

Cognitive Effort and Motor Learning

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Recent research on the role of practice variables during the acquisition of motor skills is reviewed. These practice variables include (a) the effects of a model's skill level during observation, (b) how augmented feedback is provided to a learner and (c) how practice conditions are arranged when learning multiple tasks. The results of research in these areas suggest that cognitive processes play an important role during the early stages of skill acquisition. Moreover, the effort by which these cognitive processes are undertaken is influenced by practice variables. Motor learning is enhanced when these variables are manipulated to promote cognitive effort by a learner.

Despite their best intentions, people sometimes tend to be lazy thinkers during practice. For instance, hitting a bucket of golf balls at the driving range can be monotonous. At times, the swing seems to go into "autopilot" - the mind takes a short rest, and individuals tend to repeat previously determined goals without giving the swing pattern much planning. On some days, much of the practice seems to be conducted on autopilot. What are the consequences of this type of practice?

Early theoretical views of motor learning suggested that the motor commands and the sensory feedback that resulted from the movement were all that needed to be stored in memory for learning to occur (e.g., Adam, 1971). By this view, thinking was not too important for purposes of motor learning. More recent views stress the role of cognition in motor skills (e.g., Magill, 1993b; Schmidt, 1988). In general, cognition refers to a collective group of thought processes. The hockey goalie tries to predict the direction of a shot by searching for perceptual clues that provide advance information. The golfer without a clear shot to the green tries to remember how to hit a controlled fade. The figure skater about to perform a triple axel jump followed immediately by a triple toe loop must prepare for this combined action with the flexibility in mind to change the plan if something goes wrong. All of these are examples of decision-making processes regarding the anticipation, planning, regulation and interpretation of motor performance.

Accepting that cognition plays an important function in performing motor skills, the question of the role of cognition during practice takes on more importance. Motor learning involves more than storing sensory and motor information that arises as a consequence of movement. Skill is highly cognitive (Starkes & Allard, 1993), and the cognitive processes that subserve movement must be practiced as well. Our goal in this paper is to highlight some selected issues of major learning research that illustrate the importance of cognitive processes during practice.

In this paper we present the differences that arise as a consequence of different practice conditions in terms of *cognitive effort*. In general, cognitive effort refers to the mental work involved in making decisions. In some cases, practice conditions result in more intense use of processing resources. In other cases research suggests that different types of decision-making processes are affected by practice conditions. Using cognitive effort as a focal point, one can view practice as an opportunity to either promote or impede the decision-making processes that underscore movement.

In this paper, we develop the concept of cognitive effort from research on three distinct areas of motor learning research. First, we review some recent findings from research on modeling that watching an unskilled model learn a motor skill can benefit the observer by providing a vicarious opportunity to join the problem-solving process. This section is followed by a review of some findings that augmented feedback can sometimes be presented in such a way as to be detrimental to learning. The final area of research suggests that, while drill-type practice conditions can facilitate improvements during practice, such conditions also result in poor retention and transfer. Collectively, these three areas of research suggest that learning is promoted when the practice conditions promote cognitive effort.

Model Skill Level and Observational Learning

Demonstrating a motor skill to a class of students is one of the fundamental tools in teaching. Despite a strong research base that supports the use of models, there are many instances in which the characteristics of the model determine its potential usefulness (McCullagh, 1993). For instance, few would challenge the assumption that experts in a motor skill make good models for the purposes of demonstration. But are experts always the best models to use?

Early theoretical support for the use of expert models was offered by Sheffield (1961). According to his view, symbolic behavior could be coded and modeled by means of a *perceptual blueprint*, a precise representation of the perceptual demands of the task. The purpose of the blueprint was to serve both as a representation of what to do and as a referent for making corrections. Observation provided a means by which the perceptual blueprint could be acquired, and Sheffield's theory provided a rationale for the use of experts as optimal models.

The use of expert models also has considerable pedagogical support, as one may discover from a visit to the sports instruction section of a video store. These tapes (on sports such as, golf, tennis, skiing, bowling, etc.) often feature a repetitive view of top-level athletes demonstrating a particular motor skill. But, are these types of video useful? There are both theoretical and empirical reasons to be skeptical.

