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The Locus of Contextual Interference in Motor-Skill Acquisition

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Three experiments are reported that investigate the curious paradox that randomly ordering practice trials during motor-skill acquisition is detrimental to practice performance (relative to blocked or repetitively ordered trials) but facilitates retention performance. The results of Experiment 1 refute a notion that this contextual variety effect was actually due to a methodological confounding of the type of reaction paradigm (simple or choice) with the practice order manipulations. In Experiments 2 and 3, a third practice trial order (serial) was added, which contained identifiable conditions similar to both the blocked and random trial orders. Results indicated that this serial order was almost identical to findings observed under random practice conditions. These data were considered evidence that event repetitions during skill acquisition have critical consequences on the development of memory and speeded accessibility of action plans. The results were discussed in a theoretical framework that incorporates recently revamped notions of the role of cognition and mental effort in motor-skill acquisition. Relationships between contextual interference and related empirical and theoretical issues in cognition and the area of motor skills are also explored.

A considerable amount of research activity has recently examined the general issue of how intentions for action evolve into motor performance. For highly practiced tasks, a common view is that there is an automated translation from intention to movement (e.g., Schneider & Fisk, 1983; Stelmach & Larish, 1980). However, for tasks that are not well learned, the implication is that conscious mechanisms subserve this translation process (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). The process of skill acquisition, then, seems to be the product of an interaction between cognition and motor control. Whereas the latter stages of skill acquisition seem to involve the refinement of neuromotor coordination, the initial phase is more heavily influenced by changes in the cognitive aspects of performance (Adams, 1971; Fitts, 1964).

One remarkable demonstration of this interaction between cognition and skill acquisition has been termed the *contextual interference effect*. For unpracticed tasks, interfering with the cognitive events that subserve the intention-to-action translation process may be accomplished by simply structuring the acquisition trials in a highly unpredictable (random) manner. Although the resultant decrement to performance is understandable, this interference produces a surprising, yet consistent, *facilitation* in retention, relative to low-interference practice conditions (see Shea & Zimny, 1983, for a review).

Originally identified as a curious paradox in the verbal learning literature (Battig, 1966, 1972, 1979), contextual interference may be manifested (a) when there is an increase in the similarity among items to be learned or (b) when there is an increase in the variety of processing requirements on successive trials. This latter aspect of interference, contextual variety, was the focus of the first experiment demonstrating this paradox in the acquisition of motor skills (Shea & Morgan, 1979). Shea and Morgan found that for the retention of three practiced movement patterns, response time was a function of the practice conditions

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under which acquisition trials were performed: Faster response times occurred under acquisition trials where all three movement patterns were practiced randomly, as opposed to a blocked condition where all practice trials for one pattern were completed before practice on another pattern was undertaken. Keeping the number of trials on each pattern the same across conditions, Shea and Morgan demonstrated that the contextual variety conditions alone were sufficient to produce considerable retention effects. Indeed, a number of studies conducted in Shea's lab and elsewhere (summarized by Shea & Zimny, 1983) have shown this advantage of random over blocked contextual variety conditions to be a very robust phenomenon.

Consonant with the skill acquisition theories of Fitts (1964) and Adams (1971), Shea has attributed the contextual variety effect in motor learning primarily to the cognitive processing requirements needed to perform the task (Battig & Shea, 1980; Shea & Morgan, 1979; Shea & Zimny, 1983). Indeed, this attribution seems tenable when the contextual variety paradox is compared with the spacing-of-repetitions effect in the verbal memory literature (Melton, 1967). Beyond the obvious procedural similarities with respect to the repetition of events during the practice or presentation phase (random/distributed vs. blocked/massed conditions), these phenomena show parallel effects on performance as well: Whereas nonrepetition of events during practice/presentation is much more demanding of processing requirements, there is an ultimate facilitation on retention (Cuddy & Jacoby, 1982; Johnston & Uhl, 1976; Shea & Zimny, 1983). Experiments 2 and 3 in the present series are designed to explore further the nature of the contextual variety phenomenon as an effect of spacing repetitions. Prior to these theoretically motivated studies, however, there is a need to explore a methodological problem inherent in all previously reported empirical investigations that has critical implications for identifying the locus of the contextual variety effect.

Experiment 1

In the Shea and Morgan experiments the subjects' task was to respond to a particular stimulus light as quickly as possible by knocking down a series of hinged barriers in an order specific to the color of the signal to respond. Under random acquisition conditions, any of three possible signals to respond could be illuminated, making the task a *choice-reaction paradigm*. However, under blocked conditions, only one signal and one diagram illustrating the appropriate response were present during the practice trials for that movement pattern, reducing this condition to a *simple-reaction paradigm*. Thus, due to the confounding of practice schedule effects (i.e., random vs. blocked practice schedules) with reaction paradigm effects (i.e., choice vs. simple reactions), it is impossible to determine whether the locus of the contextual variety effect arises from the manipulation of practice schedules, reaction paradigms, or an interaction of these two variables.[1]

In the present experiment the procedures used by Shea and Morgan were altered such that the unconfounded effects of contextual variety and reaction paradigm might be assessed. In addition to a replication of Shea and Morgan's interference groups (denoted here as the cued–blocked and uncued–random groups), two new groups were tested (designated as uncued–blocked and cued–random). Here, the cuing factor (cued vs. uncued) referred to whether a warning light provided information as to the nature of the upcoming signal to respond. The contextual variety factor (blocked vs. random) referred to the sequential nature of presenting the different signal–pattern trials. Together, these groups provide the necessary controls to permit an assessment of contextual variety and reaction paradigm effects on contextual interference. Under these arrangements, the following comparisons were of particular interest: (a) cued–blocked versus uncued–random (to attempt to replicate Shea & Morgan's findings), (b) cued–random versus

[1] In a related study (Del Rey, Wughalter, & Whitehurst, 1982), contextual variety effects were produced using a task that involved timing a response coincident with the "arrival" of a series of lights in apparent motion. As such, the experiment does not suffer exactly the same problems of choice versus simple reactions as does the Shea and Morgan study. Nevertheless, the problem is still apparent because the subjects in the random condition did not know prior to the beginning of apparent motion which of three learning speeds was being tested, whereas subjects in the blocked group knew this at all times.

uncued–random (to assess the relative contribution of reaction paradigm holding contextual variety constant), and (c) cued–blocked versus cued–random (to assess the relative contribution of contextual variety, holding reaction paradigm constant.)[2]

If the contextual variety effect is due to a methodological confounding of reaction paradigms, then cuing the random trials condition should eliminate the retention advantage of random practice. On the other hand, if the effect is not confounded by the type of reaction paradigm during practice, the retention advantage of the random condition should be maintained regardless of cuing.

Method

Subjects

Twenty-four right-handed undergraduates (12 males and 12 females; mean age = 22.9 years) from psychology and physical education classes at Louisiana State University participated in the experiment for course credit. Assignment of subjects to groups was determined randomly with the restriction that group size was balanced ($n = 6$) and contained an equal number of males and females. All subjects were naive as to the purposes of the study.

