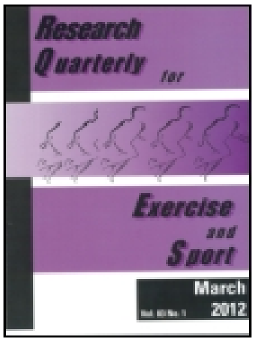

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This paper is based on a symposium celebrating the 26th anniversary of the publication of "A Schema Theory of Discrete Motor Skill Learning" (Schmidt, 1975) held at the annual conference of the North American Society for the Psychology of Sport and Physical Activity in June 2001. We provide a brief historical context for schema theory and a review of the development of the mechanistic approach to motor learning in general. We explore recent findings in mental practice, observational learning, augmented feedback presentation, and the variability of practice that are inconsistent with schema theory and provide a rationale for the importance of cognitive activity in motor learning.

Key words: augmented feedback, observational learning, variability of practice

A symposium, held at the annual conference of the North American Society for the Psychology of Sport and Physical Activity in June 2001, celebrated the 26th anniversary of the publication of " A Schema Theory of Discrete Motor Skill Learning " (Schmidt, 1975). The papers that accompany the present article reflect some of the comments of the other featured speakers in this symposium (Newell, 2003; Schmidt, 2003). The goals of the symposium were to examine how research and theory development over the past quarter century have: (a) supported the theory, (b) uncovered weaknesses in the theory, and (c) paved the way for developing a new theory of motor learning that builds specifically on the theoretical tenets of schema theory. We take up this third purpose in the present paper and discuss how the concept of cognitive effort relates to schema theory and how different levels of cognitive activity relate to the motor learning process. We are not proposing a new theory of motor learning. Rather, we wish to present some ideas, which, in the context of schema theory, may serve as a prelude to new theory.

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The Context of Schema Theory a Quarter Century Ago

Schmidt's (1975) schema theory of motor learning was developed from a theory of motor control—the concept of the generalized motor program being featured as a primary construct. Schmidt developed the generalized motor program concept in response to two prevailing views. One was closed-loop control, in which movement was considered to evolve as a series of chained reactions that used proprioceptive feedback as the sensory stimulant for the generation of the next efferent signal in the movement (e.g., Adams, 1971, 1977, 1984). Adams' theory was intentionally limited to explaining the production of slow positioning movements and, as such, left unexplained how the control of fast movements might be achieved.

The other prevailing view schema theory challenged was the concept of a motor program. Schmidt (1975) argued that many definitions of motor programs, most notably the versions articulated by Henry and Rogers (1960) and Keele (1968), left little flexibility in what the motor program represented and how it unfolded in time. The core concept of Henry's view of motor programming was specificity—that motor learning was specific to a particular skill. As such, individuals with well developed motor programs might perform that skill well but would not necessarily perform another skill well, even if it was closely related. In this context, the idea that motor programs were the underlying representations of motor skill was specific to the task that had been practiced. Presented for the sake of stating an extreme argument, Keele (1968) and others suggested that a strict view of a motor program is one in which a motor command is executed without the influence of peripheral feedback. By extension, this view is similar to that of Henry and Rogers (1960), because the motor program would have to be specific to underlie all the conceivably different ways in which we move. This notion of extreme specificity and, by extension, its inflexibility as an adaptable structure in the motor control process, left the concept of a motor program in need of some modification, in Schmidt's view.

In schema theory, Schmidt proposed the existence of two constructs: the generalized motor program and the schema. Many discussions of these constructs have appeared over the years, and their particular merit will not be our focus here (e.g., see Schmidt, 1985). Our only comment instead is that some simple facts support the impact of the theory. The theory received so many citations within 8 years of its publication that the Institute for Scientific Information honored it as a "Citation Classic" (Schmidt, 1983). Schema theory has been cited over 700 times in journal articles alone (an average of over 29 journal citations per year), and this impact remains strong: in the period, 1995–2001, the citation frequency has maintained a steady rate (36, 29, 25, 27, 31, and 30 journal citations per year). Another statement of impact is the breadth of journals in which these citations have appeared. In addition to the journals in which one might expect citations to appear (i.e., specialist motor behavior, general kinesiology, and experimental psychology journals), the theory has received frequent citations in neuroscience, ergonomic, rehabilitation, pedagogy, and lifespan journals. Without question, schema theory has made a significant impact on research in the past quarter century.

