

Skill Acquisition in Sport. Research, Theory + Practice

5 Contextual interference Edited by Nicola J. Hodges Generalizability and limitations + Mark Williams Timothy D. Lee (2012)

Interest in practice schedules has motivated motor learning research for many years. Distribution of practice was an early example, in which longer rest intervals, inserted between periods of practice, produced better retention than short rest intervals. The distribution of practice effect had implications for theory (e.g., Ammons, 1947; Hull, 1943) and practical applications for training efficiency and effectiveness in industry (e.g., Baddeley & Longman, 1978) and sport (e.g., Dail & Christina, 2004), and remained a driving force in motor learning research for several decades. The distribution of practice effect had a particularly large influence on the learning of continuous motor skills, such as tracking, but the effect was smaller when rest periods were applied to discrete skills (Lee & Genovese, 1988).

Researchers interested in the learning of discrete motor skills frequently turn their attention to the contextual interference (CI) effect. Similar to distribution of practice, CI concerns how practice is structured during the training environment, but in contrast to distribution of practice, in which only one task was typically practiced, CI concerns how the organization of practice for multiple skills influences performance and learning. The implications of CI research for motor learning theory and applications to training are many and are discussed in this chapter.

What is the CI effect?

Perhaps the best way to understand the CI effect is to describe how it is studied, and there is no better point to begin than with Shea and Morgan (1979). Their study was straightforward: two groups of participants responded to colored light stimuli with one of three patterns of arm movements. The goal was to respond to a stimulus by picking up a tennis ball from the apparatus base, knocking over three of the six small barriers located on the base, and then replacing the ball. Three light colors were used as stimuli, each associated with a specific movement pattern (defined by the order of barriers). The task goal was to respond to the light quickly and accurately (i.e., correct sequence of barrier contacts), with reaction time, movement time, and response errors as the dependent variables. Participants in the experiment practiced each of the three tasks for 18 trials, for a total of 54 trials. Half of the participants in each group returned for retention tests after one of two delay periods: one subgroup after a brief delay (10 min), the other after a much longer delay (10 days).

The primary experimental manipulation was the practice schedule by which participants completed their trials during the learning period. One group, the *blocked-practice order group*, completed all 18 trials for any one pattern before another block of trials on a different pattern was undertaken. The other group, the *random practice-order group*, completed only one, or at most two, trials of any pattern before practice on another pattern was undertaken. The order of practice for the random group was unsystematic, except that no more than two trials of any one pattern was completed in succession and that three trials of each pattern were completed after every set of nine trials.

The results of the Shea and Morgan (1979) study for response time are illustrated in Figure 5.1. During the practice period (left side of Figure 5.1), the blocked group attained a large performance advantage compared with the random group within the first block of nine trials, and this performance advantage was maintained throughout the entire practice period. The response times demonstrated by the blocked and random groups reflected large differences, perhaps due to (a) enhanced performance for the blocked group caused by repeatedly performing the same task, (b) a decrement for the random group caused by the frequent task switching, or (c) some combination of these two influences. However, the differences between the blocked and random groups exhibited during the practice period could not be described as being due to differences in *learning*; inferences about learning could only be made by examining the impact of these practice schedules in tests of retention (for a more complete discussion of the distinction between performance and learning, see Schmidt & Lee, 2011). Shea and Morgan conducted two retention tests that allowed a more appropriate examination of any differences that may have occurred because of learning. The practice groups performed these retention test trials using both random and blocked test orders.

