What Is Repeated in a Repetition? Effects of Practice Conditions on Motor Skill Acquisition

The nature of repetition and its contribution to the acquisition of motor skills in neurologically healthy subjects are examined in this article. We argue that cognitive processing is a key component of practice, which is undermined by repetitive performances. The effects on motor learning of contextual interference, knowledge-of-results delivery schedules, and observation of models are examined, with particular reference to the nature of practice. The role of repetition in learning with respect to physical therapy is also discussed. [Lee TD, Swanson LR, Hall AL. What is repeated in a repetition? Effects of practice conditions on motor skill acquisition. Phys Ther. 1991;71:150–156.]

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We believe that one of the commonalities between movement science and physical rehabilitation is that motor improvement results from *repetition*. The concept of repetition in movement science, however, with respect to its role in the acquisition, retention, and transfer of skill, is poorly understood. We argue that the physical act of repetition is only part of the process undertaken during a repetition of an action. Of considerable importance also are the cognitive processes that determine, and are affected by, movement repetition.

Actions can be considered in terms of what to do and how to do them. By *cognitive processes*, we refer to the conscious, goal-directed thoughts and behaviors that occur before, during, and after action. These processes include, but are not limited to, the strategies, decisions, and evaluations related to action. In this article, we explore the concept of repetition, and how cognitive processes are affected, by examining some recent research in movement science and the implications for physical therapy.

The Nature of Repetition

Few would question that *practice* is the key ingredient toward the learning of motor skills. Furthermore, there would be little disagreement that *movement repetition* is a key ingredient, if not the key ingredient, in practice. But what is the underlying nature of a movement repetition? Suppose you are returning ball after ball that are served by a tennis machine. What processes are undertaken in order to complete the first return? More importantly, what are the processes undertaken on the second, third, and fourth consecutive attempts to return the tennis serve, and how do they differ from the first attempt?

Every movement we make draws upon previous experience. However, how do we refer to previous experience (or memory) in order to execute that movement? Sir Frederick Bartlett once commented about tennis, "When I make the stroke I do not, as a matter of fact, produce something absolutely new, and I never repeat something old."[1(p202)] One usually does not need to refer explicitly to how or when that experience was attained in order to produce the movement. Nevertheless, we do

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retain in memory some references to the experiences that are manifested in daily skilled activities.[2] Yet, it is unlikely that one simply calls on a stored representation for movement and unfolds a copy of that representation. Even if this mechanism for storage and retrieval was available, our minds would require a virtually limitless storage capacity for those representations and we would need the capability for instantaneous retrieval. A further problem would be encountered when a situation calls for an action that has never before been performed (ie, transfer).

The problems associated with detailed memory representations were addressed by Schmidt's schema theory. According to Schmidt's theory, memory for movement entails two fundamentally different representations. One representation is the memory for the basic details of movement, which Schmidt called the *invariant characteristics* of movement. These invariant characteristics include the common features among a particular class of actions such as the ordering, phasing, and relative forces of each element in the action.[4] The second representation is the *parameterization schema*. This representation is responsible for supplying the specific details (movement parameters) for a particular action. These details reflect the best estimate for satisfying the goal of the action, given the environmental and bodily constraints imposed on the individual at the time the movement is made. The movement parameters include such specifications as the individual muscles or muscle groups to be used, in addition to force, time, and space details. Implementation of these parameters is based on the schema, which is a learned rule for movement generation. Being a rule, the schema requires neither a memory for the parameters of a previous generation to be retained in memory nor a specific experience in order to produce a novel action.

Schema theory may also be considered as a contrast to the concept of skill as represented by rigidly ingrained habits, or engrams. According to an engram theory (eg, Kottke et al[5]), practice must be very precise, because errors inhibit development of the motor skill. Engram theories, however, cannot reconcile how a skill can be performed when it has never before been specifically practiced.[6] In contrast, schema theory can easily accommodate such a finding, because the precise parameters of movement need not be repeated in a repetition. A wide variety of parameterizations can facilitate the development of the capability to execute novel parameters when so required. Schema theory provides flexibility to the concept of motor skill representation, and it is this flexibility that we use as a basis for discussing the role of cognitive processes in practice.