At the time schema theory was published, motor learning research had begun to undergo a shift in emphasis (Adams, 1987). For example, in 1975 studies on distribution of practice had all but disappeared, and the interest in short-term motor memory research was on the rise. Interest was strong in certain predictions arising from Adams' (1971) closed-loop theory, and research on the roles of movement-produced feedback, augmented feedback, and error detection was emerging. However, the behaviorist tradition that had flavored much of the motor learning research to date remained a dominant force, and this tradition was reflected prominently in both closed-loop theory and schema theory. Neither the theories of Adams (1971) nor Schmidt (1975) could be called behaviorist, although some flavor of behaviorism remained in them. For example, the use of augmented feedback as a source of error information that the learner thought about and acted on clearly reflected cognitive processing. Nevertheless, the mechanism by which increments in learning developed maintained a traditional view. An emphasis in Adams' theory was to get the learner to produce the "correct" movement. Each movement toward a goal resulted in a perceptual trace, and increasing the number of practice trials increased the accumulation of perceptual traces in memory. Augmented feedback was viewed as a method by which the learner sought the "correct" movement more often than an incorrect movement, thereby accumulating a greater number of correct perceptual traces than incorrect traces. The "strength" of the perceptual trace was an increasing function of the number of repetitions.

Although learning was achieved in a different theoretical manner according to schema theory, the mechanism for the accumulation of learning strength was similar to Adams' theory. In schema theory, each movement resulted in the abstraction of various sources of information. Depending on the type of schema being considered, performance (recall schema) or perceptual identification (recognition schema), a movement resulted in the abstraction of three sources of information. Like closed-loop theory, these abstracted "data" were assumed to accumulate with practice, and the strength of the schema was directly related to the amount of repetition experienced in practice.

The mechanistic approach to motor learning—as increments in response strength due to movement repetition—is a remnant of the behaviorist tradition inconsistent with research that has been conducted in the past quarter century. In the next section, we identify three areas of research, the results of which have proven difficult for mechanistic approaches to learning but at the same time implicate an important role for cognition in future theory development.

Three Areas of Research Inconsistent With Schema Theory

Learning in the Absence of Movement

In the absence of movement, there should be neither intrinsic feedback nor augmented feedback about action from which to extract information to strengthen a schema. However, considerable research on such issues as mental practice, imagery, and observational learning (modeling) since 1975 have clearly demonstrated strong and positive learning gains, all in the absence of movement (e.g., Adams, 1987; McCullagh & Weiss, 2001).

Augmented Feedback Presentation

Central to the theories of both Adams and Schmidt was the importance of augmented feedback (or knowledge of results, "KR," and knowledge of performance, "KP"). Augmented feedback was considered a crucial variable to the learner—to be presented to the learner as often, as possible as soon after completing the movement as possible, and otherwise in such a way as to enhance its use in evaluating movement and updating the memory representation (Schmidt, 1991). A considerable body of evidence that focused on the effects of augmented feedback variables in acquisition performance supported this prediction, during that time when these variables were undergoing their experimental manipulations. What this research did not support, however, was the theoretical role for augmented feedback when retention and transfer tests were administered, which many have argued reflects the true influence of an experimental variable on learning (Salmoni, Schmidt, & Walter, 1984; Schmidt, 1972). The evidence regarding learning, when these retention and transfer data are evaluated, supports a role for augmented feedback different from that predicted by schema theory (Salmoni et al., 1984; Schmidt, 1991).

Schema theory was also limited regarding the kind of variables influenced by KR manipulations. The theory predicted that high KR frequencies were crucial for establishing the recall and recognition schemata as measured by the accuracy of parameter specification and error detection, respectively. The theory did not address the effect of KR frequency manipulations on motor program variables, because the program acquisition was assumed. This distinction between program and parameter variables is important. Recent research has shown that reducing KR frequency has little effect on parameterization errors but instead influences the acquisition of the motor program (e.g., Lai & Shea, 1998, 1999).