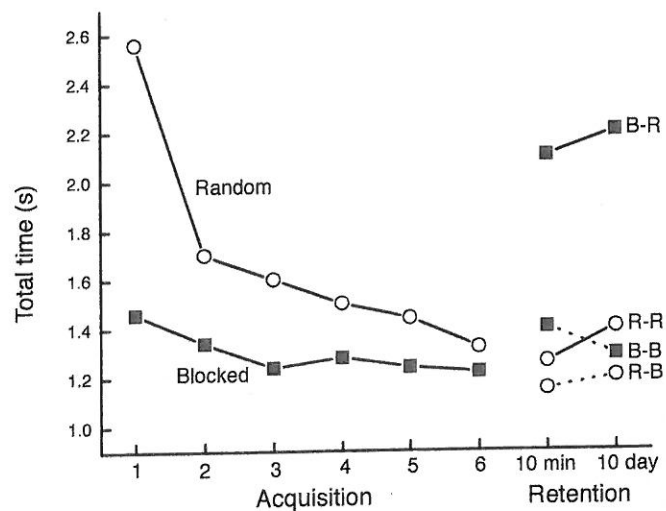


Figure 5.1 Results of the Shea and Morgan (1979) study.

The results of the retention tests are presented in the right side of Figure 5.1. These retention test scores can be considered from two different perspectives. First, from a perspective that considers each group's retention performance *relative to the end of the practice period*, the blocked group's performance diminished slightly when tested in blocked-ordered retention trials (designated with the "B-B" label in Figure 5.1), but dropped off dramatically in randomly ordered retention trials (B-R). In contrast, the random group maintained their level of performance when tested in randomly ordered trials (R-R), and improved their level of performance in the blocked-ordered retention trials (R-B). However, a more direct comparison of the effects of these practice schedules is from a perspective of their *relative impact on retention*. For blocked-ordered retention trials, previous practice in the random practice schedule (R-B) provided a small but important advantage compared with having practiced in the blocked schedule (B-B). For the randomly ordered retention trials, having previously practiced in the random schedule (R-R) provided a rather large advantage relative to the blocked schedule group (B-R).

Shea and Morgan (1979) found that blocked practice facilitated performance during acquisition trials, but that the random group facilitated learning as a result of these practice trials. This pattern of results has become synonymous with what is now called the CI effect (after Battig, 1979) and greatly puzzled researchers who had been conducting motor learning research. After all, how could a variable that had such a large impact on acquisition performance have an equally large, but opposite, effect on learning? Such an effect was considered counterintuitive, if not bizarre, on the basis of theoretical and practical accounts of motor learning at the time.

On the generality of the CI effect

Hundreds of studies have been performed by researchers since the time that Shea and Morgan (1979) published their findings, and reviews of this work abound (Barreiros, Figueiredo, & Godinho, 2007; Brady, 1998, 2004; Lee & Simon, 2004; Magill & Hall, 1990; Merbah & Meulemans, 2011). Many of these reviews provide excellent insights into the limitations of the CI effect. The intention in this chapter is to present some key findings in the literature that illustrate the generalizability of the CI effect and to identify, specifically, some factors to which CI is not limited. Shea and Morgan (1979) used a laboratory task that was learned in a very short practice period and demonstrated differences among young adults in a speeded movement task. A survey of the literature conducted since Shea and Morgan's experiment was published reveals that the impact of their findings has extended well beyond these modest beginnings. The goal is to impress upon the reader that these effects apply *not just* to (1) laboratory tasks practiced in a single session, (2) task outcomes, (3) young adults, (4) motor learning, and (5) learners who are expecting the effect. The intention is to summarize evidence for an effect that is both wide-ranging and cross-disciplinary – one that touches upon a fundamental feature of human learning.