Apparatus

The apparatus used was similar to that used and depicted in the study by Shea and Morgan (1979, Figure 1). In general, the equipment consisted of two sets of light signals mounted on the rear panel of the apparatus (which comprised the "stimuli"), a push-button microswitch, six hinged wooden barriers, and a telegraph key mounted on the base of the apparatus (which comprised the "response").

The warning signal consisted of a 1.6-cm hole cut in the rear panel and covered by a small sheet of white tracing paper (to project the light). Behind the hole, on the back side of the rear panel was attached a small plastic box lined with aluminum foil that housed four colored lights (red, green, blue, and white). The three lights that served as the signals to respond were located 13 cm below the warning light and 20 cm apart (blue directly below the warning light with the green and red to the left and right, respectively). All lights were base-threaded incandescent bulb units fitted with removable colored lens caps. Experimenter control over the choice of colored lights for a particular trial, as well as the time period between the warning light and the signal to respond (i.e., the foreperiod), was afforded by a noncommercial unit located behind the rear panel and out of the subject's view.

Reaction time (RT) and movement time (MT) were measured using two Lafayette millisecond timers (Model #54035), also located behind the rear panel of the apparatus. The RT clock was initiated in parallel with the illumination of the signal to respond and terminated when the subject's index finger lifted off the push-button microswitch. The MT clock *began* when the index finger left the push-button microswitch and stopped when the telegraph key was depressed.

The barriers were 8.0 × 12.1 cm wooden blocks that were attached to the wooden base by metal hinges (arranged to fall outward). All of the blocks were foam padded. The base of the apparatus was arranged such that the push-button microswitch and the telegraph key were centered at the front and rear of the base, respectively, 47.8 cm apart. The six barriers were arranged from front to rear in three pairs (one left and one right of center), each pair 20 cm from the midline of the base and 10 cm from the next pair (i.e., on each side the barriers were 10 cm apart, from front to rear). The first pair was located 10 cm to the rear of the start microswitch. The last pair was parallel with the telegraph key.

Illustrations for each movement pattern were drawn on 6 × 12 cm tags and hung on small metal hooks attached to the rear panel directly below its paired colored light. These illustrations displayed the following barrier knockdown sequences: *green*—left front, right middle, left middle; *blue*—left middle, right middle, left rear; *red*—right front, left middle, left rear.

Procedure

In total, the experiment consisted of the following four phases: (a) the preliminary phase, (b) the acquisition phase, (c) the interpolated phase, and (d) the retention phase.

Preliminary phase. During the preliminary phase the subject was given instructions regarding the nature of the task, as well as three practice trials. The instructions informed the subject that on each trial two lights would be illuminated, a warning light and a signal to respond, and that a 2–5-sec variable foreperiod would separate these lights. Subjects in the cued groups were told that both lights would be of identical color, whereas subjects in the uncued groups were told that the warning light would always be white. Their task was to depress the push-button start microswitch when the warning light occurred and, upon illumination of the signal to respond, to knock over the wooden barriers in the order prescribed by the corresponding diagram and to depress the telegraph key.

Following these instructions, the experimenter replaced the middle (blue) lens cap with a white lens cap and hung a card illustrating a practice pattern (used only for these practice trials). Prior to the three practice trials the experimenter demonstrated the task, emphasizing that the response should be made as rapidly as possible. Following this, the subject performed three (errorless) practice trials.

Acquisition phase. After the practice trials, the illustration was removed, the white lens cap was replaced by the blue cap, and the three acquisition patterns were hung below their associated signals to respond. Subjects were then given 1 min. to familiarize themselves with the three patterns but not to practice knocking down the barriers

[2] It should be noted that the uncued–blocked versus cued–blocked comparison is *not* an assessment of reaction paradigm, holding contextual variety constant, because on only three trials (the start of each new block of trials) is the task a choice reaction. On all other trials, the very nature of the blocked trial sequence reduces the task to a simple-reaction paradigm.

while studying the illustrations. All subjects were told that the acquisition phase consisted of 54 trials, with 18 trials on each signal–pattern pair. The only difference in instructions given to each group was with respect to how the practice schedule would be arranged (i.e., trials occurred in a blocked or random sequence). Subjects were further informed that MT feedback would be provided after each trial and that they should try to improve their time throughout the entire acquisition phase. After any questions had been answered, the acquisition phase was begun.

For the blocked groups all 18 trials on a particular pattern were performed consecutively. The six permutations of testing order (red-blue-green; blue-red-green; etc.) were distributed across subjects. For the random groups, the order of presentation was constrained only such that in each of the six sets of 9 trials the three signal-pattern pairs occurred three times, but no same pattern occurred more than twice in succession. When an error occurred (1 trial out of 20 on the average), the trial was repeated (immediately for the blocked groups and at the end of that set of trials for the random groups). The warning light and signal to respond were illuminated for approximately 300 msec each. Immediately following each trial, knowledge of results (KR) regarding the elapsed time of the movement (to the nearest millisecond) was given verbally as the subjects set the knocked-down barriers upright. The interval between MT feedback and the next warning signal was approximately 8 sec.

Interpolated phase. During this phase the subjects were led into a small room adjoining the testing room and performed a variation of the Stroop (1935) task. This task required subjects to read letters from two sheets of paper by speaking, as rapidly as possible, the colors in which the letters were printed. On the first page the letters formed rows of Xs. On the second page were color names that were printed in incompatible ink colors (e.g., the word *green* printed in red ink would require the subject to respond "red"). The Stroop task was deemed appropriate to prevent mental rehearsal of the movement patterns due to its cognitive demand. The time to perform the Stroop task was approximately 4 min.

Retention phase. Following the interpolated activity, the subject returned to the testing room where the retention procedures were described. The retention phase consisted of three trials of each signal-pattern pair, arranged such that a pair was never repeated immediately (i.e., randomly). Further, the warning signal was white (i.e., a choice response required) and KR was not provided. Before testing began, the experimenter emphasized that although responses were to be made as fast as possible, errors should be kept to a minimum. During retention, all illustrations of the movement patterns were removed. If a subject could not remember a particular movement pattern, the experimenter demonstrated the appropriate response by pointing to the sequence of barriers to be knocked down. Trials on which errors occurred (mean error rate = 17%) were repeated at the end of the retention sequence. Only errorless trials were subjected to data analysis.

Statistical Analyses

For each pattern the 18 acquisition trials were arranged into blocks of three trials each for analysis (identical to the procedure adopted by Shea & Morgan, 1979). One block of three trials for each of the particular signal-pattern pairs comprised the retention data.

Separate statistical analyses were conducted to assess acquisition and retention performance. For each analysis, a multivariate analysis of variance (MANOVA) was initially performed with both RT and MT as dependent measures. Following the MANOVA, separate analyses of variance (ANOVAS) on each dependent measure were performed, with only the significant effects from the MANOVA tested. Post hoc comparisons of means were performed on significant ANOVA effects using the Newman-Keuls procedure. In addition to these analyses, adjusted variances accounted for by the significant effects from the ANOVA (ω^2) were calculated (Tolson, 1980). The level for statistical significance was set at .05. However, ω^2 was used to place into perspective those significant effects whose variance accounted for is quite small (<2%).