Variability and Order of Practice

A key prediction of schema theory had to do with practice variability—that the versatility of the schema to be used in novel situations was a direct result of the various conditions in which the learner was asked to add parameters to the generalized motor program. For example, practicing a jump shot in basketball would be expected to benefit from taking the shots from various positions on the court compared with just one position. A factor in this prediction that was not considered important at the time was the order in which these variable practice conditions were arranged. Given five different positions on the floor and 20 shots taken from each position, schema theory would predict that learning would not be differently affected, whether all 20 shots were taken from one position in succession before moving to another spot or whether the repetitions be organized in a different way. However, research by Shea and Morgan (1979) and others since have identified this variable to be critically important in learning. Drill practice of the sort suggested above, reminiscent of the augmented feedback literature discussed earlier, has a beneficial effect on performance during practice that does not last well in retention and transfer. In contrast, nonrepetitive practice (e.g., random or serial) has a much stronger, positive influence on learning, despite a temporarily degrading influence during acquisition performance.

As noted earlier, schema theory was limited by its focus on parameter learning. Greater variability of practice allowed for greater generalization of parameter specification from recall schema and provided better error detection capability via recognition schema. However, the theory did not make predictions concerning the acquisition motor program characteristics like the proper relative timing pattern or the movement sequencing. In fact, the theory assumed that the motor program had already been acquired. In fact, scheduling variations using random, variable or blocked practice may have a differential effect on program and parameter variables (e.g., Wulf & Lee, 1993).

Therefore, despite schema theory's many conceptualizations about the learning process that remain logically consistent with research evidence, a number of other factors have arisen that require a different conceptual approach. We believe the concept of cognitive effort may have some positive features to offer toward that end. In the next part of the paper we sketch a few issues that make cognitive effort a potentially fruitful construct for a "new" theory of motor learning.

A Possible Role for Cognitive Effort in Motor Learning

Cognitive effort can be conceptualized as "the mental work involved in making decisions" (Lee, Swinnen, & Serrien, 1994, p. 329). In specific reference to motor skills, cognitive effort refers to those decisions that result in perceptual and motor processes involved in movement control. For example, an ice hockey goalie needs to learn how to anticipate where a shot will go to by using perceptual and decision-making processes. A golfer who decides to hit a specific shot in a certain situation might be deciding how to choose a particular generalized motor program or the program parameters. An athlete focusing on potential errors in a just-completed performance might be interpreting movement-produced feedback and deciding on corrections for future performances. Lee et al. (1994) suggested that not only do movement skills need to be practiced but that the cognitive, decision-making processes underlying skilled behavior need practice as well. Thus, practice should be organized to allow for acquiring such processes. They also suggested that manipulation of variables involved in practice such as observation, augmented feedback, and organizing the order of practice trials could result in different levels of cognitive effort with which these processes are undertaken. Practice manipulations that require more cognitive effort were predicted to be more effective for motor learning compared to practice manipulations that require less cognitive effort.

What cognitive processes were involved in the learning process proposed by schema theory? Cognition played a minor role in learning, if at all, according to schema theory. (Perhaps it is unfair to say that no cognition was required throughout the learning process, because performers were faced with some decision making. For example, one had to select the proper program parameter to meet the movement goal and evaluate movement-produced feedback to detect movement errors). Schema theory assumed that the generalized motor program, which controlled the sequencing and timing of muscle activity, was already acquired via prior practice. The learner acquired the capability of correct program parameterization by forming the recall schema, by practicing with different program parameters (e.g., force, duration), using augmented feedback (KR), and different initial conditions. Movement evaluation and error detection was accomplished via recognition schema that required knowledge of the sensory consequence of the action and the movement outcome. Schema strength was increased by practicing with a wide array of program parameters that also allowed for generalization to novel movement situations. Therefore, learning for schema theory was a function of the number of practice trials with KR and the amount of varied practice, rather than the level of cognition invoked in the practice session. However, schema theory had nothing at all to say about which practice organization would result in the most effective learning of the schema.