1. *CI is not limited just to laboratory tasks, practiced in a single session*

A hallmark of an important effect in a field of study is its generalizability beyond the laboratory, and research by Goode and Magill (1986) represented an early extension of CI research outside the laboratory. The study compared novices who practiced three types of badminton serves (long, short, and drive serves) for nine sessions, over a 3-week period, before performing retention and transfer tests. Goode and Magill used methods for the blocked practice group that were slightly different from the Shea and Morgan procedures: practice of one type of serve was conducted in a blocked order *within* a session, but *repeated* once each week, resulting in three sessions of blocked practice on each serve, separated by blocked practice sessions on the other serves. In the Shea and Morgan study there was no return to a task once a practice block had been completed. Thus, Goode and Magill used a less "extreme" form of blocked practice than had Shea and Morgan - "extreme" in the sense of a continuum, where at one end a task is practiced repeatedly for a series of trials and then never practiced again (which is typical of many training regimes, sport skill classes, and university courses in which a limited amount of time is available for instruction). Nevertheless, this less extreme form of blocked practice resulted in acquisition performance that was superior to random practice during the acquisition sessions, but inferior to random practice in a retention test. Moreover, a transfer test, in which serves were made from the left service side (all practice sessions were performed from the right service court), produced much better performance by the random group than the blocked group. Thus, among the many significant contributions of this study was the demonstration of a CI effect in a recreational task, over multiple practice sessions, using valid measures of learning, and despite the fact that they used a less extreme form of blocked practice.

Another frequently cited study of random and blocked practice reported findings in which a sport skill (baseball batting) involved participants who were already highly experienced in the task. Hall, Domingues, and Cavazos (1994) recruited members of a collegiate baseball team and gave them "extra" batting practice twice a week over a period of 6 weeks. Each player received 15 pitches of three different types (fastballs, curveballs, and change-ups), ordered in blocked or random schedules during each batting practice session. A group of controls did not engage in the extra practice sessions. The findings of the Hall et al. (1994) study are presented in Figure 5.2.

Several points should be noted when reviewing the data presented in Figure 5.2. First, blocked practice was conducted in an even less "extreme" manner than in Goode and Magill. Blocked practice on each of the pitch types was conducted within *each* of the practice sessions, and still performance during the two recorded practice sessions was better than performance by participants in the random group. Thus, perhaps it should not be surprising that retention performance (in both blocked and randomly ordered trials), was significantly better by the blocked group than by the control group, which had received no extra batting practice during the 6-week period. Nevertheless, this blocked-practice group performed both retention tests more poorly than members of the random group, replicating the essential findings of Shea and Morgan (and Goode & Magill, 1986). Another important

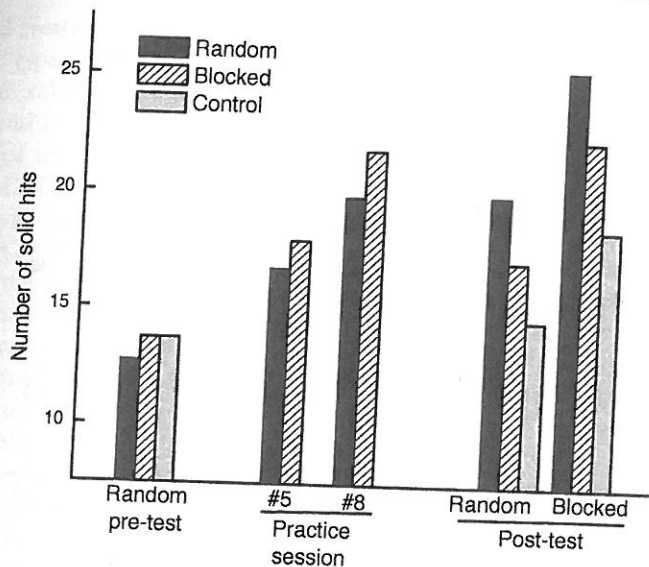


Figure 5.2 Results of the Hall et al. (1994) study.

finding to remember is that these results were produced with members of a collegiate baseball team, who, presumably, had less "room" for improvement than the novices used in the Shea-Morgan and Goode-Magill studies.

2. CI is not limited just to task outcomes

The CI effect in Shea and Morgan (1979) was an observed reduction in response time and errors. For Goode and Magill (1986) the outcome measured was the final location of the badminton serves; for Hall et al. (1994) it was the number of baseballs contacted with a solid hit. A question that remains unanswered from these studies is whether CI represents more than just an effect on observable task outcomes. Does CI have a direct influence on changes in movement control? A study by Tsutsui, Lee, and Hodges (1998) suggests so.