Results and Discussion

A summary of the group means for acquisition performance and retention are illustrated in Figures 1 and 2 (for RT and MT, respectively).

Acquisition Phase

The analyses (MANOVA and ANOVAS) involved 2 (cuing) × 2 (contextual variety) × 6 (trial blocks) × 3 (movement pattern) models with repeated measures on the last two factors. For the separate groups' factors the MANOVA revealed significant main effects for cuing, Wilk's exact $F(2, 19) = 18.27$; contextual variety, $F(2, 19) = 11.45$; and a significant interaction, $F(2, 19) = 6.61$. A follow-up univariate ANOVA for RT also showed these significant effects: cuing, $F(1, 20) = 30.64$, $\omega^2 = 23.5\%$; contextual variety, $F(1, 20) = 22.34$, $\omega^2 = 16.9\%$; and their interaction, $F(1, 20) = 13.92$, $\omega^2 = 11.8\%$. Post hoc analyses on the interaction revealed that the RT for the uncued–random group was significantly longer than the other three groups, which were themselves not significantly different. The univariate ANOVA for MT, however, revealed only a cuing effect, $F(1, 20) = 10.52$, $\omega^2 = 11.2\%$, indicating that the cued groups performed significantly faster, on the whole, than did the uncued groups.

The MANOVA also revealed a significant trial blocks effect, $F(10, 198) = 37.21$, as well as second-order interactions of block with cuing, $F(10, 198) = 7.45$, and contextual variety, $F(10, 198) = 5.21$. The univariate ANOVAS for RT and MT both mirrored the block main

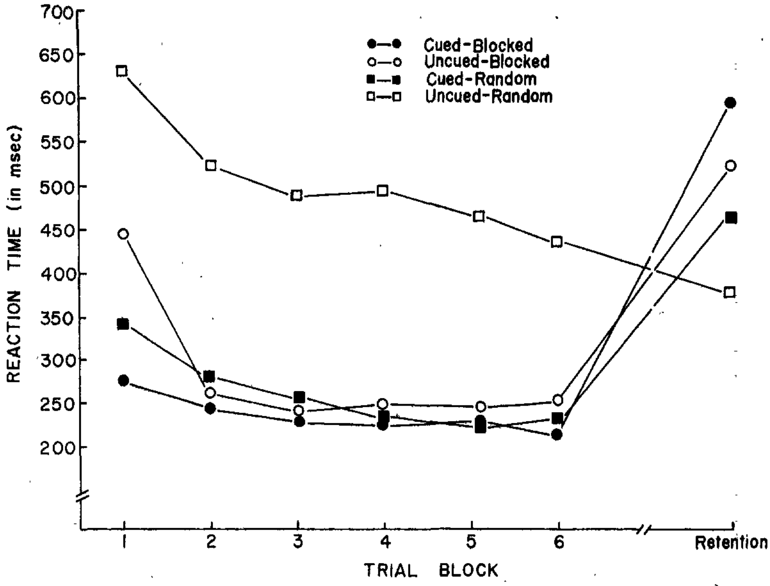

Figure 1. Group reaction time performance across acquisition and retention phases for Experiment 1.

effect, $F(5, 100) = 27.97$, $\omega^2 = 9.6\%$, and $F(5, 100) = 117.14$, $\omega^2 = 28.7\%$, for RT and MT, respectively. Of the second-order interactions with blocks, only the Cuing × Blocks interaction was significant for RT, $F(5, 100) = 4.69$, $\omega^2 = 1.3\%$. As may be seen in Figure 1, the first block of trials for the uncued–blocked group (the first trial of which was a choice response) seemed to have contributed most to this interaction. Indeed, the small variance accounted for reflects this lack of a powerful interaction. For MT, blocks interacted with

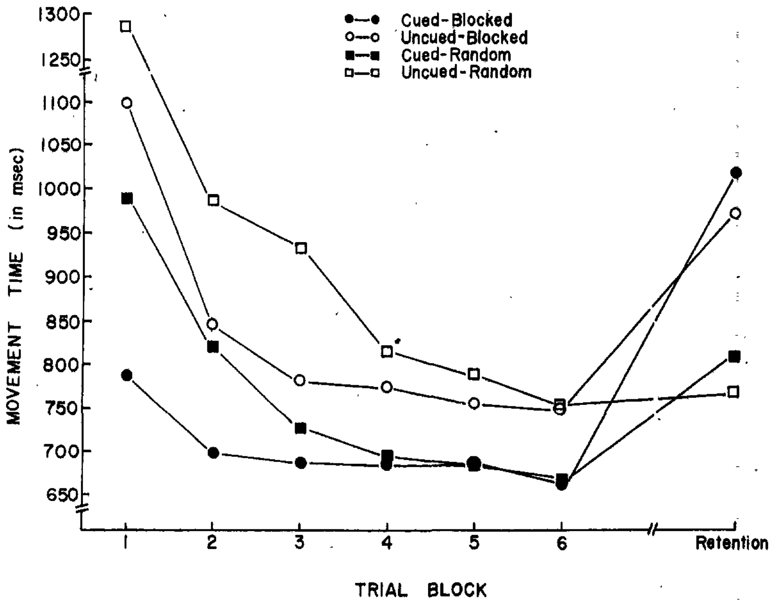

Figure 2. Group movement time performance across acquisition and retention phases for Experiment 1.

cuing, $F(5, 100) = 12.95$, $\omega^2 = 2.9\%$, and with contextual variety, $F(5, 100) = 10.91$, $\omega^2 = 2.4\%$. As may be seen in Figure 2, the general trend is for a more rapid asymptoting of the cued groups and for the blocked groups (substantiated by the post hoc tests).[3]

These data support and clarify the nature of contextual variety effects during the acquisition phase reported by Shea and Morgan (1979). Considering their original groups (here denoted as cued–blocked and uncued–random), the present findings clearly replicate these performance differences. However, as is apparent in Figure 1, the major impact on RT performance was the effect of reaction paradigm. As expected, choice reactions (uncued–random) were produced much slower than simple reactions. Under cued conditions though, there was no effect of blocked versus random practice schedules during acquisition. For MT a different pattern emerges. The interaction of reaction paradigm over trial blocks supports Kerr's (1978) contention that choice-reaction conditions produce influences that have an impact on both RT and MT. More important, the contextual variety effects for MT are consonant with the findings reported by Shea and Morgan. That is, random practice produces effects on MT, which are eventually overcome with practice (relative to blocked conditions).

The MANOVA revealed two further significant effects, due to the specific movement pattern performed, $F(4, 78) = 7.76$, and a Blocks × Pattern interaction, $F(20, 398) = 1.97$. Follow-up tests revealed only the MT main effect for pattern to be of consequence, $F(2, 40) = 18.09$, $\omega^2 = 4.1\%$. Post hoc analysis revealed that the "red" movement pattern was performed faster ($M = 752$ msec) than the "green" ($M = 806$) and "blue" patterns ($M = 863$), which were themselves not different. Significant ANOVA effects were found for the RT movement pattern effect, $F(2, 40) = 5.56$, $\omega^2 = .6\%$, and for the MT Blocks × Pattern interaction, $F(10, 200) = 2.65$, $\omega^2 = .6\%$, but because the variance accounted for was so small in these cases, post hoc tests might be hazardous.