Variability of Practice

Based on what we know now about cognitive effort and motor learning, can schema theory account for some of these results, or is a more comprehensive theory needed? Perhaps the most logical area to examine first is that of variable practice, because it is required to form the recall and recognition schemata. Does it matter if these variable practice conditions are organized in a blocked or random order? In general, the contextual interference (CI) effect refers to the finding that blocked (or drilled) practice is relatively ineffective for learning compared to a random (or some other nonrepetitive) practice order. Would variable practice involving tasks that differ only in a parameter change create enough difference between random or blocked schedules to produce typical CI effects? Sherwood (1996) suggested it would. This study showed that random variable practice of a rapid aiming movement over different amplitudes was more effective in retention than blocked variable practice. This effect occurred for spatial accuracy (CE), which reflected recall schema strength, and for the mean objective-subjective difference, a measure of error detection capability and recognition schema strength. Green and Sherwood (2000) replicated the Sherwood (1996) study by varying movement duration in a rapid timing task. Again, retention (and transfer to a novel duration) was better after random practice compared to blocked practice. These findings support earlier work (e.g., Shea & Morgan, 1979) suggesting that random variable practice can create higher levels of CI than blocked practice, resulting in better retention.

The implication for schema theory is that the structure of variable practice is an important consideration in the learning process. According to Lee et al. (1994), random practice results in greater cognitive effort and, hence, better learning of the cognitive aspects that might be subserving variable practice. However, this cannot be the complete story, as recent research suggests that cognitive effort does not explain all variable practice effects. For example, Shea, Lai, Wright, Immink, and Black (2001) contrasted random, blocked, and serial variable practice in a multiduration key pressing task. They showed that random practice was more effective in absolute timing than either blocked or serial practice, particularly on transfer tests when a novel parameter specification was required. However, Shea, Lai, et al. (2001) also demonstrated that blocked practice was more effective than random practice in producing a consistent relative timing during acquisition and retention. Does the effect of cognitive effort depend on the nature of the task that is being learned? Clearly, neither schema theory nor the cognitive effort view can explain the dissociation in learning effectiveness in these two different aspects of this task.

Modeling

What do studies on modeling or observation suggest about the role of cognitive effort in motor learning? Clearly, motor skills can benefit from observation, a feature not predicted by schema theory. However, modeling can undermine learning, if it prevents or reduces the cognitively effortful problem-solving processes that might ordinarily be undertaken. According to Bandura (1986), learning can occur by observing a model and coding information about the performance into a cognitive representation. The cognitive representation is responsible for producing the modeled behavior as well as serving as an internal reference of correctness. Whether or not learning takes place is a function of several cognitive information processing factors. For example, one must pay attention to the spatial and temporal aspects of the skill, particularly those complex and difficult sequences that may require repeated exposure. Cognitive rehearsal is then required to establish the representation in memory. Movement production requires that the cognitive representation be transformed into the proper spatial-temporal action.

Can observation speed learning of the schemata? Shea, Wulf, Park, and Gaunt (2001) taught a five-segment timing pattern with and without a series of auditory tones that "modeled" the required timing of the to-be-learned task. In acquisition and retention, the groups that practiced with the tones were better at producing the required relative and absolute timing compared to the no-tone groups. In a second experiment, they asked whether the timing pattern could be acquired based on observation alone or combined with the auditory tones. After 90 observation or physical practice trials, participants attempted to perform the timing pattern. Interestingly, the groups that practiced with the tones (with physical practice or observation) acquired the relative timing pattern better that those without the tone model. However, for absolute timing, the physical practice groups performed better than the observation groups. Based on these findings, one might suggest that observation helped to establish recall schemas and motor programs but that physical practice was also required to improve movement accuracy following the presentation of the model.