Studies of bimanual coordination reveal that rhythmic movements of the upper limbs tend to fall naturally into one of two coordination timing patterns – in-phase (or 0° relative-phase timing) and anti-phase (180° relative-phase timing) – but that other timing patterns can be acquired with practice (for review, see Kelso, 1995; Swinnen & Wenderoth, 2004). In Tsutsui et al. (1998, Experiment 2), participants learned to perform bimanual timing patterns of 45° , 90° , and 135° relative phase. Participants in the blocked group practiced 45 trials of one pattern on the first day, 45 trials of another pattern on a second day, and 45 trials of the remaining pattern on the third day (an "extreme" type of blocked practice, as in Shea & Morgan). Participants in the random group performed 15 trials of each pattern on each of the three practice days. As revealed in Figure 5.3, the first block of 15 trials on each day of practice was performed with similar overall relative timing error by the random

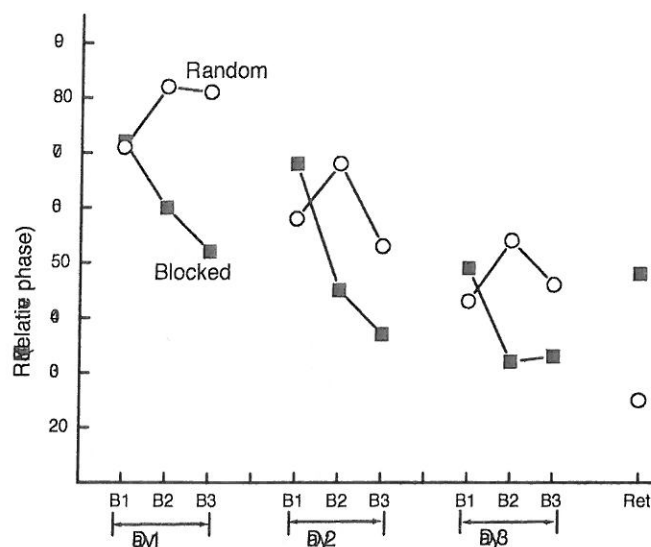


Figure 5.3 Results of the Tsutsui et al. (1998) study.

and blocked groups (remember that the blocked group was practicing a previously unlearned pattern at the start of each day of practice). However, trials 16–45 (blocks 2 and 3) were performed better by the blocked group on each practice day, consistent with the typical CI effect in acquisition. A retention test, performed 1 week later, demonstrated that random practice resulted in a significant and permanent coordination learning advantage, relative to the blocked group. That is a relatively permanent improvement in the capability to perform coordination patterns that were previously not part of the learner's repertoire had been facilitated by random practice.

Neuroscientific evidence also suggests that blocked and random practice have different manifestations in terms of brain activity. In a study by Cross, Schmitt, and Grafton (2007), groups of blocked-ordered and random-ordered participants practiced a finger-sequencing task and found typical CI effects during acquisition trials and in retention. In addition, Cross et al. examined pre-movement study times: the amount of time that an individual voluntarily chose to prepare for the upcoming trial. Replicating previous studies (Immink & Wright, 1998; Lee, Magill, & Weeks, 1985), participants who engaged in random practice self-selected longer study times prior to movement execution than did individuals during blocked practice. However, as a key additional feature during these study times, Cross et al. (2007) examined the blood flow activity in selected regions of the brain using fMRI (functional magnetic resonance imaging) techniques. These fMRI data were collected during the early and later stages of acquisition performance and revealed considerable differences in the regions of the brain that are known to be involved in movement preparation. Levels of fMRI activity are believed to be strongly associated with mental processing, leading Cross et al. to suspect that random practice

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activated greater movement preparation processes during practice than in blocked practice, especially late in learning. These behavioral and neurophysiological findings were subsequently replicated and extended by Wymbs and Grafton (2009) using a within-participant design.