Retention Phase

In the retention phase, data from the last block of acquisition trials and from the block of retention trials were used, resulting in 2 (cuing) × 2 (contextual variety) × 2 (trial blocks) × 3 (movement pattern) models, with repeated measures on the last two factors. The MANOVA revealed significant effects for trial blocks, $F(2, 19) = 26.72$, as well as Cuing × Blocks and Contextual Variety × Blocks interactions, $F(2, 19) = 5.29$ and $F(2, 19) = 8.83$, respectively. Follow-up ANOVAs on the blocks effect was significant for RT, $F(1, 20) = 47.22$, $\omega^2 = 27.0\%$, and for MT, $F(1, 20) = 38.36$, $\omega^2 = 17.3\%$. For RT, ANOVAs on the Cuing × Blocks effect were significant, $F(1, 20) = 10.96$, $\omega^2 = 5.8\%$, and small but significant for MT as well, $F(1, 20) = 4.46$, $\omega^2 = 1.6\%$. Post hoc ANOVA test on RT revealed that although the choice-reaction conditions were significantly slower than the simple-reaction conditions on the last block of acquisition trials, no differences were found between groups during the choice condition retention test. Thus, it appears that reaction paradigms had an effect on *performance,* which was not manifested in the differences exhibited on *learning.*

Further, the Contextual Variety × Blocks interaction was also significant for both RT, $F(1, 20) = 16.09$, $\omega^2 = 8.8\%$, and MT, $F(1, 20) = 12.02$, $\omega^2 = 5.1\%$. For RT, although random groups (most important, the uncued–random group) were slower than blocked groups on trial block 6, the reverse occurred during retention. Under identical retention conditions, the random group performed significantly faster than the blocked group. For MT, a similar trend occurred, only that blocked and random groups had not been different at trial block 6.

These retention data also support and clarify the findings of Shea and Morgan. The influence of reaction paradigm on RT, although critical

[3] In Figures 1 and 2 the uncued–blocked group appears to have performed much poorer than the cued–blocked group on the first block of trials. This apparent anomaly occurred because subjects in the uncued–blocked group were not made aware of the first movement pattern for any particular run of 18 trials. Indeed, an analysis comparing the two blocked groups on the first and second trials for each pattern reveals an average reduction of 328 msec (RT) and 534 msec (MT) for the uncued–blocked group but only reductions of 99 msec (RT) and 147 msec (MT) for the cued–blocked group. Two-way ANOVAS (Group × Trial) revealed this interaction to be significant for MT only, however, $F(1, 10) = 25.27$, $\omega^2 = 11.6\%$.

to the interpretation of contextual variety effects during acquisition, seems to have much less of an impact on retention. Rather, the major retention effects (for RT and MT) were due to the contextual variety factor. Similar to the Shea and Morgan findings, random practice schedules promoted better retention performance than blocked practice schedules.

The MANOVA further revealed an effect of movement pattern, $F(4, 78) = 10.85$, with follow-up ANOVAs significant for both RT, $F(2, 40) = 16.51$, $\omega^2 = 3.7\%$, and MT, $F(2, 40) = 12.79$, $\omega^2 = 5.6\%$. Post hoc analyses revealed that the red movement pattern was performed significantly faster than the green and blue patterns. Finally, the MANOVA also revealed significant two-way interactions of blocks and contextual variety with movement pattern and a triple interaction of contextual variety, blocks, and movement pattern. However, because all variances accounted for by the follow-up ANOVAs were small, these interactions will not be statistically elaborated.

In summary, the findings for Experiment 1 suggest that contextual variety effects in motor-skill acquisition as demonstrated by Shea and Morgan are due to different factors at different phases. The elevated RTs found for the random groups were likely due to the reaction paradigm used, whereas MT differences were affected by both reaction paradigm and contextual variety effects. The retention data, though, clearly support Shea and Morgan's contention that random contextual variety conditions facilitate remembering motor skills relative to blocked contextual variety conditions. Thus, these findings suggest that the methodological locus of contextual variety effects arises from the manipulation of practice schedules and is not due to the effects of reaction paradigm or the interaction of practice schedule with reaction paradigm.

An argument against such an interpretation could be made based on the nature of the acquisition–retention conditions. That is, acquisition trials included random and blocked practice, whereas retention trials were only randomly ordered. Based on the benefit of similarity of transfer conditions and the effects that similarity have on retention of motor skills (cf. Magill, 1983; Lee & Magill, Note 1), it would be expected that the random practice group would have a clear advantage during the retention trials under the procedures used in this experiment. However, this explanation is clearly inadequate in the present case based on the findings of Shea and Morgan (1979). In their experiment, retention trials were performed under blocked as well as randomly ordered conditions. Their data (10-min. retention) revealed that the random acquisition group actually performed *better* under blocked retention trials than the blocked acquisition group! Indeed, similar effects have also been observed by Del Rey (Note 2). Clearly, the findings point to practice schedule manipulations as the potentially critical variable to theoretical accounts of skill acquisition. Experiments 2 and 3 are designed in an attempt to uncover the underlying processing responsible for this practice schedule effect.

Experiment 2

A focus on the practice schedule differences between blocked and random conditions places an emphasis on the effects of repetition/nonrepetition of events. Blocked practice conditions for a particular movement pattern involve a repetition of similar neuromotor synergies and cognitive processes on repeated trials. Random conditions, on the other hand, typically require a different action plan and motor response on succeeding trials.

Research findings related to cognitive skills and event or word repetitions suggest that spacing these repetitions leads to a retention advantage as compared with repeating all instances of the word successively during list presentation (sometimes denoted as distributed vs. massed presentations; Hintzman, 1974; Melton, 1967). Indeed, this phenomenon for word recall has been likened to the process of solving a mathematical or some other cognitive problem (Jacoby, 1978). That is, after solving the problem, immediate presentation of the same problem allows the correct solution to be remembered without the necessity of having to go through the operations involved in resolving the problem. Under spaced presentations, however (i.e., the repetition effect), the answer to the solution is not available, and hence the problem-solving process is again undertaken. Jacoby (1978) has suggested that retention performance is poorer for immediately re-presented problems because "the solution is remembered rather then being constructed" (p. 666).

Jacoby's arrangements are strikingly reminiscent of arguments offered on motor skill acquisition many years ago by the Russian physiologist Bernstein (1967):

> The processes 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. (p. 134)

The implications of the above arguments towards the locus of contextual variety effects attributes the repetition/nonrepetition of movement patterns to cognitive processes involved in learning the goals of the task. That is, the planning decisions regarding an upcoming movement must be "constructed" rather than just "remembered" from the action plans for the previous trial under random practice conditions. Further, a facilitation of retention is consonant with the robust phenomenon that constructing action plans leads to superior memorial performance relative to when action plans do not have to be formed for movement (viz., the preselection effect—Kelso & Wallace, 1978; Lee & Gallagher, 1981).