In 1984, the United States National Academy of Sciences was asked by Army Research Institute to form a committee to investigate the value of various instructional techniques. One of the techniques investigated was a series of tapes known as *SyberVision*. The use of expert models from which to learn sport skills such as tennis, golf, or bowling was justified by their "neuromuscular programming" theory. According to the documentation provided by *SyberVision*, "the more you see and hear pure movement, the deeper it becomes imprinted in your nervous system ... and the more likely you are to perform it as a conditioned reflex" (cited in Druckman & Swets, 1988, p. 7; see also Devore, DeVore, & Michaelson, 1981). However, the committee found no specific evidence that supported these claims (see also Austin & Miller, 1992).

These conclusions, should not be all that surprising. The use of experts as models appears to encourage more the process of imitation than true learning through observation. When watching these videos, the observer is encouraged to mimic what the model has demonstrated. Bandura, a pioneer in the field of social modeling, discredits imitation as a method that minimizes the power of modeling. In his words, "modeling imparts conceptions and rules for generating variant forms of behavior to suit different purposes and circumstances. In skill acquisition, modeling is more accurately represented as rule learning than as response mimicry" (Bandura 1986, p. 48).

The repetitious nature of the skills demonstrated by experts in these videos also appears to imply that repeated exposure to a desirable performance will "stamp in" a representation of consistent, errorless performance. This assumption, however, appears to ignore the fact that errorless practice and role repetition are poor learning strategies (Magill, 1993b; Schmidt, 1988). Although research suggests that observational learning does occur using expert models, the findings suggest that a novice who is learning a motor skill can

also be an effective model. Although most of this research is recent, it was anticipated many years ago by Twitmyer (1931). He compared two groups of objects who learned to trace a pencil maze while blindfolded. Subjects in one group (the learning models), practiced the task on two different days. During his time, subjects in his second group (the observers) watched and recorded (the results of the learning models). These observers then performed the task on a third day. Since the learning models performed without previous observation of a model, their results were used as control data. The performance of the observers was better than the models' performance on the very first trial, and remained better throughout the learning session.

Although Twitmyer may have done the first study using unskilled models in an observation experiment, a study by Adams (1986) has sparked the recent search efforts. Similar to the Twitmyer method, a model practiced in the presence of an observer, after which the observer practiced the task. In Adams' study, the model practiced a movement timing task for 50 trials and observed under one of two conditions. The two groups of observers differed in terms of the augmented feedback provided while observing: one group received the movement time augmented feedback that was delivered to the model whereas the other group did not receive this additional information (this feedback was crucial for the model to learn the task). Adams found that the observers performed better than the models, with the best performance achieved by the observers who also received the models' augmented feedback.

But how effective is a learning model when directly compared to an expert model? A few studies have made this comparison, but the results are mixed.

Experiments by Weir and Leavitt (1990) and by Pollock and Lee (1992) found no differences due to the performance level of the model. For example, in the Pollock and Lee (1992) study, subjects watched a model perform 15 trials on a computer game that required pursuit tracking. The benefit due to previous observation was evident on the first post-observational trial, and this benefit remained throughout practice. There was no difference due to the model's skill level.

However, a study by McCullagh and Caird (1990) did find that performance after watching a learning model was better than after watching an expert model. McCullagh and Caird's task was similar to the task used by Adams (1986). Subjects conducted a series of six acquisition blocks. Each block included watching five performances of a model, followed by five performance trials. The different observation groups watched either an expert model or a learning model. While watching the learning model, groups of observers either received the model's augmented feedback after each attempt or did not receive the feedback (similar to Adams' method).

The findings of the observers' performance trials during acquisition, an immediate retention test, a retention test 1 day later, and a delayed transfer test (to a novel timing goal) are illustrated in Figure 1. The findings are clear. Observation of the learning model while also receiving the model's augmented feedback resulted in the best observational learning.

While studies comparing the value of expert versus learning models in acquiring sport skills has begun (McCullagh & Meyer, 1993), we can conjecture that at a minimum, observing a learning model will be no less effective than observing an expert model. In some circumstances, it may even be more effective. The skill level of the model has an impact on the observer's cognitive effort to learn from the motor behavior that was demonstrated. An expert model provides a precise representation of how a skilled action should be performed. However, a learning model more actively engages the observer in the problem solving processes that characterize learning (Adams, 1996). The observer can clearly observe the movement behavior of the model and the success of the model's subsequent attempts to reduce performance error. Indeed, observers have reported to us that it was difficult to suppress making comments to a live, learning model when the model failed to make an obvious correction of a movement behavior. One implication of this finding is that observing the possible errors that can be made on a task and the success of various attempts to solve these

errors provides a conceptual insight into the cognitive basis of the task to be learned. Such a process seems well suited to the skill observation process.