One of the brain regions identified by Cross et al. (2007) and Wymbs and Grafton (2009) was the M1 (primary motor cortex) region, ipsilateral to the limb involved in learning. In a follow-up experiment, Cohen, Cross, Wymbs, and Grafton (2009) paired TMS (transcranial magnetic stimulation) to the ipsilateral M1 with the presentation of the movement stimuli with the intention of disrupting movement preparatory processing during random practice. Compared with practiced movement sequence controls (i.e., without paired TMS pulses), the patterns learned under simultaneously paired TMS were performed more poorly on a retention test conducted 1 day later, suggesting that the TMS had disrupted the learning of preparatory processes during practice. A potential limitation of the Cohen et al. (2009) study was the absence of blocked control groups that did or did not receive the TMS during practice trials. Lin, Fisher, Winstein, Wu, and Gordon (2008) and Lin, Winstein, Fisher, and Wu (2010) included these important control conditions and extended the Cohen et al. findings. Lin et al. (2008, 2010) found that the random-practice advantage in retention was eliminated when TMS was applied to the M1 region, contralateral to the arm practiced, immediately after trial feedback was presented. However, the typical CI effect was observed in learners who received either no TMS or a sham TMS procedure (in which an auditory click was accompanied by a slight pressure on the scalp, instead of the TMS). Thus, despite differences between the studies reviewed above in terms of where the TMS was applied (ipsilateral or contralateral to the moving arm) and when it was delivered (during movement preparation or after feedback was delivered), application of TMS to the M1 appeared to disrupt the retention of movement patterns practiced in a random order. The evidence from these fMRI and TMS studies suggests that CI has an effect not only on the behavioral expression of motor learning, but also on specific neural activities that underlie this expression, and implicate specific planning and/or reflective processes as the locus of the CI effect. More will be presented about these theoretical issues later in the chapter.

3. CI is not limited just to young adults

Two studies, one with children and the other with older adults, demonstrate that CI is not limited just to the learning of motor skills by healthy, young university students. In three experiments reported by Ste-Marie, Clark, Findlay, and Latimer (2004), children between the ages of 5 and 8 years practiced handwriting various characters according to blocked or random schedules. In one study, for example, young children practiced the individual letters "h," "a," and "y" and were required to perform a transfer test in which the word "hay" was written. The group who had practiced these individual letters in a random order performed "hay" much faster than the blocked group, yet without a sacrifice in writing quality.

Towards the other end of the age continuum, Lin, Wu, Udompholkul, and

Knowlton (2010) examined CI effects in younger adults (mean age 30 years) and older adults (mean age 65 years). Random and blocked subgroups of both ages performed three 4-element (stimulus-response) reaction-time sequences over two consecutive days of practice and a retention test 3 days later. Although the younger adults performed faster overall than the older adults, typical CI effects were found for both: blocked practice resulted in faster response times than random practice during acquisition, but the random subgroups performed faster in retention than the blocked subgroups. A similar, beneficial effect on retention for learning ATM (automatic teller machine) procedures following random practice was found in younger and older adults by Jamieson and Rogers (2000). The above studies suggest that CI effects are not limited to young adults serving as participants in a motor learning experiment. Furthermore, the Jamieson and Rogers study suggests that the CI effect may apply to other types of learning, which is examined next.

4. CI is not limited just to motor learning

An interesting, and more recent, trend in the literature has been the study of CI in research areas not specifically related to motor learning (see also Schmidt & Bjork, 1992). For instance, participants in Kornell and Bjork's (2008) study learned to identify 12 painters by studying six samples of their works of art. Participants studied half of the artists' samples in a blocked order and the others were studied in an interleaved order (a more "structured" type of random practice). Following this study period, the participants were presented with 48 previously unseen samples of the artists' work in a random order, and their task was to select the correct identity of the artist from a multiple choice list (followed by corrective feedback). The results of these transfer trials are presented in Figure 5.4, with the results of the first image from each artist presented in "test block 1," and so forth. The results revealed a large advantage for having previously studied the artists' samples in an interleaved order. Moreover, this advantage persisted throughout the 48 transfer trials, despite the corrective, augmented feedback that was provided after each test. Similar findings were found in a follow-up experiment that included older adults (mean age 77 years) as participants (Kornell, Castel, Eich, & Bjork, 2010).