In addition to the repetition effect basis for explaining the contextual variety paradox, consideration must also be given to the possible effect of the predictability of upcoming events. This possibility seems plausible when the predictability patterns of random and blocked practice schedules are considered. Previous research has shown that when a highly predictable, nonrepetitive event occurs, the problem-solving process may be circumvented. This "alternation effect" (Keele, 1973; Kirby, 1980) would suggest then that when a practice sequence is highly predictable, there is little uncertainty as to the choice of response, resulting in less information to be processed. For random practice schedules, the unpredictable nature of the event sequence creates a more resource- or effort-demanding state of readiness, which produces an ultimate facilitation on retention.

In the present experiment a comparison of the possible influence of repetition effects and event predictability on the contextual variety phenomenon was made possible by adding a third practice order group. This condition, termed *serial,* combined a feature of the random practice schedule (nonrepetition of events) with a feature of the blocked group (perfect predictability of events). Under this serial practice schedule, subjects are presented trials in blocked orders of triplets (i.e., the 54 trials are blocked into 18 presentations of a particular testing order, e.g., red-blue-green). If nonrepetition of events produces the contextual variety effect, this serial condition should produce delayed retention results similar to the random condition. Alternatively, if contextual variety effects are due to the unpredictability of upcoming events, then delayed-retention results for this serial group should be similar to the blocked practice condition (i.e., yield poorer retention than practice under random schedules).

Method

Subjects

Thirty undergraduates (21 females and 9 males; mean age = 19.8 years) from psychology and physical education classes at Louisiana State University participated in the experiment for course credit. Assignment to groups was random with the restriction that group size was equal (n = 10). None of the volunteers had served as subjects in Experiment 1.

Apparatus

The apparatus and materials were identical to those used in Experiment 1. To combat possible effects of intratask similarity,[4] the illustration used for the red light

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[4] An examination of the task procedures as well as subjects' verbal reports indicated that the red pattern facilitated RT and MT regardless of other experimental variables (although the ω^2s were generally small). This could be due to the fact that the red signal-to-respond light, which was located on the right side of the rear panel, was associated with the only response whose initial movement was to a barrier on the right. Thus, the mnemonic R could be developed to associate the red light, its right spatial location, and the right initial movement direction. That is, the response for this pattern was more readily retrievable for action. Recalling that Battig (1979) promoted increased similarity among items to be learned as a factor contributing to contextual interference (in addition to contextual variety), this mnemonic suggests that the production of a cognitive action strategy might be one way in which the constraints of contextual interference might be overcome (cf. Wughalter, 1981).

was switched to the blue. The blue pattern was changed slightly (the last barrier knocked over was the right rear instead of the left rear) and moved to be paired with the red signal to respond.

Procedure

All task-related and statistical procedures were identical to those used for the cued-random and cued-blocked groups in Experiment 1, with three exceptions. First, an additional contextual variety group was tested. Subjects in this "serial" group received the 54 acquisition trials in 18 triplets of 3 identical testing sequences (order balanced across subjects). Second, instructions to the subject provided information as to the exact nature of the retention test and prompted that he or she should learn to remember which pattern was paired with each light in addition to learning to move as quickly as possible. This change in procedures was also used to help eliminate possible confounding effects of intratask similarity (see Footnote 3, Shea & Zimny, 1983). Third, following the Stroop test during the interpolated phase, subjects were presented a written recall test. On the standard test sheet were three illustrations of the task, similar to those used to illustrate the movement patterns, but without the lines illustrating the direction of movement. Above each illustration was the name of a color. The subject's task was simply to draw the pattern of movement execution associated with each of the signal colors. This recall test was performed, usually, in less than a minute.

Results and Discussion

Acquisition Phase

The analyses (MANOVA and ANOVAS) involved 3 (groups) × 6 (trial blocks) × 3 (movement pattern) models with repeated measures on the last two factors. The MANOVA revealed significant main effects for blocks, $F(10, 268) = 36.54$, and a significant Groups × Block interaction, $F(20, 268) = 2.86$. Follow-up ANOVAS revealed that the blocks effect was significant for both RT, $F(5, 135) = 37.41$, $\omega^2 = 20.8\%$, and MT, $F(5, 135) = 105.49$, $\omega^2 = 23.0\%$. Newman-Keuls tests revealed that although RT asymptoted by the second block of trials, MT did not asymptote until block 4 (see Figures 3 and 4). The ANOVA also revealed that the Group × Block interaction was only significant for MT. As may be seen in Figure 4, post hoc analyses revealed a significant difference between the blocked group and the other two groups at trial blocks 1–3.

These findings are consistent with the results from Experiment 1 for both RT and MT. However, the more interesting finding is the virtual overlapping of group means for the random and serial groups (see Figures 3 and 4). Thus, from the acquisition data, it appears that factors producing contextual variety effects under random practice schedules may also be affecting the serial group as well (at least for acquisition performance).

The MANOVA also revealed one further significant effect for movement pattern, $F(4, 106) = 14.77$. Follow-up analyses showed this effect to be significant only for MT, $F(2, 54) =$

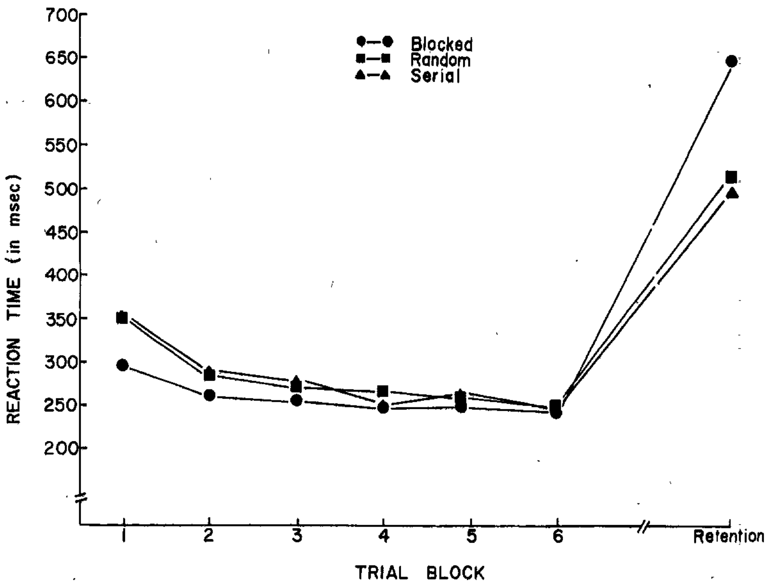

Figure 3. Group reaction time performance across acquisition and retention phases for Experiment 2.

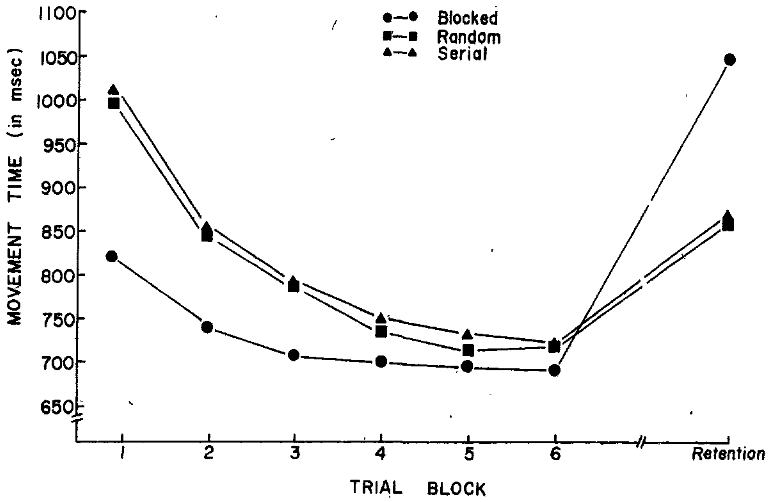

Figure 4. Group movement time performance across acquisition and retention phases for Experiment 2.