Repetition and the Role of Cognitive Processes in Practice

In a sense, a repetition can be viewed as an attempt to solve a goal-related movement problem, given previous experience with the same problem. In this view, cognition takes on an essential role in skill acquisition. In this article, the concept of repetition is viewed toward identifying some features of learning that are affected by the way practice situations are structured. We consider how practice is structured to be an important contribution to the effectiveness of motor learning. Specifically, the problem-solving activity engaged in by a learner when repeating an event makes an important contribution to how well the skill is learned.

Practice Schedules for Multiple Tasks

There is evidence that the procedure for practicing more than one motor task affects learning. For example, Shea and Morgan[7] provided evidence that the cognitive activities of the subject, as affected by practice schedules, determined how well several motor tasks were learned. They compared two groups of subjects who had practiced three patterns of arm movements. A pattern of arm movement required the subject to move as rapidly as possible from a resting position, knock over three wooden barriers, and return to a resting position. The three patterns to be learned were distinguished by the spatial trajectory through which the arm moved. One group practiced these three variations according to a *blocked* order; that is, all practice trials on one pattern were completed before practice on another pattern was undertaken (maximally concentrated practice on each pattern). The second group practiced according to a *random* order, such that practice trials on all three of the patterns were conducted intermittently. The results showed that the performance of the blocked-order group was superior to that of the random-order group at the end of practice, in terms of both the speed and the accuracy of performance. However, did the blocked-order group demonstrate learning better than the random-order group? The authors conducted two tests of retention for the practiced patterns; the first test was conducted 10 minutes after the practice period, and the second test was conducted 10 days later. For both retention tests, the random-order group performed better than the blocked-order group. Tests of transfer using a novel, more complex version of the movement pattern were also performed better by the random-order group. If learning is defined simply as the acquisition of skill, then the results clearly favored the blocked-order group. However, learning is more often defined as a relatively permanent improvement in skilled behavior. As indicated by the retention and transfer tests that followed a period of no practice, learning was better when practiced according to a random-order pattern as compared with a blocked-order pattern.

According to Battig,[8] the learning and performance differences resulting from blocked- and random-order practice schedules can be considered a type of *contextual interference*. Contextual interference refers to practice situations in which performance of one activity results in a performance detriment for another activity, but leads, paradoxically, to better learning. This effect is consistent with the view that cognitive activities of the performer are assumed to play an important role in learning.

The role of repetition in practice was also addressed some years ago by Bernstein,[9] and his view holds considerable merit today. According to Bernstein,

> The process of practice towards the achievement of new motor habits essentially consists in the gradual success of a search for optimal motor solutions to the appropriate problems. Because of this, practice, when properly undertaken, does not consist in repeating the *means of solution* of a motor problem time after time, but in the *process of solving* this problem again and again by techniques which we changed and perfected from repetition to repetition. It is already apparent here that, in many cases, "practice is a particular type of repetition without repetition" and that motor training, if this position is ignored, is merely mechanical repetition by rote, a method which has been discredited in pedagogy for some time.[9(p134)]

Bernstein's insightful comments imply a number of factors about the structure of practice. His emphasis on motor learning as a problem-solving process gives considerable importance to the cognitive activities of the performer during practice. The nature of these problem-solving activities includes the evaluation of feedback for a previous action as well as the formulation of a new plan of action for a forthcoming movement.[10]

The differences between the effects of blocked- and random-order practice can also be considered in terms of the problem-solving activities promoted in practice. If a problem-solving approach to skill acquisition is the intention of practice, then practice conditions that promote this approach should be most successful. Lee and Magill[11,12] argued that random-order practice facilitates problem-solving to a much greater extent than blocked-order practice. Consider the following analogy, provided by Jacoby.[13] Suppose you were asked for the sum of two large numbers. Without a calculator, the sum would be attained by going through the process of addition. If you were asked to add the same numbers again, after only a brief interval, the answer could be quickly retrieved without going through the addition process. In all likelihood, the sum would be attained by remembering the solution of the previous addition, rather than by adding the numbers again. The problem-solving process would be by-passed because retrieval of the results of the previous process would be easily accessible. If a significant period of time had elapsed before the question was again asked (such that the answer had been forgotten), however, the process of problem solving would again be required.