Other examples of the beneficial impact of random practice in non-motor learning tasks have now been reported. Carlson and Yaure (1990) found that individuals learning Boolean logic rules by switching between problems that used a different function were faster in problem-solving transfer trials than participants who repeatedly practiced using the same function. Rohrer and Taylor (2007; Taylor & Rohrer, 2007) found improved transfer accuracy following random practice of problems in mathematics compared with blocked practice. Helsdingen, van Gog, and van Merriënboer (2011a, 2011b) found random advantages following practice on complex, problem-solving judgment tasks. These findings extend the range of tasks, perceptual, motor, and cognitive, for which random practice advantages have been demonstrated.

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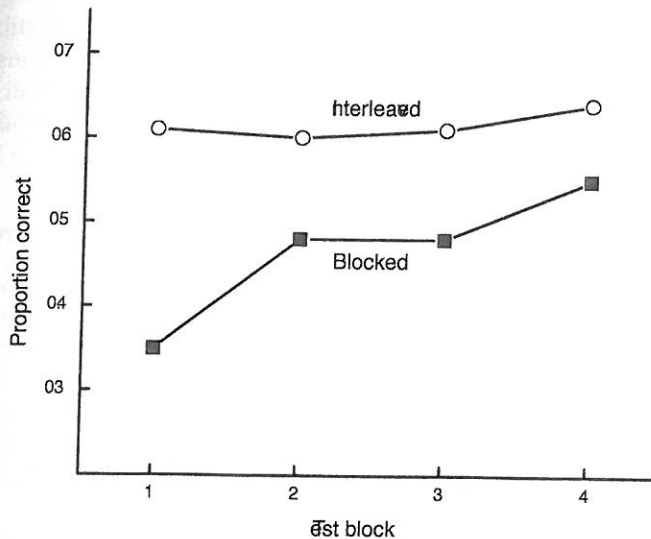


Figure 5.4 Results of the Kornell and Bjork (2008) study.

5. CI is not limited to learners who expect the effect

A methodological issue that could undermine all of the findings listed above would be validated if participants who practiced in random and blocked schedules *expected* to perform in retention tests at a certain level, and then did so. Such a methodological artifact, a type of expectancy bias effect, might suggest that individuals learned to the degree that simply matched their preconceived expectations. For example, if participants in a random practice group expected to learn better than those in a blocked group, and did so, then perhaps the findings are at least partially confounded by this expectancy bias. Simon and Bjork (2001), however, not only refuted this suggestion, but found that learners performed in retention tests at a level that was in stark contrast to their expectations.

In Simon and Bjork's (2001) study, random and blocked practice schedule participants underwent typical experimental protocols, and replicated the classic CI findings in acquisition and retention performance. During the acquisition phase learners were asked to predict, in terms of performance error, how accurate they expected their retention performance to be 1 day later. Also, when these learners did return a day later, they were asked once again to predict their performance on the retention test. Not surprisingly, the participants' predictions about their future retention performance, made during the acquisition trials, corresponded closely with their actual performance in these acquisition trials. One day later, learners in the blocked group still maintained that they would perform well in the retention test, and their predicted judgments of retention error were much less (i.e., at a performance level that was better) than the learners in the random group. However, as illustrated in Figure 5.5, members of the blocked group were clearly overconfident