28.57, $\omega^2 = 3.2\%$, and that the red movement pattern was performed more slowly than the other two patterns.

Written Recall

A one-way ANOVA was performed on the number of patterns correctly remembered (in their proper sequence and associated with the correct signal). Although the mean recalls appear different (blocked $M = 2.0$, random M 2.2, serial $M = 2.7$), the ANOVA failed to reach statistical significance, $F(2, 27) = 2.00$.

Retention Phase

The MANOVA revealed significant effects for blocks, $F(2, 26) = 139.13$, a Group × Block interaction, $F(4, 52) = 6.99$, and a main effect for movement pattern, $F(4, 106) = 7.63$. Follow-up ANOVAs revealed significant block effects for both RT, $F(1, 27) = 169.05$, $\omega^2 = 61.2\%$, and MT, $F(1, 27) = 141.53$, $\omega^2 = 24.6\%$. The difference between responding on the last block of acquisition trials versus the retention trials reflects the change, for all groups, from a simple- to choice-reaction paradigm. The Groups × Blocks interaction, as illustrated in Figures 3 and 4, was also significant for both RT, $F(2, 27) = 4.28$, $\omega^2 = 2.4\%$, and MT, $F(2, 27) = 15.16$, $\omega^2 = 5.0\%$. Post hoc analyses for both RT and MT indicated the same results: Whereas all groups performed similarly in the last block of acquisition trials, the blocked group was significantly slower on the retention trials than the random and serial groups, which were themselves not different.

The significant MANOVA effect for movement pattern was only found to be significant in the MT ANOVA, $F(2, 54) = 16.49$, $\omega^2 = 4.0\%$. Post hoc tests revealed that the blue pattern (which was the red pattern in Experiment 1) was still performed faster ($M = 768$ msec) than either the green ($M = 810$ msec) or the red ($M = 877$ msec) patterns. Further, the green pattern was also performed faster than the red pattern. However, the interaction of movement pattern with contextual variety conditions observed in Experiment 1 was not revealed here. Thus, the possible confounding of contextual variety effects with interresponse similarity effects was eliminated.

Again, these data also replicate and extend the results of Shea and Morgan (1979) and the findings from Experiment 1. Although the random–blocked difference was replicated, the critical finding was the similarity of results for the serial and random conditions (see Figures 3 and 4). Given that the primary methodological similarity between random and serial practice schedules is the order in which events are practiced, it seems apparent that the methodological locus of the contextual variety effect lies more in the nonrepetitive nature of the practice schedules rather than in the predictability of upcoming events.

Under event repetition conditions (i.e., blocked practice schedules), the decisions regarding where to move are easily remembered from trial to trial, involving less problem-solving activities for solution of the task and consequently leading to poor retention performance. Under nonrepetitive event conditions (i.e., random and serial practice schedules), intervening movement patterns between repetitions of the same motor problem necessitate that the action commands on each trial be resolved, resulting in a facilitation of retention.

It is interesting to note that although the pattern of RT and MT results found in the present experiment would be predicted based on the spacing effect phenomenon, no differences were found between groups with respect to the written recall data. Although these data may suggest possible ceiling effects (cf. Shea & Zimny, 1983), this failure to detect a difference may provide some insights into the distinction between effects on some memory construct (e.g., memory strength—Cuddy & Jacoby, 1982) versus an influence on remembering as the *accessibility of knowledge*. In Experiments 1 and 2 the speed by which plans for action are accessed both prior to movement onset (as measured by RT) and during movement itself (as measured by MT) is affected by the practice schedules. That is, accessibility and implementation of an appropriate plan of action is faster when acquisition conditions have occurred under random or serial practice schedules. The lack of a between-group difference in written recall, however, does not imply that memory strength is similarly affected. One approach to testing these speculations is present in the following experiment.

Experiment 3

In the present experiment the task was changed from performing each movement pattern as rapidly as possible to a task in which the goal was to perform the movement pattern as close to a criterion time as possible (i.e., as close as possible to 900, 1,050, and 1,200 msec for the blue, green, and red patterns, respectively). Because each trial was begun at the subject's discretion (i.e., not a *reaction* paradigm), the decisions regarding the pattern's directional sequence could be accessed before the movement was begun, thus eliminating the emphasis on the *speed* by which action plans are accessed. Instead, the emphasis was placed on remembering the *timing* requirements for each pattern. Consequently, by measuring the retention effects on timing accuracy and consistency (i.e., measures of timing error), a better indication of contextual variety effects on memory may be gleaned. If, as suggested in the previous discussion, memory per se is not directly influenced by the type of practice schedule used during skill acquisition, then no contextual variety retention effects should be predicted in the present experiment.

Method

Subjects

Thirty female undergraduates (mean age = 21.9 years) from psychology and physical education classes at Louisiana State University participated in the present experiment for course credit. Assignment to groups was made at random with the restriction of equal group sizes (n = 10). None of the volunteers had participated in Experiments 1 or 2.

Apparatus

The apparatus and all materials were the same as those used for Experiment 2. The only modifications involved covering the warning signal light and using only one of the millisecond timers.

Procedure

In the present experiment all manipulations with respect to the ordering of trials in the three groups were consonant with Experiment 2. The major difference in the present experiment was the goal of the task.

Here, no warning light was provided because the signal to respond merely indicated which pattern was to be performed. Subjects were prompted to begin their performance for a particular pattern by depressing the start microswitch after the associated light was illuminated. Holding the start button down, subjects were encouraged to begin their movement *only when they were ready.* Directly above the illustrations associated with each colored light were tags indicating the criterion time for each pattern (blue = 900 msec; green = 1,050 msec; red = 1,200 msec). Subjects were informed that a millisecond timer began after leaving the start button and terminated upon depression of the telegraph key. Further, it was explained that the goals of the task were to learn to perform each pattern as close to the associated criterion time as possible. The experimenter also explained that KR, given as the MT immediately after the trial, could be used as a basis for speeding up or slowing down future attempts on that pattern. (For example, KR such as "932 msec" for a trial on the blue pattern indicated that the MT was too slow [by 32 msec] and needed to be made somewhat faster on the next trial for that particular pattern.)

Following the acquisition phase, subjects again performed the interpolated task, but not the written recall test (used in Experiment 2). In order to deemphasize the importance of decisions regarding where to move as the primary cognitive learning component, the movement pattern illustrations were available for viewing during retention trials. Further, the number of randomly ordered, no-KR retention trials was doubled (to 18) in order to assess the impact of the information withdrawal over a longer period of time.