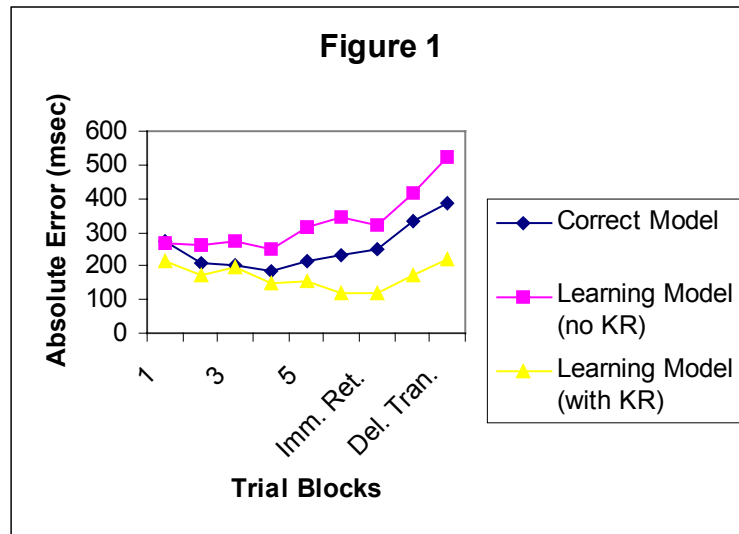


Figure 1 - Effects of model skill level on acquisition, retention, and transfer of a movement timing task. Note, From "A Comparison of Exemplary and Learning Sequence Models and the Use of Model Knowledge of Results to Increase Learning and Performance" by P. McCullagh and J. Caird, 1990, *Journal of Human Movement Studies* 18, p. 114 Copyright 1990 by Teviot Scientific Publications. Reprinted with Permission.

The Guiding Influence of Augmented Feedback

Augmented feedback refers to information that a learner does not normally receive directly from the senses. For example, a tennis player will know that the serve was not good because the ball hit the net. However, the exact reason for this result may not be obvious. Augmented feedback refers to making explicit something that might be difficult, if not impossible, to know implicitly. Usually this information is augmented by a teacher or coach using verbal statements or by means of visual aids.

In this way, the information is "fed back" to the learner (for reviews of augmented feedback effects in motor learning see Magill, 1993a; Swinnen, in press).

For years, researchers and educators seemed content with the following general view on the role of augmented feedback in motor learning: The use of augmented feedback is most effective whenever it is provided as soon after performance as possible, as often as possible, and in such a way as to reduce performance errors as efficiently as possible. That view was challenged a few years ago by Richard Schmidt and his colleagues (Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991).

Schmidt made some rather startling conclusions after reexamining some previously published experiments and conducting new studies. The first conclusion was that the general view on augmented feedback given above was based largely on data gathered during practice. Schmidt argued that this was weak methodology since changes during practice reflected temporary influences on performance and not always true learning effects. A better assessment of learning was provided by retention and transfer tests after temporary effects no longer exerted an influence on performance (see Schmidt 1988). The second conclusion was that if the augmented feedback literature was re-evaluated using retention and transfer data, the evidence pointed to a view that was quite different from the prevailing view. We begin by considering some of the augmented feedback

variables and their effects on learning, then describe Schmidt's ideas about the guiding role of augmented feedback on motor learning.

Error Estimation and Temporal Delay

One view for optimizing the benefits of augmented feedback was to present the feedback as soon after movement as possible. Findings by Swinnen, Schmidt, Nicholson and Shapiro (1990) indicated a different interpretation. In these studies, augmented feedback was provided either instantaneously with the completion of a movement or after an 8-second delay. Subjects that received this short delay during practice either sat silently during the interval or attempted to estimate the magnitude of the augmented feedback that they were about to receive. Learning was assessed when subjects again performed the task 10 minutes and 2 days after the practice period. All groups performed without augmented feedback during these retention tests.

Results from one of the experiments in the Swinnen et al. (1990) studies are illustrated in Figure 2. There was little difference between the groups during the practice (acquisition) period. However, a pattern of results began to emerge after 10 minutes that was further clarified on the 2-day retention test. This pattern of results indicated (a) relatively good retention following practice in which estimation of the augmented feedback was made during the delay period and (b) relatively poor results for the group that was given instantaneous augmented feedback. The delayed group performed at an intermediate level. These findings not only argued against the prevailing view of providing feedback as soon as possible after a movement but suggested that, in fact, such a procedure could be detrimental to learning. Moreover, the results suggested that estimating the magnitude of the error prior to receiving the augmented feedback had an additional benefit to learning beyond that of simply delaying the feedback.