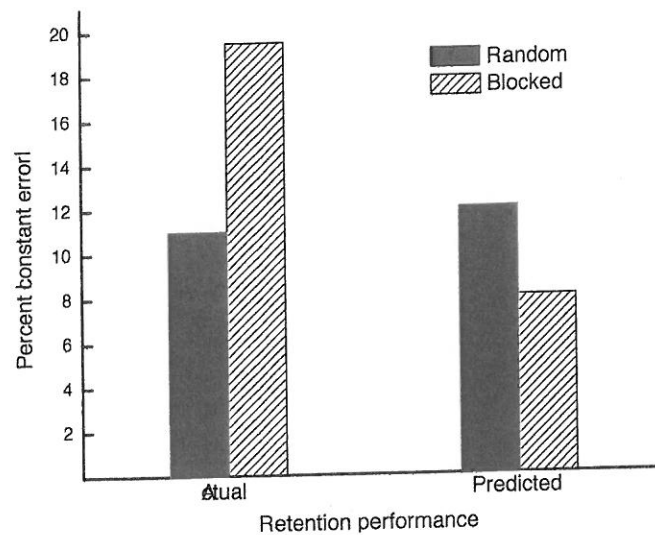


Figure 5.5 Results of the Simon and Bjork (2001) study.

in their ability to perform the retention test, and members of the random group were, perhaps, surprised by their retention performance.

A similar and dramatic level of misattribution about learning was present in the Kornell and Bjork (2008) experiments discussed earlier. Kornell and Bjork asked participants to identify artists from paintings presented during blocked and interleaved samples of the artists' work (their participants saw six artists in a blocked order and the other six artists in an interleaved order). After the four test blocks had been completed, Kornell and Bjork told the participants about the experimental manipulations (blocking vs. interleaving the study paintings) and asked which method they perceived to be more effective. Although interleaved practice resulted in test trial performance that was far superior to blocked practice, Kornell and Bjork found that 78% of their participants (94 out of 120 individuals) believed that they had learned more in the blocked trials than during interleaved practice (a similar result was also found in Kornell et al., 2010).

These findings suggest that CI is not a manifestation of expected outcomes, but in fact occurs *despite* the actual outcomes of the test trials. The vast majority of participants remained convinced that blocked study would be better than interleaved study, even though the reverse was actually true. The conclusions of Kornell and Bjork suggest that learners typically believe the "illusion that a sense of ease or fluency accompanies effective learning, whereas a sense of difficulty signifies ineffective learning . . . [in many] types of learning, spacing appears to be sometimes, if not always, a desirable difficulty" (Kornell & Bjork, 2008, p. 591).

To sum up, the impact of the Shea and Morgan (1979) experiment provided a modest start to what has become an area of intensive research in motor learning.

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During this time, the effects of blocked and random practice have been extended to different population groups, tested in a variety of skills, demonstrating changes not only in task outcomes but also in the learners' central nervous system, and despite the fact that the learners themselves were probably highly skeptical of the results of these studies.

What are the limits to the CI effect?

The evidence presented above might appear to suggest that the CI effect is an enormously robust effect with magic-bullet implications for learning. This is not so. Numerous researchers have failed to find beneficial effects of random practice when compared with blocked practice, particularly in studies involving the acquisition of sport-specific skills (e.g., see Brady, 1998). Some studies found a random practice advantage in retention or transfer in the absence of a detrimental effect in acquisition, leading them to question whether or not there is such a thing as a "typical CI effect." The order of retention and transfer trials seems to have a moderating effect on the size of random/blocked differences in some studies, but not always. Moreover, the CI effect appears to be larger when examined in discrete skills than in continuous skills, but this is not always the case either (e.g., as in the Tsutsui et al., 1998 study discussed earlier). Issues of statistical power may account for some of these discrepancies, but it is doubtful that this explanation extends very far.

There are two general conclusions however, that appear to have few exceptions:

- 1 When *acquisition performance* differences exist between individuals who practice according to blocked and random schedules, the advantage almost always favors the blocked practice group. Only rarely does random practice exceed blocked practice in acquisition performance outcomes (e.g., accuracy, speed, quality, and so on).
- 2 When *learning* differences exist between individuals who practice according to blocked and random schedules, the advantage almost always favors the random practice group in tests of retention and transfer.