Statistical Procedure

Performance scores on each trial were transformed into signed error scores (i.e., error = MT − criterion time). Using the trial blocks procedures from Experiments 1 and 2, we calculated three error measures. Absolute constant error (/CE/) is the absolute value of the arithmetic mean of signed error scores within a trial block and is considered a measure of performance accuracy. Variable error (VE) is a standard deviation about a particular /CE/ and is considered a measure of performance consistency. Total error (E) is a composite error measure (where $E^2 = /CE/^2 + VE^2$) and reflects a more general indicant of performance error (see Schutz, 1977, for a more thorough discussion of these and other error measures). Due to problems of multicollinearity (Thomas, 1977), only /CE/ and VE were included in the initial MANOVA. A separate ANOVA was performed on the E data.

Results and Discussion

Acquisition Phase

The analyses involved 3 (groups) × 6 (trial blocks) × 3 (movement patterns) models with repeated measures on the last two factors. The ANOVA for E revealed significant main effects for groups, $F(2, 27) = 6.55$, $\omega^2 = 3.8\%$, and for trial blocks, $F(5, 135) = 20.81$, $\omega^2 = 14.9\%$. The MANOVA on /CE/ and VE also revealed main effects for groups, $F(4, 52) = 5.21$, and for blocks, $F(10, 268) = 8.62$. Follow-up ANOVAS were significant for the group effect only for /CE/, $F(2, 27) = 12.56$, $\omega^2 = 4.3\%$. However, the ANOVAS revealed significant differences over trial blocks for both /CE/, $F(5, 135) = 14.10$, $\omega^2 = 10.3\%$, and VE, $F(5, 135) = 11.19$, $\omega^2 = 8.1\%$. Post hoc tests on the differences between groups revealed the same results for E and /CE/: Subjects in random and serial groups performed less accurately during the acquisition phase than did subjects in the blocked group. For the trial blocks effect, the analyses revealed that although performance in general (E) and performance accuracy (/CE/) asymptoted by block 3, consistency of responding (VE) asymptoted by block 2. These data show trends similar to the findings of Experiment 2 in that the random and serial groups performed with equivalent accuracy yet poorer than the blocked group. However, these results differ in that no Groups × Trial Blocks interaction was found. That is, at the end of the acquisition phase there remained a marked decrement to performance accuracy for both the random and serial groups, compared with the blocked group.

Retention Phase

The analyses involved 3 (groups) × 3 (trial block 6 plus the two retention trial blocks) × 3 (movement patterns) models with repeated measures on the last two factors. The ANOVA on E revealed a main effect for trial blocks, $F(2, 54) = 2.32$, $\omega^2 = 1.9\%$, as well as a Groups × Blocks interaction, $F(4, 54) = 6.38$, $\omega^2 = 8.6\%$. The MANOVA for /CE/ and VE also revealed these effects for blocks, $F(4, 106) = 4.57$, and for the Groups × Blocks interaction, $F(8, 106) = 3.08$. Follow-up ANOVAS revealed significant differences on the blocks effect, $F(2, 54) = 6.43$, $\omega^2 = 4.3\%$, and the interaction, $F(4, 54) = 6.12$, $\omega^2 = 8.1\%$, for /CE/ but not for VE. Post hoc analyses revealed that for the blocked group, the retention trial blocks were performed significantly poorer than the last block of acquisition trials. However, for both the serial and random groups, there were no differences between these trial blocks. Further, the random group was significantly more accurate than the blocked group on the second set of retention trials. No significant differences were observed between the serial group and the other two groups (see Figure 5).

In addition, a Group × Movement Pattern interaction was also significant for E, $F(4, 54) = 2.88$, $\omega^2 = 2.0\%$. The Newman-Keuls test, however, failed to detect any differences among the means.

The results of the present experiment are very enlightening in several regards. Of primary importance, the basic retention test difference between random and blocked groups, which has been observed previously (Del Rey

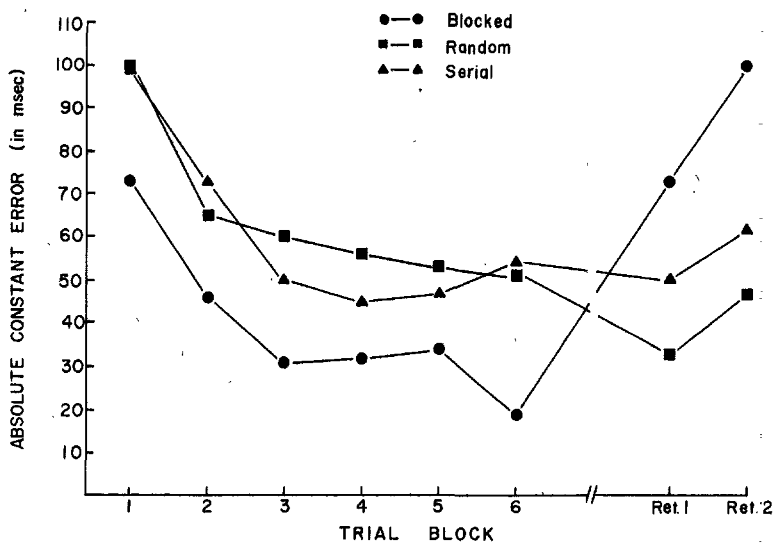

Figure 5. Group absolute constant error performance across acquisition and retention phases for Experiment 3. (Ret. = retention.)

et al., 1982; Shea & Morgan, 1979; Shea & Zimny, 1983) and in Experiments 1 and 2 here, was extended to a task with different movement goals. Indeed, the extremely rapid decline in performance during retention trials for the blocked group (when KR was removed) suggests that a very weak memory for the patterns' timing requirement had been established, relative to that developed in the serial and random groups (see Figure 5). This finding suggests, then, that the practice schedule influence not only facilitates the accessibility of action plans from memory but serves to enhance memorial quality as well.

The nature of this memory effect may be gleaned somewhat from a more descriptive analysis of the /CE/ and VE data. An examination of the biases in response accuracy differences observed during retention (CE, rather than /CE/) reveals a consistent shift toward overestimating the timing requirements for the blocked group only. Of the 10 subjects in the blocked group, 9 showed positively biased timing errors (overall group mean CE = +75 msec). This shift during the KR-withdrawn trials, however, was not observed for the other groups. Under the random acquisition conditions, 6 subjects revealed positive error shifts (M = +24 msec), and 4 subjects had negative response biases (M = −23 msec) across the no-KR trials. For the serial group, 4 subjects were positively biased (M = +37 msec), and 6 subjects underestimated the criterion times (M = −37 msec). These CE data not only suggest, then, that learning under blocked acquisition conditions is detrimental to later retention accuracy but also that this inaccuracy is due to a shift toward overestimating the criterion times.

For VE, no differences between the practice schedule manipulation were observed. This finding suggests that although the blocked group produced much greater biases in timing judgment following the removal of KR, their consistent ability to access and produce what they believed to have been accurate judgments was equivalent to the VE retention performance of the serial and random groups.