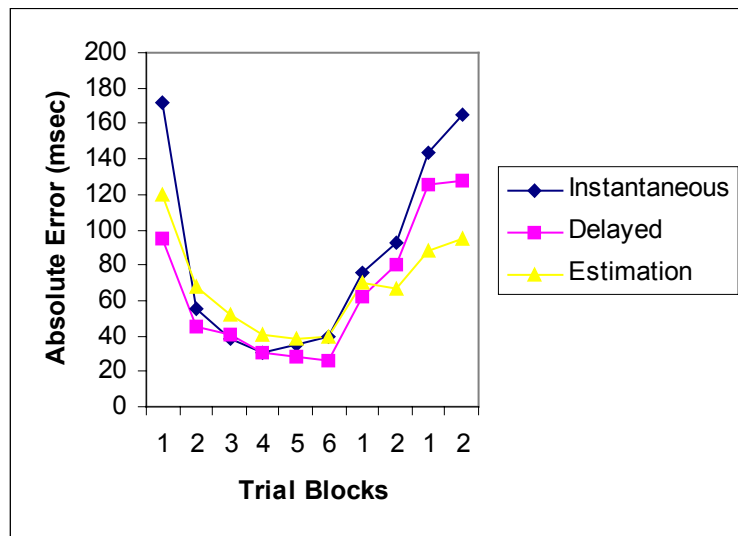


Figure 2 - Effects of augmented feedback when provided either instantaneously, after an unfilled delay period, or after a delay during which an estimate of the feedback is made. Note from "Information feedback for skill Acquisition: Instantaneous Knowledge of Results Degrades Learning" by S.P. Swinnen, R.A. Schmidt, D.E. Nicholson and D.C. Shapiro, 1990, Journal of Experimental Psychology: Learning, Memory and Cognition, 16, p. 709, Copyright 1990 by American Psychological Association. Reprinted with permission

Summary Feedback

Summary feedback is related to the temporal delay of feedback discussed above. In this method, feedback is delayed until after a series of trials have been completed; feedback is then provided in a manner that summarizes the receding trials (Lavery 1962). An experiment by Schmidt, Young, Shapiro and Swinnen (1989) illustrates the effects of summary feedback

Subjects in this study were divided into four groups according to the number of trials that were summarized on a graph and presented to the subject as augmented feedback. In the "Sum 1" group, feedback was provided after every trial. In the "Sum 5", "Sum 10" and "Sum 15" groups, feedback was provided on a graph about the 5, 10 or 15 preceding trials, illustrating how performance either changed or remained consistent over trials. Immediate and delayed tests of retention followed the practice period.

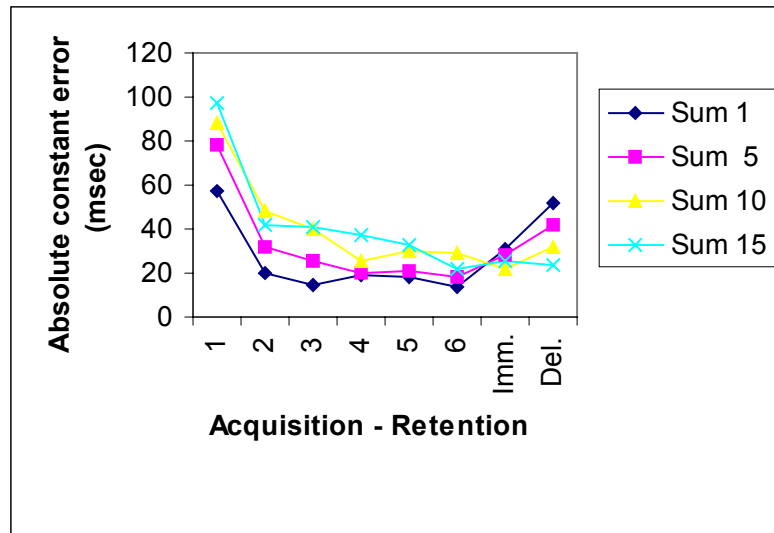


Figure 3 - Effects of augmented feedback when provided as a summary of the preceding 5, 10, or 15 trials. Note. From "Summary Knowledge of Results for Skill Acquisition: Support for The Guidance Hypothesis" by R.A. Schmidt, D.F. Young, D.C. Shapiro and S. Swinnen, 1989, Journal of Experimental Psychology Learning Memory and Cognition, 15, p. 355. Copyright 1989 by American Psychological Association. Reprinted with permission