So, what are these "almost always" exceptions? Some investigations have suggested that a blocked schedule is superior to random when the amount of practice is very limited. For example, in Shea, Kohl, and Indermill's (1990) findings, retention following blocked practice was better than after random practice when each task to be learned was performed for only 10 trials each. The reverse (i.e., the typical CI effect) was found, however, when retention was assessed following 80 trials of practice on each task. These findings, along with others, suggest that blocked practice may be more beneficial than random practice when the demands on learning are made particularly difficult as a function of the amount of practice, the nature of the task, and/or the capabilities of the learner. These (and other) exceptions and detailed findings are reviewed more thoroughly in Wulf and Shea (2002) and Guadagnoli and Lee (2004).

Theoretical implications of CI

A number of hypotheses for the CI effect have been suggested since the original publication of Shea and Morgan's results, each one emphasizing the cognitive operations of the learner as an integral part of the learning process. Two ideas in particular, seem to have maintained their presence in the literature.

One view, sometimes called the *elaboration and distinctiveness* hypothesis (Shea & Morgan, 1979; Shea & Zimny, 1983), suggests that the CI effect is caused by the contrast that occurs when multiple tasks are practiced together. In blocked practice, tasks are practiced virtually in isolation, and therefore there is little opportunity to gain knowledge from the comparison and contrastive nature of practicing sets of task combinations in succession, as in the case of random practice. The retention difference is due to the differences in elaborative and distinctive processing that are promoted in random practice, and/or degraded by blocked practice, and the result that these processes contribute to the durability of the memories.

The other view, sometimes called the *forgetting and reconstruction* hypothesis (Lee & Magill, 1983, 1985), suggests that the CI effect is due to the planning processes that are influenced by the spacing of practice (Cuddy & Jacoby, 1982). In blocked practice, short-term forgetting due to memory decay and/or interference is minimal, which limits the amount of new planning that is required in repeated practice. Short-term forgetting is abundant during random practice, requiring that learners undertake more extensive planning operations. The retention effect is due to the differences in the amount of planning that is promoted in random practice and/or diminished by blocked practice; greater planning processes enhance learning (see also the TMS and fMRI evidence reviewed above).

Although the two views differ in the details of their hypotheses about learning mechanisms, they share commonalities too. For example, cognitive operations provide the basis for both views, and in particular the role of memory processes, both short- and long-term, are the foundation for the learning differences that distinguish between random and blocked practice schedules.

Future directions for CI research

Experiments examining CI using neuroscience methods (e.g., fMRI and TMS) have begun (see 'On the generality of the CI effect' above) and hold the potential to provide new evidence that will confirm or refute existing theoretical positions, or provide new theories for the reasons why learning is different under random and blocked practice schedules. At the same time, new behavioral paradigms are being developed to explore CI. Some researchers have suggested that practice schedules that are specifically tailored to the individual needs of the learner can be as effective as, or more so than, random practice. Several different methods have been used to tailor these practice schedules, and include (1) self-selected practice methods, in which the learner is provided with the opportunity to define the order in which tasks are practiced (Hodges, Edwards, Luttin, & Bowcock, 2011; Keetch & Lee, 2007); (2) reference-based contingencies, in which the decision to repeat the same task or switch to a new task is based on a performance algorithm (Simon, Lee, &

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Cullen, 2008); and (3) adapted practice schedules, which are specifically tailored to provide more or less practice as needed, and which change the difficulty of the task based on the learner's progress (Choi, Qi, Gordon, & Schweighofer, 2008). The study of CI as an expanded study of effects influencing the acquisition of motor, perceptual and cognitive tasks is likely to continue to grow. In more than 30 years of study since Shea and Morgan (1979) first reported their findings, CI continues to remain a "hot topic" in the literature, with no signs of cooling down in the near future.

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