The point of Jacoby's[13] analogy is that a solution can be either the product of a process or the retrieval from memory of a previously executed process. The degree to which the problem-solving process is engaged again depends on the availability of the previous solution. If the solution is readily available, the process is circumvented. If one wishes to ensure that the process is again engaged, however, then the previous solution must be unavailable.

By analogy, blocked-order practice also circumvents much of the retrieval process. Under blocked-order practice, much of what is repeated on consecutive trials on the same task does not require the same problem-solving process. This problem-solving process is quite different from that involved in random-order practice.

To solve a motor problem, we must first construct an action plan. According to schema theory, the action plan would include a generalized motor program and a parameterization of that program. Constructing an action plan on each trial is a *process*. Learning how to construct appropriate action plans is a critical step in skill acquisition. Repeated practice on the same variation of a task, as defined by blocked-order practice schedules, serves to circumvent the process of action-plan construction. Given a previously generated action plan and knowledge of the correctness of that plan, the succeeding trial can evolve as a simple modification of the preceding action; hence, performance is good. But what have the subjects learned? We suggest that learning how to construct action plans is not optimal under blocked-order practice schedules.

Random-order practice, by comparison, intersperses practice on all task variations throughout motor skill acquisition. In our view, the interference arising from the construction, execution, and evaluation of a trial for one task reduces the availability of a previously constructed action plan for another task. Hence, performance on each trial requires more complete reconstruction than would be undertaken in blocked-order practice. The consequence of random practice is relatively poor performance during motor skill acquisition. However, having better learned the process of action-plan construction, subjects who have practiced under a random order perform superior to subjects who have practiced under a blocked order on tests of retention and transfer. To return to the addition analogy, if the goal is to *teach* someone the process of problem solving, it would be unwise to create a practice situation in which the process of problem solving would be circumvented. Similarly, given that the process to be learned is how to construct an appropriate action plan, it would be unwise to create a practice situation whereby this process is avoided.

The implication of the research regarding the manner in which practice is scheduled for multiple tasks determines, in no small way, the cognitive processes engaged during "repetition." Furthermore, these practice strategies will determine what is ultimately learned and retained.

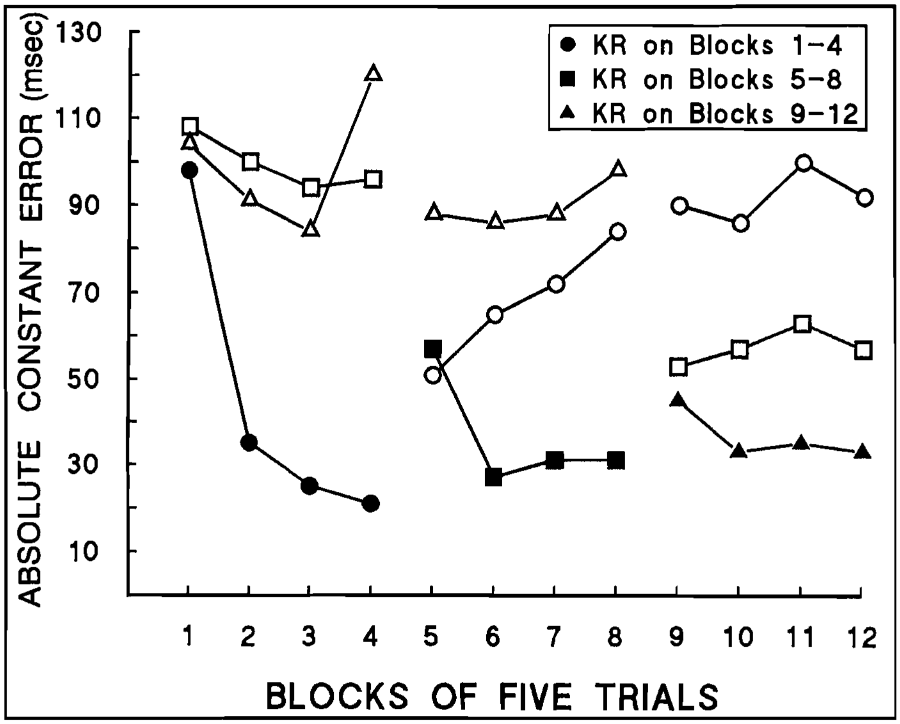

Figure 1. *Absolute constant error for acquisition performance for each movement segment by the blocked-order group as a function of when knowledge of results (KR) was provided. Filled symbols denote performance on that segment receiving KR during those blocks of trials. Unfilled symbols denote performance for segments not receiving KR at that time.*