The results are illustrated in Figure 3. Two sets of findings are important. First acquisition performance was negatively related to size of the summary; the larger the summary the poorer the acquisition performance. Second, delayed retention performance was achieved by the "Sum 15" and "Sum 10" groups, and the worst performance by the "Sum 5" and "Sum 1" groups. These findings are particularly interesting because of the opposite effects that the summary conditions had on the practice performance and on learning and because of the direct findings to teaching sport skills (Wright, Snowden & Willoughby, 1990), .

Relative Frequency

The frequency of providing augmented feedback was another of the prevailing views that was challenged by Schmidt. The belief (e.g., Bilodeau 1966) was that the absolute frequency of augmented feedback (i.e. the number of times that feedback was provided) was a critical variable in learning, but that relative frequency (the ratio of feedback-provided trials to the total number of trials) was not an important variable for learning. However, much of the evidence to support this view was based on data from the practice period rather than from retention tests. In their review of this literature, Salmoni et al. (1984) found a few studies that included retention tests following relative frequency manipulations. Surprisingly, these studies showed that relative frequency might indeed be an important variable in learning - that low relative frequencies might be better than high relative frequencies of augmented feedback. Subsequent studies have since confirmed these effects (e.g. Lee, White & Carnahan, 1990; Winstein & Schmidt, 1990; Wulf & Schmidt, 1989).

An interesting corollary to the relative frequency effects has also emerged. Using a movement timing task, Sherwood (1998) provided subjects with augmented

feedback only when their errors exceeded certain tolerance limits about the goal. For one group of subjects, augmented feedback was provided on every trial (a "0% bandwidth"). For other subjects, augmented feedback was provided only when performance error was greater than +/- 5%, or greater than +/- 10% of the goal. By this manipulation, Sherwood also influenced the frequency schedule by which augmented feedback was provided (since feedback was not provided for trials on which performance was within the bandwidth limits).

Early in practice, when many errors occurred, the relative frequency of augmented feedback was fairly high. However, as performance improvements were made over practice, the relative frequency became less frequent. Performance on a retention test was best for the group that had received the 10% bandwidth and poorest for the 0% bandwidth group, with the 5% group performing at an intermediate level. At a minimum, these findings are consistent with the effects of reduced relative frequency, although it seems that the bandwidth manipulation has an additional learning effect (Lee & Carnahan, 1990). The other similarity is that "fading" the relative frequency of feedback over practice (giving frequent feedback early in practice and infrequently later) is both an effective strategy (see Winstein, & Schmidt, 1990) and one that occurs as a natural consequence of the bandwidth procedure (Magill, 1993b).

A Guidance Role for Augmented Feedback

Collectively, these findings have been interpreted by Schmidt as evidence in support of a guidance role (or augmented feedback (e.g., Salmoni et al., 1984; Schmidt, 1988, 1991). Although augmented feedback can be useful under the right circumstances, providing augmented feedback can be detrimental to learning under other conditions. In general, these conditions occur (a) when augmented feedback is necessary for learning to occur and (b) when augmented feedback is presented such that it guides the learner toward certain corrective actions. In these cases, the learner becomes too reliant upon the augmented feedback to correct movement errors. For example, the provision of instantaneous feedback during practice tends to detract the learner from interpreting intrinsic sources of feedback, such as vision and proprioception. Schmidt suggests that it is these sources of feedback that one must learn to interpret since they will always be available to the learner. Augmented feedback (such as the feedback received from a teacher) will not always be available (e.g., during a game). Indeed, the goal in most learning situations is for the learner to become independent of the teacher. Learning to rely upon the information provided by these people will ultimately be detrimental to achieving independence.

From a different perspective, the Swinnen et al. (1990) study showed that encouraging subjects to estimate their augmented feedback produced a benefit to learning beyond that achieved by simply delaying the instantaneous provision of the feedback. This suggests that the cognitive effort in attempting to learn to interpret one's own intrinsic feedback, in combination with augmented feedback, can be a potent influence on learning. Augmented feedback might be most beneficial to learning when it serves to augment the cognitive efforts in learning self-evaluation skills using the sources of information that will be available during competition.