A model can also disrupt learning, if it undermines the cognitive effort expended in practice. In a study by Lee, Wishart, Cunningham, and Carnahan (1997), participants practiced three timing tasks, in either a blocked or random order, in a manner similar to studies discussed previously. However, in a third practice group, which also practiced the tasks randomly, three repetitions of an auditory model were presented immediately prior to each practice trial. The effect of this model was to undermine the cognitive effort that was otherwise required to learn the patterns in a random practice order. The result was that this random practice condition was no more effective in learning the patterns than blocked practice (see also Simon & Bjork, 2002).

A study by Weeks, Hall, and Anderson (1996) showed an effect similar to the findings of the Lee et al. (1997) study discussed above. In the Weeks et al. (1996) experiment, delaying imitation of modeled behavior after a demonstration actually improved retention relative to an immediate imitation. Participants learned the American manual alphabet using either concurrent imitation with the model or delayed imitation after three hand shapes were demonstrated, or they learned in a combination method using both delayed and concurrent imitation. The delayed group was better than the concurrent group on delayed retention and recognition tests. Weeks et al. (1996) suggested the better retention performance was due to the greater cognitive effort demands on the delayed group that had to hold all three shapes in memory before movement production, compared to the concurrent group where rehearsal was not necessary.

Thus, the role of observation and modeling in motor learning, a feature not considered in schema theory, appears to be to be rather complex. The information provided by models can influence cognitive processing in the learner, which should normally have a positive effect on learning. However, this effect can be undermined, if the modeled information is provided in such a way that the cognitive effort with which the processes are undertaken become diminished.

Mental Practice

Another area where schema theory is silent but where cognitive effort may make a theoretical contribution has been mental practice and imagery. According to the cognitive hypothesis, the benefits of mental practice come from rehearsing the visual, spatial and symbolic aspects of the task. Mental practice is more effective in tasks with a high cognitive component, because what is rehearsed has a more direct link to the motor commands needed to carry out the action than tasks with a high motor component (Heuer, 1989). It follows from the ideas on cognitive effort that if imagery requires more effort, then the memory strength of the representations will be strengthened. One study that investigated the relationship between cognitive effort and imagery was by Gabriele, Hall, and Lee (1989). In their study, participants practiced four movement patterns using a factorial combination of both random and blocked physical and mental practice. One physical practice trial was followed by three mental practice trials in which the order of the physical and mental practice trials was either blocked or random. In retention, the random physical and mental practice groups performed better than their blocked practice counterparts. The finding suggests that random mental practice can increase contextual interference (and cognitive effort), resulting in better retention.

Augmented Feedback

The viewpoint proposed by schema theory was that augmented feedback (e.g., KR) should be provided on every trial to best relate outcome information to both the program parameter and the sensory consequences. If

KR was not provided on a given trial, then the performer would have to rely on less precise subjective reinforcement for error detection, resulting in a weaker recognition schema. However, numerous studies have challenged this viewpoint by showing that reductions in the frequency of KR actually result in better retention when compared to a 100% schedule of KR (Schmidt, 1991). Although the finding that lower relative feedback frequencies produce better learning than 100% relative feedback frequencies is not unequivocal, there is little support for the reverse conclusion as predicted by schema theory. In a low relative frequency of KR condition, learners must depend on their own analysis of response-produced feedback and generate an error correction for the next attempt. Under 100% KR conditions, the self-error detection is not required, and the correction is precisely indicated to the learner. Therefore, reducing the frequency of KR should result in increased cognitive effort. Hence, the equivocality in the literature seems to be clearly unsupportive of schema theory yet ambiguous on the predictions of cognitive effort.

One factor that may be important to the learning process is what the learner does before receiving the KR. If learners create hypotheses about their own performance using sensory feedback, they can use the KR to verify the hypothesis about their movement. By focusing on movement-produced feedback and engaging in this kind of information processing, learners may develop more effective error detection mechanisms that can provide accurate error information, especially when augmented feedback is not available. If learners do not do this, then they may simply use KR to guide their response, which may result in poorer long-term retention (Schmidt, 1991). Support for this notion comes from a study by Guadagnoli and Kohl (2001), who varied KR frequency (20% or 100%) and error estimation in a force-production task. Half the participants were asked to estimate their force-production errors on each trial, while the remaining participants gave no estimate. On retention, the 100% KR group who estimated errors performed better than the 100% KR group that did not. The findings suggested that negative guiding effects of KR could be avoided by having the learner engage in additional information processing during acquisition.