Scheduling Knowledge of Results for a Multisegmented Task

The focus on how motor learning is affected by cognitive processes was further illustrated in a study by Lee and Carnahan.[14] The task in this experiment was to complete an arm movement that consisted of three segments. In each segment, there was a distinct timing requirement. The timing goals for the three successive movement segments were 160, 380, and 250 milliseconds, respectively. Thus, subjects were asked to complete this timing task by first moving rapidly, slowing down for segment two, and then speeding up for the final segment. Completion of the three segments as close to goal times as possible was the task for each trial of the experiment. The actual movement time regarding one of the three segments was provided as knowledge of results (KR) after each trial during the acquisition phase of the experiment.

The manipulation of interest in this study was the schedule that determined which segment was to receive KR on any particular trial. Subjects received KR according to either a blocked or a random order. In the blocked order, KR was provided for a particular segment for 20 consecutive trials. Knowledge of results for a different movement segment was provided on trials 21 through 40. The segment that had not received KR was provided this information on the last 20 trials of practice. Two random-order schedules for delivering KR were tested for comparison with the blocked-order schedule. In both random-order schedules, the decision about which segment was to receive KR was determined at random (with the restriction that each segment receive KR on 20 trials each). The difference between the two random-order schedules was that one group (cued random order) was told which segment was to receive KR before the movement was made. In contrast, the uncued random-order group did not know which segment was to receive KR before the movement. The present practice manipulation differs from the contextual-interference effect previously discussed, because in this experiment all subjects performed the same movement on each trial during practice.

All groups performed 60 practice trials each with KR provided for one segment on each trial. Following a brief rest, all groups performed 12 retention trials each without KR. The results revealed that the first few acquisition trials were performed more accurately by the blocked-order group than by the uncued random-order group. However, after about 18 trials, the uncued random-order group performed much better than the blocked-order group in terms of both performance accuracy and consistency. This superiority was maintained for the remainder of the practice trials. The performance of the cued random-order group was similar to that of the uncued random-order group throughout practice for timing consistency, although the uncued random-order group performed the last 20 trials more accurately than the cued random-order group. Results of the retention test were similar to the practice findings. Both random-order groups performed more accurately and consistently in the absence of KR than the blocked-order group.

This experiment provides some interesting observations regarding the effect of KR schedules on the cognitive strategies used by a performer in learning a multisegmented task. When practicing the task, subjects in the blocked-order group appeared to develop an action plan with particular attention to the movement segment that was to receive KR following the trial. Even though subjects performed the *entire* movement on each trial, the blocked-order KR schedule directed subjects toward planning only part of the action. The effects of this strategy are shown in Figure 1.

The accuracy data (absolute constant error) from the blocked-order group are plotted in Figure 1 according to the order in which each segment received KR. The first segment to receive KR (filled circles) was performed much better than the two segments that had not yet received KR. However, the performance of the first segment to receive KR did not remain accurate following the withdrawal of KR on trials 21 through 60 (the unfilled circles). Performance accuracy on the last 20 trials was no better than at the beginning of practice. The trend in performance for accuracy to improve with KR but to decline following the removal of KR was also observed for the segment that received KR on trials 21 through 40. In sharp contrast, performance on all segments of the movement by the random-order group progressed at a relatively common level throughout practice.

This evidence suggests that the blocked-order KR schedule induced the learner to prepare for only a part of the movement in each trial. The blocked order encouraged the learner to prepare only for the movement segment that was scheduled to receive KR. Although this strategy was clearly beneficial for performing those segments receiving KR *at that time*, it is unlikely that these parts were learned in the context of the other parts of the movement. In contrast, the random-order KR schedule forced the learner to more fully plan the entire action in advance. Preparation of the more complete action plan encouraged the learning of each segment in the context of the other segments.