Contextual Interference

Another intriguing research issue investigated in recent years is the contextual interference effect. This finding was first studied by Shea and Morgan (1979) and has been replicated many times since (for reviews see Chamberlin & Lee, 1993; Magill & Hall, 1990). In the Shea and Morgan (1979) study, two groups of subjects each learned these simple laboratory tasks. All aspects of the practice were identical with the exception of the order in which the tasks were practiced. Under the blocked order, all practice trials on one of the tasks were completed before another task was undertaken. This procedure is similar to practice "drills" because of the repetitive nature of the practice.

In contrast, the other group practiced the tasks in a random order, such that they were switching from one task to another throughout practice. The random order resulted in considerably more interference between tasks compared to a blocked order. Thus, it was not too surprising that random practice resulted in much poorer acquisition performance than blocked practice (see Figure 4). What was rather surprising were the results of these two groups on retention tests conducted minutes and days later. On both retention tests the random group performed better than the blocked group. These results resemble the findings of the summary experiment seen in Figure 3, in which the same conditions that led to poor acquisition performance also led to very good retention. However, in the case of random and blocked practice orders, it was not the manipulation of augmented feedback but the interference arising from the order by which the tasks were practiced that produced the results. Hence, the cause for the contextual interference findings has been

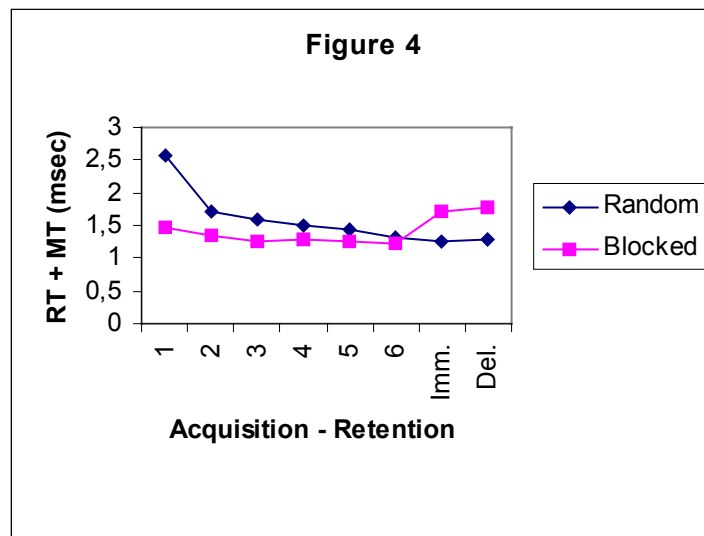


Figure 4 - Effects of blocked and random practice orders on acquisition and retention performance. Note. From "Contextual Interference Effects on the Acquisition, Retention, and Transfer of a Motor Skill" by J.B. Shea and R.L. Morgan, 1979, *Journal of Experimental Psychology: Human Learning and Memory*, 5, p. 183. Copyright 1979 by American Psychological Association Reprinted with permission.

discussed in terms of different theoretical constraints than described for the augmented feedback findings.

One account for the contextual interference effect (e.g., Shea & Morgan, 1979; Shea & Zimny, 1983) is that random practice encourages a learner to compare and contrast the methods and strategies used for performing the different tasks. Switching between tasks during practice provides the learner with better contrastive knowledge than the drill, repetitive-type practice that occurs under a blocked order. This contrast between tasks makes learning each task more distinctive and memorable, resulting in the advantages seen later in retention.

Another explanation for the contextual interference effect can best be described using an analogy. If you are asked to mentally multiply two numbers (e.g. $34 \times 26 = ?$), it would take some work, but could be done with effort. If the same question were asked a short time later, the answer could be given right away if the solution from the previous mental effort was still in working memory. If however, that answer had been forgotten, then the question would have to be solved again. Lee and Magill (1983, 1985) used a similar idea to explain the contextual interference effect. Random practice requires a learner to approach