Cognitive Effort as a Testable Theoretical Construct

One criticism of cognitive effort as a construct in motor learning is that it is a circular argument. By its nature, increases in cognitive effort lead to diminished performance, and diminished performance can be attributed to practice-related situations requiring greater cognitive effort. As well, performance measures that seem to be appropriate indicators of cognitive effort also may fall prey to circular logic. For example, it is tempting to attribute longer premovement delays (e.g., reaction time [RT]: Shea & Morgan, 1979; or voluntary premovement delay: Immink & Wright, 1998, 2001) to increased cognitive effort in movement planning. However, a stronger argument could be made if independent measures of cognitive effort were used. A number of possibilities exist. Perhaps the simplest way is to obtain measures of perceived effort by asking participants to rate the effort required by their performance (or practice context), such as using a Borg scale. Rosenbaum and Gregory (2002) presented a recent approach along these lines, showing that measures of perceived effort are highly correlated with measures of task difficulty in a Fitts-type task. It would seem reasonable that such a method of self-report could be used in a learning experiment to examine the cognitive effort for various practice variables.

Secondary task measures, such as probe RTs, might also be used as indicators of cognitive effort. A study by Li and Wright (2000), for example, used such an approach and found that probe RTs during the premovement planning phase were about 150 ms slower in random practice compared to blocked practice and about 50 ms slower in random than blocked practice during the intertrial interval.

Researchers might also consider less obtrusive, psychophysiological measures of cognitive effort. Kahneman (1973) argued that pupil dilation was the single best psychophysiological measure of effort, as increased pupil dilation corresponds with increased task load in a wide variety of cognitive tasks (Kahneman, 1973). And, although we know of no studies to date, new technologies in brain imaging might also be useful physiological tools to study the cognitive effort in motor learning.

In summary, we believe that schema theory falls short in terms of two main ideas. One is the role of cognitive processes in motor learning. How can learning be advanced in the absence of or the combination with movement? This represents a fundamental problem for a new motor learning theory. The second idea is the role of cognitive effort and its impact on the learning process. According to schema theory (and most other theories too), each "repetition" carries the same impact on the learning process. Research on the CI effect and various effects of augmented feedback suggest that the potential influence of each repetition on learning is not equal. Cognitive effort appears to be a factor that adds a weighted contribution of a repetition to the learning process. How these weighted repetitions specifically influence learning as a function of other variables (such as task related variables) will also be a fundamental problem for a new theory of motor learning to explain.

References

Adams, J. A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior, 3*, 111–150.

Adams, J. A. (1977). Feedback theory of how joint receptors regulate the timing and positioning of a limb. *Psychological Review, 84*, 504–523.

Adams, J. A. (1984). Learning of movement sequences. *Psychological Bulletin, 96*, 3–28.

Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention, and transfer of human motor skills. *Psychological Bulletin, 101*, 41–74.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory.* Englewood Cliffs, NJ: Prentice-Hall.

Gabriele, T., Hall, C. R., & Lee, T. D. (1989). Cognition in motor learning: Imagery effects on contextual interference. *Human Movement Science, 8*, 227–245.

Green, S., & Sherwood, D. E. (2000). The benefits of random variable practice for accuracy and temporal error detection in a rapid aiming task. *Research Quarterly for Exercise and Sport, 71*, 398–402.

Guadagnoli, M. A., & Kohl, R. M. (2001). Knowledge of results for motor learning: Relationship between error estimation and knowledge of results frequency. *Journal of Motor Behavior, 33*, 217–224.

Henry, F. M., & Rogers, D. E. (1960). Increased response latency for complicated movements and a "memory drum" theory of neuromotor reaction. *Research Quarterly, 31*, 448–458.

Heuer, H. (1989.) A multiple-representations' approach to mental practice of motor skills. In B. Kirkcaldy (Vol. Ed.), *Medicine and science in sports: Vol. 29. Normalities and abnormalities in human movement* (pp. 36–57). New York: Karger.