The effects of random- versus blocked-order KR schedules seen in this experiment underscore the importance of cognitive operations in movement planning. Because all groups were performing the same movement on every trial, it cannot be argued that differences in performance and learning were due to differences in the amount of movement repetition experienced during the course of practice. It also cannot be argued that these results are due to the prior knowledge about which segment was to receive KR, because the uncued and cued random-order groups performed similarly during retention. Indeed, these findings extend the work on KR variables that also suggests that the information-processing activities of the subject determine the quality of learning that results from repetitive practice.[15,16]

Collectively, these two examples of the effects of practice schedules illustrate how motor learning can be affected by the conditions under which practice is conducted. Furthermore, these operations determine the importance of what is, and what is not, repeated in a repetition.

Learning in the Absence of Repetition—Effects of Observation

Perhaps the most interesting evidence for the influence of cognitive processes on motor learning is provided by the effects of observation. If motor learning occurs only by means of the repeated execution of movement, then there should be no benefit for learning by merely watching someone perform a movement task. The evidence clearly shows, however, that considerable learning may occur in the absence of any overt physical practice.

The early work of Sheffield[17] and Bandura[18] regarding the social and cognitive learning that occurs vicariously was eagerly received by students of motor behavior. Pedagogical dictum suggested that modeling a desired performance was an effective teaching and coaching strategy. The assumption was that someone learning a skill would benefit by observing a skilled performer demonstrate the desired action. The theoretical views presented by Sheffield[17] and Bandura[18] supported what educators had suspected all along. The research on observational learning of motor skill, however, is far less equivocal.[19] The positive benefits of observation depend on a number of factors, including the characteristics of the observer, the model, and the task.[19]

One method of modeling that has a compelling impact on observational motor learning was demonstrated by Adams.[20] In his study, Adams compared the effect on observational learning by having the observer watch an unskilled model practice a timing task. When the observers later performed the task, their performance was considerably better than the performance of subjects, who were without the benefit of observation, especially if the observer also received the model's KR. That watching someone *learn* a motor skill is an effective teaching strategy appears to have very important theoretical and practical value.

Adams's[20] finding was replicated and extended by Lee and White[21] using a perceptual-motor video game. In this experiment, pairs of subjects who had never before performed the video game were randomly assigned to be either a model or an observer. The model performed 36 trials on the video game, while the observer watched and plotted the model's performance improvements on a graph. The observer then performed 36 trials on the same video game. The effects are illustrated in Figure 2. The performance of the observer on the first trial of physical performance was significantly better than the model's first trial. Moreover, this superiority remained throughout the entire practice period.

The benefits of watching an unskilled model learn a movement task are of considerable theoretical and pedagogical interest. Indeed, some recent research[22,23] suggests that watching an unskilled model may be more fruitful for later performance than watching a skilled model. These findings have been discussed in terms of the problem-solving efforts of the observer.[20,21] The argument is that by watching an unskilled model learn, the observer can determine how a variety of errors occur, how the model attempts to correct those errors, and how successful the model was on the attempted correction. Thus, the observer learns more about the

