________  ________________
Signature of Participant                     Date

_________________________________________  ________________
Participant Name (Print)                     Experiment
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APPENDIX E

PARTICIPANT INSTRUCTIONS

0% Error Estimation Groups

The task that you will be asked to complete is a key press timing task. First you will be asked to place four fingers from your right hand on the ‘1’, ‘2’, ‘3’, and ‘4’ keys on the top left hand side of the keyboard. For each trial, you will see three numbers that represents the amount of time in millisecond that you need to wait between each key press. The goal of the task is to complete the sequence with the same timing pattern that is displayed on the screen. For example, you may see, ‘200-300-400’. This means that you need to press the ‘1’ key, wait 200 milliseconds, press the ‘2’ key, wait 300 milliseconds, press the ‘3’ key, wait 400 milliseconds and then press the ‘4’ key. You may start the trial once the three numbers have disappeared from the screen. After completing the trial, there will be a short delay that will then be followed by feedback on your response. The screen will display the original timing sequence and the values that were generated for each response. On the first day, you will complete three blocks of 30 trials. On the second day you will complete one block of fifteen, no-KR trials.

100% Error Estimation Groups

The task that you will be asked to complete is a key press timing task. First you will be asked to place four fingers from your right hand on the ‘1’, ‘2’, ‘3’, and ‘4’ keys on the top left hand side of the keyboard. For each trial, you will see three numbers that represents the amount of time in millisecond that you need to wait between each key press. The goal of the task is to complete the sequence with the same timing pattern that is displayed on the screen. For example, you may see, ‘200-300-400’. This means that you need to press the ‘1’ key, wait 200 milliseconds, press the ‘2’ key, wait 300 milliseconds, press the ‘3’ key, wait 400 milliseconds and then press the ‘4’ key. You may start the trial once the three numbers have disappeared from the screen. After completing the trial, you will be given time to estimate how well you performed on that trial. This will then be followed with feedback on your response. The screen will display the original timing sequence and the values that were generated for each response. On the first day, you will complete three blocks of 30 trials. On the second day you will complete one block of fifteen, no-KR trials.
REFERENCES


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VITA

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College of William and Mary

Publications:

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Thesis Examination Committee:
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Committee Member, Dr. John Mercer, Ph.D.
Graduate Faculty Representative, Dr. Carl Reiber, Ph.D.