Immink, M. A., & Wright, D. L. (1998). Contextual interference: A response planning account. *The Quarterly Journal of Experimental Psychology, 51A*, 735–754.

Immink, M. A., & Wright, D. L. (2001). Motor programming during practice conditions high and low in contextual interference. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 423–437.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice-Hall.

Keele, S. W. (1968). Movement control in skilled motor performance. *Psychological Bulletin, 70*, 387–403.

Lai, Q., & Shea, C. H. (1998). Generalized motor program (GMP) learning: Effects of reduced frequency of knowledge of results and practice variability. *Journal of Motor Behavior, 30*, 51–59.

Lai, Q., & Shea, C. H. (1999). Bandwidth knowledge of results enhances generalized motor program learning. *Research Quarterly for Exercise and Sport, 70*, 79–83.

Lee, T. D., Swinnen, S. P., & Serrien, D. J. (1994). Cognitive effort and motor learning. *Quest, 46*, 328–344.

Lee, T. D., Wishart, L. R., Cunningham, S., & Carnahan, H. (1997). Modeled timing information during random practice eliminates the contextual interference effect. *Research Quarterly for Exercise and Sport, 68*, 100–105.

Li, Y., & Wright, D. L. (2000). An assessment of the attention demands during random- and blocked-practice schedules. *The Quarterly Journal of Experimental Psychology, 53A*, 591–606.

McCullagh, P., & Weiss, M. R. (2001). Modeling: Considerations for motor skill performance and psychological responses. In R. N. Singer, H. A. Hausenblaus, & C. M. Janelle (Eds.), *Handbook of sport psychology* (2nd ed., pp. 205–238). New York: Wiley.

Newell, K. M. (2003). Schema theory (1975): Retrospectives and prospectives. *Research Quarterly for Exercise and Sport, 74*, 383–388.

Rosenbaum, D. A., & Gregory, R. W. (2002). Development of a method for measuring movement-related effort: Biomechanical considerations and implications for Fitts' law. *Experimental Brain Research, 142*, 365–373.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95*, 355–386.

Schmidt, R. A. (1972). The case against learning and forgetting scores. *Journal of Motor Behavior, 4*, 79–88.

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82*, 225–260.

Schmidt, R. A. (1983, June 20). This week's citation classic. *Current Contents (Social and Behavioral Sciences), 15*(25), 20.

Schmidt, R. A. (1985). The search for invariance in skilled movement behavior. *Research Quarterly for Exercise and Sport, 56*, 188–200.

Schmidt, R. A. (1991). *Motor learning and performance: From principles to practice.* Champaign IL: Human Kinetics Publishers.

Schmidt, R. A. (2003). Motor schema theory after 27 years: Reflections and implications for a new theory. *Research Quarterly for Exercise and Sport, 74*, 366–375.

Shea, C. H., Lai, Q., Wright, D. L., Immink, M., & Black, C. (2001). Consistent and variable practice conditions: Effects on relative and absolute timing. *Journal of Motor Behavior, 33*, 139–152.

Shea, C. H., Wulf, G., Park, J-H, & Gaunt, B. (2001). Effects of an auditory model on the learning of relative and absolute timing. *Journal of Motor Behavior, 33*, 127–138.

Shea, J. B., & Morgan, R. L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory, 5*, 179–187.

Sherwood, D. E. (1996). The benefits of random variable practice for spatial accuracy and error detection in a rapid aiming task. *Research Quarterly for Exercise and Sport, 67*, 35–43.

Simon, D., & Bjork, R. A. (2002). Models of performance in learning multi-segment movement tasks: Consequences for acquisition, retention, and judgments of learning. *Journal of Experimental Psychology: Applied, 2*, 222–232.

Weeks, D. L., Hall, A. K., & Anderson, L. P. (1996). A comparison of imitation strategies in observational learning of action patterns. *Journal of Motor Behavior, 28*, 348–358.

Wulf, G., & Lee, T. D. (1993). Contextual interference in movements of the same class: Differential effects on program and parameter learning. *Journal of Motor Behavior, 25*, 254–263.

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