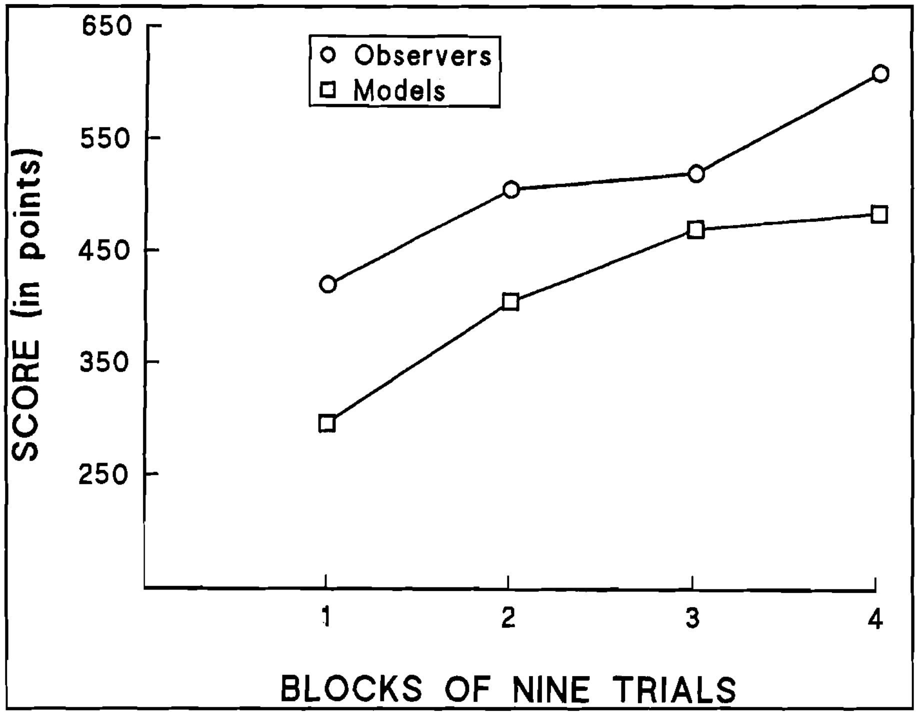

Figure 2. *Score (in decathlon points) for models acquiring a perceptual-motor skill and for observers after having watched the models learn the skill.*

problem-solving process of correcting errors than would ordinarily be available from watching a skilled model demonstrate the action. Because the observer will be put into a problem-solving process when physical practice is eventually undertaken, the prior problem-solving activity during observation is the most appropriate factor for later performance. In this sense, observing an unskilled model learn a task is a very "transfer-appropriate" method of observation.[24,25]

Summary and Implications for Physical Therapy

Effective practice requires more than just movement repetition. The problem-solving operations undertaken by the learner, especially those involved in the development of an action plan, make important contributions to the development of skill. The contextual-interference effect illustrated that repeated practice on a single task can undermine action-planning processes. Although this effect may benefit immediate performance, the trade-off is poor retention and transfer. The research on scheduling KR revealed that the planning operations underlying a repetition of the same task was affected considerably by the profile of KR deliveries over preceding trials. Blocked-order KR schedules directed the learner toward specifically planning only one part (segment) of the whole task. In contrast, a random-order schedule encouraged the learner to more fully prepare the entire action in advance. The research on observational learning revealed that the acquisition of skill can proceed in the absence of physical practice. Moreover, the observation of an unskilled model learning a task appears more fruitful than watching a skilled model perform the task.

These three examples of practice-variable effects illustrate how cognitive operations subserve the learning of motor skills in neurologically healthy subjects. However, the effects of manipulating practice variables that influence the cognitive processes in normal motor learning have not been studied in relation to populations who are the focus of physical therapy. Although the findings from studies on healthy subjects have implications for all physical therapy practice, they are particularly relevant to motor relearning in rehabilitation populations.

There is often an implicit assumption that repetition of an action is necessary for gaining skilled movement in physical therapy interventions designed for rehabilitation of neurologically impaired patients.[26] Moore[27] provides explicit support for this assumption in her cardinal principles of rehabilitation. She asserts, as one of her principles, that repetition of a skill is a prerequisite for learning. Furthermore, in guidelines for therapy for post-stroke patients, Bach-y-Rita and Balliet suggest that

> volitional motor control sequences will ultimately have to be practiced thousands of times in order to store a new motor program that is relatively fast i.e. automatic, co-ordinated, effortless, functional and generalizable.[28(p98)]

Moore[26] and Bach-y-Rita and Balliet[28] add the stipulation that variation in therapeutic modalities and techniques should be an integral part of practice in order to maintain motivation and attention. But, is variation of practice only for motivational gains, or is it essential for activating the cognitive processes that are an integral element of motor learning? The findings from the motor learning literature presented in this article challenge physical therapists to consider what is actually being repeated in the repetition of motor tasks during the rehabilitation process. Based on these findings, perhaps the improvements achieved within the physical therapy session as a result of repetition of movement and KR may only be temporary changes. These improvements do not necessarily translate into permanent changes. Perhaps the structure of practice and the scheduling of KR need to be altered in order to enhance learning rather than performance. The use of observation of unskilled motor learners may influence how our patients learn as well. Future investigation will clarify the role of practice conditions in motor relearning in rehabilitation populations and thus may provide a theoretical basis for structuring the retraining of motor skills.

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