General Discussion

The present series of experiments both support and extend previous investigations regarding contextual interference in motor-skill acquisition. Similar to earlier studies (Del Rey et al., 1982; Shea & Morgan, 1979; Shea & Zimny, 1983), the basic practice schedule effects of facilitated acquisition performance under blocked ordered trials—but better retention for random practice schedule groups—was both supported and extended to a task with new (and perhaps more difficult) movement goals (Experiment 3). In addition, Experiment 1 refuted the notion that this difference was due to type of reaction paradigm used in previous studies.

Of particular importance to the question concerning the locus of contextual interference was the addition of the serial group in these experiments. The significance of this group is seen in the virtually identical pattern of results found under random and serial practice schedule manipulations. This suggests that cognitive–motor event repetition rather than event predictability is the major influence on the acquisition and retention effects.

For immediate performance benefits (i.e., during acquisition), the blocked practice schedule facilitated accessibility of action plans (RT and MT in Experiments 1 and 2) and reduction of timing errors (/CE/ in Experiment 3) because subsequent practice on a particular movement pattern occurred in the absence of any other pattern. Thus, for this group, action strategies that could be devised and tested to solve the motor problem could be concentrated on only a singular movement pattern without the intervention of planning for another motor problem. Under random and serial conditions, however, strategies for solving the motor problem for any one particular movement pattern could not be immediately devised and tested, because action plans for intervening trials needed to be generated. Indeed, this effect of event repetition has been previously shown as both a facilitation of response speed (see Kirby, 1980, for a review) and as a benefit to timing error reduction during acquisition performance (Lee & Magill, in press).

The critical finding, however, is that event repetitions that facilitate *acquisition* performance appear to be *detrimental* to retention performance. Although this finding would seem consonant with the impact that massed versus distributive word-list repetitions have on verbal memory, there seems to be a much more significant implication being made by this contextual variety effect. As suggested previously (Namikas, 1983), skill learning is not merely a reinstatement of some previously known information (an episodic memory task) but rather involves the acquisition of knowledge. The contextual variety effect on skill acquisition, then, not only seems to have its influence on memory or memory strength but also determines the refinement of cognitive operations, which is learning (Shea & Zimny, 1983).

With respect to an event-repetition view of contextual variety effects, the results of Experiment 3 are particularly interesting given Schmidt's (1982, chap. 13) recent reevaluations of the role of KR in skill acquisition. He argued that under conditions in which the processing of error information is impeded (as in the trials-delay studies and under low relative-KR conditions), subjects are forced to find less efficient, task-relevent cues to improve performance. Conversely, when made readily available to solve motor problems, KR acts to *guide* performance, serving as a "crutch" on which performance may be facilitated. When KR is later removed, Schmidt noted that these conditions in which KR earlier served to guide performance produced large performance decrements relative to the cases where KR was not availble to be used as a crutch.

Indeed, the paradox noted by Schmidt is quite similar to the contextual variety effects as produced in Experiment 3. That is, event repetitions (blocked practice trials) promote the immediate utilization of KR, serving to guide performance, yet are detrimental to no-KR retention trials. However, under conditions in which KR cannot be used immediately to solve motor problems (under random and serial practice schedules), the cognitive problem-solving activities involve more of the task-relevant information as gathered from the performance of nonrepetitive, but related, events.

Although the results from Experiment 3 seem to fit Schmidt's arguments well, the findings from Experiment 1 and 2 cannot be so directly subsumed under this KR rationale. Moreover, the evidence from these experiments seems to point to a more general phenomenon of cognitive-motor functioning during skill acquisition, of which the KR paradoxes noted by Schmidt and the contextual variety effect demonstrated herein are simply paradigms that produce this phenomenon. In the case of the KR-related studies noted by Schmidt and the KR/contextual-variety study reported here (Experiment 3), by making the direct utilization of error feedback more difficult (e.g., by delaying KR [trials-delay technique] or by using random or serial practice schedules), there is a performance decrement in acquisition trials but a facilitation of retention in KR-withdrawn trials. A similar result also occurs under contextual variety conditions in which remembering the actions is the relevant cognitive activity (as in Experiments 1 and 2). The common elements among all of these findings, though, is the manner by which these experimental manipulations force subjects to adopt strategies in the attempt to improve performance (cf. Singer & Pease, 1976). In all cases an emphasis is placed on the performer to adopt more *cognitively effortful* problem-solving activities. In the KR-related cases, the increased effortful processing invokes greater use of task-relevant features and sensory feedback to augment the interference involved in utilizing KR (Schmidt, 1982). In the contextual variety situations present in Experiments 1 and 2 and elsewhere (Del Rey et al., 1982; Shea & Morgan, 1979), the increase in effortful processing due to random and serial practice schedules is manifested because subjects must *actively regenerate* a new movement plan on each trial during the acquisition phase, whereas under blocked practice schedules action plans may be passively *remembered* (i.e., not *reconstructed*) on each subsequent trial. Indeed, this effort-related explanation to the above phenomenon is consonant with recent perspectives on the acquisition of purely cognitive tasks (Eysenck & Eysenck, 1979; Kunen, Green, & Waterman, 1979; Tyler, Hertel, McCallum, & Ellis, 1979) as well as for short-term retention of preselected movements (e.g., Kelso, 1981; Lee & Gallagher, 1981).

The contextual variety effect also seems to be related to recent empirical tests of the variability of practice hypothesis based on Schmidt's (1975, 1976) schema theory. According to this theory, a goal-directed action results in the abstraction of four movement-related consequences: (a) the preresponse conditions of the motor system, (b) the movement parameters of the action plan, (c) the sensory feedback, and (d) the outcome of the response—KR. With practice, a schema supposedly develops as an abstract representation of the *relationship* between these four sources of information. One fundamental prediction of the theory is that the greater the variety or variability among and within these sources of information, the stronger the schema development. Further, stronger schemas should result in better retention of the acquired skill as well as a facilitation in transfer to novel variations of the skill (Posner & Keele, 1970; Schmidt, 1975, 1976).

To some extent, then, schema theory affords similar predictions as contextual interference theory. One major difference between the two, however, is that schema theory makes no predictions regarding the *order* by which practice trials should be undertaken. Indeed, the equivocality of research that has examined the transfer predictions of schema theory may be reconciled, in part, given contextual interference theory. Of six published articles testing schema theory's variability of practice hypothesis in adults (see Shapiro & Schmidt, 1982, for a review of these articles and related, unpublished papers), three manipulated practice variability conditions used a blocked practice schedule design, whereas a random practice schedule was adopted in the other three studies. Not surprisingly (according to contextual interference theory), the three "blocked" studies showed little or no support based on schema theory predictions (Husak & Reeve, 1979; Newell & Shapiro, 1976; Zelaznik, 1977), whereas the three "random" studies supported schema theory predictions quite well (McCracken & Stelmach, 1977; Wrisberg & Ragsdale, 1979; Zelaznik, Shapiro, & Newell, 1978).

Although this reinterpretation does not refute the potential benefits of *motor* practice variability, it does suggest that in conjunction with random practice schedules, the development of movement schemas underscores the dynamics between cognition and motor control. Future research regarding the interaction of the various factors that underlie practice variability effects would seem a fruitful endeavor toward a better understanding of the processes involved in skill acquisition.

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