a task by developing a strategy or plan of action. However, such a plan is inappropriate to maintain in memory since the task on the next trial is different. Thus, a new plan of action needs to be developed. By the time the previous task is performed again, the plan that had been developed for it last time has been lost from memory, and a new plan of action must be developed. This process continues throughout random practice. In contrast, the same plan of action can be used again and again during blocked practice since the same task is practiced repeatedly. The consequence is that having learned to develop a plan of action when necessary (under random practice) makes the learning both more memorable and better suited for novel performance simulations. Both theoretical orientations to the contextual interference effect have received quite a bit of empirical attention (for recent studies, see Shea & Titzer, 1993; Wulf & Lee, 1993). It is also interesting to note that there have been a number of experiments undertaken to examine the contextual interference effect in acquiring sport skills, and the findings appear to replicate the findings from laboratory experiments quite well. Practice and retention /transfer findings showing the "typical" blocked/random differences have been found for learning badminton serves (Goode & Magill, 1986; Wrisberg, 1991; Wrisberg & Liu, 1991) and in rifle shooting (Boyce & Del Rey, 1990). Most of the laboratory experiments and field tests of contextual interference effects have been conducted using subjects who were unskilled at the tasks to be learned. However, in a recent study, Hall, Domingues, and Cavazos (1994) found interesting contextual interference effects for athletes who had already achieved a high level of performance. In this study, college-level baseball players received two sessions of extra batting practice per week for 6 weeks. One group of subjects received 15 curve balls, 15 fast balls and 15 change-ups in a blocked order during each session. Another group of subjects received the same number and types of pitches in a random order. A control group of subjects received no extra batting practice. Scores (in terms of the number of solid hits) were recorded on a random pretest, on two practice sessions (Sessions 5 and 8), and on both a randomly ordered and a blocked ordered transfer test.

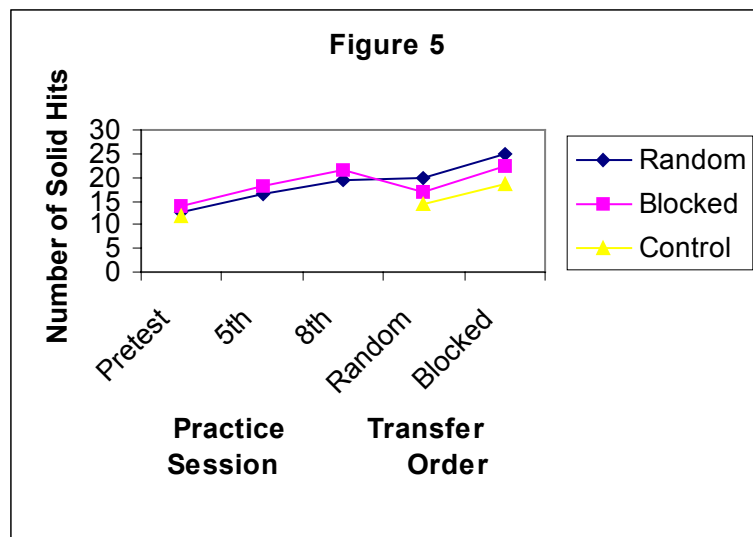


Figure 5 - Efforts of blocked, random and no extra practice on the batting performance of college-level baseball players. Note. From "The Effects of Contextual Interference on Extra Barring Practice" by K.G. Hall, D.A. Domingues and R. Cavazos, 1994, *Perceptual and Motor Skills*, 78, p. 838. Copyright 1994 by Perceptual and motor Skills. Reprinted by permission.

The findings from the Hall et al. (1994) study are illustrated in Figure 5. Several points of interest are notable. First, the extra batting practice improved performance as noted by the better performance on the transfer tests by both the random and blocked groups, compared to the control group. Second, performance during the practice sessions was generally better by the blocked group than for the random group. Third, transfer performance was better for the random practice group than for the blocked practice group, regardless of the order in which the transfer trials were conducted. The most exciting aspect of these results however, was that this "typical" contextual interference effect was found for subjects who had previously achieved a high level of performance on the criterion task.

Cognitive Effort

The three areas of research discussed above provide rather diverse examples of cognitive effort in motor skill learning. In each area of research we have provided examples that illustrate how conditions of practice either promoted or diminished the decision-making activities of the subject learning a motor skill. Some instructors feel that watching the expert execute the same sport skill time and again, with flawless precision, should engender some type of passive diffusion of that knowledge into the observer. The advantages seen by observing a learning model suggest an advantage gained through a rather different process. In this case, the observer is watching the model attempt a performance. If the observer is also able to receive some feedback about the success of that performance, then the observer is in the position to judge, independent of the model, what would be appropriate to do next. In short, the observer becomes actively involved, albeit vicariously, in the process of learning. The observer joins the learning model in the trial-and-error process.

Augmented feedback is a means of supplementing the sources of feedback normally available to an individual. As a source of information that complements the always present sources, augmented feedback serves a restrictive role. Optimally, augmented feedback should be used to help a person to interpret the sources of feedback that are always available. Augmented feedback should provide a knowledge referent, or "reliability check," to insure that intrinsic sources of feedback are correctly being interpreted. For example, the reasons for an errant golf shot are often available from watching the flight of the ball. How to interpret this intrinsic feedback, however, is something that must be learned (Miller, Cross & Barnhart, 1992). The optimal role of augmented feedback is to assist the learner to correctly interpret this intrinsic feedback.

For augmented feedback to serve its most useful role, it must be given in such a way that it helps without discouraging the performer from learning to interpret intrinsic feedback. Learning to interpret one's own intrinsic feedback requires cognitive effort. However, that learning can be weakened if the augmented

feedback serves a role in which it undermines the effort to learn to interpret one's own intrinsic feedback. There is no need for the learner to try to interpret the intrinsic feedback when augmented feedback is provided instantaneously upon movement completion and when it follows every trial. In a way, cognitive effort is suppressed, yet performance improves quite well without it. Encouraging the interpretation of performance, reducing the relative frequency (combined with performance bandwidths), and increasing the summary sizes of augmented feedback all positively impact the cognitive effort to interpret intrinsic sources of information.

Practice drills are good procedures for learning skills. However, many motor skills that are undertaken daily do not involve repetitive actions. This problem became clear recently when one of us was teaching a boy how to tie his shoes. The thought processes that he undertook in tying his shoes were clearly evident by the slow and deliberate actions of his fingers as work. These were repeated on the next shoe, but to a far less degree. We wonder what would have happened if he had been asked to keep practicing for 15 minutes. No doubt, success would have come more quickly and easily. However, would success have been achieved any easier the next morning? Evidence regarding the contextual interference effect suggests not.

Solving a problem by recalling a recent solution bypasses the cognitive effort involved in the decision-making process. When a task requires that these decisions be learned, conditions should be arranged such that these decisions are practiced. Arranging practice conditions that serve to avoid this cognitive effort hinders the learning process.

Learning motor skills involves also learning cognitive skills. We have provided three instances of research that collectively suggest that the cognitive effort expected during practice has a critical impact on the learning process. The functional independence of students and athletes lies in their ability to think and act on their own. Promoting that purpose in practice and training sessions is compatible with that goal.

A Caveat for Instructors

An interesting question was recently posed by Robert Bjork (in press): "if the research picture is so clear, then why are massed practice, excessive feedback, fixed conditions of training and limited opportunities for retrieval practice - among other non-productive manipulations - such common features of real world training conditions?". There are several answers to the question. One could be that the research picture is not all that clear. In this paper we have built an argument for the role of cognitive effort in learning motor skills based on a limited set of data. The generalizability of these ideas await further research. If the research picture is accurate however, then Bjork argues that nonproductive training manipulations continue to be used for at least two further reasons. One relates to the performance / learning distinction. Some of the temporary benefits to performance seen during practice favored the use of practice manipulations that actually resulted in poor retention. One example is contextual interference. If an instructor were to value a practice manipulation in terms of how quickly a standard of performance was achieved then blocked training would be seen as a much better arrangement of practice orders than random training. However, an appreciation for the assessment of learning in terms of retention and transfer (Magill, 1993b; Schmidt, 1988) would produce the opposite conclusion. Related to this same issue is the fact that instructors of training programs may only be involved with the learner for the period of time during which the practice occurs. Perhaps they are satisfied with the benefits to performance seen by their training methods, or perhaps they are not aware of the impact their training regimes have on longer term retention or transfer after their involvement with the learner has been completed.

The second reason given by Bjork (in press) for the continued use of nonproductive training conditions is due to the subjective experiences of the learner. Rapid improvements on a motor skill are reassuring, and the learner may develop illusions about time progress made on a skill as a result of conditions

of practice that favor rapid, short-term) benefits. These incorrect subjective sometimes anecdotal assessments tend to foster continued belief in the training programs. In contrast, training programs that are structured to promote cognitive effort during learning may not be given full value by the subjective experiences of the learner because of the decelerated rates of improvement that may occur.

For these reasons the instructor is faced with roles of both assisting the learner with the skill to be learned and educating the learner about learning.

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